LUXEMBOURG’S NATIONAL INVENTORY REPORT 1990-2022

ADMINISTRATION DE L‘ENVIRONNEMENT

ENVIRONMENT AGENCY

D‘ËMWELTVERWALTUNG

Am Déngscht vu Mënsch an Ëmwelt

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Executive Summary

ES.1. Background information on greenhouse gas (GHG) inventories and climate change

ES.1.1. Background information on climate change

Climate as such is the totality of all atmospheric conditions at a particular location. It undergoes natural variability. Since industrialisation started some 150 years ago, mankind has been influencing the climate via the emission of greenhouse gases. In 1994, by setting up the United Nations Framework Convention on Climate Change (UNFCCC), the nations of the world came together to start a process to prevent dangerous effects of climate change. However, the Convention did not include binding commitments. To go this step further, the Kyoto Protocol was adopted in 1997 and sets binding targets for 37 industrialized countries for the period 2008-2012. The so-called Doha Agreement extends the Kyoto Protocol until 2020 and entered into force on 31 December 2020.

ES.1.2. Background information on greenhouse gas (GHG) inventories

In order to evaluate the trend of greenhouse gas emissions and the progress in achieving the reduction target, it is necessary to regularly compile an emissions inventory. The compilation of these inventories follows rules as set up by the UNFCCC. The Global Warming Potential Values (GWP) defined in the IPCC Fifth Assessment Report[1] (AR5) were applied.

ES.2. Summary of National Emission and Removal related Trends

In 2022, Luxembourg's greenhouse gas emissions amounted to a total of 8.192 million tonnes calculated in CO_2 equivalents (CO_2 eq) – excluding land-use, land-use change and forestry (LULUCF). Table 0-1 splits the total GHG emissions of Luxembourg into the different greenhouse gases reported in the inventory. Carbon dioxide (CO_2) was the main source of greenhouse gases (GHG) in Luxembourg. This source counted for 88.82% of the total GHG emissions (excluding LULUCF). The second source of GHG was methane (CH_4) with 7.91% of the total emissions excluding LULUCF. Nitrous oxide (N_2O) was the third source with 2.64%. Fluorinated gases (F-gases) only accounted for 0.63% of the total emissions excluding LULUCF, with hydrofluorocarbons (HFCs) representing 0.52%, and sulphur hexafluoride (SF_6) representing 0.11% of the national total (excl. LULUCF).

In 2022, total GHG emissions decreased by 12.69% compared to 2021 and are currently 35.63% below their base year level[2]. The decrease in GHG emissions from 2021 to 2022 is due to reduced energy consumption as a consequence of high global energy prices and national energy saving efforts. For the different greenhouse gases, trends over the period 1990-2022 (and 2021-2022) were as follows:

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1 https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf

2 The base year for CO_2, CH_4 and N_2O is 1990. For the F-gases, the base year is 1995.

- CO_2: ………………………………………… -38.40% (-13.58%)
- CH_4: ……………………………………… -4.93% (-2.13%)
- N_2O: ………………………………………… -6.40% (-12.33%)
- F-gases: …………………………………… +237.05%[3] (-4.86%)

Carbon dioxide emissions, over the period 1990-2022, are characterised by a V-shape evolution driven by changes in the sources of emissions: declining emissions in industry due to technological changes in the iron and steel production, increasing emissions from transport and natural gas fired power plants. The last emission peak was attained in 2005 and, since then, the emissions seem to be continuously decreasing until 2009. This decrease was interrupted in 2010, where emissions increased by 5.36% compared to 2009. However, since 2005 emissions have decreased by 39.75%. The 13.58% decrease of carbon dioxide emissions in 2022 compared to 2021 is due to reduced energy consumption as a consequence of high global energy prices and national energy saving efforts.

Total methane emissions have remained fairly stable over the period 1990-2022. In 2022, reduced methane emissions were observed in waste management (-31.86%) and in energy use (-3.98%) as compared to 1990, with the latter showing an upward trend for fugitive emissions from natural gas distribution and use and a slight downward trend (and strong decrease for 2022) of combustion related emissions, and increasing emissions in agriculture (+0.80%). Compared to 2021, the CH_4 emissions decreased by 2.13% in 2022, with the main driver being the energy sector.

Nitrous oxide emissions development between 1990 and 2022 (-6.40%) is closely linked to liquid fuels related emissions from mobile combustion activities (+209.09% in the road transportation sector) and to emissions from the waste sector (+85.47%) that could not compensate the declining emissions from the agriculture (-27.49%) and industrial products and product use sectors (-39.27%). Compared to 2021, total N_2O emissions (excl. LULUCF) decreased by 12.33% in 2022, with the main drivers being the energy, agriculture, and waste sectors.

With regard to F-gases, HFCs emissions increased by 205.50% in 2022 compared to the base year (1995) mainly due to the increasing use of mobile and stationary cooling equipment. Likewise, SF_6 emissions showed a 541.29% increase between 1995 and 2022 due to, in large parts, the increasing use of high-voltage electrical devices and noise reduction windows.

Finally, when including emissions and removals from land use, land use change and forestry (LULUCF), Luxembourg's greenhouse gas emissions amounted to a total of 7544.12 million tonnes CO_2 eq. in 2022. Net removals from the LULUCF sector amounted to 648.21 Gg CO_2 eq. Since 1990, net emissions have decreased by 7317.93% (the sector was a source of net emissions in 1990 - with 8.98 Gg CO_2 eq. - and then a source of net removals in 1991-2022).

ES.3. Overview of Source and Sink Category Emission Estimates and Trends

Table 0-2 splits the total GHG emissions of Luxembourg into the five CRF sectors included in the inventory. In 2022, the energy sector accounted for 84.31% of the total GHG emissions, excluding LULUCF. Two sectors represented between 6% and 9% of the total

3 The trend indicated here corresponds to the period 1995 to 2022, as the base year for F-gases is 1995.

emissions, excluding LULUCF: industrial processes and product use (6.53%) and agriculture (8.12%). The waste sector[4] (1.03%) was at 1% of the total GHG emitted in Luxembourg in 2022, and emissions from the LULUCF sector were -7.91% of the national total emissions. The sector "other" is not reported for Luxembourg.

For the different sectors, trends over the period 1990-2022 (and 2021-2022) were as follows:

- Energy: ………………………………………………………………… -32.89% (-14.09%)
- Industrial processes & product use: ………………………. -66.75% (-4.29%)
- Agriculture: …………………………………………………………. -6.08% (-4.20%)
- LULUCF:………………………………………………………………. -7317.93% (+7.08%)
- Waste: ………………………………………………………………… -27.26% (-5.40%)
- Other: ………………………………………………………………….. NA (NA)

Since 1990, emission reductions were observed in all sectors, especially for energy related emissions whose contributions to the total GHG emissions, excluding LULUCF, ranged from 80.87% to 88.83% over the period 1990 to 2022. Within the energy sector, the fastest growing sub-sectors were energy industries (1A1) and transportation (1A3): +566.83% and +60.55% respectively, between 1990 and 2022 (-11.90% and -14.27% from 2021 to 2022). For the other sub-sectors, the observed trends between 1990 and 2022 are -83.78% for manufacturing industries (1A2), +4.20% for the other sectors (1A4), -96.39% for Other (1A5), and +20.23% for fugitive emissions from fuels (1B).[5] The decrease in energy-related GHG emissions of 14.06% in 2022 compared to 2021 is mainly due reduced energy consumption as a consequence of high global energy prices and national energy saving efforts.

Trends in agriculture, which was the second largest sector in 2022 in terms of GHG emissions, were overall stable between 1990 and 2022: declining GHG emissions were observed for agricultural soils (-31.19%) and enteric fermentation (-1.85%), whereas manure management increased by 5.44% and liming by 3332%. While no urea related emissions were occurring in the agriculture sector prior to 2005, the GHG emissions from carbon-containing fertilizers show a decrease of 62.85% in 2022 compared to 1990 levels.

The third largest sector in Luxembourg with regard to 2022 GHG emissions, i.e. industrial processes and product use, shows a declining trend between 1990 and 1998, then a relative stabilisation. This evolution was mainly driven by process changes that occurred in the steel industry (recorded under 2C1), which moved from blast to electric arc furnaces between 1994 and 1998. As a consequence, GHG emissions of the iron and steel industry decreased by 91.74% since 1990. Compared to 2021, emissions from industrial processes and product use decreased by 4.29% in 2022, which is equally due to decreases in the categories 2.A - Mineral industry and 2.C – Metal industry.

In the waste sector, the overall reductions in GHG emissions of -27.26% from 1990 to 2022 are driven by the solid waste disposal on land (5A) category, which contributed the most to the total sector emissions (52.22%) even though it has seen a steady decrease of 57.22% from 1990 levels to 2022. This decrease is due to overall reduced amounts of landfilled waste and an increase in composting activities (5B), with the latter contributing 40.56% to the total waste GHG emissions in 2022. Wastewater handling emissions (5D) decreased by 53.22% from 1990 to 2022. The waste sector saw a small decrease in GHG emissions of 5.40% from 2021 to 2022.

4 The waste sector covers only landfilled waste, wastewater handling and composting activities. Waste incineration, which is the main treatment method for municipal waste in Luxembourg, is carried out in the sole incinerator of the country where energy is recovered. Consequently, waste incineration related emissions are accounted for in CRF sector 1 – Energy (details in Chapters 3 and 8 respectively).

5 Fugitive emission growth is closely linked to natural gas use in Luxembourg.

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From the above analysis, it is obvious that the biggest challenge Luxembourg is facing, with regard to GHG emissions reduction, is the limitation of emissions from the energy sector, and more particularly from the transportation sector. Detailed explanations on the very high shares of CO_2 from the energy sector are provided in Chapter 2, where the trends in Luxembourg's GHG emissions are analyzed. Specific national circumstances need to be kept in mind when appreciating GHG emissions trends and composition in Luxembourg. These circumstances are elaborated in Chapter 2 as well.

ES.4. Other information: Emission Estimates and Trends of Indirect GHG and SO_2

Some indirect GHG – NO_x, CO, NMVOCs – and SO_2 emissions are recorded and reported in the inventory. The emissions of these air pollutants are estimated and reported under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). For more details on the emissions of these pollutants please refer to Luxembourg's Air Pollutant Emission Inventory and its related Informative Inventory report, which are both published on the Center on Emission Inventories and Projections website:

http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting

Table 0-1– Luxembourg's GHG emissions (excl. LULUCF) – overview by main gases: 1990-2022. Percentages are relative to the total GHG emissions excluding LULUCF.

Gg (1000 t.) CO_2eq	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
CO_2 excl. LULUCF	11813.17	12423.83	12192.27	12341.04	11525.18	9135.57	9186.14	8546.76	7654.72	8117.36	8702.43	9205.64	9978.71	10451.04	11819.38	12076.77
	92.82%	93.07%	92.97%	92.94%	92.69%	90.79%	90.74%	90.12%	89.12%	89.63%	90.29%	90.76%	91.39%	91.88%	92.73%	92.89%
CH_4 (1)	681.91	685.49	672.42	683.97	656.08	673.40	679.07	677.41	675.76	674.10	667.64	672.61	672.84	668.27	653.70	660.65
	5.36%	5.14%	5.13%	5.15%	5.28%	6.69%	6.71%	7.14%	7.87%	7.44%	6.93%	6.63%	6.16%	5.87%	5.13%	5.08%
N_2O (2) excl. LULUCF	230.73	239.04	243.69	240.36	237.95	238.26	241.29	239.00	235.69	239.13	237.73	227.12	226.38	213.92	229.94	221.09
	1.81%	1.79%	1.86%	1.81%	1.91%	2.37%	2.38%	2.52%	2.74%	2.64%	2.47%	2.24%	2.07%	1.88%	1.80%	1.70%
HFCs (3)	0.00	0.00	4.99	11.76	12.91	13.81	15.80	18.31	20.92	23.89	28.33	34.86	37.84	38.09	38.26	36.95
	0.00%	0.00%	0.04%	0.09%	0.10%	0.14%	0.16%	0.19%	0.24%	0.26%	0.29%	0.34%	0.35%	0.33%	0.30%	0.28%
PFCs (3)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SF_6 (3)	0.90	1.01	1.11	1.22	1.34	1.43	1.61	1.75	1.79	1.88	1.98	2.66	3.28	3.88	4.45	5.03
	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.03%	0.03%	0.03%	0.03%	0.04%
Total GHG excluding LULUCF	12726.71	13349.37	13114.48	13278.36	12433.46	10062.47	10123.90	9483.23	8588.89	9056.36	9638.12	10142.89	10919.05	11375.19	12745.74	13000.50
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Gg (1000 t.) CO_2eq	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2 excl. LULUCF	11908.74	11304.99	11169.35	10625.16	11194.66	11097.07	10866.49	10333.66	9816.08	9345.27	9090.39	9262.84	9567.29	9761.76	8074.93	8420.58	7276.72
	92.82%	92.34%	92.07%	91.72%	92.08%	92.19%	92.06%	91.60%	91.04%	90.62%	90.19%	90.28%	90.58%	90.97%	89.35%	89.74%	88.82%
CH_4 (1)	655.27	664.22	679.07	677.34	672.90	643.61	641.68	647.20	657.82	660.39	675.51	676.32	678.20	654.61	665.33	662.36	648.27
	5.11%	5.43%	5.60%	5.85%	5.53%	5.35%	5.44%	5.74%	6.10%	6.40%	6.70%	6.59%	6.42%	6.10%	7.36%	7.06%	7.91%
N_2O (2) excl. LULUCF	220.73	223.45	230.65	228.45	234.14	237.71	233.21	234.47	237.99	236.86	244.39	249.71	252.21	254.99	241.21	246.34	215.96
	1.72%	1.83%	1.90%	1.97%	1.93%	1.97%	1.98%	2.08%	2.21%	2.30%	2.42%	2.43%	2.39%	2.38%	2.67%	2.63%	2.64%
HFCs (3)	39.61	43.77	46.09	47.16	49.25	51.87	54.03	57.49	61.55	61.38	59.80	61.92	54.96	49.45	45.72	44.08	42.19
	0.31%	0.36%	0.38%	0.41%	0.41%	0.43%	0.46%	0.51%	0.57%	0.60%	0.59%	0.60%	0.52%	0.46%	0.51%	0.47%	0.52%
PFCs (3)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SF_6 (3)	5.46	5.90	6.32	6.73	7.11	7.57	7.95	8.33	8.72	9.19	9.55	9.73	10.03	10.26	9.91	9.92	9.18
	0.04%	0.05%	0.05%	0.06%	0.06%	0.06%	0.07%	0.07%	0.08%	0.09%	0.09%	0.09%	0.09%	0.10%	0.11%	0.11%	0.11%
Total GHG excluding LULUCF	12829.81	12242.32	12131.48	11584.83	12158.06	12037.83	11803.37	11281.15	10782.16	10313.09	10079.64	10260.52	10562.69	10731.07	9037.10	9383.28	8192.33
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Environment Agency

Notes:

(1) The methane emissions are converted in CO_2 equivalents by multiplying the emissions by 28, i.e. the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

(2) The nitrous oxide emissions are converted in CO_2 equivalents by multiplying the emissions by 265, i.e. the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

(3) The F-gases are those not covered by the Montreal Protocol, i.e. HFCs, PFCs and SF_6 expressed in CO_2 equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Table 0-2– Luxembourg's GHG emissions and removals – overview by main CRF Sectors: 1990-2022. Percentages are relative to the total GHG emissions excluding LULUCF.

Gg (1000 t.) CO_2eq	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1. Energy	10291.98	10987.70	10829.69	10998.17	10280.73	8249.42	8358.17	7829.76	7094.35	7524.01	8085.96	8648.06	9420.62	9945.67	11266.16	11548.86
	80.87%	82.31%	82.58%	82.83%	82.69%	81.98%	82.56%	82.56%	82.60%	83.08%	83.90%	85.26%	86.28%	87.43%	88.39%	88.83%
2. Industrial Processes	1609.76	1532.26	1465.28	1454.06	1357.04	998.71	944.66	836.11	679.76	718.26	747.37	700.38	718.98	668.31	723.30	694.51
	12.65%	11.48%	11.17%	10.95%	10.91%	9.93%	9.33%	8.82%	7.91%	7.93%	7.75%	6.91%	6.58%	5.88%	5.67%	5.34%
3. Agriculture	708.68	710.68	699.92	705.13	683.60	702.84	707.24	700.78	696.21	696.09	688.80	678.00	662.27	638.77	639.47	638.91
	5.57%	5.32%	5.34%	5.31%	5.50%	6.98%	6.99%	7.39%	8.11%	7.69%	7.15%	6.68%	6.07%	5.62%	5.02%	4.91%
4. Land use, land-use change and forestry	8.98	-58.92	-464.53	-591.23	-443.44	-522.65	-558.38	-644.32	-538.44	-604.75	-614.76	-593.38	-583.05	-563.32	-609.47	-565.98
	0.07%	-0.44%	-3.54%	-4.45%	-3.57%	-5.19%	-5.52%	-6.79%	-6.27%	-6.68%	-6.38%	-5.85%	-5.34%	-4.95%	-4.78%	-4.35%
5. Waste	116.29	118.73	119.59	121.01	112.09	111.51	113.82	116.58	118.57	118.00	115.99	116.44	117.19	122.45	116.81	118.22
	0.91%	0.89%	0.91%	0.91%	0.90%	1.11%	1.12%	1.23%	1.38%	1.30%	1.20%	1.15%	1.07%	1.08%	0.92%	0.91%
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total GHG including LULUCF	12735.69	13290.45	12649.95	12687.13	11990.02	9539.82	9565.52	8838.91	8050.45	8451.62	9023.35	9549.51	10336.00	10811.87	12136.27	12434.52
Total GHG excluding LULUCF	12726.71	13349.37	13114.48	13278.36	12433.46	10062.47	10123.90	9483.23	8588.89	9056.36	9638.12	10142.89	10919.05	11375.19	12745.74	13000.50
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Gg (1000 t.) CO_2eq	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1. Energy	11332.34	10734.44	10653.08	10177.43	10733.38	10622.25	10429.55	9911.32	9387.71	8922.40	8644.12	8811.91	9117.30	9293.40	7616.59	8039.85	6906.87
	88.33%	87.68%	87.81%	87.85%	88.28%	88.24%	88.36%	87.86%	87.07%	86.52%	85.76%	85.88%	86.32%	86.60%	84.28%	85.68%	84.31%
2. Industrial Processes	749.39	745.56	694.80	625.97	651.03	660.72	629.16	611.78	622.02	613.36	637.45	646.00	643.02	658.13	632.00	559.29	535.30
	5.84%	6.09%	5.73%	5.40%	5.35%	5.49%	5.33%	5.42%	5.77%	5.95%	6.32%	6.30%	6.09%	6.13%	6.99%	5.96%	6.53%
3. Agriculture	629.01	641.35	660.99	659.04	663.17	648.55	639.19	652.24	665.07	675.20	697.23	701.75	704.24	686.13	698.34	694.73	665.57
	4.90%	5.24%	5.45%	5.69%	5.45%	5.39%	5.42%	5.78%	6.17%	6.55%	6.92%	6.84%	6.67%	6.39%	7.73%	7.40%	8.12%
4. Land use, land-use change and forestry	-484.99	-392.73	-410.69	-423.05	-205.40	-298.17	-368.20	-513.84	-422.59	-369.21	-468.32	-379.43	-241.15	-363.59	-447.65	-605.34	-648.21
	-3.78%	-3.21%	-3.39%	-3.65%	-1.69%	-2.48%	-3.12%	-4.55%	-3.92%	-3.58%	-4.65%	-3.70%	-2.28%	-3.39%	-4.95%	-6.45%	-7.91%
5. Waste	119.06	120.97	122.61	122.40	110.49	106.30	105.47	105.82	107.36	102.12	100.83	100.86	98.12	93.41	90.16	89.42	84.59
	0.93%	0.99%	1.01%	1.06%	0.91%	0.88%	0.89%	0.94%	1.00%	0.99%	1.00%	0.98%	0.93%	0.87%	1.00%	0.95%	1.03%
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total GHG including LULUCF	12344.82	11849.59	11720.78	11161.78	11952.66	11739.66	11435.17	10767.32	10359.57	9943.88	9611.32	9881.09	10321.54	10367.48	8589.45	8777.94	7544.12
Total GHG excluding LULUCF	12829.81	12242.32	12131.48	11584.83	12158.06	12037.83	11803.37	11281.15	10782.16	10313.09	10079.64	10260.52	10562.69	10731.07	9037.10	9383.28	8192.33
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Source: Environment Agency

Notes: Percentages are relative to the total GHG emissions excluding LULUCF.

1 Introduction

1.1 Background information on greenhouse gas inventories and climate change

1.1.1 Background information on climate change

1.1.1.1 Global Warming

Global warming is the increase in the average temperature of Earth's near-surface air and oceans since the mid-20th century and its projected continuation. Global surface temperature increased 0.74 ± 0.18 °C between the start and the end of the 20th century (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) concludes that most of the observed temperature increases since the middle of the 20th century was very likely caused by increasing concentrations of greenhouse gases resulting from human activity such as fossil fuel burning and deforestation. The IPCC also concludes that variations in natural phenomena such as solar radiation and volcanic eruptions had a small cooling effect after 1950.

Climate model projections summarized in the latest IPCC report indicate that the global surface temperature is likely to rise a further 1.1 to 6.4 °C during the 21st century. The uncertainty on this estimate arises from the use of models with differing sensitivity to greenhouse gas concentrations and the use of differing estimates of future greenhouse gas emissions. Most studies focus on the period leading up to the year 2100. However, warming is expected to continue beyond 2100 even if emissions stop, because of the large heat capacity of the oceans and the long lifetime of carbon dioxide in the atmosphere.

An increase in global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, probably including expansion of subtropical deserts. Warming is expected to be strongest in the Arctic and would be associated with continuing retreat of glaciers, permafrost and sea ice. Other likely effects include changes in the frequency and intensity of extreme weather events, species extinctions, and changes in agricultural yields. Warming and related changes will vary from region to region around the globe, though the nature of these regional variations is uncertain.

1.1.1.2 Climate Change in Luxembourg

Annual mean temperatures for Luxembourg-City are nowadays usually above the 30 years averages of the last century. Indeed, the 1951-1980, the 1961-1990 or the 1971-2000 mean yearly temperatures for the capital city – around 9°C – are nowadays regularly exceeded: since the turn of the 21st century, annual mean temperatures are comprised between 9.3°C (2001) and 11.3°C (2007), 9.9°C in 2016. The variation of yearly averages is mainly driven by variations in air temperatures during winter seasons. Other meteorological stations disseminated throughout the country show similar results. With regard to other meteorological parameters – rainfalls, sunshine hours, relative humidity – no clear trends can be identified yet, probably because the very small size of the country (2 586 km2) limits the identification of such changes.

Climate change effects are also witnessed by increasing frost-free periods, earlier blooming seasons and higher flood frequencies over the last 20 years. For the future, higher average yearly temperatures are anticipated with consequences on public health (heat waves), floods (higher frequency and intensity), vegetation cycles (longer periods with frost risks after early blooming) and forests (degradation of its phytosanitary state).

More details are provided in Section 2.1.2 of this NIR.

1.1.1.3 The Convention, the Kyoto Protocol and its flexible mechanisms

In 1992, Luxembourg signed the United Nations Framework Convention on Climate Change (UNFCCC) which sets an ultimate objective of stabilizing atmospheric concentrations of greenhouse gases at levels that would prevent “dangerous” human interference with the climate system. Such levels, which the Convention does not quantify, should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The UNFCCC covers all greenhouse gases not covered by the Montreal protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as hydrogenated fluorocarbons (HFCs), perfluorated halocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

Five years after adoption of the Climate Change Convention in 1997, governments took a further step forward and adopted the Kyoto Protocol (KP). Building on the Convention, the Kyoto Protocol sets out legally binding constraints on greenhouse gas emissions and “mechanisms” aimed at cutting the cost of curbing emissions. Under the terms of the Protocol, the industrialised parties – known as Annex 1 countries – pledged to reduce their greenhouse gas (GHG) emissions by 5% below the 1990 levels by the period 2008–2012. The European Union is also a Party to the Convention and the KP and agreed on a reduction target of 8% below 1990 levels during the five-year commitment period from 2008 to 2012. The EU and its Member States decided to achieve this goal jointly, for Luxembourg an emission target of minus 28% was set.

During an extensive review process in 2007, the so called Pre-commitment period review, the percentual reduction commitments of the Annex 1 countries were converted and fixed to absolute emission values, the so called assigned amounts.

Luxembourg signed the KP on 29th April 1998, and ratified the protocol on 31st May 2002. The KP entered into force on 16 February 2005, triggered by Russia’s ratification in November 2004 which fulfilled the requirement that at least 55 Parties to the Convention ratified the Protocol.

The Protocol sets out three 'flexible mechanisms' to help countries meet their obligations to cut emissions.

Emission Trading: Article 17 of the Kyoto Protocol allows Annex I Parties (basically, the industrialised nations) to purchase the rights to emit GHG from other Annex I countries which have reduced their GHG emissions below their assigned amounts. Trading can be carried out by intergovernmental emission trading, or entity-source trading where assigned amounts are allocated to sub-national entities.

Joint Implementation: Article 6 allows an Annex I Party to gain a credit (converted to As-signed Amounts) by investing in another Annex I country in a project which reduces GHG emissions.

Clean Development Mechanism: Article 12 allows an Annex I country (or companies in an Annex 1 country) which funds projects in developing countries (non-Annex I Party) to get credits for certified emission reductions providing that "benefits" accrue for the host country.

Tradable emission permits tie the emissions to a fixed ceiling, the costs of emission reduction being as low as possible.

The final assessment on compliance with the goals of the first commitment period of the KP will be made in the true up process after finalization of the last review reports in 2015.

The so called Doha Agreement extends the Kyoto Protocol until 2020, establishing a second commitment period. For those parties that have accepted the amendment, it entered into force on 31 December 2020.

Independently of the setting into force of the Doha Agreement, the European Community has fixed its goal in the so called Effort Sharing Decision (Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020), with the goal of a 20% cut of emissions below the 1990 emission level by 2020. The ESD also sets national emission targets for the member states with regards to their GDP. Luxembourg's target is −20% related to 2005 (not considering the sectors/sources regulated by the EU ETS).

In 2015, a new agreement for the period after 2020 was adopted and became thereby known as the Paris Agreement. The Paris Agreement was concluded on behalf of the Union on October 5, 2016 by Council Decision (EU) 2016/1841 (Council Decision (EU) 2016/1841 of 5 October 2016 on the conclusion, on behalf of the European Union, of the Paris Agreement adopted under the United Nations Framework Convention on Climate Change). Its objective is to keep the global temperature increase well below 2°C above pre-industrial levels and to pursue efforts to keep it to 1.5°C above pre-industrial levels. To do so, the so-called Effort Sharing Regulation (Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013) continues the commitments of the ESD and sets stronger greenhouse gas emission reduction targets for the period 2021-2030. For Luxembourg, a 40% reduction in 2030 in relation to its 2005 levels was fixed.

Nationally, Luxembourg formulated its own reaction to the Paris Agreement with its very first climate law (Loi du 15 décembre 2020 relative au climat), setting a 55% greenhouse gas emission reduction goal for 2030 compared to its 2005 levels (not considering the sectors/sources regulated by the EU ETS).

In 2021, the European Commission adopted the so-called LULUCF Regulation (Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2023 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU) that requires EU Member States to ensure that accounted greenhouse gas emissions from land use, land use change and forestry are balanced by at least an equivalent accounted removal of CO_2 from the atmosphere (known as the "no debit" rule) in the period 2021 to 2030. Although Member States already partly undertook this commitment individually under the Kyoto Protocol up to 2020, the LULUCF Regulation enshrines the commitment for the first time in EU law for the period 2021-2030.

1.1.2 Background information on greenhouse gas inventories

Following article 26 of Regulation (EU) 2018/1999 (Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulation (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing

Regulation (EU) No 525/2013 of the European Parliament and of the Council), Luxembourg is required to produce and regularly update a national greenhouse gas inventory. To date, greenhouse gas inventories have been produced for the years 1990 to 2022. Furthermore, article 26 of Regulation (EU) 2018/1999 also requires Luxembourg to submit a National Inventory Report (NIR) containing detailed and complete information on their inventories.

Responsible for the preparation of Luxembourg's National Greenhouse Gas Inventory and the related NIR is the Unité surveillance et évaluation de l'environnement of the Environment Agency, under the political responsibility of the Ministry for the Environment, Climate and Biodiversity.

The present NIR documents Luxembourg's GHG emission inventory in accordance with the updated UNFCCC reporting guidelines on annual inventories. It is aimed at complying with decisions 11/CP.4, 3/CP.5, 18/CP.8, 14/CP.11, 15/CP.17 and 24/CP.19 of the COP, decisions 14/CMP.1, 15/CMP.1, 16/CMP.1, 19/CMP.1, 6/CMP.3 of the CMP, decision 18/CMA.1 of the CMA, and with Regulation (EU) 2018/1999 concerning a mechanism for monitoring Community GHG emissions and for implementing the Kyoto Protocol. It includes a description of the methodologies and data sources used for estimating emissions by sources and removals by sinks, a discussion of these estimates and their trends (including an analysis of the key source categories), and information on recalculation, uncertainties, quality assessment and quality control.

This report is an update of the previous NIR submitted in 2023.[6] It is based on data submitted to the UNFCCC in the Common Reporting Format (CRF) on 15th April 2024: submission 2024v1.[7]

The structure of this NIR follows, as much as possible, the outlines as set out in the updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 24/CP.19 (see document FCCC/CP/2013/10/Add.3)[8], as well as the annotated outline of the NIR that can be found on the UNFCCC website.[9]

This report was compiled by Dr Nora Becker (Environment Agency), Dr Max Wolter (Environment Agency), and Dr Marc Schuman (Environment Agency). Specific responsibilities for this 2024 NIR have been as follows:

Executive Summary:	Marc Schuman, Nora Becker, Max Wolter
Chapter 1:	Nora Becker, Max Wolter, Marc Schuman
Chapter 2:	Max Wolter, Nora Becker, Marc Schuman
Chapter 3:	Max Wolter, Nora Becker, Marc Schuman
Chapter 4:	Ermin Hadzic, Thomas Weiβ, Pierre Dornseiffer

6 Luxembourg's National Inventory Report dated 15 April 2023 (covering inventory years 1990 to 2022)

7 Submission 2024v1 can be downloaded from:
a) The Central Data Repository of the European Environment Information and Observation Network (EIONET) of the European Environment Agency (EEA): https://cdr.eionet.europa.eu/lu/eu/govreg/inventory/
b) The UNFCCC web site: https://unfccc.int/ghg-inventories-annex-i-parties/2024

8 http://unfccc.int/resource/docs/2006/sbsta/eng/09.pdf

9 Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol: http://unfccc.int/files/national_reports/annex_i_ghg_inventories/reporting_requirements/application/pdf/annotated_nir_outline.pdf

Chapter 5:	Marie-Josée Mangen
Chapter 6:	Tim Mirgain with the help of Georges Kugener and Peter Weiss (UBA Vienna);
Chapter 7:	Tim Mirgain, Fabien Wahl, Dominique Manetta, Tom Bechet
Chapters 8 & 9:	Marc Schuman
Chapter 10:	Marc Schuman, Nora Becker, Max Wolter
Chapter 11:	Marc Schuman, Nora Becker
Annexes 1 & 2 :	Marc Schuman, Nora Becker
Annex 3:	Marie-Josée Mangen
Annexes 4, 5, 6, 7	Marc Schuman, Nora Becker
Annex 8:	Martine Kemmer
References & Layout:	Nora Schintgen

The GHG inventory reviewed in the present NIR covers the period 1990-2022 and contains information on anthropogenic emissions by sources and removals by sinks for direct GHG (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3). With regard to indirect greenhouse gases (CO, NO_x, NMVOCs) and SO_2, though also recorded in this inventory, they are derived from the air pollutant emission inventory Luxembourg is compiling for the United Nations Economic Commission for Europe's Convention on Long-Range Transboundary Air Pollution (UN-ECE CLRTAP). Consequently, indirect GHG and SO_2 emissions are not discussed in this NIR. For more details on the emissions of these pollutants please refer to Luxembourg's Air Pollutant Emission Inventory and its related Informative Inventory report, which are both published on the Center on Emission Inventories and Projections website[10].

1.2 A Description of the national inventory arrangements

1.1.1 Institutional, legal and procedural arrangements

1.1.1.1 Overview of Luxembourg's obligations

Some obligations are directly linked with GHG emission reporting:

- Annual obligations under Regulation Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament

10 http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting

and of the Council as well as its related Commission Implementing Regulation (EU) 2020/1208 (Commission Implementing Regulation (EU) 2020/1208 of 7 August 2020 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and of the Council and repealing Commission Implementing Regulation (EU) No 749/2014) and Commission Delegated Regulation (EU) 2020/1044 (Commission Delegated Regulation (EU) 2020/1044 of 8 May 2020 supplementing Regulation (EU) 2018/1999 of the European Parliament and of the Council with regard to values for global warming potentials and the inventory guidelines and with regard to the Union inventory system and repealing Commission Delegated Regulation (EU) No 666/2014;

- Obligations under the UNFCCC. Relevant COP Decisions and Guidelines are:
    - Decision 3/CP.5 – Guidelines for the preparation of National Communications by Parties included in Annex I to the Convention, Part I: UNFCCC Reporting Guidelines on Annual Inventories (referring to Document FCCC/CP/1999/7) revised with Decision 18/CP.8 (referring to Document FCCC/CP/2002/8);
    - Decision 4/CP.5 – Guidelines for the preparation of National Communications by Parties included in Annex I to the Convention, Part II: UNFCCC Reporting Guidelines on National Communications (referring to Document FCCC/CP/1999/7) revised with Decision 19/CP.8 (referring to Document FCCC/CP/2002/8);
    - Document FCCC/CP/1999/7 – Review of the Implementation of Commitments and of other Provisions of the Convention – UNFCCC Guidelines on Reporting and Review revised with Document FCCC/CP/2002/8;
    - Decision 11/CP.4 – National communications from Parties included in Annex I to the Convention;
    - Document FCCC/CP/2001/13/Add.3 – Report of the Conference of the Parties on its seventh session, held at Marrakech from 29 October to 10 November 2001, Addendum, Part two: Action taken by the Conference of the Parties, Volume III (Decision 20/CP.7: Guidelines for national systems under Article 5, paragraph 1, of the Kyoto Protocol; Decision 21/CP.7: Good practice guidance and adjustments under Article 5, paragraph 2, of the Kyoto Protocol; Decision 22/C.7: Guidance for the preparation of the information required under Article 7 of the Kyoto Protocol; Decision 23/CP.7: Guidelines for review under Article 8 of the Kyoto Protocol).
    - Decision 24/CP.19 - Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention – introducing the 2006 IPCC Guidelines.
    - Decision 14/CMP.1: Standard electronic format for reporting Kyoto Protocol units.
    - Decision 15/CMP.1: Guidelines for the preparation of the information required under Article 7 of the Kyoto Protocol.
    - Decision 16/CMP.1: Land use, Land-use change and forestry.
    - Decision 17/CMP.1: Good practice guidance for land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol.
    - Decision 19/CMP.1: Guidelines for national systems under Article 5, paragraph 1, of the Kyoto Protocol.

- Decision 6/CMP.3: Good practice guidance for land use, land-use change and forestry activities under Artlcle 3, paragraphs 3 and 4, of the Kyoto Protocol.

- Decision 18/CMA.1: Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement.

Some provide, indirectly, information that can be used to produce GHG inventories:

- Annual obligations under the UNECE Convention on Long-Range Transboundary Air Pollution (*CLRTAP*) and its Protocols comprising the annual reporting of national emission data on SO_2, NOx, NMVOCs, NH_3, CO, TSP, PM_{10}, and $PM_{2.5}$ as well as on the heavy metals Pb, Cd and Hg and persistent organic hydrocarbons (*PAHs*), dioxins and furans and hexachlorobenzene (*HCB*);

- Annual obligations under Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants, (known as the "NEC Directive") comprising the annual reporting of national emission data on SO_2, NOx, NMVOCs and NH_3;

- Obligations under the European Pollutant Emission Register (EPER), which was the first Europe-wide register for emissions from industrial facilities both into air and water. The legal basis of EPER is Article 15 of the IPPC Directive (EPER Decision 2000/479/EU), which stipulates that information on environmental pollution has to be provided to the public. The reporting years under EPER were 2001 or 2002 and 2004. EPER was replaced by the European Pollutant Release and Transfer Register (E-PRTR) in 2007, which was established by the E-PRTR Regulation No 166/2006.

- Obligations under the framework of the European Union Emission Trading Scheme (EU-ETS) established by Directive 2003/87/EC of the European Parliament. It includes heavy energy-consuming installations in power generation and manufacturing. The activities covered are energy activities, the production and processing of ferrous metals, the mineral industry and some other production activities. From 2012 onwards, CO_2 emissions from aviation have also been included. For the trading period 2013–2020 the scope of the EU ETS has been further extended to include additional installations from the metal and chemical industry and compressor stations.

1.1.1.2 Luxembourg's National Inventory System

A new Grand-Ducal Regulation (GDR, 04/2017)- hereafter the "Regulation" – of April 2017 designates a Single National Entity, the National Inventory Compiler and the National GHG Inventory Focal Point. It also defines and allocates specific responsibilities for the realization of the GHG inventories both within the Single National Entity and within the other administrations and/or services that will be involved in the inventory preparation in the future. This Regulation also sets up a system for reporting on emissions of certain atmospheric pollutants under Directive (EU) 2016/2284, and more largely under the UNECE LRTAP Convention (CLRTAP). Consequently, the system put in place aims at reporting under both the UNFCCC and CLRTAP. Moreover, the Regulation proposes a national system for reporting on policies and measures and for reporting on projections of anthropogenic GHG emissions by sources and removals by sinks as required by Articles 37 and 39 Governance Regulation (Regulation (EU) 2018/1999).

1.1.1.2.1 Single National Entity and other cross-cutting roles

The Grand-Ducal Regulation designates the Minister having environment in his or her attributions as the "Single National Entity" (SNE). The SNE designates both the UNFCCC and CLRTAP National Focal Points (NFPs), but also the Inventory and Projections Focal Points as well as the Inventory and Projections Sectoral Experts. With regard to GHG inventory reporting under the UNFCCC and the Governance Regulation, the overall management of the SNE is assigned to the Inventory Focal Point that is presently located at the Environment Agency – *Unité surveillance et évaluation de l'environnement* – and which also acts as National Inventory Compiler (NIC) compiling and checking the information and GHG emission estimates coming from sector experts working in other administrations or services (Figure 1-1). The Inventory Focal Point and the NIC are actually the same person.[11]

The Environment Agency has therefore the "technical" knowledge and responsibility for the GHG inventories, but the "political" responsibility is staying with the Ministry for the Environment, Climate and Biodiversity – hereafter designated as MECB – acting as UNFCCC National Focal Point (NFP). Thus, it is the Department that officially submits the inventories and their related reports to the UNFCCC Secretariat and to the EC (see Article 11 of the Regulation).

Thus, Luxembourg has adopted an integrated approach to avoid redundant and overlapping activities in different administrative services. This concentration of air emissions reporting in one department also allows an improved consistency between different reporting schemes. As an example, indirect GHG and SO_2 emissions that are to be recorded in the GHG inventory are extracted and adapted from the CLRTAP/NEC reporting schemes.

With regard to inputs for the monitoring of GHG emissions, having E-PRTR managed by the *Unité surveillance et évaluation de l'environnement* of the Environment Agency (and EU ETS also within the Environment Agency) ensures easy access to facilities' reported fuel and/or emissions that are subsequently integrated in GHG emissions calculations. The Environment Agency also gathers information from establishments and installations subordinated to operational permits to carry out certain activities, the so-called "*établissements classés*". There, too, valuable information for the inventories is found. More details on these AD and, sometimes, EF sources are presented in Section 1.3.

With regards to outputs from the *Unité surveillance et évaluation de l'environnement*, not only are they used for the various inventory reporting obligations (GHG, CLRTAP, NEC), but also for other reporting activities, such as those linked to Spatial Data Information (such as the EC INSPIRE Directive[12]) and under the Shared Environmental Information System.[13] Of course, these are also used for various national publications, as well as, for defining policies and measures (PaMs).

Figure 1-1 *summarizes the organisation* of the GHG reporting in Luxembourg in accordance with the national Regulation for setting-up a National Inventory System (NIS), as well as the data flow process that is implied by the setting-up of the NIS. The *Unité surveillance et évaluation de l'environnement* of the Environment Agency not only collects and validates AD, EFs, parameters and emission estimates from sector experts, but also produces emission estimates. This flexibility is introduced in Luxembourg's system to ensure a better quality for the reporting of GHG emissions.

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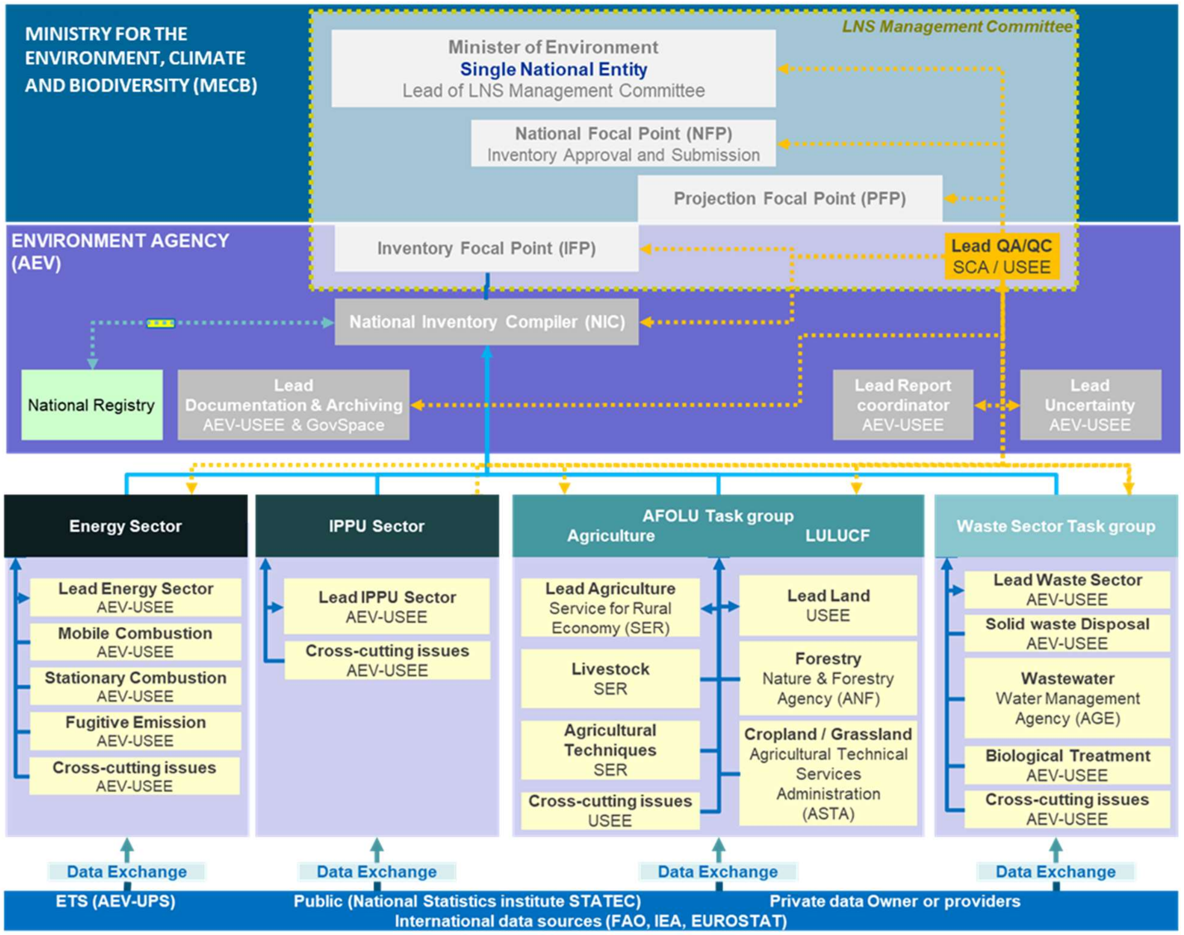
11 Luxembourg being a small country, its administrations and public services are small too. Hence, it is frequent that its staff members wear different hats. Nevertheless, this conjunction of responsibilities makes sense.
The Environment Agency is also the Inventory Focal Point for reporting under the CLRTAP and Directive (EU) 2016/2284.

12 http://inspire.jrc.it/.

13 http://ec.europa.eu/environment/seis/index.htm.

Figure 1-1- Luxembourg's NIS and data flow process according to the regulation of April 2017



1.1.1.2.2 Specific responsibilities for the GHG Inventory compilation and development process

Article 4 of the Regulation indicates that the Single National Entity designates sectoral experts. Articles 6 and 8 describe the tasks of the Inventory Focal Point and of the Sectoral Experts. In a few words, the Inventory Focal Point – i.e. the Environment Agency – provides sector experts for all the IPCC Sectors except Agriculture and Wastewater Handling (Figure 1-1). It is also the Agency that:

- manages the NIS and coordinates the work on GHG Inventories by informing the experts of any changes and evolutions in the Guidelines;
- as National Inventory Compiler (NIC), compiles the GHG emissions estimates produced by sector experts;
- prepares the NIR (notably on the basis of chapters received from the sector experts), including the Key Category Analysis (KCA) and the calculation of the uncertainties;
- prepares and defines work plans to secure timely data supply;
- assists sector experts in their assignments and their training;
- defines and approves, together with sector experts, activity/background data (AD), emission factors (EF), methods to estimate GHG emissions;
- archives the relevant information on the inventories and the NIS;

- implements recommendations from the quality assurance/quality control (QA/QC) annual exercise (section 1.5).

Article 8 describes the tasks that fall to sector experts, among others:

- choice of the best methods to evaluate GHG emissions, using IPCC Guidelines (these methods have to be approved by the Single National Entity as indicated above);
- collection of the necessary AD and EFs;
- calculation of emission estimates;
- recalculation of emission estimates when possible and desirable: new AD sources, new parameters, new methods, etc.;
- proceeding with first quality checks (using, inter alia, tools embedded in CRF Reporter that allow to verify completeness and consistency);
- preparation of the NIR relevant chapters.

Finally, Article 10 indicates that activity/background data providers have to transmit quality AD using formats, and respecting the deadlines, defined by the Single National Entity.

Table 1-1– CRF sector responsibilities within the NIS

CRF Sector	AD	Choice of EFs	Emissions estimation methods
Energy, excl. road transportation – CRF 1 except 1A3b	AEV – STATEC	AEV	AEV
Road transportation – CRF 1A3b	AEV – STATEC – SNCT	AEV	AEV
Industrial Processes – CRF 2	AEV	AEV	AEV
Agriculture – CRF 3	ASTA – SER	ASTA – SER	ASTA – SER
LULUCF – CRF 4	ANF – SER – ASTA - AEV	ANF – SER – ASTA - AEV	ANF – SER – ASTA – AEV
Waste – CRF 5A, 5B & 5D	AEV	AEV	AEV
Wastewater Handling – CRF 5B	AGE	AGE	AGE

Abbreviations:

Ministry of Agriculture:

ASTA = Agriculture Technical Services Administration (*Administration des Services Techniques de l'Agriculture*): https://agriculture.public.lu/de/dienststellen/asta.html

SER = Agriculture Economic Service (*Service d'Economie Rurale*) https://agriculture.public.lu/de/dienststellen/ser.html:

Ministry of the Economy:

STATEC = National Statistical Institute: http://www.statec.public.lu/fr/index.html

Ministry for the Environment, Climate and Biodiversity: http://www.emwelt.lu/:

ANF = Nature & Forestry Administration (*Administration de la Nature et des Forêts*)

AEV = Environment Agency (*Administration de l'Environnement*)

AGE = Water Management Administration (*Administration de la Gestion de l'Eau*): http://www.eau.public.lu/

Ministry for Mobility and Public Works:

SNCT = Technical Vehicle Inspection Administration (*Société Nationale de Contrôle Technique*): http://www.snct.lu/

1.1.1.2.3 Luxembourg’s emissions trading registry

Luxembourg’s emissions trading registry has been operational since 2005 and serves both as registry for the EU Emissions Trading Scheme, and as the national registry for Luxembourg as a Party of the Kyoto Protocol.

Since July 2013, Luxembourg's national registry was migrated to a European based consolidated system operated by the European Commission. Please refer to Annex 7: for more information on the consolidated system.

1.1.1.2.4 Changes to Luxembourg’s national system

No changes have been applied to Luxembourg’s national system since the previous submission 2023v1.

1.1.2 Overview of inventory planning, preparation and management

The main planning of Luxembourg's GHG inventory is performed once a year during summer at the so called Decision Making Body meeting: a meeting between the Director of the Environment Agency, the head of the Unité surveillance et évaluation de l’environnement, the quality manager, and the national inventory compiler.

During the meeting, the quality manger and the national inventory compiler present an overview of the activities, during the previous reporting year, including information on audits and fulfilments of last year’s improvement plan. On the basis of this report, the quality management system (QMS) is judged by the director and the head of the Unité surveillance et évaluation de l’environnement, in collaboration with the quality manager and the national inventory compiler. If required, measures to optimize the QMS are defined. Finally, the improvement plan is elaborated on the basis of the previously conducted discussions. It consists of two parts:

Quality management improvement plan: bases on findings of internal and external audits; it also includes a training plan for sector experts.

Inventory improvement plan: bases on particular findings of reviews of the GHG inventory.

The decision making body prioritises the recommended improvements (including a timeline and responsibilities) and cares for associated resources.

Table 1-2 gives an overview on the tasks of inventory preparation together with a typical timeline.

Table 1-3 gives an overview on the registry related tasks for providing the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol including a timeline.

Finally, an official approval process has been established between the Single National Entity (SNE, Environment Agency) and the UNFCCC National Focal Point (NFP, MECB). Thus, the SNE notifies the NFP, in writing, that the inventory has been compiled according to the rules established by the UNFCCC and uploads the submission onto the Sharepoint data archive (see Section 1.2). The NFP informs the Minister in charge of environmental affairs accordingly. Upon acceptance, the NFP uploads the submission from the Sharepoint archive onto the UNFCCC submission portal and onto the European central data repository hosted by the EEA.

Table 1-2– Inventory preparation timeline

Task	Description	Deadline
Decision making body meeting	Evaluation of the fulfilment of the previous improvement plan Preparation of a plan for QMS and inventory improvement, i.a. based on audit and review findings.	Summer
Kick-Off	Meeting of sector experts, quality manager and national inventory compiler; definition of a work plan	Summer
Activity data collection	Collection of activity data, including contracting out studies.	November 1st
Inventory preparation	Estimation of emissions for all sources, including collection of background data.	December 1st
Compilation of national inventory	Stocking the database and transfer to CRF reporter ; key category analysis and uncertainty assessment	December 31
Quality checks	Tier 1 and Tier 2 QA/QC activities	December
Compilation of report (Short-NIR)	Compilation of an inventory report "Short NIR" and submission to the European Commission (Regulation (EU) 2018/1999)	January 15
Preparation of NIR	Compilation of the National Inventory Report	January - March
EU Submission NIR	Submission of the National Inventory Report to the EC	March 15
UNFCCC Submission NIR	Submission of the National Inventory Report to the UNFCCC	April 15
Archive submission	All relevant calculation and documentation files as well as the NIR are archived on Sharepoint	May

Table 1-3– Timeline for registry related tasks

Task	Description	Deadline
Standard Electronic Format (SEF)	Compilation of the SEF for the previous year	January 15
Information on changes in the national registry	Preparation of the chapter on the changes in the national registry, which is part of the NIR	March 15
Information on accounting of Kyoto Protocol units	Preparation of the chapter on information on the accounting of Kyoto Protocol units, which is part of the NIR. Compilation of the files for the Standard Independent Assessment Report (SIAR), which are submitted together with the NIR.	March 15

1.2 Inventory preparation, and data collection, processing and storage

Luxembourg's greenhouse gas inventory for the period 1990 to 2022 was compiled according to the recommendations for inventories set out in the revised UNFCCC reporting guidelines according to Decision 24/CP.19 and according to Article 3 of Commission Delegated Regulation (EU) 2020/1044. IPCC Guidelines have been applied as much as possible. These Guidelines are:

- the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[14];
- the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[15]

During the inventory preparation process, sector experts collect activity data, emission factors and all relevant information needed for estimating the emissions. The sector experts also have specific responsibilities regarding the choice of methods, data processing and archiving and for contracting studies, if needed. As part of the quality management system, the national inventory compiler approves the methodological choices. Sector experts are also responsible for performing Quality Control (QC) activities that are incorporated in the Quality Management System (QMS). All data collected together with emission estimates are archived on a central archiving system (see below), together with the well documented data sources in order to be able to perform future reconstructions of the inventory.

1.2.1 Data collection, processing and storage

For estimating GHG emissions, Luxembourg mostly used Microsoft Excel™ spreadsheets (Table 1-4).

Table 1-4 – Programs and software used for generating emission estimates

CRF Sector	Emissions calculated using …
Energy – CRF 1 – stationary combustion, fugitive emissions	MS Excel 2016
Energy – CRF 1 – mobile combustion	NEMO 5.0 and MS Excel 2016
Industrial Processes – CRF 2	MS Excel 2016
Agriculture – CRF 3	MS Excel 2016 and the add-in software Palisade @Risk 7.5 l
LULUCF – CRF 4	MS Excel 2016
Waste – CRF 5	MS Excel 2016

This way of proceeding offers a very flexible system that can be easily adjusted to new requirements. It is only for the estimation of road transportation emissions, where a dedicated model is used:

NEMO 5.0 is a Microsoft Windows™ software tool for the calculation of emissions from road transport. The emissions calculated include all major pollutants (CO_2, CO, CH_4, NOx, VOC, and PM) and several more (N_2O, NH_3, SO_2...). Data produced is then transformed using MS Excel spreadsheets into the UNFCCC common reporting format, according to the IPCC Guidelines, to comply with the reporting obligations under the UNFCCC.

14 http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

15 https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/#:~:text=The%202019%20Refinement%20was%20not,with%20the%202006%20IPCC%20Guidelines.

GHG emission estimates produced by the sector experts are then being centralized and verified by the Single National Entity (i.e. the National Inventory Compiler (Environment Agency)).

A centralised data management and archiving system (Sharepoint) has been implemented. This system is hosted by the National IT Administration, and access is password protected. This system enables sector experts to quickly and easily exchange and store data between administrations, which are not connected through a single network. The data stored on this system are backed up daily for the needs of data security. Furthermore, as part of the QMS, backups of the entire inventory information are made regularly on write-protected DVDs. This ensures the necessary documentation and archiving for future reconstruction of the inventory and for the timely response to requests during the review process.

For the generation of the CRF tables and the XML submission file, Luxembourg used the latest version of the UNFCCC's CRF-Reporter, i.e. v6.0.10_AR5. As a large number of GHG source categories are not occurring in Luxembourg, only around a hundred values per inventory year – other than notation keys – need to be transferred to the CRF-Reporter. This is why, so far, CRF Reporter has been "manually" populated by having recourse to "copy-paste" from Microsoft Excel™ inventory work files.

However, with the increasing number of LULUCF data, which needs to be transferred to the CRF-Reporter, this manual data transfer becomes prone to errors. Therefore, it is foreseen to centralise the emission estimates (and all the associated data such as EFs, AD, Documentation, etc) in a centralised database. Specific software tools embedded in this database would then allow the automatic data transfer into the CRF-reporter software, without the need of the "copy-paste" procedure. Currently, Luxembourg is in the process of switching to the centralised database, and it is expected that the automatic transfer will be used for the next submission. Nevertheless, this is not an absolute "must do" for Luxembourg since, as underlined above, yearly data to be included in CRF Reporter are not numerous. Furthermore, "manually" populating CRF Reporter offers concrete advantages compared to automated operations: mistakes and missing values can be directly identified, recalculations cross-checked, explanations for notation keys or recalculations not forgotten and documentation boxes filled accordingly when needed.

1.2.2 Quality assurance/quality control (QA/QC) procedures and extensive review of GHG inventory and KP-LULUCF inventory

QA/QC procedures are performed as defined in the QMS plan (see Chapter 1.5).

Quality assurance, control and plausibility assessments of the estimates are being performed through internal audits covering all sectors, by the SNE in collaboration with Umweltbundesamt Wien. In addition, various checking procedures, included in the CRF-Reporter software are undertaken.

The NIR is circulated after publication to experts that are involved in the estimation on greenhouse gas emissions in Luxembourg as identified by the National Inventory Compiler and the QA/QC manager.

Comments received from experts are considered for the inventory improvement plan.

1.3 Methodologies and Data Sources Used

The following table briefly presents the activity data (AD) sources, the types of emission factors (EF) used, as well as the methods applied for estimating GHG emissions reported in this submission. A more detailed listing can be found in CRF table Summary 3.

Table 1-5 – Methodologies, data sources and EFs used by Luxembourg – main CRF Sectors

	CO_2			CH_4			N_2O		
CRF Sector	Method applied	AD	EF	Method applied	AD	EF	Method applied	AD	EF
Energy – CRF 1 – stationary combustion, fugitive emissions	Tier 1 Tier 2	NS PS Q TÜV	D CS PS	Tier 1	NS PS Q TÜV	D CS	Tier 1	NS PS Q TÜV	D
Energy – CRF 1 – mobile combustion	CIV CS	NS SNCT	CS	CIV	NS SNCT	OTH D	CIV	NS SNCT	OTH
Industrial Processes – CRF 2	Tier 2 CS	NS PS	CS PS	NA	NO	NA	Tier 1	CS	D
Agriculture – CRF 3	Tier 1	EJ NS	D	Tier 1 Tier 2	EJ NS	CS D OTH	Tier 1 Tier 2	EJ NS	CS D
LULUCF – CRF 4	Tier 1 Tier 2	NS EJ	CS D	NA	NA	NA	Tier 1	NS EJ	D
Waste – CRF 5	NA	NA	NA	Tier 1	NS Q PS	CS D	Tier 1	NS Q PS	PS D

Note: for F-gases (IPCC Category 2F) methods applied = CS; AD = NS & Q; EF = CS.
Abbreviations:

CS = Country Specific CIV = NEMO D = IPCC Default

EJ = Expert Judgement NS = National Statistics OTH = Other PS = Plant Specific Data

Q = Specific Questionnaire/Survey/Annual Reports TÜV = TÜV Rheinland, *Emissionskataster für das Großherzogtum Luxemburg*, Köln, 1990

Detailed information on data sources for activity and emission data, as well as for EFs used by sector, can be found in the methodological chapters of this report (chapters 3 to 7). A few general comments are, however, presented in the next sub-sections.

1.3.1 Activity and background data

Data used to produce the annual air emission (including GHG) inventories are mainly:

- taken from official statistics published by the National Statistical Institute (STATEC). Concerning energy data (energy balance), STATEC has recently developped a new system for data collection, treatment, checking and compilation. This new system was implemented in such a way to ensure that both the needs of public administrations dealing with energy questions and the reporting obligations to the European regulation 1099/2008/EC on energy statistics and to the IEA (IEA Joint Questionnaires[16]), are fulfilled. The data sources and methodologies for preparing Luxembourg's energy balance as well as the new compilation system are described in STATEC 08_2010[17];
- extracted from statistical information received by other ministries and public administrations;
- coming from information supplied directly by facilities (annual reports, emission measurement reports);
- on occasion, from specific surveys or questionnaires and from expert judgements.

For large point sources – and after careful assessment of data plausibility – activity data that are reported by facilities are preferably used. Indeed, these data usually reflect the actual consumptions better than aggregated national statistics data, because the facility is supposed having the best information about its own emissions. Such plant specific data have been used for CRF sectors 1 and 2.

Besides plant specific data collected under EU legal requirements, national obligations are also a source of activity and emission data for single facilities. This is the case under the law for "établissements classés"[18] that imposes regular reporting obligations to those units – the "établissements classés" – which, by their activities, could represent a risk with regards to security, public health and convenience for both the citizens and the workers occupied in these units, as well as regards the environment.[19] These "établissements classés" could be public or private industrial or commercial establishments and craft industries, as well as single specific equipments or processes within an installation.

Most of the plant specific data, whether they are collected for European or national obligations, are actually transmitted and managed by the Environment Agency which eases a more systematic use of data provided directly by facilities. In particular, it is investigated

16 The energy balance is based on several databases mainly prepared by:

- Ministère de l'Economie
- Ministère de l'Environnement, du Climat et de la Biodiversité
- Ministère de la Mobilité et des Travaux publics (Département de la mobilité et des transports)
- Administration de l'environnement: Unité surveillance et évaluation de l'environnement, Unité permis et subsides, Registre des quotas d'émissions à effet de gaz de serre (ETS);
- Administration des Douanes et Accises (Ministère des Finances);
- Service Central de la Statistique et des Etudes Economiques (STATEC);
- Société Nationale des Chemins de fer Luxembourgeois (CFL)
- all relevant fuel importers and distributors;
- plant operators;

The methodology used to compile the enrgey balance follows the International Energy Agency (IEA) and Eurostat conventions. The aggregated balances are harmonised with the IEA tables.

17 http://www.statistiques.public.lu/catalogue-publications/bulletin-Statec/2010/PDF-Bulletin-8-2010.pdf

18 See http://www.environnement.public.lu/etablissements_classes/index.html (in French).

19 "Permitting activities", *i.e.* activities subordinated to a permit.

whether it will be feasible, both technically and legally, that facilities would report only once for various purposes – such as EU-ETS, E-PRTR, permitting activities, etc. – in order to avoid extra and unnecessary burden for them.

1.3.2 Emission factors

For EFs, besides country-specific and plant specific factors derived from emission data transmitted by facilities (see above), it is also made use of default IPCC values published in the 2006 IPCC Guidelines, as well as the 2019 Refinement to these Guidelines. Other sources for EFs are the EMEP/EEA air pollutant emission inventory guidebook — 2023[20] and national / international studies or calculations leading to country-specific EFs.

1.4 Description of key categories

The identification of key categories is described in Chapter 4 of the 2006 IPCC Guidelines. It stipulates that a key category is one that is prioritised within the National System because its estimate has a considerable influence on a country's total inventory of GHG in terms of the absolute level of emissions or removals, the trend in emissions or removals, or both. Any category meeting the 95% threshold in any year of the Level Assessment (LA) or in the Trend Assessment (TA) is considered a key category. Then, whenever a method used for the estimation of emissions/removals of a key category is not consistent with the requirements of the 2006 IPCC Guidelines, the method will have to be improved to reduce uncertainty, which is considered in the emission inventory improvement programme (see Chapter 10.4).

All notations, descriptions of identification and results for key categories included in this section are based on the 2006 IPCC Guidelines. The identification includes all reported GHG CO_2, CH_4, N_2O, HFC, PFC and SF_6, and all IPCC categories.

The key category analysis was performed using the Tier 1 approach based on submission 2024v1. It comprises a level assessment for all years between 1990 and 2022, as well as a trend assessment for the trend of the year 2022 with respect to base year emissions, i.e. 1990 (1995 for F-gases). Key categories have been identified excluding LULUCF categories and also for the full inventory including LULUCF.

1.4.1 GHG inventory (including and excluding LULUCF)

1.4.1.1 Level Assessment (Tier 1)

The key categories (LA) identified for 2022 are listed in Table 1-6 (excl. LULUCF) and Table 1-8 (incl. LULUCF). The 15 key categories without LULUCF comprise 7815.2 Gg CO_2e in 2022, which is a share of 95.40% of Luxembourg's total GHG emissions, excluding LULUCF.

20 https://www.eea.europa.eu/publications/emep-eea-guidebook-2023

Table 1-6 – 2022 key categories (Tier 1, LA) excluding LULUCF based on emission data reported in submission 2024v1

IPCC category	Category name	Fuel	Gas	2022 emissions in Gg CO2e	Share in 2022 national total GHG emissions (excl. LULUCF)
1A1	Fuel combustion - Energy industries	gaseous	CO_2	119.4	1.46%
1A1	Fuel combustion - Energy industries	other	CO_2	103.1	1.26%
1A2	Fuel combustion - Manufacturing Industries and Construction	liquid	CO_2	292.6	3.57%
1A2	Fuel combustion - Manufacturing Industries and Construction	solid	CO_2	153.2	1.87%
1A2	Fuel combustion - Manufacturing Industries and Construction	gaseous	CO_2	427.9	5.22%
1A2	Fuel combustion - Manufacturing Industries and Construction	other	CO_2	116.7	1.42%
1A3b	Road Transportation	gasoline	CO_2	977.9	11.94%
1A3b	Road Transportation	Diesel oil	CO_2	3173.3	38.73%
1A4	Fuel combustion – Other sectors	Liquid	CO_2	698.2	8.52%
1A4	Fuel combustion – Other sectors	gaseous	CO_2	701.8	8.57%
2A1	Cement production		CO_2	368.9	4.50%
2C1	Iron & steel production		CO_2	79.4	0.97%
3A	Enteric fermentation		CH_4	420.7	5.14%
3B	Manure management		CH_4	99.5	1.22%
3D1	Direct N_2O emissions from managed soils		N_2O	82.7	1.01%
All	Sum of all 2022 key categories	all	all	7815.2	95.40%

Table 1-7 specifies for which years any source category has been identified as key category (LA) for from 1990 to 2022 (excl. LULUCF).

Table 1-7 – Key categories (Tier 1, LA) excluding LULUCF of submission 2024v1: 1990-2022

IPCC source category	gas	fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1A1	CO2	gaseous									X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A1	CO2	other																							X	X	X	X	X	X	X	X	X	X	X
1A2	CO2	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO2	solid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO2	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO2	other																											X	X	X	X	X	X	X
1A3b	CO2	gasoline	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A3b	CO2	diesel oil	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO2	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO2	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A5	CO2	liquid										X																							
2A1	CO2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2A3	CO2																											X							
2C1	CO2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3A	CH4		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3B	CH4							X	X	X	X	X	X	X	X						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3D1	N2O		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5A	CH4							X	X	X	X	X	X	X	X	X	X		X	X		X					X								

Table 1-8 indicates which source categories – including LULUCF - have been identified as key categories (LA) for 2022. The 17 key categories comprise 8539.6 Gg CO_2e in the year 2022, which is a share of 95.26% of Luxembourg's 2022 total GHG emissions, including LULUCF.

Table 1-8 – 2021 key categories (Tier 1, LA) including LULUCF based on emission data recorded in submission 2024v1

IPCC	IPCC source category	Fuel	Gas	2022 emissions in Gg CO_2e	Share in 2022 national total GHG emissions (incl. LULUCF)
1A1	Fuel combustion - Energy industries	gaseous	CO_2	119.36	1.33%
1A1	Fuel combustion - Energy industries	other	CO_2	103.05	1.15%
1A2	Fuel combustion – Manufacturing industries and construction	liquid	CO_2	292.63	3.26%
1A2	Fuel combustion – Manufacturing industries and construction	solid	CO_2	153.21	1.71%
1A2	Fuel combustion – Manufacturing industries and construction	gaseous	CO_2	427.85	4.77%
1A2	Fuel combustion – Manufacturing industries and construction	other	CO_2	116.66	1.30%
1A3b	Fuel combustion – Transport - Road transportation	gasoline	CO_2	977.89	10.91%
1A3b	Fuel combustion – Transport - Road transportation	diesel oil	CO_2	3173.28	35.40%
1A4	Fuel combustion – Other sectors	liquid	CO_2	698.18	7.79%
1A4	Fuel combustion – Other sectors	gaseous	CO_2	701.77	7.83%
2A1	Cement production		CO_2	368.94	4.12%
2C1	Iron and steel production		CO_2	79.44	0.89%
3A	Enteric fermentation		CH_4	420.68	4.6f9%
3B	Manure management		CH_4	99.54	1.11%
3D1	Direct N_2O emissions from managed soils		N_2O	82.68	0.92%
4A1	Forest Land remaining Forest Land		CO_2	680.28	7.59%
5A	Solid waste disposal		CH_4	44.17	0.49%
all	Sum of all 2022 key categories	all	all	8539.6	95.26%

Table 1-9 specifies for which years any source category has been identified as key category (LA) for from 1990 to 2022 (incl. LULUCF).

The key category with the highest contribution to the national total emissions in 2022 is *1A3b Road Transportation – diesel oil (CO_2)*. The contribution to the national total emissions in the base year was 10.10%, whereas in 2022 this contribution has increased to

38.73%.[21] This strong increase is due to the general increase of road performance, but also due to a shift from gasoline to diesel driven vehicles. Category *1A3b Road Transportation – diesel oil (CO_2)* is the most important category in terms of emission trends and, since 1990 emissions have increased by 147%.

The second most important source of greenhouse gas emissions in 2022 in Luxembourg is *1A3b Road Transportation – gasoline (CO_2).* Its contribution to national total emissions is 11.94% for 2022 compared to 10.02% in the base year, followed by *1A4 – Other sectors-gaseous fuels (CO_2)* with a contribution of 8.57% in 2022 (2.67% in 1990).

The key category with the highest contribution to national removals is *4.A.1 Forest land remaining forest land (CO_2)*. In the key category analysis including LULUCF it is the 5th largest category in the level assessment (7.59%) in 2022 and is also a key category in the trend assessment.

1.4.1.2 Trend Assessment (Tier 1)

Table 1-10 presents the key categories (excluding and including LULUCF) according to the trend assessment for the year 2022 as compared to the base year.

21 The percentages given here are those obtained by the level assessment excluding LULUCF.

Table 1-9 – Key categories (Tier 1, LA) including LULUCF based on emission data recorded in submission 2024v1: 1990-2022

IPCC source category	gas	fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1A1	CO_2	gaseous						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A1	CO_2	other									X	X	X	X	X		X							X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO_2	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO_2	solid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO_2	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO_2	other																								X	X	X	X	X	X	X	X	X	X
1A3b	CO_2	gasoline	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A3b	CO_2	diesel oil	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO_2	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO_2	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A5	CO_2	liquid										X																							
2A1	CO_2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2A3	CO_2							X	X	X	X	X	X	X		X				X			X				X	X	X	X	X	X	X		
2C1	CO_2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3A	CH_4		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3B	CH_4							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3D1	N_2O		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4A1	CO_2				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4B2	CO_2										X				X	X		X	X	X	X	X	X	X	X										
4C2	CO_2, N_2O																				X	X	X	X	X										
5A	CH_4		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X

Table 1-10 –Key categories (excluding and including LULUCF) according to the trend assessment for 2022.

IPCC Category	Category Name	Fuel	GHG	TA excl. LULUCF	TA incl. LULUCF
1A1	Energy Industries	other	CO_2	X	
1A2	Manufacturing Industries and Construction	gaseous	CO_2		X
1A2	Manufacturing Industries and Construction	solid	CO_2	X	X
1A2	Manufacturing Industries and Construction	liquid	CO_2	X	X
1A3b	Road Transportation	diesel oil	CO_2	X	X
1A3b	Road Transportation	gasoline	CO_2	X	X
1A4	Other Sectors	gaseous	CO_2	X	X
2A3	Glass Production		CO_2	X	X
2C1	Iron & Steel Production		CO_2	X	X
3A	Enteric Fermentation		CH_4	X	X
4A1	Forest Land remaining FL		CO_2		X

Source: Environment Agency

1.4.2 Comparison with the key category analysis from CRF Table 7

The results of the automatic key category analysis in the CRF Reporter (CRF Table 7) are shown in Table 1-11. Cells filled in grey refer to categories which have not been identified as key category for 2022 by Luxembourg's key category analysis. Cells with diagonal stripes refer to categories which have been identified as key category for 2022 by Luxembourg's key category analysis. These differences, which only occur in the trend assessment, are due to a different level of aggregation of the the sub-categories, for example, the category 1A3b was considered as a whole in the CRF reporter key category analysis, while Luxembourg's key category analysis splits 13Ab into 5 sub-categories corresponding to the fuel types (diesel oi, gasoline, LPG, biomass, and other fossil fuels).

Table 1-11 - Results of the automatic key category from the CRF Reporter (Table 7) for the year 2022. Cells filled in grey refer to categories which have not been identified as key category for 2022 by Luxembourg's key category analysis. Cells with diagonal stripes refer to categories which have been identified as key category for 2022 by Luxembourg's key category analysis.

KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	X	X	X	X
1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	X	X	X	X
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	X	X	X	X
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CO2	X	X	X	X
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	X		X	X
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	X	X	X	X
1.A.3.b Road Transportation	CO2	X	X	X	X
1.A.4 Other Sectors - Liquid Fuels	CO2	X	X	X	X
1.A.4 Other Sectors - Gaseous Fuels	CO2	X	X	X	X
2.A.1 Cement Production	CO2	X	X	X	X
2.C.1 Iron and Steel Production	CO2	X	X	X	X
3.A Enteric Fermentation	CH4	X	X	X	X
3.B Manure Management	CH4	X	X	X	X
3.D.1 Direct N2O Emissions From Managed Soils	N2O	X		X	X
4.A.1 Forest Land Remaining Forest Land	CO2	X	X		X
5.A Solid Waste Disposal	CH4	X			X

1.5 Information on the QA/QC plan including verification and treatment of confidentiality issues where relevant

The overall responsibility for the establishment and existence of a Quality Management System (QMS), in order to prepare the national inventory of greenhouse gases and air pollutants, lies with the Environment Agency (Administration de l'environnement, AEV).

Being designated by a grand-ducal regulation (GDR, 08/2007) as the single national entity (SNE), the AEV, has the overall technical responsibility for the national GHG Inventory. Political responsibility lies with the Ministry for the Environment, Climate and Biodiversity (MECB). Within the AEV, the Unité surveillance et évaluation de l'environnement is responsible for the following tasks:

The National Inventory Compiler (NIC):

- supervises the inventory preparation process for various obligations as outlined below;
- is the national inventory focal point to the Ministry (MECB).

The national, European and international obligations are:

- UNECE Convention on Long Range Transboundary Air Pollution and its protocols
- UNFCCC
- European Union:
  - EU Governance Regulation (Regulation (EU) 2018/1999)
  - NEC Directive (2001/81/EC)
  - Ambient Air Quality Directive (2008/50/EC).

1.5.1 Quality Policy

The quality policy is the central aspect of a Quality Management System. It defines the understanding of quality in relation to all topics of inventory preparation and specifies its basic principles.

The single national entity has:

- to establish and maintain the quality policy and quality objectives regarding GHG Inventories;
- to promote the quality policy and quality objectives regarding GHG Inventories throughout the organisation to increase awareness, motivation and involvement;
- to ensure focus on the fulfilment of the Kyoto Protocol and the requirements of the IPCC GPG Chapter 8 QA/QC;
- to ensure that appropriate processes are implemented to enable requirements of the IPCC GPG Chapter 8 QA/QC (and other interested parties) to be fulfilled and quality objectives to be achieved;
- to ensure that an effective and efficient QMS is established, implemented and maintained in order to achieve these quality objectives;
- to ensure the availability of necessary resources;
- to review the Quality Management System periodically;
- to decide on actions regarding the quality policy and quality objectives regarding GHG Inventories;
- to decide on actions for the improvement of the Quality Management System;
- to decide on actions for the improvement of national GHG inventories.

1.5.2 Quality Management System Build-up

The build-up of the Quality Management System (QMS) of the GHG emission reporting was outsourced and supervised by SEG Umwelt-Service GmbH until 2018[22]. Since 2018, the QMS has been internalized within AEV in collaboration with Umweltbundesamt Wien.

Luxembourg's QMS follows a Plan-Do-Check-Act-Cycle (PDCA-cycle)[23], which is an accepted model for pursuing a continual improvement of performance according to international standards and is in line with procedures described in decision 19/CMP.1 and in the IPCC Good Practice Guidance.

Due to Luxembourg's clear extent, its QMS deals with a manageable quantity of documents. Following are the specifications of Luxembourg's Quality Management System:

- firm build-up with a quality manual consisting of a chart with all relevant documents, handling instructions and deadlines for check (Figure 1-2);
- good manageability (instead of a complex system);
- usable and effective quality control procedures (user-friendly, clearly arranged).

Since the QMS has been implemented in the year 2008, it has evolved continuously and many improvements have already been realised.

The QMS shall ensure and continuously improve the quality (measured by transparency, accuracy consistency, comparability, completeness (TACCC) and timeliness) of Luxembourg's GHG Inventory in order to fulfil the party's obligations. The QMS therefore supplies procedures to:

- check integrity, correctness and completeness of data;
- identify errors and omissions;
- reduce uncertainties of emission estimates;
- document and archive inventory calculation sheets and background data.

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22 SEG Umwelt-Service GmbH, Auf der Haardt 2, D – 66693 Mettlach, http://www.seg-online.de
23 http://www.asq.org/learn-about-quality/project-planning-tools/overview/pdsa-cycle.html

1.5.3 QMS Structure

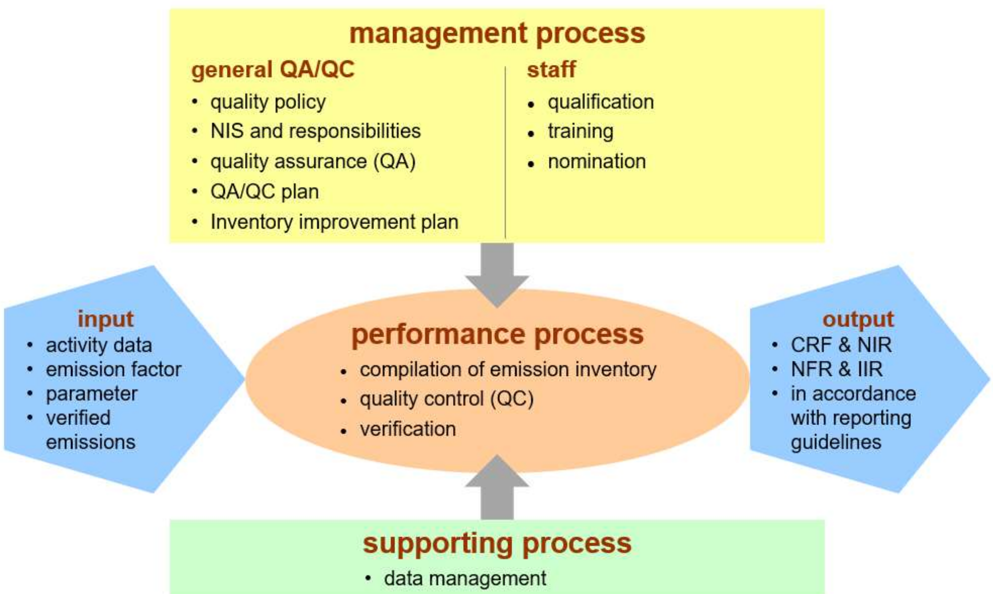
Luxembourg's Quality Management System (QMS) of the GHG Inventory is organised in three layers (Figure 1-2):

Performance processes: Performance processes directly concern the compilation of the GHG Inventory. They comprise input data, data acquisition, calculations, and generation of CRF tables and NIR as well as quality control checks and the outcomes of the NIR and CRF-tables.

Management processes: Management processes control the system's performance by defining quality objectives, responsibilities, quality assurance procedures, improvement plans and the personnel's qualifications and obligations.

Supporting processes: Supporting processes assist the system's performance by providing technical requirements and standards.

Figure 1-2 – QMS structure



1.5.4 Quality Manual

The applied quality manual adopts the structure of the QMS and is divided in management, performance and supporting processes.

For each process, a list of related documents exists with information on content, handling, interval of document check and planned improvement. An extract of the quality manual is given below (Figure 1-3).

Figure 1-3 – Extract of QA/QC Manual

	QA/QC procedure	purpose	document	content	handling	interval of document check
management processes	quality policy	basis of the implemented quality management system	quality policy	obligation to prepare and improve the emission inventory according the demands resulting from ● UNFCCC, Kyoto protocol, Paris Agreement ● EU MMR ● UNECE/LRTAP and its protocols & amendments, ● EU NECD	the head of administration, National Focal Point (NFP), Inventory Focal Point (IFP/NIC), (former National Inventory Compiler (NIC)) and Quality Manager (QM) -> check validity of quality policy -> adjustment if necessary -> announcement	yearly before kick-off meeting
	general QA/QC	organisation of inventory work	definitions and list of abbreviations	explanation of important terms and abbreviations that are used	Inventory Focal Point (IFP/NIC) and Quality Manager (QM) -> check validity -> adjustment if necessary	yearly before kick-off meeting
			Luxembourg's National Inventory System	organisation of Luxembourg's National System, organigram, position of QA/QC within the organisation, handling of submission	"Règlement grand-ducal du 24 avril 2017 relatif à la mise en place d'un système national pour la surveillance, l'évaluation et la déclaration des émissions de gaz à effet de serre et des polluants atmosphériques et la déclaration d'autres informations ayant trait au changement climatique et à la pollution atmosphérique." RGD dictates handling of submission ● AEV -> EIONET, ● MEV -> UNFCCC ● MEV oder AEV -> UNECE/LRTAP Inventory Focal Point (IFP/NIC) and Quality Manager (QM) -> check validity -> adjustment if necessary -> announcement	yearly before kick-off meeting
			responsibilities	personnel involved in inventory work (collection of activity data, selection of emission factors and methods, calculation of emissions, data compilation, uncertainties, recalculations, identification of key categories, etc.)	nomination of sector experts and data suppliers according RGD; IFP/NIC and quality manager check validity -> adjustment if necessary -> announcement	yearly before kick-off meeting
	personnel		nomination	nominations of sector experts and data suppliers according RGD	nomination by minister of environment; IFP/NIC and quality manager check validity -> information of ministry if necessary -> nomination proposed by IFP/NIC	yearly before kick-off meeting or in case of staff changing the function/unit/devision, etc.
			personal file	proof of sector expert's qualification	sector experts complete their personal file	regular
	quality assurance	to support and complete quality control measures	Checklist for internal audit	checklist for performance of internal reviews (conformity with IPCC Guidelines, target-performance comparison)	internal audit of general aspects by quality manager, of sector specific aspects by IFP/NIC -> internal audit report -> QA/QC plan	yearly before kick-off meeting
		check of formal aspects	internal audit report	audited sectors, observations, proposed improvements	report prepared by quality manager and IFP/NIC -> generation of QA/QC plan	yearly before kick-off meeting
		check of applicability & comparisons	external audit report	audited sectors, observations, proposed improvements	report prepared by external persons or organisations -> generation of QA/QC plan	obligatory
			audit list	date, audit character, audited sectors, auditors, hence prepared audit reports and QA/QC plans	auditlist completed by IFP/NIC and quality manager	regular
			inconsistencies	procedure for handling of inconsistencies (that are detected during compilation of inventory, in internal or external audits)	documenting and archiving of indication of inconsistency (audit report, annotation) -> informing of IFP/NIC and quality manager -> entry of proposals for improvement in QA/QC plan	yearly before kick-off meeting
	improvement plan	list of objectives and proposed actions in order to improve inventory's quality	improvement plan	QAQC plan, inventory improvement plan, priority list	result of internal and external audits; documenting of detected inconsistencies or possibilities for improvement in QA/QC plan by IFP/NIC and quality manager -> definition of deadlines -> check if objectives have been achieved during the following audits	regular
			Criteria for the priorizitation of the QAQC plan	criteria for the priorizitation of the QAQC plan	QAQC plan is set up according the criteria for the priorizitation;	yearly before kick-off meeting
performance processes	inventory		Inventory timetable'	timetable for inventory planning and preparation, sector specific timetable for inventory planning and preparation, QAQC timetable, submission deadlines	IFP/NIC, quality manager and sector experts check validity -> adjustment if necessary -> announcement per mail	yearly before kick-off meeting
			calculation sheets	calculated emissions; information on activity data, data suppliers (QA/QC), emission factors, calculation methods and special events; information on completeness, revisions and planned improvements of emission data	sector experts complete their calculation sheets -> transfer to IFP/NIC before deadline; check of document by IFP/NIC and quality manager; check of data content by sector expert	yearly before kick-off meeting
			NIR and CRF-tables	national greenhouse gas inventory	sector experts submit calculation sheets to IFP/NIC before deadline -> IFP/NIC generates CRF-tables and compiles NIR -> submission of crf-tables and NIR to EU and UNFCCC	regular according the deadlines
			IIR and NFR-tables	national air pollutant emission inventory	sector experts submit calculation sheets to IFP/NIC before deadline -> IFP/NIC generates NFR-tables and compiles IIR -> submission of NFR-tables and IIR to EU and UNECE/LRTAP	regular according the deadlines
	quality control	activities to assess and maintain the quality of the inventory being compiled	sector specific QA/QC Checklist	Accuracy checks on data acquisition and calculations, verification of activity data, emission factors and methods	performance by sector experts before submission; completion of checklists; archiving of checks; transmission of completed checklists in common with NIR data to IFP/NIC	yearly before kick-off meeting
			checklist data supplier	validation of data that are submitted by plant operators and other organisations	performance by data supporter before submission; check and archiving by sector expert	yearly before kick-off meeting

supporting	**data management**	definition of data naming and archiving	**data flow**	cooperation between the competent authorities and organisations; exchange and archiving of data and information	sector experts calculate emissions and perform data validation checks -> submission of calculations to IFP/NIC -> IFP/NIC validates methods, activity data and emission factors, generates crf-tables and compiles NIR; IFP/NIC and quality manager perform internal audit on NIR compilation -> generation of a QA/QC plan including proposed improvements -> information of sector experts and implementation of improvements	yearly before kick-off meeting
			data management on CTIE	instruction for data naming and archiving	IFP/NIC designates access authorisation	yearly before kick-off meeting

Sources: SEG Umwelt-Service GmbH and Environment Agency.

1.5.5 Inventory Timetable

The inventory timetable gives several schedules to control the performance of inventory compilation, quality control and quality assurance procedures, implementation of inventory improvements and inventory publication (see Table 1-2 in Section 1.1.2).

In addition, there are summaries of deadlines regarding EU and UNFCCC submissions.

1.5.5.1 Timetable for inventory planning and preparation

This schedule refers to general inventory work:

- Yearly meetings of the inventory work group and the decision making body
- Key category analysis
- Uncertainty analysis
- Generation of CRF-tables
- NIR preparation and finalisation
- NIR and CRF submission
- Publication and archiving of NIR
- Consideration and implementation of EU review recommendations
- Consideration and implementation of UNFCCC review recommendations
- Internal and external training
- Documentation and archiving

1.5.5.2 Sector specific timetable for inventory planning and preparation

This schedule refers to sector specific compilation work and quality control checks:

- Collection of activity data, emission factors and other parameters
- Calculation of emissions and removals
- Quality check of data, comparison with previous years, documentation of calculations and assumptions
- Uncertainty analysis
- Completion of checklists and other QC activities
- Documentation and archiving

1.5.5.3 QA/QC timetable

This schedule especially refers to QA procedures:

- Internal audit
- Implementation of internal review recommendations
- Yearly meetings of the inventory work group and the decision making body
- QA/QC training for the National Inventory Compiler and the sector experts.

1.5.6 Quality Control and Quality Assurance procedures

The first steps to implement quality control and quality assurance procedures have already been undertaken but need further improvement. The current status and planned improvements are described in the following sub-sections.

Figure 1-4 – QA/QC Procedures

<table>
<tr><td>Does NOT require knowledge of the emission source category</td><td>Requires knowledge of the emission source category</td></tr>
<tr><td>general</td><td>source specific</td></tr>
<tr><td colspan="2">QC procedures
Sector experts (1st party) performed throughout preparation of inventory</td></tr>
<tr><td>TIER 1</td><td>TIER 2</td></tr>
<tr><td>Data validation, calculation sheet (check of formal aspects)</td><td>Preparation of NIR, comparision with Guidelines (check of applicability, comparisions)</td></tr>
<tr><td colspan="2">QA procedures
Quality manager (2nd or 3rd party; staff not directly involved, preferably independent) performed after inventory work was finished</td></tr>
<tr><td colspan="2">TIER 1
Basic, before submission</td></tr>
<tr><td></td><td>Internal audit /EU ‘initial check `
(Expert Peer Review)</td></tr>
<tr><td></td><td>Evaluate if TIER 2 QC is effectively performed (check if methodologies are applicable)</td></tr>
<tr><td colspan="2">TIER 2
extensive</td></tr>
<tr><td>System audit by Umweltbundesamt (Audit)</td><td>ICR by UNFCCC (Expert Peer Review)</td></tr>
<tr><td>Evaluate if TIER 2 QC is effectively performed</td><td>Evaluate if TIER 2 QC is effectively performed (Check if methodologies are applicable)</td></tr>
</table>

Sources: Umweltbundesamt Austria, SEG Umwelt-Service GmbH and Environment Agency.

1.5.6.1 Quality Control procedures

The following Quality Control procedures are conducted:

a) Yearly meeting of the decision making body (the decision making body consists of the head of the AEV, the National Inventory Compiler and the quality manager) in order to appoint responsibilities, priorities and schedules for inventory work.

b) Checklists for data supplier that have to be completed by external suppliers of input data in order to assure the reliability of reported data.

c) Checklists for validation of data that have to be completed by sector experts until data are transmitted to the National Inventory Compiler. An example of a data validation checklist is given in Figure 1-5.

Figure 1-5 – Data Validation Checklist

Data:	1990 - 2xxx																	
Source:	CRF	XXX		Snap	XX XX													
	Activity data			check done			Emission factor			check done			Emissions			check done		
Greenhouse gas	CO2	CH4	N2O	Remarks	Date	Person	CO2	CH4	N2O	Remarks	Date	Person	CO2	CH4	N2O	Remarks	Date	Person
Content check																		
Trend checks																		
For each category, current inventory estimates should be compared to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any differences																		
Data plausible in comparison to other references																		
Check time series consistency																		
For each category check input data for temporal consistency in time series																		
Check methodological and data changes resulting in recalculations																		
Check that the effects of mitigation activities have been appropriately reflected in time series calculations																		
Check completeness																		
Confirm that estimates are reported for all categories and for all years from the appropriate base year to the period of the current inventory																		
For subcategories, confirm that entire category is being covered																		
Provide clear definition of "Other" type categories																		
Check that known data gaps that result in incomplete estimates are documented, including a qualitative evaluation of the importance of the estimate in relation to total emissions																		
Uncertainty estimation of data existent																		
data relying on a legal reporting commitment																		
Formal check																		
Collection of data is understandable																		
Check that assumptions and criteria for the selection of data are documented																		
Assumptions and criteria for the selection of data are documented																		
Cross-check descriptions of activity data, emission factors and other estimation parameters with information on categories and ensure that these are properly recorded and archived																		
Check for transcription errors in data input and reference																		
data correctly entered and transcribed																		
Confirm that bibliographical data references are properly cited in the internal documentation																		
Cross-check a sample of data from each source category (either measurements or parameters used in calculations) for transcription errors																		
Accurate data aggregation and correctness of calculations																		
Parameters and units are correctly recorded																		
Data fields are properly labelled																		
Data transmission of intermediate result is correct																		
Check that parameters and units are correctly recordedand that appropriate conversion factors are used																		
Units are properly labelled and correctly carried through from beginning to end of calculations																		
Conversion factors respectively temporal and spatial adjustment factors are correct																		
Data path and data coherence are understandable																		
Consistency given for the multiple use of data																		
Archiving of data and records ensured																		
Emissions complete																		
Uncertainty estimation of emissions existent																		
emission measurements in compliance with international accredited standards																		

	Uncertainties			check done		
Greenhouse gas	CO2	CH4	N2O	Remarks	Date	Person
Content check						
Check that uncertainties in emissions and removals are estimated and calculated correctly						
Check that qualifications of individuals providing expert judgement for uncertainty estimates are appropriate						
Check that qualifications, assumptions and expert judgements are recorded						
Formal check						
Designation of uncertainties is understandable						
Uncertainties complete						
documentation of fundamental assumption concerning expert judgement						
Archiving of data and records ensured						

Sources: Umweltbundesamt Austria, SEG Umwelt-Service GmbH and Environment Agency.

Checks for validation of data include:

- Checks of activity data (trend checks, time series consistency, completeness, check of assumptions and criteria for activity data, check for transcription errors in data input and reference)
- Checks of emission factors (trend checks, time series consistency, completeness, check of correct recording of units and the use of appropriate conversion factors, check of documentation of assumptions and criteria for the selection of emission factors, check for transcription errors in data input and reference)
- Checks of emissions (trend checks, time series consistency, completeness, check of documentation of assumptions and criteria for emissions, check for transcription errors in data input and reference, check of correct recording of units and the use of appropriate conversion factors)
- Check of uncertainties (check of correct calculation and estimation of uncertainties in emissions and removals).

Checklists for verification of methods, activity data and emission factors that have to be completed by sector experts.

Checklist for the monitoring of internal and external reviews that has to be completed by the quality manager.

1.5.6.2 Quality Assurance procedures

The following Quality Assurance procedures are conducted:

- Internal audit during NIR preparation time performed by the quality manager, the National Inventory Compiler and a consultant from the "Umweltbundesamt Wien". The internal review analyses every sector as well as the QMS system and checks:
  - whether inventory work and the inventory comply with IPCC 2006 Guidelines and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
  - whether data acquisition, calculation, referencing and archiving is handled according to the defined methods
  - whether there are enough resources for inventory work
  - whether relevant data are available and if the reliability of external data is guaranteed
  - whether the QMS system needs improvement
  - whether recommendations of EU reviews, UNFCCC reviews and previous internal audits have been considered and implemented.
- QA/QC training for the sector experts and the National Inventory Compiler during execution of the internal audit.
- Support by inventory experts from the "Umweltbundesamt Wien".
- External audits conducted by experts who provide support for inventory work, EU or UNFCCC.

1.5.6.3 Improvement plan

The results from internal and external audits are merged in the improvement plan. This plan lists the relevant sector, recommendations for improvement, priorities, responsibilities, deadlines and gives opportunity for attest.

The improvement plan is segmented in a QA/QC plan, that contains recommendations for the improvement of the QMS and an inventory improvement plan that contains recommendations for inventory improvement.

The decision making body prioritises the recommended improvements and cares for associated resources.

1.5.6.4 Planned improvements

The following QMS improvements shall be implemented in the following years:

- Strengthening the implementation of the QMS in general
- Improvement of QC procedures in the LULUCF sector
- Development of the four-eyes principle in inventory work
- Continuance in QA/QC training of NIC and sector experts

1.5.7 Archiving and documentation

Within the inventory system, a system for transparent documentation of inventory data and related information (special circumstances, assumptions etc.) is implemented. Archiving takes place on the Sharepoint server, where the data is secure for at least fifteen years.

As a principle every file shall be named clearly, shall be write/delete protected and supply relevant information concerning validity in the footer.

1.5.8 Treatment of confidentiality issues

In this submission, data is reported using the notation key C (confidential) in categories 2.C.7 - Metal Industry - Other (secondary aluminium production) and 2.G.4 Other – Manufacture Solvents.

1.6 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

Uncertainty estimates are an essential element of a complete inventory of greenhouse gas emissions and removals and requires a detailed understanding of the uncertainties of the respective input parameters. They should be derived for both the national level and the trend estimate, as well as for the component parts such as emission factors, activity data and other estimation parameters for each category.[24] Principally, two different TIER for the estimation of combined uncertainties are presented in the IPCC GPG: TIER 1 uses simple error propagation equations, while TIER 2 uses Monte Carlo.

TIER 1 is based upon error propagation and is used to estimate uncertainty in individual categories, in the inventory as a whole, and in trends between a year of interest and a base year. The key assumptions, requirements, and procedures are described here. TIER 1 should be implemented using Table 3.2 of the IPCC Guidelines for National Greenhouse Gas Inventories (2006).

The TIER 2 is based on a Monte Carlo analysis, which is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, the algorithms are complex functions and/or there are correlations between some of the activity sets, emissions factors, or both.

For submission 2024v1, only a Tier 1 uncertainty analysis has been carried out (for the inventory year 2022 and the base year). A new Tier 2 uncertainty analysis will only be carried out if important methodological changes have occurred.

1.6.1 Results using the Tier 1 (error propagation) approach

The input parameters and the results (level and trend uncertainties, with and without LULUCF) of the error propagation approach for the year 2022 and for the base year are presented in Table 1-12 and Table 1-13. Detailed uncertainty descriptions of the agriculture sector are provied in the relevant sections of Chapter 5.

The overall level uncertainty as well as trend uncertainty is being derived as the square root of the squares of the respective contributions.

For the inventory year 2022, the Tier 1 approach including LULUCF suggests an overall level uncertainty of 5.89% and a trend uncertainty of 5.78%, and the Tier 1 approach excluding LULUCF suggests an overall level uncertainty of 2.12% and a trend uncertainty of 2.08% (Table 1-12 and Table 1-13).

For the inventory base year, the Tier 1 approach including LULUCF suggests an overall level uncertainty of 2.17%, and the Tier 1 approach excluding LULUCF suggests an overall level uncertainty of 2.17% (Table 1-12 and Table 1-13).

Compared to the results of other countries, level and trend uncertainties in Luxembourg are on the lower end of the range. This is plausible, as the situation in Luxembourg is characterized by high energy consumption and emission density, compared to other countries. With respect to GHG emissions, energy data are among the best known, and also CO_2 emission factors are much better

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understood (can be derived from material balances) than emission factors of CH_4 or N_2O. The fact that at the same time, in the total inventory, N_2O and CH_4 emissions are less important, leads to a structurally lower uncertainty.

1.6.2 Tier 2 approach

The TIER 2 method is based on a Monte Carlo analysis, which is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, the algorithms are complex functions and/or there are correlations between some of the activity sets, emissions factors, or both.

A study from 2011 on the uncertainty assessment of Luxembourg's GHG inventory also covers a Tier 2 analysis. A full description of the Tier 2 uncertainty evaluation from 2011, including the required tables, can be provided upon request.

1.6.3 Scope for improvement

Compared to other countries, the uncertainty of the Luxembourg GHG inventory is quite small already. Still the potential exists to even further improve, as the share of (well understood) emissions from combustion sources is particularly large in the case of Luxembourg, and thus the highly uncertain area-related contributors to GHG inventories play a less important role.

Nevertheless, for Luxembourg like for many other countries where these features have been investigated, the emissions of N_2O from soils and the uptake/release of CO_2 from LULUCF are dominant factors to the uncertainty of the national GHG inventory. It is thus useful to focus on these parameters in an evaluation of possible improvements.

Opportunities may actually exist to provide the improvements needed to just these sectors which have been identified the major contributors to uncertainty. In the case of LULUCF, national activities that provide an update to the national forest inventory should be utilized also for the GHG inventory in order to remove major obstacles to data quality also affecting uncertainty. Moreover, close observation should be given to developments on validation of the currently used soil N_2O emission factors. Such validation exercises might provide a closure of the error margins.

Table 1-12 – Input parameters and results of the Tier 1 uncertainty analysis for the inventory year 2022 (submission 2024v1).

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
1A - Stationary Combustion - Gaseous Fuels	CO2	1035.80	1248.99	2%	0.5%	0.0206	0.0000	0.0416	0.0980	0.0002	0.0028	7.72E-06	
1A - Stationary Combustion - Gaseous Fuels	CH4	1.16	2.01	2%	50%	0.5004	0.0000	0.0001	0.0002	0.0000	0.0000	2.27E-09	
1A - Stationary Combustion - Gaseous Fuels	N2O	0.48	0.59	2%	50%	0.5004	0.0000	0.0000	0.0000	0.0000	0.0000	1.04E-10	
1A - Stationary Combustion - Liquid Fuels	CO2	1138.83	688.76	2%	0.5%	0.0206	0.0000	0.0079	0.0540	0.0000	0.0015	2.34E-06	
1A - Stationary Combustion - Liquid Fuels	CH4	3.71	2.52	2%	50%	0.5004	0.0000	0.0000	0.0002	0.0000	0.0000	3.53E-11	
1A - Stationary Combustion - Liquid Fuels	N2O	2.32	1.44	2%	50%	0.5004	0.0000	0.0000	0.0001	0.0000	0.0000	5.49E-11	
1A - Stationary Combustion - Other Fuels	CO2	32.46	218.69	8%	20%	0.2154	0.0000	0.0154	0.0172	0.0031	0.0019	1.32E-05	
1A - Stationary Combustion - Other Fuels	CH4	0.28	2.06	8%	50%	0.5064	0.0000	0.0001	0.0002	0.0001	0.0000	5.70E-09	
1A - Stationary Combustion - Other Fuels	N2O	0.35	2.60	8%	50%	0.5064	0.0000	0.0002	0.0002	0.0001	0.0000	9.08E-09	
1A - Stationary Combustion - Biomass	CH4	6.19	14.68	7%	50%	0.5049	0.0000	0.0008	0.0012	0.0004	0.0001	1.79E-07	
1A - Stationary Combustion - Biomass	N2O	1.65	9.80	7%	60%	0.6041	0.0000	0.0007	0.0008	0.0004	0.0001	1.72E-07	
1A - Stationary Combustion - Solid Fuels	CO2	5317.44	155.26	1%	3%	0.0316	0.0000	0.2758	0.0122	0.0083	0.0002	6.85E-05	
1A - Stationary Combustion - Solid Fuels	CH4	6.05	0.63	1%	50%	0.5001	0.0000	0.0003	0.0000	0.0001	0.0000	1.96E-08	
1A - Stationary Combustion - Solid Fuels	N2O	5.28	0.65	1%	50%	0.5001	0.0000	0.0002	0.0001	0.0001	0.0000	1.39E-08	
1A3a - Transport - Civil Aviation	CO2	0.21	0.54	10%	5%	0.1118	0.0000	0.0000	0.0000	0.0000	0.0000	3.78E-11	
1A3a - Transport - Civil Aviation	CH4	0.00	0.00	10%	100%	1.0050	0.0000	0.0000	0.0000	0.0000	0.0000	3.85E-17	
1A3a - Transport - Civil Aviation	N2O	0.00	0.00	10%	150%	1.5033	0.0000	0.0000	0.0000	0.0000	0.0000	1.22E-13	
1A3b - Road Transportation - Diesel Oil	CO2	1285.97	3173.28	2%	2%	0.0283	0.0001	0.1788	0.2489	0.0036	0.0070	6.23E-05	
1A3b - Road Transportation - Diesel Oil	CH4	0.76	2.12	2%	20%	0.2010	0.0000	0.0001	0.0002	0.0000	0.0000	6.44E-10	
1A3b - Road Transportation - Diesel Oil	N2O	2.28	37.63	2%	20%	0.2010	0.0000	0.0028	0.0030	0.0006	0.0001	3.27E-07	

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
1A3b - Road Transportation - Gasoline	CO2	1274.98	977.89	2%	2%	0.0283	0.0000	0.0074	0.0767	0.0001	0.0022	4.73E-06	
1A3b - Road Transportation - Gasoline	CH4	13.07	1.03	2%	20%	0.2010	0.0000	0.0006	0.0001	0.0001	0.0000	1.59E-08	
1A3b - Road Transportation - Gasoline	N2O	11.38	1.34	2%	20%	0.2010	0.0000	0.0005	0.0001	0.0001	0.0000	1.06E-08	
1A3b - Road Transportation - LPG	CO2	11.43	0.77	2%	2%	0.0283	0.0000	0.0006	0.0001	0.0000	0.0000	1.29E-10	
1A3b - Road Transportation - LPG	CH4	0.11	0.00	2%	40%	0.4005	0.0000	0.0000	0.0000	0.0000	0.0000	5.42E-12	
1A3b - Road Transportation - LPG	N2O	0.11	0.00	2%	100%	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	3.63E-11	
1A3b - Road Transportation - biomass	CH4	0.00	0.27	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.89E-11	
1A3b - Road Transportation - biomass	N2O	0.00	3.82	2%	20%	0.2010	0.0000	0.0003	0.0003	0.0001	0.0000	3.66E-09	
1A3b - Road Transportation - other fossil fuels	CO2	0.00	11.69	20%	2%	0.2010	0.0000	0.0009	0.0009	0.0000	0.0003	6.76E-08	
1A3b - Road Transportation - other fossil fuels	CH4	0.00	0.01	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	4.57E-14	
1A3b - Road Transportation - other fossil fuels	N2O	0.00	0.14	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	1.44E-11	
1A3c - Railways - liquid fuels	CO2	24.82	5.94	2%	2%	0.0283	0.0000	0.0009	0.0005	0.0000	0.0000	4.86E-10	
1A3c - Railways - liquid fuels	CH4	0.05	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.79E-13	
1A3c - Railways - liquid fuels	N2O	0.03	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	7.48E-14	
1A3c - Railways - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	4.54E-17	
1A3c - Railways - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	6.31E-17	
1A3c - Railways - other fossil fuels	CO2	0.00	0.02	20%	2%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.37E-13	
1A3c - Railways - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	1.87E-19	
1A3c - Railways - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	2.60E-19	
1A3d - Navigation - liquid fuels	CO2	1.31	0.54	2%	2%	0.0283	0.0000	0.0000	0.0000	0.0000	0.0000	1.76E-12	
1A3d - Navigation - liquid fuels	CH4	0.04	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.23E-13	
1A3d - Navigation - liquid fuels	N2O	0.10	0.03	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.58E-13	
1A3d - Navigation - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.49E-17	
1A3d - Navigation - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.30E-15	
1A3d - Navigation - other fossil fuels	CO2	0.00	0.00	20%	2%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.60E-15	
1A3d - Navigation - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	1.59E-21	
1A3d - Navigation - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	9.41E-18	

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
1A - other mobile machinery - liquid fuels	CO2	83.36	304.27	2%	2%	0.0283	0.0000	0.0193	0.0239	0.0004	0.0007	6.05E-07	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	CH4	0.72	0.20	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.20E-11	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	N2O	7.30	8.28	2%	20%	0.2010	0.0000	0.0003	0.0006	0.0001	0.0000	2.89E-09	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - biomass	CH4	0.00	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	4.34E-14	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - biomass	N2O	0.00	0.82	2%	20%	0.2010	0.0000	0.0001	0.0001	0.0000	0.0000	1.69E-10	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CO2	0.00	1.10	20%	2%	0.2010	0.0000	0.0001	0.0001	0.0000	0.0000	6.01E-10	1A2gvii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	1.23E-18	1A2gvii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	N2O	0.00	0.03	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	6.94E-13	1A2gvii, 1A4cii, 1A5b
1B2 - Fugitive Emission from Natural Gas	CO2	0.03	0.03	2%	100%	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	1.03E-12	
1B2 - Fugitive Emission from Natural Gas	CH4	21.92	26.36	2%	100%	1.0002	0.0000	0.0009	0.0021	0.0009	0.0001	7.69E-07	
2A1 - Cement Production	CO2	539.36	368.94	1%	3%	0.0269	0.0000	0.0004	0.0289	0.0000	0.0004	1.68E-07	
2A3 - Glass Production	CO2	53.57	2.36	2%	5%	0.0539	0.0000	0.0027	0.0002	0.0001	0.0000	1.86E-08	
2C1 - Iron & Steel Production	CO2	984.91	79.44	5%	5%	0.0707	0.0000	0.0473	0.0062	0.0024	0.0004	5.79E-06	
2C7 - Other Metal Industry	CO2	0.00	1.93	0.4%	50%	0.5000	0.0000	0.0002	0.0002	0.0001	0.0000	5.72E-09	
2D1 - Lubricant use	CO2	6.20	4.59	5%	50%	0.5025	0.0000	0.0000	0.0004	0.0000	0.0000	7.72E-10	
2D2 - Paraffin wax use	CO2	0.21	2.87	5%	100%	1.0012	0.0000	0.0002	0.0002	0.0002	0.0000	4.60E-08	
2D3 - solvent use	CO2	16.23	7.66	50%	50%	0.7071	0.0000	0.0003	0.0006	0.0001	0.0004	2.00E-07	
2D3 - urea-based catalysts	CO2	0.00	11.05	20%	5%	0.2062	0.0000	0.0009	0.0009	0.0000	0.0002	6.20E-08	

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
2F1a - Commercial refrigeration	F-gases	0.13	2.38	25%	25%	0.3536	0.0000	0.0002	0.0002	0.0000	0.0001	6.35E-09	
2F1b - Domestic refrigeration	F-gases	0.00	0.00	1%	1%	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	4.10E-18	
2F1d - Transport refrigeration	F-gases	0.44	1.56	2%	25%	0.2508	0.0000	0.0001	0.0001	0.0000	0.0000	6.16E-10	
2F1e - Mobile air-conditioning	F-gases	2.41	30.93	2%	25%	0.2508	0.0000	0.0023	0.0024	0.0006	0.0001	3.34E-07	
2F1f - Stationary air-conditioning	F-gases	0.04	2.40	25%	25%	0.3536	0.0000	0.0002	0.0002	0.0000	0.0001	6.60E-09	
2F2 - Foam blowing agents	F-gases	9.29	1.12	25%	5%	0.2550	0.0000	0.0004	0.0001	0.0000	0.0000	1.40E-09	
2F4a - Meter dose inhalers	F-gases	0.00	0.88	25%	0%	0.2500	0.0000	0.0001	0.0001	0.0000	0.0000	5.94E-10	
2F4b - Other	F-gases	1.50	0.03	25%	0%	0.2500	0.0000	0.0001	0.0000	0.0000	0.0000	5.54E-13	
2G - Other Product Manufacture and Use	F-gases	1.43	12.08	7%	0%	0.0660	0.0000	0.0009	0.0009	0.0000	0.0001	7.83E-09	
2G - Other Product Manufacture and Use	N_2O	8.37	5.08	20%	20%	0.2828	0.0000	0.0001	0.0004	0.0000	0.0001	1.28E-08	
3A - Enteric fermentation	CH_4	428.62	420.68	20%	0%	0.2000	0.0001	0.0097	0.0330	0.0000	0.0093	8.71E-05	total subcategory uncertainty
3Ba - Manure management	CH_4	87.49	99.54	20%	0%	0.2000	0.0000	0.0030	0.0078	0.0000	0.0022	4.88E-06	total subcategory uncertainty
3Bb - Manure management	N_2O	38.69	33.51	50%	0%	0.5000	0.0000	0.0005	0.0026	0.0000	0.0019	3.45E-06	total subcategory uncertainty
3D - Agricultural soils	N_2O	147.83	101.73	115%	0%	1.1500	0.0002	0.0001	0.0080	0.0000	0.0130	1.68E-04	total subcategory uncertainty
3G - Liming	CO_2	0.23	7.90	30%	0%	0.3000	0.0000	0.0006	0.0006	0.0000	0.0003	6.91E-08	total subcategory uncertainty
3H - Urea application	CO_2	0.00	0.05	15%	0%	0.1500	0.0000	0.0000	0.0000	0.0000	0.0000	7.92E-13	total subcategory uncertainty
3I - Other Carbon-containing Fertilizers	CO_2	5.82	2.16	30%	0%	0.3000	0.0000	0.0001	0.0002	0.0000	0.0001	5.18E-09	total subcategory uncertainty
4 - Land Use, Land-Use Change and Forestry	CO_2, N_2O	8.98	648.21	75%	0%	0.7500	0.0030	0.0504	0.0508	0.0000	0.0539	2.91E-03	total sector uncertainty
5A - Solid Waste disposal on Land	CH_4	103.25	44.17	8%	42%	0.4276	0.0000	0.0021	0.0035	0.0009	0.0004	9.69E-07	
5B1 - Composting	CH_4	0.00	7.14	5%	100%	1.0012	0.0000	0.0006	0.0006	0.0006	0.0000	3.15E-07	
5B1 - Composting	N_2O	0.00	4.05	5%	100%	1.0012	0.0000	0.0003	0.0003	0.0003	0.0000	1.02E-07	
5B2 - Anaerobic Digestion at Biogas Facilities	CH_4	0.00	22.90	7%	68%	0.6836	0.0000	0.0018	0.0018	0.0012	0.0002	1.52E-06	
5B2 - Anaerobic Digestion at Biogas Facilities	N_2O	0.00	0.22	85%	0%	0.8500	0.0000	0.0000	0.0000	0.0000	0.0000	4.30E-10	total subcategory uncertainty
5D - Wastewater treatment and discharge	CH_4	8.48	1.91	10%	50%	0.5099	0.0000	0.0003	0.0002	0.0002	0.0000	2.47E-08	
5D - Wastewater treatment and discharge	N_2O	4.56	4.19	10%	50%	0.5099	0.0000	0.0001	0.0003	0.0000	0.0000	3.77E-09	
						Inventory Uncertainty including LULUCF	**5.89%**				**Trend uncertainty incl. LULUCF**	**5.78%**	
						Total Inventory Uncertainty excluding	**2.12%**				**Trend uncertainty excl. LULUCF**	**2.08%**	

Table 1-13– Input parameters and results of the Tier 1 uncertainty analysis for the base year (submission 2024v1).

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%			
		input data	input data	input data Note A	input data Note A		refers to C instead of D	
1A - Stationary Combustion - Gaseous Fuels	CO2	1035.80	1248.99	2%	0.5%	0.0206	0.0000	
1A - Stationary Combustion - Gaseous Fuels	CH4	1.16	2.01	2%	50%	0.5004	0.0000	
1A - Stationary Combustion - Gaseous Fuels	N2O	0.48	0.59	2%	50%	0.5004	0.0000	
1A - Stationary Combustion - Liquid Fuels	CO2	1138.83	688.76	2%	0.5%	0.0206	0.0000	
1A - Stationary Combustion - Liquid Fuels	CH4	3.71	2.52	2%	50%	0.5004	0.0000	
1A - Stationary Combustion - Liquid Fuels	N2O	2.32	1.44	2%	50%	0.5004	0.0000	
1A - Stationary Combustion - Other Fuels	CO2	32.46	218.69	8%	20%	0.2154	0.0000	
1A - Stationary Combustion - Other Fuels	CH4	0.28	2.06	8%	50%	0.5064	0.0000	
1A - Stationary Combustion - Other Fuels	N2O	0.35	2.60	8%	50%	0.5064	0.0000	
1A - Stationary Combustion - Biomass	CH4	6.19	14.68	7%	50%	0.5049	0.0000	
1A - Stationary Combustion - Biomass	N2O	1.65	9.80	7%	60%	0.6041	0.0000	
1A - Stationary Combustion - Solid Fuels	CO2	5317.44	155.26	1%	3%	0.0316	0.0002	
1A - Stationary Combustion - Solid Fuels	CH4	6.05	0.63	1%	50%	0.5001	0.0000	
1A - Stationary Combustion - Solid Fuels	N2O	5.28	0.65	1%	50%	0.5001	0.0000	
1A3a - Transport - Civil Aviation	CO2	0.21	0.54	10%	5%	0.1118	0.0000	
1A3a - Transport - Civil Aviation	CH4	0.00	0.00	10%	100%	1.0050	0.0000	
1A3a - Transport - Civil Aviation	N2O	0.00	0.00	10%	150%	1.5033	0.0000	
1A3b - Road Transportation - Diesel Oil	CO2	1285.97	3173.28	2%	2%	0.0283	0.0000	
1A3b - Road Transportation - Diesel Oil	CH4	0.76	2.12	2%	20%	0.2010	0.0000	
1A3b - Road Transportation - Diesel Oil	N2O	2.28	37.63	2%	20%	0.2010	0.0000	

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%			
		input data	input data	input data Note A	input data Note A		refers to C instead of D	
1A3b - Road Transportation - Gasoline	CO2	1274.98	977.89	2%	2%	0.0283	0.0000	
1A3b - Road Transportation - Gasoline	CH4	13.07	1.03	2%	20%	0.2010	0.0000	
1A3b - Road Transportation - Gasoline	N2O	11.38	1.34	2%	20%	0.2010	0.0000	
1A3b - Road Transportation - LPG	CO2	11.43	0.77	2%	2%	0.0283	0.0000	
1A3b - Road Transportation - LPG	CH4	0.11	0.00	2%	40%	0.4005	0.0000	
1A3b - Road Transportation - LPG	N2O	0.11	0.00	2%	100%	1.0002	0.0000	
1A3b - Road Transportation - biomass	CH4	0.00	0.27	2%	20%	0.2010	0.0000	
1A3b - Road Transportation - biomass	N2O	0.00	3.82	2%	20%	0.2010	0.0000	
1A3b - Road Transportation - other fossil fuels	CO2	0.00	11.69	20%	2%	0.2010	0.0000	
1A3b - Road Transportation - other fossil fuels	CH4	0.00	0.01	20%	20%	0.2828	0.0000	
1A3b - Road Transportation - other fossil fuels	N2O	0.00	0.14	20%	20%	0.2828	0.0000	
1A3c - Railways - liquid fuels	CO2	24.82	5.94	2%	2%	0.0283	0.0000	
1A3c - Railways - liquid fuels	CH4	0.05	0.00	2%	20%	0.2010	0.0000	
1A3c - Railways - liquid fuels	N2O	0.03	0.01	2%	20%	0.2010	0.0000	
1A3c - Railways - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	
1A3c - Railways - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	
1A3c - Railways - other fossil fuels	CO2	0.00	0.02	20%	2%	0.2010	0.0000	
1A3c - Railways - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	
1A3c - Railways - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	
1A3d - Navigation - liquid fuels	CO2	1.31	0.54	2%	2%	0.0283	0.0000	
1A3d - Navigation - liquid fuels	CH4	0.04	0.00	2%	20%	0.2010	0.0000	
1A3d - Navigation - liquid fuels	N2O	0.10	0.03	2%	20%	0.2010	0.0000	
1A3d - Navigation - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	
1A3d - Navigation - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	
1A3d - Navigation - other fossil fuels	CO2	0.00	0.00	20%	2%	0.2010	0.0000	
1A3d - Navigation - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	
1A3d - Navigation - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%			
		input data	input data	input data Note A	input data Note A		refers to C instead of D	
1A - other mobile machinery - liquid fuels	CO2	83.36	304.27	2%	2%	0.0283	0.0000	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	CH4	0.72	0.20	2%	20%	0.2010	0.0000	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	N2O	7.30	8.28	2%	20%	0.2010	0.0000	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - biomass	CH4	0.00	0.01	2%	20%	0.2010	0.0000	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - biomass	N2O	0.00	0.82	2%	20%	0.2010	0.0000	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CO2	0.00	1.10	20%	2%	0.2010	0.0000	1A2gvii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	1A2gvii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	N2O	0.00	0.03	20%	20%	0.2828	0.0000	1A2gvii, 1A4cii, 1A5b
1B2 - Fugitive Emission from Natural Gas	CO2	0.03	0.03	2%	100%	1.0002	0.0000	
1B2 - Fugitive Emission from Natural Gas	CH4	21.92	26.36	2%	100%	1.0002	0.0000	
2A1 - Cement Production	CO2	539.36	368.94	1%	3%	0.0269	0.0000	
2A3 - Glass Production	CO2	53.57	2.36	2%	5%	0.0539	0.0000	
2C1 - Iron & Steel Production	CO2	984.91	79.44	5%	5%	0.0707	0.0000	
2C7 - Other Metal Industry	CO2	0.00	1.93	0.4%	50%	0.5000	0.0000	
2D1 - Lubricant use	CO2	6.20	4.59	5%	50%	0.5025	0.0000	
2D2 - Paraffin wax use	CO2	0.21	2.87	5%	100%	1.0012	0.0000	
2D3 - solvent use	CO2	16.23	7.66	50%	50%	0.7071	0.0000	
2D3 - urea-based catalysts	CO2	0.00	11.05	20%	5%	0.2062	0.0000	

IPCC category/Group	Gas	Base year emissions or removals	Year 2022 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%			
		input data	input data	input data Note A	input data Note A		refers to C instead of D	
2F1a - Commercial refrigeration	F-gases	0.13	2.38	25%	25%	0.3536	0.0000	
2F1b - Domestic refrigeration	F-gases	0.00	0.00	1%	1%	0.0141	0.0000	
2F1d - Transport refrigeration	F-gases	0.44	1.56	2%	25%	0.2508	0.0000	
2F1e - Mobile air-conditioning	F-gases	2.41	30.93	2%	25%	0.2508	0.0000	
2F1f - Stationary air-conditioning	F-gases	0.04	2.40	25%	25%	0.3536	0.0000	
2F2 - Foam blowing agents	F-gases	9.29	1.12	25%	5%	0.2550	0.0000	
2F4a - Meter dose inhalers	F-gases	0.00	0.88	25%	0%	0.2500	0.0000	
2F4b - Other	F-gases	1.50	0.03	25%	0%	0.2500	0.0000	
2G - Other Product Manufacture and Use	F-gases	1.43	12.08	7%	0%	0.0660	0.0000	
2G - Other Product Manufacture and Use	N2O	8.37	5.08	20%	20%	0.2828	0.0000	
3A - Enteric fermentation	CH4	428.62	420.68	20%	0%	0.2000	0.0000	total subcategory uncertainty
3Ba - Manure management	CH4	87.49	99.54	20%	0%	0.2000	0.0000	total subcategory uncertainty
3Bb - Manure management	N2O	38.69	33.51	50%	0%	0.5000	0.0000	total subcategory uncertainty
3D - Agricultural soils	N2O	147.83	101.73	115%	0%	1.1500	0.0002	total subcategory uncertainty
3G - Liming	CO2	0.23	7.90	30%	0%	0.3000	0.0000	total subcategory uncertainty
3H - Urea application	CO2	0.00	0.05	15%	0%	0.1500	0.0000	total subcategory uncertainty
3I - Other Carbon-containing Fertilizers	CO2	5.82	2.16	30%	0%	0.3000	0.0000	total subcategory uncertainty
4 - Land Use, Land-Use Change and Forestry	CO2, N2O	8.98	648.21	75%	0%	0.7500	0.0000	total sector uncertainty
5A - Solid Waste disposal on Land	CH4	103.25	44.17	8%	42%	0.4276	0.0000	
5B1 - Composting	CH4	0.00	7.14	5%	100%	1.0012	0.0000	
5B1 - Composting	N2O	0.00	4.05	5%	100%	1.0012	0.0000	
5B2 - Anaerobic Digestion at Biogas Facilities	CH4	0.00	22.90	7%	68%	0.6836	0.0000	
5B2 - Anaerobic Digestion at Biogas Facilities	N2O	0.00	0.22	85%	0%	0.8500	0.0000	
5D - Wastewater treatment and discharge	CH4	8.48	1.91	10%	50%	0.5099	0.0000	
5D - Wastewater treatment and discharge	N2O	4.56	4.19	10%	50%	0.5099	0.0000	
						Inventory Uncertainty including LULUCF	**2.17%**	
						Total Inventory Uncertainty excluding	**2.17%**	

1.7 General assessment of completeness

CRF table 9 on completeness has been filled for every reported year 1990 to 2022. It is expected that this table recapitulates all the explanations given for the notation keys reported in Luxembourg's GHG inventory for a given year since all the checks included in CRF Reporter were passed successfully by submission 2024v1. Hence, if missing information is encountered in CRF table 9 for some years, this is not due to a lack of explanations from the side of Luxembourg, but well due to conversion problems in CRF Reporter when the CRF tables are created.

A completeness overview by CRF category and by gas is presented in Table 1-14. In this section, some additional information is presented. An assessment of completeness for each CRF sector is given in the sector overview part of each of the sector chapters.

Table 1-14 - Completeness overview for submission 2024v1.

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
1. ENERGY	X	X	X				
A. Fuel Combustion	X	X	X				
1. Energy Industries	X	X	X				
a. public electricity & heat production	X	X	X				
b. petroleum refining	NO	NO	NO				
c. manufacture of solid fuels and other energy industries	NO	NO	NO				
2. Manufacturing industries & construction	X	X	X				
a. iron & steel	X	X	X				
b. non-ferrous metals	X	X	X				
c. chemicals	X	X	X				
d. pulp, paper & print	X (2000-2022)	X (2000-2022)	X (2000-2022)				
e. food processing, beverages & tobacco	X	X	X				
f. non-metallic minerals	X	X	X				
g. other	X	X	X				
3. Transport	X	X	X				
a. civil aviation	X	X	X				
b. road transportation	X	X	X				
c. railways	X	X	X				
d. navigation	X	X	X				
e. other transportation	NO	NO	NO				
4. Other sectors	X	X	X				
a. commercial/institutional	X	X	X				
b. residential	X	X	X				
c. agriculture/forestry/fish farms	X	X	X				
5. Other non-specified	X	X	X				
a. stationary	X (1990-2003)	X (1990-2003)	X (1990-2003)				
b. mobile	X	X	X				
B. Fugitive Emissions from Fuels	X	X	NO				
1. solid fuels	NO	NO	NO				
a. coal mining & handling	NO	NO	NO				
b. solid fuel transformation	NO	NO	NO				
c. other	NO	NO	NO				
2. oil & natural gas	NA	NA	NO				
a. oil	NA	NA	NO				
b. natural gas	X	X					
c. venting & flaring	X	X	NO				
d. other	NA	NA	NA				
C. CO_2 transport and storage	NO						
2. Industrial Processes and Product Use	X	NO	X	X	NO	X	NO

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
A. mineral products	X						
1. cement production	X						
2. lime production	NO						
3. glass production	X						
4. other process uses of carbonates	NO						
B. chemical industry	NO	NO	NO	NO	NO	NO	NO
1. ammonia production	NO	NO	NO				
2. nitric acid production			NO				
3. adipic acid production	NO		NO				
4. caprolactam, glyoxal and glyoxylic acid production	NO		NO				
5. carbide production	NO	NO					
6. titanium dioxide production	NO						
7. soda ash production	NO						
8. petrochemical and carbon black production	NO	NO					
9. fluorochemical production				NO	NO	NO	NO
10. other	NO	NO	NO	NO	NO	NO	NO
C. metal production	X	NO	NO	NO	NO	NO	NO
1. iron and steel production	X	NO					
2. ferroalloys production	NO	NO					
3. aluminium production	NO				NO	NO	
4. magnesium production	NO			NO	NO	NO	
5. lead production	NO						
6. zinc production	NO						
7. other	X (2016-2022)	NO	NO	NO	NO	NO	NO
D. non-energy products from fuels and solvent us	X						
1. lubricant use	X	NO	NO				
2. paraffin wax use	X	NO	NO				
3. other (solvent use & urea based catalysts)	X	NO	NO				
E. Electronics industry				NO	NO	NO	NO
1. integrated circuit or semiconductor				NO	NO	NO	NO
2. TFT flat panel display				NO	NO	NO	NO
3. photovoltaics				NO	NO	NO	NO
4. heat transfer fluid				NO	NO	NO	NO
5. other				NO	NO	NO	NO
F. Product uses as substitutes for ODS				X	NO	NO	NO
1. refrigeration and air conditioning				X	NO	NO	NO
2. foam blowing agents				X	NO	NO	NO
3. fire protection				NO	NO	NO	NO
4. aerosols				X (1992-2022)	NO	NO	NO
5. solvents				NO	NO	NO	NO
6. other applications				NO	NO	NO	NO
G. other product manufacture and use	NO	NO	X	NO	NO	X	NO

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
1. electrical equipment				NO	NO	X	NO
2. SF6 and PFCs from other product use				NO	NO	X	NO
3. N2O from product uses			X				
4. other	NO	NO	NO	X (2013-2022)	NO	NO	NO
H. Other	NO	NO	NO	NO	NO	NO	NO
3. Agriculture	X	X	X				
A. Enteric Fermentation		X					
1. cattle		X					
2. sheep		X					
3. swine		X					
4. other livestock (poultry, horses, deer, mules and asses, goats, other)		X					
B. Manure Management		X	X				
1. CH_4 emissions		X					
1. cattle		X					
2. sheep		X					
3. swine		X					
4. other livestock (poultry, horses, deer, mules and asses, goats, other)		X					
2. N_2O and NMVOC emissions			X				
1. cattle			X				
2. sheep			X				
3. swine			X				
4. other livestock (poultry, horses, deer, mules and asses, goats, other)			X				
5. indirect N_2O emissions			X				
C. Rice Cultivation		NO					
D. Agricultural Soils			X				
1. direct emissions from managed soils			X				
2. indirect emissions from managed soils			X				
E. Prescribed Burning of Savannas		NO	NO				
F. Field Burning of Agricultural Residues		NO	NO				
G. Liming	X						
H. Urea Application	x						
I. Other Carbon-containing Fertilisers	x						
J. Other	NO						
4. Land Use, Land-Use Change and Forestry	X	NO	X				
A. Forest Land	X	NO	NO				
1. forest land remaining forest land	X	NO	NO				
2. land converted to forest land	X	NO	NO				
B. Cropland	X	NO	X				
1. cropland remaining cropland	X	NO	X				
2. land converted to cropland	X	NO	X				
C. Grassland	X	NO	X				

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
1. grassland remaining grassland	NO	NO	NO				
2. land converted to grassland	X	NO	X				
D. Wetlands	X	NO	X				
1. wetlands remaining wetlands	NE,NO	NO	NO				
2. land converted to wetlands	X	NO	X				
E. Settlements	X	NO	X				
1. settlements remaining settlements	NO	NO	NO				
2. land converted to settlements	X	NO	X				
F. Other Land	X	NO	X				
1. other land remaining other land							
2. land converted to other land	X	NO	X				
G. Harvested Wood Products	NO						
H. Other	NO	NO	NO				
5. Waste	NO, IE	X	X				
A. Solid Waste Disposal	NO	X					
1. Managed waste disposal sites	NO	X					
2. Unmanaged waste disposal sites	NO	IE					
3. Uncategorized waste disposal sites	NO	NO					
B. Biological Treatment of Solid Waste		X	X				
1. Composting		X (1993-2022)	X (1993-2022)				
2. Anaerobic digestion at biogas facilities		X (1992-2022)	X (1998-2022)				
C. Incineration and Open Burning of Waste	IE	IE	IE				
1. Waste incineration	IE	IE	IE				
2. Open burning of waste	NO	NO	NO				
D. Wastewater Treatment and Discharge		X	X				
1. Domestic wastewater		X	X				
2. Industrial wastewater		NO	X				
3. Other		NO	NO				
E. Other	NO	NO	NO				
6. Other	NO	NO	NO	NO	NO	NO	NO
Memo Items	X	X	X				
International Bunkers	X	X	X				
aviation	X	X	X				
marine	X	X	X				
Multilateral Operations	NA	NA	NA				
CO_2 emissions from biomass	X						
CO_2 captured	NO						

Note: an X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

1.7.1 Sources and sinks

All sources and sinks included in the IPCC Guidelines are covered.

1.7.2 Gases

Both direct GHGs and indirect GHGs – NOx, CO, NMVOCs – and SO_2 are covered by Luxembourg's inventory.

1.7.3 Geographic coverage

The geographic coverage is complete. There is no part of the national territory not covered by the inventory.

1.7.4 Notation keys

The sources and sinks not considered in the inventory, but included in the IPCC Guidelines, are clearly indicated. The reasons for such exclusions are explained. In addition, the notation keys presented below are used to fill in the blanks in all the CRF tables.

Notation keys used in the NIR are consistent with those reported in the CRF tables. Notation keys used are those described on page 12 of document FCCC/CP/2013/10/Add.3 dated 22nd November 2013.

Allocations to categories may differ from Party to Party. The main reasons for different category allocations are different allocations in national statistics, insufficient information in national statistics and/or national methods, and the impossibility to disaggregate emission declarations.

IE (included elsewhere)

The notation key IE is used for emissions by sources and removals by sinks of GHG that have been estimated but included elsewhere in the inventory instead of the expected source/sink category. Where IE is used in the inventory, CRF table 9 indicates where (in the inventory) these emissions or removals have been included. Such deviation from the expected category is also explained.

NE (not estimated)

The notation key NE is used for existing emissions by sources and removals by sinks of GHG which have not been estimated. Where NE is used in an inventory for emissions or removals, CRF table 9 indicates why emissions or removals have not been estimated.

NA (not applicable)

The notation key NA is used for activities or processes in a given source/sink category that do not produce emissions or lead to removals of a specific gas.

NO (not occurring)

The notation key NO is used for activities or processes in a given source/sink category that do not occur within Luxembourg.

C (confidential)

The notation key C is used for emissions which could lead to the disclosure of confidential information if reported at the most disaggregated level. In this case, a minimum of aggregation is required to protect business information.

1.7.5 Transparency and completeness indexes

In Table 1-15, transparency and completeness of submission 2024v1 is presented. The exercise focuses on the inventory year 2022 and the sectoral report tables only. The level of detail for CRF sources and categories is up to 4 digits for the energy sector (e.g. IPCC Subcategory 1A1a) and 3 digits for the other sectors (e.g. IPCC Sub-category 4D3). Finally, only the 6 GHGs are covered by this exercise. The total number of estimates (including IE, NE, NA, NO, and empty cells in the CRF reporting tables) for each CRF sector is counted as well as the numbers reported as 'not estimated' and 'included elsewhere'.

Transparency and completeness indexes are calculated as follows:

- Transparency (TR) [%] = [1 – (number of IE/number of estimates)] * 100
- Completeness (CP) [%] = [1 – (number of NE/number of estimates)] * 100

Table 1-15 - Transparency and completeness indexes for submission 2024v1.

CRF Sector	Submission 2024v1				
	# estimates	*IE*	*NE*	*TR*	*CP*
Energy (sectoral approach) – CRF 1	90	0	0	100%	100%
Industrial Processes – CRF 2	144	1	0	99%	100%
Agriculture – CRF 3	57	3	0	95%	100%
LULUCF – CRF 4	66	0	1	100%	98%
Waste – CRF 5 (*)	60	3	4	95%	93%
Total	**417**	**7**	**5**	**98%**	**99%**

(*) IE from Waste includes waste incineration that is reported under IPCC Sub-category 1A1a since the energy produced while burning waste is recovered.

2 Trends in Greenhouse Gas Emissions

According to the Kyoto Protocol, Luxembourg's GHG emissions had to be 8% below base year emissions during the five-year commitment period from 2008 to 2012. The European Community and its Member States also had a common reduction target of 8%, which they decided to achieve jointly. In April 2002, the Council of the European Union has adopted a decision, the so-called "burden sharing agreement", which includes reduction targets for each Member State. Luxembourg agreed to reduce its GHG emissions for 2008–2012 by 28% compared to the base year emissions level. The second commitment period bridged the gap between the end of the 1st Kyoto period and the start of the new global agreement in 2020. Luxembourg, together with 27 other EU member states and Iceland, agreed to make further cuts by 20% of GHG emissions compared to 1990 (Doha Agreement). Nationally, Luxemburg set itself a GHG emission reduction target of -55% for 2030 compared to its 2005 levels in its climate law. This reduction is stronger than the one fixed in the Effort Sharing Regulation (-40% for 2030 compared to 2005 levels).

When estimating GHG emission composition and trends in Luxembourg, one should keep in mind that the IPCC methodology used for compiling GHG inventories is raising some peculiar issues for small countries, in particular because of the "territory" or "origin" principle underpinning it. Therefore, in Section 2.1, specific national circumstances are examined. These specific conditions are relating to socio-economic characteristics that have significant effects on Luxembourg's GHG total emissions when applying IPCC accounting rules. This first section is complemented by a discussion of how both the UNFCCC and the Kyoto Protocol are challenging Luxembourg's action with regard to climate change (Section 2.2) and by a general overview of the national circumstances (Section 2.3). Section 2.4 concludes this chapter with an overview of the main developments of and drivers to GHG emissions in Luxembourg since 1990.

2.1 National Circumstances

2.1.1 The Grand-Duchy of Luxembourg

The Grand-Duchy of Luxembourg has been an independent sovereign state since the Treaty of London was signed on 19 April 1839. The country is a parliamentary democracy in the form of a constitutional monarchy and is the second smallest Member State of the EU-28, after Malta. For many years, it has been characterized by high economic and demographic growth rates. The country is located in the heart of North-Western Europe and has direct borders with Belgium, Germany and France (Figure 2-1). It is therefore a crossroads for international trade and related transport flows, the most dynamic source of its GHG emissions.

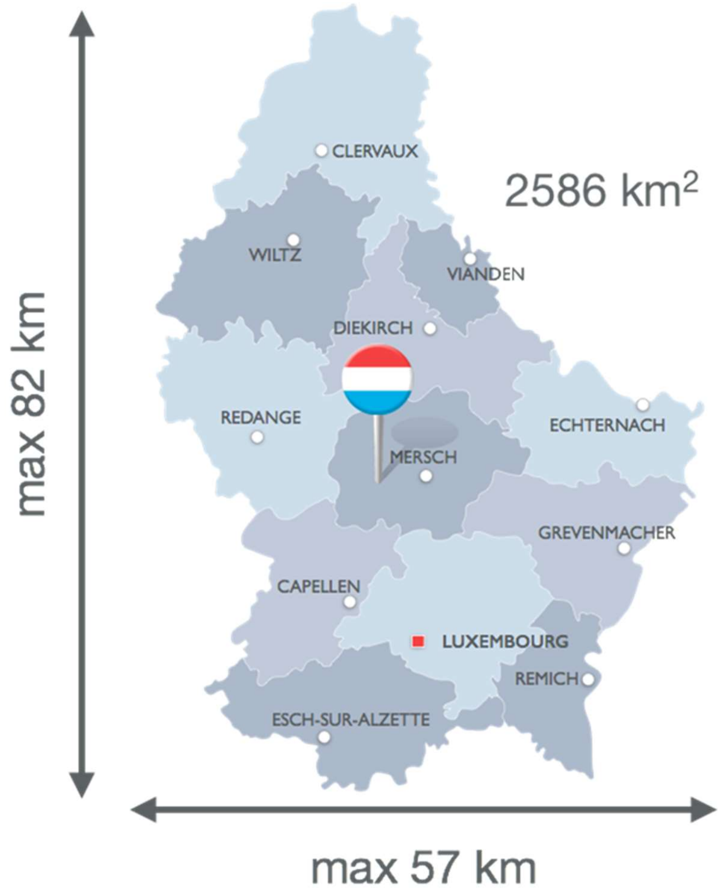
Luxembourg has a territory of 2 586 km². The maximum distance from North to South is some 82 km and from West to East about 57 km (Figure 2-2). In 2022, 84.5% of the total area of Luxembourg was agricultural land and land under forest. The built-up areas occupied 10.3% of the total surface while land covered by water and transport infrastructure covered about 5.2% (Table 2-1 & Figure 2-3).

The North of Luxembourg is a part of the Ardennes and is called "Ösling". Its altitude is at an average of 400 to 500 meters above sea level. The "Ösling" landscape is affected by hills and deep river valleys, as for instance the Sure (Sauer) river. With 560 m, the highest elevation is called the "Kneiff" in Wilwerdange. In the South of Luxembourg lies the rank "Gutland", which belongs to the "Lothringer Stufenland". This area has higher population and industrial densities than "Ösling". The lowest point in the country, called "Spatz" (129 m above sea level), is located at the confluence of the Moselle and the Sure rivers in Wasserbillig. The most important rivers are the Moselle, the Sure, the Our – all three delimiting the border with Germany – and the Alzette.

Figure 2-1 – GEOGRAPHIC LOCATION OF LUXEMBOURG

Source: Google Maps.

Figure 2-2 – LUXEMBOURG SIZE



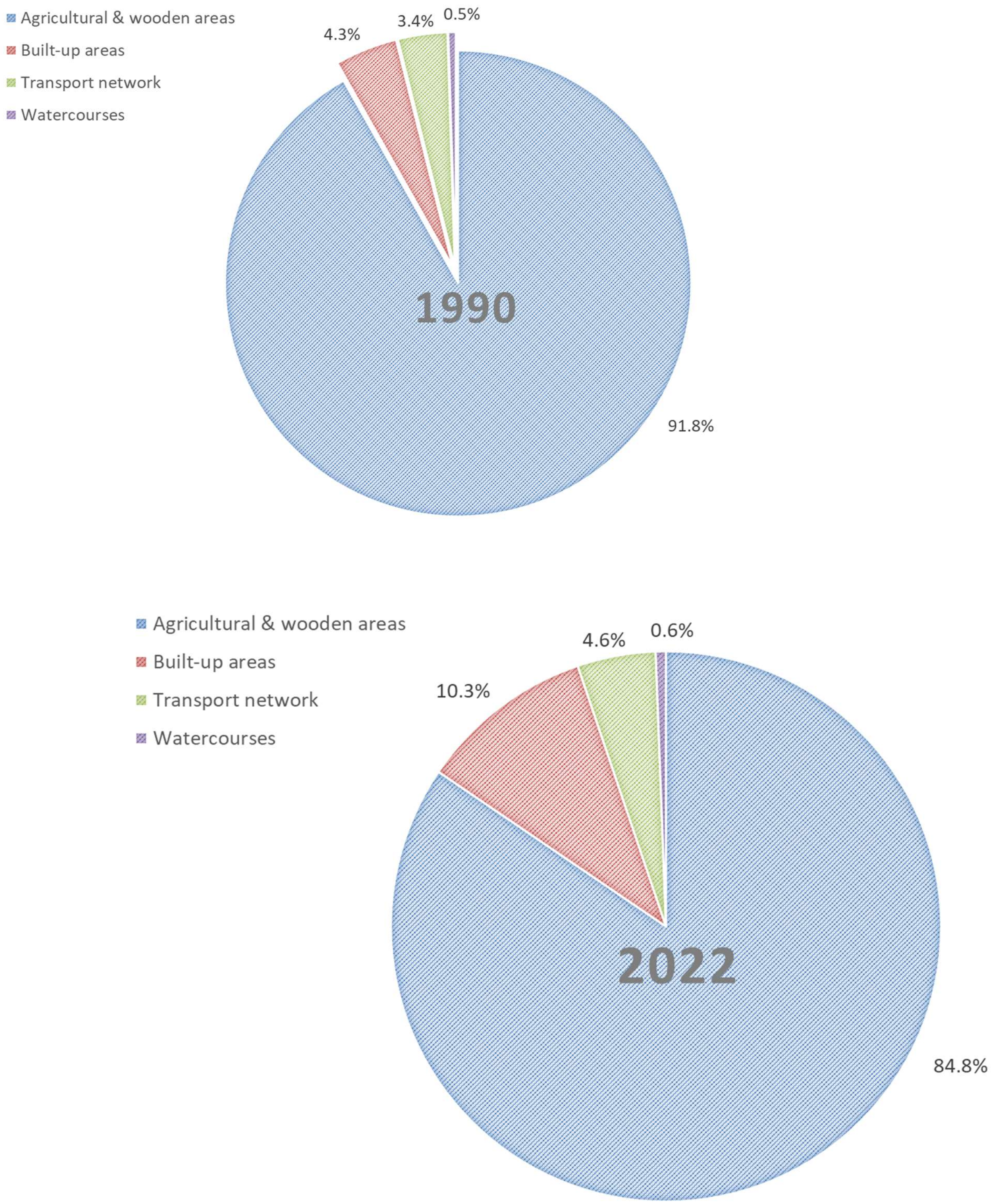
Source: Google Maps.

Table 2-1 – Land use in Luxembourg: 1972-2022

Percentages	1972	1990	2000	2010	2015	2016	2017	2018	2019	2020	2021	2022
Total land	100	100	100	100	100	100	100	100	100	100	100	100
Agriculture & wooden area	93.2	91.8	87.4	85.7	85.3	85.1	85.1	85.2	84.8	84.7	84.6	84.5
Built-up area	3.1	4.3	8.1	9.3	9.7	9.8	9.8	9.7	10.1	10.1	10.2	10.3
of which industrial area & other	NA	NA	2.7	3.0	3.0	3.1	3.1	3.0	3.1	3.1	3.2	3.2
Transport network & sheets of water	3.2	3.4	3.9	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.6
Watercourses	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

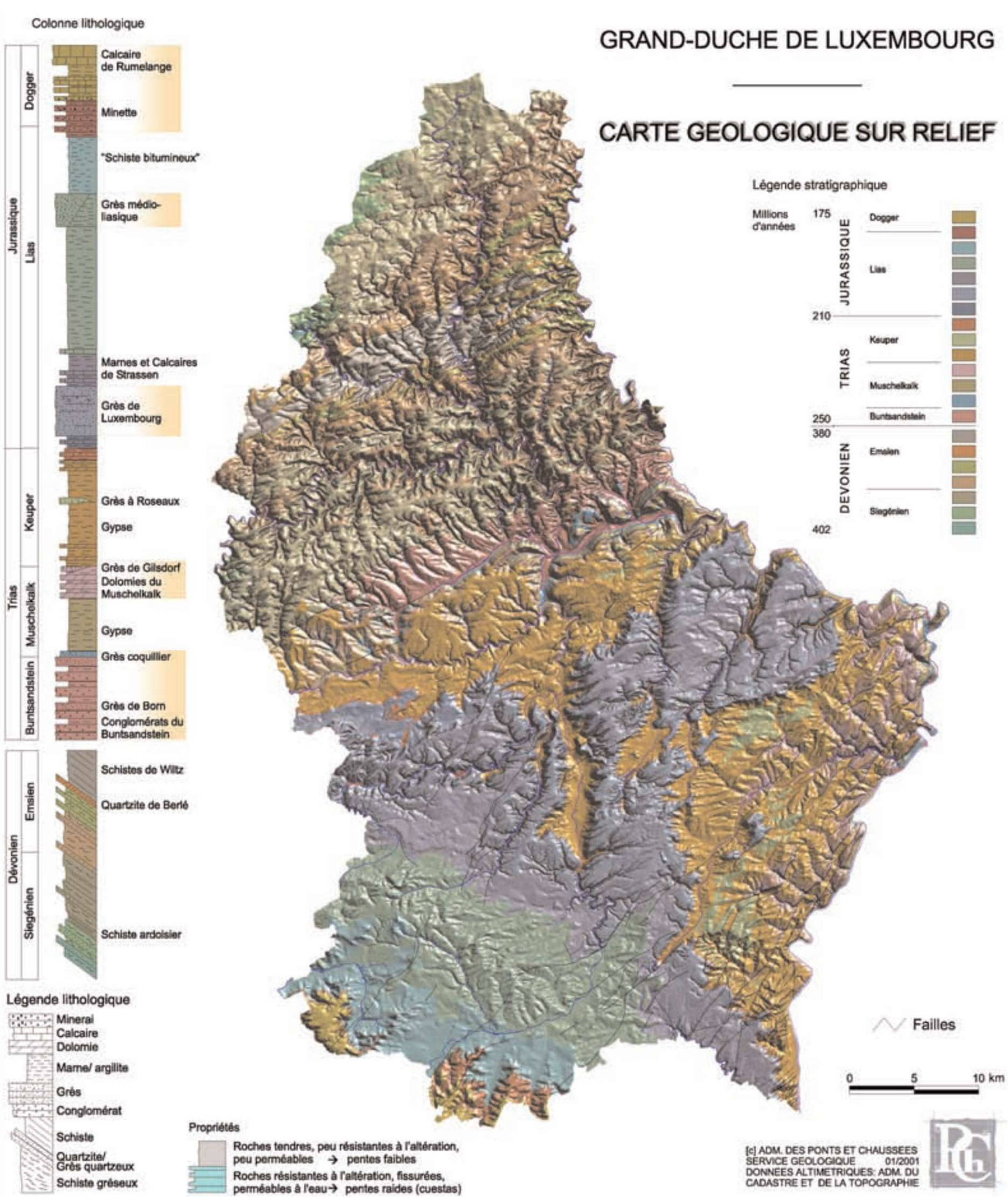
Source:STATEC (accessed 3 April 2024):
https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CTerritoire%20environnement%20et%20%C3%A9nergie%23A%23%7CTerritoire%23A1%23&pg=0&fc=Th%C3%A8mes&df[ds]=ds-release&df[id]=DF_A1101&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A

Figure 2-3 – Land use: 1990 & 2021



Source: STATEC (updated 3 April 2024): https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CTerritoire%20environnement%20et%20%C3%A9nergie%23A%23%7CTerritoire%23A1%23&pg=0&fc=Th%C3%A8mes&df[ds]=ds-release&df[id]=DF_A1101&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A

Figure 2-4 – Geological map of Luxembourg's territory



Source: STATEC, *Annuaire statistique du Luxembourg 2012*, page 39: http://www.statistiques.public.lu/fr/publications/series/annuaire-stat-lux/index.html.

2.1.2 Climate [25]

2.1.2.1 Present climate: increasing average air temperatures and high variability in precipitation patterns during the last decades

The climate in Luxembourg can be characterized as a **moderate oceanic Western European climate** with mild winters and comfortable summers (Goergen, Beersma, Hoffmann, & Junk, 2013).

As shown by the long-term annual means (WMO reference period from 1961-1990 and 1981-2010) measured at the Findel-Airport meteorological station WMO 06590 (Table 2-2), temperatures have an unimodal distribution, with the lowest long-term mean values occurring during January (0.0°C for the period 1961-1990) and the highest air temperature in July (16.9°C for the period 1961-1990). Absolute minimum and maximum air temperatures ever recorded at Findel station until 31 December 2016 were -20.2°C (2 February 1956) and 37.9°C (8 and 12 August 2003)[26].

Table 2-2: Long-term mean values (1961-1990 & 1981-2010) of air temperature and precipitation for Findel-Airport station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean air temperature [°C] (1961-1990)	0.0	1.1	4.0	7.5	11.8	14.9	16.9	16.4	13.4	9.1	3.8	1.0	8.3
Mean air temperature [°C] (1981-2010)	0.8	1.6	5.2	8.7	13.0	15.9	18.2	17.7	13.9	9.5	4.7	1.8	9.3
Mean minimum air temperature [°C] (1961-1990)	-2.3	-1.8	0.6	3.3	7.1	10.2	12.0	11.8	9.3	5.7	1.2	-1.3	4.7
Mean minimum air temperature [°C] (1981-2010)	-1.6	-1.3	1.6	4.4	8.4	11.1	13.3	13.0	10.0	6.3	2.2	-0.5	5.6
Mean maximum air temperature [°C] (1961-1990)	2.3	4.2	7.9	12.1	16.8	20.0	22.0	21.6	18.2	13.0	6.6	3.3	12.3
Mean maximum air temperature [°C] (1981-2010)	3.1	4.7	9.1	13.3	17.8	20.7	23.2	22.8	18.4	13.1	7.3	3.9	13.1
Mean monthly precipitation sum [mm] (1961-1990)	71.1	61.7	70.1	61.0	81.2	81.5	68.4	72.2	69.8	74.7	83.1	79.6	874.4
Mean monthly precipitation sum [mm] (1981-2010)	76.6	62.5	69.1	58.2	78.5	79.9	71.0	75.4	76.3	86.8	76.0	86.7	896.9

Sources: 1961-1990–MeteoLux (http://meteolux.lu/filedownload/73/2016_Informations_sur_le_climat_au_Luxembourg_en_2016_Anglais.pdf)
1981-2010 –MeteoLux (http://meteolux.lu/fr/climat/normales-et-extremes/).

According to definitions for GHG reporting, **Luxembourg is situated in a cool climate region** since its annual average air temperature is below 15°C: 8.3°C for the reference period 1961-1990 (Table 2-2) and 9.3°C for the reference period 1981-2010.

A regional analysis of different stations operated by the Agriculture Technical Services Administration (Administration des Services Techniques de l'Agriculture – ASTA) throughout Luxembourg, shows that temperatures in the North of the country (Ösling) are on average up to 1°C lower than at Findel airport, whereas in the Moselle valley they are on average nearly 1°C higher (Table 2-3 to Table 2-5).

Table 2-3: Long-term mean values (1981-2010) of mean air temperature for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asselborn	0.3	0.7	4.0	7.5	11.9	14.8	17.0	16.3	12.6	8.7	4.0	1.2	**8.3**
Clemency	1.0	1.5	5.0	8.5	13.1	16.2	18.2	17.4	13.4	9.4	4.7	2.0	**9.2**
Grevenmacher	1.7	2.5	5.9	9.5	13.9	17.0	19.1	18.2	14.1	10.1	5.5	2.7	**10.0**
Remich	1.6	2.5	6.2	9.8	14.2	17.1	19.3	18.5	14.5	10.3	5.5	2.7	**10.2**

25 The text of this Section has been prepared by Junk, J., Trebs, I., Hoffmann, L. of the Luxembourg Institute of Science and Technology (LIST), Department Environmental Research and Innovation (ERIN), with additions by Andrew Ferrone of the Administration des services techniques de l'agriculture (ASTA), Meteorological Service.

26 http://meteolux.lu/fr/climat/normales-et-extremes/.

Table 2-4: Long-term mean values (1981-2010) of maximum air temperature for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asselborn	2.7	3.9	7.9	12.2	16.7	19.5	21.9	21.5	17.3	12.5	6.6	3.2	**12.2**
Clemency	3.4	5.0	9.3	13.5	18.0	20.9	23.4	23.0	18.6	13.5	7.5	4.2	**13.4**
Grevenmacher	4.3	6.1	10.7	15.2	19.7	22.6	25.1	24.6	20.2	14.6	8.6	5.3	**14.7**
Remich	4.1	6.0	10.6	14.9	19.3	22.3	24.6	24.2	19.7	14.4	8.3	5.1	**14.5**

Table 2-5: Long-term mean values (1981-2010) of minimum air temperature for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asselborn	-1.8	-2.0	0.6	2.9	6.9	9.5	11.6	11.0	8.4	5.5	1.8	-0.5	**4.5**
Clemency	-1.5	-1.5	1.2	3.2	7.4	10.1	12.1	11.6	8.7	5.8	2.3	-0.3	**4.9**
Grevenmacher	-0.8	-0.8	1.9	4.1	8.1	11.0	13.0	12.4	9.6	6.8	2.8	0.6	**5.7**
Remich	-0.7	-0.4	2.4	4.8	8.8	11.5	13.6	13.0	10.0	6.8	3.0	0.5	**6.1**

Source: ASTA, Agrimeteo (http://asta.public.lu/meteorologie/meteo.html).

The regional distribution of precipitation (Table 2-6) shows higher regional variability. A general gradient from the North-West to the South-East of the country can be noted, with highest annual average values recorded in Arsdorf (1055 mm) and lowest values in Remich (725 mm).

Table 2-6: Long-term mean values (1981-2010) of precipitation for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Altrier, Hersdorf	72	56	60	51	62	65	65	61	63	69	70	81	775
Arsdorf	120	84	88	69	75	75	74	78	76	100	96	120	1055
Asselborn	81	64	69	58	68	71	68	74	69	75	75	84	856
Berdorf	73	59	63	50	63	65	68	60	68	73	68	82	791
Beringen	76	58	61	53	64	63	59	64	64	69	66	85	781
Bettborn, Pratz	90	67	69	55	66	65	60	67	66	81	75	96	857
Clemency	92	73	73	52	64	65	62	63	64	78	77	94	856
Ermsdorf	78	62	64	55	68	66	73	70	66	76	68	83	830
Fourhen	77	56	62	51	61	61	64	62	63	72	68	82	780
Grevenmacher	66	53	54	46	58	67	61	61	60	69	63	73	729
Holler	86	69	79	59	73	73	76	74	73	76	76	89	903
Hosingen	93	71	78	67	72	67	73	70	75	84	83	97	930
Kehmen	102	75	78	65	73	67	67	74	71	86	86	106	951
Koerich	88	70	69	54	62	65	56	63	62	78	76	95	834
Lorentzweiler	83	67	66	55	68	70	64	66	66	75	72	90	843
Mamer	85	68	68	54	70	68	64	64	65	79	74	94	852
Mullendorf	84	66	67	54	65	69	60	63	66	77	73	93	837
Remerschen	70	56	58	51	63	67	71	60	64	75	65	78	779
Remich	63	51	55	47	58	68	61	59	62	70	60	71	725
Saeul	93	65	68	55	67	65	60	61	64	80	75	98	852
Troine, Wincrange	92	73	80	67	76	76	74	78	76	84	83	100	959

Source: ASTA, Agrimeteo (http://asta.public.lu/meteorologie/meteo.html).

Climate conditions have significant impacts on energy use for heating or cooling purposes. An increase in average air temperature in the forthcoming years could have a positive impact on energy consumption, especially in the residential, commercial and institutional sectors. However, in case of a substantial increase of air temperatures, an increase in energy consumption related to a more frequent use of air conditioning systems could also be expected.

As shown by measurements at the Findel-Airport meteorological station (Table 2-7), two conclusions can be drawn: firstly, an increase in average air temperature is observed over the last decades (Figure 2-5 and Figure 2-6); secondly, annual precipitation does not show such clear trends (Figure 2-7 and Figure 2-8). Similar observations have been obtained in scientific studies on the climate in Luxembourg, notably in (Goergen, Beersma, Hoffmann, & Junk, 2013), Lokys et al. (2016) and Junk et al. (2016). From 1990 onwards, annual mean air temperatures for the Findel-Airport station started to increase rather sharply to systematically exceed the 1961-1990 mean value (Figure 2-5). Temperature maxima have mostly been observed during the last 25 years (Figure 2-6). Further analysis of the data suggests that the average air temperature in Luxembourg has increased mainly during the winter seasons, coupled with longer frost-free periods (Molitor, et al., 2014).

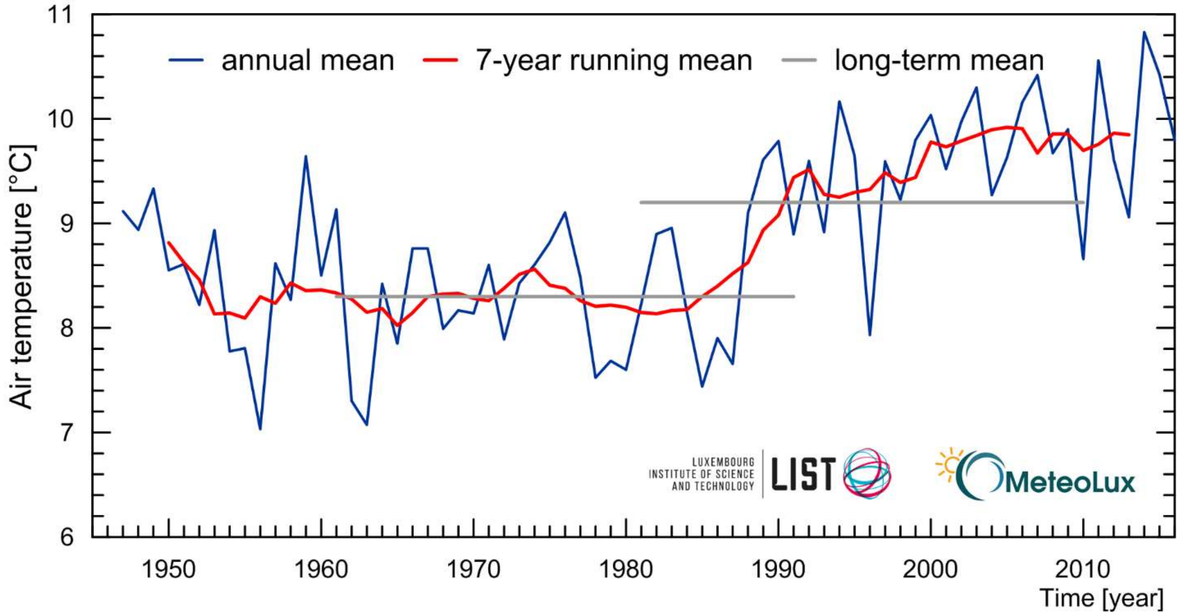
Further analysis of the data suggests that the average air temperature in Luxembourg has increased during the winter seasons, coupled with longer frost-free periods.

Table 2-7: Mean values of air temperature (daily mean, maximum & minimum) and precipitation for the Findel-Airport station for different time spans and individual years.

	1961-1990	1981-2010	2005	2010	2015	2016
Mean air temperature [°C]	8.3	9.3	9.6	8.7	10.4	9.8
Mean minimum air temperature [°C]	4.7	5.6	5.9	5.1	6.6	6.1
Mean maximum air temperature [°C]	12.3	13.1	13.6	12.4	14.3	13.7
Mean yearly precipitation sum [mm]	874.4	896.9	722.5	917.2	605.9	864.6

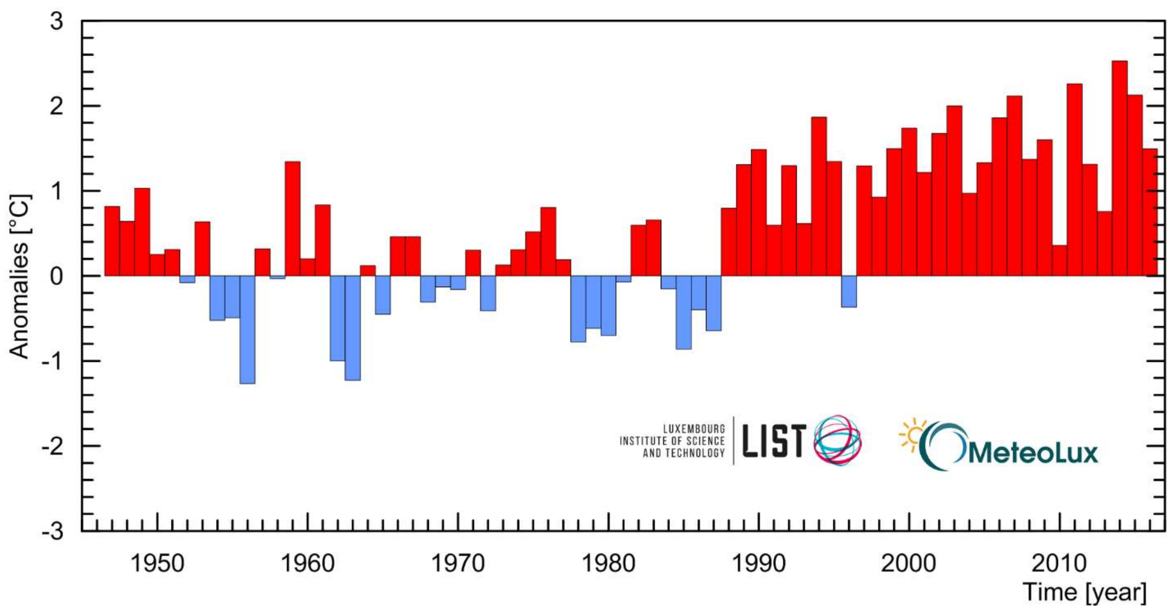
Sources: MeteoLux (http://meteolux.lu/filedownload/73/2016_Informations_sur_le_climat_au_Luxembourg_en_2016_Anglais.pdf)

Figure 2-5: Average annual air temperature (blue line), 7-year running mean (red line) and long-term annual mean 1961-1990 and 1981-2010 (grey lines) for the Findel-Airport station: 1947-2016



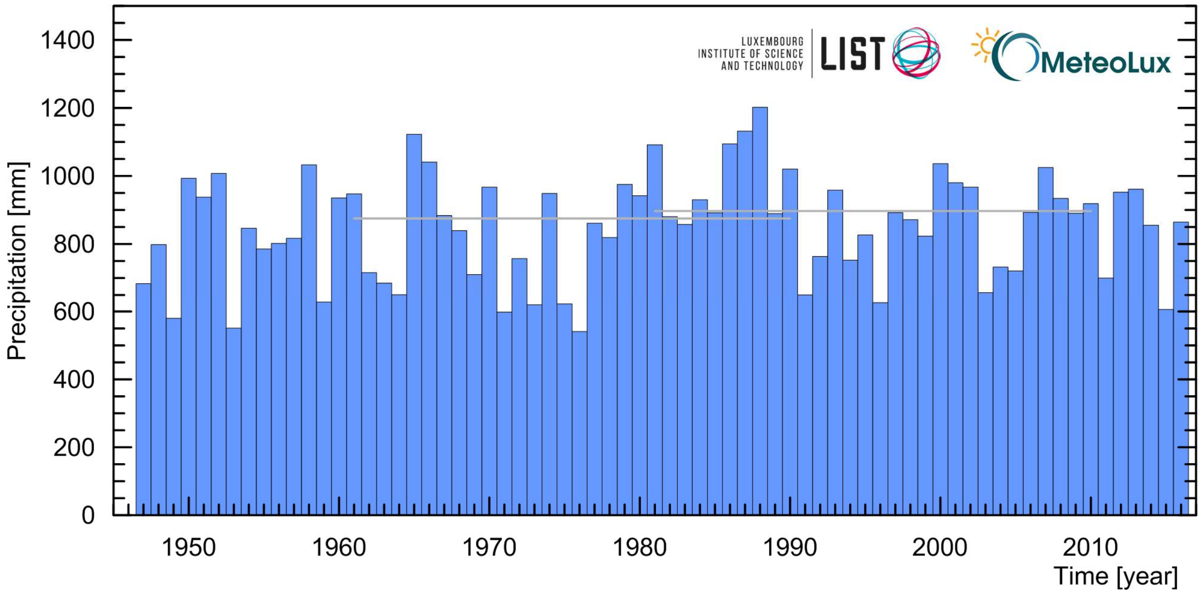
Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

Figure 2-6: Anomalies of annual air temperature from the reference period 1961-1990 for the Findel-Airport station: 1947-2016



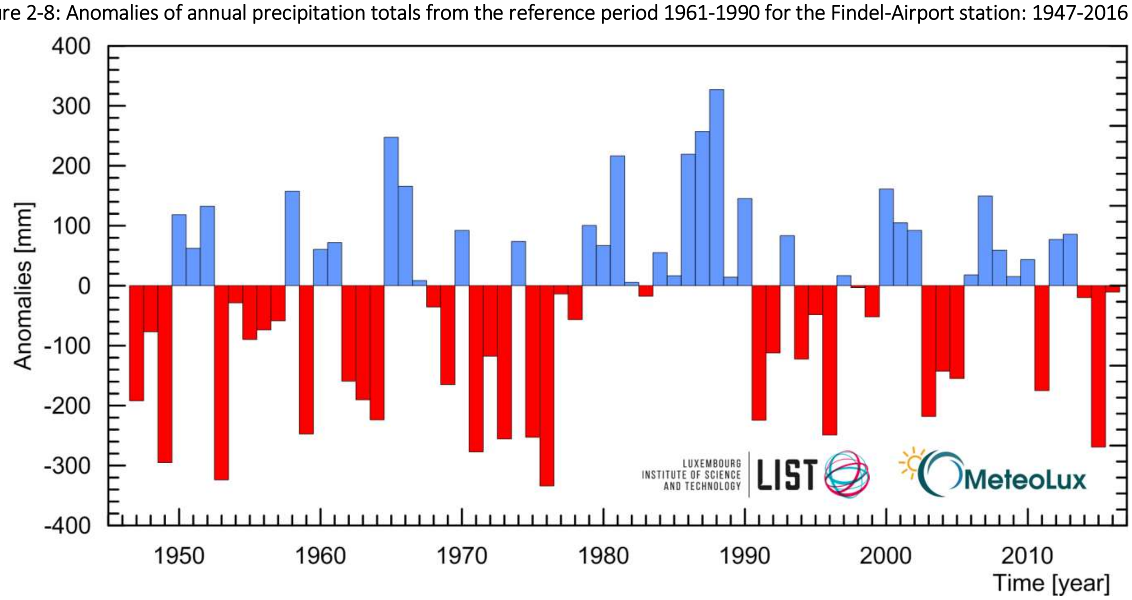
Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.
Note: anomalies from the reference period 1961 until 1990: long-term mean: 8.3°C.

Figure 2-7: Annual precipitation totals (blue columns) and long-term annual mean 1961-1990 and 1981-2010 (grey lines) for the Findel-Airport station: 1947-2016



Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

Figure 2-8: Anomalies of annual precipitation totals from the reference period 1961-1990 for the Findel-Airport station: 1947-2016

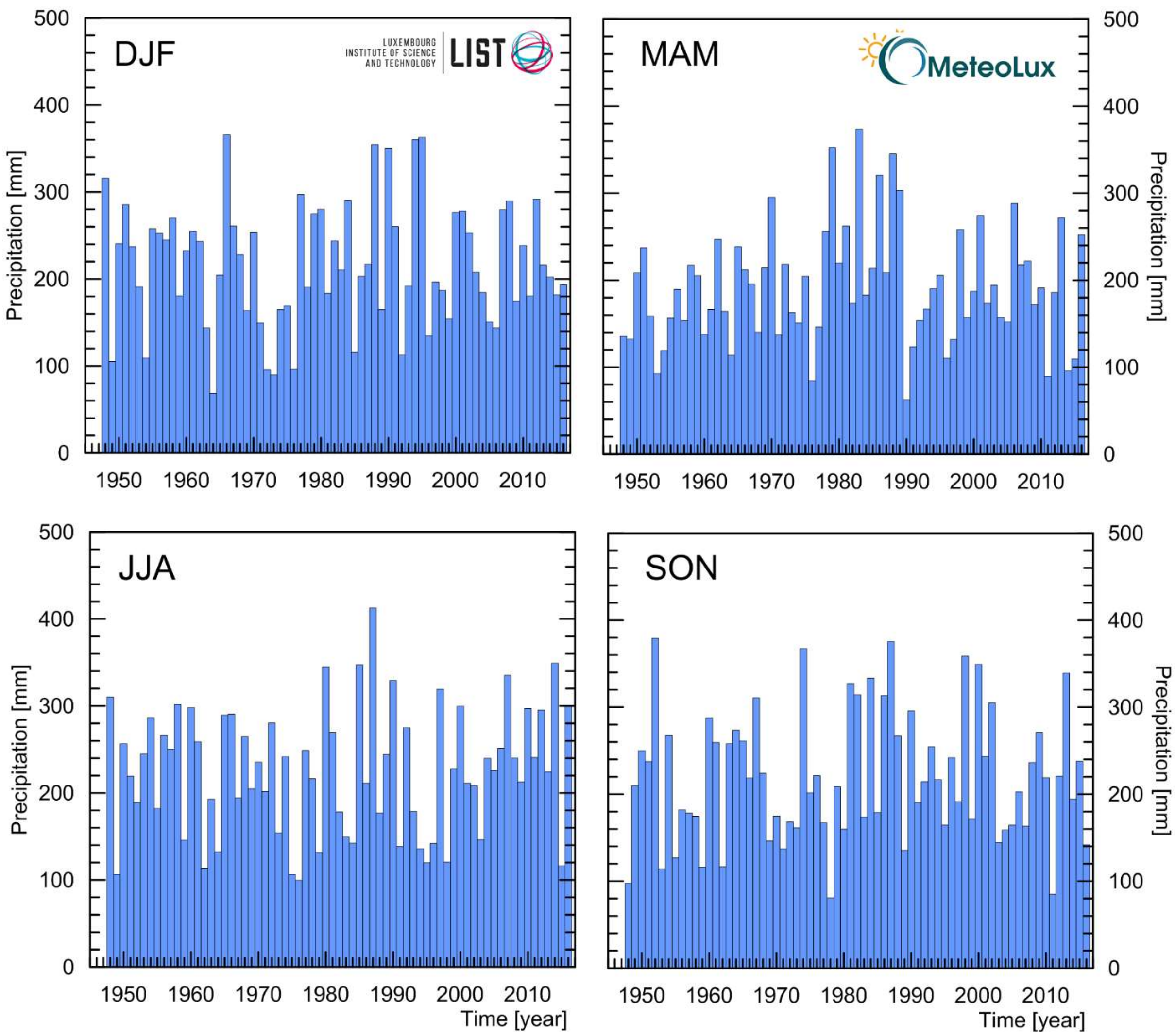


Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.
Note: anomalies from the reference period 1961 until 1990: long-term mean: 874 mm.

With regard to annual precipitation, no clear changes can be detected from the direct measurements (Table 2-7). During the hydrological winter half-year (October / November to March / April) evaporation is rather unimportant, which means that the precipitation falling during this period is almost completely discharged or stored underground. The most part of the precipitations falling during the summer half year evaporates and is very important for the development of the vegetation. However, the seasonal distribution of precipitation totals has shown substantial variability through the past 70 years (Figure 2-9).

Most of this variability can be attributed to changes in the large-scale atmospheric circulation patterns. An increase in westerly atmospheric fluxes during winter months was shown by Buchholz et al. (2010) for the past years. In combination with higher air temperatures, this has led to higher flood frequencies in most national river basins (Pfister, Hoffmann, & Humbert, 2000) (Pfister, et al., 2004).

Figure 2-9: Seasonal precipitation totals (DJF = winter; MAM = spring; JJA = summer; SON = autumn) for the Findel-Airport station: 1947-2016

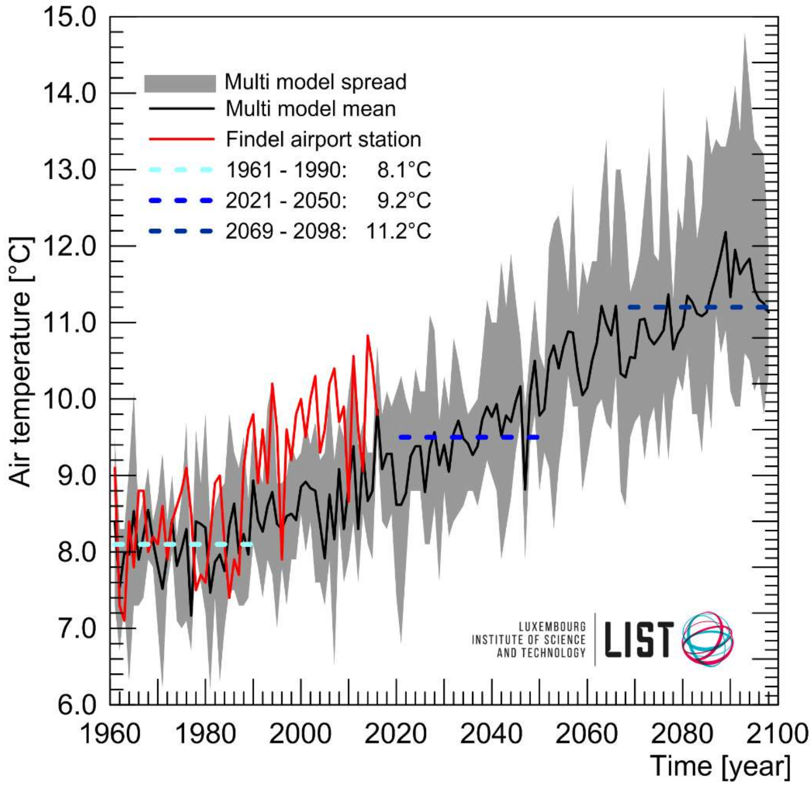


Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

2.1.2.2 Climate projections for air temperature and precipitation

Results of a research project (FNR-CLIMPACT) show an increase in mean air temperature for the Grand Duchy of Luxembourg. Based on selected results of the FP_6 ENSEMBLES project climate change projections[27], mean annual temperatures are expected to reach up to 11.6°C for the period 2071 until 2100. This value refers to the GHG emission scenario A1B (Figure 2-10).[28]

Figure 2-10: Projections of mean annual temperature.



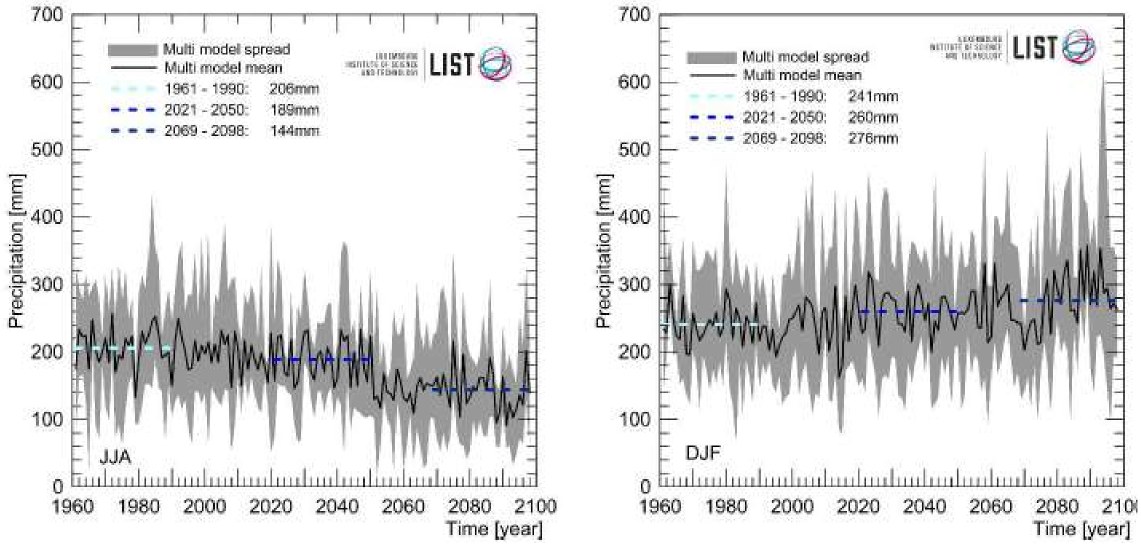
Source: Luxembourg Institute of Science and Technology (LIST). unpublished.
Notes: (1) based on selected ENSEMBLES data sets. A1B emission scenario.
(2) anomalies from the reference period 1961 until 1990: long-term mean: 8.9°C.

The results concerning changes in precipitation suggest a relative stability in annual totals until 2100 (Figure 2-11). However, a substantial redistribution of seasonal precipitation totals can be expected in the second half of the 21st century, with a decrease in summer rainfall and an increase in winter precipitation (Figure 2-12). It is also likely that there will be an increase in heavy rain events, especially during the summer months. In addition, the winter precipitation will probably fall more often as rain and less often as snow, whereby the risk for floods will increase especially during the winter months and spring.

27 More details on ENSEMBLE are provided in Box VI.1-1 in Section V.1.1. see also http://ensembles-eu.metoffice.com.

28 Results were published in a series of peer reviewed papers e.g.: (Eickermann, Beyer, Goergen, Hoffmann, & Junk, 2014), (Goergen, Beersma, Hoffmann, & Junk, 2013), Junk et al. (2014), Junk et al. (2016), (Matzarakis, Rammelberg, & Junk, 2013), (Molitor, Junk, Evers, Hoffmann, & Beyer, 2013), (Molitor, et al., 2014)

Figure 2-11: Projections of precipitation sums for the meteorological winter and summer seasons.

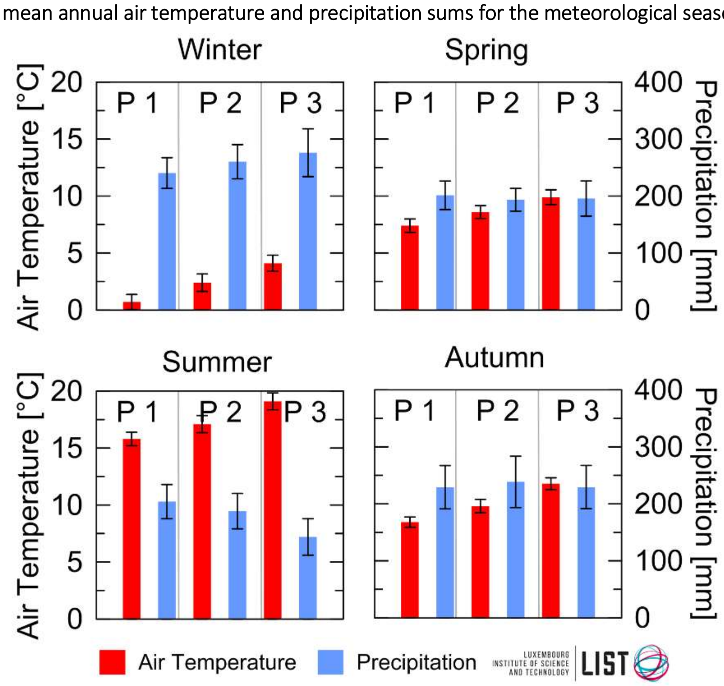


Source: Luxembourg Institute of Science and Technology (LIST). Unpublished.

Notes: (1) based on selected ENSEMBLES data sets. A1B emission scenario.

(2) JJA = meteorological summer season (June-July-August); DJF= meteorological winter season (December – January – February).

Figure 2-12: Projections of mean annual air temperature and precipitation sums for the meteorological seasons.



Source: Luxembourg Institute of Science and Technology (LIST). Georgen et al. (2013).

Notes: (1) based on selected ENSEMBLES data sets. A1B emission scenario.

(2) periods: P1 = 1961-1990 // P2 = 2021-2050 // P3 = 2069-2098.

2.1.2.3 Expected impacts of climate change in Luxembourg: vegetation and water in the forefront

According to a report published in 2016 by the EEA [European Environment Agency (2016)], Luxembourg is part of the biogeographical "Continental Region" area as defined under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) – see Map ES.1, p. 25 of the aforementioned report. The threats identified for this peculiar region are:

- increase in heat extremes;
- decrease in summer precipitation;
- increasing risks of river floods;
- increasing risk of forest fire;
- decrease in economic value of forests;
- increase in energy demand for cooling.

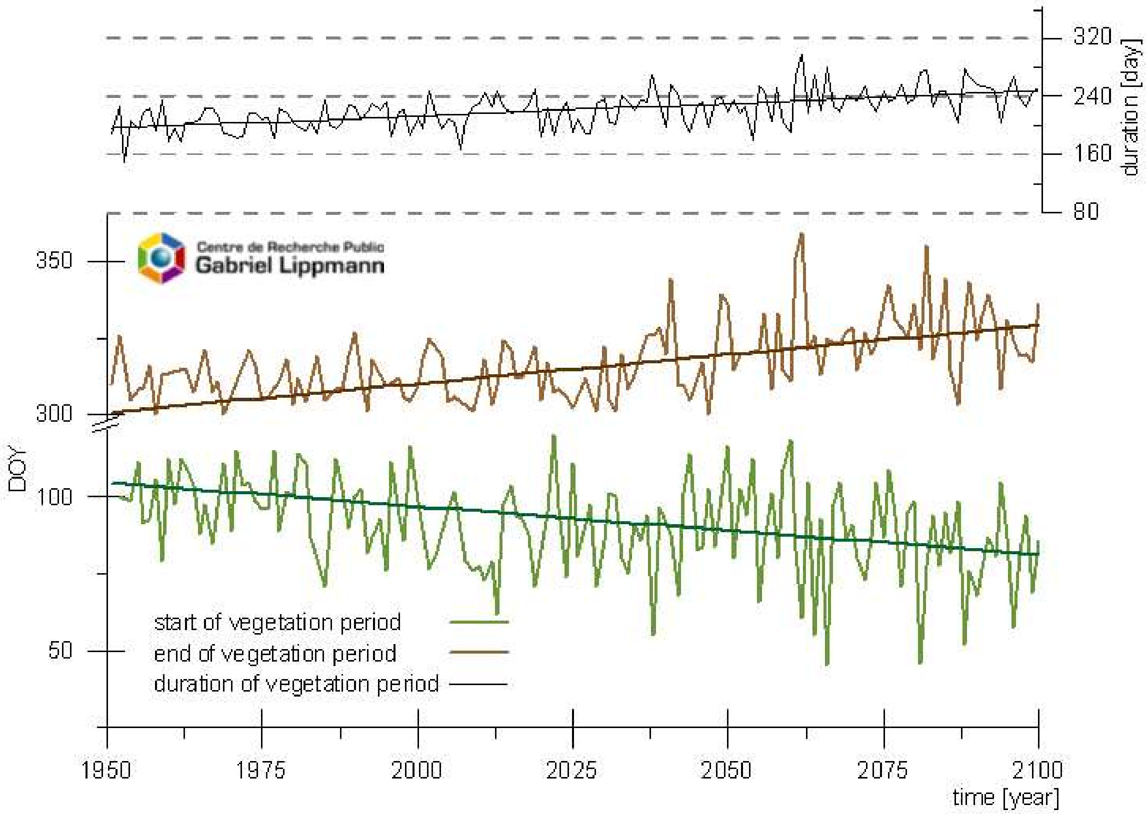
Two of these threats are of main concern for Luxembourg, those relating to forests. Temperature extremes and summer precipitation reduction are also causes for concern due to their impacts on human health, especially of the most fragile persons and the elderly (heat, air quality), and impacts on water quality in summer when rivers flows are usually at their lowest.

According to the researchers of the Luxembourg Institute of Science and Technology (LIST), the projected changes in air temperature (section 2.1.2.2) are likely to induce a modification of the vegetation period in Luxembourg. The start of the vegetation period is defined as the exceedance of the 5°C daily mean temperature threshold in spring for at least 5 successive days; the end of the vegetation period corresponds to the undershooting of this threshold until the end of the year (Chmielewski & Rötzer, 2001).

In Luxembourg, the vegetation period is expected to be initiated earlier in spring and to last longer into autumn (Figure 2-13). During the early stages of the vegetation period this might cause an increased risk of frost damages to vegetation (Goergen, Beersma, Hoffmann, & Junk, 2013).

The increase of temperatures, especially during the winter period (section 2.1.2.1), already has significant impacts on the phenology of plants (earlier flowering dates) and animals (e.g. earlier breeding dates of birds, advancement of life cycle of insects (Junk, Eickermann, Georgen, Beyer, & Hoffmann, 2012); (Eickermann, Beyer, Goergen, Hoffmann, & Junk, 2014), three instead of two yearly cycles), but also on the migratory behaviour of birds and insects (i.e. species now winter in Luxembourg that in former times migrated to Spain or northern Africa). Furthermore, the temperature changes have an impact on the bio-geography of plants and animals, with new species with a Mediterranean distribution, formerly unknown in Luxembourg, which recently appeared in the country fauna (e.g. Nomophila noctuella, Udea ferrugalis, Brenthis daphne) and flora (some moss species). Bio-climatic approaches also indicate that some relict species of the last glaciation period (e.g. Lycaena helle) will disappear from Luxembourg with the expected temperature increase.

Figure 2-13 - Start, end and duration of the vegetation period



Source: Luxembourg Institute of Science and Technology, unpublished.
Notes: (1) based on selected ENSEMBLES data sets, A1B emission scenario.
(2) End and duration of the vegetation period as defined by (Chmielewski & Rötzer, 2001)
(3) DOY = day(s) of year.

The climate projections for the second half of this century will also have significant impacts on the bio-meteorological conditions in Luxembourg. The higher air temperatures, especially stressful for humans during night in their recreation time, also increase the likelihood of extreme heat events such as the one that struck Europe in August 2003. Besides impact on the human health, this will also lead to more frequent and more stringent stress conditions for agricultural plants and forestry, most severely impacting perennial forest trees. Observations on the phytosanitary state of Luxembourg forest – a rather "old" forest – show a sharp degradation – which seems to have stabilised nowadays – resulting, among other factors, from climate change. The ageing of the forest also increases the risk of outbreak of diseases and of infestation by insects as well as other parasites that could proliferate if more mild winters and overall general temperatures are recorded in Luxembourg.

With regard to water, the most analysed phenomena so far are floods. It is known that; due to major redistributions of winter rainfalls, essentially, a higher inundation frequency is being recorded since the river systems have reacted to these changes with a statistically significant increase of maximum daily runoff during winter. (Pfister, Drogue, Poirier, & Hoffmann, 2005)this is why an observation hydro-climatic network (réseau d'observation hydro-climatologique) has been put in place in the mid-1990s.[29] Its main functions

29 http://www.hydroclimato.lu.

consist in continuously (24/7) monitoring Luxembourg's water courses, and in the realization and the updating of an atlas of areas of the national territory subjected to swellings and floods. The network also suggests anti-flooding measures and participates to renaturation projects aiming at re-creating natural areas which have been used as natural reservoirs containing rising waters.[30]

2.1.3 Population and Workforce

2.1.3.1 A strong population growth driven by immigration

At the beginning of 2022, the **population of Luxembourg** was estimated to 645 397 inhabitants. Since 1990, the residential population has grown by some 266 097 inhabitants, and it has more than doubled since 1960 (

Table 2-8). The average annual growth rate of the resident population of Luxembourg is elevated compared to the rates of its neighbouring regions: between 1990 and 2015, the average annual growth rate for Luxembourg (1.64%) was about 4 times higher than its equivalent for the Grande Région.[31] It even reached 1.79% p. a. since 2000 (Figure 2-15).

Demographic growth in Luxembourg is actually dominated by **immigration**. Nationals themselves saw their number stagnating, and without immigrants taking the citizenship of Luxembourg they would even have fallen. At the end of 2021, 47.1% of the residential population did not have the citizenship of Luxembourg. This percentage was only 28.7% in 1990, as depicted in Figure 2-14. The main driver behind these demographic trends is the economic restructuring and development of the country towards the tertiary sector coupled with attractive wages, which is presented in Section 2.1.4.

Since population projections are based on scenarios derived from past statistical data, population forecasts a continuation of the demographic trend in Luxembourg. Projections calculated by STATEC in 2017 forecast, under the assumption of a 3% annual gross domestic product increase, that almost 980 000 inhabitants could be living in Luxembourg by 2050 (Figure 2-15).[32] As it is the case for any forecasts, these predictions should be treated with caution because they cannot predict radical changes in the economic structure or demographics of a country, especially a small one whose economy relies heavily on a few economic sectors. However, since population growth is one of the key drivers for domestic energy use, mainly in the housing and transportation sector, these forecasts illustrate the scale of one of the many challenges Luxembourg is facing in the definition of measures aiming at reducing its GHG emissions.

Table 2-8 – Population: 1960-2022

Calculated on 31st December	1960	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020	2021	2022
Resident population (x 1000)	314.9	384.4	411.6	439.0	461.2	502.1	563.0	590.7	602.0	613.9	626.1	634.7	645.4

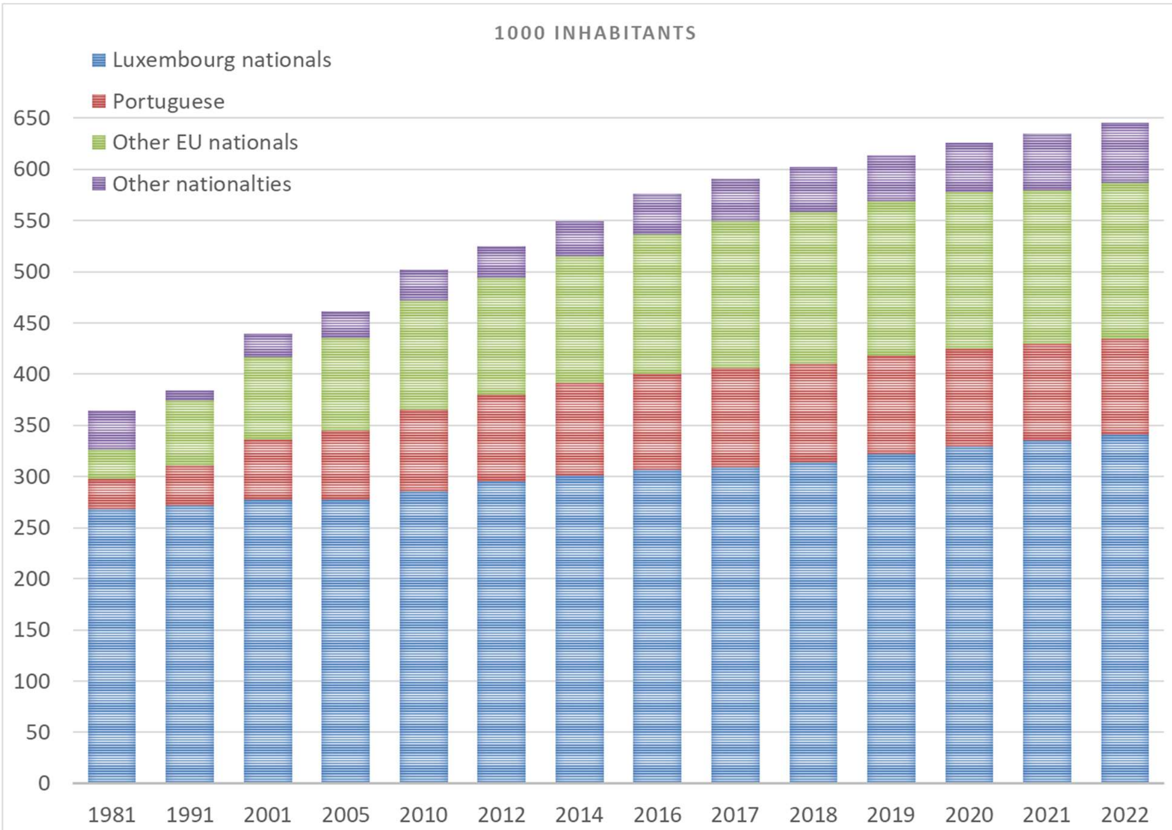
30 For an example, look at http://www.luxnatur.lu/alzrena1.htm.

31 Refer to Box 2-1 for a presentation of the Grande Région.

32 For details, see STATEC (2017), Projections macroéconomiques et démographiques de long terme : 2017-2060, Bulletin du STATEC N° 3-17, Luxembourg, page 31 (https://statistiques.public.lu/catalogue-publications/bulletin-Statec/2017/PDF-Bulletin3-2017.pdf). Other projections, which are a bit lower than STATEC's baseline scenario, are also produced in the framework of the European Commission Ageing Working Group: http://europa.eu/epc/working_groups/ageing_en.htm and http://europa.eu/epc/pdf/2012_ageing_report_en.pdf, as well as http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_projections.

Source: STATEC, (updated 21 March 2023):
https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CPopulation%20et%20emploi%23B%23%7CEtat%20de%20la%20population%23B1%23&pg=0&fc=Th%C3%A8mes&df[ds]=ds-release&df[id]=DF_B1115&df[ag]=LU1&df[vs]=1.0&pd=1990%2C2022&dq=.A

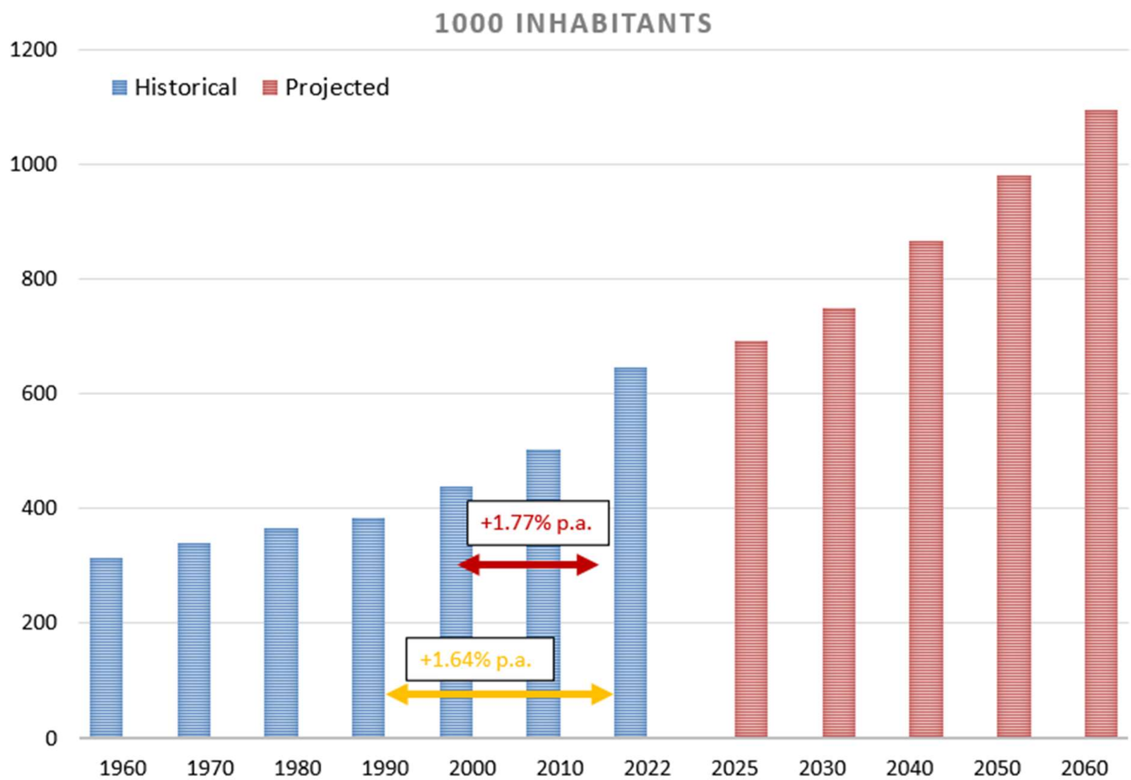
Figure 2-14 – Population structure on 31st December: 1981-2022



Source: STATEC, (updated 21 March 2023):
https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CPopulation%20et%20emploi%23B%23%7CEtat%20de%20la%20population%23B1%23&pg=0&fc=Th%C3%A8mes&df[ds]=ds-release&df[id]=DF_B1113&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2022&dq=.A

Note: 1981, 1991, 2001 and 2011 data are coming from population censuses held every decade, other years are calculated by STATEC.

Figure 2-15 – Population growth on 31st December: 1960-2060 assuming a 3% annual increase of the gross domestic product



Sources: STATEC, Statistical Yearbook, Table B.1101 (updated 16.03.2022):
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1.
STATEC, Projections macroéconomiques et démographiques de long terme: 2017-2060:
https://statistiques.public.lu/catalogue-publications/bulletin-Statec/2017/PDF-Bulletin3-2017.pdf.

Box 2-1 – The *Grande Région*

The *Grande Région* is the geographic unit that includes Luxembourg, the Region of Wallonia in Belgium, Lorraine in France and two German *Länder*: Saarland and Rheinland-Pfalz.

Today, this structure is more a cooperative space than an effective integrated region defining and modelling its own policies and development. This is the result of the diversity of the territories constituting the *Grande Région*, of its dimension and of the barriers created by institutional and administrative structures in each country. De facto, being a sovereign state amongst country regions, Luxembourg has a special status in this cooperative space: it is the main driving force behind the *Grande Région*, a position re-enforced by its demographic and economic development as shown by the figures in the table below.

***Grande Région* entity**	**Population change** (1st January) *% 1990-2015*	**Population annual average growth rate** (1st January) *% 1990-2015*	**GDP at current price annual average growth rate** *% 1990-2015*	**Total employment in 2015** *1990=100*
BE-Wallonia	10.67%	0.41%	3.57%	116
DE-Rheinland-Pfalz	8.37%	0.32%	2.35%	117
DE-Saarland	-7.12%	-0.29%	2.48%	116
FR-Lorraine	1.51%	0.06%	2.06%	102
Luxembourg	**48.42%**	**1.59%**	**7.23%**	**201**

More information on the *Grande Région* can be found on line:
http://www.granderegion.net/fr/index.html
http://www.grande-region.lu/eportal/pages/HomeTemplate.aspx

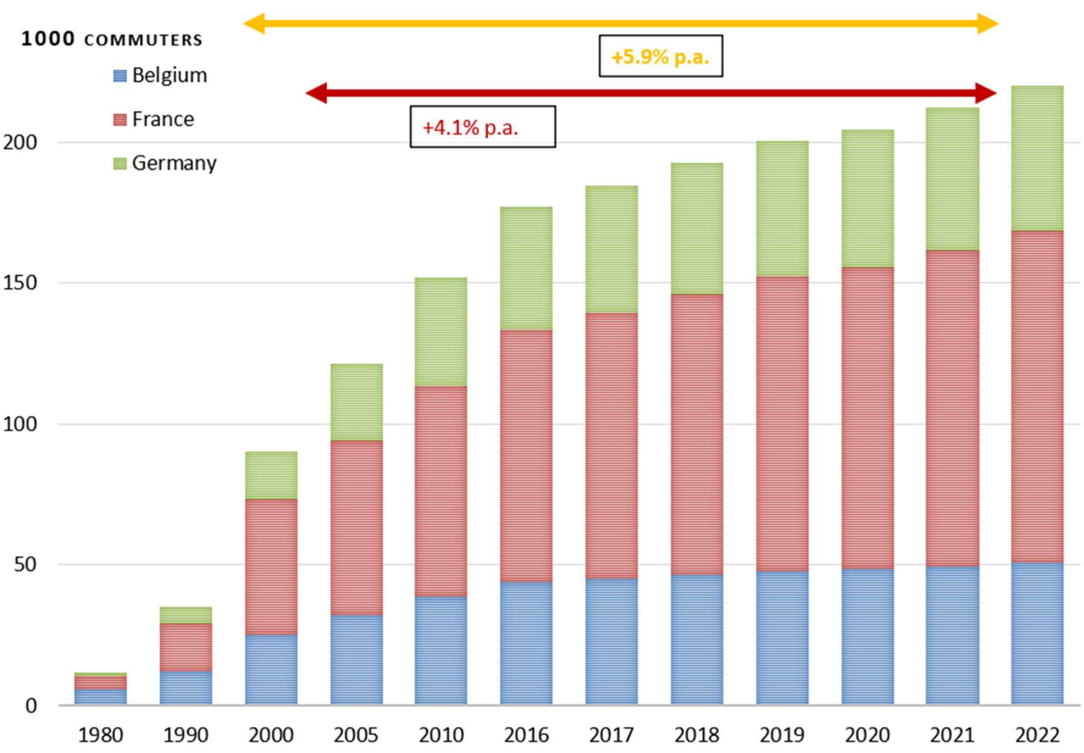
2.1.3.2 Workforce: the importance of cross-border commuters

The economic restructuring and development of Luxembourg led to a doubling of the workforce in the last 20 years. The resident population of Luxembourg nationality was unable to meet this increasing demand for labour. How, therefore, could this urgent economic need be satisfied? The initial response was to resort to immigration. The number of foreign employees living and working in Luxembourg rose from 56 900 in 1995 to 122 339 in 2020 - but, this was not enough. So the cross-border commuters came into play. Between 1995 and 2022, the number of cross-border workers increased from 56 834 to 220 200 (Figure 2-16).[33]

For 2022, among the commuters employed in Luxembourg, 53.5% came from France, 23.1% from Germany and 23.5% from Belgium. In total, the commuters accounted for 46% of the total workforce in Luxembourg and for 33% of the residential population.[34] The commuting flows amongst the various regions of the *Grande Région* clearly show the economic attraction of Luxembourg (Figure 2-17).

A vast majority of workers from abroad commute by car.[35] However, in order to alter the current modal split of home-work journeys, Luxembourg invests predominantly and jointly with the neighbouring regions into the public transport offer. Since 2020, public transportation services are free of charge in Luxembourg.

Figure 2-16 – Cross-border commuters' growth: annual cumulative averages 1980-2022



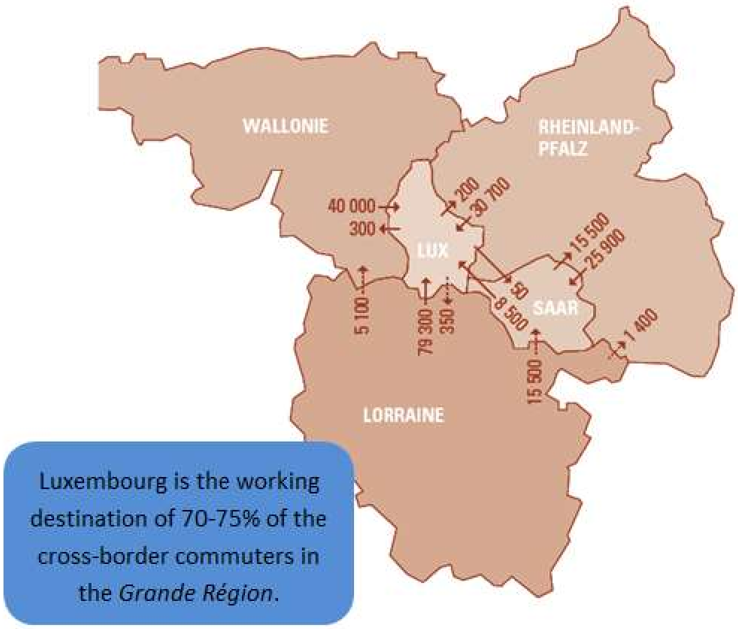
Source: STATEC (updated 03.04.2024): https://lustat.statec.lu/vis?pg=0&df[ds]=ds-release&df[id]=DF_B3107&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A&tm=frontaliers

33 Figures indicated in this paragraph are annual cumulative averages.

34 Calculated from STATEC: https://lustat.statec.lu/vis?pg=0&df[ds]=ds-release&df[id]=DF_B3107&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A&tm=frontaliers

35 According to a recent study, for 2010, it was estimated that 86% of the cross-border commuters were only using their car for their home-work journeys. This percentage was 91% in 2007: http://www.ceps.lu/?type=module&id=104&tmp=1900.

Figure 2-17 – Commuting flows 2015



Source: INSEE, IGSS, STATEC, IWEPS, Statistisches Amt Saarland, Statistisches Landesamt Rheinland-Pfalz: http://www.statistiques.public.lu/stat/TableViewer/document.aspx?ReportId=498&IF_Language=fra&MainTheme=2&FldrName=3&RFPath=92..

2.1.4 Economic profile

One of the main characteristics of economic growth in Luxembourg is its volatility. Generally speaking, the economic cycle in Luxembourg follows that of other European countries, but the amplitude of the GDP variations is more pronounced. This is a common feature of small economies, open to the outside world, and therefore more vulnerable to external shocks. It would however appear that over the past ten years the amplitude of GDP variations in Luxembourg has diminished, as has the gap in relation to the European cycle.

The economic restructuring and development of the country towards the tertiary sector from the 1960s-70s, led to the following economic cycles since 1990:

- up to 1992, the continuation of the exceptional growth initiated around 1985;
- the effects of the economic slowdown in Luxembourg during the period between 1992 and 1996 and the economic downturn in 2001 – as well as the less impressive growth in 2002-2004 – which is mirrored by a stagnation of the GDP level per inhabitant in Luxembourg in comparison with the EU-15;
- the good economic performance of Luxembourg between 2005 and 2008;
- the financial and economic crisis that started at the end of 2008 and that has been particularly pronounced in the first semester of 2009;
- from 2010 onwards, a very slow recovery could be observed, though it flattened quickly for the industry and commercial sectors.

Nowadays, gross value added is mainly generated in the financial intermediation (banking and insurances), real estate and services to business sector. The share of total gross value added in this branch has increased from about 37.9% in 1995 to 47.7% in 2022.[36] While the commercial sector has maintained a relatively constant share at about 14% to 19%, the share of the industry sector has decreased significantly from 15.2% in 1995 to 5.7% in 2022. Other service activities ranged between a share of 20.5% to 24.7% and construction kept a rather constant share in total gross value added around 6.0%. The contribution of the agricultural sector is negligible with less than 1% (Table 2-9 & Figure 2-18).

Nevertheless, GHG emissions trends in Luxembourg are not so much influenced by the economic profile of the country, but for the most part by:

- the energy-mix for both production and consumption of fuels (liquid, solid, gaseous, biomass): more on this in the next section;
- due to its size and the size of its energy and industrial sector, structural changes in these sectors that could be initiated by a single entity;
- road transportation related fuel sales: more on this in Section 2.1.6.

36 Data prior to 1995 are and will not be translated into the new European System of Accounts (ESA).

Table 2-9 – Sectoral gross value added at current prices: 1995-2022

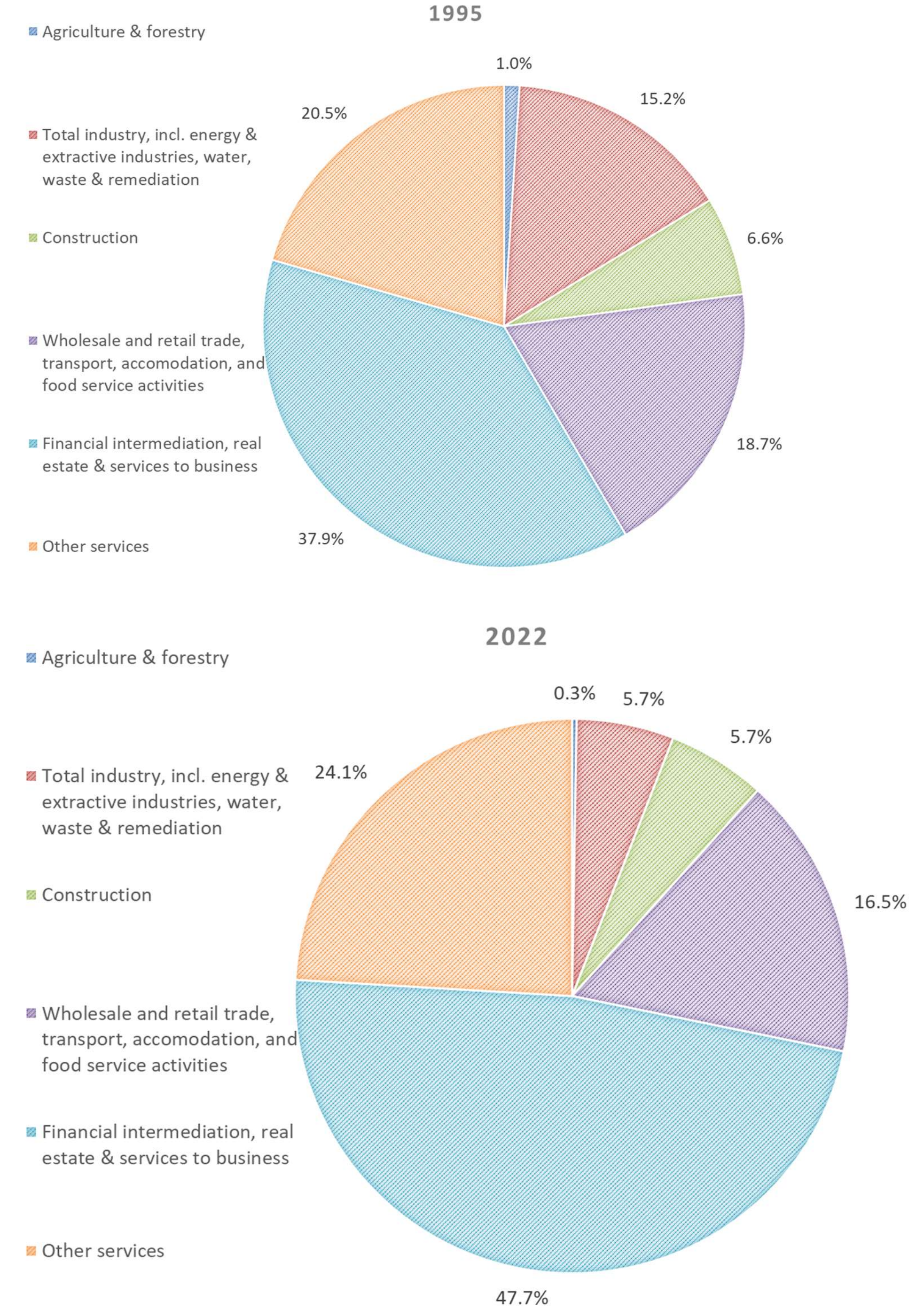
mio. EUR		1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Agriculture, forestry & fishing (A)		142	137	108	107	137	123	91	114	111	134	129	150	121	120	136	141	134	128	138	187
	%	1.0%	0.7%	0.4%	0.3%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.3%	0.3%	0.2%	0.2%	0.2%	0.3%
Total industry, including extractive industries, energy production & distribution, water supply, sewerage, waste		2087	2571	2857	2946	3528	3169	2381	2657	2701	2652	2837	3122	3663	4001	3487	3703	3913	3975	4199	4008
management and remediation activities (B to E)	%	15.2%	12.5%	10.6%	9.6%	10.5%	8.8%	6.8%	6.9%	6.8%	6.4%	6.4%	6.7%	7.4%	7.8%	6.6%	6.8%	6.9%	6.7%	6.4%	5.7%
Construction (F)		908	1257	1524	1675	1921	1954	1917	2007	2046	2199	2290	2477	2585	2798	2806	2898	3328	3324	3559	4053
	%	6.6%	6.1%	5.7%	5.5%	5.7%	5.4%	5.5%	5.2%	5.1%	5.3%	5.2%	5.4%	5.2%	5.4%	5.3%	5.3%	5.9%	5.6%	5.4%	5.7%
Wholesale and retail trade, transport,		2569	3524	4236	4707	4757	5743	5446	6112	7191	6930	7303	7559	7613	7903	8418	8593	8789	9068	10448	11654
accomodation (G-I)	%	18.7%	17.2%	15.7%	15.3%	14.1%	16.0%	15.5%	16.0%	18.1%	16.6%	16.6%	16.3%	15.4%	15.4%	15.9%	15.7%	15.5%	15.4%	15.9%	16.5%
Financial and insurance activities; real estate activities; professional, scientific and technical activities;		5196	8593	11879	14537	16082	17307	16845	18445	18332	19728	21142	22151	24172	25114	26007	26304	26719	27868	31611	33684
administrative and support service activities (K to N)	%	37.9%	41.9%	44.2%	47.4%	47.8%	48.1%	48.0%	48.2%	46.1%	47.3%	48.0%	47.9%	48.8%	48.9%	49.1%	48.1%	47.1%	47.3%	48.0%	47.7%
Other services: information and communication; public administration, defence, education, human health and social work activities; arts, entertainment and recreation;		2820	4420	6291	6713	7233	7701	8436	8901	9421	10040	10320	10796	11384	11450	12157	12992	13887	14526	15916	16982
Oher service activities; activities of household (J & O to P)	%	20.5%	21.6%	23.4%	21.9%	21.5%	21.4%	24.0%	23.3%	23.7%	24.1%	23.4%	23.3%	23.0%	22.3%	22.9%	23.8%	24.5%	24.7%	24.2%	24.1%
Total: all NACE rev2 branches		**13722**	**20502**	**26894**	**30684**	**33658**	**35998**	**35117**	**38236**	**39801**	**41683**	**44019**	**46255**	**49537**	**51386**	**53011**	**54632**	**56771**	**58889**	**65870**	**70568**
Annual growth rate - current prices					**13.8%**	**9.7%**	**2.8%**	**-3.1%**	**9.1%**	**7.2%**	**1.7%**	**5.4%**	**6.9%**	**5.1%**	**3.5%**	**3.9%**					
Annual growth rate - constant prices/in volume					**5.7%**	**8.5%**	**-1.5%**	**-4.6%**	**5.0%**	**2.0%**	**-0.8%**	**3.6%**	**3.9%**	**4.1%**	**2.5%**	**1.7%**					

Source: STATEC (updated 3 April 2024):

https://lustat.statec.lu/vis?pg=0&tm=E2304&hc[dataflowId]=DF_E2304&df[ds]=ds-release&df[id]=DF_E2304&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2022&dq=.A

https://lustat.statec.lu/vis?pg=0&tm=E2304&hc[dataflowId]=DF_E2304&df[ds]=ds-release&df[id]=DF_E2304&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2022&dq=.A

Figure 2-18 – Sectoral gross value added at current prices: 1995 & 2022



Source: STATEC (updated 3 April 2024): https://lustat.statec.lu/vis?pg=0&tm=E2304&hc[dataflowId]=DF_E2304&df[ds]=ds-release&df[id]=DF_E2304&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2022&dq=.A

2.1.5 Energy

2.1.5.1 A total change in Luxembourg's energy-mix

Primary and final energy consumption in Luxembourg experienced dramatic changes since 1990. Overall primary energy consumption increased by 7.9% between 1990 and 2021. Whereas solid fuels and coal declined by 96.6% over the period, liquid fuels (incl. kerosene) and natural gas consumptions increased by 47.8% and 22.8% respectively (Table 2-10 & Figure 2-19).

Table 2-10 – Primary energy consumption: 1990-2022

TJ	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Solid fuels & coal	49939.83	45812.91	43145.01	44770.76	38726.29	22010.21	20893.02	13306.17	4861.42
	33.23%	28.98%	27.20%	27.75%	24.76%	15.90%	14.78%	9.57%	3.57%
Liquid fuels (incl. kerosene)	66030.62	76910.67	79078.34	78994.97	78578.11	72455.60	74715.90	77882.37	82209.79
	43.94%	48.66%	49.86%	48.97%	50.24%	52.35%	52.85%	56.00%	60.30%
Natural gas (1)	19925.91	20717.94	21593.35	22427.07	22593.81	25819.65	28324.39	29023.46	29305.68
	13.26%	13.11%	13.61%	13.90%	14.45%	18.65%	20.03%	20.87%	21.50%
Electricity	13256.15	13464.58	13631.32	14006.50	15423.82	17083.75	16644.80	17889.96	18859.16
	8.82%	8.52%	8.59%	8.68%	9.86%	12.34%	11.77%	12.86%	13.83%
Heat	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
Renewable energy sources & waste	1125.52	1167.21	1167.21	1125.52	1083.84	1042.15	808.71	964.61	1100.93
Incineration (with heat recovery) (2)	0.75%	0.74%	0.74%	0.70%	0.69%	0.75%	0.57%	0.69%	0.81%
Total	**150278.03**	**158073.31**	**158615.23**	**161324.82**	**156405.87**	**138411.36**	**141386.82**	**139066.58**	**136336.98**

TJ	1999	2000	2001	2002	2003	2004	2005	2006	2007
Solid fuels & coal	4814.73	4594.52	4957.84	3083.62	2369.15	3328.54	3248.87	3876.79	3280.32
	3.33%	2.96%	3.02%	1.79%	1.31%	1.65%	1.58%	1.91%	1.65%
Liquid fuels (incl. kerosene)	87715.26	96236.54	102063.69	104261.62	111789.85	126709.57	130884.49	124310.30	121227.03
	60.72%	61.99%	62.27%	60.42%	61.74%	62.91%	63.82%	61.24%	60.92%
Natural gas (1)	30397.85	31231.01	34718.00	49629.00	50238.00	55632.00	54720.18	57237.24	53426.14
	21.04%	20.12%	21.18%	28.76%	27.74%	27.62%	26.68%	28.20%	26.85%
Electricity	19580.75	21059.69	19649.82	12952.77	13931.02	12698.58	12323.47	13490.64	14981.85
	13.55%	13.56%	11.99%	7.51%	7.69%	6.30%	6.01%	6.65%	7.53%
Heat	NO	0.03	1.21	4.04	6.43	8.86	11.54	14.48	19.65
	NA	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
Renewable energy sources & waste	1946.32	2128.82	2520.68	2630.06	2736.22	3041.45	3883.23	4049.26	6063.63
Incineration (with heat recovery) (2)	1.35%	1.37%	1.54%	1.52%	1.51%	1.51%	1.89%	1.99%	3.05%
Total	**144454.91**	**155250.60**	**163911.23**	**172561.09**	**181070.66**	**201419.00**	**205071.80**	**202978.71**	**198998.62**

TJ	2008	2009	2010	2011	2012	2013	2014	2015	2016
Solid fuels & coal	3136.57	2801.27	2745.48	2475.56	2295.39	2200.64	2180.81	2060.54	2132.32
	1.57%	1.48%	1.37%	1.26%	1.20%	1.19%	1.21%	1.16%	1.19%
Liquid fuels (incl. kerosene)	122653.44	114781.92	120101.37	122553.58	118269.72	116290.12	112065.91	110129.11	109970.55
	61.51%	60.83%	60.08%	62.57%	61.77%	62.65%	62.11%	61.77%	61.60%
Natural gas (1)	50856.70	51751.75	55665.22	48021.10	48894.89	41398.28	39223.62	35770.96	32988.07
	25.51%	27.43%	27.85%	24.52%	25.54%	22.30%	21.74%	20.06%	18.48%
Electricity	16412.67	12987.43	15290.40	16677.00	15567.70	18791.88	18634.28	21238.39	23821.51
	8.23%	6.88%	7.65%	8.51%	8.13%	10.12%	10.33%	11.91%	13.34%
Heat	26.29	36.03	50.68	63.92	80.70	98.72	116.07	141.14	166.65
	0.01%	0.02%	0.03%	0.03%	0.04%	0.05%	0.06%	0.08%	0.09%
Renewable energy sources & waste	6310.98	6320.76	6052.85	6067.59	6363.53	6846.43	8208.16	8956.07	9453.39
Incineration (with heat recovery) (2)	3.17%	3.35%	3.03%	3.10%	3.32%	3.69%	4.55%	5.02%	5.30%
Total	**199396.66**	**188679.15**	**199905.99**	**195858.76**	**191471.93**	**185626.07**	**180428.85**	**178296.21**	**178532.49**

TJ	2017	2018	2019	2020	2021	2022
Solid fuels & coal	1972.66	1748.41	1915.81	1609.51	1761.99	1719.63
	1.07%	0.91%	0.99%	0.95%	0.98%	1.06%
Liquid fuels (incl. kerosene)	115043.66	121479.76	122897.51	99811.13	107180.82	97620.46
	62.45%	63.55%	63.68%	59.17%	59.67%	60.18%
Natural gas (1)	32244.57	31802.53	31822.35	28901.45	31159.23	24469.59
	17.50%	16.64%	16.49%	17.13%	17.35%	15.08%
Electricity	23785.11	23858.70	23030.57	21847.96	22761.51	22173.88
	12.91%	12.48%	11.93%	12.95%	12.67%	13.67%
Heat	198.33	233.02	262.38	305.56	347.26	393.33
	0.11%	0.12%	0.14%	0.18%	0.19%	0.24%
Renewable energy sources & waste	10981.21	12030.51	13068.76	16222.48	16423.53	15847.67
Incineration (with heat recovery) (2)	5.96%	6.29%	6.77%	9.62%	9.14%	9.77%
Total	**184225.53**	**191152.94**	**192997.38**	**168698.09**	**179634.33**	**162224.55**

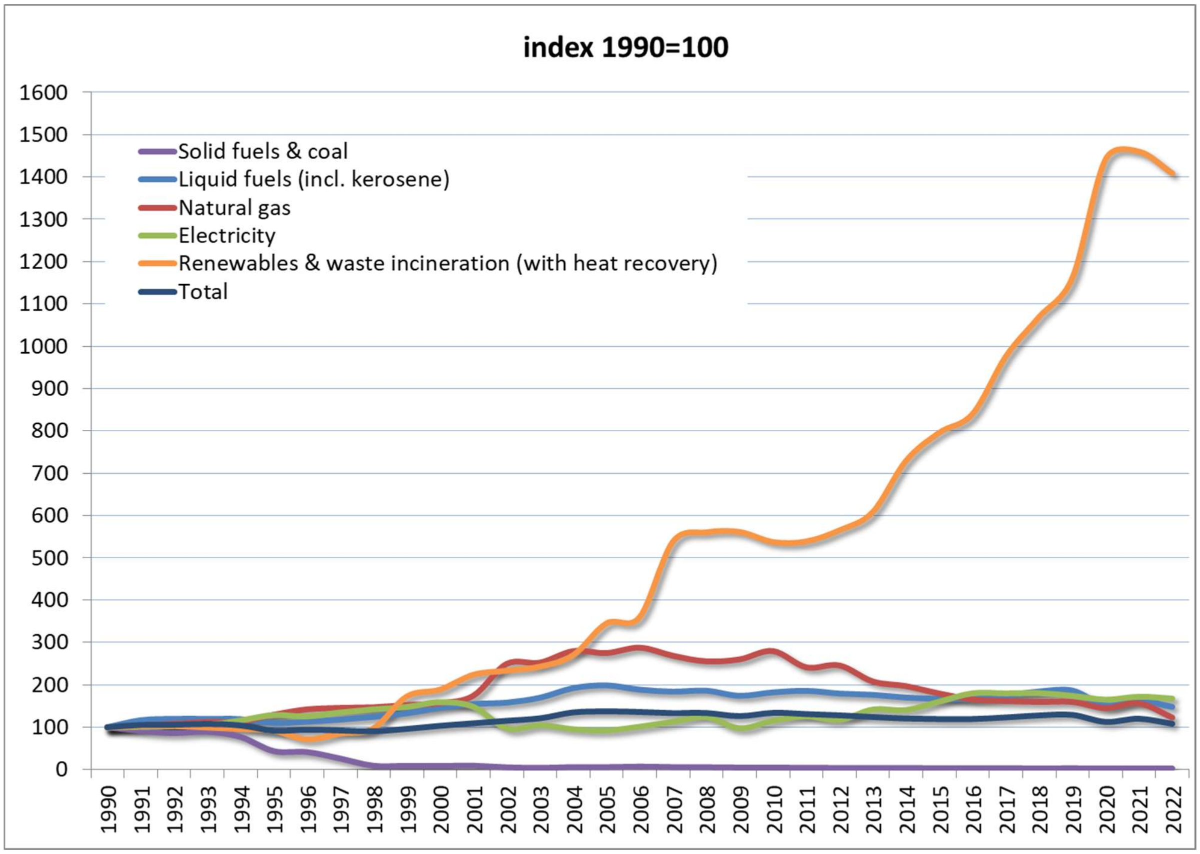
Source: STATEC, Table A.4200 (updated 3 April 2024): https://lustat.statec.lu/vis?pg=0&tm=a%204200&hc[dataflowId]=DF_A4200&hc[dimensions]=Sp%C3%A9cification&hc[Fr%C3%A9quence]

=Annuelle&df[ds]=ds-release&df[id]=DF_A4200&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A.A01&ly[cl]=TIME_PERIOD&ly[rw]=SPECIFICATION

Notes: (1) Natural gas is expressed in GCV;

(2) Only the organic fraction of waste is counted. The biogas included as renewable energy source is expressed in GCV that also comprises blended biofuels. There is a break in the time-series between 1999 & 2000 (II).

Figure 2-19 –Primary energy consumption: 1990-2022



Source: STATEC, Table A.4200 (updated 3 April 2024): https://lustat.statec.lu/vis?pg=0&tm=a%204200&hc[dataflowId]=DF_A4200&hc[dimensions]=Sp%C3%A9cification&hc[Fr%C3%A9quence]=Annuelle&df[ds]=ds-release&df[id]=DF_A4200&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A.A01&ly[cl]=TIME_PERIOD&ly[rw]=SPECIFICATION

Final energy consumption increased by 8.4% between 1990 and 2022. As for primary energy consumption, all the energy sources have seen their consumption increase over the period, except solid fuels and coal and blast furnace gases (Table 2-11 & Figure 2-20).

Over the period 1990-2022, the final energy-mix of Luxembourg changed considerably with a dropping share for solid fuels – for which the main part was used in the iron and steel industry – in favour of liquid fuels and natural gas and, to a lesser extent, to new energy sources based on biomass. Indeed, in 2022, 77.3% of the final energy consumption was covered by fossil fuels – 62.1% by liquid fuels including the important volume of road fuels as well as kerosene,[37] 14.2% by natural gas and 1.1% by solid fuels and coal. The remaining 22.7% of the consumption were either electricity (14.2%) and heat (3.5%) or renewable energy sources, including organic waste incineration with energy recovery, biogas, and biofuels (5.0%). Going back to 1990, 23.8% of the final energy consumption was

37 Diesel being the first liquid fuel in terms of volumes sold. The liquid fuel consumption in Luxembourg is much lower than the level of fuel sales, because large amounts of road fuels are bought by foreign commuters and transit traffic passing through Luxembourg: see section 2.1.6 below.

stemming from solid fuels and coal, 46.0% from liquid fuels, 13.5% from natural gas, and 10.4% from electricity (Table 2-11 & Figure 2-20). The following elements caused the shift from 1990 to 2022 in terms of final energy consumption:

- Regarding solid fuels and coal, the important decline (-95.0%) is the result of a change in production processes in the steel industry sector: the production process was moved from blast furnaces to electric arc furnaces between 1994 and 1998 and, therefore, solid fuels (mainly imported coke, but also imported anthracite) were replaced, to a very large extent, by electricity and natural gas;
- Liquid fuels increase (+46.5%) was driven by road fuel sales and kerosene, but with the former being 4 to 5 times higher in quantity than the latter. It is especially the "road fuel sales to non-residents" that explains a great deal of the sharp increase in liquid fuels consumption (see Section 2.1.6);
- The 13.7% increase in natural gas final consumption followed the continuous extension of the natural gas network in Luxembourg so that this fuel ranked second after the consumption of liquid fuels in 2022 – and even first if "road fuel sales to non-residents" and kerosene are not considered.

Due to the COVID-19 pandemic, the fuels that are used in the industry and for transportation saw a strong decrease from 2019 to 2020. The strongest decline, however, was observed for liquid fuels (incl. kerosene) where the 2020 consumption was 18.7% lower than in 2019. In 2021, all fossil fuels saw an increase again but their consumption remained below the 2019 levels. In 2022, all fossil fuels decreased again due to the high energy prices.

Table 2-11 – Final energy consumption: 1990-2022

TJ	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Solid fuels & coal	34331.76	30814.85	29475.07	30689.24	27268.21	16035.03	15670.77	10422.20	4882.65
	23.83%	20.38%	19.46%	19.85%	18.05%	11.91%	11.35%	7.64%	3.60%
Liquid fuels (incl. kerosene)	66193.31	76911.52	78669.97	78837.44	78753.71	72682.85	74734.38	78046.98	82554.07
	45.95%	50.87%	51.93%	51.00%	52.14%	53.99%	54.13%	57.20%	60.90%
Natural gas (1)	19426.75	20389.72	21227.08	22064.44	21989.91	23906.63	26251.24	27155.58	27436.94
	13.49%	13.49%	14.01%	14.27%	14.56%	17.76%	19.01%	19.90%	20.24%
Blast furnaces gas	8'457.34	7'234.79	6'196.46	6'514.24	5'503.55	2'731.89	2'511.66	1'347.31	NO
	5.87%	4.79%	4.09%	4.21%	3.64%	2.03%	1.82%	0.99%	NA
Electricity	14988.74	15198.08	15281.82	15826.10	16747.20	18045.11	17710.16	18254.45	19091.81
	10.41%	10.05%	10.09%	10.24%	11.09%	13.40%	12.83%	13.38%	14.08%
Heat (2)	NO	NO	NO	NO	125.60	586.15	547.21	563.54	949.98
	NA	NA	NA	NA	0.08%	0.44%	0.40%	0.41%	0.70%
Renewable energy sources & waste	644.77	644.77	644.77	644.77	644.77	644.77	644.77	644.77	644.77
Incineration (with heat recovery) (3)	0.45%	0.43%	0.43%	0.42%	0.43%	0.48%	0.47%	0.47%	0.48%
Total	**144042.67**	**151193.72**	**151495.17**	**154576.24**	**151032.95**	**134632.42**	**138070.20**	**136434.83**	**135560.21**

TJ	1999	2000	2001	2002	2003	2004	2005	2006	2007
Solid fuels & coal	4835.75	4594.52	4957.84	3083.62	2369.15	3328.54	3248.87	3876.79	3280.32
	3.39%	3.07%	3.16%	1.95%	1.41%	1.78%	1.71%	2.07%	1.77%
Liquid fuels (incl. kerosene)	88082.74	94660.74	100748.47	103139.16	110837.88	125735.24	130190.32	123620.38	120557.57
	61.67%	63.27%	64.30%	65.18%	65.84%	67.37%	68.35%	65.86%	65.22%
Natural gas (1)	28435.91	28125.74	27997.84	28258.28	28673.98	29942.32	29338.04	30622.60	29822.71
	19.91%	18.80%	17.87%	17.86%	17.03%	16.04%	15.40%	16.32%	16.13%
Blast furnaces gas	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
Electricity	19835.80	20790.21	21033.19	21260.54	22252.42	23007.38	22149.43	23806.48	24097.50
	13.89%	13.90%	13.42%	13.44%	13.22%	12.33%	11.63%	12.68%	13.04%
Heat (2)	986.41	503.93	623.54	1084.56	2815.05	3031.39	3050.00	3203.55	2572.81
	0.69%	0.34%	0.40%	0.69%	1.67%	1.62%	1.60%	1.71%	1.39%
Renewable energy sources & waste	644.77	929.70	1321.31	1405.98	1406.76	1586.77	2489.86	2562.50	4518.54
Incineration (with heat recovery) (3)	0.45%	0.62%	0.84%	0.89%	0.84%	0.85%	1.31%	1.37%	2.44%
Total	**142821.40**	**149604.80**	**156682.20**	**158232.10**	**168355.20**	**186631.70**	**190466.50**	**187692.30**	**184849.50**

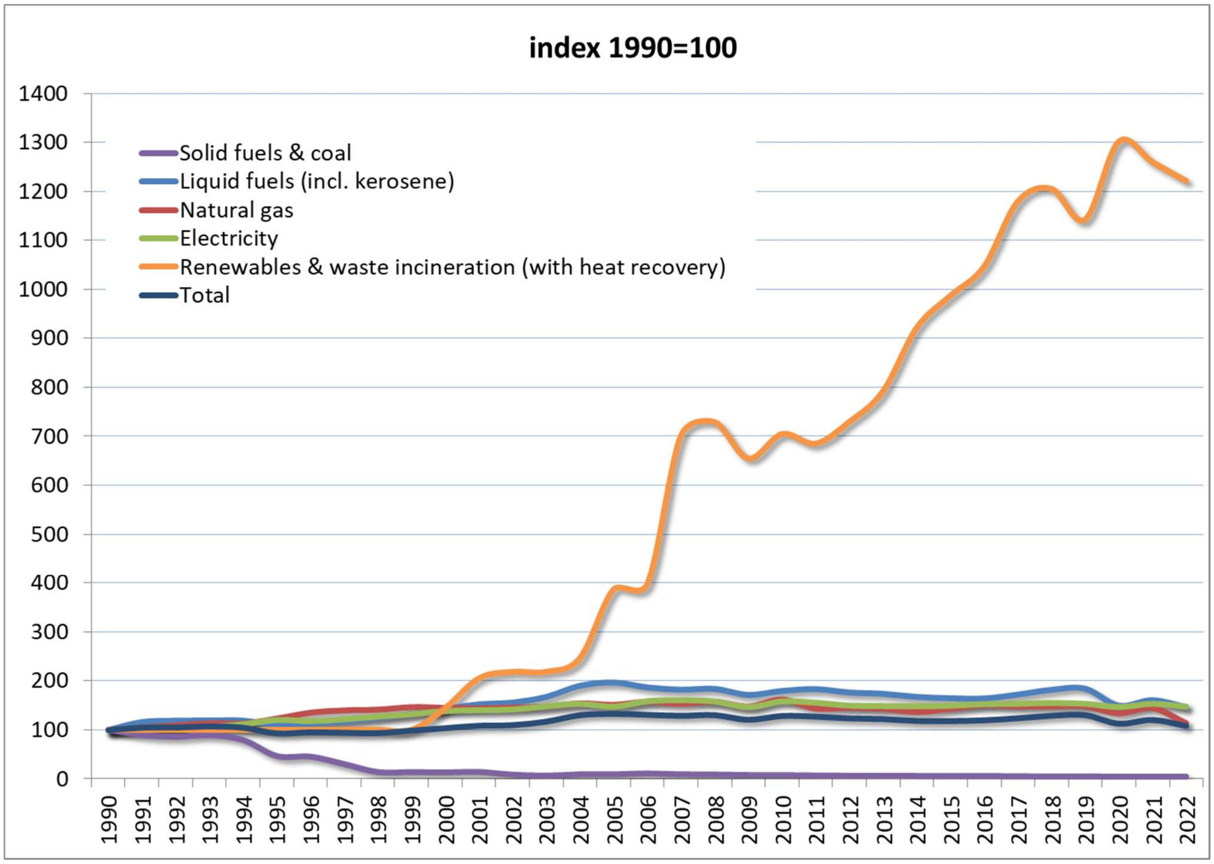
TJ	2008	2009	2010	2011	2012	2013	2014	2015	2016
Solid fuels & coal	3136.57	2801.27	2745.48	2475.56	2295.39	2200.64	2180.81	2060.54	2132.32
	1.68%	1.61%	1.49%	1.36%	1.29%	1.25%	1.28%	1.21%	1.24%
Liquid fuels (incl. kerosene)	121629.35	113546.50	118873.18	121286.04	116795.34	114971.98	110843.99	108958.23	108686.97
	65.13%	65.37%	64.50%	66.46%	65.80%	65.49%	65.13%	64.14%	63.16%
Natural gas (1)	30616.00	28658.82	31411.99	27916.40	28262.17	27789.82	26536.40	27791.20	29226.32
	16.40%	16.50%	17.04%	15.30%	15.92%	15.83%	15.59%	16.36%	16.98%
Blast furnaces gas	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
Electricity	23750.44	22004.89	23734.71	23343.11	22449.55	22315.52	22256.43	22406.96	22922.20
	12.72%	12.67%	12.88%	12.79%	12.65%	12.71%	13.08%	13.19%	13.32%
Heat (2)	2907.26	2457.70	3002.57	3059.72	2993.01	3167.93	2445.50	2288.41	2367.73
	1.56%	1.42%	1.63%	1.68%	1.69%	1.80%	1.44%	1.35%	1.38%
Renewable energy sources & waste	4697.03	4219.33	4540.66	4414.70	4700.14	5103.19	5938.31	6360.25	6742.48
Incineration (with heat recovery) (3)	2.52%	2.43%	2.46%	2.42%	2.65%	2.91%	3.49%	3.74%	3.92%
Total	**186736.65**	**173688.50**	**184308.58**	**182495.52**	**177495.59**	**175549.07**	**170201.43**	**169865.59**	**172078.03**

TJ	2017	2018	2019	2020	2021	2022
Solid fuels & coal	1972.66	1748.41	1915.81	1609.51	1761.99	1719.63
	1.11%	0.95%	1.03%	0.99%	1.02%	1.10%
Liquid fuels (incl. kerosene)	113904.45	120388.23	121854.08	99061.70	106364.91	96941.56
	64.02%	65.09%	65.21%	60.97%	61.43%	62.09%
Natural gas (1)	28751.14	28761.50	28845.58	26020.92	28074.40	22092.54
	16.16%	15.55%	15.44%	16.02%	16.21%	14.15%
Blast furnaces gas	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA
Electricity	23015.79	23251.37	23029.02	22030.23	23014.29	22115.27
	12.94%	12.57%	12.32%	13.56%	13.29%	14.16%
Heat (2)	2668.88	3028.45	3844.64	5353.81	5826.51	5390.91
	1.50%	1.64%	2.06%	3.30%	3.36%	3.45%
Renewable energy sources & waste	7599.27	7766.05	7361.13	8387.12	8117.97	7869.54
Incineration (with heat recovery) (3)	4.27%	4.20%	3.94%	5.16%	4.69%	5.04%
Total	**177912.18**	**184944.00**	**186850.25**	**162463.28**	**173160.07**	**156129.45**

Source: STATEC, Table A.4300 (updated 3 April 2024): https://lustat.statec.lu/vis?pg=0&tm=a%204300&hc[dataflowId]=DF_A4300&hc[dimensions]=Sp%C3%A9cification&hc[Fr%C3%A9quence]=Annuelle&df[ds]=ds-release&df[id]=DF_A4300&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=A.A01.

Notes: (1) Natural gas is expressed in GCV;
(2) from 2000 onwards, heat that is consumed by the cogeneration power plants themselves is no longer included, hence there is a break in the time series (II);
(3) only the organic fraction of waste is counted. The biogas included as renewable energy source is expressed in GCV that also comprises blended
biofuels. There is a break in the time series between 1999 & 2000 (II).

Figure 2-20 – Final energy consumption: 1990-2022



Natural gas has also become the main energy source of Luxembourg's national electricity production capacity. In 1990, more than 90% of Luxembourg's electric energy consumption was imported and one medium size power plant of about 70 MW was run by the iron and steel company Arbed.[38] That power plant was mainly run on blast furnace gas – a side product of the blast furnaces in the steel industry – and was phased out in 1998 after the last blast furnace went out of service. In the early 1990s, small combined heat-power (CHP) installations (or cogeneration) plants appeared. Their installation was encouraged financially by the Government. This development was followed later by some industrial companies which installed gas turbines to produce electricity and heat simultaneously. In mid-2002, the ultra-modern TWINerg power plant started its commercial operation. Located in Esch-sur-Alzette, TWINerg is a gas and steam turbine power station running on natural gas, with an electrical output of 376 MWel (efficiency 55.7%).[39] If almost all of these cogeneration plants run on natural gas, gas oil remains the emergency fuel in case of a natural gas supply disruption.

The impact of TWINerg on the primary energy consumption mix is clearly visible in Table 2-10 and its associated Figure 2-19: electricity imports dropped and natural gas primary consumption increased in 2002, while in 2015 they reverted back to similar values than in

38 Then Arcelor and now, ArcelorMittal.

39 http://www.twinerg.lu/en_index.html, "Environment" tab and http://www.ilr.public.lu/gaz/documents/statistiques/rapport2011.pdf, p. 29.

2001. After a few years of reduced activity, the TWINerg plant was finally shut down in 2016. To complement this analysis, a balance for the electrical energy is provided (Table 2-12 & Figure 2-21).

Table 2-12 – Balance for electrical energy: 1990-2022

GWh	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Net import	4665.46	4718.45	4523.56	4440.97	5015.24	5693.47	5712.33	6026.52	6366.60
Net national production	1322.04	1327.54	1144.30	1019.29	1150.11	1236.06	1251.78	1243.99	1311.39
Net inland consumption	4163.54	4221.69	4244.95	4396.14	4652.00	5012.53	4919.49	5070.68	5303.28

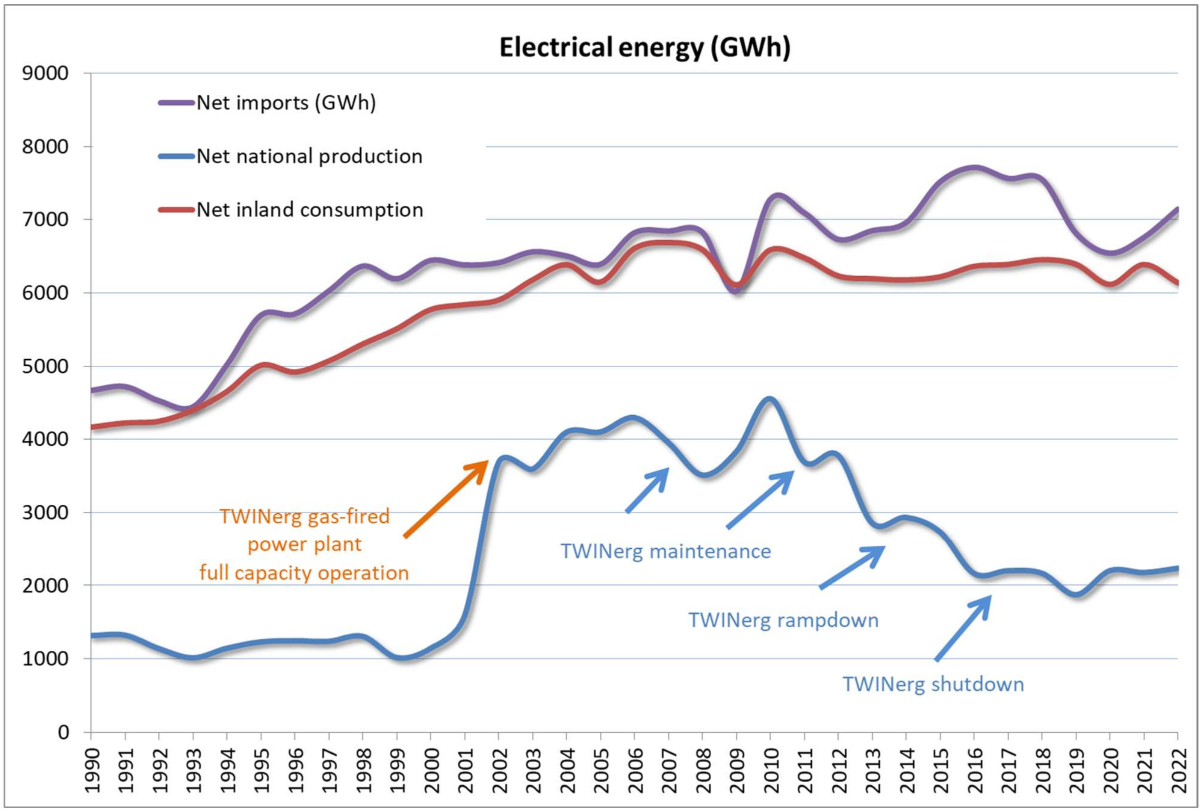
GWh	1999	2000	2001	2002	2003	2004	2005	2006	2007
Net import	6193.53	6445.38	6383.25	6413.64	6562.18	6506.31	6391.61	6823.54	6846.58
Net national production	1311.39	1022.59	1148.34	1591.96	3687.51	3597.10	4102.05	4104.41	4301.31
Net inland consumption	5509.95	5775.06	5842.55	5905.71	6181.23	6390.94	6152.62	6612.91	6693.75

GWh	2008	2009	2010	2011	2012	2013	2014	2015	2016
Net import	6829.87	6022.47	7279.51	7096.34	6732.10	6851.52	6961.18	7518.76	7718.39
Net national production	3516.43	3835.95	4560.28	3693.17	3786.31	2859.81	2937.81	2737.71	2167.69
Net inland consumption	6597.35	6112.47	6592.97	6484.20	6235.99	6198.76	6182.34	6224.16	6367.28

GWh	2017	2018	2019	2020	2021	2022
Net import	7566.69	7553.01	6817.52	6543.49	6758.47	7146.09
Net national production	2204.81	2170.45	1877.38	2205.48	2179.71	2238.26
Net inland consumption	6393.27	6458.71	6396.95	6119.51	6392.86	6143.13

Source: STATEC, Tables A.4203, A.4208, A.4300 (updated 3 April 2024)

Figure 2-21 – Balance for electrical energy: 1990-2022



Sources: Compiled by the Environment Agency on 3 April 2024 using data published by the Ministry of the Economy – Energy Department,
the *Institut Luxembourgeois de Régulation* and STATEC (Tables A.4203, A.4208, A.4300).

Notes: (1) The net national production is the difference between the national production and the conversion process uses and losses.

2.1.6 Road transportation

2.1.7 Diverse inland and cross-border road transport flows

Luxembourg's location and its economic development have made it a focal point for international road traffic. Luxembourg is located at the heart of the main traffic axes for Western Europe (Figure 2-22) and, therefore, has traditionally had a high volume of road transit traffic for both goods (freight transport) and passengers (tourists on their way to or back from southern Europe). The latter has increased even further by the high number of commuter journeys observed every working day. In comparison with international traffic, domestic traffic plays only a relatively small role since it responsible for only one quarter of the total road fuels sold in Luxembourg.

Road traffic is also the largest source of emissions in Luxembourg's GHG balance. Fuel quantities sold at Luxembourg's petrol stations, after having been converted into GHG volumes, are, according to IPCC reporting rules, totally included in the GHG balance, although usually around 70% of the emissions cannot be assigned to vehicles registered in Luxembourg and are actually emitted mostly abroad. This phenomenon is referred to as "road fuel sales to non-residents" whether they are in transit or commuting for work or leisure.

Indeed, due to a policy of low taxed fuel (gasoline and diesel), Luxembourg is an attractive "fuelling station" for daily commuters from neighbouring countries and cross-border shoppers, but, most importantly, for international road transit traffic crossing its territory (mainly freight transport). "Road fuel sales to non-residents" is briefly defined in Box 2-2.

With numerous trucks transiting through Luxembourg, as well as a passenger cars market dominated by diesel vehicles in at least two of its neighbouring countries – namely Belgium and France – it is not surprising that diesel oil is the first liquid fuel in terms of volumes sold (Figure 2-23).

The allocation of fuel sales between residents ("domestic") and non-residents ("exports") is not made on the basis of statistics or counting, but by using the Network Emission Model (NEMO). Details are provided in Section 3.2.9.3.2.2 of this report.

Box 2-2 – Road fuel sales to non-residents

It covers fuel sales to non-residents, i.e.:

1. Road vehicles in transit: freight trucks, buses & coaches, passenger cars, that fill up in Luxembourg because of lower fuel prices;
2. Cross-border commuters who are also benefiting from the cheaper fuel prices;
3. "Fuel tourism", known as "Tanktourismus" in Luxembourg: people driving purposefully to Luxembourg to benefit from the lower fuel prices, as well as lower prices on other commodities such as non-alcoholic & alcoholic drinks, tobacco, etc. (Luxembourg usually applies the lower taxation rates adopted at EU levels, i.e. 17%).

In the subsequent chapters & sections of this NIR, "road fuel sales to non-residents" is sometimes referred to as "(road) fuel exports".

2.1.7.1 Effects on GHG emissions: an atypical situation

Combining the size of the country and its economy, on the one side, and lower road fuel prices that imply a disproportionate volume of road fuel sales compared to its resident population on the other side, Luxembourg presents a completely untypical and unique structural feature in its GHG emission balance. In 2022, 4.19 Mio. t CO_2eq were produced by the road transportation sector and out of these, 2.55 Mio. t CO_2eq, corresponding to 60.9%, are based on fuel sales to commuting and transiting vehicles. That last amount represented around 31.2% of the total 2022 GHG emissions for Luxembourg (excluding LULUCF) while the whole CRF sub-category 1A3b accounted for 51.2% of the total 2022 GHG emissions for Luxembourg (excluding LULUCF) (Figure 2-24). In previous years, the share of GHG emissions based on fuel sales to commuting and transiting vehicles was much higher, but because of the SARS-CoV-2 outbreak, the fuel sales decreased considerably in 2020 (-30.7% as compared to 2019) and only partly recovered in 2021 (+7.1% as compared to 2020) before dropping again sharply in 2022 (-22.9% as compared to 2021) due to the high energy prices.

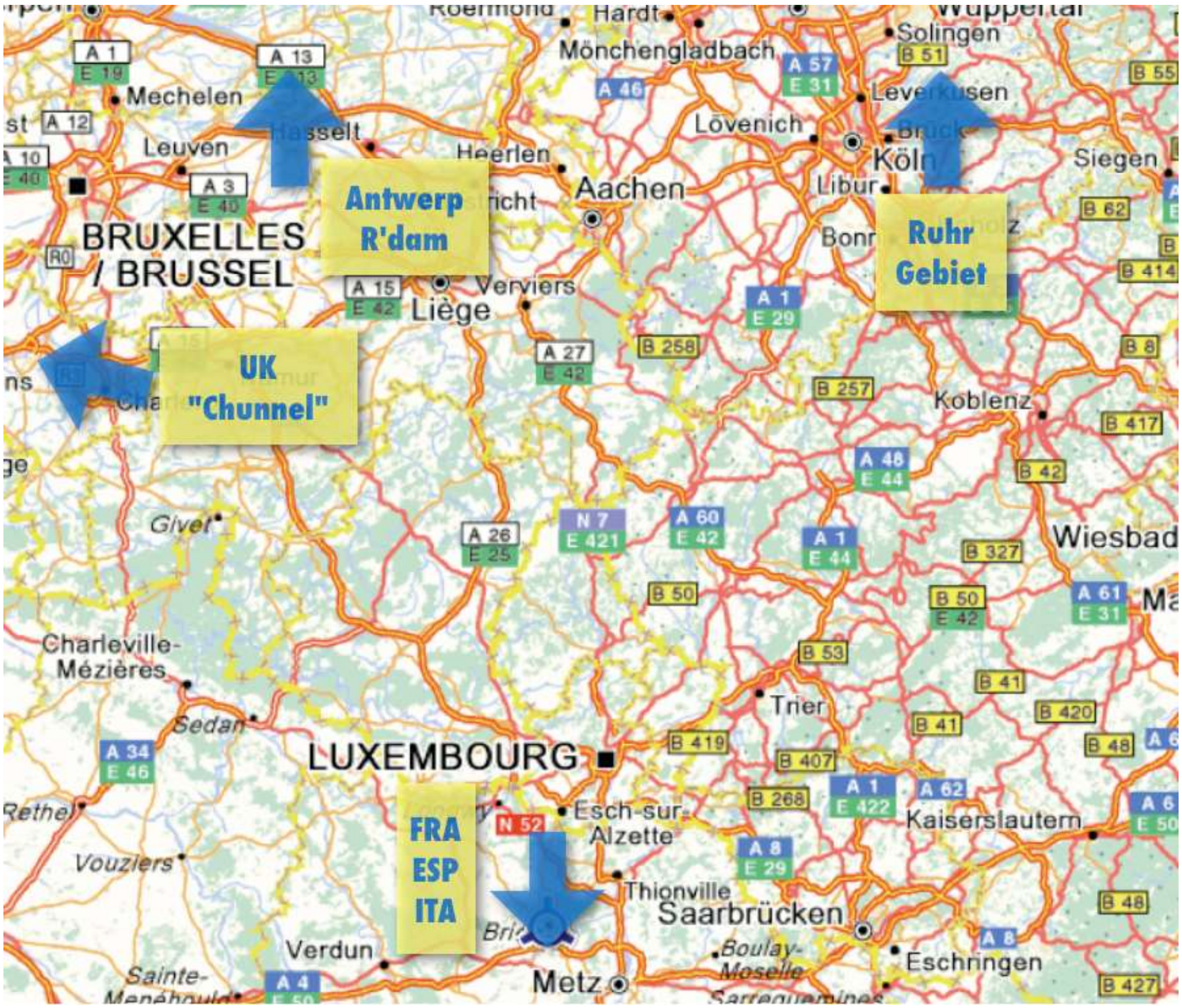
Both the emissions generated by the national vehicles fleet and by the non-residents – "road fuel sales to non-residents" – showed dramatic increases over the 1990-2022 period: +91.9% and +46.3%, respectively.[40] For the national fleet, the evolution correlates with both the population and economic activity growth. It is also explained by an increasing rate for passenger cars per inhabitants (from 499 to 676 passenger cars per 1000 inhabitants between 1990 and 2018, i.e. the highest rate within the EU[41]). Regarding "road fuel

40 Corresponding percentages were +70% and +232% in 2005, the peak year with regard to road transportation related emissions. These percentages differ slightly from those reported under Table 3-67 since the latter includes CO2 emissions from biomass which are not counted here.

41 Data extracted from https://ec.europa.eu in April 2020

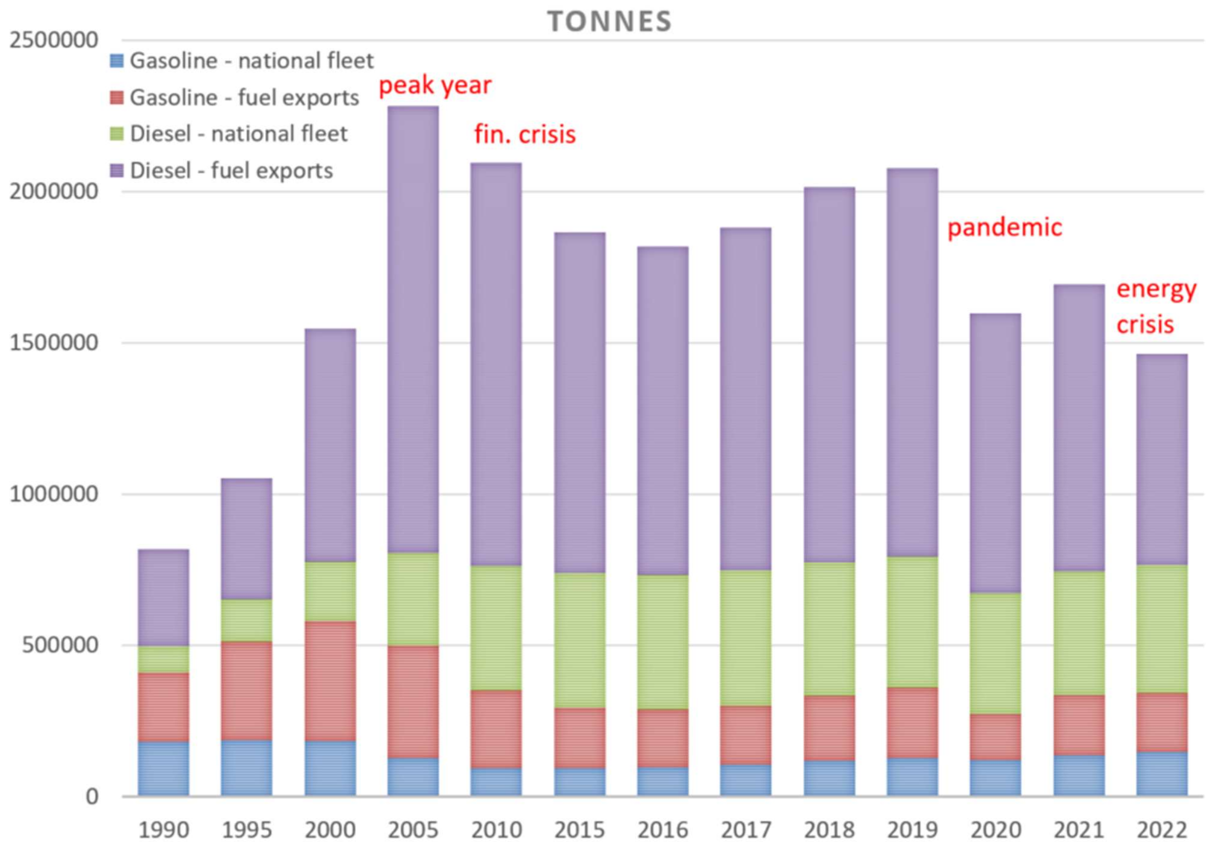
sales to non-residents", the rise is undoubtedly linked to the growing number of commuters crossing the borders every working day as well as to the general increase of road freight traffic in Europe.

Figure 2-22 – MAIN ROAD FREIGHT AXES CROSSING LUXEMBOURG



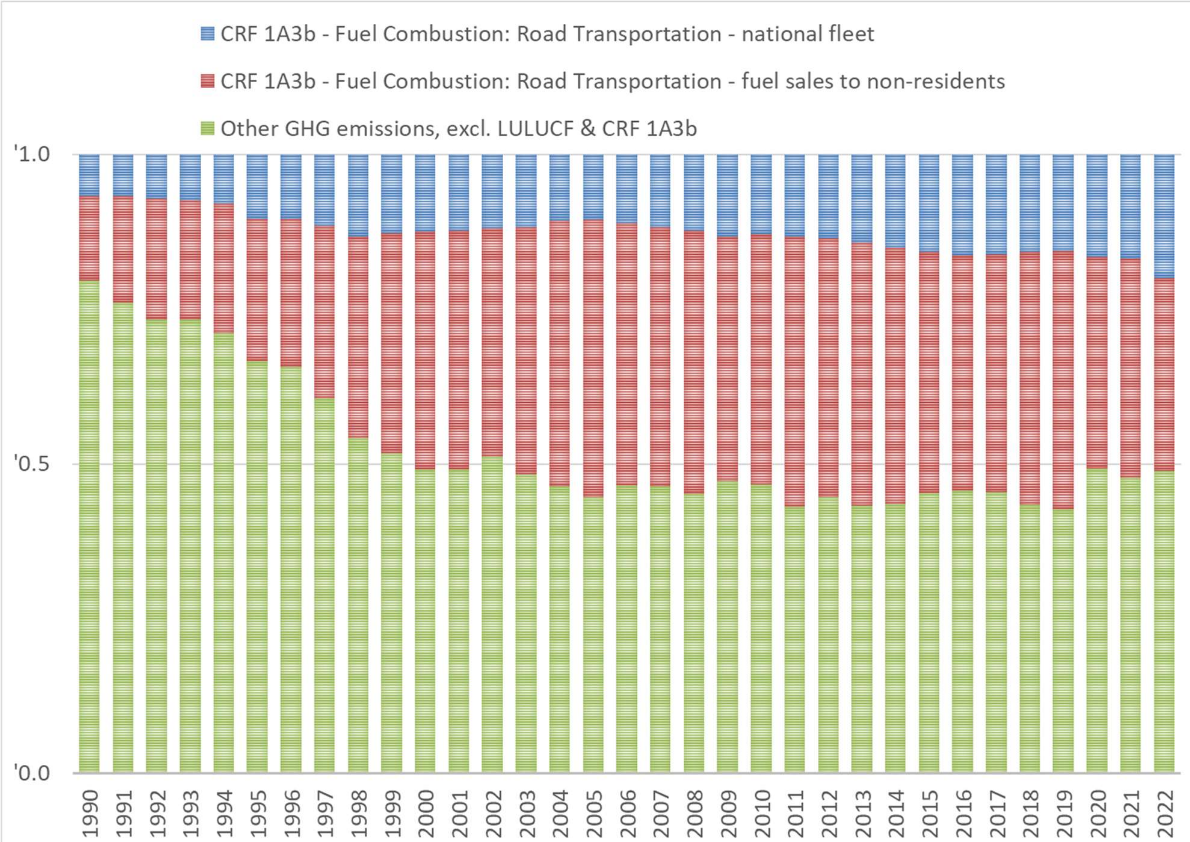
Source: ViaMichelin.

Figure 2-23 – Road blended fuel sales: 1990-2022 in tonnes



Source: based on Table 3-67 in Section 3.2.9.3.

Figure 2-24 – GHG emissions for road transportation (CRF sub-category 1A3b): 1990-2022



Source: Submission 2024v1.
Note: CO_2 emissions from biofuels are excluded, and reported as "memo item".

2.1.8 UNFCCC and Kyoto Protocol: a demanding challenge for Luxembourg

2.1.8.1 The road transportation dilemma

Since Luxembourg is a small open economy integrated in the European internal market where mobility of tax bases are likely to be high, only marginal variations in the price differentials for petrol and diesel can be initiated by the authorities. Indeed, if Luxembourg's rates of taxation and prices were higher than those in the surrounding countries, it would be rather easy for any citizen of Luxembourg to avoid domestic taxation and to practise arbitrage: no location in Luxembourg is further than a maximum of 25-30 km away from a border with a neighbouring country. Lower taxation rates for certain goods – such as fuels, e.g. – have therefore always been part of Luxembourg fiscal policy and will remain crucial in the future, because of the country's geographical location and its small area. Whereas in larger neighbouring states, increasing certain tax rates would result in a slight shift in demand and in arbitrage deals at the outer fringes of their national territory – with a corresponding relatively slight reduction in tax revenues – this would not be the case for Luxembourg where such a policy may result in big losses in tax incomes. However, since road transportation, and more precisely "road fuel sales to non-residents", is the main contributor to GHG emissions in Luxembourg, as underlined in the second national

"Action Plan for reducing CO_2 emissions"[42], Luxembourg will use a policy mix of instruments with the aim of progressively reducing road transport related emissions.

With regard to the instrument of excise duties, Luxembourg will gradually increase road fuels excise rates following a cautious approach based on a better knowledge of the factors determining road fuel sales in Luxembourg that also takes into account the impact on the public finances of the country. Furthermore, in its programme, the actual Government that took office early December 2013 underlines that a feasibility study on the progressive way out of "fuel tourism" – and more generally of "road fuel sales to non-residents" – should be realized so to evaluate the economic impacts of such a decision on the medium and long terms[43]. This study has been released in November 2016 (Königswinter, 2016). Its outcomes led to the setting-up of an inter-ministerial working group with the aim to inform the Government on possible venues to reduce the weight of road fuel sales in the GHG balance of Luxembourg, as well as making public finances less dependent from that source of income. In parallel, STATEC is working on evaluating price-elasticities of road fuel sales.

With regard to other instruments, the Luxembourg Government considers the organization of transport and the necessity to overcome existing problems linked to the traffic intensity as primary objectives. In this context, it promotes sustainable ways of transport consisting of public and non-motorized modes of transport. The re-organisation is intended to encompass both the national territory and the neighbouring regions of Germany, France and Belgium where many commuters come from, leading to a doubling of the workforce in Luxembourg during the day. All this is done in a conceptual way where new modes of transport such as electro-mobility and car sharing are promoted.

42 http://www.developpement-durableinfrastructures.
public.lu/fr/actualites/articles/2013/05/presentation_plan_action_climat/2_Nationaler-Aktionsplan-Klimaschutz.pdf

43 http://www.gouvernement.lu/3322796/Programme-gouvernemental.pdf

2.1.8.2 Country and economy sizes

Special attention must also be made for the small size of the country's economy in a different context: it is a contributory factor to the fact that, in spite of the healthy economic situation, the courses of the overall development of the country, of the demand for energy and of the emissions balance are often affected by a single plant which is starting its activities, closing them down or changing its production processes. This became particularly clear when the steel industry switch from blast furnaces to electric arc furnaces was completed during the 1990s: from 1990 to 1998, GHG emissions in Luxembourg were reduced by one third (see Section 2.4 for details).

Furthermore, the construction of a single power station, the TWINerg gas and steam plant, represents a further illustrative example as depicted in Section 2.1.5. When TWINerg started its operation in mid-2002, Luxembourg, which did not yet have any substantial electricity generating capacity, saw, at once, its GHG emissions increasing by 0.9 to 1 Mio. t CO2e per year. To give another illustration on how this project affected the GHG emissions pattern in Luxembourg, one can underline that it represents 35% of the allocated emissions volume of the whole GHG EU Emissions Trading Scheme sector (EU-ETS) for the first commitment period under the Kyoto Protocol.

The impact that single industrial projects might have, plays also the other way round when a production unit or a plant is closed down. After a few years of reduced activity, the TWINerg power plant was finally shut down in 2016, which has a very high impact on Luxembourg's total GHG emissions. Also, a sufficiently long breakdown in one of the main industrial unit of the country could have impacts on the total GHG emissions, such as the long maintenance operations of the TWINerg plant in 2008 and 2011 demonstrated (cf. Figure 2-21).

If these issues might not be a major concern for large economies, it is for Luxembourg, as shown by the examples discussed above.

2.1.8.3 Limited GHG emissions reduction potentials

As of today, Luxembourg does not have those significant technical potentials which exist in other countries where residual "old-technology" industrial and power plants still operate. In Luxembourg, there were almost none, and there still is none of those GHG reduction potentials stemming from the modernisation or the replacement of existing national industrial or power plants. In fact, with the move from blast to electric arc furnaces in the steel sector during the 1990s, Luxembourg very soon exhausted its only major technical potential for GHG emissions reduction. With the process change in the steel industry – an activity which accounted for 50% of Luxembourg's total GHG emissions in 1990 (excluding LULUCF)[44] – total emissions from industry and electricity generation – i.e. largely the sectors covered by the EU-ETS – decreased to 1.78 Mio. t CO_2e in 2022 – about 21.7% of total GHG emissions (excluding LULUCF) – coming from 7.9 Mio. t CO_2e in 1990 - or about 62.0% of total GHG emissions (excluding LULUCF).[45]

Also, any ultramodern fossil fuel-based electricity generating plant that Luxembourg might decide to construct will automatically lead to an increase of its national GHG emissions, since there are no existing power plants which can be stopped in return. Thus, those highly efficient CHP installations and the ultramodern gas and steam power station (TWINerg, shut down in 2016) that have been promoted and are operating in Luxembourg since 1998, and that use natural gas and, sometimes, gas oil as inputs, have led to an

44 Sum of CRF sub-categories 1A2a and 2C1.

45 Sum of CRF sub-categories 1A1a, 1A2 and 2, excluding F-gases.

additional amount of up to 1.2 Mio. t CO_2e per year in the GHG balance.[46] It is therefore clear that any new fossil-fuel power generating installation that might be constructed will inevitably lead to a deterioration of Luxembourg's GHG balance. This also implies that the implementation of the EU CHP installation guidelines, which in other countries may lead to CO_2 reductions thanks to increased efficiency, is counterproductive for Luxembourg. For this reason, Luxembourg's authorities will only promote heat production from renewable energy sources, focusing mainly on biomass, wood and solar energy.[47] More precisely, CHP installations using renewable energies, biogas addition in distribution networks and the mobilization of wood resources will be favoured.

2.1.8.4 The "origin" principle of the IPCC reporting Guidelines vs. "polluter pays" principle

For the period 2002-2015, the "origin" or "territorial" principle, applied for reporting GHG emissions under the IPCC Guidelines, generates a GHG balance for Luxembourg that looks significantly less favourable than a "consumer" or "polluter pays" approach would produce (Figure 2-25). The "origin" principle is in favour of Luxembourg in that its imports of electricity are excluded from its GHG emission balance: those emissions are attributed to the electricity producing countries. But, as indicated above, "road fuel sales to non-residents" related emissions are reported in Luxembourg's GHG balance.

Now, if the "polluter pays" principle is used as a yardstick, Luxembourg's assessment reveals that GHG emissions according to the IPCC Guidelines are significantly higher from 2002-2015 (the period during which the TWINerg power plant was operational and during which Luxembourg exported significantly greater quantities of electricity), and about 0.025 Mio. t CO_2e higher for 2021 (Figure 2-25).[48] This illustrates that the presence of a single power plant – even though it was highly efficient – has a significant impact on Luxembourg's national total GHG emissions.

Luxembourg's efforts to develop efficient, low-carbon electricity production are not rewarded in the actual reporting system for GHG emissions. Luxembourg has, for many years, promoted the construction and the development of highly efficient CHP installations and of a modern gas and steam power plant. Luxembourg has also actively supported power generation and uses based on renewable energies and, in addition to all these policies, further developments are still in the offing. The impact of these policies has been evaluated using GEMIS 4.2:[49] it has been estimated that electricity net imports – with, nowadays, an average emission factors of 0.75 (kt CO_2 per GWh) – have fallen by more than 1 200 GWh since 2001 – the last year before the TWINerg power plant operated at full capacity – and have been replaced by national electricity generation with a current average emission factor of 0.24 (kt CO_2 per GWh).

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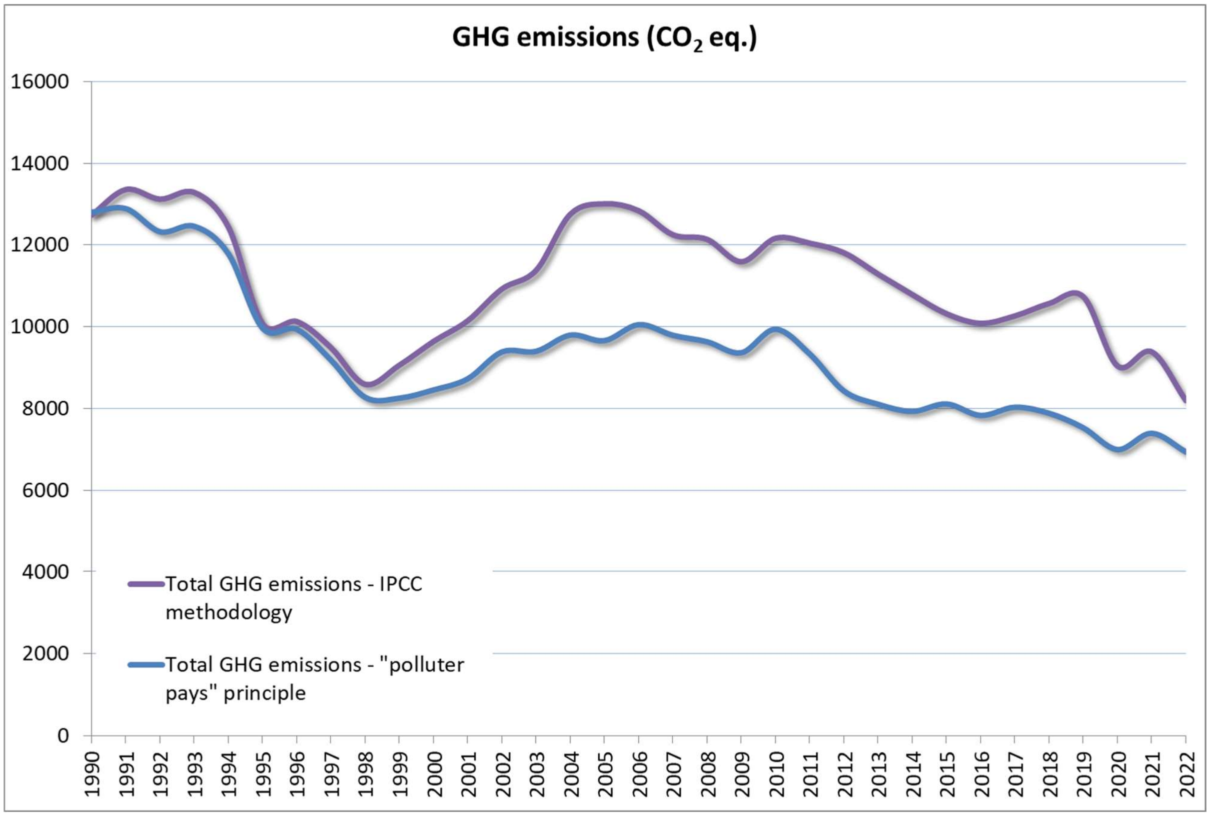
46 Max. 1 Mio. t CO2e for the TWINerg and about 0.2 Mio. t CO2e for CHP installations.

47 See the second Action Plan for Reducing CO2 Emissions (http://www.environnement.public.lu/actualites/2013/05/plan_action_climat/index.html).

48 After having reached a "surplus" of 2.5 Mio. t CO2e in 2005.

49 GEMIS stands for Global Emission Model for Integrated Systems: http://www.iinas.org/gemis-de.html.

Figure 2-25 – Total GHG emissions, excluding LULUCF – two approaches: 1990-2022



Sources: Environment Agency and MECB.
Notes: The "polluter pays" principle figures have been obtained from the total GHG emission according to the IPCC methodology by excluding emissions from "road fuel sales to non-residents" and for electricity generated that is exported, and by adding an estimate for electricity production emissions generated abroad for satisfying Luxembourg consumption (i.e. emissions relating to electricity imports): Emissions "polluter pays" principle = emissions IPCC methodology – emissions "road fuel sales to non-residents" + emissions electricity net imports

So, in terms of the GHG balance, the promotion of renewable energies in the electricity sector, which is associated with major investments, is of little interest. Moreover, additional capacities based upon renewable energies cannot actually be used to replace any electricity from inefficient existing fossil-fuel plants in Luxembourg. Nor will they substitute the modern and highly efficient national production plants. In reality, they will replace the imported electricity which does not contribute to Luxembourg's GHG balance. In this sense, the existing system provides Luxembourg with the incentive not to earmark the generally scant subsidies for Europe's priority investments in renewable energies but, instead, to invest these in measures which might improve its GHG balance.

2.1.9 National circumstances: overview

Key points that play a role on GHG emissions trends in the past and in the future are:

- a country characterized by both **high demographic** and **high economic growth** in a stagnating region, hence an **attractive economic destination**;
- **strong population growth** due to immigration and that is expected to go on;
- **even stronger cross-border commuters growth** that is expected to continue as well;
- **increase of built-up areas** (housing, offices, services, infrastructures) as a consequence of the previous statements;
- location at the **heart** of the main Western Europe **transit routes** for both **goods and passengers**;
- **increase of transport flows** as a consequence of the previous statements;
- **small size** and open economy: a new industrial project, a technological change, a closure or a breakdown of a production unit might have significant impacts on the GHG emissions and increase the overall uncertainty of GHG projections;
- **limitations in taxation policies** due to short distances to neighbouring countries;
- a country that **needs to co-operate and to interact with its neighbours** since environmental issues become quickly cross-border issues;
- **limited national** GHG emissions reduction potential.

Figure 2-26, Figure 2-27 and Figure 2-28 provide a quick overview of the trends of some key variables since 1990.

Figure 2-26 – Key variables trends – 1: 1990-2022

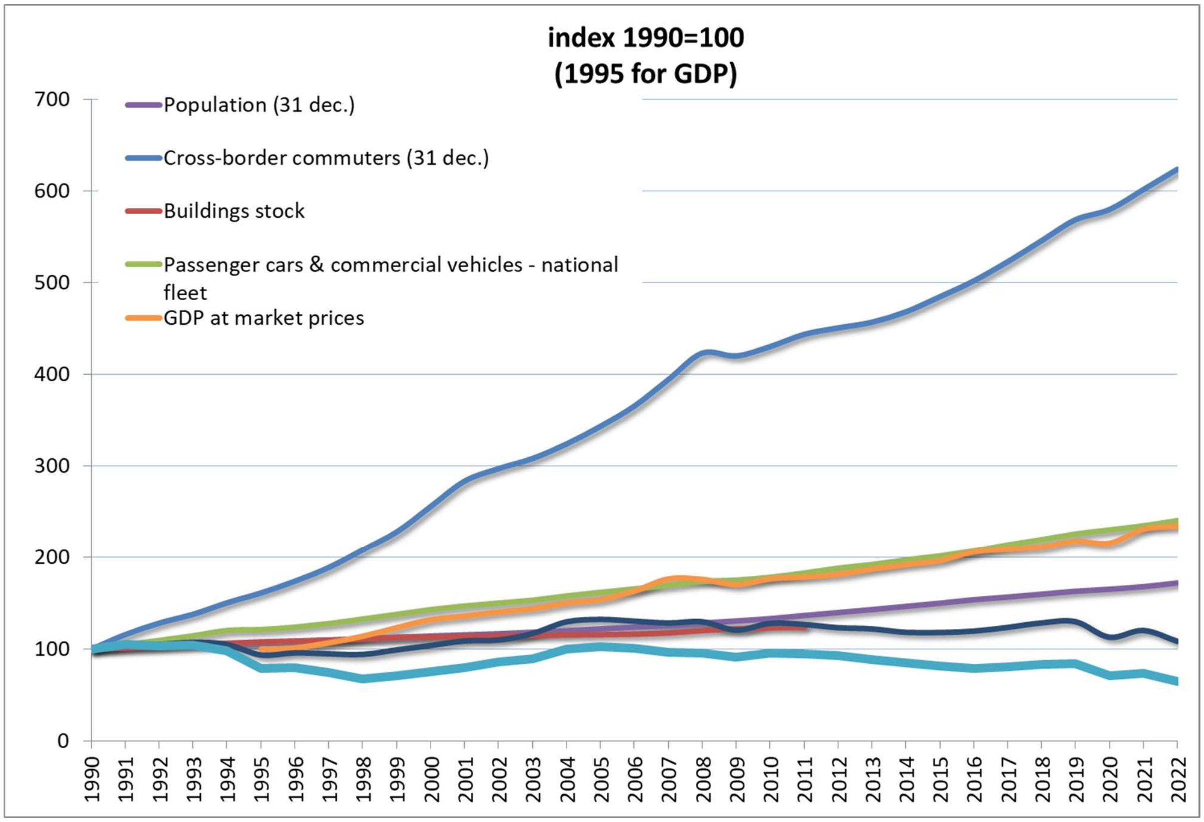


Figure 2-27 – Key variables trends – 1: 1990-2022 (excl. cross-border commuters)

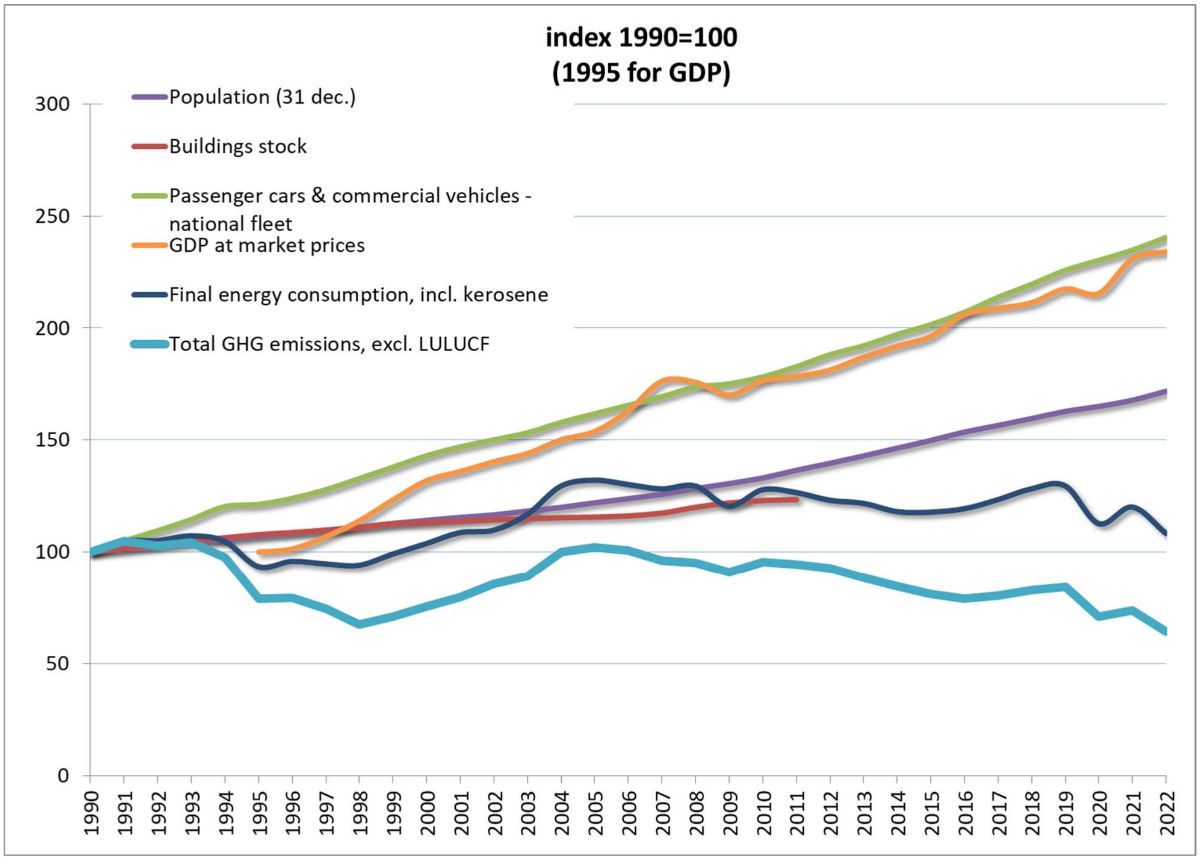
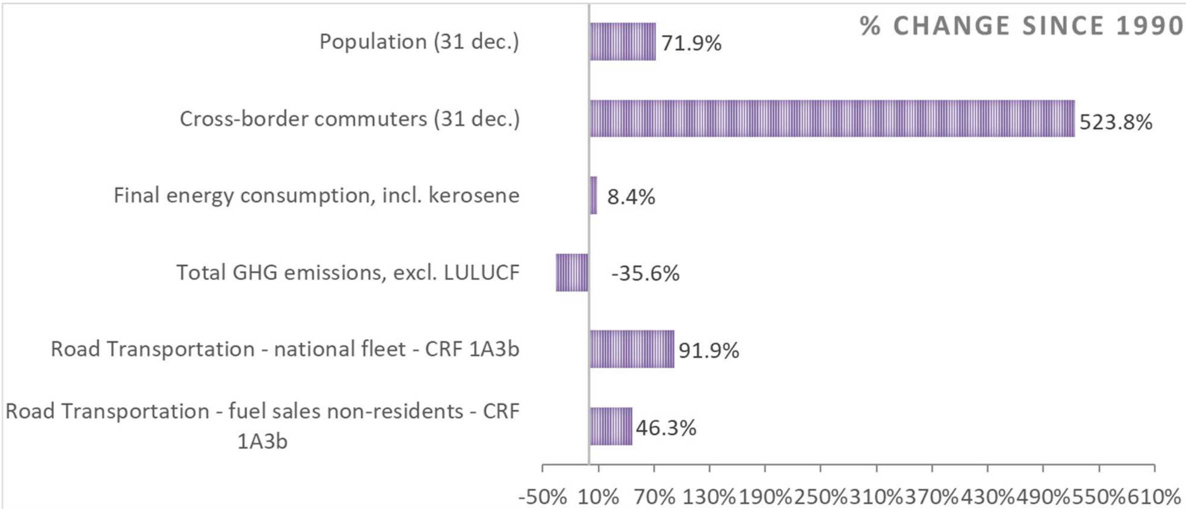


Figure 2-28 – Key variables trends – 2: 1990 & 2022



Sources: Population: STATEC, Table B.1100 (updated 3 April 2024).
https://lustat.statec.lu/vis?pg=0&tm=B1100%20&hc[dataflowId]=DF_B1100&df[ds]=ds-release&df[id]=DF_B1100&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A&lo=5
Commuters: STATEC, Table B.3107 (updated 3 April 2024).
https://lustat.statec.lu/vis?pg=0&tm=B3107&hc[dataflowId]=DF_B3107&df[ds]=ds-release&df[id]=DF_B3107&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=.A
Buildings stock: MECB estimates on the basis of STATEC, Table D.4200 & results from the 2011 population census.
https://lustat.statec.lu/vis?pg=0&tm=4200&hc[dataflowId]=DF_D4200&df[ds]=ds-release&df[id]=DF_D4200&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2019&dq=..A&ly[cl]=TIME_PERIOD%2CBUILDINGS&ly[rw]=SPECIFICATION
Cars & vehicles: STATEC, Table D.6102 (updated 3 April 2024).
https://lustat.statec.lu/vis?pg=0&tm=6102&hc[dataflowId]=DF_D6102&df[ds]=ds-release&df[id]=DF_D6102&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2023&dq=A.
GDP: STATEC, Table E.2101 (updated 3 April 2024).
https://lustat.statec.lu/vis?pg=0&tm=2101&hc[dataflowId]=DF_E2101&df[ds]=ds-release&df[id]=DF_E2101&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2022&dq=.A
Energy: STATEC, Table A.4300 (updated 3 April 2024).
https://lustat.statec.lu/vis?pg=0&tm=4300&hc[dataflowId]=DF_A4300&df[ds]=ds-release&df[id]=DF_A4300&df[ag]=LU1&df[vs]=1.0&pd=2015%2C2021&dq=A.A01.
GHG: Environment Agency and MECB – Submission 2024v1.

Notes: (1) Energy: there is a break in time series between 1999 & 2000.
(2) Buildings stocks = stock of permanently occupied dwellings.

2.2 Description of Emission Trends for Aggregated GHG Emissions

Luxembourg ratified the United Nations Framework Convention on Climate Change in 1994, and the Kyoto Protocol in 2002. Pursuant to that Protocol and the terms of the European agreement distributing the burden among, at that time, the EU-15 Member States, Luxembourg committed itself to reduce its GHG emissions by 28% below their 1990 level over the period 2008-12. This is the deepest cut of any agreed by the 15 Member States. When the Act approving the Kyoto Protocol was adopted in Luxembourg (2001), its GHG emissions were down by more than 30% between 1990 and 1998 (Table 2-13). Now for the 2nd commitment period EU Member States aim to reduce GHG emissions by 20% with regard to the reference year 1990.

In 2022, carbon dioxide was the main source of GHG in Luxembourg. This source accounted for 88.8% of the total GHG emissions calculated in CO_2e – total excluding LULUCF.[50] The second source of GHG was methane with 7.9% of the total GHG emissions. Nitrous oxide was the third source with 2.6%. Fluorinated gases only accounted for 0.63% of the total GHG emissions, with hydrofluorocarbons representing 0.52% of the total GHG emissions and sulphur hexafluoride representing 0.11% of the total GHG emissions.

In 2022, total GHG emissions amounted to 8.192 Mio. t CO_2e, i.e. 35.6% below their level in 1990 and 35.6% below the level retained for the base year under the Kyoto Protocol.[51] As Figure 2-29 shows, several phases can clearly be distinguished over the period 1990 to 2022:

- from base year up to 1993, Luxembourg's emissions remained rather stable;
- then, between 1994 and 1998, they started to decrease significantly to reach their lowest value in 1998, when they were down by more than 30%;
- from 1999 up to 2004, emissions augmented recurrently;
- from 2004 to 2006, a stabilisation peaking around 13 Mio. t CO_2e is observed;
- a decrease occurred between 2006 and 2007 followed by a period of two years impacted by the financial and economic crisis;
- following the financial and economic crisis, the emissions fell steadily until 2016, after which they picked up again;
- in 2020, the emissions fell by 15.8% due to the repercussions of the COVID-19 pandemic;
- in 2022, the global energy crisis led to a decrease in emissions of 12.7%.

The evolution during those 30 years can essentially be explained by changes in production techniques, as well as by changes in the final "energy-mix" consumption. Of course, increasing or decreasing activities for certain source categories also played a crucial role in Luxembourg's GHG emissions trend. During the years 2008-2010, the financial and economic crisis and its aftermaths also played a part. The decreasing trend in emissions since 2012 is mainly due to the progressive shutdown of the TWINerg power plant and slowly

50 In Section 2.2, "total (GHG) emissions" means "total GHG emissions excluding LULUCF". Reference is made to total emissions excluding LULUCF since this is the one that counts for the reduction target under the Kyoto Protocol.

51 The level of emissions considered for the base year is 12.727 Mio. t CO2e. The base year for CO2, CH4 and N2O is 1990. For the F-gases, the base year is 1995. When the assigned amount under the Kyoto Protocol was determined, F-gases emissions were equal in 1990 and 1995 due to a lack of background data and methods at that time. Now, as Table 2-13 shows, F-gases emissions are no longer the same in 1990 and 1995.

declining sales volumes of road fuels. The recent increases of GHG emissions until 2019 were due to steadily increasing sales volumes of road fuels.

Table 2-13 – Luxembourg's GHG emissions and removals – overview by main gases and CRF Sectors: 1990-2022

Gg (1000 t.) CO_2 equivalent	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
CO_2 emissions, incl. net CO_2	11812.01	12354.77	11717.60	11739.67	11071.59	8602.77	8617.62	7892.30	7106.14	7502.47	8077.53	8602.11	9379.66	9871.72	11193.92	11494.79
from LULUCF (1)	92.75%	92.96%	92.63%	92.53%	92.34%	90.18%	90.09%	89.29%	88.27%	88.77%	89.52%	90.08%	90.75%	91.30%	92.24%	92.44%
CO_2 emissions, excl. net CO_2	11813.17	12423.83	12192.27	12341.04	11525.18	9135.57	9186.14	8546.76	7654.72	8117.36	8702.43	9205.64	9978.71	10451.04	11819.38	12076.77
from LULUCF	92.82%	93.07%	92.97%	92.94%	92.69%	90.79%	90.74%	90.12%	89.12%	89.63%	90.29%	90.76%	91.39%	91.88%	92.73%	92.89%
CH_4 (2) emissions, incl. net CH_4	681.91	685.49	672.42	683.97	656.08	673.40	679.07	677.41	675.76	674.10	667.64	672.61	672.84	668.27	653.70	660.65
from LULUCF (1)	5.35%	5.16%	5.32%	5.39%	5.47%	7.06%	7.10%	7.66%	8.39%	7.98%	7.40%	7.04%	6.51%	6.18%	5.39%	5.31%
CH_4 (2) emissions, excl. net CH_4	681.91	685.49	672.42	683.97	656.08	673.40	679.07	677.41	675.76	674.10	667.64	672.61	672.84	668.27	653.70	660.65
from LULUCF	5.36%	5.14%	5.13%	5.15%	5.28%	6.69%	6.71%	7.14%	7.87%	7.44%	6.93%	6.63%	6.16%	5.87%	5.13%	5.08%
N_2O (3) emissions, incl. net N_2O	240.87	249.18	253.83	250.50	248.10	248.41	251.43	249.14	245.83	249.27	247.88	237.26	242.38	229.92	245.94	237.09
from LULUCF (1)	1.89%	1.87%	2.01%	1.97%	2.07%	2.60%	2.63%	2.82%	3.05%	2.95%	2.75%	2.48%	2.34%	2.13%	2.03%	1.91%
N_2O (3) emissions, excl. net N_2O from LULUCF	230.73	239.04	243.69	240.36	237.95	238.26	241.29	239.00	235.69	239.13	237.73	227.12	226.38	213.92	229.94	221.09
	1.81%	1.79%	1.86%	1.81%	1.91%	2.37%	2.38%	2.52%	2.74%	2.64%	2.47%	2.24%	2.07%	1.88%	1.80%	1.70%
HFCs (4)	0.00	0.00	4.99	11.76	12.91	13.81	15.80	18.31	20.92	23.89	28.33	34.86	37.84	38.09	38.26	36.95
	0.00%	0.00%	0.04%	0.09%	0.10%	0.14%	0.16%	0.19%	0.24%	0.26%	0.29%	0.34%	0.35%	0.33%	0.30%	0.28%
PFCs (4)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SF_6 (4)	0.90	1.01	1.11	1.22	1.34	1.43	1.61	1.75	1.79	1.88	1.98	2.66	3.28	3.88	4.45	5.03
	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.03%	0.03%	0.03%	0.03%	0.04%
1. Energy	10291.98	10987.70	10829.69	10998.17	10280.73	8249.42	8358.17	7829.76	7094.35	7524.01	8085.96	8648.06	9420.62	9945.67	11266.16	11548.86
	80.87%	82.31%	82.58%	82.83%	82.69%	81.98%	82.56%	82.56%	82.60%	83.08%	83.90%	85.26%	86.28%	87.43%	88.39%	88.83%
2. Industrial Processes	1609.76	1532.26	1465.28	1454.06	1357.04	998.71	944.66	836.11	679.76	718.26	747.37	700.38	718.98	668.31	723.30	694.51
	12.65%	11.48%	11.17%	10.95%	10.91%	9.93%	9.33%	8.82%	7.91%	7.93%	7.75%	6.91%	6.58%	5.88%	5.67%	5.34%
3. Agriculture	708.68	710.68	699.92	705.13	683.60	702.84	707.24	700.78	696.21	696.09	688.80	678.00	662.27	638.77	639.47	638.91
	5.57%	5.32%	5.34%	5.31%	5.50%	6.98%	6.99%	7.39%	8.11%	7.69%	7.15%	6.68%	6.07%	5.62%	5.02%	4.91%
4. LULUCF	8.98	-58.92	-464.53	-591.23	-443.44	-522.65	-558.38	-644.32	-538.44	-604.75	-614.76	-593.38	-583.05	-563.32	-609.47	-565.98
	0.07%	-0.44%	-3.67%	-4.66%	-3.70%	-5.48%	-5.84%	-7.29%	-6.69%	-7.16%	-6.81%	-6.21%	-5.64%	-5.21%	-5.02%	-4.55%
5. Waste	116.29	118.73	119.59	121.01	112.09	111.51	113.82	116.58	118.57	118.00	115.99	116.44	117.19	122.45	116.81	118.22
	0.91%	0.89%	0.91%	0.91%	0.90%	1.11%	1.12%	1.23%	1.38%	1.30%	1.20%	1.15%	1.07%	1.08%	0.92%	0.91%
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total GHG including LULUCF	12735.69	13290.45	12649.95	12687.13	11990.02	9539.82	9565.52	8838.91	8050.45	8451.62	9023.35	9549.51	10336.00	10811.87	12136.27	12434.52
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total GHG excluding LULUCF	12726.71	13349.37	13114.48	13278.36	12433.46	10062.47	10123.90	9483.23	8588.89	9056.36	9638.12	10142.89	10919.05	11375.19	12745.74	13000.50
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Gg (1000 t.) CO_2 equivalent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2 emissions, incl. net CO_2	11407.76	10896.26	10740.91	10184.35	10971.50	10781.15	10480.54	9810.88	9384.54	8967.12	8613.56	8874.90	9317.63	9389.66	7618.77	7806.72
from LULUCF (1)	92.41%	91.95%	91.64%	91.24%	91.79%	91.84%	91.65%	91.12%	90.59%	90.18%	89.62%	89.82%	90.27%	90.57%	88.70%	88.94%
CO_2 emissions, excl. net CO_2	11908.74	11304.99	11169.35	10625.16	11194.66	11097.07	10866.49	10333.66	9816.08	9345.27	9090.39	9262.84	9567.29	9761.76	8074.93	8420.58
from LULUCF	92.82%	92.34%	92.07%	91.72%	92.08%	92.19%	92.06%	91.60%	91.04%	90.62%	90.19%	90.28%	90.58%	90.97%	89.35%	89.74%
CH_4 (2) emissions, incl. net CH_4	655.27	664.22	679.07	677.34	672.90	643.61	641.68	647.20	657.82	660.39	675.51	676.32	678.20	654.61	665.33	662.36
from LULUCF (1)	5.31%	5.61%	5.79%	6.07%	5.63%	5.48%	5.61%	6.01%	6.35%	6.64%	7.03%	6.84%	6.57%	6.31%	7.75%	7.55%
CH_4 (2) emissions, excl. net CH_4	655.27	664.22	679.07	677.34	672.90	643.61	641.68	647.20	657.82	660.39	675.51	676.32	678.20	654.61	665.33	662.36
from LULUCF	5.11%	5.43%	5.60%	5.85%	5.53%	5.35%	5.44%	5.74%	6.10%	6.40%	6.70%	6.59%	6.42%	6.10%	7.36%	7.06%
N_2O (3) emissions, incl. net N_2O	236.72	239.45	248.40	246.21	251.90	255.46	250.97	243.41	246.94	245.80	252.90	258.22	260.72	263.50	249.72	254.85
from LULUCF (1)	1.92%	2.02%	2.12%	2.21%	2.11%	2.18%	2.19%	2.26%	2.38%	2.47%	2.63%	2.61%	2.53%	2.54%	2.91%	2.90%
N_2O (3) emissions, excl. net N_2O from LULUCF	220.73	223.45	230.65	228.45	234.14	237.71	233.21	234.47	237.99	236.86	244.39	249.71	252.21	254.99	241.21	246.34
	1.72%	1.83%	1.90%	1.97%	1.93%	1.97%	1.98%	2.08%	2.21%	2.30%	2.42%	2.43%	2.39%	2.38%	2.67%	2.63%
HFCs (4)	39.61	43.77	46.09	47.16	49.25	51.87	54.03	57.49	61.55	61.38	59.80	61.92	54.96	49.45	45.72	44.08
	0.31%	0.36%	0.38%	0.41%	0.41%	0.43%	0.46%	0.51%	0.57%	0.60%	0.59%	0.60%	0.52%	0.46%	0.51%	0.47%
PFCs (4)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SF_6 (4)	5.46	5.90	6.32	6.73	7.11	7.57	7.95	8.33	8.72	9.19	9.55	9.73	10.03	10.26	9.91	9.92
	0.04%	0.05%	0.05%	0.06%	0.06%	0.06%	0.07%	0.07%	0.08%	0.09%	0.09%	0.09%	0.09%	0.10%	0.11%	0.11%
1. Energy	11332.34	10734.44	10653.08	10177.43	10733.38	10622.25	10429.55	9911.32	9387.71	8922.40	8644.12	8811.91	9117.30	9293.40	7616.59	8039.85
	88.33%	87.68%	87.81%	87.85%	88.28%	88.24%	88.36%	87.86%	87.07%	86.52%	85.76%	85.88%	86.32%	86.60%	84.28%	85.68%
2. Industrial Processes	749.39	745.56	694.80	625.97	651.03	660.72	629.16	611.78	622.02	613.36	637.45	646.00	643.02	658.13	632.00	559.29
	5.84%	6.09%	5.73%	5.40%	5.35%	5.49%	5.33%	5.42%	5.77%	5.95%	6.32%	6.30%	6.09%	6.13%	6.99%	5.96%
3. Agriculture	629.01	641.35	660.99	659.04	663.17	648.55	639.19	652.24	665.07	675.20	697.23	701.75	704.24	686.13	698.34	694.73
	4.90%	5.24%	5.45%	5.69%	5.45%	5.39%	5.42%	5.78%	6.17%	6.55%	6.92%	6.84%	6.67%	6.39%	7.73%	7.40%
4. LULUCF	-484.99	-392.73	-410.69	-423.05	-205.40	-298.17	-368.20	-513.84	-422.59	-369.21	-468.32	-379.43	-241.15	-363.59	-447.65	-605.34
	-3.93%	-3.31%	-3.50%	-3.79%	-1.72%	-2.54%	-3.22%	-4.77%	-4.08%	-3.71%	-4.87%	-3.84%	-2.34%	-3.51%	-5.21%	-6.90%
5. Waste	119.06	120.97	122.61	122.40	110.49	106.30	105.47	105.82	107.36	102.12	100.83	100.86	98.12	93.41	90.16	89.42
	0.93%	0.99%	1.01%	1.06%	0.91%	0.88%	0.89%	0.94%	1.00%	0.99%	1.00%	0.98%	0.93%	0.87%	1.00%	0.95%
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total GHG including LULUCF	12344.82	11849.59	11720.78	11161.78	11952.66	11739.66	11435.17	10767.32	10359.57	9943.88	9611.32	9881.09	10321.54	10367.48	8589.45	8777.94
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total GHG excluding LULUCF	12829.81	12242.32	12131.48	11584.83	12158.06	12037.83	11803.37	11281.15	10782.16	10313.09	10079.64	10260.52	10562.69	10731.07	9037.10	9383.28
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Gg (1000 t.) CO_2 equivalent	2022
CO_2 emissions, incl. net CO_2 from LULUCF (1)	**6625.72** 87.83%
CO_2 emissions, excl. net CO_2 from LULUCF	**7276.72** 88.82%
CH_4 (2) emissions, incl. net CH_4 from LULUCF (1)	**648.27** 8.59%
CH_4 (2) emissions, excl. net CH_4 from LULUCF	**648.27** 7.91%
N_2O (3) emissions, incl. net N_2O from LULUCF (1)	**218.76** 2.90%
N_2O (3) emissions, excl. net N_2O from LULUCF	**215.96** 2.64%
HFCs (4)	**42.19** 0.52%
PFCs (4)	**NO** NA
SF_6 (4)	**9.18** 0.11%
1. Energy	**6906.87** 84.31%
2. Industrial Processes	**535.30** 6.53%
3. Agriculture	**665.57** 8.12%
4. LULUCF	**-648.21** -8.59%
5. Waste	**84.59** 1.03%
6. Other	**NA** 0.00%
Total GHG including LULUCF	**7544.12** 100.00%
Total GHG excluding LULUCF	**8192.33** 100.00%

Source: Environment Agency and MECB.

Notes: (1) These percentages are relative to the total GHG emissions, including LULUCF.

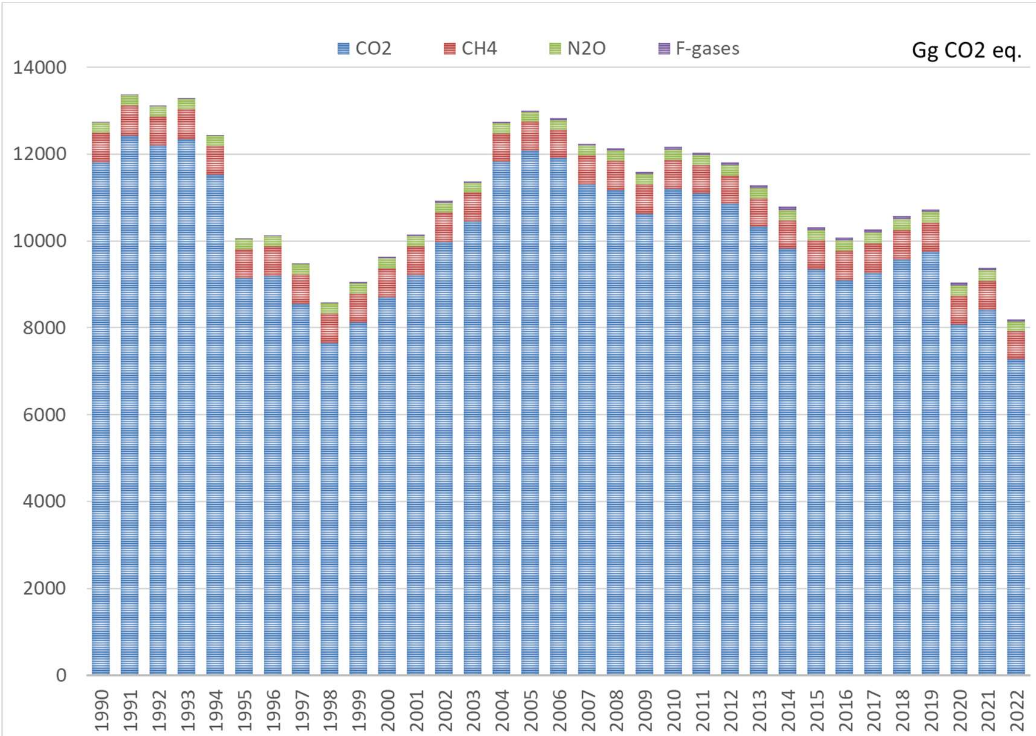
(2) The methane emissions are converted into CO_2 equivalents by multiplying the emissions by 28, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

(3) The nitrous oxide emissions are converted into CO_2 equivalents by multiplying the emissions by 265, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

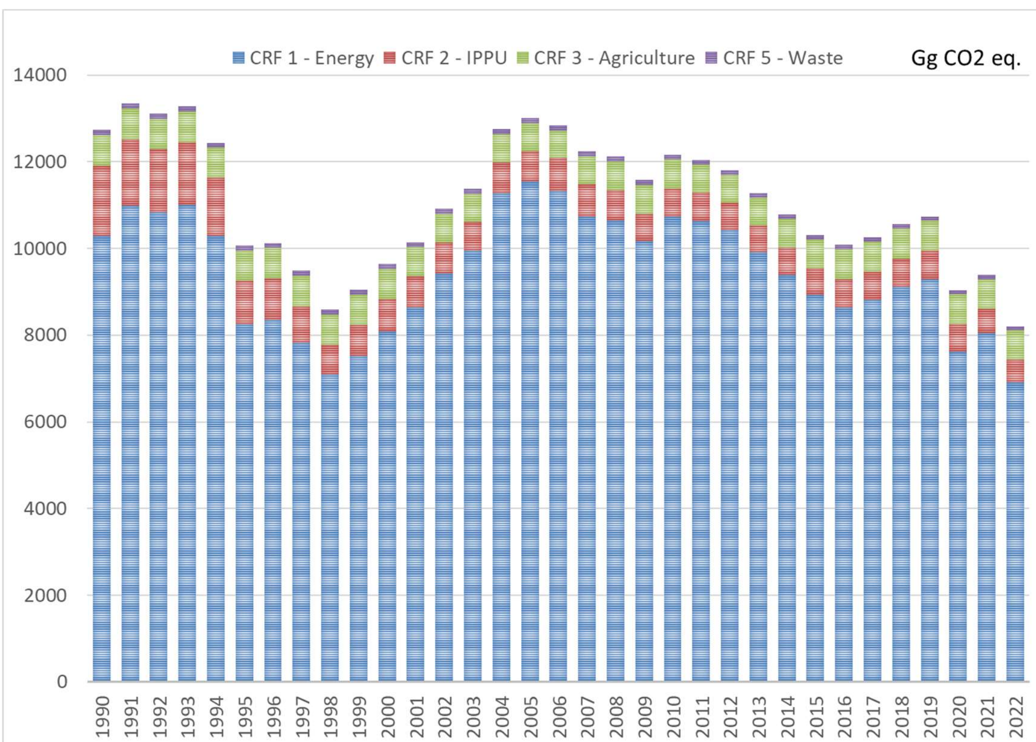
(4) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF_6 expressed in CO_2 equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Figure 2-29 – Luxembourg's GHG emissions (excl. LULUCF) – absolute values: 1990-2022

GHG



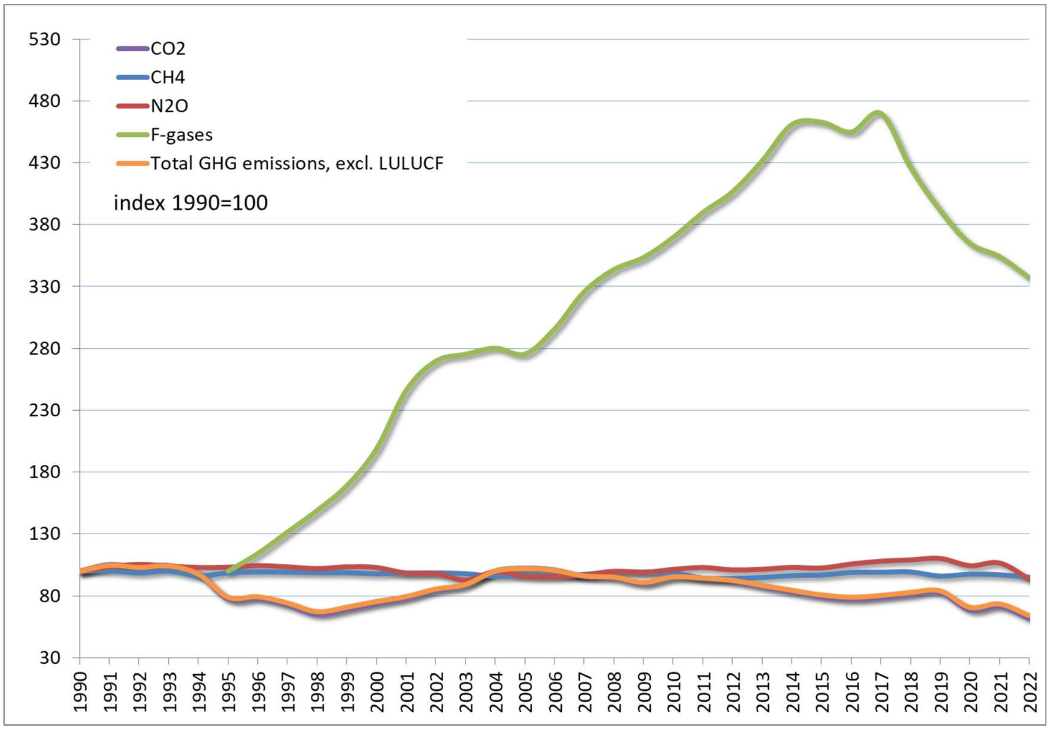
CRF Sectors



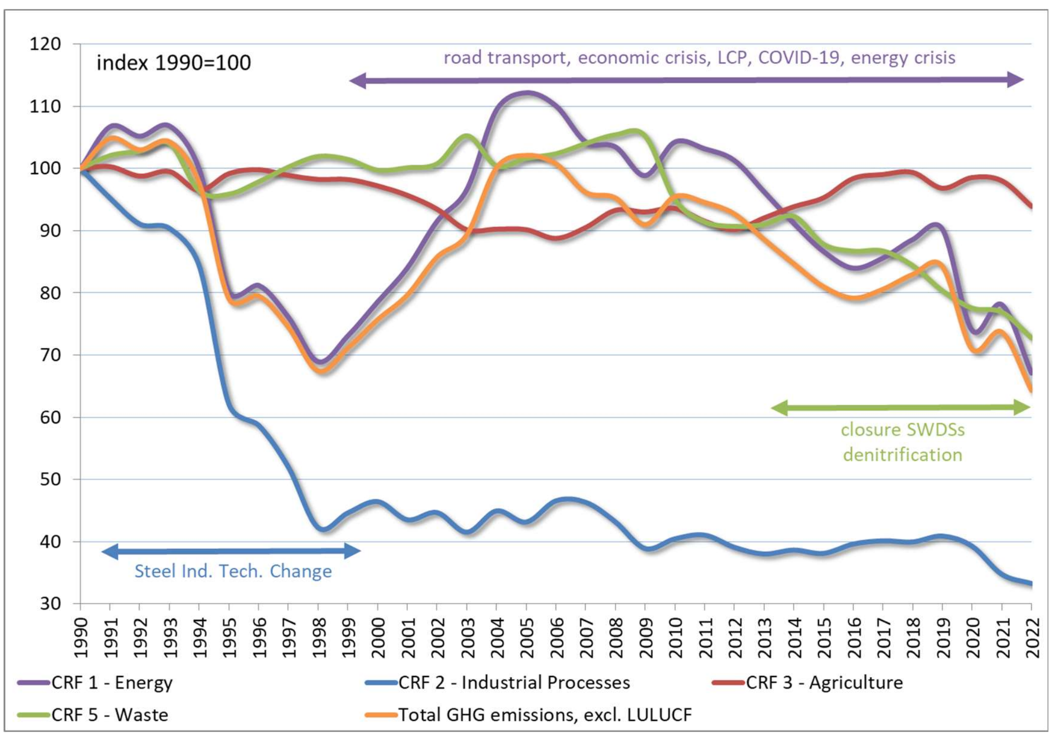
Sources: Environment Agency and MECB.

Figure 2-30 – Luxembourg's GHG emissions (excl. LULUCF) – indexes: 1990-2022

GHG



CRF Sectors



Sources: Environment Agency and MECB.

A good example for a technological change in production took place in the iron and steel industry, where the steel production process was moved from blast furnaces to electric arc furnaces between 1994 and 1998 and, therefore, solid fuels (coke) were replaced to a very large extent by electricity and natural gas. Due to that technological change, the total energy consumption in the steel industry was significantly reduced and the "energy-mix" greatly modified. This process change was the main driver for the reduction in GHG emissions observed between 1994 and 1998. Changes also occurred in the industrial and residential/commercial/institutional sectors, where the consumption of liquid fuels (residual oil, gasoil) was reduced in favour of natural gas in conjunction with the extension of the natural gas network in Luxembourg.

The road transportation sector is a clear example about how activity levels of a source category can influence the overall GHG emission trend. Indeed, the upward trend for GHG emissions recorded from 1999 to 2004 was merely justified by increasing energy consumption and fuel sales in the transport sector. The stabilization spotted for the inventory years 2004 to 2006 was largely the result of relatively steady sales of road fuels that peaked in 2005. Finally, the decrease in total emissions from 2006 to 2007 and the period of relative stability that followed was driven by a "road fuel sales to non-residents" related emissions reduction, which reached its lower level in 2009 (financial and economic crisis), combined with a reduction of GHG emissions from the power generation sector, the latter being exceptionally important for 2008 when the main power plant of the country underwent a lengthy maintenance. The steady decrease of GHG emission following the year 2010 can mainly be attributed to another lengthy maintenance in 2011 as well as the steady and gradual rampdown of the turbine. Since 2016, the GHG emissions have been rising again, mainly due to increased sales of liquid fuels in the transport sector. In 2020, the GHG emissions fell suddenly due to the SARS-CoV-2 outbreak and the effects of the lockdown periods and the onset of a predominant home office working culture on the transportation sector. And in 2022, the global energy crisis led to an even stronger decrease of emissions.

More detailed explanations are provided in Sections 2.3 (dealing with gases) and 2.4 (dealing with CRF Sectors), as well as in the analysis of emission trends for each sector (see the first sections of CRF Sector Chapters 0 to 1).

A fundamental point worth mentioning when analysing Luxembourg's GHG emission trends and their composition over time, is the small size of Luxembourg, and therefore, the special nature of its economy. Indeed, the structure of the economy, the related energy demand and the energy and emission balances may vary significantly, whether a new economic activity starts its operations or an existing one ceases them. This characteristic explains, for instance, the reduction of emissions pertaining to the industrial sector: with 7.9 Mio. t in 1990, CO_2e emissions from industrial processes and fuel combustion in industry accounted for 62% of total GHG emissions. They could eventually be reduced to 2.1 Mio. t in 1998 – i.e. 25% of total GHG emissions – mainly after the reorganization of the steel industry took place in the mid-nineties (move from blast furnaces to electric arc furnaces indicated above). At that time, GHG emissions of Luxembourg were almost one third below the base year level. Another illustrative example is the TWINerg power plant. This plant started its operation in mid-2002 and, by 2010, was responsible for about 0.96 Mio. t CO_2, i.e. around 8% of the total GHG emissions. In the years following 2010, the plant's activity level progressively decreased until its final shutdown in 2016.

2.3 Description of Emission Trends by Gas

For the different GHG, trends over the period 1990-2022 (and 2021-2022) were as follows:

- CO_2: …………………………………………… -38.40% (-13.58%)
- CH_4: …………………………………………… -4.93% (-2.13%)
- N_2O: …………………………………………… -6.40% (-12.33%)
- F-gases: …………………………………… +237.05% (-4.86%)

For carbon dioxide, the development between 1990 and 2022 hides a V-shape evolution over the period as well as important changes in the sources of CO_2 emissions: declining emissions in industrial combustion, increasing emissions from transport and natural gas fired power plants – as underlined in the previous section.

Total methane emissions have remained fairly stable over the period 1990-2022 with a reduction of only 4.93%. In 2022, reduced methane emissions were observed in waste management (-31.86%) and in energy use (-3.98%) as compared to 1990, the latter being due to an upward trend for fugitive emissions from natural gas distribution and use (+20.23%), and to a downward trend of combustion related emissions in the energy production industries and the commercial and residential sectors (-20.49%). The methan gas saw increasing emissions in agriculture (+0.80%) compared to 1990.

Nitrous oxide emissions development between 1990 and 2022 (-6.40%) is closely linked to an increase of liquid fuels related emissions from mobile combustion activities (+209.09% in the road transportation sector) and to emissions from the waste sector (+85.47%) that were overcompensated by declining emissions from the agriculture (-27.49%) and industrial products and product use sectors (-39.27%).

With regard to F-gases, HFCs emissions increased by 205.51% in 2022 compared to the base year (1995), whereas SF_6 emissions showed a 541.29% increase between 1995 and 2022. In the case of HFCs emissions, the increase is due to a wider use of mobile and stationary cooling equipement while, in the case of SF_6, the increase is due to an increase in the use of high-voltage electrical equipement as well as noice reduction windows. Table 2-14 shows the detailed evolution of the greenhouse gases and the sector emissions over time while Table 2-15 shows, for each greenhouse gas, the emissions of the main source categories. Figure 2-31 visualizes the data of Table 2-15. These tables and figure offer the opportunity to further analyse emission trends for each one of the gases.

Finally, when including emissions and removals from land use, land use change and forestry (LULUCF), Luxembourg's greenhouse gas emissions amounted to a total of 7544.12 million tonnes CO_2 eq in 2022. Net removals from the LULUCF sector amounted to 648.21 Gg CO_2 eq. Since 1990, net emissions have decreased by 7317.93% per cent (the sector was a source of net emissions in 1990 (8.98 Gg CO_2 eq) and a source of net removals in 1991-2022).

Table 2-14 – Luxembourg's GHG emissions (excl. LULUCF) –sector-based breakdown: 1990-2022

Gg (1000 t.) CO_2 equivalent	CRF Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Public Electricity & Heat Production	**1A1a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**60.48**	**56.78**	**59.44**	**99.57**	**108.93**	**56.33**	**218.56**	**965.01**	**971.27**	**1186.26**	**1178.05**
(excl. waste incineration)		NA	NA	0.00%	0.00%	0.00%	0.60%	0.56%	0.63%	1.16%	1.20%	0.58%	2.15%	8.84%	8.54%	9.31%	9.06%
Iron & Steel	**1A2a + 2C1**	**6384.72**	**6077.02**	**5596.54**	**5829.21**	**4823.23**	**2765.70**	**2500.48**	**1611.42**	**431.95**	**458.50**	**452.01**	**519.88**	**505.54**	**505.78**	**547.02**	**524.76**
(fuel combustion & processes)		50.17%	45.52%	42.67%	43.90%	38.79%	27.49%	24.70%	16.99%	5.03%	5.06%	4.69%	5.13%	4.63%	4.45%	4.29%	4.04%
Other Manufacturing Industries &	**1A2b/c/d/e/f/g + 2A**	**1437.62**	**1497.50**	**1559.15**	**1448.02**	**1642.13**	**1483.96**	**1535.84**	**1546.66**	**1517.72**	**1619.51**	**1589.50**	**1549.80**	**1473.89**	**1376.61**	**1478.14**	**1481.90**
Construction (fuel combustion & processes)		11.30%	11.22%	11.89%	10.91%	13.21%	14.75%	15.17%	16.31%	17.67%	17.88%	16.49%	15.28%	13.50%	12.10%	11.60%	11.40%
Road Transportation - national fleet	**1A3b**	**854.85**	**898.39**	**937.88**	**983.93**	**991.26**	**1042.76**	**1060.47**	**1094.65**	**1141.56**	**1154.13**	**1205.03**	**1253.46**	**1305.23**	**1346.37**	**1356.00**	**1377.95**
		6.72%	6.73%	7.15%	7.41%	7.97%	10.36%	10.47%	11.54%	13.29%	12.74%	12.50%	12.36%	11.95%	11.84%	10.64%	10.60%
Road Transportation - fuel export	**1A3b**	**1745.24**	**2299.98**	**2554.58**	**2553.29**	**2603.00**	**2313.87**	**2409.89**	**2644.95**	**2792.98**	**3212.31**	**3691.14**	**3899.65**	**4029.61**	**4528.70**	**5481.47**	**5827.55**
		13.71%	17.23%	19.48%	19.23%	20.94%	23.00%	23.80%	27.89%	32.52%	35.47%	38.30%	38.45%	36.90%	39.81%	43.01%	44.83%
Residential Fuel Combustion	**1A4b**	**682.13**	**817.16**	**750.70**	**745.27**	**709.71**	**719.64**	**789.51**	**765.01**	**795.41**	**714.23**	**1082.26**	**1174.93**	**1118.23**	**1161.10**	**1241.41**	**1215.54**
		5.36%	6.12%	5.72%	5.61%	5.71%	7.15%	7.80%	8.07%	9.26%	7.89%	11.23%	11.58%	10.24%	10.21%	9.74%	9.35%
Commercial & Institutional Fuel	**1A4a**	**642.21**	**772.45**	**712.33**	**704.69**	**679.22**	**684.67**	**763.98**	**740.61**	**774.65**	**694.13**	**549.35**	**499.78**	**501.72**	**498.17**	**463.76**	**418.98**
Combustion		5.05%	5.79%	5.43%	5.31%	5.46%	6.80%	7.55%	7.81%	9.02%	7.66%	5.70%	4.93%	4.59%	4.38%	3.64%	3.22%
Agriculture (fuel combustion,	**1A4c+3**	**745.25**	**748.09**	**735.59**	**738.68**	**719.55**	**737.08**	**743.11**	**738.10**	**734.26**	**751.53**	**716.25**	**702.27**	**688.12**	**664.89**	**666.96**	**665.75**
livestock, crops, soils)		5.86%	5.60%	5.61%	5.56%	5.79%	7.33%	7.34%	7.78%	8.55%	8.30%	7.43%	6.92%	6.30%	5.85%	5.23%	5.12%
Municipal Waste Incineration	**1A1a (5C)**	**34.82**	**36.43**	**36.33**	**38.48**	**41.48**	**43.27**	**36.31**	**46.37**	**48.74**	**59.57**	**61.53**	**64.36**	**64.22**	**62.18**	**69.24**	**59.24**
(with energy & heat recovery)		0.27%	0.27%	0.28%	0.29%	0.33%	0.43%	0.36%	0.49%	0.57%	0.66%	0.64%	0.63%	0.59%	0.55%	0.54%	0.46%
Other Transport	**1A3a/c/d**	**26.57**	**26.81**	**26.87**	**27.09**	**26.40**	**21.65**	**23.98**	**23.64**	**23.49**	**23.64**	**23.22**	**25.02**	**22.44**	**20.00**	**16.15**	**11.10**
		0.21%	0.20%	0.20%	0.20%	0.21%	0.22%	0.24%	0.25%	0.27%	0.26%	0.24%	0.25%	0.21%	0.18%	0.13%	0.09%
Other Energy Sources	**1A5 + 1B2**	**25.09**	**25.92**	**50.66**	**48.42**	**47.00**	**39.15**	**49.60**	**54.81**	**66.17**	**96.39**	**46.21**	**62.07**	**67.64**	**58.05**	**60.91**	**59.99**
		0.20%	0.19%	0.39%	0.36%	0.38%	0.39%	0.49%	0.58%	0.77%	1.06%	0.48%	0.61%	0.62%	0.51%	0.48%	0.46%
F-gases	**2F**	**0.00**	**0.00**	**4.99**	**11.76**	**12.91**	**13.81**	**15.80**	**18.31**	**20.92**	**23.89**	**28.33**	**34.86**	**37.84**	**38.09**	**38.26**	**36.95**
		0.00%	0.00%	0.04%	0.09%	0.10%	0.14%	0.16%	0.19%	0.24%	0.26%	0.29%	0.34%	0.35%	0.33%	0.30%	0.28%
Municipal Waste Disposal on Land	**5A**	**103.25**	**105.53**	**105.94**	**104.52**	**94.71**	**94.40**	**94.33**	**96.54**	**96.67**	**96.70**	**92.65**	**91.60**	**91.15**	**91.37**	**85.90**	**83.61**
		0.81%	0.79%	0.81%	0.79%	0.76%	0.94%	0.93%	1.02%	1.13%	1.07%	0.96%	0.90%	0.83%	0.80%	0.67%	0.64%
Waste Water Handling	**5D**	**13.05**	**13.20**	**13.37**	**13.53**	**13.68**	**12.64**	**12.57**	**12.66**	**12.85**	**13.03**	**11.65**	**12.19**	**11.82**	**11.97**	**11.10**	**11.17**
		0.10%	0.10%	0.10%	0.10%	0.11%	0.13%	0.12%	0.13%	0.15%	0.14%	0.12%	0.12%	0.11%	0.11%	0.09%	0.09%
Biological Treatment of Solid Waste	**5B**	**0.00**	**0.00**	**0.29**	**2.96**	**3.70**	**4.47**	**6.92**	**7.38**	**9.05**	**8.27**	**11.69**	**12.65**	**14.23**	**19.10**	**19.81**	**23.45**
		0.00%	0.00%	NA	0.02%	0.03%	0.04%	0.07%	0.08%	0.11%	0.09%	0.12%	0.12%	0.13%	0.17%	0.16%	0.18%
Total GHG excluding LULUCF		**12726.71**	**13349.37**	**13114.48**	**13278.36**	**12433.46**	**10062.47**	**10123.90**	**9483.23**	**8588.89**	**9056.36**	**9638.12**	**10142.89**	**10919.05**	**11375.19**	**12745.74**	**13000.50**
		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
International Bunkers - Aviation		**397.95**	**415.94**	**402.19**	**397.73**	**504.48**	**571.74**	**621.18**	**743.06**	**900.64**	**1016.08**	**968.43**	**1047.35**	**1134.65**	**1182.02**	**1286.12**	**1306.77**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
International Bunkers - Marine		**0.08**	**0.09**	**0.08**	**0.11**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.11**	**0.12**	**0.12**	**0.12**	**0.12**	**0.12**	**0.15**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CO_2 Emissions from Biomass		**162.60**	**166.79**	**167.44**	**162.41**	**160.05**	**155.83**	**136.83**	**147.96**	**150.24**	**160.49**	**160.96**	**175.23**	**177.46**	**182.46**	**204.01**	**299.06**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Gg (1000 t.) CO_2 equivalent	CRF Categories	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Public Electricity & Heat Production	**1A1a**	**1235.92**	**1110.87**	**923.01**	**1121.47**	**1141.68**	**933.94**	**972.18**	**617.24**	**591.41**	**374.11**	**156.13**	**145.71**	**122.45**	**105.16**	**110.96**	**159.83**
(excl. waste incineration)		9.63%	9.07%	7.61%	9.68%	9.39%	7.76%	8.24%	5.47%	5.49%	3.63%	1.55%	1.42%	1.16%	0.98%	1.23%	1.70%
Iron & Steel	**1A2a + 2C1**	**646.31**	**621.50**	**569.08**	**455.71**	**507.03**	**452.88**	**396.78**	**374.72**	**374.36**	**399.25**	**386.84**	**374.06**	**419.59**	**397.87**	**362.65**	**365.76**
(fuel combustion & processes)		5.04%	5.08%	4.69%	3.93%	4.17%	3.76%	3.36%	3.32%	3.47%	3.87%	3.84%	3.65%	3.97%	3.71%	4.01%	3.90%
Other Manufacturing Industries &	**1A2b/c/d/e/f/g + 2A**	**1512.04**	**1441.10**	**1383.72**	**1301.36**	**1329.46**	**1415.38**	**1389.72**	**1342.11**	**1332.30**	**1262.62**	**1345.65**	**1347.13**	**1325.96**	**1401.92**	**1325.07**	**1285.05**
Construction (fuel combustion & processes)		11.79%	11.77%	11.41%	11.23%	10.93%	11.76%	11.77%	11.90%	12.36%	12.24%	13.35%	13.13%	12.55%	13.06%	14.66%	13.70%
Road Transportation - national fleet	**1A3b**	**1427.91**	**1441.51**	**1490.71**	**1543.89**	**1565.20**	**1595.11**	**1597.70**	**1600.93**	**1622.93**	**1627.13**	**1637.46**	**1654.28**	**1670.90**	**1676.69**	**1496.13**	**1580.69**
		11.13%	11.77%	12.29%	13.33%	12.87%	13.25%	13.54%	14.19%	15.05%	15.78%	16.25%	16.12%	15.82%	15.62%	16.56%	16.85%
Road Transportation - fuel export	**1A3b**	**5433.37**	**5115.23**	**5156.47**	**4563.75**	**4919.46**	**5251.82**	**4936.24**	**4801.10**	**4458.96**	**4019.86**	**3830.18**	**3946.32**	**4309.86**	**4463.71**	**3093.66**	**3314.01**
		42.35%	41.78%	42.50%	39.39%	40.46%	43.63%	41.82%	42.56%	41.35%	38.98%	38.00%	38.46%	40.80%	41.60%	34.23%	35.32%
Residential Fuel Combustion	**1A4b**	**1203.58**	**1163.74**	**1196.56**	**1183.29**	**1161.18**	**1063.88**	**1083.21**	**1075.85**	**973.03**	**1086.19**	**1119.40**	**1139.30**	**1042.55**	**951.08**	**1040.02**	**997.02**
		9.38%	9.51%	9.86%	10.21%	9.55%	8.84%	9.18%	9.54%	9.02%	10.53%	11.11%	11.10%	9.87%	8.86%	11.51%	10.63%
Commercial & Institutional Fuel	**1A4a**	**395.82**	**349.01**	**377.71**	**381.71**	**502.53**	**305.05**	**409.62**	**437.46**	**381.77**	**486.62**	**511.16**	**548.00**	**569.31**	**657.28**	**546.88**	**624.40**
Combustion		3.09%	2.85%	3.11%	3.29%	4.13%	2.53%	3.47%	3.88%	3.54%	4.72%	5.07%	5.34%	5.39%	6.13%	6.05%	6.65%
Agriculture (fuel combustion,	**1A4c+3**	**656.36**	**667.54**	**689.34**	**687.46**	**691.74**	**675.74**	**666.41**	**675.44**	**688.66**	**699.22**	**720.99**	**725.19**	**728.52**	**709.58**	**721.22**	**717.47**
livestock, crops, soils)		5.12%	5.45%	5.68%	5.93%	5.69%	5.61%	5.65%	5.99%	6.39%	6.78%	7.15%	7.07%	6.90%	6.61%	7.98%	7.65%
Municipal Waste Incineration	**1A1a (5C)**	**63.93**	**63.47**	**64.02**	**66.62**	**62.91**	**77.49**	**82.64**	**90.07**	**87.96**	**97.37**	**110.13**	**110.91**	**110.81**	**112.88**	**104.11**	**103.73**
(with energy & heat recovery)		0.50%	0.52%	0.53%	0.58%	0.52%	0.64%	0.70%	0.80%	0.82%	0.94%	1.09%	1.08%	1.05%	1.05%	1.15%	1.11%
Other Transport	**1A3a/c/d**	**8.62**	**11.22**	**12.73**	**12.07**	**12.98**	**13.00**	**11.90**	**10.30**	**11.58**	**8.43**	**7.92**	**8.52**	**8.88**	**8.39**	**7.72**	**8.54**
		0.07%	0.09%	0.10%	0.10%	0.11%	0.11%	0.10%	0.09%	0.11%	0.08%	0.08%	0.08%	0.08%	0.08%	0.09%	0.09%
Other Energy Sources	**1A5 + 1B2**	**62.95**	**58.91**	**56.34**	**56.94**	**61.23**	**53.10**	**54.31**	**46.27**	**43.69**	**39.30**	**36.13**	**35.59**	**35.00**	**35.04**	**31.63**	**34.02**
		0.49%	0.48%	0.46%	0.49%	0.50%	0.44%	0.46%	0.41%	0.41%	0.38%	0.36%	0.35%	0.33%	0.33%	0.35%	0.36%
F-gases	**2F**	**39.61**	**43.77**	**46.09**	**47.16**	**49.25**	**51.87**	**54.03**	**54.91**	**59.83**	**59.38**	**57.76**	**57.00**	**50.37**	**47.56**	**43.30**	**40.50**
		0.31%	0.36%	0.38%	0.41%	0.41%	0.43%	0.46%	0.49%	0.55%	0.58%	0.57%	0.56%	0.48%	0.44%	0.48%	0.43%
Municipal Waste Disposal on Land	**5A**	**82.26**	**81.72**	**79.85**	**78.75**	**65.82**	**66.01**	**62.85**	**64.19**	**63.46**	**60.85**	**55.45**	**56.82**	**53.42**	**51.69**	**50.23**	**48.19**
		0.64%	0.67%	0.66%	0.68%	0.54%	0.55%	0.53%	0.57%	0.59%	0.59%	0.55%	0.55%	0.51%	0.48%	0.56%	0.51%
Waste Water Handling	**5D**	**11.25**	**11.33**	**10.36**	**9.92**	**9.98**	**10.31**	**9.34**	**9.21**	**9.14**	**8.61**	**8.40**	**7.76**	**7.56**	**7.04**	**6.58**	**6.56**
		0.09%	0.09%	0.09%	0.09%	0.08%	0.09%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.07%	0.07%	0.07%	0.07%
Biological Treatment of Solid Waste	**5B**	**25.55**	**27.92**	**32.40**	**33.73**	**34.69**	**29.98**	**33.29**	**32.41**	**34.75**	**32.66**	**36.98**	**36.28**	**37.14**	**34.68**	**33.36**	**34.67**
		0.20%	0.23%	0.27%	0.29%	0.29%	0.25%	0.28%	0.29%	0.32%	0.32%	0.37%	0.35%	0.35%	0.32%	0.37%	0.37%
Total GHG excluding LULUCF		**12829.81**	**12242.32**	**12131.48**	**11584.83**	**12158.06**	**12037.83**	**11803.37**	**11281.15**	**10782.16**	**10313.09**	**10079.64**	**10260.52**	**10562.69**	**10731.07**	**9037.10**	**9383.28**
		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
International Bunkers - Aviation		**1222.97**	**1314.39**	**1323.12**	**1267.63**	**1300.90**	**1217.15**	**1123.08**	**1128.14**	**1225.10**	**1381.00**	**1532.36**	**1732.55**	**1852.59**	**1812.28**	**1648.80**	**1881.02**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
International Bunkers - Marine		**0.16**	**0.13**	**0.14**	**0.11**	**0.11**	**0.10**	**0.07**	**0.06**	**0.07**	**0.06**	**0.07**	**0.08**	**0.07**	**0.06**	**0.01**	**0.01**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CO_2 Emissions from Biomass		**301.04**	**445.05**	**459.73**	**436.16**	**453.62**	**450.25**	**471.31**	**511.57**	**639.97**	**702.31**	**816.27**	**912.97**	**1022.45**	**1170.44**	**1444.63**	**1496.35**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Gg (1000 t.) CO_2 equivalent	CRF Categories	2022
Public Electricity & Heat Production (excl. waste incineration)	**1A1a**	**124.64**
		1.52%
Iron & Steel (fuel combustion & processes)	**1A2a + 2C1**	**311.14**
		3.80%
Other Manufacturing Industries & Construction (fuel combustion & processes)	**1A2b/c/d/e/f/g + 2A**	**1152.66**
		14.07%
Road Transportation - national fleet	**1A3b**	**1640.13**
		20.02%
Road Transportation - fuel export	**1A3b**	**2553.93**
		31.17%
Residential Fuel Combustion	**1A4b**	**919.25**
		11.22%
Commercial & Institutional Fuel Combustion	**1A4a**	**475.52**
		5.80%
Agriculture (fuel combustion, livestock, crops, soils)	**1A4c+3**	**688.83**
		8.41%
Municipal Waste Incineration (with energy & heat recovery)	**1A1a (5C)**	**107.56**
		1.31%
Other Transport	**1A3a/c/d**	**7.09**
		0.09%
Other Energy Sources	**1A5 + 1B2**	**26.50**
		0.32%
F-gases	**2F**	**39.29**
		0.48%
Municipal Waste Disposal on Land	**5A**	**44.17**
		0.54%
Waste Water Handling	**5D**	**6.10**
		0.07%
Biological Treatment of Solid Waste	**5B**	**34.31**
		0.42%
Total GHG excluding LULUCF		**8192.33**
		100.00%
International Bunkers - Aviation		**1952.95**
		NA
International Bunkers - Marine		**0.02**
		NA
CO_2 Emissions from Biomass		**1455.06**
		NA

Sources: Environment Agency and MECB.

Notes: (1) These percentages are relative to the total GHG emissions, excluding LULUCF.
(2) The methane emissions are converted in CO_2 equivalents by multiplying the emissions by 28, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.
(3) The nitrous oxide emissions are converted in CO_2 equivalents by multiplying the emissions by 265, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.
(4) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF_6 expressed in CO_2 equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Table 2-15 – Luxembourg's GHG emissions and removals – details by main gases: 1990-2022

Gg (1000 t.) CO_2 equivalent	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
CO_2	**11813.17**	**12423.83**	**12192.27**	**12341.04**	**11525.18**	**9135.57**	**9186.14**	**8546.76**	**7654.72**	**8117.36**	**8702.43**	**9205.64**	**9978.71**	**10451.04**	**11819.38**	**12076.77**
	92.82%	93.07%	92.97%	92.94%	92.69%	90.79%	90.74%	90.12%	89.12%	89.63%	90.29%	90.76%	91.39%	91.88%	92.73%	92.89%
of which																
CRF 1 - Energy	10206.63	10894.19	10733.74	10900.59	10182.62	8152.41	8259.00	7730.18	6996.41	7424.02	7983.54	8541.02	9298.35	9823.03	11136.03	11420.19
	80.20%	81.61%	81.85%	82.09%	81.90%	81.02%	81.58%	81.51%	81.46%	81.98%	82.83%	84.21%	85.16%	86.35%	87.37%	87.84%
CRF 1A1 - Fuel Combustion from	32.46	33.96	33.86	36.03	38.98	101.22	91.05	103.30	145.73	165.44	114.83	279.69	1025.31	1029.64	1251.29	1233.39
Energy Industries	0.26%	0.25%	0.26%	0.27%	0.31%	1.01%	0.90%	1.09%	1.70%	1.83%	1.19%	2.76%	9.39%	9.05%	9.82%	9.49%
CRF 1A2 - Fuel Combustion from	6229.34	6057.60	5708.92	5847.07	5130.26	3275.98	3118.19	2350.20	1301.98	1392.38	1329.67	1411.20	1305.67	1259.13	1348.59	1357.71
Manuf. Industries & Construction	48.95%	45.38%	43.53%	44.03%	41.26%	32.56%	30.80%	24.78%	15.16%	15.37%	13.80%	13.91%	11.96%	11.07%	10.58%	10.44%
CRF 1A3 - Fuel Combustion from	2598.73	3192.17	3483.81	3528.59	3583.69	3343.40	3459.43	3728.10	3923.98	4355.99	4884.68	5144.35	5324.74	5862.30	6820.61	7184.00
Transport	20.42%	23.91%	26.56%	26.57%	28.82%	33.23%	34.17%	39.31%	45.69%	48.10%	50.68%	50.72%	48.77%	51.54%	53.51%	55.26%
of which, "road fuel export"**(1)**	1729.55	2279.46	2531.69	2530.33	2578.76	2291.93	2387.96	2622.41	2771.09	3189.75	3667.60	3876.71	4007.62	4506.18	5458.26	5804.61
	13.59%	17.08%	19.30%	19.06%	20.74%	22.78%	23.59%	27.65%	32.26%	35.22%	38.05%	38.22%	36.70%	39.61%	42.82%	44.65%
CRF 1A4 - Fuel Combustion from	1342.96	1607.31	1480.38	1465.25	1407.61	1421.00	1571.78	1525.54	1590.63	1447.18	1642.10	1681.47	1629.02	1668.64	1715.35	1644.89
Other Sectors	10.55%	12.04%	11.29%	11.03%	11.32%	14.12%	15.53%	16.09%	18.52%	15.98%	17.04%	16.58%	14.92%	14.67%	13.46%	12.65%
CRF 1A5 & 1B2b - Other Energy	3.12	3.13	26.74	23.62	22.04	10.77	18.51	23.01	34.06	62.99	12.22	24.27	13.55	3.26	0.12	0.12
Sources	0.02%	0.02%	0.20%	0.18%	0.18%	0.11%	0.18%	0.24%	0.40%	0.70%	0.13%	0.24%	0.12%	0.03%	0.00%	0.00%
CRF 2 - Industrial Processes	1600.49	1523.17	1451.39	1433.56	1335.56	976.50	920.58	809.65	650.94	686.68	711.56	657.70	672.65	621.28	675.95	648.17
	12.58%	11.41%	11.07%	10.80%	10.74%	9.70%	9.09%	8.54%	7.58%	7.58%	7.38%	6.48%	6.16%	5.46%	5.30%	4.99%
Other Sources **(2)**	22.65	21.79	20.38	19.78	16.90	16.54	16.04	14.55	15.01	13.91	13.50	13.98	13.89	12.59	14.18	15.03
	0.18%	0.16%	0.16%	0.15%	0.14%	0.16%	0.16%	0.15%	0.17%	0.15%	0.14%	0.14%	0.13%	0.11%	0.11%	0.12%
CH_4 (3)	**681.91**	**685.49**	**672.42**	**683.97**	**656.08**	**673.40**	**679.07**	**677.41**	**675.76**	**674.10**	**667.64**	**672.61**	**672.84**	**668.27**	**653.70**	**660.65**
	5.36%	5.14%	5.13%	5.15%	5.28%	6.69%	6.71%	7.14%	7.87%	7.44%	6.93%	6.63%	6.16%	5.87%	5.13%	5.08%
of which																
CRF 1 - Energy	54.07	57.27	56.12	55.18	52.91	53.51	55.05	54.73	53.81	54.43	55.28	59.71	75.12	75.57	82.20	80.82
	0.42%	0.43%	0.43%	0.42%	0.43%	0.53%	0.54%	0.58%	0.63%	0.60%	0.57%	0.59%	0.69%	0.66%	0.64%	0.62%
CRF 3A+3B - Enteric Fermentation and	516.11	514.13	501.43	513.56	497.20	514.75	517.33	513.46	511.50	509.64	505.04	505.64	489.80	480.84	465.13	472.86
Manure Management	4.06%	3.85%	3.82%	3.87%	4.00%	5.12%	5.11%	5.41%	5.96%	5.63%	5.24%	4.99%	4.49%	4.23%	3.65%	3.64%
Other Sources **(4)**	111.73	114.09	114.87	115.23	105.97	105.14	106.69	109.22	110.45	110.02	107.31	107.26	107.91	111.87	106.38	106.97
	0.88%	0.85%	0.88%	0.87%	0.85%	1.04%	1.05%	1.15%	1.29%	1.21%	1.11%	1.06%	0.99%	0.98%	0.83%	0.82%
N_2O (5)	**230.73**	**239.04**	**243.69**	**240.36**	**237.95**	**238.26**	**241.29**	**239.00**	**235.69**	**239.13**	**237.73**	**227.12**	**226.38**	**213.92**	**229.94**	**221.09**
	1.81%	1.79%	1.86%	1.81%	1.91%	2.37%	2.38%	2.52%	2.74%	2.64%	2.47%	2.24%	2.07%	1.88%	1.80%	1.70%
of which																
CRF 1 - Energy	31.28	36.24	39.83	42.41	45.21	43.50	44.12	44.86	44.12	45.55	47.13	47.33	47.14	47.06	47.93	47.85
	0.25%	0.27%	0.30%	0.32%	0.36%	0.43%	0.44%	0.47%	0.51%	0.50%	0.49%	0.47%	0.43%	0.41%	0.38%	0.37%
CRF 3D - Agricultural Soils	147.83	151.48	154.65	147.85	143.05	144.00	145.44	143.06	141.53	144.01	141.50	130.53	130.97	117.92	133.25	125.09
	1.16%	1.13%	1.18%	1.11%	1.15%	1.43%	1.44%	1.51%	1.65%	1.59%	1.47%	1.29%	1.20%	1.04%	1.05%	0.96%
Other Sources **(6)**	51.62	51.32	49.21	50.10	49.70	50.76	51.73	51.08	50.04	49.56	49.10	49.26	48.27	48.94	48.77	48.15
	0.41%	0.38%	0.38%	0.38%	0.40%	0.50%	0.51%	0.54%	0.58%	0.55%	0.51%	0.49%	0.44%	0.43%	0.38%	0.37%
F-gases (7)	**0.90**	**1.01**	**6.10**	**12.99**	**14.25**	**15.24**	**17.40**	**20.06**	**22.71**	**25.77**	**30.32**	**37.52**	**41.12**	**41.96**	**42.71**	**41.99**
	0.01%	0.01%	0.05%	0.10%	0.11%	0.15%	0.17%	0.21%	0.26%	0.28%	0.31%	0.37%	0.38%	0.37%	0.34%	0.32%
Total GHG excluding LULUCF	**12726.71**	**13349.37**	**13114.48**	**13278.36**	**12433.46**	**10062.47**	**10123.90**	**9483.23**	**8588.89**	**9056.36**	**9638.12**	**10142.89**	**10919.05**	**11375.19**	**12745.74**	**13000.50**
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
LULUCF	**8.98**	**-58.92**	**-464.53**	**-591.23**	**-443.44**	**-522.65**	**-558.38**	**-644.32**	**-538.44**	**-604.75**	**-614.76**	**-593.38**	**-583.05**	**-563.32**	**-609.47**	**-565.98**

Gg (1000 t.) CO_2 equivalent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2	**11908.74**	**11304.99**	**11169.35**	**10625.16**	**11194.66**	**11097.07**	**10866.49**	**10333.66**	**9816.08**	**9345.27**	**9090.39**	**9262.84**	**9567.29**	**9761.76**	**8074.93**	**8420.58**
	92.82%	92.34%	92.07%	91.72%	92.08%	92.19%	92.06%	91.60%	91.04%	90.62%	90.19%	90.28%	90.58%	90.97%	89.35%	89.74%
of which																
CRF 1 - Energy	11201.49	10606.76	10525.23	10049.64	10596.16	10490.33	10293.84	9781.31	9258.01	8795.89	8516.56	8681.84	8981.49	9156.01	7491.66	7908.90
	87.31%	86.64%	86.76%	86.75%	87.15%	87.14%	87.21%	86.70%	85.86%	85.29%	84.49%	84.61%	85.03%	85.32%	82.90%	84.29%
CRF 1A1 - Fuel Combustion from	1295.72	1170.30	983.10	1183.89	1200.52	1007.03	1050.21	702.72	673.93	465.58	260.13	249.53	225.21	210.72	206.70	255.66
Energy Industries	10.10%	9.56%	8.10%	10.22%	9.87%	8.37%	8.90%	6.23%	6.25%	4.51%	2.58%	2.43%	2.13%	1.96%	2.29%	2.72%
CRF 1A2 - Fuel Combustion from	1456.94	1370.53	1325.14	1198.77	1257.26	1282.09	1234.85	1187.96	1168.94	1132.87	1182.69	1165.52	1186.97	1218.89	1120.11	1155.74
Manuf. Industries & Construction	11.36%	11.19%	10.92%	10.35%	10.34%	10.65%	10.46%	10.53%	10.84%	10.98%	11.73%	11.36%	11.24%	11.36%	12.39%	12.32%
CRF 1A3 - Fuel Combustion from	6837.99	6541.69	6629.81	6089.51	6462.39	6818.43	6503.97	6369.97	6052.66	5617.93	5438.05	5573.64	5950.90	6108.79	4569.22	4867.74
Transport	53.30%	53.44%	54.65%	52.56%	53.15%	56.64%	55.10%	56.47%	56.14%	54.47%	53.95%	54.32%	56.34%	56.93%	50.56%	51.88%
of which, "road fuel export"**(1)**	5411.32	5091.75	5129.82	4538.06	4889.72	5217.24	4901.79	4766.06	4424.42	3987.31	3798.16	3912.80	4272.87	4425.72	3067.55	3286.46
	42.18%	41.59%	42.29%	39.17%	40.22%	43.34%	41.53%	42.25%	41.03%	38.66%	37.68%	38.13%	40.45%	41.24%	33.94%	35.02%
CRF 1A4 - Fuel Combustion from	1610.64	1524.06	1587.00	1577.28	1675.80	1382.60	1504.63	1520.49	1362.32	1579.34	1635.53	1692.99	1618.25	1617.45	1595.48	1629.61
Other Sectors	12.55%	12.45%	13.08%	13.62%	13.78%	11.49%	12.75%	13.48%	12.63%	15.31%	16.23%	16.50%	15.32%	15.07%	17.65%	17.37%
CRF 1A5 & 1B2b - Other Energy	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11
Sources	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
CRF 2 - Industrial Processes	699.70	690.98	637.07	567.32	590.88	597.64	563.63	542.72	548.32	539.46	564.22	570.38	573.88	594.03	571.69	500.46
	5.45%	5.64%	5.25%	4.90%	4.86%	4.96%	4.78%	4.81%	5.09%	5.23%	5.60%	5.56%	5.43%	5.54%	6.33%	5.33%
Other Sources **(2)**	14.17	14.57	23.23	21.73	24.52	23.75	23.81	25.79	22.63	22.31	25.86	26.30	27.34	29.27	25.22	26.91
	0.11%	0.12%	0.19%	0.19%	0.20%	0.20%	0.20%	0.23%	0.21%	0.22%	0.26%	0.26%	0.26%	0.27%	0.28%	0.29%
CH_4 (3)	**655.27**	**664.22**	**679.07**	**677.34**	**672.90**	**643.61**	**641.68**	**647.20**	**657.82**	**660.39**	**675.51**	**676.32**	**678.20**	**654.61**	**665.33**	**662.36**
	5.11%	5.43%	5.60%	5.85%	5.53%	5.35%	5.44%	5.74%	6.10%	6.40%	6.70%	6.59%	6.42%	6.10%	7.36%	7.06%
of which																
CRF 1 - Energy	83.07	77.55	75.11	75.58	80.27	69.95	72.65	65.29	63.50	60.41	59.56	58.62	59.15	57.62	55.18	58.42
	0.65%	0.63%	0.62%	0.65%	0.66%	0.58%	0.62%	0.58%	0.59%	0.59%	0.59%	0.57%	0.56%	0.54%	0.61%	0.62%
CRF 3A+3B - Enteric Fermentation and	464.75	477.85	494.11	491.73	494.79	478.41	473.86	486.20	497.47	507.15	524.97	526.14	530.39	513.05	528.95	524.11
Manure Management	3.62%	3.90%	4.07%	4.24%	4.07%	3.97%	4.01%	4.31%	4.61%	4.92%	5.21%	5.13%	5.02%	4.78%	5.85%	5.59%
Other Sources **(4)**	107.44	108.82	109.85	110.03	97.84	95.25	95.17	95.72	96.85	92.83	90.98	91.56	88.66	83.94	81.20	79.83
	0.84%	0.89%	0.91%	0.95%	0.80%	0.79%	0.81%	0.85%	0.90%	0.90%	0.90%	0.89%	0.84%	0.78%	0.90%	0.85%
N_2O (5)	**220.73**	**223.45**	**230.65**	**228.45**	**234.14**	**237.71**	**233.21**	**234.47**	**237.99**	**236.86**	**244.39**	**249.71**	**252.21**	**254.99**	**241.21**	**246.34**
	1.72%	1.83%	1.90%	1.97%	1.93%	1.97%	1.98%	2.08%	2.21%	2.30%	2.42%	2.43%	2.39%	2.38%	2.67%	2.63%
of which																
CRF 1 - Energy	47.78	50.13	52.75	52.20	56.95	61.97	63.05	64.72	66.20	66.10	68.00	71.45	76.66	79.78	69.75	72.53
	0.37%	0.41%	0.43%	0.45%	0.47%	0.51%	0.53%	0.57%	0.61%	0.64%	0.67%	0.70%	0.73%	0.74%	0.77%	0.77%
CRF 3D - Agricultural Soils	124.45	123.02	125.51	124.83	127.10	128.18	124.21	123.75	123.97	123.93	128.02	129.71	126.78	126.64	123.24	125.22
	0.97%	1.00%	1.03%	1.08%	1.05%	1.06%	1.05%	1.10%	1.15%	1.20%	1.27%	1.26%	1.20%	1.18%	1.36%	1.33%
Other Sources **(6)**	48.50	50.30	52.38	51.42	50.10	47.55	45.95	46.00	47.82	46.83	48.37	48.55	48.77	48.57	48.22	48.60
	0.38%	0.41%	0.43%	0.44%	0.41%	0.40%	0.39%	0.41%	0.44%	0.45%	0.48%	0.47%	0.46%	0.45%	0.53%	0.52%
F-gases (7)	**45.08**	**49.67**	**52.41**	**53.88**	**56.36**	**59.43**	**61.99**	**65.82**	**70.27**	**70.57**	**69.35**	**71.65**	**64.99**	**59.71**	**55.63**	**54.00**
	0.35%	0.41%	0.43%	0.47%	0.46%	0.49%	0.53%	0.58%	0.65%	0.68%	0.69%	0.70%	0.62%	0.56%	0.62%	0.58%
Total GHG excluding LULUCF	**12829.81**	**12242.32**	**12131.48**	**11584.83**	**12158.06**	**12037.83**	**11803.37**	**11281.15**	**10782.16**	**10313.09**	**10079.64**	**10260.52**	**10562.69**	**10731.07**	**9037.10**	**9383.28**
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
LULUCF	**-484.99**	**-392.73**	**-410.69**	**-423.05**	**-205.40**	**-298.17**	**-368.20**	**-513.84**	**-422.59**	**-369.21**	**-468.32**	**-379.43**	**-241.15**	**-363.59**	**-447.65**	**-605.34**

Gg (1000 t.) CO_2 equivalent	2022
CO_2	**7276.72** 88.82%
of which	
CRF 1 - Energy	6787.78 82.86%
CRF 1A1 - Fuel Combustion from Energy Industries	224.53 2.74%
CRF 1A2 - Fuel Combustion from Manuf. Industries & Construction	990.35 12.09%
CRF 1A3 - Fuel Combustion from Transport	4170.67 50.91%
of which, "road fuel export"**(1)**	2532.18 30.91%
CRF 1A4 - Fuel Combustion from Other Sectors	1402.08 17.11%
CRF 1A5 & 1B2b - Other Energy Sources	0.11 0.00%
CRF 2 - Industrial Processes	478.83 5.84%
Other Sources **(2)**	26.17 0.32%
CH_4 (3)	**648.27** 7.91%
of which	
CRF 1 - Energy	51.91 0.63%
CRF 3A+3B - Enteric Fermentation and Manure Management	520.22 6.35%
Other Sources **(4)**	76.13 0.93%
N_2O (5)	**215.96** 2.64%
of which	
CRF 1 - Energy	67.18 0.82%
CRF 3D - Agricultural Soils	101.73 1.24%
Other Sources **(6)**	47.05 0.57%
F-gases (7)	**51.38** 0.63%
Total GHG excluding LULUCF	**8192.33** 100.00%
LULUCF	**-648.21**

Sources: Environment Agency and MECB.

Notes: (1) The methane emissions are converted in CO_2 equivalents by multiplying the emissions by 28, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

(2) The nitrous oxide emissions are converted in CO_2 equivalents by multiplying the emissions by 265, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

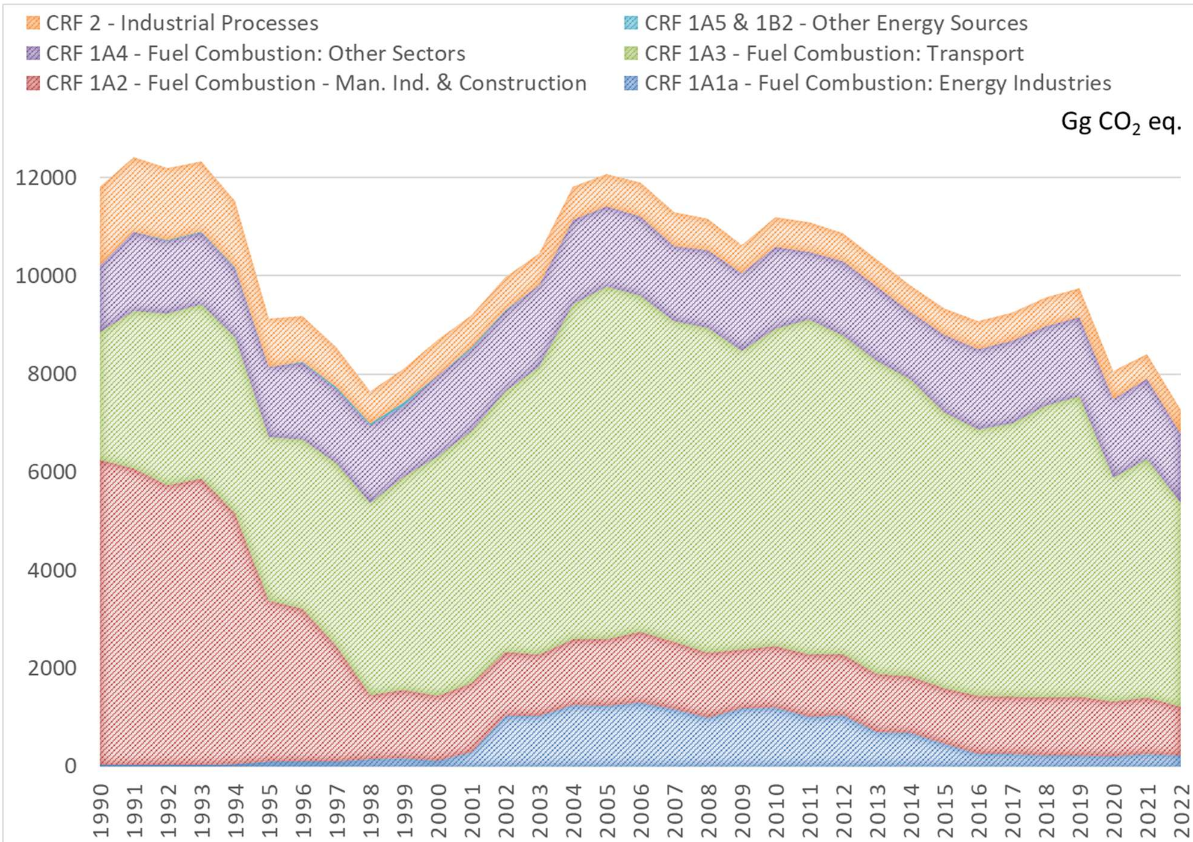
(3) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF_6 expressed in CO_2 equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

(4) CRF 1A4a&b: there are breaks in time series between 1999 & 2000: the two CRF 1A4 sub-categories had a very similar level because national energy statistics does not allow for distinguishing these two sub-categories before 2000. Hence, a 50-50 distribution was carried out in the inventories.

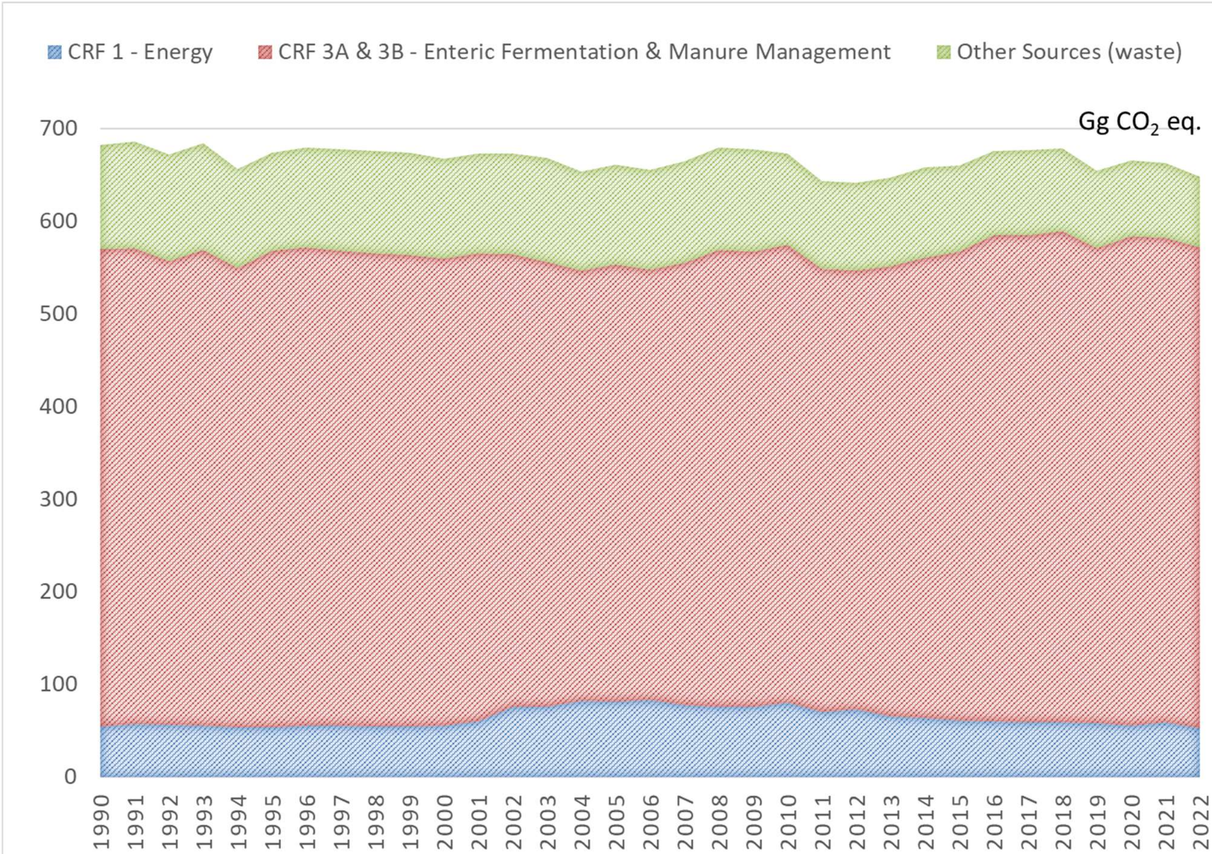
Figure 2-31 – Luxembourg's GHG emissions (excl. F-gases & LULUCF) – details by main gases:

1990-2022

$\underline{CO_2}$

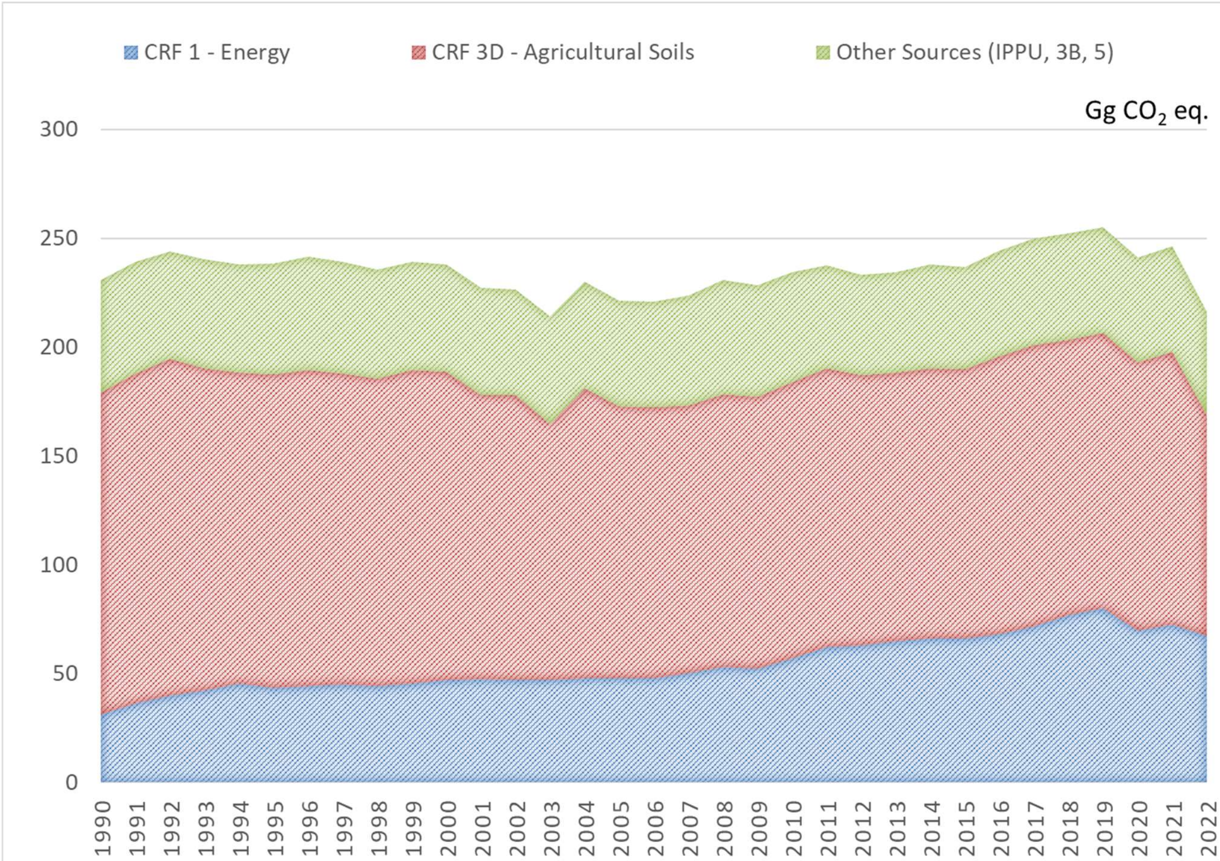


CH_4



CRF 1 - Energy
CRF 3A & 3B - Enteric Fermentation & Manure Management
Other Sources (waste)
Gg CO2 eq.
700
600
500
400
300
200
100
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

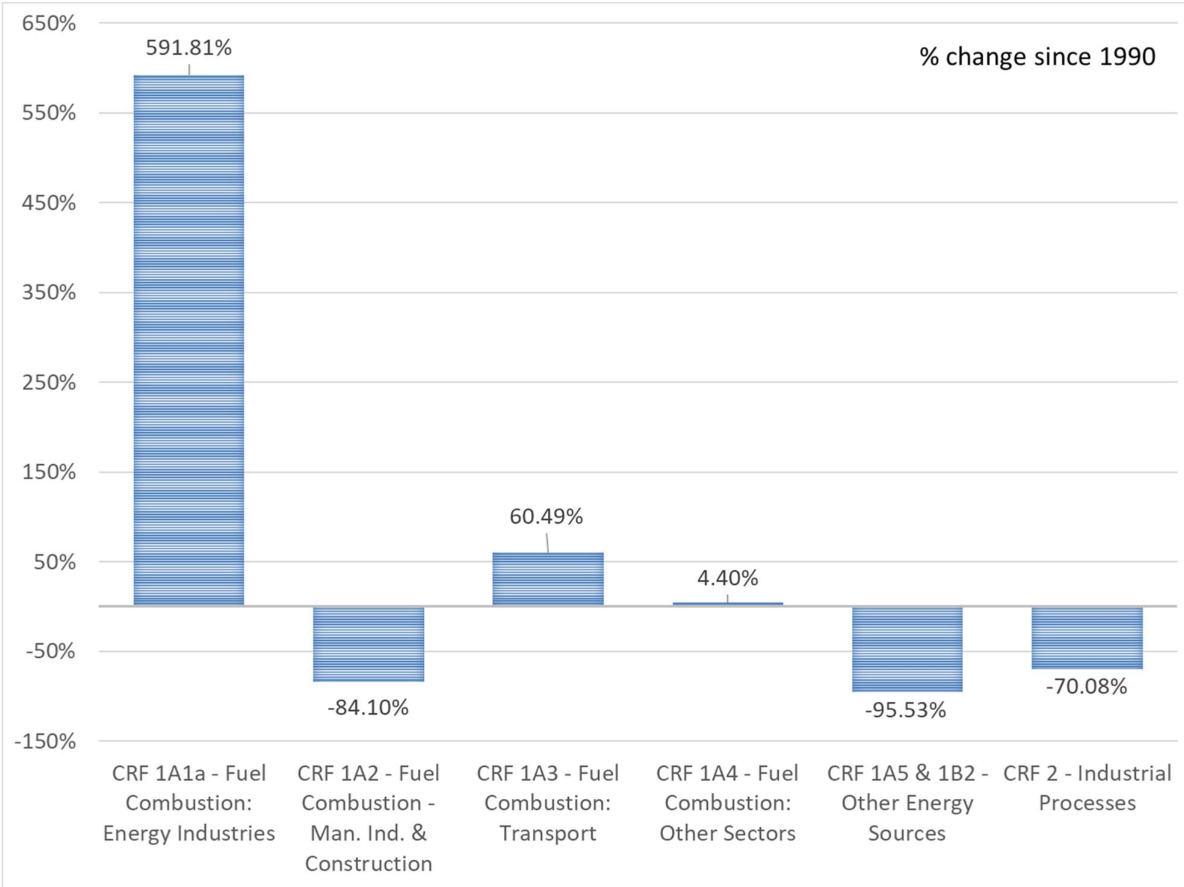
N_2O



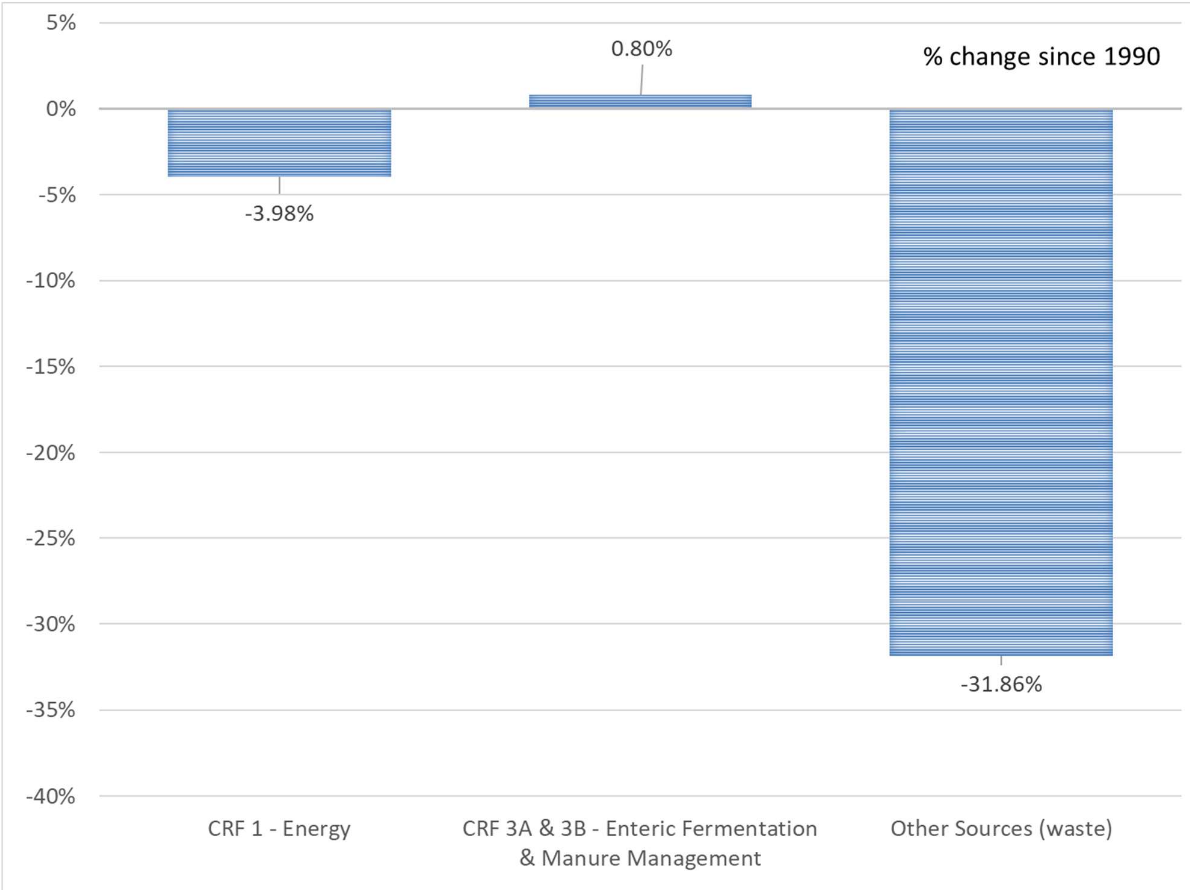
Sources: Environment Agency and MECB.

Figure 2-32 – Luxembourg's GHG emission trends in % (excl. LULUCF) – details by main gases: 1990-2022

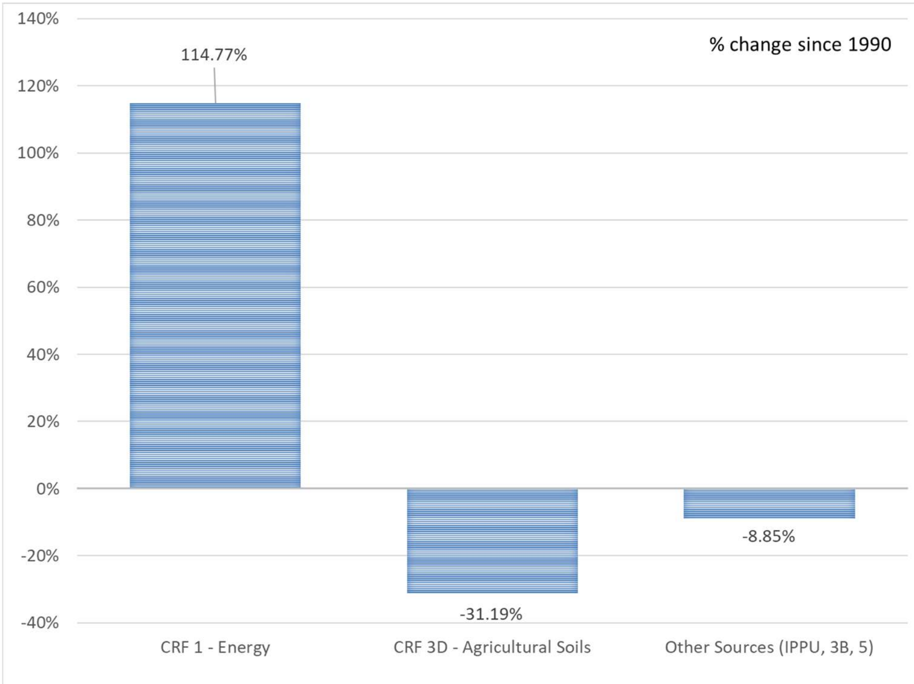
CO_2



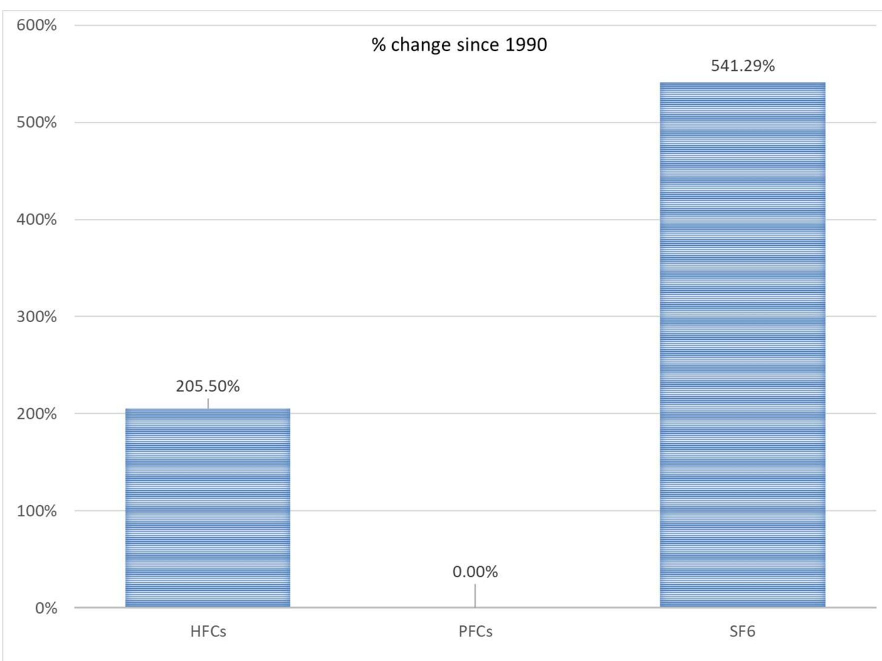
CH_4


5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
0.80%
% change since 1990
-3.98%
-31.86%
CRF 1 - Energy
CRF 3A & 3B - Enteric Fermentation & Manure Management
Other Sources (waste)

N_2O



F-gases



Sources: Environment Agency and MECB.

2.3.1 Carbon dioxide – CO_2

CRF (sub-) categories covered	1 (1A1, 1A2, 1A3, 1A4, 1A5, 1B2), 2, 3, 4		
Share in total GHG emissions, excl. LULUCF	1990	92.82% =	11 813.17 Gg CO_2e
	2022	88.82% =	7 276.72 Gg CO_2e

Throughout the period 1990-2022, carbon dioxide has remained the main GHG and accounted for 88% to 93% of the total GHG emissions. However, the structure of CO_2 emissions has evolved with an increase in fuel combustion, which accounted for 80.20% of total GHG emissions for the base year (1990) and climbed up to 82.85% in 2022.

Road transport, and more precisely "road fuel sales to non-residents", is the main culprit for this development. Indeed, in 1990, fuel combustion from the transport sector accounted for 20.46% of total GHG emissions. Then, with 4.17 Mio. t CO_2, this percentage reached 50.91% in 2022.[52] CO_2 emissions due solely to "road fuel sales to non-residents" amounted to about 1.7 Mio. t in 1990 and reached 2.5 Mio. t in 2022,[53] i.e. a 46.41% increase (the same comparison shows a 92.18% increase for road fuel consumed by the national vehicle fleet). In 2022, "road fuel sales to non-residents" represented 60.71% of CO_2 emissions of the transport sector and 34.80% of the total CO_2 emissions. In 1990, these percentages were 66.55% and 14.64%, respectively.

Another important source of CO_2 in Luxembourg are industrial processes, mainly carbon oxidizing of pig iron from the steel industry (basic oxygen furnace steel production) and decarbonisation of mineral input in the clinker and glass industry. The steel production process change described above was the main driver behind declining emissions for this sector.

In 2022, the CO_2 emissions saw a very strong decrease compared to previous years (-13.6% compared to 2021) since the global energy crisis affected the industrial and road transportation activities, where CO_2 is predominantly emitted, the most. The main culprit for the strong CO_2 decrease was the "road fuel sales to non-residents" sub-category, which fell by a whopping 23.0%.

2.3.2 Methane – CH_4

CRF (sub-) categories covered	1, 3A, 3B, 5A, 5B, 5D			
Share in total GHG emissions, excl. LULUCF	1990	5.36%	=	681.91 Gg CO_2e
	2022	7.91%	=	648.27 Gg CO_2e

Methane emissions originate above all from the agricultural sector, and more precisely from enteric fermentation and from manure production and management: around 70-80% of methane emissions over the period 1990-2022. As these emissions have been rather stable, total methane emissions have not varied very much.

For the other methane emitting source categories, there is a decline in waste and waste water management related emissions (-31.86%) and decline of emissions in energy use (-3.98%). The decrease noted for waste is the result of reduced methane emissions from waste landfill sites. The increase observed for energy is mainly due to fugitive emissions from natural gas distribution and use.

52 The highest amount of emissions was recorded for the year 2005: 7.18 Mio. t CO2 but "only" 55% of total GHG emissions

53 5.8 Mio. t in 2005.

2.3.3 Nitrous oxide – N_2O

CRF (sub-) categories covered	1, 2G, 3B, 3D, 5B and 5D		
Share in total GHG emissions, excl. LULUCF	**1990**	1.81% =	230.73 Gg CO_2e
	2022	2.64% =	215.96 Gg CO_2e

The major part of nitrous oxide emissions is caused by agricultural soils. Total emissions of N_2O over the period 1990-2022 are rather stable and fluctuate between 214 and 255 Gg CO_2e excl. N_2O from LULUCF, and between 230 and 263 Gg CO_2e incl. N_2O from LULUCF. Another important source that has been generating increasing N_2O emissions since 1990 is road transportation, where the incomplete NO_X reduction in catalytic converters of diesel oil motor vehicles leads to N_2O emissions that were multiplied by a factor 4 over the entire period. This increase is due to the increasing share of diesel vehicles on the roads. The increase in N_2O emissions from 1990-2022 (+35.9 Gg CO_2e or +114.77%) observed for the Energy sector is counterbalanced by diminishing nitrous oxide emissions from the Agriculture sector (-51.3 Gg or -27.49%).

2.3.4 Hydrofluorocarbons – HFCs, perfluorocarbons - PFCs and sulphur hexafluoride – SF_6

CRF (sub-) categories covered	2D, 2F, 2G		
Share in total GHG emissions, excl. LULUCF	**1990**	0.01% =	0.90 Gg CO_2e
	2022	0.63% =	51.38 Gg CO_2e

The increase in HFCs emissions between 1990 and 2022 is explained by a more wide spread use of mobile and stationary cooling equipment as well as of aerosols.

No use of PFCs is reported.

SF_6 emissions increased from 1990 onwards following an increasing use of high-voltage electrical devices and a higher amount of gas emitted from noise reduction windows.

2.4 Description of Emission Trends by Category

In 2022, the energy sector accounted for 84.31% of the total GHG emissions, excluding LULUCF. Two sectors represent around 7% to 8% of the total emissions, excluding LULUCF: industrial processes (6.53%) and agriculture (8.12%). The remaining sector[54] (waste[55] (1.03%) did barely surpass 1% of the total GHG emitted in Luxembourg: see Table 2-13 as well as Figure 2-29 and Figure 2-30.

For the different sectors, trends over the period 1990-2022 (and 2021-2022) were as follows:

- Energy: ………………………………………………………………………………… -32.89% (-14.09%)
- Industrial Processes: ……………………………………………………………… -66.75% (-4.29%)
- Agriculture: ………………………………………………………………………… -6.08% (-4.20%)
- LULUCF: ……………………………………………………………………………… -7318% (+7.08%)
- Waste: ………………………………………………………………………………… -27.26% (-5.40%)

2.4.1 CRF 1 – Energy

GHG covered	CO_2, CH_4 & N_2O	
Share in total GHG emissions, excl. LULUCF	**1990**	80.87% = 10 291.98 Gg CO_2e
	2022	84.31% = 6906.87 Gg CO_2e

Energy production and consumption related GHG emissions have decreased by 32.89% between 1990 and 2022 - from 10.292 Mio. t CO_2e in 1990 to 6.907 Mio. t CO_2e in 2022. For carbon dioxide, methane and nitrous oxide, the changes over the period 1990-2022 were -33.50%, -3.98% and +114.77%, respectively.

However, the overall trends at sector level hide very different developments at the CRF sub-category level. Within the energy sector, the fastest growing sub-sectors were **energy industries** (1A1) (due to the increasing number of cogeneration (CHP) plants) and **transport** (1A3): +566.83% and +60.55%, respectively between 1990 and 2022. For the other sub-sectors, the observed trends between 1990 and 2022 are -83.78% for **manufacturing industries and construction** (1A2), +4.20% for the **other sectors** (1A4), and +20.23% for **fugitive emissions from fuels** (1B). [56]

In fact, over the period, GHG emissions have been strongly influenced by varying fuel consumption levels in industry, in particular in the energy and the iron and steel industries, as well as in the road transport sector as percentage growths recorded for CRF sub-categories 1A1, 1A2 and 1A3 demonstrate. There are several industrial sites which had relatively high levels of GHG emissions, and which, therefore, have had a strong impact on the national total of GHG emissions. Examples of such sites are the TWINerg power plant (2001-2016), as already described in previous paragraphs, and to a lesser extent several cogeneration (CHP) plants. In the transport sector, road fuel consumption, and even more so road fuel sales, have a very important weight in the national energy balance and, consequently, a significant impact on the total GHG emissions.

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54 The sector "Others" is not reported for Luxembourg.

55 The waste sector covers only landfilled waste, wastewater handling and composting activities. Waste incineration, which is the main treatment method for municipal waste in Luxembourg, is carried out in the sole incinerator of the country where energy is recovered. Consequently, waste incineration related emissions are accounted for in CRF sector 1 – Energy (details in Chapters 3 and 8 respectively).

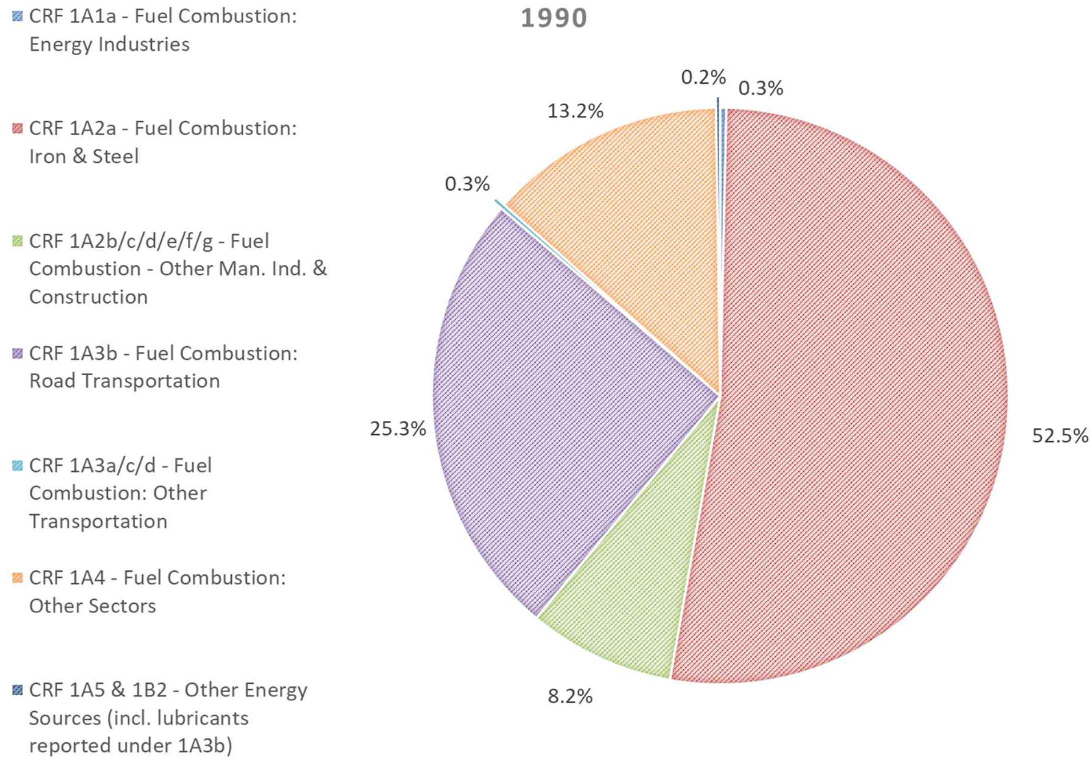
56 Fugitive emission growth is closely linked to natural gas use in Luxembourg.

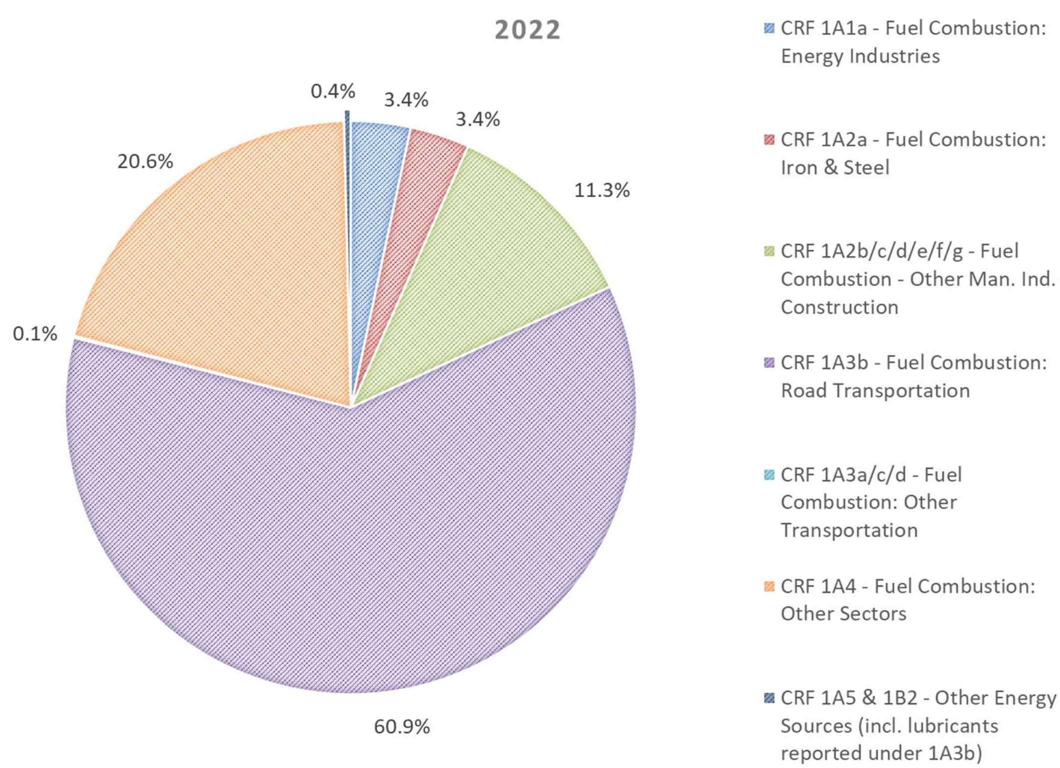
In the iron and steel industry, the passage from blast furnaces to electric arc furnaces allowed to significantly reduce GHG emissions between 1994 and 1998. Due to the importance of the iron and steel industry in Luxembourg, this evolution hid many other emission trends between 1990 and 1998. After 1998, the increase of road fuel sales and, to a lesser extent, of electric energy production has led to a rather steep increase of GHG emissions in the 1A1 and 1A3 sectors and, by extension, of the national total for GHG emissions.

All these changes briefly presented in the previous paragraphs completely modified the pattern of the energy related GHG emissions with regard to CRF sub-categories share (Figure 2-33) and to the "energy-mix" or fuel usage for energy production and consumption (

Table 2-10 and Table 2-11; Figure 2-19 and Figure 2-20).

Figure 2-33 – CRF sub-categories share in GHG emissions for CRF 1 – Energy: 1990 & 2022





Sources: Environment Agency and MECB.

2.4.2 CRF 2 – Industrial Processes

GHG covered	**CO2, N2O, F-gases**		
Share in total GHG emissions, excl. LULUCF	**1990**	**12.65% =**	**1 609.76 Gg CO2e**
	2022	**6.53% =**	**535.30 Gg CO2e**

Industrial processes represent the third largest sector in Luxembourg with regard to GHG emissions. The sector includes emissions from industrial installations and from consumption of halocarbons, perfluorocarbons and SF_6 (the fluorinated gases or F-gases). In Luxembourg, when leaving F-gases out, only a few companies and their various production installations are part of CRF sector 2:

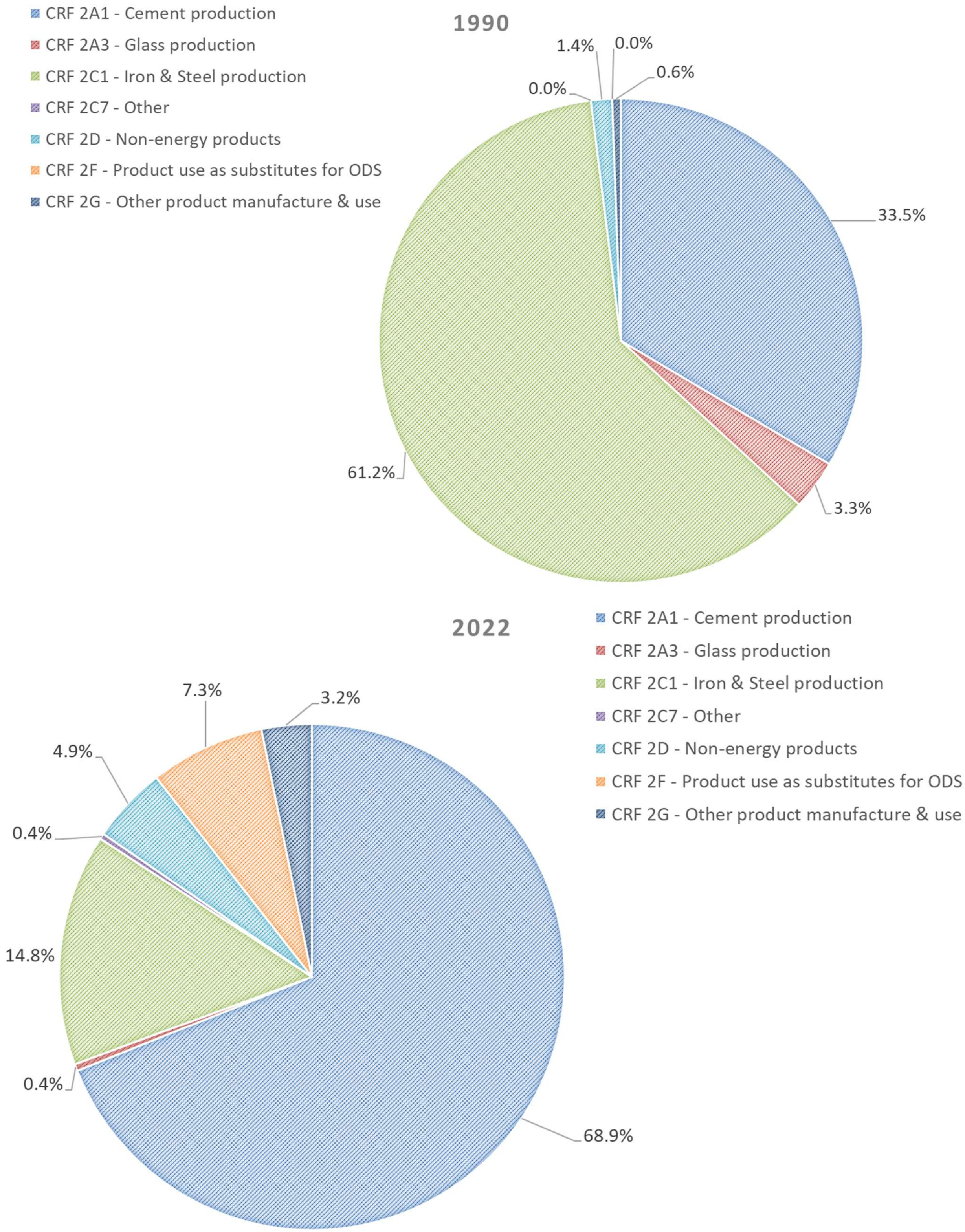
- CRF sub-categories 2A1 & 2A3: one cement works unit and one flat glass manufacturing company;
- CRF sub-category 2C1: the iron and steel manufacturing company ArcelorMittal.

Emissions from industrial processes show a declining trend between 1990 and 1998, following which the emissions became stable. This evolution was mainly driven by process changes that occurred in the iron & steel industry. As indicated above, this industry moved from blast to electric arc furnaces between 1994 and 1998. As a consequence, steel industry process emissions in CO_2e decreased by 91.93% over the period 1990-2022. Overall sector emissions in CO_2e fell by about 66.75% between 1990 and 2022, reducing the weight of this sector in total GHG emissions from 12.65% in 1990 to 6.53% in 2022. By gas, however, the picture is different. For carbon dioxide, the decrease over the period 1990-2022 was 70.08% while nitrous oxide saw a decrease of 39.27%. F-gases emissions, on the contrary, increased regularly: +237.05% over the period 1995-2022, but these emissions are minor compared to the total emissions as Figure 2-34 shows.

The striking increase of F-gases emissions is the consequence of a growing use in the country, notably due to an increasing use of air conditioning, high-voltage electrical equipment, and noise reduction windows (see Section 4.7). The increasing use of these devices is mainly due to an increase in the number of residents (see Figure 2-15) and of the workforce (see Figure 2-16). The inhabitants and foreign commuters occupy more and more residential, institutional, and commercial buildings, which leads to a greater need for air conditioning (HFC) as well as high-voltage electrical devices (SF_6).

The emission trends briefly described in the previous paragraphs led to a significant change in the composition of industrial processes' GHG emissions: see Figure 2-34.

Figure 2-34 – CRF sub-categories share in GHG emissions for CRF 2 – Industrial Processes: 1990 & 2022



Sources: Environment Agency and MECB.

2.4.3 CRF 3 – Agriculture

GHG covered	**CO_2, CH_4, N_2O**		
Share in total GHG emissions, excl. LULUCF	**1990**	**5.57% =**	**708.68 Gg CO_2e**
	2022	**8.12% =**	**665.57 Gg CO_2e**

Trends in agriculture were quite stable between 1990 and 2022: in general GHG related to agricultural activities have decreased by 6.08% (+67.14% for CO_2, +0.80% for methane and -27.49% for nitrous oxide). Enteric Fermentation (3A) saw its emissions decreasing by 1.85%, whereas for agricultural soils (3D), the decrease reached 31.19%. For manure management (3B), emissions increased by 5.44% between 1990 and 2022, though opposite variations are observed for the two GHG emitted by this activity: methane increased by 13.77% and nitrous oxide decreased by 13.39%. In Luxembourg, GHG emissions from liming (3G), urea application (3H) and other carbon-containing fertilizers (3I) are small compared to the other agriculture-related emissions (combined less than 2% of all agriculture GHG emissions in 2022).

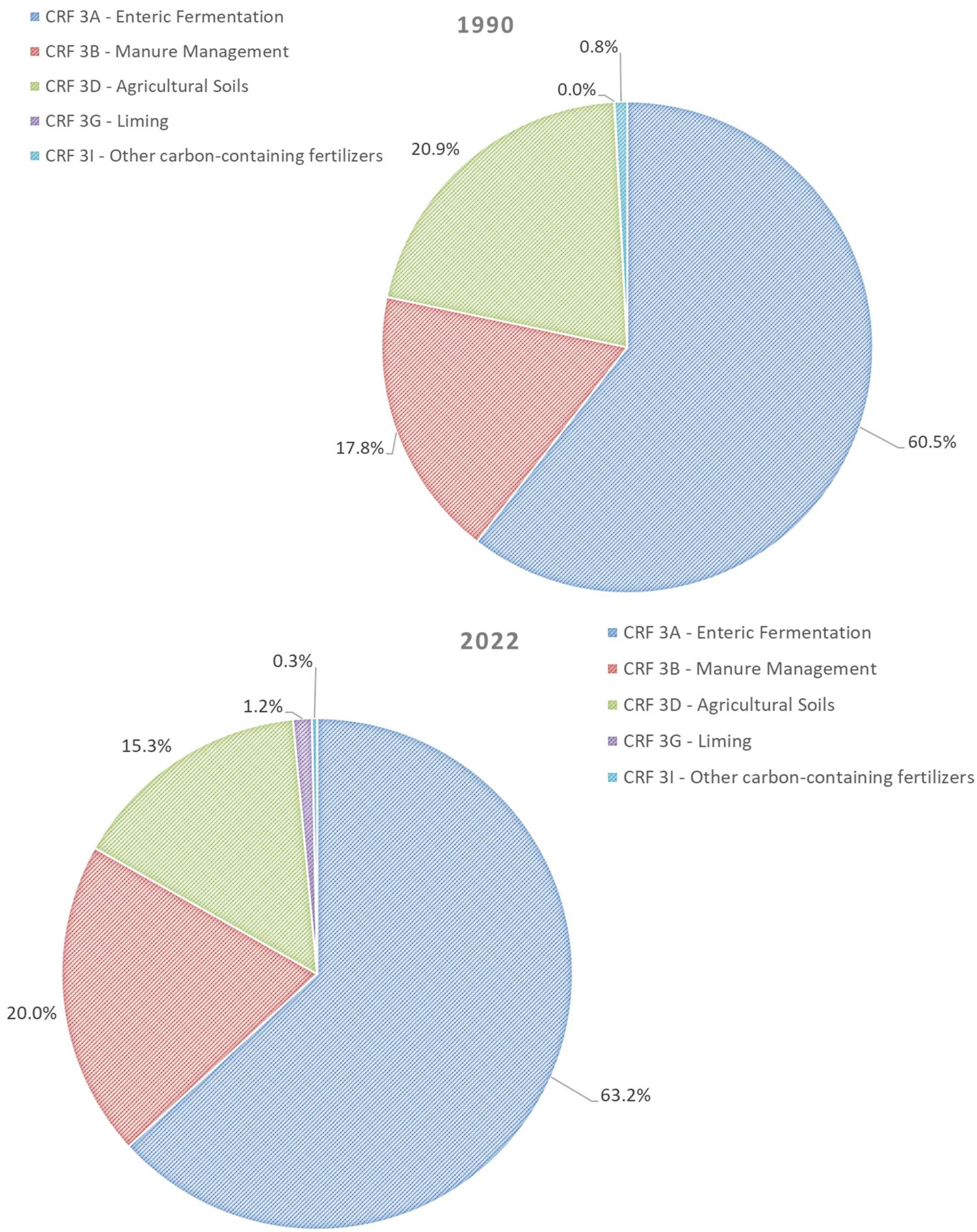
The evolution of methane emissions stemming from enteric fermentation (3A) shapes the overall agriculture emission pattern. Indeed, for all the years 1990-2022, CRF category 3A is the biggest contributor to agriculture related emissions. Category 3D is, as for other Annex I Parties, the agriculture category that shows the highest uncertainty in the inventory. It is also worth noting that the shares of each CRF category under CRF sector 3 for which GHG emissions are reported have barely changed over the period: see Figure 2-35.

Looking at methane emissions from manure management, an increase of 13.78% can be observed for the period 1990-2022. Animals who contributed the most to these emissions were cattle and swine. As far as nitrous oxide emissions from manure management are concerned, a decrease of 13.39% is observed for the period 1990-20221. These emissions are mainly due to cattle.

Finally, nitrous oxide emissions from agricultural soils are mainly driven by:

- nitrogen input to soils (such as application of synthetic fertilizers and manure) as well as nitrogen fixed by crops or crop residues;
- nitrogen excretion on pasture, range and paddock;
- by indirect soil emissions due to atmospheric deposition as well as to nitrogen from fertilizers and animals that is lost through leaching and run-off.

Figure 2-35 –CRF sub-categories share in GHG emissions for CRF 3 – Agriculture: 1990 & 2022



Source: Rural Economics Service, Environment Agency, and MECB.

2.4.4 CRF 5 – Waste

GHG covered	**CH_4 & N_2O**		
Share in total GHG emissions, excl. LULUCF	**1990**	**0.91% =**	**116.29 Gg CO_2e**
	2022	**1.03% =**	**84.59 Gg CO_2e**

In the waste sector, the main source of GHG was solid waste disposal on land (5A), but its weight decreased over the period 1990-2022 due to the combination of reduced amounts of waste disposed in landfills and of increased emissions arising from composting activities (5B). However, GHG emission reduction for solid waste disposal on land between 1990 and 2022 (-57.22%) still drove a reduction for the overall waste sector despite rising emissions from composting. Wastewater handling emissions (5D) experienced a 53.22% decline in emissions between 1990 and 2022. This decrease was driven by domestic and commercial wastewater treatment – and, more specifically methane related emissions – since industrial wastewater management remained fairly stable throughout the period.

For solid waste disposal on land, methane emissions have been reduced due to:

- a decrease in the quantity of waste being stored in authorised landfill sites (two as of today, three in the early 1990s), notably through the development of recycling schemes and the expansion of both the numbers of and the various waste categories collected by recycling centres;
- the aerobic pre-treatment before storage in one of the two landfill sites;
- the recent installation of methane recovery systems at waste dumping sites.

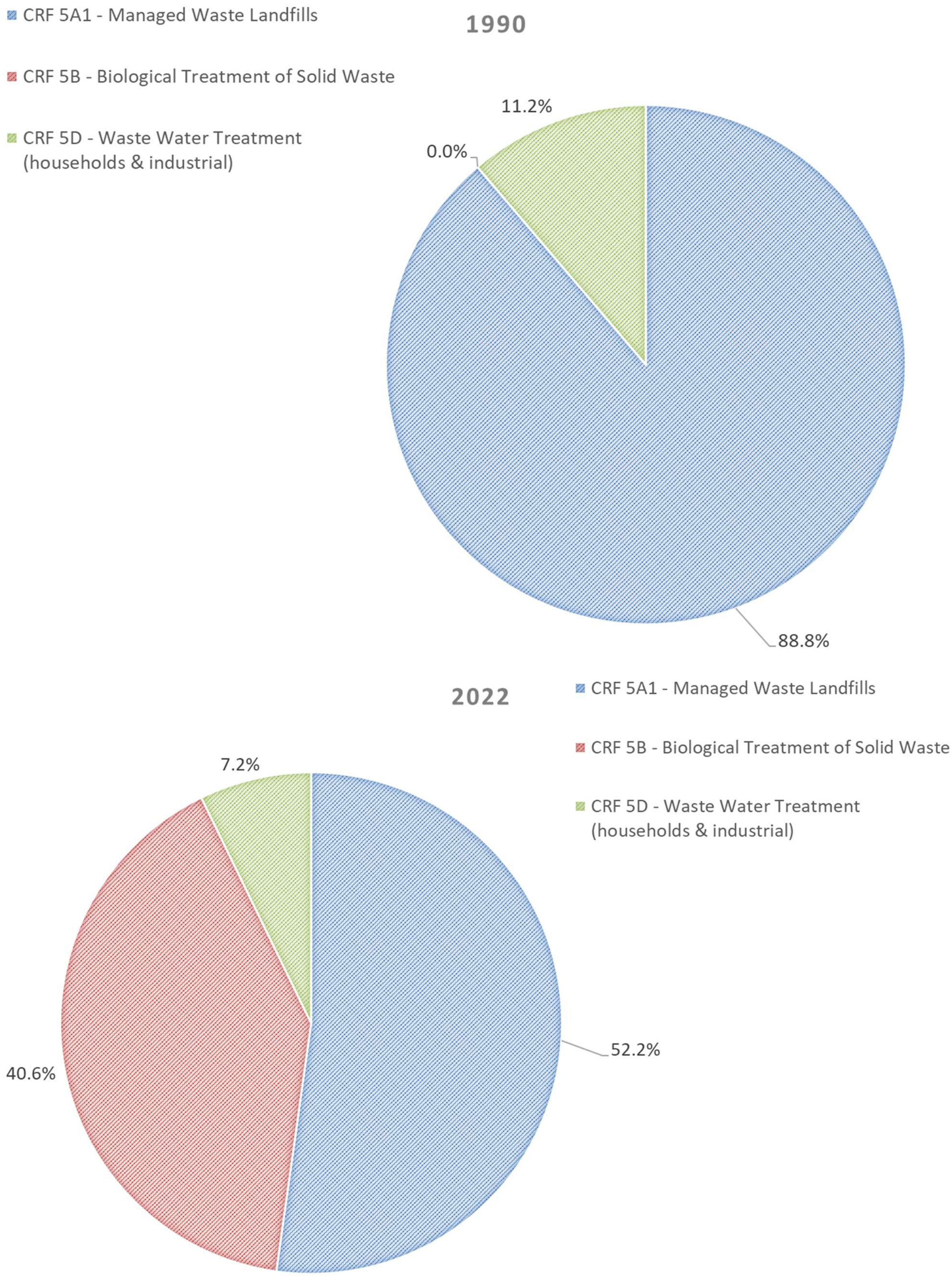
Wastewater treatment plant (WWTP) capacities expressed in population-equivalents have steadily grown since 1990. However, methane and nitrous oxide emissions decreased since 1990. Therefore, technical changes, with regard to wastewater treatment, have had an undeniable role too.

Concerning compost production, this activity started on an “industrial scale” only in the early 1990s. It experienced a steady growth from 1993 to 2003 and then more or less stabilizes. Nowadays, 7 composting installations operate in Luxembourg, plus one that co-compost sewage sludge. The latter uses active ventilation and fully operates aerobically – without methane formation. The other plants operate in part under anaerobic conditions, with a residence time in the “composter” of a few weeks.

It is recalled that waste incineration related emissions are part of CRF sub-category 1A1a (public electricity and heat production) since energy is recovered in the sole incinerator of the country and injected in the network.

The emission trends briefly described in the previous paragraphs led to a significant change in the composition of waste related GHG emissions: see Figure 2-36.

Figure 2-36 – CRF sub-categories share in GHG emissions for CRF 5 – Waste: 1990 & 2022



Sources: Environment Agency, Water Agency and MECB.

2.4.5 CRF sectors – overview

The fact that the iron and steel industry has abandoned blast furnaces between 1994 and 1998, that the TWINerg power plant started fully its operations in 2002, and that fossil fuel consumption as well as road fuel sales have experienced a continuous increase up to 2005, hide many other emission trends and, due to their importance in the national total GHG emissions, they shape the overall pattern of Luxembourg's GHG emissions trend.

2.5 Description of Emission Trends of Indirect GHG and SO2

Indirect GHG – NO_x, CO, NMVOCs – and SO_2 emissions as recorded in the inventory were extracted from the air pollutants emission inventory Luxembourg is compiling for the UNECE CLRTAP. Please refer to the Informative Inventory Report for more information on the estimation of the air pollutant emissions.[57]

57 https://www.ceip.at/status-of-reporting-and-review-results/2023-submission

3 Energy (CRF Sector 1)

3.1 Sector Overview

Emissions from this sector comprise emissions from fuel combustion activities (source category 1A) and fugitive emissions from fuels (source category 1B). For more details on categories where no emissions occur and categories that are not estimated or that are included elsewhere, please refer to Table 3-4.

Chapter 3 also includes information on and description of methodologies used for estimating GHG emissions as well as references to activity data and emission factors reported under CRF categories 1A – Fuel Combustion Activities and 1B – Fugitive Emissions from Fuels for the period 1990 to 2022.

GHG emissions from fossil fuel combustion are the main source of greenhouse gas emissions in the Grand-Duchy of Luxembourg. In 2022, about 83.99% of national total GHG emissions (excl. LULUCF) were caused by fossil fuel combustion activities in the energy and manufacturing industry, in the transportation sector and in the commercial and residential sector (category 1A). Fugitive emissions only made up about 0.32% of the national total GHG emissions (excl. LULUCF)

GHG emissions related to waste incineration are allocated to IPCC sub-category 1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production (see Section 3.2.6 of this chapter) since energy is recovered and injected into the public electricity and district heating networks.

Process related emissions are considered in CRF Sector 2 – Industrial Processes and Products Use (see Chapter 3.1).

3.1.1 Emission Trends

Figure 3-1 and Table 3-1 show the GHG emission trends from 1990 to 2022 for each of the IPCC categories under CRF Sector 1 - Energy, for which GHG emissions are reported. These are expressed in CO_2 equivalents and include CH_4 and N_2O emissions from biomass, but exclude CO_2 emissions from biomass combustion. CO_2 emissions from biomass combustion are reported under Memory Items and are not accounted for in the national total. GHG emissions from category 5C - Incineration and open burning of waste are accounted for in sub-category 1A1a - Public Electricity and Heat Production, as energy from waste burning is recovered and injected into the public electricity and district heating networks.

Fuel combustion activities (category 1A) related GHG emissions have decreased by 32.89% between 1990 and 2022 from 10.29 million tonnes CO_2 equivalents in 1990 to 6.91 million tonnes CO_2 equivalents in 2022. Carbon dioxide emissions decreased by 33.50% in 2022 compared to the base year. Methane emissions decreased by 3.89%, whereas nitrous oxide emissions increased by 114.77%, for the same period. In 2022, GHG emissions from CRF Sector 1 – Energy have decreased with respect to 2021 levels (-14.09%). This decrease is due to a notable decline of energy consumption across all subsectors following the sudden increase of global fossil fuel prices.

Figure 3-1 – GHG emission trends for CRF Sector 1-Energy: 1990-2022

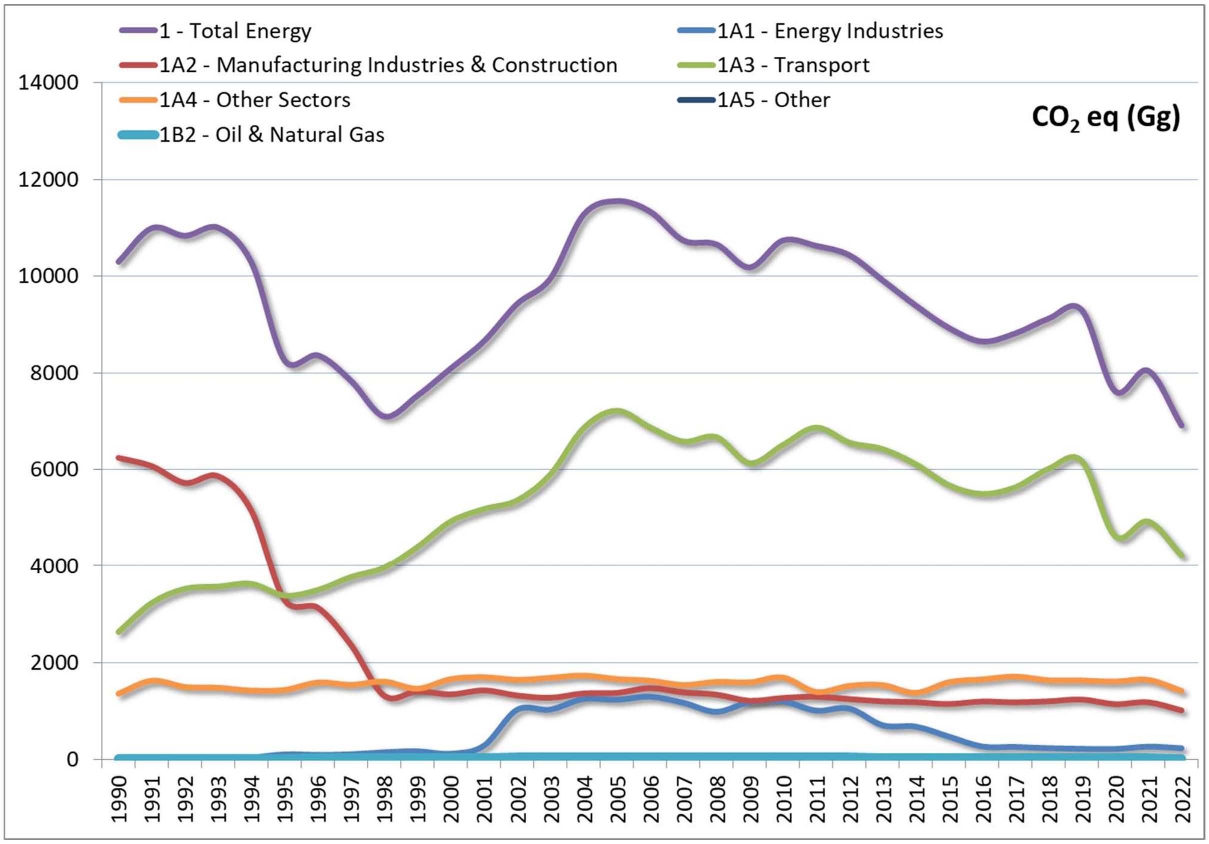


Figure 3-2 illustrates that the overall trend observed at sector level hides very different developments at the sub-category level. Indeed, between 1990 and 2022, GHG emissions have been strongly influenced by varying fuel consumption levels in industry, in particular in the iron and steel industry, as well as in the road transport sector as percentage growths recorded for sub-categories 1A2 – Manufacturing Industries and Construction and 1A3 – Transport demonstrate. There are several industrial sites which had relatively high levels of GHG emissions, and which, therefore, have had a large impact on the national total of GHG emissions. In the transport sector, road fuel consumption, and even more so road fuel sales[58], have a very important weight in the national energy balance, and, consequently, have also a very important impact on the total GHG emissions.

In the iron and steel industry, the technological change from blast furnaces to electric arc furnaces allowed reducing GHG emissions significantly between 1993 and 1998. Due to the importance of the iron and steel industry in Luxembourg, this evolution hid many other emission trends between 1990 and 1998. After 1998, the increase of road fuel sales and, to a lesser extent, the increase of electric energy production has led to a rather steep increase of GHG emissions in these sub-categories and, by extension, of the national total for GHG emissions. In more recent years, the closure of some industrial sites (mainly in the iron and steel industry), the decrease in local electricity production, a reduction in the road fuel sales and the implementation of energy efficiency measures in the building sector, led to a more or less steady decrease in emissions from 2005 onwards.

58 See Section 2.2.

All the changes briefly presented in the previous paragraphs – as well as in Chapter 2 - completely modified the pattern of the energy related GHG emissions between 1990 and 2022 with regard to the share between sub-categories – see Figure 3-3 – and to the "energy-mix" or fuel use for energy production and consumption – see Table 3-2.

Table 3-1 – GHG emission trends in CO_2eq for CRF Sector 1 – Energy: 1990-2022

1 - Energy GHG emissions by source & sink category (Gg)																
	1A1 - Energy Industries				1A2 - Manufacturing Industries & Construction				1A3 - Transport				1A4 - Other Sectors			
Year	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	34.82	32.46	0.037	0.005	6 244.49	6 229.34	0.157	0.041	2 626.66	2 598.73	0.501	0.052	1 360.91	1 342.96	0.452	0.020
1991	36.43	33.96	0.039	0.005	6 073.15	6 057.60	0.152	0.043	3 225.18	3 192.17	0.542	0.067	1 627.02	1 607.31	0.499	0.022
1992	36.33	33.86	0.039	0.005	5 724.68	5 708.92	0.148	0.044	3 519.32	3 483.81	0.501	0.081	1 498.70	1 480.38	0.465	0.020
1993	38.48	36.03	0.039	0.005	5 863.45	5 847.07	0.150	0.046	3 564.31	3 528.59	0.432	0.089	1 483.51	1 465.25	0.467	0.020
1994	41.48	38.98	0.039	0.005	5 146.70	5 130.26	0.145	0.047	3 620.67	3 583.69	0.384	0.099	1 424.89	1 407.61	0.433	0.019
1995	103.76	101.22	0.040	0.005	3 289.69	3 275.98	0.095	0.042	3 378.28	3 343.40	0.322	0.098	1 438.54	1 421.00	0.442	0.020
1996	93.09	91.05	0.032	0.004	3 131.78	3 118.19	0.096	0.041	3 494.34	3 459.43	0.296	0.100	1 589.37	1 571.78	0.435	0.020
1997	105.80	103.30	0.040	0.005	2 362.98	2 350.20	0.075	0.040	3 763.24	3 728.10	0.279	0.103	1 542.93	1 525.54	0.428	0.020
1998	148.31	145.73	0.041	0.005	1 313.73	1 301.98	0.055	0.039	3 958.03	3 923.98	0.258	0.101	1 608.10	1 590.63	0.425	0.021
1999	168.50	165.44	0.048	0.006	1 405.24	1 392.38	0.058	0.042	4 390.07	4 355.99	0.247	0.103	1 463.81	1 447.18	0.404	0.020
2000	117.86	114.83	0.048	0.006	1 343.45	1 329.67	0.062	0.045	4 919.38	4 884.68	0.241	0.105	1 659.05	1 642.10	0.411	0.020
2001	282.93	279.69	0.052	0.007	1 425.96	1 411.20	0.072	0.048	5 178.13	5 144.35	0.229	0.103	1 698.98	1 681.47	0.433	0.020
2002	1 029.23	1 025.31	0.064	0.008	1 320.66	1 305.67	0.064	0.050	5 357.28	5 324.74	0.216	0.100	1 645.80	1 629.02	0.409	0.020
2003	1 033.45	1 029.64	0.063	0.008	1 273.70	1 259.13	0.060	0.049	5 895.08	5 862.30	0.214	0.101	1 685.39	1 668.64	0.409	0.020
2004	1 255.51	1 251.29	0.069	0.009	1 363.38	1 348.59	0.066	0.049	6 853.71	6 820.61	0.208	0.103	1 732.65	1 715.35	0.424	0.020
2005	1 237.29	1 233.39	0.064	0.008	1 373.52	1 357.71	0.094	0.050	7 216.69	7 184.00	0.186	0.104	1 661.37	1 644.89	0.406	0.019
2006	1 299.85	1 295.72	0.068	0.008	1 472.82	1 456.94	0.099	0.049	6 869.99	6 837.99	0.160	0.104	1 626.74	1 610.64	0.399	0.019
2007	1 174.34	1 170.30	0.067	0.008	1 386.19	1 370.53	0.095	0.049	6 576.07	6 541.69	0.145	0.114	1 538.94	1 524.06	0.366	0.017
2008	987.03	983.10	0.064	0.008	1 338.97	1 325.14	0.095	0.042	6 668.14	6 629.81	0.131	0.131	1 602.61	1 587.00	0.387	0.018
2009	1 188.09	1 183.89	0.069	0.009	1 211.49	1 198.77	0.081	0.039	6 127.48	6 089.51	0.116	0.131	1 593.42	1 577.28	0.407	0.018
2010	1 204.58	1 200.52	0.067	0.008	1 270.12	1 257.26	0.090	0.039	6 505.17	6 462.39	0.108	0.150	1 692.28	1 675.80	0.422	0.018
2011	1 011.43	1 007.03	0.072	0.009	1 294.36	1 282.09	0.086	0.037	6 867.24	6 818.43	0.111	0.172	1 396.12	1 382.60	0.340	0.015
2012	1 054.82	1 050.21	0.075	0.009	1 246.68	1 234.85	0.082	0.036	6 553.68	6 503.97	0.107	0.176	1 520.05	1 504.63	0.398	0.016
2013	707.31	702.72	0.074	0.010	1 199.91	1 187.96	0.085	0.036	6 421.31	6 369.97	0.101	0.183	1 536.52	1 520.49	0.426	0.015
2014	679.38	673.93	0.087	0.011	1 180.97	1 168.94	0.086	0.036	6 105.29	6 052.66	0.106	0.187	1 378.38	1 362.32	0.434	0.015
2015	471.48	465.58	0.094	0.012	1 144.72	1 132.87	0.082	0.036	5 670.07	5 617.93	0.111	0.185	1 596.83	1 579.34	0.473	0.016
2016	266.26	260.13	0.097	0.013	1 196.45	1 182.69	0.110	0.040	5 490.96	5 438.05	0.118	0.187	1 654.32	1 635.53	0.517	0.016
2017	256.62	249.53	0.112	0.015	1 179.15	1 165.52	0.106	0.040	5 629.81	5 573.64	0.127	0.199	1 710.74	1 692.99	0.483	0.016
2018	233.26	225.21	0.127	0.017	1 201.25	1 186.97	0.113	0.042	6 011.66	5 950.90	0.139	0.215	1 636.14	1 618.25	0.489	0.016
2019	218.05	210.72	0.116	0.015	1 237.31	1 218.89	0.175	0.051	6 171.19	6 108.79	0.141	0.221	1 631.81	1 617.45	0.381	0.014
2020	215.07	206.70	0.133	0.018	1 141.89	1 120.11	0.224	0.059	4 618.22	4 569.22	0.112	0.173	1 609.78	1 595.48	0.379	0.014
2021	263.55	255.66	0.125	0.017	1 178.92	1 155.74	0.241	0.062	4 919.20	4 867.74	0.122	0.181	1 644.16	1 629.61	0.390	0.014
2022	232.20	224.53	0.121	0.016	1 013.06	990.35	0.229	0.061	4 217.08	4 170.67	0.123	0.162	1 418.03	1 402.08	0.439	0.014
Trend 1990-2022	566.83%	591.81%	225.13%	223.45%	-83.78%	-84.10%	46.24%	51.35%	60.55%	60.49%	-75.51%	209.09%	4.20%	4.40%	-2.91%	-30.89%
Trend 2021-2022	-11.90%	-12.18%	-2.89%	-2.75%	-14.07%	-14.31%	-4.64%	-0.98%	-14.27%	-14.32%	0.92%	-10.57%	-13.75%	-13.96%	12.70%	0.34%

1 - Energy
GHG emissions by source & sink category (Gg)

Year	1A5 - Other				1B2 - Oil & Natural Gas				1 - Total Energy			
	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	3.14	3.12	0.000	0.000	21.95	0.03	0.78	NA, NO	10 291.98	10 206.63	1.93	0.12
1991	3.15	3.13	0.000	0.000	22.77	0.03	0.81	NA, NO	10 987.70	10 894.19	2.05	0.14
1992	26.90	26.74	0.003	0.000	23.76	0.03	0.85	NA, NO	10 829.69	10 733.74	2.00	0.15
1993	23.76	23.62	0.003	0.000	24.66	0.03	0.88	NA, NO	10 998.17	10 900.59	1.97	0.16
1994	22.17	22.04	0.003	0.000	24.83	0.03	0.89	NA, NO	10 280.73	10 182.62	1.89	0.17
1995	10.83	10.77	0.001	0.000	28.31	0.03	1.01	NA, NO	8 249.42	8 152.41	1.91	0.16
1996	18.62	18.51	0.002	0.000	30.98	0.04	1.10	NA, NO	8 358.17	8 259.00	1.97	0.17
1997	23.13	23.01	0.003	0.000	31.68	0.04	1.13	NA, NO	7 829.76	7 730.18	1.95	0.17
1998	34.24	34.06	0.004	0.000	31.93	0.04	1.14	NA, NO	7 094.35	6 996.41	1.92	0.17
1999	63.33	62.99	0.008	0.000	33.06	0.04	1.18	NA, NO	7 524.01	7 424.02	1.94	0.17
2000	12.26	12.22	0.001	0.000	33.95	0.04	1.21	NA, NO	8 085.96	7 983.54	1.97	0.18
2001	24.34	24.27	0.002	0.000	37.73	0.04	1.35	NA, NO	8 648.06	8 541.02	2.13	0.18
2002	13.60	13.55	0.001	0.000	54.04	0.06	1.93	NA, NO	9 420.62	9 298.35	2.68	0.18
2003	3.28	3.26	0.000	0.000	54.77	0.06	1.95	NA, NO	9 945.67	9 823.03	2.70	0.18
2004	0.13	0.12	0.000	0.000	60.78	0.07	2.17	NA, NO	11 266.16	11 136.03	2.94	0.18
2005	0.13	0.12	0.000	0.000	59.86	0.07	2.14	NA, NO	11 548.86	11 420.19	2.89	0.18
2006	0.13	0.12	0.000	0.000	62.82	0.07	2.24	NA, NO	11 332.34	11 201.49	2.97	0.18
2007	0.13	0.12	0.000	0.000	58.78	0.07	2.10	NA, NO	10 734.44	10 606.76	2.77	0.19
2008	0.13	0.12	0.000	0.000	56.21	0.07	2.01	NA, NO	10 653.08	10 525.23	2.68	0.20
2009	0.12	0.12	0.000	0.000	56.82	0.07	2.03	NA, NO	10 177.43	10 049.64	2.70	0.20
2010	0.12	0.12	0.000	0.000	61.11	0.07	2.18	NA, NO	10 733.38	10 596.16	2.87	0.21
2011	0.12	0.12	0.000	0.000	52.97	0.06	1.89	NA, NO	10 622.25	10 490.33	2.50	0.23
2012	0.12	0.12	0.000	0.000	54.19	0.06	1.93	NA, NO	10 429.55	10 293.84	2.59	0.24
2013	0.12	0.12	0.000	0.000	46.14	0.05	1.65	NA, NO	9 911.32	9 781.31	2.33	0.24
2014	0.12	0.12	0.000	0.000	43.57	0.05	1.55	NA, NO	9 387.71	9 258.01	2.27	0.25
2015	0.12	0.12	0.000	0.000	39.18	0.05	1.40	NA, NO	8 922.40	8 795.89	2.16	0.25
2016	0.12	0.12	0.000	0.000	36.01	0.04	1.28	NA, NO	8 644.12	8 516.56	2.13	0.26
2017	0.12	0.11	0.000	0.000	35.47	0.04	1.27	NA, NO	8 811.91	8 681.84	2.09	0.27
2018	0.12	0.11	0.000	0.000	34.88	0.04	1.24	NA, NO	9 117.30	8 981.49	2.11	0.29
2019	0.12	0.11	0.000	0.000	34.92	0.04	1.25	NA, NO	9 293.40	9 156.01	2.06	0.30
2020	0.11	0.11	0.000	0.000	31.52	0.04	1.12	NA, NO	7 616.59	7 491.66	1.97	0.26
2021	0.11	0.11	0.000	0.000	33.90	0.04	1.21	NA, NO	8 039.85	7 908.90	2.09	0.27
2022	0.11	0.11	0.000	0.000	26.39	0.03	0.94	NA, NO	6 906.87	6 787.78	1.85	0.25
Trend 1990-2022	-96.39%	-96.48%	-99.63%	-73.34%	20.23%	19.38%	20.23%	NA	-32.89%	-33.50%	-3.98%	114.77%
Trend 2021-2022	-0.95%	-0.91%	-2.54%	-2.13%	-22.17%	-22.64%	-22.17%	NA	-14.09%	-14.18%	-11.13%	-7.37%

Source: Environment Agency.

Notes: CH_4 emissions are converted in CO_2eq by multiplying the emissions by 28, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon. N_2O emissions are converted in CO_2eq by multiplying the emissions by 265, *i.e.* the global warming potential (*GWP*) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

Figure 3-2 – GHG emission trend indexes for CRF Sector 1 – Energy: 1990-2022

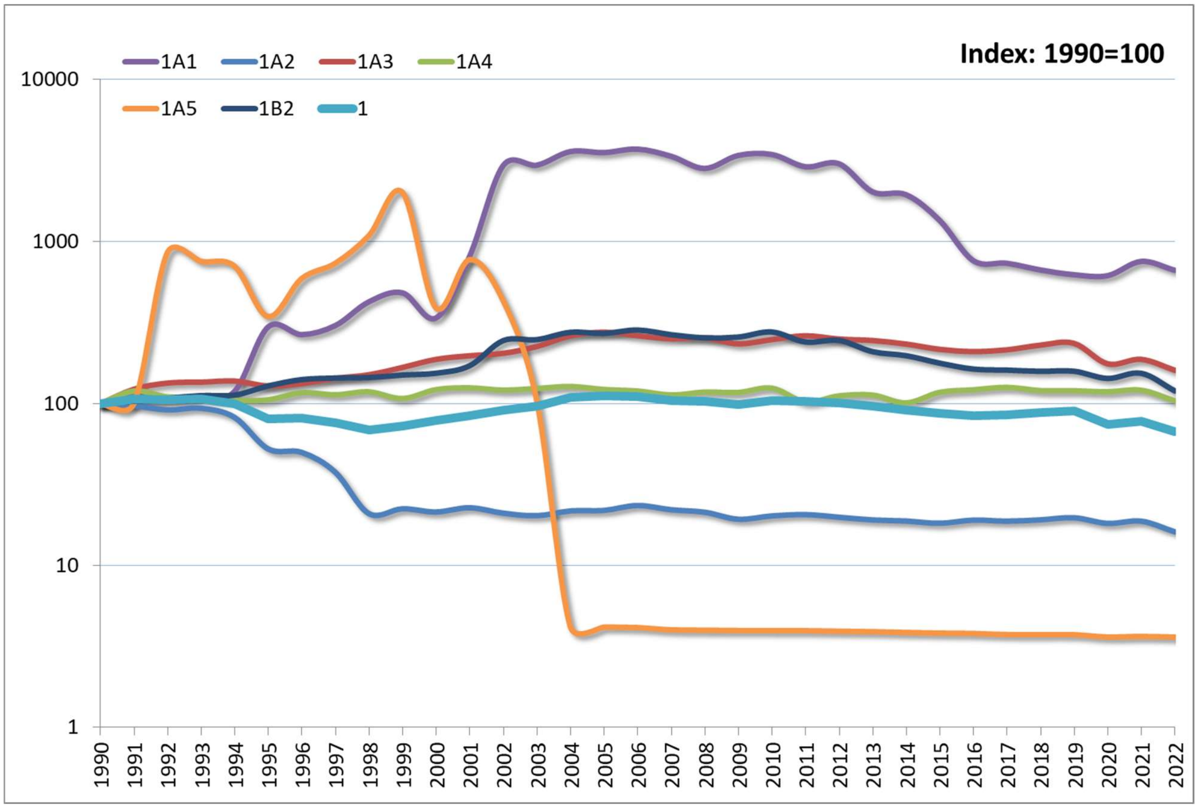


Figure 3-3 – IPCC sub-categories share in GHG emissions for CRF Sector 1 – Energy: 1990 and 2022

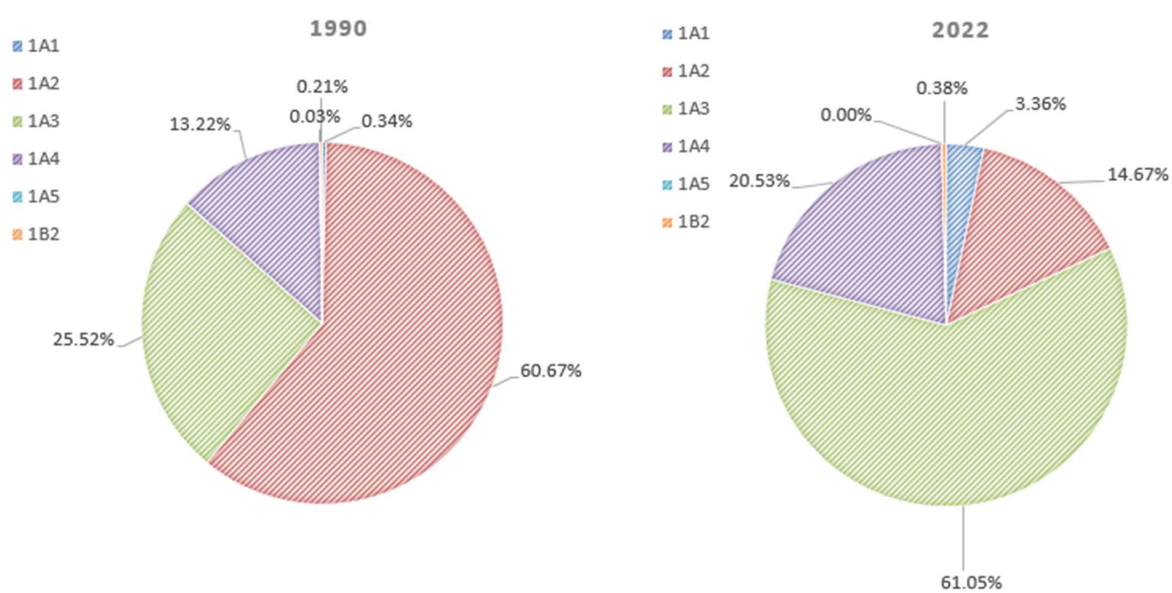


Table 3-2– Final energy consumption trends: 1990-2022

Final energy consumption in terms of different froms of energy and fuels (TJ)								
Year	Total	Coal	Blast furnace gas	Natural gas (1)	Electricity	Heat (2)	Liquid fuels	Wood & biomass (3)
1990	144 043	34'332	8'457	19'427	14'989	-	66'193	645
1991	151 194	30'815	7'235	20'390	15'198	-	76'912	645
1992	151 495	29'475	6'196	21'227	15'282	-	78'670	645
1993	154 576	30'689	6'514	22'064	15'826	-	78'837	645
1994	151 033	27'268	5'504	21'990	16'747	126	78'754	645
1995	134 632	16'035	2'732	23'907	18'045	586	72'683	645
1996	138 070	15'671	2'512	26'251	17'710	547	74'734	645
1997	136 435	10'422	1'347	27'156	18'254	564	78'047	645
1998	135 560	4'883	-	27'437	19'092	950	82'554	645
1999	142 821	4'836	-	28'436	19'836	986	88'083	645
2000	149 605	4'595	-	28'126	20'790	504	94'661	930
2001	156 682	4'958	-	27'998	21'033	624	100'748	1'321
2002	158 232	3'084	-	28'258	21'261	1'085	103'139	1'406
2003	168 355	2'369	-	28'674	22'252	2'815	110'838	1'407
2004	186 632	3'329	-	29'942	23'007	3'031	125'735	1'587
2005	190 467	3'249	-	29'338	22'149	3'050	130'190	2'490
2006	187 692	3'877	-	30'623	23'806	3'204	123'620	2'562
2007	184 849	3'280	-	29'823	24'098	2'573	120'558	4'519
2008	186 737	3'137	-	30'616	23'750	2'907	121'629	4'697
2009	173 689	2'801	-	28'659	22'005	2'458	113'546	4'219
2010	184 309	2'745	-	31'412	23'735	3'003	118'873	4'541
2011	182 496	2'476	-	27'916	23'343	3'060	121'286	4'415
2012	177 496	2'295	-	28'262	22'450	2'993	116'795	4'700
2013	175 549	2'201	-	27'790	22'316	3'168	114'972	5'103
2014	170 201	2'181	-	26'536	22'256	2'445	110'844	5'938
2015	169 866	2'061	-	27'791	22'407	2'288	108'958	6'360
2016	172 078	2'132	-	29'226	22'922	2'368	108'687	6'742
2017	177 912	1'973	-	28'751	23'016	2'669	113'904	7'599
2018	184 944	1'748	-	28'761	23'251	3'028	120'388	7'766
2019	186 850	1'916	-	28'846	23'029	3'845	121'854	7'361
2020	162 463	1'610	-	26'021	22'030	5'354	99'062	8'387
2021	173 160	1'762	-	28'074	23'014	5'827	106'365	8'118
2022	156 129	1'720	-	22'093	22'115	5'391	96'942	7'870
Trend 1990-2022	8.39%	-94.99%	NA	13.72%	47.55%	NA	46.45%	1120.52%
Share 1990	100.00%	23.83%	5.87%	13.49%	10.41%	NA	45.95%	0.45%
Share 2022	100.00%	1.10%	NA	14.15%	14.16%	3.45%	62.09%	5.04%

Source:STATEC: Statistical Yearbook, Table A4300: http://www.statistiques.public.lu/

Notes: (1) based on GCV

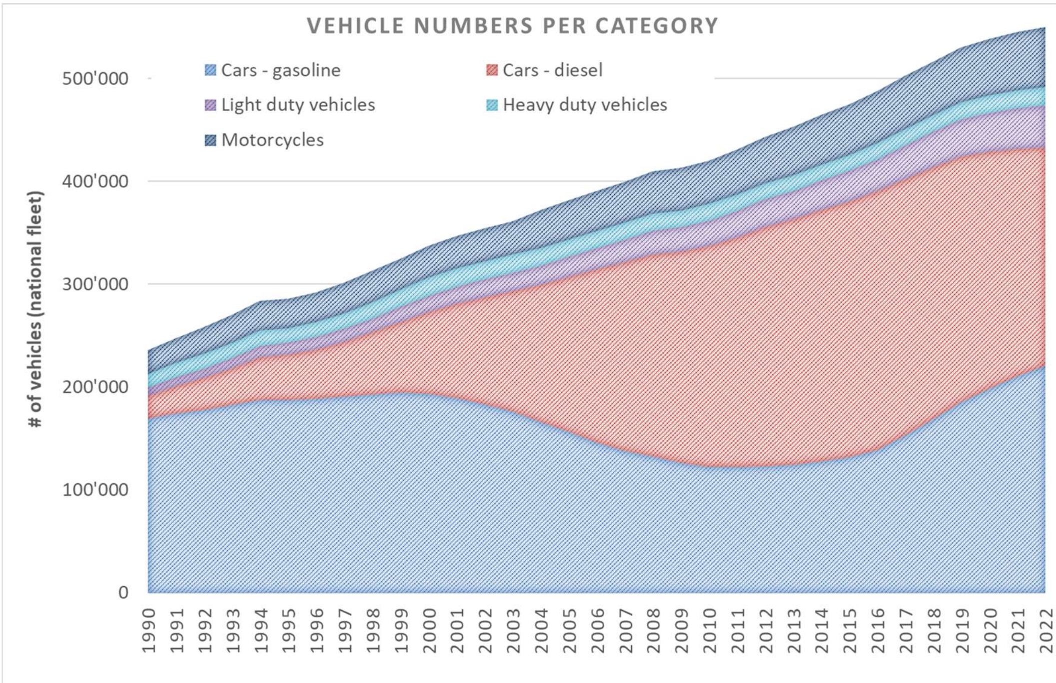
(2) heat from cogeneration, including heat recovery from waste incineration

(3) including blended biodiesel

Data extracted on 19th of January 2024 (subject to change since that date)

Final energy consumption increased by 8.39% between 1990 and 2022 and passed through a minimum in 1995 and a maximum in 2005. All the energy sources have seen their consumption increase over the period, except coal and blast furnace gas, for which the declining use in the first part of the 1990s was closely related to the discontinuation of the use of blast furnaces in the iron & steel industry. Table 3-2 also shows the dramatic change in the “energy-mix” in Luxembourg between 1990 and 2022, with a dropping share of solid fuels – for which the main part was used in the iron and steel industry – in favour of liquid fuels and natural gas and, to a lesser extent, to new energy sources such as cogeneration and biomass. Biomass is expected to increase more rapidly in the future due to European commitments, also engaged by Luxembourg, to promote the use of biomass, especially solid biomass and biogas. As a consequence of the high fossil fuel prices in 2022, the final energy consumption of fuels used in all the 1A energy subsectors saw decreases compared to 2021 (-2.40% for coal, -21.31% for natural gas, and -8.86% for liquid fuels).

In 2022, with 62.09% of the final total energy consumption in Luxembourg, liquid fuels are the most important energy source, with diesel being the first liquid fuel in terms of volumes sold. The domestic liquid fuel consumption in Luxembourg is much lower than the level of fuel sales, because large amounts of road fuels are bought by cross-border commuters and transit traffic passing through Luxembourg and thus exported on board of road vehicle tanks. Actually, in 2022, 61.00% of road fuels sold on Luxembourg's territory are exported inside vehicle tanks and combusted abroad (see Table 3-68 in Section 3.2.9.3).



The importance of natural gas has increased constantly and significantly since 1990. In 2021, natural gas consumption ranked second after the consumption of liquid fuels. This development followed the continuous extension of the natural gas network in Luxembourg and the substantial increase of Luxembourg's population since 1990, and as such, natural gas has become more and more the main fuel for heating purposes. However, given the high fossil fuel prices in 2022, more electricity than natural gas was consumed in Luxembourg for the first time ever.

Natural gas is currently one of the main energy sources of Luxembourg's national electricity production capacity[59]. In 1990, more than 90% of Luxembourg's electric energy consumption was imported. One medium size power plant of about 70 MW was owned by the iron & steel industry, and partially fed the public network when electricity was produced in excess. That power plant was mainly run on blast furnace gas and was phased out in 1997 after the last blast furnace went out of service.

In the early 1990s, small cogeneration plants appeared. Their installation was encouraged financially by the Government. This development was followed later by some industrial companies which installed gas turbines to produce electricity and heat simultaneously. In mid-2002, the TWINerg power plant – a 350MW gas turbine – started its operation, producing electricity only until 2010. From 2011 onwards, heat is also recovered and fed into a district heating network providing heat for the new developement site at Esch-Belval. The TWINerg plant was shut down in 2016. Almost all of these cogeneration plants run on natural gas. Gas oil remains, however, the emergency fuel in case of a natural gas supply disruption.

59 This cannot be seen in final energy consumption statistics but only in the primary energy consumption figures.

Table 3-3 summarises electricity production trends in Luxembourg since 1990.

Table 3-3 – Electricity production trends: 1990-2022

Year	Electricity production (GWh) Total	Thermic (1)	RES (2)	Cogeneration (3)
1990	626	559	68	NO
1991	676	622	54	NO
1992	662	594	68	NO
1993	670	608	62	NO
1994	625	506	86	33
1995	530	347	81	102
1996	474	306	53	114
1997	424	214	92	118
1998	406	105	107	195
1999	389	52	132	205
2000	415	51	144	219
2001	869	457	143	269
2002	2 817	2 333	131	352
2003	2 784	2 285	102	397
2004	3 374	2 787	144	442
2005	3 337	2 737	155	445
2006	3 519	2 866	182	471
2007	3 190	2 599	192	399
2008	2 713	2 089	202	422
2009	3 143	2 571	181	390
2010	3 224	2 607	176	440
2011	2 644	2 049	148	447
2012	2 746	2 104	204	438
2013	1 843	1 157	269	417
2014	1 918	1 241	296	381
2015	1 350	680	320	350
2016	800	113	332	355
2017	936	124	466	346
2018	1 020	124	530	366
2019	1 192	125	644	423
2020	1 464	*	836	628
2021	1 481	*	850	632
2022	1 454	*	908	546
Trend 1990-2022	132.26%	NA	1245.49%	NA
Share 1990	100.00%	89.22%	10.78%	NA
Share 2022	100.00%	NA	62.46%	37.54%

Sources: STATEC: Statistical yearbook, Table A.4203: http://www.statistiques.public.lu

Notes: (1) includes thermal power plants (TWINerg), autoproducer thermal power plants and MSW incineration.
(2) RES=Renewable Energy Sources, includes small hydro-electric power plants, wind power, photovoltaic power.
(3) Cogeneration includes biomethanisation
Data extracted on 19th of January 2024 (subject to changes since that date)

3.1.2 Completeness

Table 3-4 gives an overview of the IPCC categories included under CRF Sector 1-Energy and provides information on the status of emission estimates of all sub-categories.

Table 3-4 – Overview of CRF Sector 1 – Energy: status of emission estimates for CO_2, CH_4 and N_2O

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
1A1a	fuel combustion activities – energy industries – public electricity & heat production	X	X	X
1A1b	fuel combustion activities – energy industries – petroleum refining	NO	NO	NO
1A1c	fuel combustion activities – energy industries – manufacture of solid fuels and other energy industries	NO	NO	NO
1A2a	fuel combustion activities – manufacturing industries & construction – iron & steel	X	X	X
1A2b	fuel combustion activities – manufacturing industries & construction – non-ferrous metals	X	X	X
1A2c	fuel combustion activities – manufacturing industries & construction – chemicals	X	X	X
1A2d	fuel combustion activities – manufacturing industries & construction – pulp, paper & print	X (2000-2020)	X (2000-2020)	X (2000-2020)
1A2e	fuel combustion activities – manufacturing industries & construction – food processing, beverages & tobacco	X	X	X
1A2f	fuel combustion activities – manufacturing industries & construction – non-metallic minerals	X	X	X
1A2g	fuel combustion activities – manufacturing industries & construction – other	X	X	X
1A3a	fuel combustion activities – transport – civil aviation	X	X	X
1A3b	fuel combustion activities – transport – road transportation	X	X	X
1A3c	fuel combustion activities – transport – railways	X	X	X
1A3d	fuel combustion activities – transport – navigation	X	X	X
1A3e	fuel combustion activities – transport – other transportation	NO	NO	NO
1A4a	fuel combustion activities – other sectors – commercial/institutional	X	X	X
1A4b	fuel combustion activities – other sectors – residential	X	X	X
1A4c	fuel combustion activities – other sectors – agriculture/forestry/fish farms	X	X	X
1A5a	fuel combustion activities – non-specified – stationary	X (1990-2003)	X (1990-2003)	X (1990-2003)
1A5b	fuel combustion activities – non-specified – mobile	X	X	X
1B1a	fugitive emissions from fuels – solid fuels – coal mining & handling	NO	NO	NO
1B1b	fugitive emissions from fuels – solid fuels – solid fuel transformation	NO	NO	NO
1B1c	fugitive emissions from fuels – solid fuels – other	NO	NO	NO
1B2a	fugitive emissions from fuels – oil & natural gas – oil	NA	NA	NO
1B2b	fugitive emissions from fuels – oil & natural gas – natural gas	X	X	
1B2c	fugitive emissions from fuels – oil & natural gas – venting & flaring	X	X	NO
1B2d	fugitive emissions from fuels – oil & natural gas – other	NA	NA	NA
Memo Items	international bunkers – aviation	X	X	X
Memo Items	international bunkers – marine	X	X	X
Memo Items	multilateral operations	NA	NA	NA
Memo Items	CO2 emissions from biomass	X		

Note: X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

3.2 Fuel Combustion Activities (1.A)

In 2022, GHG emissions of category 1A - Fuel Combustion amounted to a total of 6.88 million tonnes CO_2eq (see Table 3-5). The transport sector (1A3 - Transport) represented the most important source, with a share of 61.29% of the GHG emissions within category 1A (51.48% of national total excl. LULUCF). These emissions include emissions from fuel export, i.e. fuel bought by foreign commuters and transit traffic, but mostly emitted outside of Luxembourg's territory.

Combustion in the commercial and residential sector (1A4 - Other Sectors) was the second largest source of emissions with a share of 20.61% of the GHG emissions within category 1A (17.31% of national total excl. LULUCF), followed by the industrial sector (1A2 - Manufacturing Industries and Construction) and the energy sector (1A1 - Energy) with shares of 14.72% and 3.37%, respectively (12.37% and 2.83% of national total excl. LULUCF, respectively). Emissions from sub-category 1A5 - Other, which includes emissions from other non-specified sources, represented less than 0.003% of the GHG emissions within category 1A in 2022.

Table 3-5 - GHG emission trends and shares of 1A-Fuel combustion

1A - Fuel Combustion GHG emissions by source category excluding CO_2 emissions from biomass (Gg CO_2 eq.)						
Year	1A1 Energy Industries	1A2 Manufacturing Industries & Construction	1A3 Transportation	1A4 Other Sectors	1A5 Other	1A Fuel Combustion
1990	34.8	6 244.5	2 626.7	1 360.9	3.1	10 270.0
1991	36.4	6 073.1	3 225.2	1 627.0	3.1	10 964.9
1992	36.3	5 724.7	3 519.3	1 498.7	26.9	10 805.9
1993	38.5	5 863.4	3 564.3	1 483.5	23.8	10 973.5
1994	41.5	5 146.7	3 620.7	1 424.9	22.2	10 255.9
1995	103.8	3 289.7	3 378.3	1 438.5	10.8	8 221.1
1996	93.1	3 131.8	3 494.3	1 589.4	18.6	8 327.2
1997	105.8	2 363.0	3 763.2	1 542.9	23.1	7 798.1
1998	148.3	1 313.7	3 958.0	1 608.1	34.2	7 062.4
1999	168.5	1 405.2	4 390.1	1 463.8	63.3	7 490.9
2000	117.9	1 343.5	4 919.4	1 659.1	12.3	8 052.0
2001	282.9	1 426.0	5 178.1	1 699.0	24.3	8 610.3
2002	1 029.2	1 320.7	5 357.3	1 645.8	13.6	9 366.6
2003	1 033.4	1 273.7	5 895.1	1 685.4	3.3	9 890.9
2004	1 255.5	1 363.4	6 853.7	1 732.7	0.1	11 205.4
2005	1 237.3	1 373.5	7 216.7	1 661.4	0.1	11 489.0
2006	1 299.8	1 472.8	6 870.0	1 626.7	0.1	11 269.5
2007	1 174.3	1 386.2	6 576.1	1 538.9	0.1	10 675.7
2008	987.0	1 339.0	6 668.1	1 602.6	0.1	10 596.9
2009	1 188.1	1 211.5	6 127.5	1 593.4	0.1	10 120.6
2010	1 204.6	1 270.1	6 505.2	1 692.3	0.1	10 672.3
2011	1 011.4	1 294.4	6 867.2	1 396.1	0.1	10 569.3
2012	1 054.8	1 246.7	6 553.7	1 520.1	0.1	10 375.4
2013	707.3	1 199.9	6 421.3	1 536.5	0.1	9 865.2
2014	679.4	1 181.0	6 105.3	1 378.4	0.1	9 344.1
2015	471.5	1 144.7	5 670.1	1 596.8	0.1	8 883.2
2016	266.3	1 196.5	5 491.0	1 654.3	0.1	8 608.1
2017	256.6	1 179.2	5 629.8	1 710.7	0.1	8 776.4
2018	233.3	1 201.2	6 011.7	1 636.1	0.1	9 082.4
2019	218.0	1 237.3	6 171.2	1 631.8	0.1	9 258.5
2020	215.1	1 141.9	4 618.2	1 609.8	0.1	7 585.1
2021	263.6	1 178.9	4 919.2	1 644.2	0.1	8 005.9
2022	232.2	1 013.1	4 217.1	1 418.0	0.1	6 880.5
Trend 1990-2022	566.83%	-83.78%	60.55%	4.20%	-96.39%	-33.00%
Share 1990	0.34%	60.80%	25.58%	13.25%	0.03%	100.00%
Share 2022	3.37%	14.72%	61.29%	20.61%	0.00%	100.00%

Source: Environment Agency

Table 3-6 presents the key source categories of 1A – Fuel Combustion Activities.

Table 3-6 – Key categories of 1A – Fuel Combustion Activities (1990-2022)

1A - Fuel Combustion Activities Key sources							
IPCC Category	Category Name	Fuel	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
1A1	Energy Industries	gaseous	CO_2	98-99, 01-22	95-22		
1A1	Energy Industries	other	CO_2	12-22	98-02, 04, 11-22	X	
1A2	Manufacturing Industries and Construction	gaseous	CO_2	90-22	90-22		X
1A2	Manufacturing Industries and Construction	liquid	CO_2	90-22	90-22	X	X
1A2	Manufacturing Industries and Construction	solid	CO_2	90-22	90-22	X	X
1A2	Manufacturing Industries and Construction	other	CO_2	16-22	13-22		
1A3b	Road Transportation	diesel oil	CO_2	90-22	90-22	X	X
1A3b	Road Transportation	gasoline	CO_2	90-22	90-22	X	X
1A4	Other Sectors	gaseous	CO2	90-22	90-22	X	X
1A4	Other Sectors	liquid	CO2	90-22	90-22		
1A5	Other	liquid	CO2	99	99		

Source: Environment Agency
Notes: LA= Level Assessment (Tier 1) including respectively excluding LULUCF
TA= Trend Assessment 2022 (Tier 1) including respectively excluding LULUCF

3.2.1 Comparison of the sectoral approach with the reference approach

This section provides a comparative analysis of the reference approach and the sectoral approach, and gives explanations for the differences between the two approaches. Figure 3-4 and Table 3-7 present CO_2 emissions obtained by the sectoral and the reference approaches. The difference for total CO_2 emissions from fuel combustion varies between -0.71% and +2.25% throughout the time-series.

Figure 3-4 - CO_2 emissions obtained with Reference and Sectoral Approach for 1990-2022

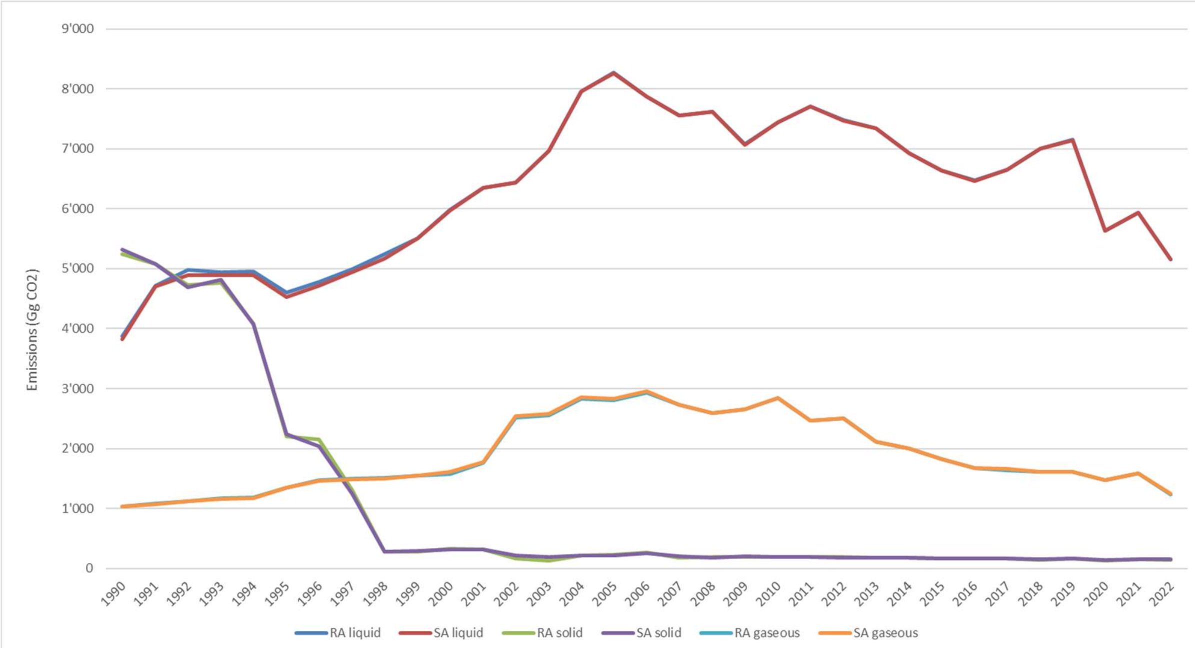


Table 3-7 – CO_2 emissions obtained with Reference and Sectoral Approach (1990-2022)

CO_2 emissions of sectoral and reference approach

[Gg CO_2]

Year	Reference Approach					Sectoral Approach - 1 A Fuel Combustion				
	Solid	Liquid	Gaseous	Other	Total	Solid	Liquid	Gaseous	Other	Total
1990	5 241	3 874	1 039	32	**10 186**	5 317	3 821	1 036	32	**10 207**
1991	5 081	4 712	1 080	34	**10 907**	5 077	4 708	1 074	34	**10 894**
1992	4 733	4 974	1 128	34	**10 869**	4 686	4 892	1 122	34	**10 734**
1993	4 768	4 945	1 173	36	**10 922**	4 813	4 891	1 161	36	**10 901**
1994	4 093	4 955	1 184	39	**10 270**	4 073	4 897	1 174	39	**10 183**
1995	2 209	4 607	1 351	41	**8 208**	2 239	4 530	1 343	41	**8 152**
1996	2 155	4 783	1 472	34	**8 445**	2 043	4 720	1 461	34	**8 259**
1997	1 315	4 994	1 500	44	**7 852**	1 247	4 948	1 491	44	**7 730**
1998	280	5 248	1 506	58	**7 092**	280	5 164	1 495	58	**6 996**
1999	287	5 509	1 552	68	**7 416**	296	5 513	1 546	68	**7 423**
2000	328	5 979	1 580	76	**7 963**	325	5 974	1 609	76	**7 983**
2001	320	6 351	1 758	99	**8 528**	317	6 345	1 781	99	**8 541**
2002	165	6 443	2 519	106	**9 232**	215	6 437	2 540	106	**9 298**
2003	133	6 965	2 556	100	**9 755**	187	6 960	2 576	100	**9 823**
2004	218	7 957	2 837	111	**11 123**	213	7 952	2 859	111	**11 136**
2005	228	8 268	2 803	104	**11 402**	224	8 263	2 829	104	**11 420**
2006	264	7 873	2 937	112	**11 186**	260	7 872	2 958	112	**11 201**
2007	178	7 552	2 731	112	**10 573**	204	7 552	2 731	120	**10 607**
2008	189	7 623	2 594	118	**10 524**	186	7 619	2 594	126	**10 525**
2009	199	7 084	2 657	104	**10 044**	211	7 070	2 658	111	**10 050**
2010	196	7 446	2 841	115	**10 599**	193	7 439	2 842	122	**10 596**
2011	194	7 709	2 463	126	**10 492**	191	7 703	2 464	132	**10 490**
2012	188	7 476	2 499	132	**10 294**	185	7 470	2 500	138	**10 294**
2013	177	7 341	2 112	147	**9 776**	175	7 335	2 115	156	**9 781**
2014	176	6 931	2 004	139	**9 249**	175	6 926	2 006	151	**9 258**
2015	162	6 644	1 827	148	**8 781**	165	6 639	1 829	162	**8 796**
2016	167	6 471	1 679	179	**8 496**	173	6 465	1 682	197	**8 517**
2017	167	6 653	1 642	182	**8 643**	173	6 648	1 657	204	**8 682**
2018	147	7 007	1 609	194	**8 957**	153	7 001	1 609	219	**8 981**
2019	162	7 151	1 606	198	**9 117**	168	7 146	1 608	233	**9 156**
2020	133	5 636	1 469	208	**7 446**	141	5 632	1 469	250	**7 492**
2021	151	5 933	1 589	199	**7 872**	157	5 929	1 589	234	**7 909**
2022	146	5 161	1 242	197	**6 746**	155	5 152	1 249	232	**6 788**

Table 3-8 presents the relative difference of CO_2 emissions between reference and sectoral approach.

Table 3-8 – Difference of CO_2 emissions by type of fuel

Difference of CO_2 emissions between sectoral and reference [%]					
Year	**Solid**	**Liquid**	**Gaseous**	**Other**	**Total**
1990	- 1.44	1.40	0.27	0.00	- 0.20
1991	0.08	0.07	0.57	0.00	0.12
1992	1.01	1.67	0.59	0.00	1.26
1993	- 0.93	1.10	1.06	0.00	0.19
1994	0.48	1.18	0.92	0.00	0.86
1995	- 1.33	1.71	0.62	0.00	0.68
1996	5.49	1.34	0.75	0.00	2.25
1997	5.41	0.93	0.56	0.00	1.58
1998	0.02	1.64	0.74	0.00	1.37
1999	- 3.04	- 0.08	0.38	0.00	- 0.10
2000	0.94	0.09	- 1.80	0.00	- 0.26
2001	1.15	0.09	- 1.27	0.00	- 0.16
2002	- 23.52	0.09	- 0.83	0.00	- 0.71
2003	- 28.75	0.07	- 0.76	0.00	- 0.69
2004	2.18	0.06	- 0.76	- 0.08	- 0.12
2005	1.67	0.06	- 0.92	- 0.09	- 0.16
2006	1.72	0.02	- 0.72	- 0.08	- 0.14
2007	- 13.02	0.01	0.00	- 6.43	- 0.32
2008	1.43	0.05	- 0.01	- 6.12	- 0.01
2009	- 5.63	0.20	- 0.03	- 6.51	- 0.06
2010	1.58	0.09	- 0.02	- 5.62	0.03
2011	1.44	0.08	- 0.04	- 4.92	0.02
2012	1.51	0.07	- 0.02	- 4.99	0.01
2013	1.48	0.07	- 0.15	- 6.06	- 0.05
2014	0.42	0.07	- 0.11	- 7.90	- 0.09
2015	- 1.84	0.07	- 0.12	- 8.72	- 0.17
2016	- 3.29	0.08	- 0.14	- 9.26	- 0.25
2017	- 3.79	0.08	- 0.90	- 10.92	- 0.45
2018	- 3.69	0.08	0.00	- 11.28	- 0.28
2019	- 3.93	0.07	- 0.10	- 15.25	- 0.42
2020	- 5.30	0.07	- 0.01	- 16.68	- 0.61
2021	- 4.11	0.07	0.03	- 15.01	- 0.47
2022	- 5.96	0.18	- 0.58	- 14.94	- 0.62

Source: Environment Agency
Note: Positive numbers indicate that CO_2 emissions from the reference approach are higher than emissions from the sectoral approach.

3.2.1.1 Methodology and data sources

The reference approach was compiled based on the 2006 IPCC Guidelines.

The primary data source for production, import, export, stock change, international bunker of fuels was the national energy balance and /or the IEA Energy questionnaires as provided and compiled by the national statistics office (STATEC).

NCVs, CO_2 emission factors and oxidation factors are identical to those used for the sectoral approach, if not otherwise stated in the CRF tables' documentation box.

The amount of carbon which does not lead to fuel combustion emissions was excluded from total carbon. Indeed, carbon excluded from fuel combustion is either emitted in another sector of the inventory (for example as an industrial process emission) or stored in the product manufactured from the fuel.

3.2.1.2 Explanation of differences

The following reasons provide explanations to the differences recorded between the Sectoral Approach and the Reference Approach (CRF table 1.A (b) and 1.A(c)):

- The sectoral approach is based on a combined bottom-up (using plant specific data where available) & top-down (national energy balance) approach. For some IPCC sub-categories, bottom-up activity data is higher than reported by the energy balance. In order to avoid potential underestimation, it is preferred to use the highest data whenever possible. Hence, emissions as calculated in the sectoral approach can be higher than the ones calculated in the reference approach. Please refer to section 3.2.5 for more details on the methodology applied to calculate emissions in the sectoral approach.
- Liquid fuels: difference in CO_2 emissions between the two approaches is +0.18% in 2022 and lies below the 2% significance threshold for the entire timeseries.
- Solid fuels: difference in CO_2 emissions between the two approaches is -5.96% for 2022. For some years there is a significant difference between both approaches (up to -28.75% for 2003). The most likely reason for these differences is that solid fuels are often stored in large quantities, and not immediately combusted after acquisition (sometimes combustion may even occur in a different calendar year).
- Gaseous fuels: difference in CO_2 emissions between the two approaches is -0.58% in 2022 and lies below the 2% significance threshold for the entire timeseries.
- Other Fossil Fuels: This category covers three dominating facilities, all covered under the emission trading scheme (ETS). One facility is using secondary fossil fuels such as tires, fluff, waste solvents and sewage sludge as a replacement of standard solid fossil fuels such as coal for its clinker production. The activity data for these secondary fossil fuels, as used in the sectoral approach, are extracted from the ETS reports. However the national energy balance, used for the reference approach, does not report the consumption of such fuels. Hence, the CO_2 emission of these secondary fossil fuels was added to the reference approach, and the difference between the two approaches tends to 0%. However, since submission 2019v1, Luxembourg has added a new type of "other fossil fuel" in its inventory: the fossil part of FAME in biodiesel is considered here since its introduction in 2004 (please refer to page 255 for details). As a consequence, the difference between the sectoral and the reference approach for other fossil fuels is -14.94% in 2022. This results from the fact that the national energy balance considers biodiesel to be 100% biomass.

Category-specific recalculations including changes made in response to the review process Table 3-9 presents the main revisions and recalculations done since submission 2023v1 relevant to the Reference Approach. For the quantitative aspect of these recalculations, please refer to Chapter 10.

Table 3-9 – Recalculations for the Reference Approach

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
Bitumen (feedstocks)	AD for 2021 was revised according to the revised energy balance (from 523.364 to 546.398 TJ)	updated AD
Lubricants (feedstocks)	AD for 2021 was revised according to the revised energy balance (from 417.929 to 264.717 TJ)	updated AD
Residual fuel oil	AD for 2021 was revised according to the revised energy balance (from 3.760 to 42.760 TJ)	updated AD
Liquid fuels	Revision of CO_2 emissions factors for gasoline, diesel/gas oil and LPG for the entire timeseries (Table 10-2)	CO_2 EF

3.2.1.3 Planned improvements

Table 3-10 lists the main improvements planned for the next submission.

Table 3-10 – Planned improvements for the Reference Approach

GHG source & sink category	Planned improvement
	No planned improvements

3.2.2 International Bunker Fuels

In 2022, GHG emissions from International Bunkers amounted to 1953 Gg CO_2e (see Table 3-11), an increase of approximately 391% compared to 1990, which is mainly due to increased international aviation activities.

Table 3-11 – Activity data and GHG emissions for International Bunkers

International Bunkers - Aviation & Marine Activity Data (GJ) and GHG emissions by source & sink category (Gg)												
Year	Aviation (Kerosene & Aviation Gasoline)					Marine (Gas Oil)					Total Activity	Total CO_2 eq
	Activity (GJ)	Total CO_2 eq	CO_2	CH_4	N_2O	Activity (GJ)	Total CO_2 eq	CO_2	CH_4	N_2O		
1990	5 516 169	397.95	394.41	0.003	0.013	992	0.081	0.074	0.000004	0.000028	**5 517 161**	**398**
1991	5 765 550	415.94	412.24	0.003	0.014	1 046	0.085	0.078	0.000004	0.000029	**5 766 596**	**416**
1992	5 574 033	402.19	398.54	0.004	0.013	1 001	0.082	0.074	0.000004	0.000028	**5 575 034**	**402**
1993	5 512 762	397.73	394.16	0.003	0.013	1 398	0.114	0.104	0.000006	0.000040	**5 514 160**	**398**
1994	6 993 817	504.48	500.06	0.004	0.016	1 238	0.101	0.092	0.000005	0.000036	**6 995 055**	**505**
1995	7 927 783	571.74	566.83	0.004	0.018	1 246	0.102	0.092	0.000005	0.000037	**7 929 029**	**572**
1996	8 614 215	621.18	615.91	0.004	0.019	1 178	0.097	0.087	0.000005	0.000035	**8 615 393**	**621**
1997	10 305 632	743.06	736.85	0.004	0.023	1 234	0.101	0.092	0.000005	0.000037	**10 306 867**	**743**
1998	12 493 294	900.64	893.27	0.004	0.027	1 165	0.096	0.086	0.000005	0.000035	**12 494 459**	**901**
1999	14 095 591	1 016.08	1 007.83	0.005	0.031	1 316	0.108	0.098	0.000005	0.000040	**14 096 907**	**1 016**
2000	13 434 073	968.43	960.53	0.005	0.029	1 411	0.116	0.105	0.000006	0.000043	**13 435 484**	**969**
2001	14 530 054	1 047.35	1 038.90	0.005	0.031	1 415	0.117	0.105	0.000006	0.000043	**14 531 469**	**1 047**
2002	15 742 564	1 134.65	1 125.59	0.005	0.034	1 462	0.120	0.108	0.000006	0.000044	**15 744 026**	**1 135**
2003	16 399 902	1 182.02	1 172.59	0.005	0.035	1 490	0.122	0.111	0.000006	0.000044	**16 401 392**	**1 182**
2004	17 844 514	1 286.12	1 275.88	0.005	0.038	1 473	0.121	0.109	0.000005	0.000043	**17 845 986**	**1 286**
2005	18 131 067	1 306.77	1 296.37	0.005	0.039	1 887	0.154	0.140	0.000006	0.000052	**18 132 953**	**1 307**
2006	16 967 777	1 222.97	1 213.19	0.005	0.036	1 932	0.157	0.143	0.000006	0.000050	**16 969 708**	**1 223**
2007	18 238 604	1 314.39	1 304.06	0.005	0.038	1 618	0.131	0.120	0.000005	0.000040	**18 240 222**	**1 315**
2008	18 359 132	1 323.12	1 312.68	0.005	0.039	1 785	0.144	0.132	0.000005	0.000043	**18 360 917**	**1 323**
2009	17 588 864	1 267.63	1 257.60	0.005	0.037	1 367	0.110	0.101	0.000004	0.000031	**17 590 231**	**1 268**
2010	18 050 982	1 300.90	1 290.64	0.005	0.038	1 405	0.112	0.104	0.000004	0.000031	**18 052 387**	**1 301**
2011	16 887 889	1 217.15	1 207.48	0.005	0.036	1 213	0.097	0.090	0.000003	0.000026	**16 889 102**	**1 217**
2012	15 581 431	1 123.08	1 114.07	0.005	0.033	908	0.072	0.067	0.000002	0.000019	**15 582 339**	**1 123**
2013	15 652 046	1 128.14	1 119.12	0.005	0.034	776	0.062	0.058	0.000002	0.000016	**15 652 822**	**1 128**
2014	16 998 090	1 225.10	1 215.36	0.005	0.036	846	0.067	0.063	0.000002	0.000017	**16 998 936**	**1 225**
2015	19 161 950	1 381.00	1 370.08	0.005	0.041	811	0.064	0.060	0.000002	0.000016	**19 162 761**	**1 381**
2016	21 263 024	1 532.36	1 520.30	0.006	0.045	856	0.068	0.063	0.000002	0.000017	**21 263 881**	**1 532**
2017	24 041 916	1 732.55	1 719.00	0.006	0.051	969	0.077	0.072	0.000002	0.000019	**24 042 885**	**1 733**
2018	25 707 727	1 852.59	1 838.10	0.006	0.054	880	0.070	0.065	0.000002	0.000016	**25 708 607**	**1 853**
2019	25 148 046	1 812.28	1 798.08	0.006	0.053	766	0.060	0.057	0.000002	0.000014	**25 148 812**	**1 812**
2020	22 887 987	1 648.80	1 636.49	0.003	0.046	164	0.013	0.012	0.000000	0.000003	**22 888 151**	**1 649**
2021	26 111 200	1 881.02	1 866.95	0.004	0.053	172	0.014	0.013	0.000000	0.000003	**26 111 372**	**1 881**
2022	27 103 423	1 952.95	1 937.89	0.006	0.056	265	0.021	0.020	0.000001	0.000005	**27 103 689**	**1 953**
Trend 1990-2022	391.35%	390.76%	391.35%	87.29%	331.25%	-73.27%	-74.23%	-73.32%	-86.49%	-83.23%	391.26%	390.66%

Source: Environment Agency

3.2.2.1 Aviation Bunkers

As there is only one airport for commercial aviation in Luxembourg (located next to Luxembourg City), all commercial flights, either coming to Luxembourg or going out of Luxembourg, are international flights. Non-commercial flights are mainly leisure or urgency (medical, police) flights made with small-sized propeller airplanes or helicopters using aviation gasoline. These flights depart and arrive at the same airport in Luxembourg. Based on communication with an expert of the sole aviation fuel reseller (Luxfuel) and with the aviation authorities, about 90% of these non-commercial flights are considered as domestic flights. The remaining 10% of the light non-commercial aviation flights using aviation gasoline are considered as international flights, as these flights depart from Luxembourg with an international destination, which could be a small leisure airport in one of the neighbouring countries.[60] Consequently, all kerosene sales (commercial flights) and 10% of the aviation gasoline sales (non-commercial flights) and their related emissions are considered as international flights and, thus, are allocated to international bunkers (see also 1A3a – Domestic aviation: section 3.2.9.2.2).

3.2.2.1.1 Activity data

Fuel consumption of jet type kerosene was obtained from the national statistics institute (STATEC) and fuel consumption of aviation gasoline was obtained from the sole vendor of aviation gasoline at the airport (Luxfuel S.A.) (see Table 3-11). Data on the number of landings and take-offs (LTO) has been obtained from the air navigation administration (ANA) and the national statistics institute (STATEC).

3.2.2.1.2 Methodological issues

The 2006 IPCC Guidelines Tier 2 approach has been applied for flights combusting jet kerosene. This methodology is based on five steps:

- Estimation of the domestic and international fuel consumption totals for aviation. In Luxembourg's case this estimation is straight forward as the entire fuel consumption of jet kerosene is considered as international.
- Estimation of LTO fuel consumption for domestic and international operations. The LTO fuel consumption of international operations (no domestic operations using jet kerosene) is estimated using the Eurostat 2004-2019 data on aircraft types and the EMEP/EEA Guidebook 2019 Master and LTO emission calculator for each aircraft type. The 1990-2003 LTO fuel consumption data are estimated through a linear extrapolation of the 2004-2019 data.
- Estimation of the cruise fuel consumption for domestic and international aviation. The cruise fuel consumption was estimated by calculating the difference between the amount of fuel sold and the LTO fuel consumption.
- Estimation of emissions from LTO and cruise phases for domestic and international aviation. The emissions of LTO and cruise phases are calculated using emission factors from the IPCC 2006 Guidelines (please refer to section 3.2.2.1.3 below for more details).
- Calculation of total emissions = LTO emissions + cruise emissions.

For non-commercial flights, combusting aviation gasoline, the 2006 IPCC Guidelines Tier 1 approach has been used. As explained above, aviation gasoline fuel consumption was split into 90% domestic non-commercial flights and 10% international non-commercial flights. The respective emissions were estimated using the IPCC default emission factors for aviation gasoline (please refer to section 3.2.2.1.3 for more details).

60 This oral communication has been documented internally by the energy expert (ARR 2011, §48).

3.2.2.1.3 Emission factors

The emission factors, used for calculating emissions from International Bunkers – Aviation, are listed in Table 3-12. Emission factors for jet kerosene are taken from the IPCC 2006 Guidelines.

Table 3-12 – Emission factors for International Bunkers - Aviation

International Bunkers - Aviation Emission Factors for 2022								
Fuel	Flight Phase	CO_2		CH_4		N_2O		Source
		EF	(unit) type	EF	(unit) type	EF	(unit) type	
Jet Kerosene	LTO	71.50	(t/TJ) D	0.00008	(t/LTO) D	0.0001	(t/LTO) D	2006 IPCC GL
	cruise	71.50	(t/TJ) D	0.00	(t/t fuel) D	0.002	(t/t fuel) D	
Aviation gasoline	all	70 000	(kg/TJ) D	0.50	(kg/TJ) D	2.00	(kg/TJ) D	

Source: Environment Agency

3.2.2.2 Marine Bunkers

As motorised navigation only occurs on the Moselle River, about 3% of the total GHG emissions from shipping are considered as international and are, thus, reported under International Bunkers – Marine.

Activity data and emissions are listed in Table 3-11.

For more details on activity data sources, methodological issues, the split between international and domestic navigation and emission factors used, please refer to Section 3.2.9.5.

3.2.2.3 Multilateral Operations

There are no multilateral operations in Luxembourg, hence notation key NO is used.

3.2.2.4 Category-specific recalculations including changes made in response to the review process

Revisions and recalculations relevant to International Bunkers since submission 2023v1 are described in Table 3-13.

Table 3-13 - Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
1D1d – International navigation	For several years (2017-2020), the country-specific CO2 EFs for diesel oil has changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	updated CO2 EF
1D1d – International navigation	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged). Activity data of	Updated AD

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
	category 1D1d is affected for the years 2004-2021 (Table 3-14).	

Table 3-14: Activity data recalculations for category 1D1b – International navigation from submission 2023v1 to 2024v1

AD changes in GJ	1D1d liquid
2004	0.0001
2005	0.0002
2006	0.0001
2007	0.0107
2008	0.0108
2009	-0.0148
2010	-0.0007
2011	-0.0027
2012	-0.0006
2013	0.0022
2014	-0.0101
2015	0.0025
2016	0.0059
2017	0.0099
2018	0.0054
2019	0.0028
2020	0.0009
2021	0.0011

3.2.2.5 Category-specific QA/QC and verification

Apart from the standard QA/QC procedures, fuel splits between International Bunker Fuels and national consumptions were checked to avoid omissions or potential double counting. Jet type kerosene consumption as reported by the national statistics institute in the national energy balance and compared to the inventory is considered to be consistent (see Table 3-15. Also noteworthy is the fact that the national statistical institute does not publish data prior to the year 2000 on its website.

When comparing inventory data with the data as reported by Eurostat, small discrepancies are observed for every year between 1990 and 1999 (which are due to the lack of decimal digits for Eurostat data), as well as for 2009.

Furthermore, cross-checking between national statistics and data provided by the fuel provider was also undertaken, and no discrepancies could be identified.

3.2.2.6 Planned Improvements

Planned improvements, as listed in Table 3-15, will be explored, based on available resources.

Table 3-15– Planned improvements for International Bunkers

GHG source & sink category	Planned improvement
International Bunkers	No further improvements planned

Table 3-16 - Discrepancies in International Bunkers – Aviation

Discrepancies in International Bunkers - Aviation between inventory data and international data

Product	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Aviation gasoline	kt	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.20	0.24	0.26	0.20	0.15	0.16	0.21	0.20	0.42	0.35	0.28	0.18	0.20	0.18	0.22	0.22	0.22	0.24	0.21	0.19	0.24	0.20
Aviation gasoline	TJ	43.50	43.50	43.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.57	8.57	10.35	11.14	8.61	6.31	7.13	9.09	8.57	18.05	15.31	12.05	7.83	8.66	7.96	9.57	9.66	9.66	10.27	9.05	8.09	10.27	8.53
Aviation gasoline	*TJ/kt or GJ/t*	*43.500*	*43.500*	*43.500*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*43.500*	*43.503*	*43.500*	*43.500*	*43.500*	*43.503*	*43.500*	*43.502*	*43.503*	*43.501*	*43.500*	*43.502*	*43.500*	*43.503*	*43.503*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*
Kerosene type jet fuel	kt	128	133	128	125	162	184	201	244	275	323	312	337	365	380	414	421	394	423	426	408	419	392	361	363	394	445	493	558	596	583	531	606	629
Kerosene type jet fuel	TJ	5'517	5'733	5'517	5'388	6'983	7'931	8'664	10'518	11'854	13'923	13'433	14'529	15'742	16'399	17'844	18'130	16'967	18'238	18'358	17'592	18'050	16'887	15'581	15'651	16'997	19'161	21'262	24'041	25'707	25'147	22'887	26'110	27'102
Kerosene type jet fuel	*TJ/kt or GJ/t*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*
Source of data	Eurostat																																	
Extracted on	12.03.24																																	

Product	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Aviation gasoline	TJ											11.484	9.701	10.353	11.136	8.613	6.308	7.134	9.092	8.570	18.053	15.312	12.050	7.844	8.657	7.961	9.570	9.657	9.657	10.223	9.048	8.091	10.266	8.864
Kerosene type jet fuel	TJ											13'433	14'529	15'742	16'399	17'844	18'130	16'967	18'238	18'358	17'588	18'050	16'887	15'581	15'651	16'997	19'161	21'262	24'041	25'707	25'147	22'887	26'110	27'103
Source of data	STATEC																																	
Extracted on	12.03.24																																	

Product	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Aviation gasoline	kt	0.078	0.119	0.168	0.217	0.257	0.277	0.283	0.287	0.247	0.253	0.241	0.239	0.221	0.258	0.226	0.224	0.191	0.202	0.194	0.198	0.195	0.207	0.180	0.172	0.183	0.220	0.222	0.222	0.235	0.208	0.186	0.236	0.196
Aviation gasoline	TJ	3.410	5.180	7.310	9.460	11.190	12.050	12.308	12.480	10.742	10.986	10.465	10.393	9.633	11.217	9.834	9.742	8.296	8.782	8.417	8.599	8.496	9.022	7.844	7.499	7.974	9.589	9.659	9.657	10.223	9.048	8.091	10.266	8.528
Aviation gasoline	*TJ/kt or GJ/t*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*
Kerosene type jet fuel	kt	127.963	133.744	129.296	127.870	162.225	183.890	199.814	239.053	289.809	326.980	311.635	337.061	365.192	380.438	413.955	420.603	393.619	423.100	425.897	408.027	418.748	391.764	361.458	363.097	394.323	444.519	493.262	557.731	596.377	583.395	530.964	605.736	628.757
Kerosene type jet fuel	TJ	5'516	5'765	5'573	5'512	6'993	7'927	8'613	10'304	12'492	14'094	13'433	14'529	15'742	16'399	17'844	18'130	16'967	18'238	18'358	17'588	18'050	16'887	15'581	15'651	16'997	19'161	21'262	24'041	25'707	25'147	22'887	26'110	27'103
Kerosene type jet fuel	*TJ/kt or GJ/t*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*	*43.105*
Source of data	GHG inventory submission 2024v2																																	
Extracted on	12.03.24																																	

Difference	Kerosene type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Inventory/Eurostat	TJ	-2	32	56	124	10	-5	-51	-213	638	172	0	0	0	0	0	0	0	0	0	-4	0	0	0	0	0	0	0	0	0	0	0	0	0
Inventory/Statec	TJ	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-0	0	0	-0	0	0	-0	-0	0	-0	-0	0	0	0	-0	0	-0	-0	-0	0	0	0	0
Negative numbers = inventory is lower than compared source																																		
Positive numbers = inventory is higher than compared source																																		
	Sum of Aviation Gasoline and Kerosene type jet fuel																																	
Inventory/Eurostat	TJ	-42	-6	20	133	21	7	-39	-201	649	183	-1	2	-1	0	1	3	1	-0	-0	-14	-7	-3	0	-1	0	0	0	0	-0	0	0	0	0
Inventory/Statec	TJ	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-1	1	-1	0	1	3	1	-0	-0	-9	-7	-3	-0	-1	0	0	0	-0	-0	0	0	0	-0

3.2.3 Feedstocks and non-energy use

Non-energy use of fuels is considered in the national energy balance. Below explanations for the reported non-energy use is provided together with information on where CO_2 emissions due to manufacture, use and disposal of carbon containing products are considered.

For the fraction of carbon stored, the IPCC default values are applied.

3.2.3.1 Lubricants

Manufacturing: manufacturing of lubricants does not occur in Luxembourg.

Use: Lubricants are either used in road transportation (motor oil and greases) or in the manufacturing and construction industry (mainly greases). Emissions from lubricants use are reported under category 2D1 – Lubricant Use. Please refer to section 4.5.1 for more details on the estimation of emissions from lubricant use.

Disposal: incineration of lubricants (waste oil) does not occur in Luxembourg. Waste oil is either recycled or exported.

3.2.3.2 Bitumen

Manufacturing: manufacturing of bitumen does not occur in Luxembourg.

Use: by default the carbon contained in bitumen is considered to be entirely stored in the product, i.e. asphalt for road paving.

Disposal: CO_2 emissions from the disposal of bitumen are assumed to be negligible. Recycling is not considered.

3.2.3.3 Coke oven coke

Manufacturing: not occurring. All coke used in the iron and steel industry is imported.

Use: CO_2 emissions from coke used in iron and steel industry are reported under 2.C.1 – Iron and Steel Production.

Disposal: not applicable.

3.2.3.4 Other bituminous coal

Manufacturing: Manufacturing of electrodes from anthracite used in the electric arc furnaces does not occur in Luxembourg.

Use: Emissions from the use of electrodes in the iron and steel production are considered in category 2.C.1 – Iron and steel production.

Disposal: not applicable.

3.2.3.5 Other oil products

Manufacturing: not occurring. All products such as white spirits, etc. are imported.

Use: CO_2 emissions from solvent and other products use are considered in category 2.D.3. - Non-energy products from fuels and solvent use – Other – Solvent use.

Disposal: emissions from the disposal of plastics in landfills are considered in 6.A and emissions from incineration, with energy recovery, of waste plastics are considered in 1 A 1 a.

3.2.3.6 Category-specific recalculations including changes made in response to the review process

The following revisions and recalculations were done since submission 2023v1:

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
Bitumen (feedstocks)	AD for 2021 was revised according to the revised energy balance (from 523.364 to 546.398 TJ)	updated AD
Lubricants (feedstocks)	AD for 2021 was revised according to the revised energy balance (from 417.929 to 264.717 TJ)	updated AD

3.2.3.7 Planned improvements

No further improvements are planned.

3.2.4 CO_2 capture from flue gases and subsequent CO_2 storage

CO_2 capture from flue gases and CO_2 storage is not occurring in Luxembourg.

3.2.5 Country specific issues

3.2.5.1 Activity data

As Luxembourg's industrial sector is relatively small compared to larger countries, one has to keep in mind, that, when analysing trends in activity data, relatively large fluctuations may occur in between years simply due to the fact that a facility was temporally switched off for maintenance reasons, or shut-down for good. This may then be reflected by a sharp decrease in the activity data. On the other hand, the bringing into service of a single installation may lead to a sharp increase of activity data in a source category, and consequently also an increase in emissions.

3.2.5.2 Methodological choices

In general, the IPCC methodologies were applied for IPCC category 1-Energy, except for road transportation and offroad mobile machinery, where detailed calculation models (NEMO and GEORG) were used for non-CO_2 greenhouse gases.

Methodologies used were mostly Tier 1 for solid fuels (except blast furnace gas) and liquid fuels (residual fuel oil, aviation gasoline, kerosene) and Tier 2 for liquid fuels (motor gasoline, diesel oil, gas oil and LPG), gaseous fuel (natural gas), blast furnace gas and waste incineration (Tier 2a, 2006 IPCC Guidelines). For CH_4 and N_2O in road transportation and the off-road sector, the model is considered as a Tier 3 methodology.

Emissions are estimated by multiplying each activity, according to its fuel input, by an emission factor.

Activity data are taken from the energy balance (2000-2022) as compiled by the national statistics institute (STATEC), or obtained directly from plant operators. Energy balance data, covering 1990 to 1999, originates from the Ministry of Economic Affairs (Energy Directorate). Customs and Excise Administration provide data on liquid fuels and biofuels which is used for QA/QC purposes. Activity data obtained through the Emission Trading System (ETS) are used for QA/QC procedures by comparing its data to the data reported by the plant operators.

Net calorific values used for conversion of fuel activity data from physical units into energy units were fixed to national values in agreement with national statistics (STATEC) and the "Office Commercial du Ravitaillement" (OCRA) of the Ministry of Economic Affairs.[61] These are mostly country-specific values, however, were no such values were available, defaults from the 2006 IPCC Guidelines or the European Directive on Statistics (2006/32/EC) were used (see Table 3-17). For natural gas, please refer to Table 3-18.

Table 3-17 – Fuel Properties for 2022

Fuel Characteristics for 2022
Country-specific Net Calorific Values and Densities

Fuel	Net calorific value			Density		
	NCV	*Unit*	*Source*	*Density*	*Unit*	*Source*
Anthracite	26.70	GJ/t	*2006 IPCC GL*			
Bituminous Coal & Coking Coal	24.40	GJ/t	*ETS*			
Patent Fuel ("boulets")	28.20	GJ/t	*2006 IPCC GL*			
Brown Coal Briquettes (incl. Lignite dust)	22.20	GJ/t	*ETS*			
Coke Oven Coke	28.50	GJ/t	*EU-2006/32/EC*			
Tires	28.20	GJ/t	*ETS*			
Dry sewage sludge	11.67	GJ/t	*ETS*			
Humid sewage sludge	2.04	GJ/t	*ETS*			
Fluff	23.05	GJ/t	*ETS*			
Waste solvents	20.42	GJ/t	*ETS*			
Residual Fuel Oil (low / high sulphur)	40.00	GJ/t	*EU-2006/32/EC*	0.92 / 0.96	kg/l	*Fuel Providers*
Gas Oil	42.49	GJ/t	*Fuel Providers*	0.85	kg/l	*Fuel Providers*
Diesel Oil	42.49	GJ/t	*Fuel Providers*	0.85	kg/l	*Fuel Providers*
Gasoline	43.05	GJ/t	*Fuel Providers*	0.76	kg/l	*Fuel Providers*
Liquefied Petroleum Gas (LPG)	46.00	GJ/t	*EU-2006/32/EC*	0.53	kg/l	*Fuel Providers*
Aviation Gasoline	43.50	GJ/t	*Fuel Provider*	0.71	kg/l	*Fuel Provider*
Jet Kerosene	43.11	GJ/t	*Fuel Provider*			
Other Kerosene	43.80	GJ/t	*2006 IPCC GL*			
Wood	7.15	GJ/m^3	*Statec*	0.69	t/m^3	*Statec*
Pellets	11.00	GJ/m^3	*Statec*	0.65	t/m^3	*Statec*
Wood chips	7.81	GJ/m^3	*Statec*	0.69	t/m^3	*Statec*
Biogas	0.02	GJ/m^3	*Statec*			
Biodiesel (pure)	39.76	GJ/t	*Fuel Providers*			
Biogasoline (pure)	26.80	GJ/t	*Fuel Providers*			
Lubricants	40.20	GJ/t	*2006 IPCC GL*			
Bitumen	40.20	GJ/t	*2006 IPCC GL*			

Source: Environment Agency

Emission factors are defaults from 2006 IPCC Guidelines for solid (except blast furnace gas) and some liquid fuels and country-specific for natural gas, motor gasoline, gas/diesel oil, and LPG.

61 ARR 2010, § 21

3.2.5.3 Country specific emission factors

Blast Furnace Gas

A country-specific CO_2 emission factor for the combustion of blast furnace gas was determined based on emission measurement data and on the CO and CO_2 contents of blast furnace gas produced in Luxembourg's blast furnaces in 1990.[62] As no further measurements were available until the closure of the blast furnaces in 1997, the same emission factor, *i.e.* 257'181 kg CO_2/TJ, was used for the years 1990 to 1997.

Similarly, a country-specific CO_2 emission factor for blast furnace gas lost in distribution or flared was determined: 245'323 kg CO_2/TJ.

Natural Gas

In Luxembourg, one operator, CREOS S.A. (formerly SOTEG S.A.)[63], operates the national natural gas network (Figure 3-5). There are four entry points, from where natural gas is imported: two with Belgium (Braz and Pétange) with a capacity of 0.16 and 0.06 mio. Nm^3/h, respectively, one with Germany (Remich) with a capacity of 0.19 Mio Nm^3/h and one with France (Esch/Alzette) with a capacity of 0.02 mio. Nm^3/h.

For the calculation of the country-specific CO_2 emission factor for natural gas, the operator provides the following parameters for each entry point and for each month of a given year:

- chemical composition (methane, ethane, propane, i-butane, n-butane, i-pentane, n-pentane, hexane & higher, CO_2 and N_2) expressed in mol%;
- physical properties: density (kg/Nm^3) and gross calorific value (GCV: MJ/Nm^3);
- monthly import/consumption (mio. Nm^3). [64]

The monthly consumption is converted into energy units (TJ) using the respective NCV, which is calculated by multiplying the GCV with a conversion factor of 0.90 [65].

From the monthly chemical composition, a monthly average "molecular" weight for natural gas (g/mol), "molecular" density (mol/Nm^3) and monthly carbon content (mol C/ mol natural gas) are derived for each entry point. The monthly carbon content is then converted into a monthly emission factor (g CO_2/MJ) assuming full oxidation of carbon to carbon dioxide. By multiplying the monthly emission factor with the respective monthly natural gas consumption, a monthly CO_2 emission is obtained. Finally, by dividing the yearly national emissions (sum of the monthly emissions of all 4 entry points) by the yearly national consumption (sum of the monthly consumptions of all 4 entry points), the country-specific emission factor for the respective year is obtained.

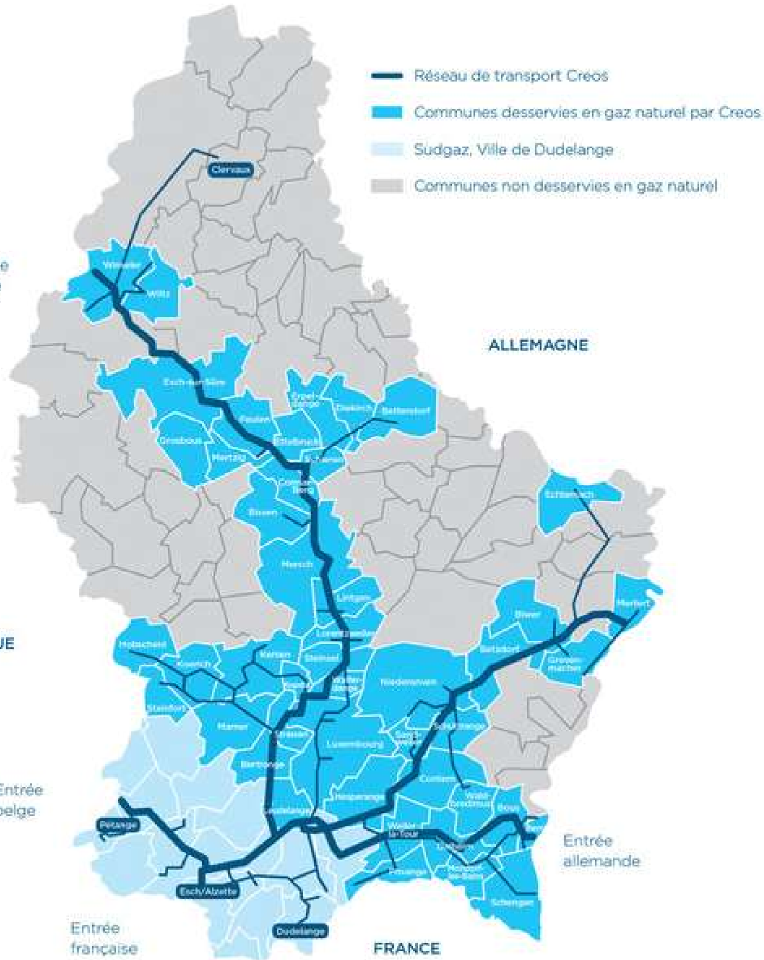
62 TÜV Rheinland, 1990, Bericht: 934/651014.

63 http://www.creos.lu

64 Nm3 is defined at a pressure of 1035 mbar and 0 degree Celsius.

65 IEA Energy Statistics Manual, 2005, Table A3.12, p.183

Figure 3-5 - Natural gas network



Source: Creos (http://www.creos-net.lu/creos-luxembourg/infrastructure/reseau-de-gaz-naturel.html)

Country-specific NCVs and emission factors have, thus, been obtained for the years 1991, 1995, 2000, 2005-2022 (Table 3-18). For the years in-between, the values have been interpolated.

Table 3-18 - Country-specific NCV and Emission Factors for Natural Gas: 1990-2022

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
EF (t CO_2/TJ)	57.76	57.74	57.85	57.89	57.94	57.93	57.55	57.20	56.86	56.52
NCV (MJ/Nm_3)	36.58	36.67	36.62	36.64	36.66	36.75	36.85	36.92	36.99	37.06
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
EF (t CO_2/TJ)	56.22	56.26	56.40	56.53	56.67	56.91	57.01	56.79	56.66	57.06
NCV (MJ/Nm_3)	37.10	37.01	36.96	36.91	36.86	36.85	36.72	36.64	36.48	36.72
Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
EF (t CO_2/TJ)	56.71	56.99	56.79	56.68	56.76	56.76	56.56	56.58	56.21	56.09
NCV (MJ/Nm_3)	36.73	36.56	36.38	36.19	36.30	36.81	36.93	36.98	36.76	36.78
Year	**2020**	**2021**	**2022**							
EF (t CO_2/TJ)	56.48	56.66	56.39							
NCV (MJ/Nm_3)	36.98	37.05	37.39							

Source: Environment Agency

Motor Gasoline, Gas/Diesel Oil, Liquefied Petroleum Gas

In Luxembourg, refined oil products such as motor gasoline, gasoil, diesel oil and liquefied petroleum gas (LPG) are exclusively imported from the neighbouring countries Belgium, the Netherlands and Germany, and to a minor extent from France. As the Luxembourgish association of mineral oil companies (Groupement Pétrolier Luxembourgeois a.s.b.l.) was not able to provide country-specific carbon contents of the before-mentioned fuels to the Environment Agency, country-specific emission factors for motor gasoline, gas/diesel oil and LPG were derived from the emission factors of the corresponding import countries in relation with the yearly quantities imported.[66] Thus, country-specific emission factors have been obtained for the entire time-series (Table 3-19).

66 ARR 2009, § 48

Table 3-19 - Country-specific Emission Factors for Gas/Diesel Oil, Motor Gasoline and LPG: 1990-2022 (tCO_2/TJ)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residual Oil	499.52	499.52	499.52	499.52	499.52	499.52	499.52	499.52	499.52	499.52
Gas Oil	94.06	94.06	94.06	94.06	94.06	94.06	94.06	94.06	94.06	94.06
Diesel Oil	94.06	94.06	94.06	94.06	94.06	94.06	23.52	23.52	23.52	23.52
Motor Gasoline	46.42	46.42	46.42	46.42	46.42	46.42	46.42	46.42	46.42	46.42
LPG	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Residual Oil	499.52	499.52	499.52	499.52	499.52	499.52	499.52	499.52	499.52	499.52
Gas Oil	94.06	94.06	94.06	94.06	94.06	94.06	94.06	94.06	47.03	47.03
Diesel Oil	16.46	11.85	1.55	1.98	2.12	1.50	1.28	1.06	0.83	0.61
Motor Gasoline	46.42	0.84	1.76	2.04	1.44	0.51	0.47	0.43	0.39	0.35
LPG	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Residual Oil	499.52	365.85	374.64	422.10	437.92	469.55	469.55	444.58	365.65	394.62
Gas Oil	45.41	39.90	42.99	42.28	41.26	41.26	1.02	0.83	0.72	0.45
Diesel Oil	0.38	0.34	0.36	0.37	0.31	0.35	0.35	0.33	0.34	0.36
Motor Gasoline	0.31	0.21	0.26	0.23	0.21	0.19	0.19	0.19	0.23	0.21
LPG	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Year	**2020**	**2021**	**2022**							
Residual Oil	449.57	489.53	489.53							
Gas Oil	0.55	0.60	0.67							
Diesel Oil	0.34	0.32	0.36							
Motor Gasoline	0.22	0.18	0.18							
LPG	0.50	0.50	0.50							

Source: Environment Agency

In submission 2012v1.2, Luxembourg's country specific emission factor was revised in accordance with a technical review recommendation during the 2012 technical review of the greenhouse gas emission inventory of Luxembourg to support the determination of annual emission allocations under the European Decision 406/2009/EC. Indeed, the TERT (Technical Expert Review Team) observed that:

"*Luxembourg is using the CO_2 EF value for gasoline used by Belgium that in turn uses the IPCC default value. CO_2 from road transportation is a key category, however the 2000 IPCC Good* Practice Guidance (GPG) states in this respect: 'For traded fuels in common circulation, it is good practice to obtain the carbon content of the fuel and net calorific values from fuel suppliers, and use local values wherever possible. If these data are not available, default values can be used.'

The TERT also notes that the implied EF is at the low end as compared with other Member States (which have country specific data), which could indicate an underestimation of emissions. The TERT also notes that local or country-specific data should be available in Luxembourg and that therefore the use of the default value is not in line with good practice."

In response to this observation and because no data on the carbon content is available in Luxembourg, Luxembourg decided to revise its CO_2 emission factor for motor gasoline, based on the CO_2 emission factor of the two other neighbouring countries from which motor gasoline is imported. Indeed, as the Netherlands and Germany both used a CO_2 EF of 72 tCO_2/TJ at that time, Luxembourg decided to apply the same EF as a country-specific EF for the entire time series, to which the TERT agreed.

Then, during the UNFCCC centralised review in September 2016, the ERT recommended that Luxembourg switches back to the previous approach where a country-specific CO_2 emission factor for gasoline is determined according to the quantities of gasoline imported from the different countries and the respective emission factors used by these countries. This approach is used in this submission for the entire time-series, in all sub-categories to which gasoline is allocated (1A2gvii, 1A3b, 1A3d, 1A4b).

Table 3-20, Table 3-21 and Table 3-22 show the data used for the calculation of the country-specific CO_2 emission factors for gas/diesel oil, motor gasoline and LPG based on imported quantities and emission factors of importing countries. The source for the emission factors of the importing countries is CRF Table1.A(a)s3 from their 2023 submissions to the UNFCCC[67].

67 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2023

Table 3-20 – Calculation of the country-specific CO_2 emission factor for gas/diesel oil based on imported quantities and emission factors of importing countries

Gas/Diesel Oil imports (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Belgium	668	768	774	825	872	829	892	926	1006	1015
Germany	14	11	17	19	15	14	6	7	17	26
Netherlands	91	135	196	109	65	52	80	81	102	93
Total imports	773	914	987	953	952	895	978	1014	1125	1134
Gas/Diesel Oil EF (tCO2/TJ)	(IPCC default EF=74.1)									
Belgium	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24
Germany	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03
Netherlands	73.72	73.72	73.72	73.72	73.72	73.72	73.72	73.55	73.55	73.55
Luxembourg	74.17	74.16	74.13	74.17	74.20	74.20	74.19	74.18	74.17	74.17

Gas/Diesel Oil imports (kt)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Belgium	1260	1329	1389	1391	1624	1715	1689	1542	1586	1574
Germany	42	73	94	228	161	174	158	367	348	201
Netherlands	31	14	8	27	178	245	218	67	133	147
Total imports	1333	1416	1491	1646	1963	2134	2065	1976	2067	1922
Gas/Diesel Oil EF (tCO2/TJ)	(IPCC default EF=74.1)									
Belgium	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24
Germany	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03
Netherlands	73.55	73.55	73.55	73.55	73.55	73.55	73.48	72.73	72.52	72.45
Luxembourg	74.21	74.22	74.22	74.20	74.16	74.14	74.14	74.15	74.09	74.08

Gas/Diesel Oil imports (kt)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	1622	1793	1747	1596	1534	1536	1473	1393.033	1487	1523
Germany	281	190	215	426	288	276	316	496.876	461	410
Netherlands	128	138	90	54	146	77	62	27.444	66	136
Total imports	2031	2121	2052	2076	1968	1889	1851	1917	2013	2069
Gas/Diesel Oil EF (tCO2/TJ)	(IPCC default EF=74.1)									
Belgium	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24
Germany	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03	74.03
Netherlands	73.04	72.69	72.49	72.45	72.45	72.45	72.45	72.45	72.45	72.45
Luxembourg	74.13	74.12	74.14	74.15	74.07	74.13	74.14	74.16	74.13	74.08

Gas/Diesel Oil imports (kt)	2020	2021	2022
Belgium	1244	1275	1093
Germany	382	386	198
Netherlands	39	35	136
Total imports	1666	1696	1428
Gas/Diesel Oil EF (tCO2/TJ)	(IPCC default EF=74.1)		
Belgium	74.24	74.24	74.24
Germany	74.03	74.03	74.03
Netherlands	72.45	72.45	72.45
Luxembourg	74.15	74.15	74.04

Table 3-21 - Calculation of the country-specific CO_2 emission factor for motor gasoline based on imported quantities and emission factors of importing countries

Motor gasoline imports (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Belgium	396	442	398	405	449	426	440	485	482	492
Germany	5	13	33	41	40	28	17	15	16	15
Netherlands	18	22	101	71	67	57	64	49	55	48
Total imports	419	477	532	517	556	511	521	549	553	555
Motor gasoline EF (tCO2/TJ)	(IPCC default EF=69.3)									
Belgium	71.98	72.02	72.02	72.06	72.07	72.09	72.16	72.14	72.18	72.18
Germany	73.07	73.06	73.06	73.06	73.07	73.07	73.08	73.07	73.08	73.09
Netherlands	76.34	76.50	76.65	76.64	76.81	76.80	76.78	76.94	76.94	76.94
Luxembourg	72.18	72.25	72.97	72.77	72.71	72.67	72.76	72.59	72.68	72.62
Motor gasoline imports (kt)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Belgium	545	507	494	515	512	451	400	383	346	348
Germany	25	35	31	16	24	22	31	27	60	23
Netherlands	25	32	29	42	15	21	23	18	1	9
Total imports	595	574	554	573	551	494	454	428	407	380
Motor gasoline EF (tCO2/TJ)	(IPCC default EF=69.3)									
Belgium	72.20	72.22	72.23	72.23	72.25	72.25	72.25	72.26	72.27	72.23
Germany	73.09	73.09	73.09	73.09	73.10	73.10	73.11	73.11	73.12	73.12
Netherlands	76.94	76.94	76.94	76.94	76.94	76.94	76.48	74.72	74.28	73.43
Luxembourg	72.44	72.54	72.52	72.60	72.41	72.49	72.53	72.42	72.40	72.31
Motor gasoline imports (kt)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Belgium	333	338	335	240	221	204	214	209	238	250
Germany	15	8	0	50	70	80	81	94	93	109
Netherlands	0	22	15	27	19	2	0	0	0	0
Total imports	348	368	350	317	310	286	295	303	331	359
Motor gasoline EF (tCO2/TJ)	(IPCC default EF=69.3)									
Belgium	72.23	72.22	72.23	72.24	72.23	72.24	72.25	72.25	72.25	72.27
Germany	73.12	73.02	73.09	73.09	73.09	75.29	75.28	75.29	75.29	75.28
Netherlands	73.43	73.22	73.56	73.39	73.22	73.02	73.02	72.30	72.30	72.20
Luxembourg	72.27	72.29	72.29	72.47	72.49	73.10	73.09	73.19	73.10	73.19

Motor gasoline imports (kt)	2020	2021	2022
Belgium	199	250	262
Germany	81	83	81
Netherlands	0	0	4
Total imports	280	334	347
Motor gasoline EF (tCO2/TJ)	(IPCC default EF=69.3)		
Belgium	72.22	72.26	72.26
Germany	74.95	74.95	74.95
Netherlands	72.20	72.20	72.20
Luxembourg	73.01	72.93	72.88

Table 3-22 - Calculation of the country-specific CO_2 emission factor for LPG based on imported quantities and emission factors of importing countries

LPG imports (kt)	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Belgium	17	16	15	15	14	14	18	24	30	26
Germany	1	2	1	0	0	0	0	0	0	0
Netherlands	1	1	0	0	0	0	0	0	0	6
France	1	1	2	0	0	0	0	0	2	0
Total imports	20	20	18	15	14	14	18	24	32	32
LPG EF (tCO2/TJ)	(IPCC default EF=63.1)									
Belgium	65.48	65.56	65.60	65.64	65.48	65.38	65.32	65.21	65.17	65.17
Germany	65.56	65.56	65.54	65.37	65.33	65.33	65.21	65.21	65.23	64.04
Netherlands	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70
France	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25
Luxembourg	65.54	65.60	65.56	65.64	65.48	65.38	65.32	65.21	65.18	65.45
LPG imports (kt)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Belgium	29	32	24	19	19	16	13	14	14	12
Germany	0	0	0	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0	0	0	0
France	1	1	2	3	1	1	1	0	0	1
Total imports	30	33	26	22	20	17	14	14	14	13
LPG EF (tCO2/TJ)	(IPCC default EF=63.1)									
Belgium	65.21	65.22	65.26	65.27	65.23	65.28	65.27	65.26	65.26	65.22
Germany	64.40	64.51	64.38	64.95	65.26	65.29	65.36	66.61	65.23	65.25
Netherlands	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70
France	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25
Luxembourg	65.22	65.22	65.26	65.27	65.23	65.28	65.27	65.26	65.26	65.22
LPG imports (kt)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Belgium	14	10	12	11	9	9	10	8	6	6
Germany	0	0	0	0	0	0	2	2	2	4
Netherlands	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0
Total imports	14	10	12	11	9	9	12	10	8	10
LPG EF (tCO2/TJ)	(IPCC default EF=63.1)									
Belgium	65.19	65.14	65.11	65.09	65.06	65.02	64.93	64.93	64.93	64.93
Germany	65.33	65.39	65.40	65.41	65.46	66.35	66.33	66.33	66.33	66.33
Netherlands	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70
France	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25
Luxembourg	65.19	65.14	65.11	65.09	65.06	65.02	65.16	65.23	65.21	65.49

LPG imports (kt)	**2020**	**2021**	**2022**
Belgium	5	10	8
Germany	3	0	0
Netherlands	0	0	0
France	0	0	0
Total imports	7	10	8
LPG EF (tCO2/TJ)	(IPCC default EF=63.1)		
Belgium	64.93	64.93	64.93
Germany	66.33	66.33	66.33
Netherlands	66.70	66.70	66.70
France	65.25	65.25	65.25
Luxembourg	65.46	64.96	64.96

3.2.6 Energy Industries (1.A.1): Public Electricity and Heat Production (1.A.1.a)

3.2.6.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in energy industries, which, in Luxembourg, only originate from public electricity and heat production plants. There is neither manufacturing of solid fuels, nor petroleum refining in Luxembourg. Hence, IPCC category *1A1 – Energy Industries* equals IPCC sub-category *1A1a – Public Electricity and Heat Production*.

In this category CO_2, CH_4 and N_2O emissions from combustion activities for electricity and heat production as well as from municipal waste incineration are reported. In Luxembourg, municipal waste is combusted with energy recovery at the sole waste incineration plant (SIDOR) where recovered heat and electricity are distributed to the urban district network. Therefore, the emissions are reported under fuel combustion emissions.

In 2022, this source category was responsible for 3.37% of GHG emissions from fuel combustion activities (0.34% in 1990) and represented 2.83% of the national total GHG emissions in CO_2e, excluding LULUCF (0.27% in 1990.)

Table 3-23 summarizes GHG emissions for category 1.A.1. - Energy Industries. Compared to 2021, GHG emissions have decreased by 11.9%.

Regarding CO_2 emissions, 1A1a - Public electricity and heat production is a key category in 2022 for gaseous fuels and other fuels (MSW): see Table 1-6 in Section 1.4.1.1.

Table 3-23 – GHG emission trends in CO_2eq in category *1A1 – Energy Industries*: 1990-2022

	1A1 - Energy Industries GHG emissions by source & sink category (Gg)											
	1A1a - Public Electricity & Heat Production				1A1b - Petroleum Refining				1A1c - Manuf. of Solid Fuels & Other Energy Ind.			
Year	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\ eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	34.82	32.46	0.037	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1991	36.43	33.96	0.039	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1992	36.33	33.86	0.039	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1993	38.48	36.03	0.039	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1994	41.48	38.98	0.039	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1995	103.76	101.22	0.040	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1996	93.09	91.05	0.032	0.004	NO	NO	NO	NO	NO	NO	NO	NO
1997	105.80	103.30	0.040	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1998	148.31	145.73	0.041	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1999	168.50	165.44	0.048	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2000	117.86	114.83	0.048	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2001	282.93	279.69	0.052	0.007	NO	NO	NO	NO	NO	NO	NO	NO
2002	1 029.23	1 025.31	0.064	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2003	1 033.45	1 029.64	0.063	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2004	1 255.51	1 251.29	0.069	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2005	1 237.29	1 233.39	0.064	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2006	1 299.85	1 295.72	0.068	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2007	1 174.34	1 170.30	0.067	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2008	987.03	983.10	0.064	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2009	1 188.09	1 183.89	0.069	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2010	1 204.58	1 200.52	0.067	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2011	1 011.43	1 007.03	0.072	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2012	1 054.82	1 050.21	0.075	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2013	707.31	702.72	0.074	0.010	NO	NO	NO	NO	NO	NO	NO	NO
2014	679.38	673.93	0.087	0.011	NO	NO	NO	NO	NO	NO	NO	NO
2015	471.48	465.58	0.094	0.012	NO	NO	NO	NO	NO	NO	NO	NO
2016	266.26	260.13	0.097	0.013	NO	NO	NO	NO	NO	NO	NO	NO
2017	256.62	249.53	0.112	0.015	NO	NO	NO	NO	NO	NO	NO	NO
2018	233.26	225.21	0.127	0.017	NO	NO	NO	NO	NO	NO	NO	NO
2019	218.05	210.72	0.116	0.015	NO	NO	NO	NO	NO	NO	NO	NO
2020	215.07	206.70	0.133	0.018	NO	NO	NO	NO	NO	NO	NO	NO
2021	263.55	255.66	0.125	0.017	NO	NO	NO	NO	NO	NO	NO	NO
2022	232.20	224.53	0.121	0.016	NO	NO	NO	NO	NO	NO	NO	NO
Trend 1990-2022	566.83%	591.81%	225.13%	223.45%	NA	NA	NA	NA	NA	NA	NA	NA
Trend 2021-2022	-11.90%	-12.18%	-2.89%	-2.75%	NA	NA	NA	NA	NA	NA	NA	NA

Source: Environment Agency.

Notes: CH_4 emissions are converted in CO_2e by multiplying the emissions by 28, *i.e.* the global warming potential (*GWP*) value for methane based on the effects of GHG over a 100-year time horizon. N_2O emissions are converted in CO_2e by multiplying the emissions by 265, *i.e.* the global warming potential (*GWP*) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

3.2.6.2 Methodological issues

3.2.6.2.1 Activity data

Activity data of the various installations considered in 1A1a:

- combined heat and power (CHP) installations, which have appeared at the beginning of the 1990s. Those installations generally use combustion engines, and they are operated with natural gas and/or gasoil and to a smaller extent with biogas or wood & wood wastes. The activity rates are based on information received from the operators and on the energy balance as compiled by the national statistics institute (STATEC).
- a CHP gas turbine (350MW) running on natural gas and operated since 2002 by Twinerg S.A. Since heat was not recovered from 2002 to 2010, this unit was counted as a thermal power plant and not as a cogeneration plant in official statistics. From 2011 on, however, heat recovery was done and the installation was considered as a cogeneration plant. This classification change has no impact on the GHG emission estimates since it is the fuel(s) used and the technology that matter. The Twinerg plant was shut down during 2016. There are several smaller CHP gas turbines that are operated on industrial sites while producing heat and electricity mainly for the respective industries. Emissions related to these are accounted for in 1A2-Manufacturing Industries and Construction, as these installations are considered as autoproducers.
- one waste incinerator (SIDOR) that is fed with natural gas, gas oil, fluff, and waste (composed of municipal solid waste and bulky waste). The incinerated waste is composed of 14 waste categories: paper/cardboard, textiles, food waste, wood, garden & park waste, nappies, rubber & leather, plastics, multilayer composite material, metal, glass, other inert waste, 0-8 sieve fraction, and 9-40 sieve fraction . The municipal soid waste (MSW) and bulky waste (BW) are provided by the three syndicates SIDEC, SIDOR, and SIGRE. Both SIDOR and SIGRE deliver the waste directly to the incinerator while the waste from SIDEC first undergoes a pre-treatment at a different facility before arriving at the incinerator (some part is not taken to the incinerator after treatment but deposited on land[68]). The waste flow to the incinerator is depicted in Figure 3-6. The sieve fractions mentioned above were added to the twelve previous MSW categories following the recent publication of an extensive study (ECO-Conseil s.à.r.l., "Laboranalytische Untersuchung ausgewählter Sortierfraktionen der landesweiten Restabfallanalyse 2022", Luxembourg, 2022). In fact, the sieve fractions consist of fine waste elements with a size between 0 and 8 mm and between 9 and 40 mm. These waste categories have always been analyzed and documented in Luxembourg's waste analyses but their combustion properties were unknown, which is why their activity data were previously allocated to the waste categories "food waste" and "other, inert waste". With the abovementioned study, their combustion properties (net calorific value, dry matter content, total carbon content, and biogenic carbon fraction) have been identified by laboratory analysis. Hence why these two waste categories were added to the previously twelve categories, which led to a reallocation of the MSW activity data (both biogenic and fossil) across the whole time series. The related changes to the biomass and fossil MSW activity data and greenhouse gas emissions are detailed in section 3.2.6.5.

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68 For the different waste treatment schemes, see Chapter 7 on waste.

Figure 3-6 Waste flow from the three syndicates SIDEC, SIDOR, and SIGRE to the incinerator. The blue lines represent municipal solid waste while the orange lines represent bulky waste. Straight lines represent untreated waste while dotted lines represent treated waste.

No industrial and hazardous wastes are incinerated because they are exported. The MSW, delivered from SIDOR and SIGRE to the incinerator, is split into the fourteen MSW fractions mentioned above according to the following studies. The years for which the studies have been done act as pillar years. For the years in-between, a linear interpolation was carried out.

- ECO-Conseil s.à.r.l., "Restabfallanalyse 1992/1994", Luxembourg, 2002;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2001 im SIDOR", Luxembourg, 2002;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2004/05 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2005;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2009/10 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2010;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2013/14 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2016.
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2018/2019 im Großherzogtum Luxemburg, Endbericht", Luxembourg, 2019;
- ECO-Conseil s.à.r.l., "Nationale Restabfallanalyse 2021/2022 im Großherzogtum Luxemburg", Luxembourg, 2022.

The BW, delivered from SIDOR and SIGRE to the incinerator, is also split into the twelve MSW fractions (i.e. all but the sieve fractions) according to the following studies. The years for which the studies have been done act as pillar years. For the years in-between, a linear interpolation was carried out.

- ECO-Conseil s.à.r.l., "Sperrmüllanalyse 2009 im Großherzogtum“, Luxembourg, 2010.
- ECO-Conseil s.à.r.l., "Sperrmüllanalyse 2015 im Großherzogtum“, Luxembourg, 2016.
- ECO-Conseil s.à.r.l., "Sperrmüllanalyse 2020 im Großherzogtum“, Luxembourg, 2020.

The part of the waste that originates from the pre-treatment plant (MBA Fridhaff), consisting of both MSW and BW, is split into the twelve fractions (i.e. all but the sieve fractions) according to the study

- ECO-Conseil s.à.r.l., "Abschätzung emittierter Klimagase durch die über die MBA Fridhaff abgeschiedene und verbrannte heizwertreiche Fraktion", Luxembourg, 2009

In the following, both MSW and BW are considered as MSW i.e. the label MSW indicates that the total waste has been split into the 14 categories mentioned above. Table 3-24 gives an overview of the energy consumption by fuel type in 1A1a – Public Electricity and Heat Production.

Table 3-24 - Activity data for IPCC sub-category 1A1a – Public Electricity and Heat Production: 1990-2022

1A1a - Public Electricity & Heat Production Activity Data by fuel type (GJ)					
Year	Activity Total (incl. biomass)	Liquid Gas Oil	Gaseous Natural Gas	Biomass Biogas, Wood, Fluff & MSW (bio. fraction)	Other Fluff & MSW (fossil fraction)
1990	1 245 232	NO	NO	916 172	329 059
1991	1 302 864	NO	NO	958 575	344 289
1992	1 316 100	NO	NO	972 806	343 294
1993	1 306 187	NO	NO	935 410	370 777
1994	1 330 484	NO	NO	923 657	406 827
1995	2 366 317	NO	1 043 100	891 878	431 339
1996	2 052 066	900	984 600	699 211	367 355
1997	2 333 909	18 919	1 013 400	825 997	475 594
1998	3 055 356	30 783	1 709 100	809 104	506 368
1999	3 468 726	31 593	1 883 700	927 169	626 264
2000	2 556 891	60 414	920 854	921 527	654 097
2001	5 483 630	55 018	3 808 343	928 835	691 434
2002	18 684 618	48 220	17 031 071	934 387	670 939
2003	18 718 894	46 054	17 102 526	939 592	630 722
2004	22 592 490	46 606	20 850 220	1 016 819	678 845
2005	22 238 796	24 344	20 647 091	982 911	584 450
2006	23 326 024	24 981	21 624 432	1 043 724	632 887
2007	21 243 684	23 409	19 508 383	1 082 681	629 211
2008	18 027 496	49 325	16 205 838	1 138 134	634 200
2009	21 466 425	76 261	19 534 163	1 194 170	661 832
2010	21 957 495	19 416	20 082 942	1 223 237	631 901
2011	18 512 240	18 530	16 344 441	1 360 114	789 155
2012	19 356 558	19 756	17 071 478	1 408 597	856 727
2013	13 305 935	15 040	10 853 489	1 487 571	949 834
2014	13 363 992	13 595	10 369 609	2 054 402	926 386
2015	9 891 252	18 944	6 533 034	2 351 666	987 608
2016	6 344 624	32 034	2 687 859	2 494 471	1 130 260
2017	6 659 719	23 553	2 496 982	2 998 002	1 141 181
2018	6 806 000	17 868	2 090 227	3 563 510	1 134 395
2019	6 140 996	17 469	1 801 657	3 169 793	1 152 077
2020	6 734 421	11 324	1 878 222	3 785 195	1 059 680
2021	7 397 806	5 040	2 752 847	3 579 986	1 059 933
2022	6 669 829	28 503	2 116 932	3 400 642	1 123 751
Trend 1990-2022	435.63%	NA	NA	271.18%	241.50%
Trend 2021-2022	-9.84%	465.50%	-23.10%	-5.01%	6.02%

Source: Environment Agency.

3.2.6.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for biomass burning (biogas & wood and wood wastes), except for the biogenic fraction of MSW. For natural gas, gas oil, and fluff the methodological approach is classified as Tier 2 methodology as country-specific emission factors were used.

For waste incineration, the IPCC methodology Tier 2a (2006 IPCC Guidelines) has been applied. For MSW, it is good practice to calculate CO_2 emissions on the basis of waste fractions (such as paper, wood, plastics) in the waste incinerated, as the following equation shows:

$$CO_2\ emissions = MSW \bullet \sum_j (WF_j \bullet dm_j \bullet CF_j \bullet FCF_j \bullet OF_j) \bullet \frac{44}{12}$$

with:

CO_2 emissions	=	CO_2 emissions in inventory year (Gg/yr)
MSW	=	total amount of municipal solid waste as wet weight incinerated or open-burned (Gg/yr)
WF_j	=	fraction of waste type/material of component j in the MSW (as wet weight incinerated or open-burned)
dm_j	=	dry matter content in the component j of the MSW incinerated or open-burned (fraction)
CF_j	=	fraction of carbon in the dry matter (i.e., carbon content) of component j
FCF_j	=	fraction of fossil carbon in the total carbon of component j
OF_j	=	oxidation factor (fraction)
44/12	=	molecular weight ratio MCO2(g/mol)/MC(g/mol)

with:

$$\sum_j WF_j = 1$$

j = component of the MSW incinerated such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

IPCC default values for CF_j, FCF_j and OF_j were taken[69]. For the dm_j of the MSW from SIDOR and SIGRE, the IPCC default values were taken. For the treated MSW from SIDEC, the dm_j were taken from the study (ECO-Conseil s.à.r.l., 2009) and are compiled in Table 3-25. For the sieve fractions, the values were extracted from the laboratory analysis (ECO-Conseil s.à.r.l., 2022) and amount to 58.13% for the 0-8 mm fraction and 43.60% for the 9-40 mm fraction.

Table 3-25 – Dry matter content in % of wet weight i.e. ratio of dry matter to wet matter.

MSW component	Dry matter content [%]	MSW component	Dry matter content [%]
Paper/cardboard	76.67	Rubber and Leather	95.00
Textiles	76.00	Multilayer composite material	98.46
Food waste	25.00	Plastics	95.78
Wood	94.95	Metal	98.71
Garden and Park waste	25.00	Glass	99.01
Nappies	46.67	Other, Inert waste	87.49

Reported CO_2 emissions of waste incineration are only CO_2 emissions from fossil MSW. However, the activity data includes both biogenic and fossil MSW fractions. This means that biogenic CO_2 emissions are reported under Memo Items.

Calorific values used for conversion of fuel activity data from tonnes into GJ are country-specific and derive from the studies commissioned by the Environment Agency (see Table 3-26) (ECO-Conseil s.à.r.l., Restabfallanalyse 2009/10 im Großherzogtum Luxemburg, Band 1: Kompendium, 2010) (ECO-Conseil s.à.r.l., 2014) (ECO-Conseil s.à.r.l., 2019). The years 2009 and 2014 act as pillar

69 2006 IPCC Guidelines, Vol. 5, Chap. 2, Tab. 2.4, p2.14

years for the net calorific value of the multilayer composite material. The NCVs for the years in-between were computed through a linear interpolation. The NCVs of the remaining 13 MSW categories remained constant according to the studies.

Table 3-26 – Net calorific values for MSW components in units of GJ/t.

Year	Paper	Textiles	Food waste	Wood	Garden and park waste	Nappies	Rubber and leather	Multilayer composite material	Plastics	Metal	Glass	Other, intert waste	0-8 sieve fraction	9-40 sieve fraction
1990-2009	13.00	13.00	5.00	5.00	5.00	10.00	5.00	15.00	30.00	0.00	0.00	7.00	8.10	15.17
2010	13.00	13.00	5.00	5.00	5.00	10.00	5.00	15.80	30.00	0.00	0.00	7.00	8.10	15.17
2011	13.00	13.00	5.00	5.00	5.00	10.00	5.00	16.60	30.00	0.00	0.00	7.00	8.10	15.17
2012	13.00	13.00	5.00	5.00	5.00	10.00	5.00	17.40	30.00	0.00	0.00	7.00	8.10	15.17
2013	13.00	13.00	5.00	5.00	5.00	10.00	5.00	18.20	30.00	0.00	0.00	7.00	8.10	15.17
2014-2022	13.00	13.00	5.00	5.00	5.00	10.00	5.00	19.00	30.00	0.00	0.00	7.00	8.10	15.17

CH_4 emissions were estimated using the 2006 IPCC Guidelines Tier 1 methodology. CH_4 emissions from incineration of waste are a result of incomplete combustion. Important factors affecting the emissions are temperature, residence time, and air ratio (i.e., air volume in relation to the waste amount). CH_4 emissions are calculated according to the following equation:

$$CH_4 \text{ Emissions} = \text{Fuel Consumption}_{MSW} \bullet \text{Emission Factor}_{MSW}$$

with:

CH_4 Emissions = CH_4 emissions (kg GHG)

Fuel Consumption_{MSW} = amount of incinerated MSW (TJ)

Emission Factor_{MSW} = emission factor (kg gas/TJ)

The CH_4 emissions are relative to the total MSW (biogenic + fossil).

Nitrous oxide is emitted in combustion processes at relatively low combustion temperatures between 500 and 950°C. Other important factors affecting the emissions are the type of air pollution control device, nitrogen type and content of the waste and the fraction of excess air. The N_2O emissions are calculated according to the following equation:

$$N_2O\ emission = \sum_j (IW_j \bullet EF_j) \bullet 10^{-6}$$

with:

N_2O Emissions = N_2O emissions in inventory year (Gg/yr)

IW_i = amount of incinerated waste of type i (Gg/yr)

EF_i = N_2O emission factor (kg N_2O /Gg of waste) for waste of type i

10^{-6} = conversion from kilogram to gigagram

i = category or type of waste incinerated (MSW)

The N_2O emissions are relative to the total MSW (biogenic + fossil).

3.2.6.2.3 Emission factors

Default emission factors are derived from the IPCC 2006 Guidelines (Table 3-27). Country-specific emission factors were determined by the Environment Agency and were calculated from specific data accessible to the Environment Agency (see section 3.2.5.3).

For MSW, CO_2 emissions were not calculated using an emission factor, but instead, the calculation is based on the carbon content of the waste. CO_2 emissions are calculated, as described in section 3.2.6.2.2, by applying the default values listed in Table 2.4 of the 2006 IPCC Guidelines for:

- dry matter content in % of wet weight;
- total carbon content in % of dry weight;
- fossil carbon fraction in % of total carbon.

For CO_2, implied emission factors (IEFs) for the different waste components were calculated by dividing the calculated emissions by the energy content of the MSW waste fraction.

For CH_4, it is good practice to apply the CH_4 emission factors provided in Volume 2, Chapter 2 of the 2006 IPCC Guidelines. The CH_4 default emission factor of 30 kg CH_4/TJ is applied.

For N_2O, the default emission factor of 4.0 kg N_2O/TJ is applied. However, this emission factor might be revised in one of the next submissions, as the 2006 IPCC guidelines recommend to use an EF of 50 g N_2O/t MSW on a wet basis (2006 IPCC Guidelines Vol.5, Chap.5, Table 5.6).

Table 3-27 gives an overview of the different emission factors used for 2022.

Table 3-27 – Emission factors for IPCC sub-category 1A1a – Public Electricity and Heat Production

1A1a - Public Electricity & Heat Production Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 037	CS	3.00	D	0.60	D	AEV, 2006 IPCC GL
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV, 2006 IPCC GL
Biogas	biomass	54 600	D	1.00	D	0.10	D	2006 IPCC GL
Wood & wood wastes	biomass	112 000	D	30.00	D	4.00	D	2006 IPCC GL
Fluff	other/biomass	83 629	CS	30.00	D	4.00	D	ETS, 2006 IPCC GL
MSW	other/biomass	94 183	IEF	30.00	D	4.00	D	AEV, 2006 IPCC GL

Source: Environment Agency.
Notes: IEFs and CS EFs were determined by the Environment Agency.

Table 3-28 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-28 – Implied emission factors for IPCC sub-category 1A1a – Public Electricity and Heat Production

1A1a - Public Electricity & Heat Production Implied Emission Factors (kg/TJ)												
Year	Liquid Gas Oil			Gaseous Natural Gas			Biomass Biogas, Wood, Fluff & MSW (bio. fraction)			Other Fluff & MSW (fossil fraction)		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	NO	NO	NO	NO	NO	NO	98 631	30.00	4.00	98 631	30.00	4.00
1991	NO	NO	NO	NO	NO	NO	98 631	30.00	4.00	98 631	30.00	4.00
1992	NO	NO	NO	NO	NO	NO	97 862	29.49	3.93	98 631	30.00	4.00
1993	NO	NO	NO	NO	NO	NO	96 395	29.47	3.93	97 168	30.00	4.00
1994	NO	NO	NO	NO	NO	NO	95 063	29.47	3.93	95 822	30.00	4.00
1995	NO	NO	NO	57 929	1.00	0.10	93 726	29.38	3.92	94 578	30.00	4.00
1996	74 192	3.00	0.60	57 546	1.00	0.10	92 371	29.21	3.89	93 426	30.00	4.00
1997	74 179	3.00	0.60	57 205	1.00	0.10	91 670	29.47	3.93	92 355	30.00	4.00
1998	74 170	3.00	0.60	56 863	1.00	0.10	90 927	29.66	3.95	91 358	30.00	4.00
1999	74 174	3.00	0.60	56 522	1.00	0.10	90 343	29.87	3.98	90 427	30.00	4.00
2000	74 213	3.00	0.60	56 221	1.00	0.10	88 960	29.41	3.92	89 556	30.00	4.00
2001	74 218	3.00	0.60	56 258	1.00	0.10	87 614	28.94	3.86	88 739	30.00	4.00
2002	74 219	3.00	0.60	56 396	1.00	0.10	89 997	28.83	3.84	91 298	30.00	4.00
2003	74 195	3.00	0.60	56 533	1.00	0.10	91 872	28.07	3.74	94 105	30.00	4.00
2004	74 156	3.00	0.60	56 671	1.00	0.10	94 345	27.60	3.68	97 560	30.00	4.00
2005	74 140	3.00	0.60	56 910	1.00	0.10	92 667	26.68	3.55	96 780	30.00	4.00
2006	74 140	3.00	0.60	57 008	1.00	0.10	91 869	26.25	3.50	96 535	30.00	4.00
2007	74 146	3.00	0.60	56 793	1.00	0.10	91 401	25.94	3.45	96 344	30.00	4.00
2008	74 090	3.00	0.60	56 665	1.00	0.10	90 798	25.38	3.38	96 410	30.00	4.00
2009	74 077	3.00	0.60	57 056	1.00	0.10	89 809	24.64	3.28	96 241	30.00	4.00
2010	74 131	3.00	0.60	56 712	1.00	0.10	86 355	22.76	3.03	95 180	30.00	4.00
2011	74 116	3.00	0.60	56 988	1.00	0.10	86 450	23.31	3.10	94 046	30.00	4.00
2012	74 137	3.00	0.60	56 793	1.00	0.10	85 029	23.02	3.06	92 455	30.00	4.00
2013	74 146	3.00	0.60	56 680	1.00	0.10	85 127	23.34	3.10	90 987	30.00	4.00
2014	74 073	3.00	0.60	56 756	1.00	0.10	90 345	23.97	3.19	91 095	30.00	4.00
2015	74 132	3.00	0.60	56 760	1.00	0.10	92 993	24.59	3.27	94 534	30.00	4.00
2016	74 140	3.00	0.60	56 561	1.00	0.10	92 171	24.21	3.22	93 546	30.00	4.00
2017	74 156	3.00	0.60	56 577	1.00	0.10	95 583	25.19	3.35	93 333	30.00	4.00
2018	74 130	3.00	0.60	56 209	1.00	0.10	97 642	25.61	3.41	93 790	30.00	4.00
2019	74 077	3.00	0.60	56 091	1.00	0.10	95 748	25.09	3.34	94 066	30.00	4.00
2020	74 145	3.00	0.60	56 482	1.00	0.10	99 057	26.12	3.48	94 154	30.00	4.00
2021	74 151	3.00	0.60	56 664	1.00	0.10	96 807	25.28	3.37	93 685	30.00	4.00
2022	74 037	3.00	0.60	56 386	1.00	0.10	95 578	25.16	3.35	91 706	30.00	4.00

Source: Environment Agency.

The unique trend of the CO_2 implied emission factor for other fuels, which is composed of the fossil fraction of incinerated fluff and MSW and as reported in

Table 3-28, is due to the varying composition of the fossil fraction over time. Indeed, as explained in section 3.2.6.2.1, the composition of the waste fraction is based on several waste analyses. The years for which the studies were done act as pillar years that fix the waste fractions. The waste fractions for the years in-between are calculated through a simple linear interpolation. In addition, since 2002, a high calorific fraction of treated waste, composed of mainly plastics, textiles, rubbers and other waste, also influences the composition of incinerated waste as this high calorific fraction is co-incinerated with the untreated MSW. Hence, the changes in the CO_2 IEF between specific years correspond to the breaks in the composition of incinerated waste.

3.2.6.3 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category 1A1 – Energy Industries are presented in Table 3-29.

Table 3-29 - Uncertainties for activity data and emission factors used for IPCC category 1A1 – Energy Industries.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A1 - Gaseous Fuels	CO_2	2%	0.5%
1A1 - Gaseous Fuels	CH_4	2%	50%
1A1 - Gaseous Fuels	N_2O	2%	50%
1A1 - Liquid Fuels	CO_2	2%	0.5%
1A1 - Liquid Fuels	CH_4	2%	50%
1A1 - Liquid Fuels	N_2O	2%	50%
1A1 - Other Fuels	CO_2	8%	20%
1A1 - Other Fuels	CH_4	8%	50%
1A1 - Other Fuels	N_2O	8%	50%
1A1 - Biomass	CH_4	7%	50%
1A1 - Biomass	N_2O	7%	60%
1A1 – Solid fuels	CO_2	1%	3%
1A1 – Solid fuels	CH_4	1%	50%
1A1 – Solid fuels	N_2O	1%	50%

The time-series are considered to be consistent with the data reported in the national energy balance.

The annual fluctuations in fuel consumption, especially for natural gas, and the resulting fluctuations of GHG emissions, are explained by the fluctuations of electricity and heat production levels of the plants covering the sector. Indeed, a sharp increase in the natural gas consumption was observed in 2002, with the operational start of a 350 MW gas turbine (Twinerg). Occasional maintenance stops of the 350 MW gas turbine in the years following the operational start (e.g. 2009, 2011) have greatly influenced the energy demand of this category. Since 2013, the electricity production level by the Twinerg gas turbine had been at a relatively low level (due to relatively low electricity prices), and the plant was finally shut down in 2016.

In addition, rotation of the gas oil stocks (used as emergency fuel) can cause fluctuations in the GHG emissions. This was the case in 2008-2009. The dip of fossil MSW incineration in 1996 was due to a fire in the incineration plant, followed by a shut-down for several months. Moreover, since 2015 the incineration plant has added fluff (both fossil and biogenic) to its list of burned materials which adds to the total amount of GHG emissions.

3.2.6.4 Source-specific QA/QC and verification

Activity data for large facilities that are under the European Union Emission Trading Scheme (EU-ETS) are cross-checked from two sources: reports obtained directly from the operator under its operational permit obligations and the EU-ETS registry operator. Both are hosted at the Environment Agency. A list with the large energy consuming facilities along with their respective fuel consumption has been compiled and enables the Single National Entity to quickly cross-check these data with the EU-ETS data. Thus, completeness can be checked on a more systematic basis.

Additionally, cross checks with other relevant sectors, mainly 5 – Waste, are performed to avoid double counting.

Finally, consistency and completeness checks are performed using the tools embedded in CRF Reporter.

3.2.6.5 Category-specific recalculations including changes made in response to the review process

Table 3-30 presents the main revisions and recalculations relevant to category 1A1a - Public Electricity and Heat Production done since the last submission. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 3-30 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
1A1a	Revision of the natural gas and biogas activity data due to changes in the national energy balance for 2021 (+733 TJ for natural gas compared to the previous submission and +62 TJ for biogas compared to the previous submission). As a result, greenhouse gas emissions in the 1A1a sector increased by 41.6 Gg CO_2 eq. for 2021 in this submission.	AD
1A1a	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-6} Gg CO_2 for any given year).	CO_2 EF

Table 3-31 shows the effect of all the recalculations listed in Table 3-30 on the total activity data and GHG emissions for the entire time.

Table 3-31 – Effect of the recalculations in 1A1 – Energy industries on the activity data and GHG emissions (CO_2 emissions from biomass are excluded) between submissions 2023v1 and 2024v1 for the entire time series.

1A1 - Energy industries Activity data (AD) of all fuels and related GHG emissions (in Gg CO_2 eq.)						
Year	Submission 2023v1		Submission 2024v1		Difference	
	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.
1990	1 245.23	34.82	1 245.23	34.82	0.00	0.00
1991	1 302.86	36.43	1 302.86	36.43	0.00	0.00
1992	1 316.10	36.33	1 316.10	36.33	0.00	0.00
1993	1 306.19	38.48	1 306.19	38.48	0.00	0.00
1994	1 330.48	41.48	1 330.48	41.48	0.00	0.00
1995	2 366.32	103.76	2 366.32	103.76	0.00	0.00
1996	2 052.07	93.09	2 052.07	93.09	0.00	0.00
1997	2 333.91	105.80	2 333.91	105.80	0.00	0.00
1998	3 055.36	148.31	3 055.36	148.31	0.00	0.00
1999	3 468.73	168.50	3 468.73	168.50	0.00	0.00
2000	2 556.89	117.86	2 556.89	117.86	0.00	0.00
2001	5 483.63	282.93	5 483.63	282.93	0.00	0.00
2002	18 684.62	1 029.23	18 684.62	1 029.23	0.00	0.00
2003	18 718.89	1 033.45	18 718.89	1 033.45	0.00	0.00
2004	22 592.49	1 255.51	22 592.49	1 255.51	0.00	0.00
2005	22 238.80	1 237.29	22 238.80	1 237.29	0.00	0.00
2006	23 326.02	1 299.85	23 326.02	1 299.85	0.00	0.00
2007	21 243.68	1 174.34	21 243.68	1 174.34	0.00	0.00
2008	18 027.50	987.03	18 027.50	987.03	0.00	0.00
2009	21 466.43	1 188.09	21 466.43	1 188.09	0.00	0.00
2010	21 957.49	1 204.58	21 957.49	1 204.58	0.00	0.00
2011	18 512.24	1 011.43	18 512.24	1 011.43	0.00	0.00
2012	19 356.56	1 054.82	19 356.56	1 054.82	0.00	0.00
2013	13 305.93	707.31	13 305.93	707.31	0.00	0.00
2014	13 363.99	679.38	13 363.99	679.38	0.00	0.00
2015	9 891.25	471.48	9 891.25	471.48	0.00	0.00
2016	6 344.62	266.26	6 344.62	266.26	0.00	0.00
2017	6 659.72	256.62	6 659.72	256.62	0.00	0.00
2018	6 806.00	233.26	6 806.00	233.26	0.00	0.00
2019	6 141.00	218.05	6 141.00	218.05	0.00	0.00
2020	6 734.42	215.07	6 734.42	215.07	0.00	0.00
2021	6 603.22	222.00	7 397.81	263.55	794.58	41.55

Source: Environment Agency.

3.2.6.6 Category-specific planned improvements including those in response to the review process

Table 3-32 presents the category-specific planned improvements relevant to category 1A1a - Public Electricity and Heat Production done since the last submission.

Table 3-32 – Planned improvements for category 1.A.1. – Energy Industries

GHG source & sink category	Planned improvement
1A1a - Public Electricity and Heat Production	No planned improvements

3.2.7 Manufacturing Industries and Construction (1.A.2)

3.2.7.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in manufacturing industries and construction.

This GHG emission inventory includes emissions from categories 1A2a – Iron and Steel, 1A2b – Non-Ferrous Metals, 1A2c – Chemicals, 1A2d – Pulp, Paper and Print, 1A2e – Food Processing, Beverages and Tobacco, 1A2f – Non-metallic minerals and 1A2g – Other.

In 2022, category 1A2 - Manufacturing Industries and Construction was responsible for 14.72% of GHG emissions from fuel combustion activities (60.80% in 1990) and represented 12.37% of the total GHG emissions of Luxembourg, excluding LULUCF (49.07% in 1990). Compared to 2021, emissions of 1A2 decreased by 14.07 % due to reduced energy consumption as a consequence of high global energy prices and national energy saving efforts.

Table 3-33 summarizes GHG emissions for 1A2 – Manufacturing Industries and Construction and the relevant sub-categories.

Regarding CO_2 emissions, 1A2 – Manufacturing Industries and Construction is a key category, in 2022 for gaseous, liquid, solid and other fuels. It has been a key category for gaseous, liquid and solid fuels from 1990 onwards: see Table 3-6 in Section 3.2.

Table 3-33 – GHG emission trends in Gg for IPCC sub-category 1A2 – Fuel Combustion Activities – Manufacturing Industries and Construction: 1990-2022

Year	1A2 - Manufacturing Industries & Construction GHG emissions by source & sink category (Gg)															
	1A2a - Iron & Steel				1A2b - Non-Ferrous Metals				1A2c - Chemicals				1A2d - Pulp, Paper & Print			
	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O
1990	5 399.80	5 392.73	0.109	0.015	28.50	28.47	0.0005	0.0000	170.24	169.83	0.005	0.001	NO	IE	IE	IE
1991	5 139.28	5 132.48	0.104	0.015	29.56	29.53	0.0005	0.0000	186.67	186.15	0.007	0.001	NO	IE	IE	IE
1992	4 743.25	4 736.91	0.096	0.014	29.83	29.80	0.0005	0.0000	173.92	173.51	0.005	0.001	NO	IE	IE	IE
1993	4 906.01	4 899.23	0.103	0.015	29.31	29.28	0.0005	0.0000	181.31	180.87	0.006	0.001	NO	IE	IE	IE
1994	4 052.40	4 046.75	0.086	0.012	35.61	35.58	0.0006	0.0001	200.58	200.13	0.006	0.001	NO	IE	IE	IE
1995	2 300.32	2 297.21	0.048	0.007	36.77	36.74	0.0006	0.0001	193.92	193.59	0.005	0.001	NO	IE	IE	IE
1996	2 083.88	2 081.03	0.044	0.006	59.11	59.05	0.0010	0.0001	195.42	195.09	0.005	0.001	NO	IE	IE	IE
1997	1 317.33	1 315.57	0.028	0.004	41.95	41.91	0.0007	0.0001	185.30	185.03	0.004	0.001	NO	IE	IE	IE
1998	291.26	290.94	0.006	0.001	43.82	43.78	0.0008	0.0001	181.79	181.61	0.003	0.000	NO	IE	IE	IE
1999	310.81	310.48	0.006	0.001	42.67	42.63	0.0007	0.0001	174.21	174.03	0.003	0.000	NO	IE	IE	IE
2000	305.97	305.67	0.005	0.001	41.48	41.44	0.0007	0.0001	191.65	191.47	0.003	0.000	11.42	11.41	0.0002	0.0000
2001	365.11	364.76	0.006	0.001	42.07	42.03	0.0007	0.0001	198.93	198.74	0.004	0.000	13.34	13.32	0.0002	0.0000
2002	350.13	349.79	0.006	0.001	40.36	40.32	0.0007	0.0001	199.24	199.04	0.004	0.000	16.99	16.98	0.0003	0.0000
2003	346.84	346.50	0.006	0.001	46.30	46.26	0.0008	0.0001	212.54	212.33	0.004	0.000	20.40	20.38	0.0004	0.0000
2004	374.56	374.20	0.007	0.001	52.65	52.60	0.0009	0.0001	217.20	216.99	0.004	0.000	17.55	17.53	0.0003	0.0000
2005	371.84	371.49	0.007	0.001	58.39	58.33	0.0010	0.0001	216.96	216.76	0.004	0.000	17.56	17.54	0.0003	0.0000
2006	436.52	436.10	0.008	0.001	61.28	61.22	0.0011	0.0001	212.09	211.89	0.004	0.000	11.02	11.01	0.0002	0.0000
2007	418.01	417.61	0.007	0.001	57.10	57.04	0.0010	0.0001	188.01	187.83	0.003	0.000	7.07	7.07	0.0001	0.0000
2008	399.78	399.40	0.007	0.001	55.54	55.49	0.0010	0.0001	187.93	187.75	0.003	0.000	9.84	9.83	0.0002	0.0000
2009	327.06	326.74	0.006	0.001	48.97	48.92	0.0009	0.0001	141.63	141.50	0.002	0.000	7.78	7.78	0.0001	0.0000
2010	373.41	373.05	0.007	0.001	56.03	55.98	0.0010	0.0001	165.56	165.40	0.003	0.000	4.98	4.98	0.0001	0.0000
2011	329.02	328.70	0.006	0.001	53.81	53.76	0.0009	0.0001	217.67	217.46	0.004	0.000	7.21	7.20	0.0001	0.0000
2012	296.55	296.27	0.005	0.001	54.50	54.45	0.0010	0.0001	203.17	202.97	0.004	0.000	9.39	9.38	0.0002	0.0000
2013	273.13	272.87	0.005	0.000	53.26	53.21	0.0009	0.0001	211.61	211.41	0.004	0.000	11.93	11.92	0.0002	0.0000
2014	271.90	271.64	0.005	0.000	51.52	51.47	0.0009	0.0001	169.81	169.64	0.003	0.000	5.78	5.77	0.0001	0.0000
2015	276.45	276.19	0.005	0.000	49.83	49.78	0.0009	0.0001	138.25	138.11	0.002	0.000	5.40	5.39	0.0001	0.0000
2016	267.51	267.25	0.005	0.000	50.74	50.69	0.0009	0.0001	147.26	147.12	0.003	0.000	5.25	5.24	0.0001	0.0000
2017	266.62	266.37	0.005	0.000	53.87	53.82	0.0010	0.0001	131.60	131.48	0.002	0.000	4.94	4.94	0.0001	0.0000
2018	307.45	307.15	0.005	0.001	51.52	51.47	0.0009	0.0001	119.87	119.76	0.002	0.000	1.27	1.27	0.0000	0.0000
2019	294.16	293.88	0.005	0.001	47.50	47.45	0.0008	0.0001	116.71	116.60	0.002	0.000	1.89	1.88	0.0000	0.0000
2020	266.50	266.24	0.005	0.000	43.16	43.11	0.0008	0.0001	110.65	110.54	0.002	0.000	0.40	0.40	0.0000	0.0000
2021	275.89	275.62	0.005	0.000	48.79	48.74	0.0009	0.0001	122.12	122.01	0.002	0.000	13.84	13.82	0.0002	0.0000
2022	231.70	231.48	0.004	0.000	47.64	47.59	0.0008	0.0001	109.68	109.56	0.002	0.000	8.35	8.35	0.0001	0.0000
Trend 1990-2022	-95.71%	-95.71%	-96.22%	-97.30%	67.16%	67.15%	82.69%	82.69%	-35.58%	-35.49%	-62.55%	-78.07%	NA	NA	NA	NA
Trend 2021-2022	-16.02%	-16.02%	-15.60%	-15.60%	-2.36%	-2.36%	-1.87%	-1.87%	-10.19%	-10.20%	-6.48%	-0.65%	-39.62%	-39.62%	-39.32%	-39.32%

1A2 - Manufacturing Industries & Construction GHG emissions by source & sink category (Gg)																
Year	1A2e - Food Processing, Beverages & Tobacco				1A2f - Non-Metallic Minerals				1A2g - Other				1A2 - Manufacturing Industries & Construction			
	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	5.45	5.44	0.000	0.000	539.06	536.58	0.0372	0.0054	101.44	96.29	0.005	0.019	6 244.49	6 229.34	0.1569	0.0406
1991	7.28	7.26	0.000	0.000	476.33	474.08	0.0337	0.0049	234.04	228.07	0.008	0.022	6 073.15	6 057.60	0.1524	0.0426
1992	7.05	7.04	0.000	0.000	515.37	512.86	0.0376	0.0055	255.26	248.80	0.008	0.024	5 724.68	5 708.92	0.1483	0.0438
1993	6.44	6.43	0.000	0.000	464.13	462.00	0.0320	0.0047	276.25	269.27	0.008	0.025	5 863.45	5 847.07	0.1500	0.0459
1994	6.72	6.71	0.000	0.000	564.57	561.77	0.0420	0.0062	286.82	279.32	0.010	0.027	5 146.70	5 130.26	0.1446	0.0467
1995	7.55	7.54	0.000	0.000	489.88	487.64	0.0337	0.0049	261.25	253.26	0.008	0.029	3 289.69	3 275.98	0.0954	0.0417
1996	6.74	6.74	0.000	0.000	518.74	516.29	0.0367	0.0054	267.89	259.99	0.009	0.029	3 131.78	3 118.19	0.0959	0.0412
1997	7.05	7.04	0.000	0.000	475.92	473.75	0.0326	0.0047	335.44	326.90	0.010	0.031	2 362.98	2 350.20	0.0749	0.0403
1998	7.39	7.38	0.000	0.000	441.78	439.45	0.0354	0.0051	347.69	338.82	0.010	0.032	1 313.73	1 301.98	0.0547	0.0386
1999	8.16	8.15	0.000	0.000	481.02	478.58	0.0371	0.0053	388.37	378.52	0.011	0.036	1 405.24	1 392.38	0.0577	0.0424
2000	18.93	18.91	0.000	0.000	523.41	520.56	0.0432	0.0062	250.60	240.21	0.009	0.038	1 343.45	1 329.67	0.0620	0.0455
2001	23.25	23.22	0.000	0.000	540.94	537.51	0.0525	0.0074	242.32	231.62	0.008	0.040	1 425.96	1 411.20	0.0719	0.0481
2002	25.79	25.76	0.001	0.000	446.56	443.61	0.0457	0.0063	241.58	230.16	0.007	0.042	1 320.66	1 305.67	0.0644	0.0498
2003	15.48	15.46	0.000	0.000	386.15	383.49	0.0412	0.0057	245.99	234.71	0.007	0.042	1 273.70	1 259.13	0.0596	0.0487
2004	14.17	14.15	0.000	0.000	438.58	435.53	0.0471	0.0065	248.67	237.59	0.007	0.041	1 363.38	1 348.59	0.0657	0.0489
2005	15.11	15.09	0.000	0.000	452.72	449.57	0.0487	0.0068	240.94	228.94	0.033	0.042	1 373.52	1 357.71	0.0941	0.0497
2006	13.11	13.09	0.000	0.000	490.79	487.25	0.0545	0.0076	248.01	236.38	0.031	0.041	1 472.82	1 456.94	0.0987	0.0495
2007	12.81	12.79	0.000	0.000	439.14	435.91	0.0500	0.0069	264.05	252.28	0.033	0.041	1 386.19	1 370.53	0.0951	0.0491
2008	13.96	13.94	0.000	0.000	424.42	421.26	0.0492	0.0068	247.49	237.48	0.034	0.034	1 338.97	1 325.14	0.0949	0.0422
2009	14.70	14.68	0.000	0.000	428.02	425.16	0.0442	0.0061	243.32	233.99	0.027	0.032	1 211.49	1 198.77	0.0808	0.0395
2010	12.41	12.39	0.000	0.000	412.79	409.64	0.0489	0.0067	244.94	235.82	0.030	0.031	1 270.12	1 257.26	0.0903	0.0390
2011	17.86	17.84	0.000	0.000	414.18	411.14	0.0471	0.0065	254.61	245.98	0.028	0.030	1 294.36	1 282.09	0.0858	0.0372
2012	15.17	15.14	0.000	0.000	403.27	400.24	0.0469	0.0064	264.64	256.39	0.025	0.029	1 246.68	1 234.85	0.0818	0.0360
2013	15.41	15.39	0.000	0.000	358.38	355.24	0.0488	0.0067	276.18	267.93	0.026	0.028	1 199.91	1 187.96	0.0846	0.0362
2014	20.94	20.91	0.000	0.000	386.22	383.19	0.0470	0.0065	274.81	266.32	0.030	0.029	1 180.97	1 168.94	0.0858	0.0363
2015	17.67	17.64	0.000	0.000	379.58	376.65	0.0455	0.0062	277.55	269.11	0.028	0.029	1 144.72	1 132.87	0.0821	0.0360
2016	19.48	19.46	0.000	0.000	405.14	401.72	0.0532	0.0073	301.07	291.21	0.049	0.032	1 196.45	1 182.69	0.1105	0.0402
2017	16.90	16.88	0.000	0.000	402.14	398.58	0.0554	0.0076	303.07	293.47	0.042	0.032	1 179.15	1 165.52	0.1060	0.0402
2018	11.96	11.94	0.000	0.000	404.65	400.93	0.0581	0.0079	304.52	294.45	0.046	0.033	1 201.25	1 186.97	0.1133	0.0419
2019	12.56	12.54	0.000	0.000	418.43	414.40	0.0629	0.0086	346.06	332.13	0.103	0.042	1 237.31	1 218.89	0.1748	0.0511
2020	12.41	12.39	0.000	0.000	360.95	356.60	0.0680	0.0092	347.83	330.83	0.148	0.049	1 141.89	1 120.11	0.2235	0.0586
2021	14.57	14.54	0.000	0.000	340.88	336.96	0.0610	0.0083	362.84	344.04	0.171	0.053	1 178.92	1 155.74	0.2406	0.0621
2022	12.75	12.73	0.000	0.000	263.81	259.98	0.0594	0.0082	339.12	320.66	0.163	0.052	1 013.06	990.35	0.2294	0.0614
Trend 1990-2022	133.99%	134.03%	121.01%	105.86%	-51.06%	-51.55%	59.61%	50.76%	234.31%	233.01%	3108.00%	177.78%	-83.78%	-84.10%	46.24%	51.35%
Trend 2021-2022	-12.45%	-12.46%	-10.00%	-7.68%	-22.61%	-22.85%	-2.65%	-1.79%	-6.54%	-6.80%	-4.97%	-0.69%	-14.07%	-14.31%	-4.64%	-0.98%

Source: Environment Agency.

Notes: CH_4 emissions are converted in CO_2e by multiplying the emissions by 28, i.e. the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon. N_2O emissions are converted in CO_2e by multiplying the emissions by 265, i.e. the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

Iron and Steel (1A2a)

3.2.7.1.1 Source category description

In 2022, fuel combustion in iron and steel was responsible for 3.37% of GHG emissions from fuel combustion activities (this share was 52.58% in 1990) and represented 2.83% of the total GHG emissions in CO_2eq, excluding LULUCF (42.43% in 1990). Compared to 2021, emissions have decreased by 16.02% and compared to 1990, decreased by 95.71%. The strong decrease from 2021 to 2022 is due to reduced energy consumtpion as a consequence of high global energy prices and national energy saving efforts.

3.2.7.1.2 Methodological issues

3.2.7.1.2.1 Activity Data

The iron and steel industry has been among the most important industrial activities in Luxembourg, both in terms of energy consumption and in terms of added value. As already stressed earlier in this report, important technological changes took place between 1993 and 1997 with the move from blast furnaces to electric arc furnaces. This led to large changes in air emissions. Today, the iron and steel industry has a specific energy consumption which is much lower than it was in 1990 but which is still relatively high at Luxembourg's scale.

Emissions from fuel combustion activities in the iron and steel industry are accounted for under category 1A2a – Iron & Steel. CO_2 process related emissions are included under category 2C1 - Iron & Steel Production (see Section 4.4.1).

Blast furnace gas is a side product of the iron produced in blast furnaces and can be used as fuel for combustion purposes. This was the case in Luxembourg until 1997, when the last blast furnace was blown out. Blast furnace gas was used by the iron and steel industry for heating purposes and for electricity production. Thus, blast furnace gas is to be considered as a secondary fuel. This has to be taken into account when comparing official energy balances (as published by the national statistics institute) with the energy balance used to prepare the emission inventories. Indeed, solid fuels, coke in particular, do not appear as fuel for combustion activities in blast furnaces in emission inventories, as these are mainly used for reduction purposes, and as such are considered in category 2C1 - Iron & Steel Production. Instead of solid fuels, blast furnace gas (although considered as a solid fuel by the IPCC) is considered in category 1A2a (see also Section 4.4.1).

Table 3-34 gives a summary of which combustion activities are included for estimating GHG emissions pertaining to category 1A2a – Iron & Steel.

Table 3-34 – Iron and steel combustion activities included in the GHG inventory

Combustion activity	SNAP[70] code
Combustion plants 50-300 MW	030102
Combustion plants <50 MW	030103
Blast Furnace Cowper's	030203
Sinter and pelletizing plants	030301
Reheating furnaces steel and iron	030302
Grey iron foundries	030303
Electric furnace steel plants	040207
Mobile Sources and Machinery in Industry	080800
Blast furnace gas distribution losses and flaring	NA

Combustion plants 50-300 MW

One power plant, operated until 1997 by the iron and steel industry, located on a site called Terres Rouges, and fed with blast furnace gas, residual fuel oil and/or natural gas. The activity rates are based on information received from the plant operator[71] and from a study (TÜV 1990). The electricity produced was used in the installations of the iron and steel industry (autoproducer). Overproduction was fed into the public electricity network.

Combustion plants <50 MW

Various combustion plants were operated mainly for heating purposes until 1997, when the last blast furnace was shut down. They were fed with blast furnace gas, residual fuel oil and/or natural gas. After 1997, these combustion plants were replaced by installations running on natural gas or gasoil. The related fuel consumption data were and still are received directly from the operator.

Blast furnace cowpers

Blast furnace cowpers have been used until 1997. They were fed with blast furnace gas and with natural gas. The related fuel consumption data were received directly from the operator.

Sinter and pelletizing plants

The sole sinter plant has been used until 1997. Its activity data, i.e. fuel consumption (coke oven coke, coal, blast furnace gas and natural gas) and production have been established in detail for the year 1990 based on information received from the operator. The fuel consumptions of the following years have been extrapolated based on the consumption data of 1990 and on the sintered ore production from 1990 - 1997.

70 Technology oriented Standardized Nomenclature for Air Pollutants (SNAP)

71 Later Arcelor-Arbed, and now Arcelor-Mittal.

Reheating furnaces steel and iron

The reheating furnaces have been used during the whole period 1990 - 2014. Their operation is directly related to steel rolling. Their activity data (natural gas consumption) were received from the operator. In 2012, as a consequence of the economic crisis, the steel rolling facilities as well as the electric arc furnace on the site in Schifflange were temporarily switched off. In 2015, it was decided to finally close these facilities.

Grey iron foundries

The activity data (coking coke consumption) of those foundries have been estimated in the early 1990s (TÜV 1990), and no new data have been received since. Therefore, the values in the inventories have been kept rather constant. In 1997, grey iron production was stopped simultaneously with the last blast furnace.

Electric furnace steel plants

The first electric furnace steel plant appeared in 1994. Beside electric energy, natural gas is used for the fusion of scrap. The related fuel consumption data were received directly from the operator.

Blast Furnace Gas Distribution Losses and Flaring

A certain amount of blast furnace gas (BFG) is either lost during distribution or vented to avoid over-pressurization of the pipes or flared. The amount of BFG lost, vented or flared was obtained from the national statistics institute (STATEC).

Mobile Sources and Machinery in Industry

Activity data on the consumption of diesel oil, used in mobile sources and machinery were derived from energy balance as produced by the national statistics institute (STATEC). Since submission 2015, emissions of mobile machinery are reported under category 1.A.2.g.vii – Off-road vehicles and other machinery (see section 3.2.7.7).

The fuel consumption data obtained by the operators (bottom-up) were matched with the top-down data obtained from the national statistics institute (STATEC) to avoid double counting or underestimation.

Table 3-35 gives a summary of the amount of energy used in category 1A2a – Iron and Steel.

Table 3-35 – Activity data for category 1A2a – Iron and Steel: 1990-2022

1A2a - Iron & Steel Activity Data by fuel type (GJ)						
		Solid	Liquid	Gaseous	Biomass	Other
Year	Activity Total	Blast Furnace Gas, Coke Oven Coke, Coking Coke, Other Bituminous Coal	Residual Fuel Oil, Gas Oil	Natural Gas		
1990	31 648 648	24 297 184	478 498	6 872 966	NO	NO
1991	29 685 953	23 212 906	906 447	5 566 599	NO	NO
1992	27 921 510	21 153 539	1 389 836	5 378 135	NO	NO
1993	28 772 086	22 278 448	1 171 733	5 321 905	NO	NO
1994	24 472 090	18 169 300	1 052 284	5 250 505	NO	NO
1995	15 910 541	9 509 657	432 350	5 968 535	NO	NO
1996	15 109 545	8 471 037	320 254	6 318 253	NO	NO
1997	11 167 216	4 700 381	266 846	6 199 989	NO	NO
1998	5 031 569	NO	235 131	4 796 437	NO	NO
1999	5 431 288	NO	167 328	5 263 960	NO	NO
2000	5 436 967	NO	NO	5 436 967	NO	NO
2001	6 483 752	NO	NO	6 483 752	NO	NO
2002	6 202 490	NO	NO	6 202 490	NO	NO
2003	6 129 185	NO	NO	6 129 185	NO	NO
2004	6 603 080	NO	NO	6 603 080	NO	NO
2005	6 527 604	NO	NO	6 527 604	NO	NO
2006	7 649 731	NO	NO	7 649 731	NO	NO
2007	7 353 192	NO	NO	7 353 192	NO	NO
2008	7 048 451	NO	NO	7 048 451	NO	NO
2009	5 726 715	NO	NO	5 726 715	NO	NO
2010	6 578 058	NO	NO	6 578 058	NO	NO
2011	5 767 862	NO	NO	5 767 862	NO	NO
2012	5 216 652	NO	NO	5 216 652	NO	NO
2013	4 814 169	NO	NO	4 814 169	NO	NO
2014	4 786 104	NO	NO	4 786 104	NO	NO
2015	4 865 850	NO	NO	4 865 850	NO	NO
2016	4 724 974	NO	NO	4 724 974	NO	NO
2017	4 708 060	NO	NO	4 708 060	NO	NO
2018	5 464 344	NO	NO	5 464 344	NO	NO
2019	5 239 252	NO	NO	5 239 252	NO	NO
2020	4 713 705	NO	NO	4 713 705	NO	NO
2021	4 864 157	NO	NO	4 864 157	NO	NO
2022	4 105 284	NO	NO	4 105 284	NO	NO
Trend 1990-2022	-87.03%	NA	NA	-40.27%	NA	NA
Trend 2021-2022	-15.60%	NA	NA	-15.60%	NA	NA

Source: Environment Agency.

3.2.7.1.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for residual fuel oil and solid fuels except for blast furnace gas (recorded under solid fuels according to the 2006 IPCC Guidelines). For natural gas, gas oil, diesel oil and blast furnace gas, the methodological approach is classified as a Tier 2 methodology as country-specific emissions factor were used.

Special care was taken with solid fuels to avoid double counting with IPCC sub-category 2C1 - Iron and Steel Production. As already stated (section 3.2.7.1.2.1), the use of natural gas and BFG is considered as a combustion activity under 1A2a, whereas the use of coal (other bituminous coal), coke oven coke, and some residual fuel oil was used in the blast furnaces to produce BFG and for reduction purposes. These emissions are accounted for in category 2C1.

3.2.7.1.2.3 Emission factors

Default emission factors are derived from the 2006 IPCC Guidelines. Country-specific or plant specific emission factors were determined by the Environment Agency and are either derived from a study (TÜV 1990) or were calculated from specific data accessible to the Environment Agency from the operator (Table 3-36).

For blast furnace gas combusted in blast furnaces or combustion plants, a plant specific CO_2 emission factor, which is at the same time country-specific as there was only one plant in Luxembourg, was applied. This EF was derived from a study in the year 1990 and is based on measurements of the BFG composition (see also section 3.2.5.3). The CH_4 and N_2O emission factors are default values from the 2006 IPCC Guidelines. The CO_2 EF for BFG lost in distribution and flaring is also plant specific and was based on measurements and BFG composition.[62] Generally, BFG consists of about 60 percent nitrogen, 18-20% carbon dioxide and some oxygen. The rest is mostly carbon monoxide, which has a fairly low heating value. When calculating the emissions from distribution losses, it is assumed that BFG is completely oxidised to CO_2 in the atmosphere. Therefore, the same emission factor as for flaring was used. Since no default values for CH_4 and N_2O from BFG lost in distribution and flaring are given in neither the 1996 Revised IPCC Guidelines nor in the 2006 IPCC Guidelines, the default values for coal were applied.

Table 3-36 gives an overview of the different emission factors used in this submission.

Table 3-36 – Emission factors for category 1A2a – Iron and Steel

1A2a Iron & Steel Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Blast furnace gas	solid	257 181	PS, CS	1.00	D	0.10	D	TüV 1990 2006 IPCC GL
BFG (DistLoss&Flar)	solid	245 323	PS, CS	1.00	D	0.10	D	TüV 1990 2006 IPCC GL
Coke Oven Coke	solid	107 000	D	10.00	D	1.50	D	2006 IPCC GL
Other Bituminous Coal	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Coking Coke	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 037	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

Table 3-37 gives an overview of the evolution of the implied emission factors per fuel type.

Time-series are considered to be consistent, also in comparison with energy data as reported by the national statistics institute. For solid fuels, the relatively high CO_2 IEF, compared to usual solid fuels, stems from the fact that blast furnace gas is the predominant fuel in this category. Other solid fuels, such as coke oven coke, other bituminous coal or coking coal only played a minor role, and were mainly used in the sole sinter and pelletizing plant and in grey iron foundries. For liquid fuels, the CO_2 IEF was higher in the early 1990s due to the increased use of residual fuel oil, which was replaced by gas/diesel oil with the switch to electric arc steel production.

Table 3-37 – Implied emission factors for IPCC sub-category 1A2a – Iron and Steel

1A2a Iron & Steel Implied Emission Factors (kg/TJ)									
Year	Solid			Liquid			Gaseous		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	204 087	4.13	0.59	77 400	3.00	0.60	57 755	1.00	0.10
1991	204 235	4.11	0.58	77 400	3.00	0.60	57 743	1.00	0.10
1992	204 137	4.11	0.58	77 400	3.00	0.60	57 848	1.00	0.10
1993	202 008	4.24	0.60	77 400	3.00	0.60	57 894	1.00	0.10
1994	201 498	4.27	0.61	77 400	3.00	0.60	57 940	1.00	0.10
1995	201 690	4.27	0.61	77 391	3.00	0.60	57 929	1.00	0.10
1996	199 816	4.37	0.62	77 384	3.00	0.60	57 546	1.00	0.10
1997	200 038	4.37	0.62	77 366	3.00	0.60	57 205	1.00	0.10
1998	NO	NO	NO	77 400	3.00	0.60	56 863	1.00	0.10
1999	NO	NO	NO	77 400	3.00	0.60	56 522	1.00	0.10
2000	NO	NO	NO	NO	NO	NO	56 221	1.00	0.10
2001	NO	NO	NO	NO	NO	NO	56 258	1.00	0.10
2002	NO	NO	NO	NO	NO	NO	56 396	1.00	0.10
2003	NO	NO	NO	NO	NO	NO	56 533	1.00	0.10
2004	NO	NO	NO	NO	NO	NO	56 671	1.00	0.10
2005	NO	NO	NO	NO	NO	NO	56 910	1.00	0.10
2006	NO	NO	NO	NO	NO	NO	57 008	1.00	0.10
2007	NO	NO	NO	NO	NO	NO	56 793	1.00	0.10
2008	NO	NO	NO	NO	NO	NO	56 665	1.00	0.10
2009	NO	NO	NO	NO	NO	NO	57 056	1.00	0.10
2010	NO	NO	NO	NO	NO	NO	56 712	1.00	0.10
2011	NO	NO	NO	NO	NO	NO	56 988	1.00	0.10
2012	NO	NO	NO	NO	NO	NO	56 793	1.00	0.10
2013	NO	NO	NO	NO	NO	NO	56 680	1.00	0.10
2014	NO	NO	NO	NO	NO	NO	56 756	1.00	0.10
2015	NO	NO	NO	NO	NO	NO	56 760	1.00	0.10
2016	NO	NO	NO	NO	NO	NO	56 561	1.00	0.10
2017	NO	NO	NO	NO	NO	NO	56 577	1.00	0.10
2018	NO	NO	NO	NO	NO	NO	56 209	1.00	0.10
2019	NO	NO	NO	NO	NO	NO	56 091	1.00	0.10
2020	NO	NO	NO	NO	NO	NO	56 482	1.00	0.10
2021	NO	NO	NO	NO	NO	NO	56 664	1.00	0.10
2022	NO	NO	NO	NO	NO	NO	56 386	1.00	0.10

Source: Environment Agency.

3.2.7.2 Non-Ferrous Metals (1A2b)

3.2.7.2.1 Source category description

In Luxembourg, non-ferrous metals activities cover mainly secondary aluminium production from aluminium scrap.

In 2022, fuel combustion due to non-ferrous metal production was responsible for 0.69% of GHG emissions from fuel combustion activities (0.28% in 1990) and represented 0.58% of the national total GHG emissions in CO_2e, excluding LULUCF (0.22% in 1990). Compared to 2021, emissions decreased by 2.36% and compared to 1990, they increased by 67.16%.

3.2.7.2.2 Methodological issues & time series consistency

3.2.7.2.2.1 Activity data

Liquefied petroleum gas (LPG) was an important fuel used in the secondary aluminium production. It was slowly substituted by natural gas. Generally, the fuel consumption data were obtained from the operators. The activity data for secondary aluminium production are listed in Table 3-38.

The activity data reported here are the data reported by the operators to the Environment Agency through their annual reporting obligations. This bottom-up data could not be matched with top-down data from the national statistics institute as no such data are reported for this category. Due to confidentiality reasons, this data are reported under the iron & steel industry by national statistics. However, to avoid double counting, the bottom-up data were subtracted from the top-down data from official statistics reported for category 1A2a - Iron and Steel.

Table 3-38 - Activity data for category 1A2b - Non-Ferrous Metals: 1990-2022

1A2b - Non-Ferrous Metals Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid LPG	Gaseous Natural Gas	Biomass	Other
1990	462 005	NO	230 000	232 005	NO	NO
1991	480 174	NO	230 000	250 174	NO	NO
1992	484 471	NO	230 000	254 471	NO	NO
1993	474 992	NO	230 000	244 992	NO	NO
1994	574 091	NO	307 372	266 719	NO	NO
1995	593 787	NO	314 594	279 193	NO	NO
1996	983 700	NO	314 594	669 106	NO	NO
1997	724 596	NO	56 951	667 645	NO	NO
1998	757 076	NO	87 447	669 629	NO	NO
1999	740 541	NO	86 796	653 745	NO	NO
2000	722 935	NO	88 251	634 683	NO	NO
2001	733 199	NO	86 796	646 403	NO	NO
2002	715 027	NO	NO	715 027	NO	NO
2003	818 250	NO	NO	818 250	NO	NO
2004	928 110	NO	NO	928 110	NO	NO
2005	1 025 041	NO	NO	1 025 041	NO	NO
2006	1 073 850	NO	NO	1 073 850	NO	NO
2007	1 004 376	NO	NO	1 004 376	NO	NO
2008	979 207	NO	NO	979 207	NO	NO
2009	857 430	NO	NO	857 430	NO	NO
2010	987 086	NO	NO	987 086	NO	NO
2011	943 399	NO	NO	943 399	NO	NO
2012	958 750	NO	NO	958 750	NO	NO
2013	938 733	NO	NO	938 733	NO	NO
2014	906 812	NO	NO	906 812	NO	NO
2015	877 014	NO	NO	877 014	NO	NO
2016	896 259	NO	NO	896 259	NO	NO
2017	951 239	NO	NO	951 239	NO	NO
2018	915 753	NO	NO	915 753	NO	NO
2019	845 966	NO	NO	845 966	NO	NO
2020	763 317	NO	NO	763 317	NO	NO
2021	860 169	NO	NO	860 169	NO	NO
2022	844 043	NO	NO	844 043	NO	NO
Trend 1990-2022	82.69%	NA	NA	263.80%	NA	NA
Trend 2021-2022	-1.87%	NA	NA	-1.87%	NA	NA

Source: Environment Agency.

3.2.7.2.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 2 approach has been applied for liquid (LPG) and gaseous fuels (natural gas).

3.2.7.2.2.3 Emission factors

Country-specific EFs for CO_2 from LPG and natural gas were used. Default EFs from the 2006 IPCC Guidelines have been applied for CH_4 and N_2O (Table 3-39).

Table 3-39 – Emission factors for category 1A2b – Non-Ferrous Metals

1A2b - Non-Ferrous Metals Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	64 957	CS	1.00	D	0.10	D	AEV 2006 IPCC
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC

Source: Environment Agency.

3.2.7.3 Chemicals (1A2c)

3.2.7.3.1 Source category description

In Luxembourg, chemical activities cover mainly the production of tires, various plastic films and synthetic non-woven textiles. Also included in this category are the emissions of two gas turbines operated by the chemical industry for heat and electricity production (autoproducers).

In 2022, fuel combustion from the chemical industry was responsible for 1.59% of GHG emissions from fuel combustion activities (1.66% in 1990) and represented 1.34% of the national total GHG emissions, excluding LULUCF (1.34% in 1990). Compared to 2021, emissions decreased by 10.19% and compared to 1990, they decreased by 35.58%.

3.2.7.3.2 Methodological issues & time-series consistency

3.2.7.3.2.1 Activity data

Annual fuel consumption data of residual fuel oil, gas oil, diesel oil and natural gas were obtained from the operators. Diesel oil is mainly used by mobile sources and machinery, whereas the remaining fuels are mainly combusted in stationary units for heating purposes.

The activity data reported here are the data reported by the operators to the Environment Agency through their annual reporting obligations. The bottom-up data on natural gas, between 1990 and 1999, could not be matched to the top-down data from the national statistics institute as no such data are reported for this category. To avoid double counting, the bottom-up data for this period were subtracted from the top-down data from official statistics reported for category 1A2g - Other. For natural gas (2000-2020) and liquid fuels (residual fuel oil, gas oil, diesel oil) the matching exercise was done within the category 1A2c as top-down data are reported for this category by the national statistics institute. Activity data for the chemical industry are listed in Table 3-40.

Fluctuations in activity data may occur due to temporal shut-down of installations (e.g. for maintenance). This may then be reflected in the activity data by a sharp decrease as in 2007 when maintenance on one of the gas turbines operated by the chemical industry led to a 9% decrease compared to the previous year.[72] The dip in 2009 is explained by the global economic downturn due to the financial and economic crisis. 2010 showed a slight recovery, with a stabilisation until 2013. The decrease observed in 2014 is mainly due to the phase out of one of the gas turbines, being replaced by energy efficient boilers.

72 ARR 2009, § 61.

Table 3-40- Activity data for category *1A2c - Chemicals*: 1990-2022

1A2c - Chemicals Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Residual Fuel Oil, Gas Oil	Gaseous Natural Gas	Biomass	Other
1990	2 455 706	NO	1 460 983	994 723	NO	NO
1991	2 563 192	NO	1 975 924	587 269	NO	NO
1992	2 520 181	NO	1 453 902	1 066 279	NO	NO
1993	2 597 533	NO	1 595 269	1 002 264	NO	NO
1994	2 964 983	NO	1 490 527	1 474 456	NO	NO
1995	3 063 188	NO	862 520	2 200 668	NO	NO
1996	3 109 185	NO	847 838	2 261 347	NO	NO
1997	3 066 885	NO	502 535	2 564 350	NO	NO
1998	3 179 058	NO	41 363	3 137 695	NO	NO
1999	3 061 094	NO	49 809	3 011 284	NO	NO
2000	3 404 315	NO	4 192	3 400 122	NO	NO
2001	3 531 748	NO	2 667	3 529 081	NO	NO
2002	3 528 026	NO	4 436	3 523 590	NO	NO
2003	3 754 091	NO	5 824	3 748 267	NO	NO
2004	3 828 433	NO	1 658	3 826 775	NO	NO
2005	3 807 920	NO	2 801	3 805 119	NO	NO
2006	3 714 993	NO	5 822	3 709 171	NO	NO
2007	3 307 014	NO	854	3 306 160	NO	NO
2008	3 313 135	NO	420	3 312 715	NO	NO
2009	2 479 771	NO	724	2 479 048	NO	NO
2010	2 916 153	NO	1 185	2 914 968	NO	NO
2011	3 815 425	NO	1 403	3 814 023	NO	NO
2012	3 573 491	NO	1 295	3 572 197	NO	NO
2013	3 728 780	NO	3 356	3 725 424	NO	NO
2014	2 988 616	NO	1 156	2 987 460	NO	NO
2015	2 433 025	NO	850	2 432 175	NO	NO
2016	2 600 928	NO	494	2 600 434	NO	NO
2017	2 323 667	NO	701	2 322 966	NO	NO
2018	2 130 375	NO	487	2 129 888	NO	NO
2019	2 078 618	NO	466	2 078 151	NO	NO
2020	1 957 022	NO	131	1 956 891	NO	NO
2021	2 153 111	NO	170	2 152 941	NO	NO
2022	1 929 945	NO	42 016	1 887 929	NO	NO
Trend 1990-2022	-21.41%	NA	-97.12%	89.79%	NA	NA
Trend 2021-2022	-10.36%	NA	24670.92%	-12.31%	NA	NA

Source: Environment Agency.

3.2.7.3.2.2 Methodological issues

The 2006 IPCC Guidelines Tier 1 approach has been applied for residual fuel oil, whereas the 2006 IPCC Guidelines Tier 2 approach was applied for gas oil and natural gas.

3.2.7.3.2.3 Emission factors

The 2006 IPCC Guidelines default EFs have been applied for CO_2 for residual fuel oil, whereas for gas oil and natural gas country-specific EFs were used. Default EFs have been applied for CH_4 and N_2O (Table 3-41).

Table 3-41 – Emission factors for category 1A2c – Chemicals

1A2c - Chemicals Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 037	CS	3.00	D	0.60	D	AEV 2006 IPCC
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC

Source: Environment Agency.

Table 3-42 gives an overview of the evolution of the implied emission factors per fuel type.

For liquid fuels, the CO_2 IEF was higher in the early 1990s due to the increased use of residual fuel oil, which was gradually replaced by gas/diesel oil in the mid 1990s.

Table 3-42 – Implied emission factors for category *1A2c – Chemicals*

1A2c - Chemicals Implied Emission Factors (kg/TJ)						
Year	Liquid			Gaseous		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	76 923	3.00	0.60	57 755	1.00	0.10
1991	77 049	3.00	0.60	57 743	1.00	0.10
1992	76 914	3.00	0.60	57 848	1.00	0.10
1993	77 005	3.00	0.60	57 894	1.00	0.10
1994	76 955	3.00	0.60	57 940	1.00	0.10
1995	76 641	3.00	0.60	57 929	1.00	0.10
1996	76 620	3.00	0.60	57 546	1.00	0.10
1997	76 293	3.00	0.60	57 205	1.00	0.10
1998	77 230	3.00	0.60	56 863	1.00	0.10
1999	76 883	3.00	0.60	56 522	1.00	0.10
2000	74 213	3.00	0.60	56 221	1.00	0.10
2001	74 218	3.00	0.60	56 258	1.00	0.10
2002	74 219	3.00	0.60	56 396	1.00	0.10
2003	74 195	3.00	0.60	56 533	1.00	0.10
2004	74 156	3.00	0.60	56 671	1.00	0.10
2005	74 140	3.00	0.60	56 910	1.00	0.10
2006	74 140	3.00	0.60	57 008	1.00	0.10
2007	74 146	3.00	0.60	56 793	1.00	0.10
2008	74 090	3.00	0.60	56 665	1.00	0.10
2009	74 077	3.00	0.60	57 056	1.00	0.10
2010	74 131	3.00	0.60	56 712	1.00	0.10
2011	74 116	3.00	0.60	56 988	1.00	0.10
2012	74 137	3.00	0.60	56 793	1.00	0.10
2013	74 146	3.00	0.60	56 680	1.00	0.10
2014	74 073	3.00	0.60	56 756	1.00	0.10
2015	74 132	3.00	0.60	56 760	1.00	0.10
2016	74 140	3.00	0.60	56 561	1.00	0.10
2017	74 156	3.00	0.60	56 577	1.00	0.10
2018	74 130	3.00	0.60	56 209	1.00	0.10
2019	74 077	3.00	0.60	56 091	1.00	0.10
2020	74 145	3.00	0.60	56 482	1.00	0.10
2021	74 151	3.00	0.60	56 664	1.00	0.10
2022	74 037	3.00	0.60	56 386	1.00	0.10

Source: Environment Agency.

3.2.7.4 Pulp, Paper and Print (1A2d)

3.2.7.4.1 Source category description

In Luxembourg, this source category only covers the printing industry. No pulp or paper production occurs in Luxembourg. Included in this sub-category are the emissions from stationary combustion plants (<50 MW). Emissions from mobile sources and machinery used in this category are reported under category 1.A.2.g.vii – Off-road vehicles and other machinery.

In 2022, fuel combustion from the paper and print industry was responsible for 0.12% of GHG emissions from fuel combustion activities and represented 0.10% of the national total GHG emissions in CO_2e, excluding LULUCF. Compared to 2021, emissions decreased by 39.62%.

3.2.7.4.2 Methodological issues

3.2.7.4.2.1 Activity data

Annual fuel consumption data for natural gas were derived from national statistics for the period 2000-2021. Diesel oil is mainly used by mobile sources and machinery (reported under category 1.A.2.g.vii – Off-road vehicles and other machinery). For 1990-1999, no activity data are available from national statistics, hence the notation key IE was used in the CRF tables. For these years, the data are included in 1A2g - Other.

Activity data for the pulp, paper and print industry are listed in Table 3-43.

Table 3-43- Activity data for category 1A2d - Pulp, Paper and Print: 1990-2022

1A2d - Pulp, Paper & Print Activity Data by fuel type (GJ)						
Year	**Activity Total**	**Solid**	**Liquid**	**Gaseous Natural Gas**	**Biomass**	**Other**
1990	IE	NO	IE	IE	NO	NO
1991	IE	NO	IE	IE	NO	NO
1992	IE	NO	IE	IE	NO	NO
1993	IE	NO	IE	IE	NO	NO
1994	IE	NO	IE	IE	NO	NO
1995	IE	NO	IE	IE	NO	NO
1996	IE	NO	IE	IE	NO	NO
1997	IE	NO	IE	IE	NO	NO
1998	IE	NO	IE	IE	NO	NO
1999	IE	NO	IE	IE	NO	NO
2000	202 968	NO	NO	202 968	NO	NO
2001	236 843	NO	NO	236 843	NO	NO
2002	301 055	NO	NO	301 055	NO	NO
2003	360 488	NO	NO	360 488	NO	NO
2004	309 314	NO	NO	309 314	NO	NO
2005	308 222	NO	NO	308 222	NO	NO
2006	193 171	NO	NO	193 171	NO	NO
2007	124 403	NO	NO	124 403	NO	NO
2008	173 495	NO	NO	173 495	NO	NO
2009	136 285	NO	NO	136 285	NO	NO
2010	87 812	NO	NO	87 812	NO	NO
2011	126 426	NO	NO	126 426	NO	NO
2012	165 172	NO	NO	165 172	NO	NO
2013	210 341	NO	NO	210 341	NO	NO
2014	101 720	NO	NO	101 720	NO	NO
2015	94 968	NO	NO	94 968	NO	NO
2016	92 645	NO	NO	92 645	NO	NO
2017	87 269	NO	NO	87 269	NO	NO
2018	22 624	NO	NO	22 624	NO	NO
2019	33 584	NO	NO	33 584	NO	NO
2020	7 117	NO	NO	7 117	NO	NO
2021	243 968	NO	NO	243 968	NO	NO
2022	148 029	NO	NO	148 029	NO	NO
Trend 1990-2022	NA	NA	NA	NA	NA	NA
Trend 2021-2022	-39.32%	NA	NA	-39.32%	NA	NA

Source: Environment Agency

3.2.7.4.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 2 approach was applied for natural gas.

3.2.7.4.2.3 Emission factors

Country-specific CO_2 EFs were used for natural gas, whereas 2006 IPCC default EFs have been applied for CH_4 and N_2O (Table 3-44).

Table 3-44 – Emission factors for category 1A2d - Pulp, Paper and Print

1A2d - Pulp, Paper & Print Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

Table 3-45 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-45 – Implied emission factors for category 1A2d - Pulp, Paper and Print

1A2d - Pulp, Paper & Print Implied Emission Factors (kg/TJ)			
Year	Gaseous		
	CO_2	CH_4	N_2O
1990	NO	NO	NO
1991	NO	NO	NO
1992	NO	NO	NO
1993	NO	NO	NO
1994	NO	NO	NO
1995	NO	NO	NO
1996	NO	NO	NO
1997	NO	NO	NO
1998	NO	NO	NO
1999	NO	NO	NO
2000	56 221	1.00	0.10
2001	56 258	1.00	0.10
2002	56 396	1.00	0.10
2003	56 533	1.00	0.10
2004	56 671	1.00	0.10
2005	56 910	1.00	0.10
2006	57 008	1.00	0.10
2007	56 793	1.00	0.10
2008	56 665	1.00	0.10
2009	57 056	1.00	0.10
2010	56 712	1.00	0.10
2011	56 988	1.00	0.10
2012	56 793	1.00	0.10
2013	56 680	1.00	0.10
2014	56 756	1.00	0.10
2015	56 760	1.00	0.10
2016	56 561	1.00	0.10
2017	56 577	1.00	0.10
2018	56 209	1.00	0.10
2019	56 091	1.00	0.10
2020	56 482	1.00	0.10
2021	56 664	1.00	0.10
2022	56 386	1.00	0.10

Source: Environment Agency

3.2.7.5 Food Processing, Beverages and Tobacco (1A2e)

3.2.7.5.1 Source category description

In Luxembourg, this category covers mainly the production of beer, milk, milk products, and tobacco products. Included in this category are the emissions from combustion plants (<50 MW) operated by the food processing, beverages and tobacco industry. Emissions from mobile sources and machinery used in this category are reported under category 1.A.2.g.vii – Off-road vehicles and other machinery.

In 2022, fuel combustion from the food processing, beverages and tobacco industry was responsible for 0.19% of GHG emissions from fuel combustion activities (0.05% in 1990) and represented 0.16% of the national total GHG emissions excluding LULUCF (0.04% in 1990). Compared to 2021, emissions decreased by 12.45% and compared to 1990, increased by 133.99%.

For liquid fuels, some exceptional inter-annual changes have been observed for the years 1994/1995 (+72%), 1998/1999 (+161%), 2000/2001 (+198%), and 2008/2009 (+62%). The main drivers of these inter-annual changes are an increase in gas oil consumption as reported by the national energy balance (1994/1995 and 2000/2001), a switch from residual fuel oil to gas oil (1998/1999), and the emptying of gas oil stocks at one facility prior to shutting down (2008/2009).

3.2.7.5.2 Methodological issues & time-series consistency

3.2.7.5.2.1 Activity data

Annual fuel consumption data of residual fuel oil, gas oil, diesel oil and natural gas were obtained from the operators through their annual reporting obligations. Diesel oil is mainly used by mobile sources and machinery (reported under category 1.A.2.g.vii – Off-road vehicles and other machinery), whereas the remaining fuels are mainly combusted in stationary units for heating purposes. The bottom-up data on natural gas, for 1990-1999, could not be matched to the top-down data from national statistics as no such data are reported for this category. To avoid double counting, the bottom-up data on natural gas were subtracted from the top-down data from national statistics reported for category 1A2g - Other. For natural gas (2000-2021) and liquid fuels (residual fuel oil, gas oil, diesel oil), the matching exercise was done within the category 1A2e as top-down data are available for this sub-category from national statistics. Activity data for the food processing, beverages and tobacco industry are listed in Table 3-46.

Table 3-46- Activity data for category 1A2e - Food Processing, Beverages and Tobacco: 1990-2022

1A2e - Food Processing, Beverages & Tobacco Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Residual fuel oil, Gas Oil	Gaseous Natural Gas	Biomass	Other
1990	87 063	NO	21 250	65 812	NO	NO
1991	118 180	NO	22 725	95 455	NO	NO
1992	116 494	NO	16 026	100 468	NO	NO
1993	108 002	NO	9 271	98 731	NO	NO
1994	112 220	NO	11 486	100 734	NO	NO
1995	124 161	NO	19 791	104 369	NO	NO
1996	113 556	NO	10 391	103 164	NO	NO
1997	118 927	NO	12 459	106 468	NO	NO
1998	124 863	NO	13 987	110 877	NO	NO
1999	132 660	NO	36 560	96 100	NO	NO
2000	331 573	NO	14 797	316 776	NO	NO
2001	397 361	NO	44 100	353 262	NO	NO
2002	441 896	NO	43 133	398 763	NO	NO
2003	259 337	NO	41 178	218 159	NO	NO
2004	239 611	NO	29 151	210 460	NO	NO
2005	254 250	NO	31 604	222 646	NO	NO
2006	217 756	NO	34 435	183 321	NO	NO
2007	212 486	NO	36 309	176 177	NO	NO
2008	228 536	NO	50 825	177 712	NO	NO
2009	230 932	NO	82 440	148 492	NO	NO
2010	202 766	NO	43 189	159 577	NO	NO
2011	297 342	NO	43 837	253 505	NO	NO
2012	250 766	NO	44 115	206 651	NO	NO
2013	257 067	NO	39 713	217 354	NO	NO
2014	353 024	NO	42 850	310 175	NO	NO
2015	295 610	NO	41 909	253 701	NO	NO
2016	329 991	NO	38 150	291 842	NO	NO
2017	284 954	NO	36 492	248 462	NO	NO
2018	197 569	NO	39 645	157 924	NO	NO
2019	206 414	NO	45 163	161 251	NO	NO
2020	204 711	NO	39 468	165 243	NO	NO
2021	242 913	NO	37 632	205 281	NO	NO
2022	211 952	NO	37 200	174 752	NO	NO
Trend 1990-2022	143.45%	NA	75.05%	165.53%	NA	NA
Trend 2021-2022	-12.75%	NA	-1.15%	-14.87%	NA	NA

Source: Environment Agency.

3.2.7.5.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for residual fuel oil, whereas the 2006 IPCC Guidelines Tier 2 approach was applied for gas oil, diesel oil and natural gas.

3.2.7.5.2.3 Emission factors

The 2006 IPCC Guidelines default EFs have been applied for CO_2 from residual fuel oil, whereas for gas oil and natural gas country specific EFs were used. Default EFs have been applied for CH_4 and N_2O (Table 3-47).

Table 3-47 – Emission factors for category 1A2e – Food Processing, Beverages and Tobacco

1A2e - Food Processing, Beverages & Tobacco Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 037	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

Table 3-48 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-48 – Implied emission factors for category 1A2e – Food Processing, Beverages and Tobacco

1A2e - Food Processing, Beverages & Tobacco Implied Emission Factors (kg/TJ)						
Year	Liquid			Gaseous		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	77 164	3.00	0.60	57 755	1.00	0.10
1991	77 134	3.00	0.60	57 743	1.00	0.10
1992	76 770	3.00	0.60	57 848	1.00	0.10
1993	76 859	3.00	0.60	57 894	1.00	0.10
1994	76 349	3.00	0.60	57 940	1.00	0.10
1995	75 449	3.00	0.60	57 929	1.00	0.10
1996	76 937	3.00	0.60	57 546	1.00	0.10
1997	76 048	3.00	0.60	57 205	1.00	0.10
1998	76 822	3.00	0.60	56 863	1.00	0.10
1999	74 244	3.00	0.60	56 522	1.00	0.10
2000	74 384	3.00	0.60	56 221	1.00	0.10
2001	75 844	3.00	0.60	56 258	1.00	0.10
2002	75 819	3.00	0.60	56 396	1.00	0.10
2003	75 827	3.00	0.60	56 533	1.00	0.10
2004	76 409	3.00	0.60	56 671	1.00	0.10
2005	76 535	3.00	0.60	56 910	1.00	0.10
2006	76 620	3.00	0.60	57 008	1.00	0.10
2007	76 673	3.00	0.60	56 793	1.00	0.10
2008	76 057	3.00	0.60	56 665	1.00	0.10
2009	75 254	3.00	0.60	57 056	1.00	0.10
2010	77 283	3.00	0.60	56 712	1.00	0.10
2011	77 346	3.00	0.60	56 988	1.00	0.10
2012	77 247	3.00	0.60	56 793	1.00	0.10
2013	77 325	3.00	0.60	56 680	1.00	0.10
2014	77 204	3.00	0.60	56 756	1.00	0.10
2015	77 363	3.00	0.60	56 760	1.00	0.10
2016	77 374	3.00	0.60	56 561	1.00	0.10
2017	77 367	3.00	0.60	56 577	1.00	0.10
2018	77 380	3.00	0.60	56 209	1.00	0.10
2019	77 359	3.00	0.60	56 091	1.00	0.10
2020	77 394	3.00	0.60	56 482	1.00	0.10
2021	77 400	3.00	0.60	56 664	1.00	0.10
2022	77 400	3.00	0.60	56 386	1.00	0.10

Source: Environment Agency

3.2.7.6 Non-Metallic Minerals (1A2f)

3.2.7.6.1 Source category description

Source category 1A2f – Non-metallic minerals covers industrial activities such as glass, clinker / cement and ceramics production.

In 2022, fuel combustion emissions reported under 1A2f – Non-metallic minerals were responsible for 3.83% of GHG emissions from fuel combustion activities (this share was 5.25% in 1990) and represented 3.22% of the national total GHG emissions excluding LULUCF (4.24% in 1990). Compared to 2021, emissions decreased by 22.61% and compared to 1990, they decreased by 51.06%.

3.2.7.6.2 Methodological issues

3.2.7.6.2.1 Activity data

Under 1A2f – Non-metallic minerals, the following activities have been considered (Table 3-49):

Table 3-49 – Combustion activities included in 1A2f – Non-metallic minerals

Description	SNAP code
Cement (Clinker)	030311
Flat glass	030314
Fine ceramic materials	030320

Cement (Clinker)

One industrial site produces clinker in Luxembourg. Its major fuel is other bituminous coal, but use is also made of residual oil, natural gas and special types of waste: shredded tires, fluff and sewage sludge. These waste types contain a certain biogenic fraction, which is annually reported by the operator and is taken into consideration when estimating the emissions. The consumption data of these fuels are transmitted annually to the Environment Agency by the operator.

Flat glass

There are two flat glass plants in Luxembourg. Their main fuel is natural gas. LPG is also used but in very little quantities.

Fine ceramic materials

One major production site of ceramic materials existed in Luxembourg (Villeroy & Boch) using natural gas as fuel. However, the production site was closed down in 2010.

Activity data for the non-metallic minerals industry are listed in Table 3-50.

Table 3-50 – Activity data by fuel type of category 1A2f – Non-metallic minerals: 1990-2022

1A2f - Non-Metallic Minerals Activity Data by fuel type (GJ)						
Year	Activity Total	Solid Other bit. coal, Lignite	Liquid Residual Fuel Oil, Gas Oil, LPG	Gaseous Natural Gas	Biomass Sewage Sludge, Tires, Fluff	Other Sewage Sludge, Tires, Fluff
1990	7 102 444	3 302 589	317 025	3 482 830	NO	NO
1991	6 241 197	3 028 845	122 474	3 089 878	NO	NO
1992	6 653 792	3 404 630	149 903	3 099 259	NO	NO
1993	6 130 253	2 850 457	132 335	3 147 461	NO	NO
1994	7 228 121	3 840 609	111 640	3 275 872	NO	NO
1995	6 480 937	3 000 573	117 786	3 362 578	NO	NO
1996	6 809 456	3 303 931	107 233	3 398 292	NO	NO
1997	6 337 530	2 886 032	190 101	3 261 397	NO	NO
1998	5 896 561	2 674 118	93 449	2 949 422	48 484	131 088
1999	6 516 553	2 819 127	75 713	3 446 649	47 267	127 797
2000	7 049 927	3 127 895	97 743	3 555 847	72 479	195 963
2001	7 318 338	3 119 891	71 600	3 543 132	157 603	426 112
2002	6 338 760	2 093 325	60 817	3 482 189	197 108	505 321
2003	5 490 992	1 793 790	72 920	2 956 142	202 949	465 191
2004	6 233 605	2 070 876	91 078	3 310 857	252 132	508 662
2005	6 365 698	2 190 698	67 920	3 333 205	236 807	537 068
2006	6 772 959	2 577 804	67 200	3 286 321	263 980	577 654
2007	6 309 554	1 989 234	62 920	3 372 178	296 661	588 562
2008	6 123 579	1 805 356	58 034	3 340 782	259 929	659 478
2009	6 072 757	2 043 207	37 557	3 314 606	198 932	478 455
2010	5 963 639	1 794 620	23 877	3 222 306	283 272	639 565
2011	5 953 493	1 819 386	29 527	3 252 680	260 635	591 265
2012	5 830 526	1 742 721	32 119	3 181 655	270 977	603 054
2013	5 061 164	1 674 635	27 785	2 370 687	278 593	709 464
2014	5 555 332	1 673 730	57 737	2 917 527	265 670	640 669
2015	5 482 985	1 588 151	50 199	2 960 631	245 290	638 714
2016	5 815 751	1 640 442	40 131	3 014 023	227 998	893 158
2017	5 739 989	1 696 898	48 057	2 810 867	234 611	949 555
2018	5 883 493	1 485 137	29 566	3 030 472	232 079	1 106 239
2019	6 079 025	1 663 002	36 293	2 940 627	286 563	1 152 540
2020	5 206 630	1 357 956	37 928	2 067 947	392 765	1 350 034
2021	4 661 430	1 471 562	49 985	1 657 621	266 549	1 215 713
2022	3 319 902	1 536 416	97 455	236 017	314 091	1 135 923
Trend 1990-2022	-53.26%	-53.48%	-69.26%	-93.22%	NA	NA
Trend 2021-2022	-28.78%	4.41%	94.97%	-85.76%	17.84%	-6.56%

Source: Environment Agency

3.2.7.6.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for solid fuels and residual fuel oil, whereas the 2006 IPCC Guidelines Tier 2 approach was applied for natural gas, gas oil and LPG. CO_2 emissions from the biogenic fractions of tires, fluff and sewage sludge are reported under memory items. The biogenic fraction of tires, which are used since 1998 in the clinker production, was set to 27% for the entire time-series in accordance with the EU-ETS declarations from the plant operator. This value is validated by two independent reports from "Verein Deutscher Zementwerke e. V."[73] and "Aliapur"[74] on the use of tires as secondary fuels.

The biogenic fraction of fluff, which is used since 2006 as secondary fuel in the clinker production, is determined annually by the plant operator, in accordance with the EU Emissions Trading System Monitoring and Reporting Guidelines[75].

3.2.7.6.2.3 Emission factors

The 2006 IPCC Guidelines default CO_2 EFs have been applied for residual fuel oil and for other bituminous coal. For tires, sewage sludge, solvents, and fluff, plant-specific CO_2 emission factors were used. For natural gas, gas oil and LPG country-specific CO_2 EFs were used. IPCC default EFs have been applied for CH_4 and N_2O (Table 3-51).

Table 3-51 – Emission factors for category 1A2f – Non-metallic minerals

1A2f - Non-Metallic Minerals Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2 EF	CO_2 type	CH_4 EF	CH_4 type	N_2O EF	N_2O type	Source
Other Bituminous Coal	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Lignite, Brown Coal	solid	97 500	D	10.00	D	1.50	D	2006 IPCC GL
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 037	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
LPG	liquid	64 957	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Sewage Sludge	other	92 376	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Sewage Sludge	biomass	92 266	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Solvents	other	79 405	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Tires	other/biomass	88 000	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Fluff	other/biomass	83 629	PS	30.00	D	4.00	D	ETS 2006 IPCC GL

Source: Environment Agency

73 http://www.vdz-online.de/fileadmin/gruppen/vdz/3LiteraturRecherche/Taetigkeitsbericht07/VDZ_Kap_II.pdf

74 http://www.aliapur.fr/media/files/RetD_new/Conferences_Publications/Pneus_usages_comme_combustible_alternatif_extrait.pdf

75 http://ec.europa.eu/clima/policies/ets/monitoring/index_en.htm

Table 3-52 gives an overview of the evolution of the implied emission factors per fuel type.

The increase of the CO_2 IEF of biomass from 2002 onwards is due to the use of different types of biomass over time. Indeed, tires (CO_2 EF: 88.00 t CO_2/TJ) are used since 1998 as secondary fuel in the clinker production. Since 2002, sewage sludge and since 2006, fluff, are co-incinerated in the clinker production.

Table 3-52 – Implied emission factors for category 1A2f – Non-metallic minerals

1A2f - Non-Metallic Minerals Implied Emission Factors (kg/TJ)															
Year	Solid			Liquid			Gaseous			Biomass			Other		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	94 600	10.00	1.50	72 559	2.18	0.40	57 755	1.00	0.10	NO	NO	NO	NO	NO	NO
1991	94 600	10.00	1.50	74 592	2.52	0.48	57 743	1.00	0.10	NO	NO	NO	NO	NO	NO
1992	94 600	10.00	1.50	76 722	2.89	0.57	57 848	1.00	0.10	NO	NO	NO	NO	NO	NO
1993	94 600	10.00	1.50	76 510	2.85	0.56	57 894	1.00	0.10	NO	NO	NO	NO	NO	NO
1994	94 600	10.00	1.50	77 400	3.00	0.60	57 940	1.00	0.10	NO	NO	NO	NO	NO	NO
1995	94 600	10.00	1.50	76 381	2.83	0.56	57 929	1.00	0.10	NO	NO	NO	NO	NO	NO
1996	94 600	10.00	1.50	76 261	2.81	0.55	57 546	1.00	0.10	NO	NO	NO	NO	NO	NO
1997	94 600	10.00	1.50	74 501	2.52	0.48	57 205	1.00	0.10	NO	NO	NO	NO	NO	NO
1998	94 600	10.00	1.50	77 336	2.99	0.60	56 863	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
1999	94 600	10.00	1.50	77 010	2.93	0.58	56 522	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
2000	94 600	10.00	1.50	76 799	2.90	0.58	56 221	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
2001	94 600	10.00	1.50	77 400	3.00	0.60	56 258	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
2002	94 600	10.00	1.50	77 229	2.97	0.59	56 396	1.00	0.10	88 680	30.00	4.00	88 062	30.00	4.00
2003	94 600	10.00	1.50	77 400	3.00	0.60	56 533	1.00	0.10	89 999	30.00	4.00	88 204	30.00	4.00
2004	94 600	10.00	1.50	77 208	2.97	0.59	56 671	1.00	0.10	91 334	30.00	4.00	88 386	30.00	4.00
2005	94 600	10.00	1.50	77 400	3.00	0.60	56 910	1.00	0.10	90 117	30.00	4.00	88 218	30.00	4.00
2006	94 600	10.00	1.50	77 400	3.00	0.60	57 008	1.00	0.10	90 119	30.00	4.00	88 016	30.00	4.00
2007	94 600	10.00	1.50	77 400	3.00	0.60	56 793	1.00	0.10	89 578	30.00	4.00	87 239	30.00	4.00
2008	94 600	10.00	1.50	76 508	3.00	0.60	56 665	1.00	0.10	88 828	30.00	4.00	86 018	30.00	4.00
2009	94 600	10.00	1.50	74 077	3.00	0.60	57 056	1.00	0.10	92 348	30.00	4.00	83 544	30.00	4.00
2010	94 600	10.00	1.50	74 131	3.00	0.60	56 712	1.00	0.10	90 986	30.00	4.00	86 547	30.00	4.00
2011	94 600	10.00	1.50	74 116	3.00	0.60	56 988	1.00	0.10	90 284	30.00	4.00	87 058	30.00	4.00
2012	94 600	10.00	1.50	74 137	3.00	0.60	56 793	1.00	0.10	89 501	30.00	4.00	86 737	30.00	4.00
2013	94 629	10.00	1.50	74 146	3.00	0.60	56 680	1.00	0.10	86 334	30.00	4.00	85 044	30.00	4.00
2014	94 653	10.00	1.50	74 073	3.00	0.60	56 756	1.00	0.10	85 657	30.00	4.00	85 691	30.00	4.00
2015	94 711	10.00	1.50	73 447	2.85	0.56	56 760	1.00	0.10	88 017	30.00	4.00	85 334	30.00	4.00
2016	94 751	10.00	1.50	73 914	2.95	0.59	56 561	1.00	0.10	85 445	30.00	4.00	81 563	30.00	4.00
2017	94 753	10.00	1.50	73 870	2.94	0.58	56 577	1.00	0.10	85 473	30.00	4.00	79 209	30.00	4.00
2018	94 736	10.00	1.50	73 708	2.91	0.58	56 209	1.00	0.10	85 101	30.00	4.00	79 290	30.00	4.00
2019	94 746	10.00	1.50	73 843	2.95	0.59	56 091	1.00	0.10	86 143	30.00	4.00	77 411	30.00	4.00
2020	94 768	10.00	1.50	72 717	2.67	0.52	56 482	1.00	0.10	84 746	30.00	4.00	80 259	30.00	4.00
2021	94 743	10.00	1.50	74 006	2.97	0.59	56 664	1.00	0.10	84 319	30.00	4.00	82 185	30.00	4.00
2022	94 808	10.00	1.50	73 257	2.83	0.56	56 386	1.00	0.10	84 653	30.00	4.00	82 636	30.00	4.00

Source: Environment Agency

3.2.7.7 Other (1A2g)

3.2.7.7.1 Source category description

Source category *1A2g – Other* covers all the remaining industrial activities not previously mentioned and is divided into two sub-categories:

- *1.A.2.g.vii – Off-road vehicles and other machinery*, which includes all types of mobile machinery used in *1A2 - Manufacturing industry and Construction*, such as power generators, fork lifts, excavators, etc.
- *1.A.2.g.viii – Other Manufacturing Industries*, which includes stationary combustion in manufacturing of transport equipment, machinery, mining and quarrying, wood and wood products, construction, textile and leather and non-specified industry.

In 2022, fuel combustion emissions reported under *1A2g - Other* manufacturing industries and construction were responsible for 4.93% of GHG emissions from fuel combustion activities (this share was 0.99% in 1990) and represented 4.14% of the national total GHG emissions excluding LULUCF (0.80% in 1990). Compared to 2021, emissions decreased by 6.54% and compared to 1990, they increased by 234.31%.

3.2.7.7.2 Methodological issues

3.2.7.7.2.1 Activity data

The following combustion activities have been considered in category *1A2g - Other* (Table 3-53):

Table 3-53 – Combustion activities included in 1A2g - Other

Description	SNAP code
Combustion plants < 50 MW	030103
Gas Turbines	030104
Asphalt concrete plants	030313
Other mobile sources and machinery in Industry	080800
Other mobile equipment	081000

Combustion plants <50 MW

This source includes all kind of smaller combustion installations for heat or steam production. As the number of this kind of boilers is quite important, they have not always been treated individually. Various types of fuel were and still are used: anthracite, residual fuel oil, gas oil, LPG, natural gas. Where information about the fuel combustion in these boilers was available, it was received directly from the operator.

Gas Turbines

This source includes one gas turbine used in the wood processing industry for heat and electricity production running on natural gas. The information about the fuel combustion is received directly from the operator.

Asphalt concrete plants

There are three asphalt concrete plants in Luxembourg. Their main fuel is lignite (brown coal briquettes) followed by natural gas and gas oil. Fuel consumption data were obtained by the operators.

Mobile Sources and Machinery in Industry and Other Mobile Equipment

Activity data are based on the stock data of mobile machinery used in industry and construction equipment (based on the results of a survey from 2021 (M. Staudner, 2022)), as well as on economic indicators such as the gross value added for the industrial sector.

Activity data for *1A2g – Other* are listed in Table 3-54.

Table 3-54 – Activity data by fuel type of category *1A2g – Other*: 1990-2022

Acitivity data in 1A2g - Other (GJ)									
		1.A.2.g.vii - Off-road vehicles and other machinery			1.A.2.g.viii - Other Manufacturing Industries				
Year	Activity Total	Liquid Diesel Oil, Gasoline	Biomass Biodiesel, Biogasoline	Other fossil fuels Fossil part of biodiesel	Solid Other Bituminous Coal, Brown Coal Briquettes	Liquid Residual Fuel Oil, Gas Oil, LPG	Gaseous Natural Gas	Biomass Wood and Wood Waste, Biogas	Other Fossil part of wood and wood waste
1990	1 325 141	706 269	NO	NO	206 140	NO	412 733	NO	NO
1991	3 541 920	801 699	NO	NO	199 769	126 073	2 414 378	NO	NO
1992	3 905 335	869 993	NO	NO	217 880	5 465	2 811 997	NO	NO
1993	4 265 556	944 354	NO	NO	161 445	29 967	3 129 790	NO	NO
1994	4 296 935	992 028	NO	NO	320 437	81 196	2 903 274	NO	NO
1995	3 924 826	1 055 789	NO	NO	160 119	123 730	2 585 188	NO	NO
1996	4 026 926	1 022 208	NO	NO	254 976	54 382	2 695 360	NO	NO
1997	5 228 433	1 088 871	NO	NO	225 135	34 300	3 880 127	NO	NO
1998	5 452 646	1 113 260	NO	NO	183 946	246 589	3 908 852	NO	NO
1999	6 077 593	1 211 086	NO	NO	218 107	527 079	4 121 322	NO	NO
2000	3 551 560	1 271 815	NO	NO	232 377	674 838	1 372 530	NO	NO
2001	3 435 358	1 303 910	NO	NO	168 958	647 408	1 315 081	NO	NO
2002	3 386 131	1 459 067	NO	NO	138 204	625 726	1 163 134	NO	NO
2003	3 444 617	1 527 918	NO	NO	145 892	644 615	1 126 193	NO	NO
2004	3 501 561	1 618 037	470	27	147 911	480 392	1 254 724	NO	NO
2005	4 283 439	1 625 614	446	25	144 819	385 772	1 208 763	918 000	NO
2006	4 332 019	1 759 312	470	27	136 831	290 011	1 288 369	857 000	NO
2007	4 620 352	2 096 797	52 906	3 018	142 414	343 521	1 056 706	924 990	NO
2008	4 449 185	1 955 757	47 964	2 737	139 665	416 051	907 342	979 670	NO
2009	4 140 485	2 093 002	52 220	2 980	156 912	188 718	891 832	754 820	NO
2010	4 205 967	2 235 546	51 182	2 780	211 674	80 905	760 510	863 371	NO
2011	4 303 339	2 378 332	50 072	2 636	171 154	79 518	821 715	799 912	NO
2012	4 416 717	2 503 634	64 673	3 091	191 369	56 137	839 412	758 400	NO
2013	4 660 491	2 631 051	79 007	3 706	138 667	48 622	948 903	795 938	14 597
2014	4 771 324	2 743 732	107 043	5 334	147 760	35 215	775 777	941 678	14 784
2015	4 798 988	2 867 157	135 059	7 507	128 089	21 850	716 768	911 066	11 491
2016	5 752 801	3 008 736	154 588	8 460	151 902	43 279	790 342	1 550 555	44 939
2017	5 647 877	3 106 658	207 175	11 542	110 221	78 016	730 607	1 364 151	39 507
2018	5 743 179	3 267 138	216 960	12 093	114 247	87 880	497 298	1 495 980	51 582
2019	8 071 685	3 436 132	226 010	12 601	100 914	55 052	830 065	3 267 179	143 733
2020	9 520 047	3 474 822	347 172	15 062	112 032	20 709	626 139	4 703 625	220 486
2021	10 414 532	3 678 412	335 206	11 051	168 861	26 921	517 835	5 475 985	200 261
2022	9 853 274	3 760 270	372 516	13 905	77 376	15 106	191 925	5 230 013	192 164
Trend 1990-2022	643.56%	432.41%	NA	NA	-62.46%	NA	-53.50%	NA	NA
Trend 2021-2022	-5.39%	2.23%	11.13%	25.82%	-54.18%	-43.89%	-62.94%	-4.49%	-4.04%

Source: Environment Agency

3.2.7.7.2.2 Methodological choices

For CO_2, the 2006 IPCC Guidelines Tier 1 approach has been applied for solid fuels, residual fuel oil and biogas fuels (wood and wood waste, biogas), whereas the 2006 IPCC Guidelines Tier 2 approach was applied for natural gas, gas oil, diesel oil, gasoline, LPG, biomass (wood and wood waste), and other (fossil part of wood waste). For CH_4 and N_2O from stationary combustion, the 2006 IPCC Guidelines Tier 1 approach has been applied for all fuels.

For CH_4 and N_2O from off-road vehicles and other machinery, the GEORG (Grazer Emissionsmodell für Off-Road Geräte) model developed by the TU Graz was used. This methodology conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. Input data to the model are:

- Machinery stock data (obtained through inquiries (M. Staudner, 2022) and statistical extrapolation);
- Assumptions on drop-out rates of machinery (broken down machinery will be replaced);
- Operating time (obtained through inquiries (M. Staudner, 2022)), related to age of machinery.

From machinery stock data and drop-out rates an age structure of the off-road machinery was obtained by GEORG. Four categories of engine types were considered. Depending on the fuel consumption of the engine the ratio power of the engine was calculated. Emissions were calculated by multiplying an engine specific emission factor (expressed in g/kWh) by the average engine power, the operating time and the number of vehicles.

3.2.7.7.2.3 Emission factors

The 2006 IPCC Guidelines default CO_2 EFs have been applied for biogas, residual fuel oil and for solid fuels. For natural gas, gas oil, diesel oil, gasoline, LPG, biomass (wood and wood waste), and other (fossil part of wood waste) country-specific EFs were used. For stationary combustion, IPCC default EFs have been applied for CH_4 and N_2O.

For mobile combustion (diesel oil, motor gasoline, biofuels), country specific CO_2 EFs for diesel oil and gasoline, as described in section 3.2.5.3**,** were used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-55). The CH_4 emission factors are based on the EMEP/EEA 2023 Guidebook (Tier 3) while N_2O emission factors are based on (Hausberger, 2006). For biogasoline, biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 255 for details), the European CO_2 implied emission factors[76] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied.

76 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-55 – Emission factors for category *1A2g – Other*

1A2g - Other Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Other Bituminous Coal	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Brown Coal Briquettes	solid	97 500	D	10.00	D	1.50	D	2006 IPCC GL
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 037	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 037	CS	0.06	CS	7.48	CS	AEV
Gasoline	liquid	72 883	CS	20.45	CS	1.60	CS	AEV
LPG	liquid	64 957	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 386	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Biogas	biomass	54 600	D	1.00	D	0.10	D	2006 IPCC GL
Wood / wood wastes	biomass	112 983	IEF	30.00	D	4.00	D	2006 IPCC GL
Wood / wood wastes	other	113 297	IEF	30.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

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Table 3-56 gives an overview of the evolution of the implied emission factors for liquid fuels used by off-road vehicles and other machinery.

Table 3-56 – Implied emission factors for category *1.A.2.g.vii – Off-road vehicles and other machinery*

1.A.2.g.vii - Off-road vehicles and other machinery Implied Emission Factors (kg/TJ)			
Year	Liquid		
	CO_2	CH_4	N_2O
1990	74 159	3.67	26.26
1991	74 146	3.66	26.30
1992	74 123	3.65	26.32
1993	74 164	3.64	26.34
1994	74 188	3.58	26.64
1995	74 193	3.49	27.21
1996	74 184	3.43	27.56
1997	74 170	3.36	27.99
1998	74 161	3.28	28.54
1999	74 165	3.18	29.11
2000	74 202	3.11	29.59
2001	74 208	3.06	29.89
2002	74 209	2.70	28.68
2003	74 186	2.31	27.08
2004	74 146	2.00	25.14
2005	74 131	1.75	23.17
2006	74 131	1.46	20.89
2007	74 136	1.09	17.13
2008	74 081	0.90	14.91
2009	74 069	0.77	13.49
2010	74 122	0.64	11.92
2011	74 108	0.54	10.74
2012	74 128	0.46	9.86
2013	74 139	0.39	9.27
2014	74 065	0.34	8.79
2015	74 128	0.29	8.40
2016	74 135	0.26	8.11
2017	74 151	0.23	7.89
2018	74 125	0.20	7.72
2019	74 073	0.19	7.60
2020	74 140	0.17	7.54
2021	74 146	0.16	7.48
2022	74 031	0.15	7.45

Source: Environment Agency

Table 3-57 gives an overview of the evolution of the implied emission factors for fuels used in stationary combustion by other manufacturing industries.

Table 3-57 – Implied emission factors for category 1.A.2.g.viii – Other manufacturing industries

1.A.2.g.viii - Other Manufacturing Industries Implied Emission Factors (kg/TJ)															
Year	Solid			Liquid			Gaseous			Biomass			Other		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	97 393	10.00	1.50	NO	NO	NO	57 755	1.00	0.10	NO	NO	NO	NO	NO	NO
1991	97 411	10.00	1.50	77 400	3.00	0.60	57 743	1.00	0.10	NO	NO	NO	NO	NO	NO
1992	97 419	10.00	1.50	77 400	3.00	0.60	57 848	1.00	0.10	NO	NO	NO	NO	NO	NO
1993	97 376	10.00	1.50	77 400	3.00	0.60	57 894	1.00	0.10	NO	NO	NO	NO	NO	NO
1994	97 438	10.00	1.50	77 400	3.00	0.60	57 940	1.00	0.10	NO	NO	NO	NO	NO	NO
1995	97 374	10.00	1.50	77 400	3.00	0.60	57 929	1.00	0.10	NO	NO	NO	NO	NO	NO
1996	97 430	10.00	1.50	77 400	3.00	0.60	57 546	1.00	0.10	NO	NO	NO	NO	NO	NO
1997	97 447	10.00	1.50	65 212	1.00	0.10	57 205	1.00	0.10	NO	NO	NO	NO	NO	NO
1998	97 401	10.00	1.50	65 176	1.00	0.10	56 863	1.00	0.10	NO	NO	NO	NO	NO	NO
1999	97 445	10.00	1.50	65 453	1.00	0.10	56 522	1.00	0.10	NO	NO	NO	NO	NO	NO
2000	97 500	10.00	1.50	68 195	1.49	0.22	56 221	1.00	0.10	NO	NO	NO	NO	NO	NO
2001	97 500	10.00	1.50	68 588	1.55	0.24	56 258	1.00	0.10	NO	NO	NO	NO	NO	NO
2002	97 500	10.00	1.50	68 428	1.52	0.23	56 396	1.00	0.10	NO	NO	NO	NO	NO	NO
2003	97 500	10.00	1.50	67 429	1.36	0.19	56 533	1.00	0.10	NO	NO	NO	NO	NO	NO
2004	97 500	10.00	1.50	66 798	1.29	0.17	56 671	1.00	0.10	NO	NO	NO	NO	NO	NO
2005	97 500	10.00	1.50	66 145	1.20	0.15	56 910	1.00	0.10	112 000	30.00	4.00	NO	NO	NO
2006	97 500	10.00	1.50	66 105	1.19	0.15	57 008	1.00	0.10	112 000	30.00	4.00	NO	NO	NO
2007	97 500	10.00	1.50	66 107	1.19	0.15	56 793	1.00	0.10	112 000	30.00	4.00	NO	NO	NO
2008	97 500	10.00	1.50	65 767	1.12	0.13	56 665	1.00	0.10	112 000	30.00	4.00	NO	NO	NO
2009	97 500	10.00	1.50	66 564	1.30	0.18	57 056	1.00	0.10	112 000	30.00	4.00	NO	NO	NO
2010	97 500	10.00	1.50	75 944	2.96	0.59	56 712	1.00	0.10	112 000	30.00	4.00	NO	NO	NO
2011	97 500	10.00	1.50	75 730	3.00	0.60	56 988	1.00	0.10	110 996	29.49	3.93	NO	NO	NO
2012	97 500	10.00	1.50	75 593	2.92	0.58	56 793	1.00	0.10	106 298	27.12	3.61	NO	NO	NO
2013	97 500	10.00	1.50	75 214	2.89	0.57	56 680	1.00	0.10	106 514	27.28	3.63	111 705	30.00	4.00
2014	97 500	10.00	1.50	74 372	2.86	0.57	56 756	1.00	0.10	106 831	27.41	3.65	111 812	30.00	4.00
2015	97 500	10.00	1.50	74 132	3.00	0.60	56 760	1.00	0.10	97 179	27.07	3.61	107 084	30.00	4.00
2016	97 500	10.00	1.50	74 943	2.90	0.58	56 561	1.00	0.10	101 464	28.38	3.78	106 329	30.00	4.00
2017	97 500	10.00	1.50	76 535	3.00	0.60	56 577	1.00	0.10	100 899	27.99	3.73	106 431	30.00	4.00
2018	97 500	10.00	1.50	76 706	3.00	0.60	56 209	1.00	0.10	102 484	28.22	3.76	107 586	30.00	4.00
2019	97 500	10.00	1.50	75 802	2.89	0.57	56 091	1.00	0.10	109 885	29.51	3.93	112 104	30.00	4.00
2020	97 500	10.00	1.50	75 013	3.00	0.60	56 482	1.00	0.10	108 475	29.49	3.93	110 022	30.00	4.00
2021	97 500	10.00	1.50	74 544	2.88	0.57	56 664	1.00	0.10	112 124	29.62	3.95	113 222	30.00	4.00
2022	97 500	10.00	1.50	74 268	3.00	0.60	56 386	1.00	0.10	112 335	29.68	3.96	113 297	30.00	4.00

Source: Environment Agency

3.2.7.8 Uncertainties and time-series consistency

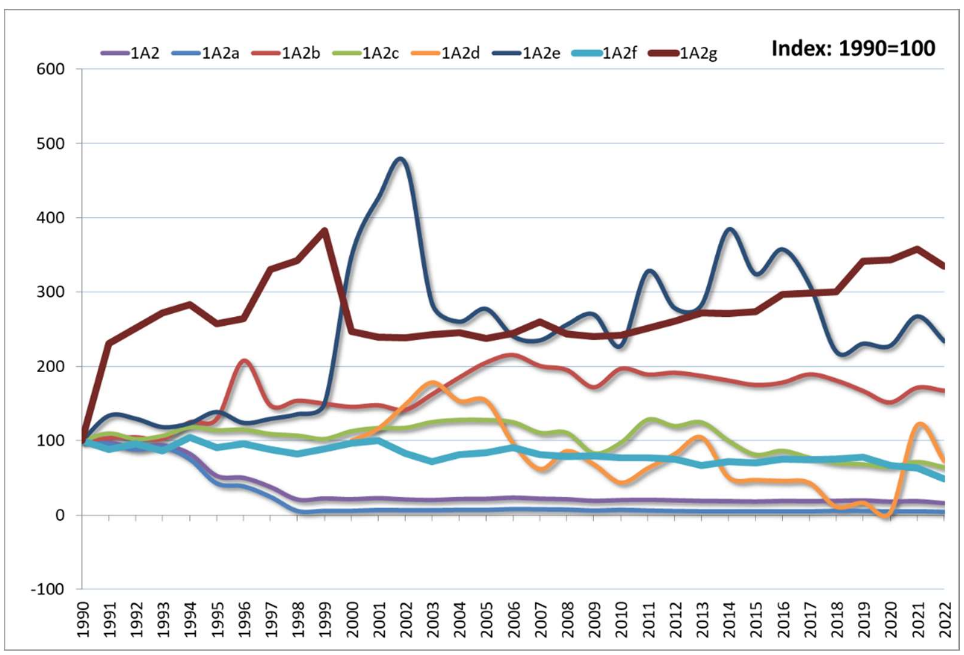
The uncertainties for activity data and emission factors used for IPCC category *1A2 – Manufacturing Industries and Construction* are presented in Table 3-58.

Table 3-58 - Uncertainties for activity data and emission factors used for IPCC category 1A2 – Manufacturing Industries and Construction.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A2 - Gaseous Fuels	CO_2	2%	0.5%
1A2 - Gaseous Fuels	CH_4	2%	50%
1A2 - Gaseous Fuels	N_2O	2%	50%
1A2 - Liquid Fuels	CO_2	2%	0.5%
1A2 - Liquid Fuels	CH_4	2%	50%
1A2 - Liquid Fuels	N_2O	2%	50%
1A2 - Other Fuels	CO_2	8%	20%
1A2 - Other Fuels	CH_4	8%	50%
1A2 - Other Fuels	N_2O	8%	50%
1A2 - Biomass	CH_4	7%	50%
1A2 - Biomass	N_2O	7%	60%
1A2 - Solid Fuels	CO_2	1%	3%
1A2 - Solid Fuels	CH_4	1%	50%
1A2 - Solid Fuels	N_2O	1%	50%

Generally, the time-series, as reported in category *1A2 - Manufacturing Industries and Construction* are considered to be consistent (Figure 3-7).

Figure 3-7 – GHG emission trend indices for category *1A2 – Manufacturing Industries and Construction*: 1990-2022



The general trend of GHG emissions in 1A2 is greatly influenced by sub-categories 1A2a - Iron and Steel and 1A2f – Non-Metallic Minerals. Fluctuations in emissions of the other sub-categories only influence the general trend on a decreased scale.

However, at a deeper level, and especially for categories 1A2d, 1A2e and 1A2g, time series seem to be less consistent. This is either due to the lack of specific activity data (for example for 1A2d where no category-specific AD is available for the years 1990-1999 so that the notation key IE is used and the corresponding emissions are reported under 1A2g), or due to short-term switches in the energy mix (rotation of gas oil stocks), maintenance stops, closure or start-up of new facilities, etc.

For more specific information on time-series consistency, please refer to the methodological issues as described in the respective categories above.

3.2.7.9 Source-specific QA/QC and verification

Activity data for large facilities that have reporting obligations under the European Union Emission Trading System (EU-ETS) are cross-checked between two sources: reports obtained directly from (1) the operator under its operational permit obligations and (2) the EU-ETS registry operator. Both are hosted at the Environment Agency. A list with the large energy consuming facilities along with their respective fuel consumption has been compiled and enables the Single National Entity to quickly cross-check this data with the EU-ETS data. Thus, completeness can be checked on a more systematic basis.

Additionally, cross checks with other relevant sectors, mainly sector 2 – Industrial Processes and Product Use, are performed to avoid double counting.

Finally, consistency and completeness checks are performed using the tools embedded in CRF Reporter.

3.2.7.10 Category-specific recalculations including changes made in response to the review process

Table 3-59 presents the main revisions and recalculations done since the last submission to the UNFCCC and relevant to category 1A2 - Manufacturng Industries and Construction. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 3-59 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
1A2c	Error correction in the calculation of greenhouse gas emissions from gas oil from a specific operator for the years 1998-2011. The recalculations are quantified in Table 3-60.	Error correction
1A2c	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-6} Gg CO_2 for any given year).	CO_2 EF
1A2e	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-6} Gg CO_2 for any given year).	CO_2 EF
1A2f	Revision of the country-specific CO_2 emissions factor for LPG for 2016-2021. The effects on the GHG emissions are marginal (less than 10^{-3} Gg CO_2 for any given year)	CO_2 EF
1A2f	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-4} Gg CO_2 for any given year).	CO_2 EF
1A2gviii	Revision of the residual fuel oil, liquid petroleum gas, and biogas activity data due to changes in the national energy balance for 2021 (+7728 GJ for RFO, +47 GJ, and +2993 GJ for biogas compared to the previous submission). As a result, greenhouse gas emissions in the 1A2gviii sector increased by 0.6 Gg CO_2 eq. for 2021 in this submission.	AD

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
1A2gviii	Revision of the country-specific CO_2 emissions factor for LPG for 2016-2021. The effects on the GHG emissions are marginal (less than 10^{-2} Gg CO_2 for any given year)	CO_2 EF
1A2gviii	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-5} Gg CO_2 for any given year).	CO_2 EF
1A2gvii	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-61).	AD
1A2gvii	For several years, the country-specific CO2 EFs for diesel oil (2017-2020) and motor gasoline (2017-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10 2 for further details.	CO_2 EF
1A2a/c/d/e/f/gv iii	In the latest national energy balance, changes were made to the allocation method of natural gas to the different sectors for the year 2021. While significant differences are observed for each sub-category, the total amount of natural gas consumed by the energy sector in 2021 decreases only by 155GJ (corresponding to -0.060 Gg CO2eq). The affected sectors and the respective recalculations are shown in Table 3-62.	AD

Table 3-60 – Changes to the greenhouse gas emissions from total gasoil combustion between submissions 2023v1 and 2024v1 in the 1.A.2.c – Chemicals category.

1A2c - Chemicals GHG emissions (in Gg CO_2 eq.) from gasoil			
Year	**Submission 2023v1**	**Submission 2024v1**	**Difference**
1998	0.10	0.16	0.06
1999	0.09	0.59	0.50
2000	0.29	0.31	0.02
2001	0.16	0.20	0.04
2002	0.26	0.33	0.07
2003	0.41	0.43	0.02
2004	0.09	0.12	0.04
2005	0.18	0.21	0.03
2006	0.40	0.43	0.03
2007	0.03	0.06	0.03
2008	0.02	0.03	0.01
2009	0.05	0.05	0.00
2010	0.07	0.09	0.01
2011	0.10	0.10	0.00

Source: Environment Agency

Table 3-61: Activity data changes in category 1A2gvii from submission 2023v1 to 2024v1

AD changes in GJ	1A2gii liquid	1A2gvii biomass	1A2gvii other
2004	0.1547	-0.1370	-0.0078
2005	0.1348	-0.1193	-0.0068
2006	0.1092	-0.0967	-0.0055
2007	13.7812	-12.2018	-0.6965
2008	11.7143	-10.3718	-0.5920
2009	-22.4934	19.9154	1.1368
2010	-1.0459	0.9284	0.0505
2011	-5.2834	4.6967	0.2481
2012	-1.5693	1.4017	0.0670
2013	7.5678	-6.7655	-0.3174
2014	-32.5810	29.0445	1.4491
2015	8.6403	-7.6600	-0.4268
2016	20.5480	-18.2311	-1.0005
2017	31.5315	-27.9517	-1.5597
2018	19.8323	-17.5797	-0.9819
2019	12.2755	-10.8802	-0.6087
2020	18.6719	-16.7473	-0.7283
2021	24.4613	-22.1615	-0.7325

Table 3-62: Activity data updates due to changes of the natural gas allocation method in the national energy balance for 2021

Natural gas AD changes due to revision of allocation in the national energy balance for 2021		
Sector	AD change (GJ)	GHG emissions change (Gg CO2eq)
1A1	732472	41.545
1A2a	-577494	-32.755
1A2c	-99715	-5.656
1A2d	234615	13.307
1A2e	12058	0.684
1A2f	45960	2.607
1A2gviii	109780	6.227
1A4	-457830	-26.019
sum	**-155**	**-0.060**

Table 3-63 shows the effect of all the recalculations listed in Table 3-59 on the total activity data and GHG emissions for the entire time series.

Table 3-63 – Effect of the recalculations in 1A2 – Manufacturing Industries and Construction on the activity data and GHG emissions (CO_2 emissions from biomass are excluded) between submissions 2023v1 and 2024v1 for the entire time series.

1A2 - Manufacturing Industries and Construction Activity data (AD) of all fuels and related GHG emissions (in Gg CO_2 eq.)						
Year	Submission 2023v1		Submission 2024v1		Difference	
	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.
1990	43 081.01	6 244.49	43 081.01	6 244.49	0.00	0.00
1991	42 630.61	6 073.15	42 630.61	6 073.15	0.00	0.00
1992	41 601.78	5 724.68	41 601.78	5 724.68	0.00	0.00
1993	42 348.42	5 863.45	42 348.42	5 863.45	0.00	0.00
1994	39 648.44	5 146.70	39 648.44	5 146.70	0.00	0.00
1995	30 097.44	3 289.69	30 097.44	3 289.69	0.00	0.00
1996	30 152.37	3 131.78	30 152.37	3 131.78	0.00	0.00
1997	26 643.59	2 362.98	26 643.59	2 362.98	0.00	0.00
1998	20 441.77	1 313.67	20 441.77	1 313.73	0.00	0.06
1999	21 959.73	1 404.73	21 959.73	1 405.24	0.00	0.50
2000	20 700.24	1 343.43	20 700.24	1 343.45	0.00	0.02
2001	22 136.60	1 425.92	22 136.60	1 425.96	0.00	0.04
2002	20 913.38	1 320.59	20 913.38	1 320.66	0.00	0.07
2003	20 256.96	1 273.68	20 256.96	1 273.70	0.00	0.02
2004	21 643.71	1 363.34	21 643.71	1 363.38	0.00	0.04
2005	22 572.17	1 373.49	22 572.17	1 373.52	0.00	0.03
2006	23 954.48	1 472.79	23 954.48	1 472.82	0.00	0.03
2007	22 931.38	1 386.16	22 931.38	1 386.19	0.00	0.03
2008	22 315.59	1 338.96	22 315.59	1 338.97	0.00	0.01
2009	19 644.38	1 211.49	19 644.38	1 211.49	0.00	0.00
2010	20 941.48	1 270.11	20 941.48	1 270.12	0.00	0.01
2011	21 207.29	1 294.36	21 207.29	1 294.36	0.00	0.00
2012	20 412.07	1 246.68	20 412.07	1 246.68	0.00	0.00
2013	19 670.75	1 199.91	19 670.75	1 199.91	0.00	0.00
2014	19 462.93	1 180.97	19 462.93	1 180.97	0.00	0.00
2015	18 848.44	1 144.72	18 848.44	1 144.72	0.00	0.00
2016	20 213.35	1 196.45	20 213.35	1 196.45	0.00	0.00
2017	19 743.05	1 179.15	19 743.05	1 179.15	0.00	0.00
2018	20 357.34	1 201.25	20 357.34	1 201.25	0.00	0.00
2019	22 554.54	1 237.32	22 554.54	1 237.31	0.00	0.00
2020	22 372.55	1 141.89	22 372.55	1 141.89	0.00	0.00
2021	23 704.31	1 193.90	23 440.28	1 178.92	-264.03	-14.98

Source: Environment Agency

3.2.7.11 Category-specific planned improvements including those in response to the review process

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-64 will be explored.

Table 3-64 – Planned improvements for category *1A2– Manufacturing Industries and Construction.*

GHG source & sink category	Planned improvement
1A2	No planned improvements

3.2.9 Transport (1.A.3)

3.2.9.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in the transport sector.

The 2024 GHG inventory submission includes emissions from IPCC sub-categories *1A3a – Domestic aviation*, *1A3b – Road Transportation*, *1A3c – Railways* and *1A3d– Domestic Navigation*. This submission does not record any GHG emissions for the IPCC sub-category *1A3e – Other Transportation*.

In 2022, this source category was responsible for 61.29% of GHG emissions from fuel combustion activities (this share was only 25.58% in 1990) and represented 51.48% of the national total GHG emissions excluding LULUCF (coming from 20.64% in 1990). Compared to 2021, emissions decreased by 14.27% and compared to 1990 they increased by 60.55%. As can be seen in Table 3-65, which summarizes the GHG emissions from the 1A3 Transport category, the recent decrease in emissions originates from the 1A3b – Road Transportation subsector and is mainly due to a significant reduction of diesel oil consumption.

Table 3-65 – GHG emission trends in CO_2eq for IPCC sub-category 1A3 – Transport: 1990-2022

1A3 - Transport GHG emissions by source & sink category (Gg)												
Year	1A3a - Civil Aviation				1A3b - Road Transportation				1A3c - Railways			
	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O
1990	0.22	0.21	0.000002	0.00001	2 600.09	2 572.38	0.50	0.05	24.91	24.823	0.0020	0.00012
1991	0.33	0.33	0.000002	0.00001	3 198.36	3 165.60	0.54	0.07	24.91	24.819	0.0020	0.00012
1992	0.46	0.46	0.000003	0.00001	3 492.45	3 457.18	0.50	0.08	24.90	24.810	0.0019	0.00012
1993	0.60	0.60	0.000004	0.00002	3 537.22	3 501.75	0.43	0.09	24.91	24.824	0.0019	0.00012
1994	0.71	0.70	0.000005	0.00002	3 594.26	3 557.53	0.38	0.10	24.19	24.105	0.0019	0.00012
1995	0.77	0.76	0.000005	0.00002	3 356.63	3 321.96	0.32	0.10	19.59	19.520	0.0015	0.00010
1996	0.78	0.78	0.000006	0.00002	3 470.36	3 435.67	0.29	0.10	21.89	21.810	0.0017	0.00011
1997	0.79	0.79	0.000006	0.00002	3 739.60	3 704.68	0.28	0.10	21.51	21.437	0.0016	0.00011
1998	0.68	0.68	0.000005	0.00002	3 934.54	3 900.71	0.26	0.10	21.51	21.434	0.0016	0.00011
1999	0.70	0.69	0.000005	0.00002	4 366.44	4 332.58	0.24	0.10	21.51	21.436	0.0016	0.00011
2000	0.66	0.66	0.000005	0.00002	4 896.16	4 861.67	0.24	0.10	21.30	21.223	0.0016	0.00011
2001	0.66	0.65	0.000005	0.00002	5 153.10	5 119.56	0.23	0.10	22.95	22.871	0.0017	0.00012
2002	0.61	0.61	0.000004	0.00002	5 334.85	5 302.54	0.21	0.10	20.28	20.211	0.0015	0.00011
2003	0.71	0.71	0.000005	0.00002	5 875.08	5 842.53	0.21	0.10	17.68	17.615	0.0012	0.00009
2004	0.62	0.62	0.000004	0.00002	6 837.56	6 804.66	0.21	0.10	14.04	13.992	0.0010	0.00007
2005	0.62	0.61	0.000004	0.00002	7 205.59	7 173.08	0.18	0.10	8.91	8.882	0.0006	0.00005
2006	0.53	0.52	0.000004	0.00001	6 861.37	6 829.52	0.16	0.10	6.64	6.623	0.0004	0.00003
2007	0.56	0.55	0.000004	0.00002	6 564.85	6 530.64	0.14	0.11	9.21	9.179	0.0006	0.00005
2008	0.53	0.53	0.000004	0.00002	6 655.42	6 617.25	0.13	0.13	10.57	10.542	0.0006	0.00005
2009	0.55	0.54	0.000004	0.00002	6 115.41	6 077.59	0.11	0.13	10.17	10.146	0.0005	0.00005
2010	0.54	0.54	0.000004	0.00002	6 492.18	6 449.56	0.11	0.15	10.98	10.953	0.0005	0.00005
2011	0.57	0.57	0.000004	0.00002	6 854.24	6 805.57	0.11	0.17	11.01	10.986	0.0005	0.00005
2012	0.50	0.49	0.000004	0.00001	6 541.79	6 492.21	0.11	0.18	9.97	9.950	0.0004	0.00005
2013	0.48	0.47	0.000003	0.00001	6 411.02	6 359.79	0.10	0.18	8.59	8.567	0.0003	0.00004
2014	0.51	0.50	0.000004	0.00001	6 093.71	6 041.19	0.11	0.19	9.77	9.749	0.0003	0.00004
2015	0.61	0.60	0.000004	0.00002	5 661.64	5 609.60	0.11	0.18	6.66	6.644	0.0002	0.00003
2016	0.61	0.61	0.000004	0.00002	5 483.04	5 430.23	0.12	0.19	6.09	6.079	0.0002	0.00002
2017	0.58	0.58	0.000004	0.00002	5 621.29	5 565.23	0.13	0.20	6.61	6.599	0.0002	0.00003
2018	0.57	0.56	0.000004	0.00002	6 002.78	5 942.13	0.14	0.21	7.03	7.014	0.0002	0.00003
2019	0.51	0.51	0.000004	0.00001	6 162.80	6 100.48	0.14	0.22	6.79	6.775	0.0002	0.00003
2020	0.50	0.49	0.000004	0.00001	4 610.50	4 561.55	0.11	0.17	6.80	6.790	0.0002	0.00003
2021	0.60	0.60	0.000004	0.00002	4 910.66	4 859.25	0.12	0.18	7.48	7.468	0.0002	0.00003
2022	0.54	0.54	0.000004	0.00002	4 209.99	4 163.64	0.12	0.16	5.97	5.962	0.0002	0.00002
Trend 1990-2022	150.10%	150.10%	150.10%	150.10%	61.92%	61.86%	-75.41%	211.76%	-76.03%	-75.98%	-91.37%	-82.81%
Trend 2021-2022	-10.20%	-10.20%	-10.20%	-10.20%	-14.27%	-14.32%	0.93%	-10.58%	-20.18%	-20.17%	-21.51%	-21.78%

1A3 - Transport GHG emissions by source & sink category (Gg)								
Year	1A3d - Navigation				1A3 - Transport			
	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O
1990	1.44	1.31	0.0013	0.00037	2 626.66	2 598.73	0.50	0.05
1991	1.58	1.43	0.0018	0.00039	3 225.18	3 192.17	0.54	0.07
1992	1.51	1.36	0.0019	0.00036	3 519.32	3 483.81	0.50	0.08
1993	1.58	1.42	0.0019	0.00040	3 564.31	3 528.59	0.43	0.09
1994	1.50	1.35	0.0018	0.00038	3 620.67	3 583.69	0.38	0.10
1995	1.29	1.16	0.0015	0.00034	3 378.28	3 343.40	0.32	0.10
1996	1.31	1.17	0.0015	0.00035	3 494.34	3 459.43	0.30	0.10
1997	1.33	1.20	0.0014	0.00037	3 763.24	3 728.10	0.28	0.10
1998	1.30	1.16	0.0014	0.00036	3 958.03	3 923.98	0.26	0.10
1999	1.43	1.28	0.0014	0.00041	4 390.07	4 355.99	0.25	0.10
2000	1.26	1.13	0.0011	0.00038	4 919.38	4 884.68	0.24	0.11
2001	1.41	1.26	0.0012	0.00042	5 178.13	5 144.35	0.23	0.10
2002	1.54	1.38	0.0013	0.00046	5 357.28	5 324.74	0.22	0.10
2003	1.61	1.45	0.0013	0.00048	5 895.08	5 862.30	0.21	0.10
2004	1.49	1.34	0.0011	0.00044	6 853.71	6 820.61	0.21	0.10
2005	1.57	1.42	0.0010	0.00045	7 216.69	7 184.00	0.19	0.10
2006	1.45	1.32	0.0009	0.00040	6 869.99	6 837.99	0.16	0.10
2007	1.45	1.32	0.0009	0.00040	6 576.07	6 541.69	0.15	0.11
2008	1.62	1.48	0.0009	0.00043	6 668.14	6 629.81	0.13	0.13
2009	1.35	1.24	0.0008	0.00034	6 127.48	6 089.51	0.12	0.13
2010	1.46	1.35	0.0008	0.00036	6 505.17	6 462.39	0.11	0.15
2011	1.42	1.31	0.0006	0.00036	6 867.24	6 818.43	0.11	0.17
2012	1.42	1.32	0.0005	0.00035	6 553.68	6 503.97	0.11	0.18
2013	1.23	1.14	0.0005	0.00029	6 421.31	6 369.97	0.10	0.18
2014	1.31	1.22	0.0005	0.00030	6 105.29	6 052.66	0.11	0.19
2015	1.16	1.08	0.0004	0.00026	5 670.07	5 617.93	0.11	0.19
2016	1.22	1.13	0.0004	0.00027	5 490.96	5 438.05	0.12	0.19
2017	1.32	1.23	0.0004	0.00031	5 629.81	5 573.64	0.13	0.20
2018	1.28	1.19	0.0004	0.00028	6 011.66	5 950.90	0.14	0.21
2019	1.10	1.03	0.0003	0.00023	6 171.19	6 108.79	0.14	0.22
2020	0.42	0.39	0.0001	0.00011	4 618.22	4 569.22	0.11	0.17
2021	0.45	0.42	0.0001	0.00010	4 919.20	4 867.74	0.12	0.18
2022	0.58	0.54	0.0001	0.00013	4 217.08	4 170.67	0.12	0.16
Trend 1990-2022	-60.01%	-58.72%	-89.54%	-65.87%	60.55%	60.49%	-75.51%	209.09%
Trend 2021-2022	27.21%	27.52%	31.84%	21.99%	-14.27%	-14.32%	0.92%	-10.57%

Source: Environment Agency

3.2.9.2 Domestic aviation (1A3a)

3.2.9.2.1 Source category description

In Luxembourg, domestic aviation, excluding international flights, is a very small activity. There is only one airport for commercial aviation in Luxembourg operated by lux-Airport (Findel). Therefore, all commercial flights, either inbound or outbound, are international flights. For this reason, emissions of kerosene consumption are not included in the national total of Luxembourg, but under international bunkers – aviation, as a memo item. However, private flights with Luxembourg as a start and return point are considered as domestic flights. These are mainly leisure or emergency (medical, police) flights made with small-sized propeller planes or helicopters using aviation gasoline.

In 2022, domestic aviation fuel consumption was responsible for 0.008% of GHG emissions from fuel combustion activities (0.002% in 1990) and represented 0.007% of the national total GHG emissions in CO_2 eq., excluding LULUCF (0.002% in 1990). Compared to 2021, emissions decreased by 10.20%, and compared to 1990 they increased by 150.10%. In absolute terms, 1A3a emitted 0.54 Gg CO_2 eq. in 2022.

Fuel consumption emissions from domestic aviation are not a key source.

3.2.9.2.2 Methodological issues & time-series consistency

3.2.9.2.2.1 Activity data

There is only one company selling aviation fuels in Luxembourg: Luxfuel S.A.. Activity data for aviation gasoline is obtained directly from this company.

For aviation gasoline, a country-specific NCV (obtained directly from the sole vendor, Luxfuel S.A.) of 43.5 GJ/t aviation gasoline has been applied for converting activity data.

Expert judgement has been made for determining the share of aviation gasoline that is being exported – international flights - and the share that is allocated to domestic flights. Based on information obtained from the airport authorities, and from the aviation sport clubs registered in Luxembourg, it can be assumed that 90% of aviation gasoline sales are directed towards domestic flights.

3.2.9.2.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for domestic fights. As it is assumed that 90% of aviation gasoline sales are directed towards domestic flights, the emissions of the remaining 10% (international flights) have been accounted for under emissions from international bunker fuels – aviation. Please also refer to section 3.2.2.1 were more details on the split between domestic aviation and international aviation are described.

3.2.9.2.2.3 Emission factors

Default CO_2, CH_4 and N_2O emission factors for aviation gasoline, from the 2006 IPCC Guidelines, were used to calculate the corresponding emissions.

Activity data and emission factors for IPCC sub-category 1A3a – Domestic aviation are listed in

Table 3-66.

The time-series are considered to be consistent, although the split between domestic and international flights - combusting aviation gasoline - is kept constant over the entire time-series due to a lack of specific annual information.

Table 3-66– Activity data and emission factors for IPCC sub-category 1A3a – Domestic aviation: 1990-2022

1A3a - Civil Aviation Aviation Gasoline								
Year	Activity data (GJ)	Emission Factors (kg/TJ)						
		CO_2	type	CH_4	type	N_2O	type	source
1990	3 069	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1991	4 662	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1992	6 579	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1993	8 514	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1994	10 071	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1995	10 845	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1996	11 078	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1997	11 232	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1998	9 667	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1999	9 887	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2000	9 418	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2001	9 354	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2002	8 670	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2003	10 095	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2004	8 850	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2005	8 768	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2006	7 466	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2007	7 904	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2008	7 576	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2009	7 739	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2010	7 646	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2011	8 120	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2012	7 059	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2013	6 749	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2014	7 176	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2015	8 630	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2016	8 693	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2017	8 291	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2018	8 068	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2019	7 238	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2020	7 053	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2021	8 548	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2022	7 676	70 000	D	0.50	D	2.00	D	2006 IPCC GL
Trend 1990-2022	150.10%	0.00%		0.00%		0.00%		
Trend 2021-2022	-10.20%	0.00%		0.00%		0.00%		

Source: Environment Agency

3.2.9.3 Road Transportation (1A3b)

3.2.9.3.1 Source category description

In 2022, road transportation was responsible for 61.19% of GHG emissions from fuel combustion activities (this share was only 25.32% in 1990) and represented 51.39% of the national total GHG emissions excluding LULUCF (20.43% in 1990). In absolute terms, GHG emissions from road transportation reached 4210 Gg CO_2 eq. in 2022. Compared to 2021, GHG emissions decreased by 14.27%. This evolution is mainly due to declining diesel oil sales to transiting vehicles because the price difference between Luxembourg and its neighbouring countries has become less important.

With 38.73% of the total GHG emissions from Luxembourg, road transportation - diesel oil is the largest key category in 2022 (please refer to Table 1-6). Regarding CO_2, sub-category 1A3b has been a key category for both diesel oil and gasoline without interruption since 1990 (with and without LULUCF, Table 1-7 and Table 1-9).

Luxembourg reports emissions from lubricants exclusively under category 2.D.1 (please refer to section 4.5.1.1). The activity data obtained from the national statistics institute (Statec) does not allow for a disaggregation of the lubricants consumption between 2-stroke engines and other applications. Furthermore, the number of 2-stroke engines in Luxembourg is very low; the gasoline consumption by this vehicle category in 2022 was less than 10 tonnes. Assuming a mixture of 1:50 as suggested by the IPCC 2006 Guidelines, the lubricant consumption of 2-stroke engines is about 0.2 tonnes, and the associated CO_2 emissions are 0.0006 kt CO_2 emissions, which is below the threshold of significance.

Emissions from road transportation, as reported in the CRF tables, are shown in Table 3-67.

As already explained in previous sections of the NIR (please refer to Chapter 2 on emission trends), Luxembourg's situation regarding emissions from *1A3b - Road Transportation* is quite unique, due to the high share of fuel export in vehicle tanks. In 2022, GHG emissions from road fuel export were 1.6 times higher than those from the domestic fleet.

Figure 3-8 shows the evolution of fuel sold (*i.e.* blended fuel) in Luxembourg. Diesel oil is by far the most sold fuel, for both the domestic and the transiting fleets.

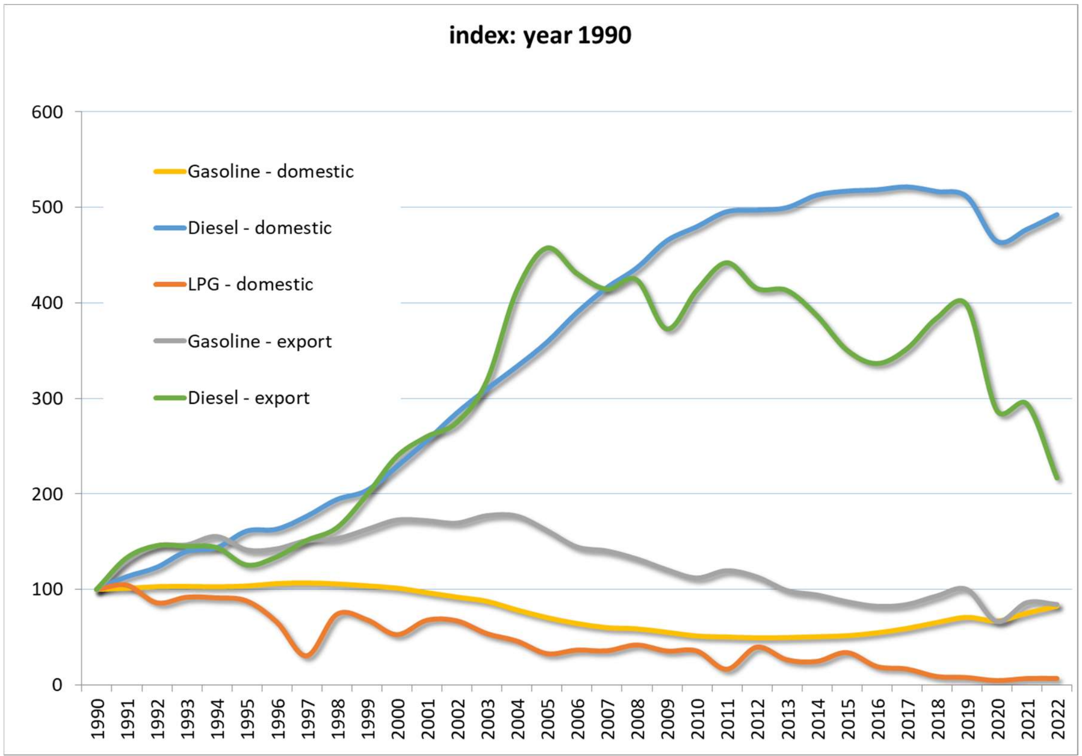
Figure 3-9 and Table 3-68 detail the quantities of blended fuel sold to the domestic fleet and the amount of fuel exported.

Table 3-67 – Activity data, emissions, and implied emission factor trends of IPCC sub-category 1A3b – Road Transportation: 1990-2022

1A3b - Road Transportation Activity Data, Emissions and Implied Emission Factors												
Year	Activity (GJ)					Emissions (Gg)				Implied Emission Factors (kg/TJ)		
	Total (excl. biomass)	Gasoline (blended)	Diesel (blended)	LPG	Biomass	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	35 176 077	17 663 767	17 337 970	174 340	NO	2 600.09	2 572.38	0.50	0.05	73 129	14.15	1.48
1991	43 240 313	20 717 891	22 339 894	182 528	NO	3 198.36	3 165.60	0.54	0.07	73 209	12.46	1.54
1992	47 006 400	22 417 370	24 438 794	150 236	NO	3 492.45	3 457.18	0.50	0.08	73 547	10.59	1.71
1993	47 655 388	22 532 552	24 962 480	160 356	NO	3 537.22	3 501.75	0.43	0.09	73 481	8.99	1.86
1994	48 433 767	23 373 265	24 901 157	159 344	NO	3 594.26	3 557.53	0.38	0.10	73 452	7.86	2.03
1995	45 241 829	22 046 321	23 041 960	153 548	NO	3 356.63	3 321.96	0.32	0.10	73 427	7.06	2.15
1996	46 754 482	22 355 084	24 284 168	115 230	NO	3 470.36	3 435.67	0.29	0.10	73 483	6.25	2.14
1997	50 446 299	23 253 609	27 139 422	53 268	NO	3 739.60	3 704.68	0.28	0.10	73 438	5.47	2.03
1998	53 077 916	23 376 613	29 572 411	128 892	NO	3 934.54	3 900.71	0.26	0.10	73 490	4.81	1.90
1999	58 932 008	24 174 316	34 638 368	119 324	NO	4 366.44	4 332.58	0.24	0.10	73 518	4.14	1.73
2000	66 117 768	24 964 535	41 061 324	91 908	NO	4 896.16	4 861.67	0.24	0.10	73 530	3.61	1.59
2001	69 549 776	24 539 046	44 892 510	118 220	NO	5 153.10	5 119.56	0.23	0.10	73 610	3.25	1.48
2002	72 005 180	23 918 767	47 969 160	117 254	NO	5 334.85	5 302.54	0.21	0.10	73 641	2.97	1.38
2003	79 281 580	24 344 654	54 843 086	93 840	NO	5 875.08	5 842.53	0.21	0.10	73 693	2.66	1.27
2004	92 325 492	23 603 711	68 640 320	80 316	5 403	6 837.56	6 804.66	0.21	0.10	73 703	2.23	1.11
2005	97 236 983	21 493 519	75 685 002	57 270	5 272	7 205.59	7 173.08	0.18	0.10	73 769	1.90	1.06
2006	92 544 683	19 310 134	73 169 717	63 710	5 259	6 861.37	6 829.52	0.16	0.10	73 797	1.72	1.12
2007	88 517 422	18 475 222	69 878 606	62 468	567 914	6 564.85	6 530.64	0.14	0.11	73 778	1.63	1.29
2008	89 725 467	17 583 741	71 967 491	73 002	574 774	6 655.42	6 617.25	0.13	0.13	73 750	1.44	1.45
2009	82 438 153	16 196 904	66 084 635	62 069	588 155	6 115.41	6 077.59	0.11	0.13	73 723	1.39	1.58
2010	87 388 088	15 049 758	72 185 930	62 187	549 809	6 492.18	6 449.56	0.11	0.15	73 804	1.22	1.71
2011	92 204 314	15 340 272	76 749 894	28 717	784 796	6 854.24	6 805.57	0.11	0.17	73 810	1.19	1.87
2012	87 953 165	14 963 056	72 830 633	69 149	699 809	6 541.79	6 492.21	0.11	0.18	73 814	1.20	2.00
2013	86 088 143	13 619 328	72 320 508	45 975	746 663	6 411.02	6 359.79	0.10	0.18	73 875	1.16	2.12
2014	81 843 670	13 064 590	68 602 023	43 065	1 050 188	6 093.71	6 041.19	0.11	0.19	73 814	1.29	2.29
2015	75 848 902	12 175 731	63 447 084	59 212	1 369 100	5 661.64	5 609.60	0.11	0.18	73 958	1.45	2.44
2016	73 416 624	11 829 646	61 379 948	33 645	1 492 458	5 483.04	5 430.23	0.12	0.19	73 965	1.60	2.55
2017	75 216 297	12 505 450	62 448 697	29 070	1 688 854	5 621.29	5 565.23	0.13	0.20	73 990	1.68	2.63
2018	80 351 881	13 663 263	66 426 214	15 439	1 833 536	6 002.78	5 942.13	0.14	0.21	73 951	1.72	2.67
2019	82 528 409	14 274 126	67 990 257	13 534	2 033 246	6 162.80	6 100.48	0.14	0.22	73 920	1.70	2.67
2020	61 691 583	10 882 231	50 581 150	7 990	2 030 602	4 610.50	4 561.55	0.11	0.17	73 941	1.81	2.80
2021	65 751 854	13 206 790	52 375 210	11 838	2 125 828	4 910.66	4 859.25	0.12	0.18	73 903	1.84	2.76
2022	56 449 306	13 417 315	42 860 961	11 833	2 348 418	4 209.99	4 163.64	0.12	0.16	73 759	2.17	2.87
Trend 1990-2022	60.48%	-24.04%	147.21%	-93.21%	NA	61.92%	61.86%	-75.41%	211.76%	0.86%	-84.68%	94.27%
Trend 2021-2022	-14.15%	1.59%	-18.17%	-0.04%	10.47%	-14.27%	-14.32%	0.93%	-10.58%	-0.19%	17.57%	4.15%

Source: Environment Agency

Figure 3-8– Fuel sold trends - indexes - for 1A3b – Road Transportation by fuel type: 1990-2022



Source: Environment Agency

Figure 3-9 – Domestic and exported fuel sold trends - indexes - for 1A3b – Road Transportation by fuel type: 1990-2022

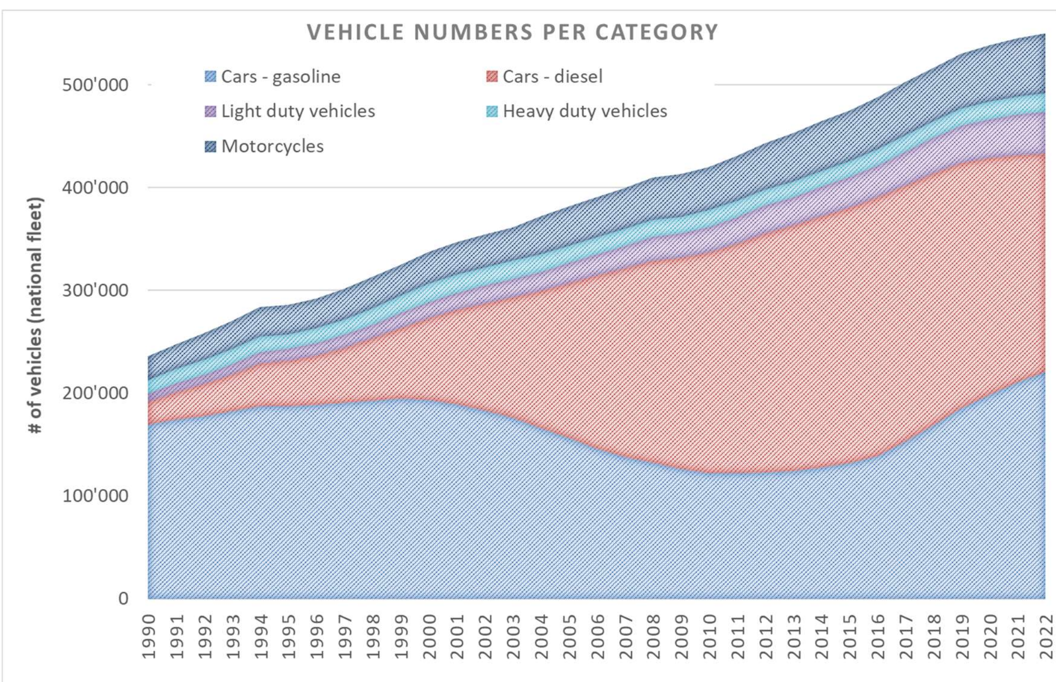


Table 3-68 – Domestic and road fuel export emissions for 1A3b - Road Transportation: 1990-2022

1A3b - Road Transportation CO_2 eq emissions (Gg)										
Year	National Total (excl. CO_2 from biomass)	CO_2 from biomass	CH_4 and N_2O from biomass	GHG from other fossil fuels	domestic road fuel emissions (excl. CO_2 from biomass)			road fuel export emissions (excl. CO_2 from biomass)		
					Gasoline	Diesel	LPG	Gasoline	Diesel	LPG
1990	2600.09	NO	NO	NO	572.66	270.55	11.65	726.77	1018.47	NO
1991	3198.36	NO	NO	NO	579.78	306.40	12.20	945.62	1354.36	NO
1992	3492.45	NO	NO	NO	595.22	332.62	10.04	1070.84	1483.73	NO
1993	3537.22	NO	NO	NO	594.93	378.27	10.73	1075.04	1478.25	NO
1994	3594.26	NO	NO	NO	592.11	388.52	10.64	1138.61	1464.39	NO
1995	3356.63	NO	NO	NO	596.57	435.95	10.23	1034.90	1278.97	NO
1996	3470.36	NO	NO	NO	611.48	441.33	7.67	1043.96	1365.93	NO
1997	3739.60	NO	NO	NO	613.21	477.91	3.54	1103.24	1541.71	NO
1998	3934.54	NO	NO	NO	607.76	525.26	8.54	1117.54	1675.44	NO
1999	4366.44	NO	NO	NO	594.92	551.28	7.93	1185.56	2026.74	NO
2000	4896.16	NO	NO	NO	579.37	619.58	6.08	1252.84	2438.30	NO
2001	5153.10	NO	NO	NO	552.60	693.05	7.81	1248.95	2650.69	NO
2002	5334.85	NO	NO	NO	525.35	772.14	7.74	1228.41	2801.20	NO
2003	5875.08	NO	NO	NO	500.17	840.02	6.19	1284.65	3244.06	NO
2004	6837.56	1.47	0.01	0.08	447.33	903.38	5.29	1277.25	4204.22	NO
2005	7205.59	1.53	0.01	0.09	402.17	972.01	3.77	1168.43	4659.12	NO
2006	6861.37	1.44	0.01	0.08	367.15	1056.57	4.19	1043.52	4389.85	NO
2007	6564.85	133.96	0.65	7.46	340.34	1097.07	4.10	1006.37	4108.86	NO
2008	6655.42	133.00	0.75	7.48	333.50	1152.42	4.79	946.88	4209.58	NO
2009	6115.41	123.84	0.79	6.99	312.93	1226.89	4.07	864.38	3699.38	NO
2010	6492.18	124.06	0.85	6.67	290.79	1270.34	4.07	802.05	4117.41	NO
2011	6854.24	137.72	0.98	6.32	277.89	1315.34	1.88	836.00	4415.82	NO
2012	6541.79	142.52	1.16	6.69	279.11	1314.07	4.52	806.80	4129.44	NO
2013	6411.02	162.09	1.40	7.58	281.73	1316.20	3.00	708.84	4092.27	NO
2014	6093.71	206.44	1.88	9.93	283.02	1337.10	2.81	667.31	3791.65	NO
2015	5661.64	241.21	2.28	12.38	284.78	1338.48	3.86	608.19	3411.67	NO
2016	5483.04	258.28	2.53	12.87	298.03	1337.23	2.20	569.27	3260.92	NO
2017	5621.29	326.72	3.39	17.31	327.82	1324.56	1.90	590.11	3356.21	NO
2018	6002.78	354.43	3.68	18.34	356.86	1313.03	1.01	644.68	3665.18	NO
2019	6162.80	379.57	3.80	18.60	375.61	1300.19	0.89	671.77	3791.94	NO
2020	4610.50	413.34	4.35	16.36	352.54	1143.07	0.52	444.02	2649.64	NO
2021	4910.66	404.26	4.21	11.74	393.59	1186.33	0.77	571.97	2742.04	NO
2022	4209.99	371.92	4.09	11.84	426.56	1212.80	0.77	553.70	2000.22	NO
Trend 1990-2022	61.92%	NA	NA	NA	-25.51%	348.27%	-93.38%	-23.81%	96.40%	NA
Trend 2021-2022	-14.27%	-8.00%	-2.86%	0.85%	8.38%	2.23%	-0.04%	-3.19%	-27.05%	NA
Share 1990	NA	NA	NA	NA	22.02%	10.41%	0.45%	27.95%	39.17%	NA
Share 2022	NA	NA	NA	NA	10.13%	28.81%	0.02%	13.15%	47.51%	NA

Source: Environment Agency

3.2.9.3.2 Methodological issues & time series consistency

3.2.9.3.2.1 Activity data

Table 3-69 and Table 3-70 show the activity data by vehicle category for fuel sold in Luxembourg and fuel used within the country's borders, respectively. The total amounts of fuel sold were taken from the national energy balance provided by STATEC, and the share of fuel used in Luxembourg was determined with the method described on page 254. Biodiesel (FAME and HVO) and biogasoline (bioethanol) are not sold individually, but they are blended in the commercially available fuels. The annual consumptions of biofuels were also taken from the national energy balance.

The online registry system for tracking biofuel supply chains derives from the legal obligations under EU directive 2009/30/EC, transposed into Luxembourg law by the modified grand-ducal regulation of 27 February 2011 defining the sustainability criteria of biofuels and bioliquids (https://environnement.public.lu/fr/emweltprozeduren/registres/Biocarburants.html). This registry is not managed by the inventory team but by another team within the Environment Agency. The inventory team has the possibility to obtain information from the registry on demand. As the biofuel import certificates are established by independent verifiers, the inventory team considers that they fulfill the quality requirements for inventory input data.

Table 3-69 – Activity data of 1A3b Road transport – Fuel sold

1 A Mobile Fuel Combustion Activity Data by vehicle category (GJ) 1 A 3 b Road transport - FUEL SOLD					
Year	Activity Total (incl. biomass)	1 A 3 b i Passenger cars	1 A 3 b ii LDV	1 A 3 b iii HDV and buses	1 A 3 b iv Mopeds & motorcycles
1990	35 176 077	21'502'103	582'351	13'050'825	40'798
1991	43 240 313	25'655'122	639'639	16'901'549	44'002
1992	47 006 400	28'011'264	673'367	18'273'501	48'269
1993	47 655 388	28'420'645	740'292	18'439'036	55'416
1994	48 433 767	30'667'142	790'750	16'914'931	60'943
1995	45 241 829	29'182'645	837'089	15'161'172	60'923
1996	46 754 482	30'009'047	877'034	15'805'139	63'263
1997	50 446 299	31'841'152	926'503	17'614'618	64'027
1998	53 077 916	32'852'652	984'668	19'175'248	65'348
1999	58 932 008	34'858'947	1'090'022	22'915'699	67'340
2000	66 117 768	37'206'426	1'189'954	27'652'357	69'030
2001	69 549 776	38'145'684	1'243'034	30'093'246	67'813
2002	72 005 180	38'846'097	1'312'058	31'776'934	70'092
2003	79 281 580	41'180'831	1'362'155	36'666'536	72'057
2004	92 345 553	42'030'187	1'433'723	48'804'421	77'222
2005	97 257 849	40'541'331	1'490'124	55'150'221	76'174
2006	92 564 332	38'832'193	1'556'393	52'098'986	76'760
2007	90 342 807	39'301'811	1'640'618	49'324'378	75'999
2008	91 537 366	39'913'664	1'717'211	49'830'611	75'880
2009	84 125 086	39'008'802	1'724'307	43'312'354	79'622
2010	89 078 059	38'189'116	1'786'819	49'023'440	78'684
2011	94 087 190	40'793'995	1'974'975	51'238'450	79'771
2012	89 895 092	40'593'872	1'891'336	47'330'100	79'784
2013	88 295 801	38'209'059	1'909'084	48'095'229	82'429
2014	84 658 139	37'645'194	1'960'639	44'965'339	86'966
2015	79 141 735	36'303'246	1'993'602	40'755'418	89'470
2016	76 943 886	35'219'652	2'095'519	39'538'196	90'519
2017	79 672 836	35'290'348	2'159'628	42'128'494	94'366
2018	85 189 640	36'814'478	2'245'252	46'032'520	97'389
2019	87 717 221	36'432'257	2'310'385	48'876'113	98'466
2020	67 336 298	27'404'082	2'341'903	37'491'325	98'989
2021	71 277 871	30'461'376	2'450'789	38'263'756	101'950
2022	61 537 640	31'033'319	2'212'969	28'184'744	106'608
Trend 1990-2022	74.94%	44.33%	280.01%	115.96%	161.30%
Trend 2021-2022	-13.67%	1.88%	-9.70%	-26.34%	4.57%

Source: Environment Agency

Table 3-70 – Activity data of 1A3b Road transport – Fuel used

1 A Mobile Fuel Combustion Activity Data by vehicle category (GJ) 1 A 3 b Road transport - FUEL USED					
Year	Activity Total (incl. biomass)	1 A 3 b i Passenger cars	1 A 3 b ii LDV	1 A 3 b iii HDV and buses	1 A 3 b iv Mopeds & motorcycles
1990	11 592 482	8'728'968	582'351	2'240'365	40'798
1991	12 172 544	9'050'053	639'639	2'438'851	44'002
1992	12 627 814	9'382'641	673'367	2'523'538	48'269
1993	13 266 976	9'642'322	740'292	2'828'946	55'416
1994	13 370 304	9'892'747	790'750	2'625'863	60'943
1995	14 065 869	10'179'888	837'089	2'987'969	60'923
1996	14 295 290	10'560'179	877'034	2'794'814	63'263
1997	14 774 026	10'902'913	926'503	2'880'584	64'027
1998	15 411 535	11'317'127	984'668	3'044'393	65'348
1999	15 590 753	11'573'478	1'090'022	2'859'913	67'340
2000	16 289 593	11'905'446	1'189'954	3'125'162	69'030
2001	16 930 507	12'223'999	1'243'034	3'395'661	67'813
2002	17 625 087	12'504'553	1'312'058	3'738'384	70'092
2003	18 169 605	12'807'742	1'362'155	3'927'650	72'057
2004	18 312 353	12'801'706	1'433'723	3'999'703	77'222
2005	18 590 102	12'968'259	1'490'124	4'055'546	76'174
2006	19 248 601	13'393'512	1'556'393	4'221'937	76'760
2007	19 829 680	13'905'285	1'640'618	4'207'777	75'999
2008	20 501 201	14'889'558	1'717'211	3'818'552	75'880
2009	21 242 559	15'060'432	1'724'307	4'378'197	79'622
2010	21 480 234	14'810'577	1'786'819	4'804'154	78'684
2011	21 899 564	14'916'765	1'974'975	4'928'054	79'771
2012	21 958 005	15'245'004	1'891'336	4'741'881	79'784
2013	22 048 473	15'418'492	1'909'084	4'638'468	82'429
2014	22 554 452	15'491'486	1'960'639	5'015'361	86'966
2015	22 763 842	15'716'448	1'993'602	4'964'323	89'470
2016	22 996 592	15'896'402	2'095'519	4'914'152	90'519
2017	23 458 107	16'026'496	2'159'628	5'177'617	94'366
2018	23 717 980	16'380'335	2'245'252	4'995'004	97'389
2019	23 880 622	16'510'662	2'310'385	4'961'109	98'466
2020	21 849 499	14'594'613	2'341'903	4'813'995	98'989
2021	22 932 966	15'557'056	2'450'789	4'823'171	101'950
2022	23 993 319	16'499'329	2'212'969	5'174'412	106'608
Trend 1990-2022	106.97%	89.02%	280.01%	130.96%	161.30%
Trend 2021-2022	4.62%	6.06%	-9.70%	7.28%	4.57%

Source: Environment Agency

Figure 3-10 shows the evolution of the vehicle numbers per category since 1990 (national fleet). The number of diesel-fuelled passenger cars has strongly increased whereas the vehicle numbers in the other categories show a less pronounced rise or even a slight decrease in the case of passenger cars with otto engines. The same trends are observed for the total mileage driven in Luxembourg (Figure 3-11). In this figure, the dip in 2020 and 2021 corresponds to the restrctions during the Covid-19 pandemic.

Figure 3-10 – Vehicle numbers per category (national fleet).

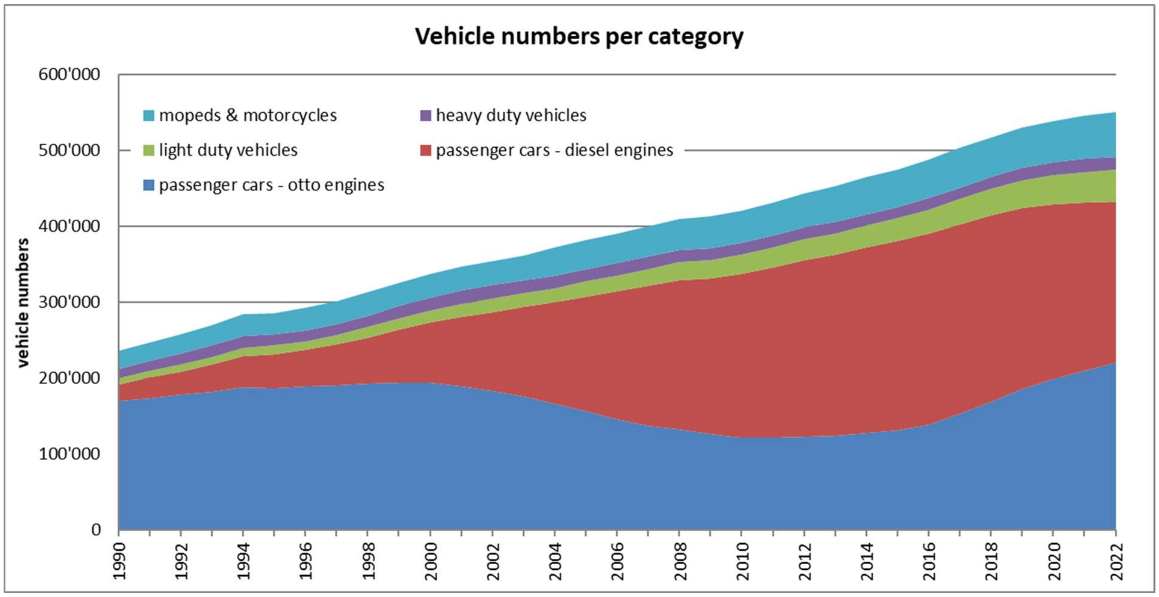


Figure 3-11 – Total mileage driven in Luxembourg.

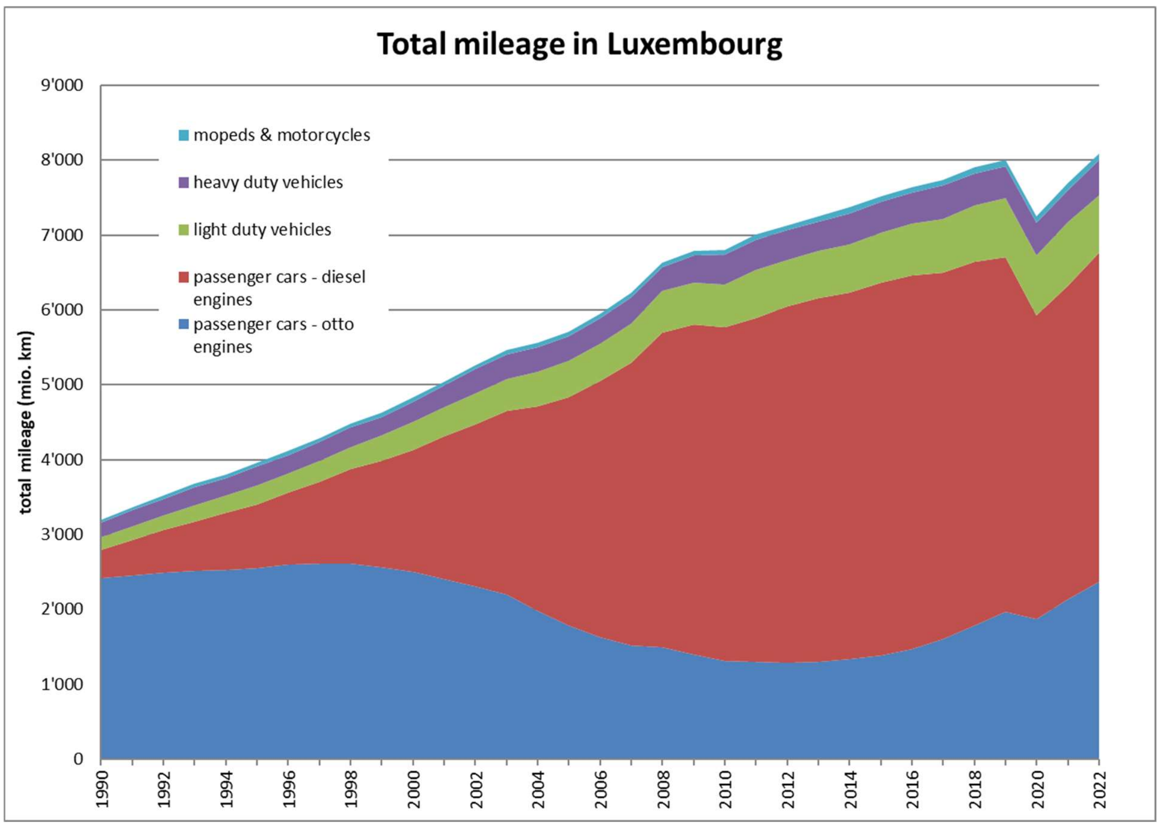
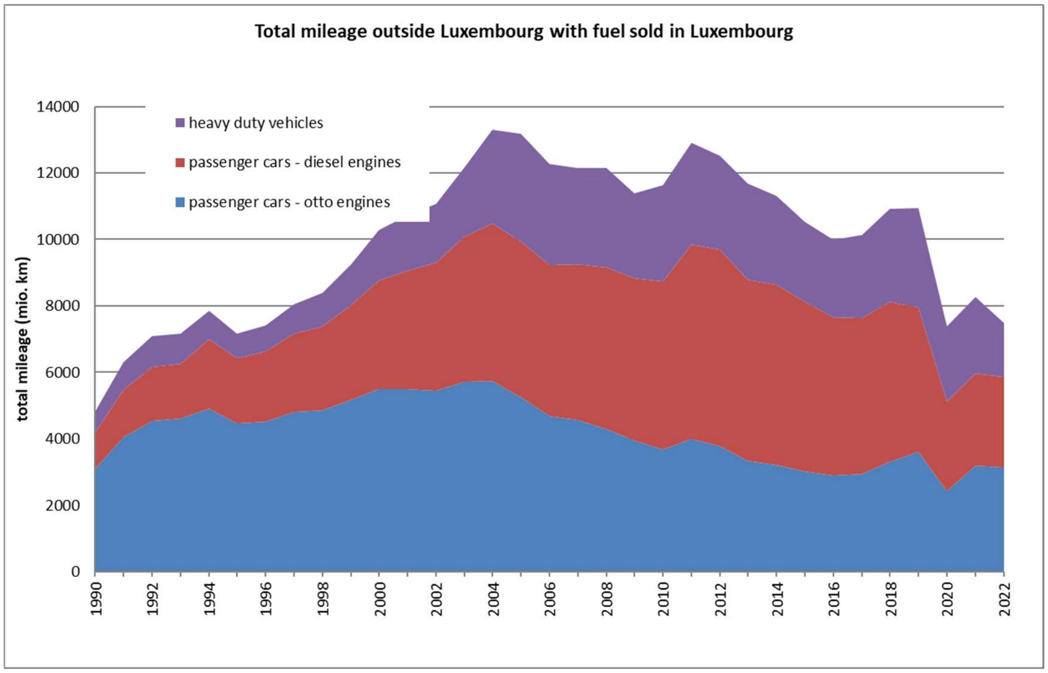


Figure 3-12 shows that the total mileage driven outside Luxembourg with fuel purchased in Luxembourg has approximately doubled since 1990. While the mileage driven with gasoline exported in passenger car tanks has remained relatively stable, the mileage driven with diesel exported from Luxembourg in the tanks of passenger cars and heavy-duty vehicles shows a decreasing trend.

Figure 3-12 – Total mileage outside Luxembourg with fuel sold in Luxembourg.



3.2.9.3.2.2 Methodology - The model NEMO and its application to Luxembourg's road transport situation

The model NEMO (Network Emission Model) was developed at the Institute for Internal Combustion Engines and Thermodynamics (IVT) at the Graz University of Technology (TUG) as tool for the simulation of traffic related emissions in road networks. Typical applications reach from emission inventories for cities, regions and countries to complex measures like environmental zones or promotion of alternative propulsion systems. An interface to macro scale traffic models, such as VISUM and to air quality modelling is available.

NEMO combines both detailed calculation of the vehicle fleet composition and simulation of emission factors on a vehicle level. NEMO calculates the percentages of different vehicle layers on the overall traffic volume as a function of year and considered road type based on data on vehicle stock, composition of new registrations and vehicle usage. The simulation of the emissions of the different vehicle layers is based on the correlation of the specific engine emission behaviour (emissions in grams per kilowatt-hour engine work) with the cycle average engine power in a normalised format. The calculation of the required engine power is based on average speed and additional kinematic parameters for the description of the cycle dynamics for a given road section. Compared to more detailed instantaneous emission models - which are usually based on simulation in 1Hz time resolution – this simplified approach gives no disadvantage for the modelling of emissions on large street networks as in most of the cases 1Hz data for vehicle operation are not available. An additional benefit of the NEMO simulation approach is the short computing time.

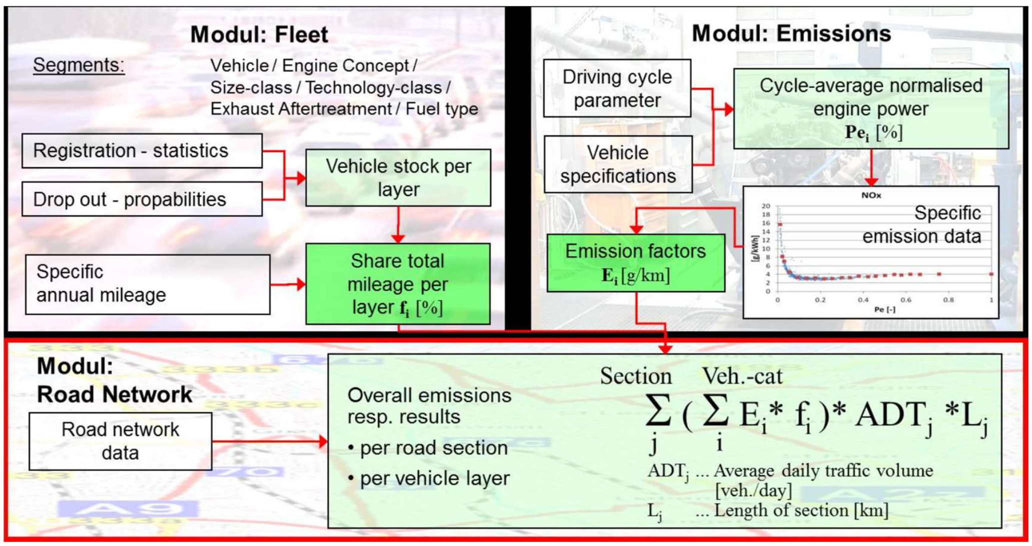
The parameterisation of NEMO is based on data from European in-use measurements which are also used for the Handbook Emission Factors of Road Transport (HBEFA)[77]. NEMO is updated regularly according to recent data on emission behaviour and vehicle technologies. For the present submission, HBEFA 5.0.4 (released in May 2023, the latest reference database including all available in-use emission tests and recent forecasts for up-coming vehicle technology) was used. All on-road vehicle categories are covered; a tool

77 http://www.hbefa.net/

for the transport sectors rail and inland waterway shipping is also available. NEMO is equipped with a Graphical User Interface which allows for efficient data editing, scenario handling and display of model results.

A crucial point in emission modelling is the characterisation of driving behaviour on the single road sections. For NEMO a method was developed, which allows for automatized derivation of driving behaviour based on a link with common traffic models. These models use the peak hour driving time between knots of the street work as resistance parameter for allocation of traffic volumes to the single road sections. NEMO imports this data together with the parameters of the capacity-restraint functions and calculates the daily average velocity for each road section. Based on functions derived from the driving cycles used in the HBEFA then the kinematic parameters needed for emission simulation (vehicle stop time and average brake deceleration) are assessed.

Figure 3-13– Schematic picture of the model NEMO



NEMO calculates the emissions for all regulated pollutants (NO_x, THC, CO, PM exhaust) for hot vehicle operation. Fuel consumption is simulated based on a slightly extended method which also considers the energy content of the applied fuel type. The emissions of CO_2 and SO_2 are simulated based on fuel consumption and fuel specifications. The non-regulated pollutants N_2O, NH_3, CH_4, NMVOC and C_6H_6 are calculated with an approach similar to the HBEFA 4.2 based on fixed emission factors for certain vehicle categories and driving situations.

Additional influencing mechanisms on the emission output of road traffic implemented in NEMO are:

- Cold start effects for each vehicle class (data and approach compatible to the HBEFA 4.2), cold start of HDV vehicles according to (Rexeis, Schwingshackl, Dippold, & Hausberger, 2013)
- Influence of mileage and maintenance on the emissions of gasoline vehicles (method and data compatible to the HBEFA4.2)
- Calibration of fuel consumption based on statistics of g/km CO_2 of new registered vehicles in the NEDC type approval and literature on the discrepancies between NEDC and real world CO_2 reduction rates (HBEFA4.2)
- Evaporation from gasoline emissions (data and approach compatible to the HBEFA 4.2)

- Ambient temperature influence on NOx emission of Diesel passenger cars and LCV (method and data compatible to the HBEFA4.2)
- Consideration of electrified propulsion systems like hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) (data and approach compatible to the HBEFA4.2).

Particle emissions due to vehicle induced abrasion processes ("PM non-exhaust") are taken into account by NEMO in addition to the PM-exhaust emissions. The calculation of the PM non-exhaust emissions is based on the EMEP/EEA Guidebook 2023.

As already mentioned above, the major part of the fuel sold in Luxembourg is exported inside vehicle tanks. The split of the total fuel into domestic fuel use and exported fuel is thus a key element of the calculation of Luxembourg's total GHG emissions. This split is performed in several steps:

(i) estimation of the domestic fuel consumption with the NEMO model

(ii) calculation of the amount of exported fuel by subtracting the amount obtained in step (i) from the total national fuel consumption obtained from Statec

(iii) the entire amount of exported gasoline is attributed to passenger cars

(iv) the amount of diesel exported by passenger cars is determined by taking into account the result of step (iii) and the shares of gasoline- and diesel-fuelled cars in the trans-border fleet

(v) the amount of diesel exported by heavy duty vehicles is obtained by subtracting the amount of diesel exported by passenger cars from the total amount of exported diesel

(vi) now the mileages of the passenger cars and heavy duty vehicles responsible for the fuel export can be determined based on their fuel consumption

(vii) finally the emissions caused by domestic fuel use and exported fuel are calculated separately by NEMO.

The share of diesel- and gasoline-fueled cars in the commuter fleets is based on the shares of the fleets of the neighboring regions (Belgium, Grand-Est for France, Rhineland-Palatinate and Saarland for Germany). However, the detailed composition of each of these fleets (age, technology) is supposed to be identical to the structures of Luxembourg's domestic fleet (i.e. the CH_4 IEF of the domestic gasoline-fueled passenger car fleet is applied to the gasoline-fueled commuting passenger car fleet, etc), due to a lack of regions-specific fleet data from the neighboring countries.

In the case of passenger cars, the justification for assuming a similar age/technology composition of the commuter fleets is that the owners of these vehicles work in Luxembourg, have significantly higher salaries than if they were working in their home country, and thus have higher living standards than their non-commuting fellow citizens. As a consequence, the commuter fleets are supposed to be more similar to Luxembourg's domestic fleet than to the average fleet of the commuters' country of residence.

For heavy-duty vehicles, the fleet composition is also considered to be identical to the one of the Luxembourgish fleet, which is rather modern. This is justified through an expert judgement (personal communication) by Luxembourg's customs office (Administration des Douanes et Accises). Indeed, the national and transiting heavy-duty vehicles fleet are very similar and consist roughly of 80% new models (aged 1-5 years), 15% older models (aged 5-10 years), and 5% even older models (aged more than 10 years).

The GHG emissions from road transportation were calculated with the NEMO model (version 5.0.4 with HBEFA 4.2) for the timeseries 1990-2022 (M. Schwingshackl, 2023).

The values of the country-specific CO_2 emission factors for gasoline, diesel oil and LPG are given in section 3.2.5.3. For an overview of the implied emission factors for motor gasoline, diesel oil, LPG and liquid biomass please refer to Table 3-19. For biogasoline and biodiesel, European CO_2 implied emission factors[78] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ), respectively, were used as emission factors.

Biodiesel sold in Luxembourg since 2004 is mainly composed of FAME (fatty acid methyl ester). In more recent years, also HVO (hydrated vegetable oil) is used for blending with diesel. While HVO is of 100% biogenic origin, FAME biodiesel from methanol contains a small proportion of fossil carbon if the methanol is produced from a fossil fuel (which is generally the case). During the production process of FAME, the vegetable oil is trans-esterified with methanol to produce the FAME and the by-product glycerol. The latter is removed during the purification process. Hence, each FAME molecule contains one carbon atom originating from methanol, which is very likely of fossil origin. The percentage of fossil carbon in FAME, thus, depends on the chain length of the different components of the oil (fatty acid derivatives), as well as the proportion of different components (origin of the oil, i.e. rapeseed oil, sunflower oil, palm oil, etc.). Based on the detailed composition of the FAME mixture sold in Luxembourg in 2019 (no detailed information is currently available for other years), it has been calculated that 5.3% of the carbon atoms are of fossil origin. The fraction of 5.3% correlates very well with the value presented in [79]. 5.3% of the FAME activity data and the associated GHG emissions are thus not allocated to "biomass" but to "other fossil fuels – biodiesel (fossil component)" in each CRF subcategory with biodiesel consumption, i.e. 1A3bi-iv, 1A3c, 1A3d and 1D1b, 1A2gvii, 1A4cii, and 1A5b. For the fossil part of biodiesel the same emission factors are applied than for biodiesel. This recalculation was done in response to a Potential Problem formulated in the course of the UNFCCC in-country review of Luxembourg's 2018 submission, which took place in October 2018.

78 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

79 Environ. Sci. Technol. 2008, 42, 2476–2482 (table 2, p. 2480)

Table 3-71 – Activity data, emissions and emission factors for other fossil fuels (fossil part of biodiesel) used in sector 1A3b – Road transportation.

1A3b - Road Transportation - Other fossil fuels Activity Data, Emissions and Implied Emission Factors								
Year	Activity data (GJ)	Emissions (Gg)				Implied Emission Factors (kg/TJ)		
		Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	NO	NO	NO	NO	NO	NO	NO	NO
1991	NO	NO	NO	NO	NO	NO	NO	NO
1992	NO	NO	NO	NO	NO	NO	NO	NO
1993	NO	NO	NO	NO	NO	NO	NO	NO
1994	NO	NO	NO	NO	NO	NO	NO	NO
1995	NO	NO	NO	NO	NO	NO	NO	NO
1996	NO	NO	NO	NO	NO	NO	NO	NO
1997	NO	NO	NO	NO	NO	NO	NO	NO
1998	NO	NO	NO	NO	NO	NO	NO	NO
1999	NO	NO	NO	NO	NO	NO	NO	NO
2000	NO	NO	NO	NO	NO	NO	NO	NO
2001	NO	NO	NO	NO	NO	NO	NO	NO
2002	NO	NO	NO	NO	NO	NO	NO	NO
2003	NO	NO	NO	NO	NO	NO	NO	NO
2004	1 145	0.08	0.08	0.000001	0.00000	73 450	0.66	0.89
2005	1 191	0.09	0.09	0.000001	0.00000	73 450	0.59	0.93
2006	1 122	0.08	0.08	0.000001	0.00000	73 450	0.54	1.06
2007	101 125	7.46	7.43	0.000049	0.00013	73 450	0.48	1.28
2008	101 234	7.48	7.44	0.000044	0.00015	73 450	0.43	1.53
2009	94 546	6.99	6.94	0.000041	0.00016	73 450	0.43	1.72
2010	90 214	6.67	6.63	0.000037	0.00017	73 450	0.41	1.87
2011	85 432	6.32	6.27	0.000038	0.00018	73 450	0.45	2.05
2012	90 327	6.69	6.63	0.000046	0.00020	73 450	0.51	2.23
2013	102 333	7.58	7.52	0.000056	0.00024	73 450	0.55	2.35
2014	133 992	9.93	9.84	0.000092	0.00034	73 450	0.69	2.52
2015	166 875	12.38	12.26	0.000147	0.00045	73 450	0.88	2.68
2016	173 384	12.87	12.74	0.000187	0.00049	73 450	1.08	2.80
2017	233 080	17.31	17.12	0.000283	0.00067	73 450	1.21	2.88
2018	246 966	18.34	18.14	0.000322	0.00072	73 450	1.30	2.93
2019	250 492	18.60	18.40	0.000327	0.00074	73 450	1.31	2.95
2020	220 212	16.36	16.17	0.000301	0.00066	73 450	1.37	3.02
2021	158 016	11.74	11.61	0.000226	0.00048	73 450	1.43	3.07
2022	159 197	11.84	11.69	0.000281	0.00053	73 450	1.77	3.31
Trend 2021-2022	0.75%	0.85%	0.75%	24.37%	8.80%	0.00%	23.44%	7.99%

Source: Environment Agency

Table 3-72, Table 3-73, Table 3-74 and Table 3-75 present the implied emission factors for each vehicle category.

Table 3-72 – Implied emission factors for passenger cars.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b i Road transport: Passenger cars		
	CO_2 (fossil)	CH_4	N_2O
1990	73081	21.826	2.077
1991	73099	19.718	2.243
1992	73556	16.511	2.522
1993	73439	13.835	2.765
1994	73412	11.314	2.905
1995	73398	9.825	3.032
1996	73382	8.650	3.026
1997	73139	7.628	2.897
1998	73369	6.776	2.730
1999	73326	6.052	2.552
2000	73191	5.485	2.406
2001	73345	5.035	2.274
2002	73377	4.631	2.146
2003	73403	4.269	2.026
2004	73307	3.905	1.931
2005	73360	3.541	1.860
2006	73448	3.189	1.808
2007	73431	2.921	1.761
2008	73458	2.605	1.729
2009	73443	2.368	1.729
2010	73499	2.235	1.799
2011	73469	2.188	1.911
2012	73560	2.133	2.013
2013	73621	2.127	2.131
2014	73587	2.324	2.313
2015	73885	2.549	2.483
2016	73839	2.825	2.618
2017	73856	3.058	2.691
2018	73761	3.229	2.742
2019	73736	3.307	2.749
2020	73683	3.332	2.783
2021	73615	3.272	2.688
2022	73528	3.267	2.738

Table 3-73 – Implied emission factors for light duty vehicles.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b ii Road transport: Light duty vehicles		
	CO_2 (fossil)	CH_4	N_2O
1990	73463	6.916	0.673
1991	73547	6.239	0.616
1992	73799	5.533	0.555
1993	73827	4.832	0.494
1994	73869	4.349	0.535
1995	73891	4.021	0.642
1996	73879	3.959	0.866
1997	73889	3.235	0.974
1998	73940	2.828	1.055
1999	73969	2.519	1.165
2000	74020	2.113	1.287
2001	74063	1.798	1.403
2002	74090	1.508	1.486
2003	74094	1.282	1.545
2004	74071	1.057	1.590
2005	74073	0.922	1.636
2006	74084	0.839	1.677
2007	74092	0.768	1.714
2008	74040	0.700	1.736
2009	74030	0.639	1.752
2010	74085	0.610	1.782
2011	74075	0.604	1.833
2012	74097	0.668	1.940
2013	74114	0.776	2.090
2014	74038	0.964	2.246
2015	74114	1.182	2.450
2016	74123	1.460	2.651
2017	74140	1.813	2.917
2018	74111	2.179	3.167
2019	74062	2.495	3.375
2020	74125	2.972	3.563
2021	74130	3.504	3.698
2022	74016	3.905	3.820

Table 3-74 – Implied emission factors for heavy-duty vehicles.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b iii Road transport: Heavy duty vehicles		
	CO_2 (fossil)	CH_4	N_2O
1990	74171	1.386	0.553
1991	74157	1.301	0.540
1992	74130	1.256	0.538
1993	74172	1.233	0.542
1994	74197	1.205	0.548
1995	74202	1.258	0.557
1996	74192	1.171	0.551
1997	74179	1.065	0.542
1998	74170	0.974	0.535
1999	74174	0.851	0.523
2000	74213	0.756	0.509
2001	74218	0.695	0.478
2002	74219	0.659	0.447
2003	74195	0.614	0.412
2004	74156	0.565	0.390
2005	74140	0.493	0.460
2006	74140	0.418	0.587
2007	74146	0.340	0.845
2008	74090	0.265	1.166
2009	74077	0.228	1.382
2010	74131	0.187	1.578
2011	74116	0.155	1.762
2012	74137	0.134	1.903
2013	74146	0.116	2.011
2014	74073	0.100	2.109
2015	74132	0.086	2.187
2016	74140	0.074	2.239
2017	74156	0.065	2.268
2018	74130	0.057	2.279
2019	74077	0.052	2.285
2020	74145	0.051	2.317
2021	74151	0.050	2.325
2022	74037	0.051	2.384

Table 3-75 – Implied emission factors for mopeds and motorcycles.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b iv Road transport: Mopeds & motorcycles		
	CO_2 (fossil)	CH_4	N_2O
1990	72181	250.975	1.224
1991	72255	237.380	1.224
1992	72965	226.382	1.226
1993	72770	204.626	1.226
1994	72712	191.474	1.218
1995	72672	191.799	1.222
1996	72756	186.634	1.204
1997	72592	185.725	1.200
1998	72676	184.204	1.196
1999	72618	170.583	1.189
2000	72439	166.505	1.186
2001	72538	166.825	1.185
2002	72524	162.301	1.183
2003	72595	158.258	1.181
2004	72414	167.177	1.187
2005	72487	164.217	1.193
2006	72525	161.520	1.191
2007	72418	160.443	1.194
2008	72397	158.916	1.196
2009	72312	151.701	1.195
2010	72270	152.539	1.200
2011	72294	150.453	1.200
2012	72287	151.451	1.205
2013	72470	146.494	1.212
2014	72487	139.665	1.217
2015	73098	134.016	1.222
2016	73087	130.433	1.227
2017	73191	123.513	1.234
2018	73104	114.537	1.240
2019	73186	111.942	1.252
2020	73008	109.114	1.258
2021	72931	103.333	1.265
2022	72883	96.552	1.269

3.2.9.4 Railways (1A3c)

3.2.9.4.1 Source category description

Railways related GHG emissions are quite low in Luxembourg. The reason is that Luxembourg's national railway company, *CFL (Chemins de Fer Luxembourgeois*), uses almost exclusively locomotives powered by electricity.

In 2022, railways fuel consumption (diesel oil and biodiesel) was responsible for 0.09% of GHG emissions from fuel combustion activities (0.24% in 1990) and represented 0.07% of the total GHG emissions in CO_2e, excluding LULUCF (0.20% in 1990). Compared to 2021, emissions decreased by 20.18% to reach 5.97 Gg CO_2 eq. in 2022. Compared to 1990, emissions decreased by 76.03%.

Activity data, GHG emissions and emission factors used to estimate emissions from *1A3c* are shown in Table 3-76.

The V-shaped emission trend is mainly due to restructuring activities in the mid 2000s, where less diesel driven locomotive were used. Since 2007, the number of diesel driven locomotives has stabilised again between 70 and 80 units being operated per year.

GHG emissions from railways are not a key source.

Table 3-76 – Activity data, emissions and emission factors for IPCC sub-category 1A3c – Railways: 1990-2022

1A3c - Railways Diesel Oil, biodiesel												
Year	Activity data (GJ)	Emissions (Gg) excl. CO_2 from biomass				Emission Factors (kg/TJ)						
		Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	CO_2	type	CH_4	type	N_2O	type	source
1990	334 678	24.91	24.82	0.0020	0.0001	74 171	CS	5.84	D	0.37	D	AEV, 2006 IPCC GL
1991	334 678	24.91	24.82	0.0020	0.0001	74 157	CS	5.83	D	0.37	D	AEV, 2006 IPCC GL
1992	334 678	24.90	24.81	0.0019	0.0001	74 130	CS	5.81	D	0.37	D	AEV, 2006 IPCC GL
1993	334 678	24.91	24.82	0.0019	0.0001	74 172	CS	5.79	D	0.37	D	AEV, 2006 IPCC GL
1994	324 884	24.19	24.11	0.0019	0.0001	74 197	CS	5.76	D	0.37	D	AEV, 2006 IPCC GL
1995	263 059	19.59	19.52	0.0015	0.0001	74 202	CS	5.72	D	0.38	D	AEV, 2006 IPCC GL
1996	293 972	21.89	21.81	0.0017	0.0001	74 192	CS	5.69	D	0.38	D	AEV, 2006 IPCC GL
1997	288 989	21.51	21.44	0.0016	0.0001	74 179	CS	5.66	D	0.38	D	AEV, 2006 IPCC GL
1998	288 989	21.51	21.43	0.0016	0.0001	74 170	CS	5.62	D	0.39	D	AEV, 2006 IPCC GL
1999	288 989	21.51	21.44	0.0016	0.0001	74 174	CS	5.58	D	0.39	D	AEV, 2006 IPCC GL
2000	285 971	21.30	21.22	0.0016	0.0001	74 213	CS	5.54	D	0.39	D	AEV, 2006 IPCC GL
2001	308 159	22.95	22.87	0.0017	0.0001	74 218	CS	5.49	D	0.40	D	AEV, 2006 IPCC GL
2002	272 319	20.28	20.21	0.0015	0.0001	74 219	CS	5.34	D	0.40	D	AEV, 2006 IPCC GL
2003	237 417	17.68	17.62	0.0012	0.0001	74 195	CS	5.25	D	0.40	D	AEV, 2006 IPCC GL
2004	188 677	14.04	13.99	0.0010	0.0001	74 156	CS	5.16	D	0.40	D	AEV, 2006 IPCC GL
2005	119 803	8.91	8.88	0.0006	0.0000	74 140	CS	4.97	D	0.39	D	AEV, 2006 IPCC GL
2006	89 333	6.64	6.62	0.0004	0.0000	74 140	CS	4.77	D	0.39	D	AEV, 2006 IPCC GL
2007	123 800	9.21	9.18	0.0006	0.0000	74 146	CS	4.48	D	0.38	D	AEV, 2006 IPCC GL
2008	142 289	10.57	10.54	0.0006	0.0001	74 090	CS	4.17	D	0.37	D	AEV, 2006 IPCC GL
2009	136 962	10.17	10.15	0.0005	0.0001	74 077	CS	3.84	D	0.36	D	AEV, 2006 IPCC GL
2010	147 748	10.98	10.95	0.0005	0.0001	74 131	CS	3.53	D	0.35	D	AEV, 2006 IPCC GL
2011	148 224	11.01	10.99	0.0005	0.0001	74 116	CS	3.21	D	0.34	D	AEV, 2006 IPCC GL
2012	134 216	9.97	9.95	0.0004	0.0000	74 137	CS	3.05	D	0.33	D	AEV, 2006 IPCC GL
2013	115 548	8.59	8.57	0.0003	0.0000	74 146	CS	2.76	D	0.31	D	AEV, 2006 IPCC GL
2014	131 621	9.77	9.75	0.0003	0.0000	74 073	CS	2.47	D	0.30	D	AEV, 2006 IPCC GL
2015	89 627	6.66	6.64	0.0002	0.0000	74 132	CS	2.33	D	0.29	D	AEV, 2006 IPCC GL
2016	82 002	6.09	6.08	0.0002	0.0000	74 140	CS	2.30	D	0.28	D	AEV, 2006 IPCC GL
2017	88 992	6.61	6.60	0.0002	0.0000	74 156	CS	2.17	D	0.27	D	AEV, 2006 IPCC GL
2018	94 622	7.03	7.01	0.0002	0.0000	74 130	CS	2.11	D	0.26	D	AEV, 2006 IPCC GL
2019	91 459	6.79	6.77	0.0002	0.0000	74 077	CS	2.06	D	0.26	D	AEV, 2006 IPCC GL
2020	91 580	6.80	6.79	0.0002	0.0000	74 145	CS	2.01	D	0.25	D	AEV, 2006 IPCC GL
2021	100 719	7.48	7.47	0.0002	0.0000	74 151	CS	1.96	D	0.24	D	AEV, 2006 IPCC GL
2022	80 525	5.97	5.96	0.0002	0.0000	74 037	CS	1.91	D	0.24	D	AEV, 2006 IPCC GL
Trend 1990-2022	-75.94%	-76.03%	-75.98%	-91.37%	-82.81%	-0.18%		-67.36%		-34.97%		
Trend 2021-2022	-20.05%	-20.18%	-20.17%	-21.51%	-21.78%	-0.15%		-2.53%		-2.87%		

Source: Environment Agency

3.2.9.4.2 Methodological issues & time-series consistency

3.2.9.4.2.1 Activity data

Diesel oil consumption is obtained directly from the sole railway company (CFL). Activity data is consistent with the data reported by the national statistics institute in their energy balance (2000-202). For the years 1990-1999, the energy balance (based on the IEA Questionnaire) does not report any consumption data for railways. Hence, the inventory fully relies on data as reported by the national railway company, which were available for the years 1993-1995 and 2001. The consumption for the years from 1996-2000 was interpolated based on the numbers of diesel driven locomotives running in the respective year. Similarly, for 1990-1992, the data was extrapolated based on the number of diesel driven locomotives.

3.2.9.4.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2 (use of country specific CO_2 emission factor). CH_4 and N_2O emissions were determined with the GEORG model (for details, please refer to section 3.2.7.7.2.2.).

3.2.9.4.2.3 Emission factors

The country specific CO_2 EF for diesel oil as described in section 3.2.5.3 was used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model based on HBEFA 4.12 (Table 3-75). The CH_4 emission factors are based on the EMEP/EEA 2023 Guidebook (Tier 3 approach, chapter 1.A.3.c Railways, p. 13, Table 3-6) while N_2O emission factors are based on (Hausberger, 2006). For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 255 for details), the European CO_2 implied emission factor[80] for diesel oil (73450 g/GJ) was applied.

3.2.9.5 Domestic Navigation (1A3d)

3.2.9.5.1 Source category description

As Luxembourg has no direct access to the sea, there are no maritime activities taking place. Similarly, Luxembourg has only one river where shipping activities are allowed, the Moselle, a border river with Germany. Shipping activities are mainly passenger (leisure and tourism) and freight activities.

In 2022, fuel consumption in navigation was responsible for 0.01% of GHG emissions from fuel combustion activities (0.01% in 1990) and represented 0.01% of the total GHG emissions in CO_2 eq., excluding LULUCF (0.01% in 1990). Compared to 2021, emissions have increased by 27.21%. Compared to 1990, emissions have decreased by 60.01%.

Activity data and GHG emissions from *1A3d* are shown in Table 3-77.

Navigation related GHG emissions are not a key source.

80 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-77 – Activity data and emissions for IPCC Sub-category 1A3d – Domestic Navigation: 1990-2022

1A3d - Navigation Gas Oil, Diesel Oil, Biodiesel, Motor Gasoline, Bioethanol					
Year	Activity (GJ)	Emissions (Gg)			
		Total $CO_{2\,eq}$	CO_2	CH_4	N_2O
1990	17 748	1.44	1.31	0.0013	0.00037
1991	19 366	1.58	1.43	0.0018	0.00039
1992	18 419	1.51	1.36	0.0019	0.00036
1993	19 273	1.58	1.42	0.0019	0.00040
1994	18 300	1.50	1.35	0.0018	0.00038
1995	15 754	1.29	1.16	0.0015	0.00034
1996	15 901	1.31	1.17	0.0015	0.00035
1997	16 200	1.33	1.20	0.0014	0.00037
1998	15 753	1.30	1.16	0.0014	0.00036
1999	17 351	1.43	1.28	0.0014	0.00041
2000	15 260	1.26	1.13	0.0011	0.00038
2001	17 107	1.41	1.26	0.0012	0.00042
2002	18 741	1.54	1.38	0.0013	0.00046
2003	19 600	1.61	1.45	0.0013	0.00048
2004	18 090	1.49	1.34	0.0011	0.00044
2005	19 246	1.57	1.42	0.0010	0.00045
2006	17 889	1.45	1.32	0.0009	0.00040
2007	17 897	1.45	1.32	0.0009	0.00040
2008	20 017	1.62	1.48	0.0009	0.00043
2009	16 744	1.35	1.24	0.0008	0.00034
2010	18 206	1.46	1.35	0.0008	0.00036
2011	17 661	1.42	1.31	0.0006	0.00036
2012	17 805	1.42	1.32	0.0005	0.00035
2013	15 468	1.23	1.14	0.0005	0.00029
2014	16 462	1.31	1.22	0.0005	0.00030
2015	14 579	1.16	1.08	0.0004	0.00026
2016	15 312	1.22	1.13	0.0004	0.00027
2017	16 640	1.32	1.23	0.0004	0.00031
2018	16 130	1.28	1.19	0.0004	0.00028
2019	13 865	1.10	1.03	0.0003	0.00023
2020	5 219	0.42	0.39	0.0001	0.00011
2021	5 716	0.45	0.42	0.0001	0.00010
2022	7 300	0.58	0.54	0.0001	0.00013
Trend 1990-2022	-58.87%	-60.01%	-58.72%	-89.54%	-65.87%
Trend 2021-2022	27.72%	27.21%	27.52%	31.84%	21.99%

Source: Environment Agency

3.2.9.5.2 Methodological issues & time-series consistency

3.2.9.5.2.1 Activity data

For tourist boats, fuel consumption data (diesel and biodiesel) is obtained directly from the two national operators as no data is available from the official statistics. Indeed, no consumption is reported in the IEA Joint Questionnaire on oil products, probably due to the fact that the consumption is below 0.5 kt and that no digits are allowed in the questionnaire. The activity data are listed in Table 3-77.

Concerning the fuel consumption of leisure boats (yachts, jet-skis, etc), no data is available at this stage. However, only one (very) small marina exists on Luxembourg's side of the Moselle River: Schwebsange. This marina is equipped with a gasoline and diesel oil filling station. It is assumed that the quantities sold at this station are being combusted entirely on Luxembourg's side of the river. These fuel quantities are included in the total fuel consumption in the national energy balance, hence there is no risk of double-counting emissions from leisure boats (Luxembourg's ARR 2018, para. E.14). The amount of fuel sold at this station was obtained from the operator for the entire time-series, except for the years 2020 and 2021, where the station was out of service. For the year 2020, activity data for leisure boats was assumed to be 20% of th value from 2019, and the value for 2021 was estimated by interpolating between 2020 and 2022. The filling station in the Schwebsange marina was put back into operation in 2022 and activity data was again directly obtained from the operator.

3.2.9.5.2.2 Methodology

The Tier 2 approach has been applied for CO_2 (use of country specific CO_2 emission factors as described in section 3.2.5.3), while CH_4 and N_2O emissions were determined with the GEORG model (Tier 3, for details, please refer to section 3.2.7.7.2.2).

Due to the particular geographical situation of the Moselle River, freight shipping activities, which are executed on barges, which do not refuel in Luxembourg's sole commercial port (Mertert), are not accounted for in Luxembourg's GHG inventory. These activities are exclusively international, *i.e.* destination is always abroad. For passenger shipping activities, the situation is different. There are two companies executing passenger shipping on the Moselle River. As communicated by these companies for the year 2022, about 94% of their journeys are to be considered domestic (from Luxembourg to Luxembourg), and the remaining 6% to be considered international (from Luxembourg to an international destination, or *vice versa*). Thus, the emissions from diesel oil, reported under IPCC sub-category *1A3d - Domestic Navigation,* cover the 94% of domestic journeys. The emissions relating to the remaining 6% international journeys are reported under international bunkers – marine.

3.2.9.5.2.3 Emission factors

Table 3-78 shows the implied emission factors for 2022. The country-specific CO_2 EFs as described in section 3.2.5.3 were used. The CH_4 emission factors are based on the EMEP/EEA 2023 Guidebook (Tier 3 approach) while N_2O emission factors are based on (Hausberger, 2006). For biofuels and other fossil fuels (fossil part of biodiesel, please refer to page 255 for details), European CO_2 implied emission factors[81] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied.

Table 3-78 – Emission factors for IPCC sub-category 1A3d – Domestic Navigation

1A3d - Navigation Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Diesel Oil	liquid	74 037	CS	2.14	CS	17.42	CS	AEV
Motor	liquid	72 883	CS	169.83	CS	0.79	CS	AEV

Source: Environment Agency

81 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

3.2.9.6 Other Transportation (1A3e)

No activities have been identified for Luxembourg, hence notation key NA.

Whereas the IPCC 2006 Guidelines recommend to report emissions from vehicles and mobile machinery used within the agriculture, forestry, industry (including construction and maintenance), residential, and sectors, such as airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles in IPCC sub-category *1A3e – Other Transportation*, Luxembourg reports these emissions in the relevant IPCC sub-categories as follows:

- 1A2 Manufacturing Industries and Construction: sub-category 1A2g vii
- 1A4b ii Residential: Household and gardening
- 1A4c ii Agriculture: Tractors, Harvesters, *etc.*
- 1A5b Mobile: military equipment

Pipeline compressors, reported under *1A3e – Other Transportation*, do not exist in Luxembourg.

3.2.9.7 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A3 – Transport* are presented in Table 3-79.

Table 3-79: uncertainties for activity data and emission factors used for IPCC category 1A3 – Transport.

IPCC category/Group	Gas	Activity data uncertainty	Emission factor / estimation parameter uncertainty
1A3a - Transport - Civil Aviation	CO_2	10%	5%
1A3a - Transport - Civil Aviation	CH_4	10%	100%
1A3a - Transport - Civil Aviation	N_2O	10%	150%
1A3b - Road Transportation - Diesel Oil	CO_2	2%	2%
1A3b - Road Transportation - Diesel Oil	CH_4	2%	20%
1A3b - Road Transportation - Diesel Oil	N_2O	2%	20%
1A3b - Road Transportation - Gasoline	CO_2	2%	2%
1A3b - Road Transportation - Gasoline	CH_4	2%	20%
1A3b - Road Transportation - Gasoline	N_2O	2%	20%
1A3b - Road Transportation - LPG	CO_2	2%	2%
1A3b - Road Transportation - LPG	CH_4	2%	40%
1A3b - Road Transportation - LPG	N_2O	2%	100%
1A3b - Road Transportation - biomass	CH_4	2%	20%
1A3b - Road Transportation - biomass	N_2O	2%	20%
1A3b - Road Transportation - other fossil fuels	CO_2	20%	2%
1A3b - Road Transportation - other fossil fuels	CH_4	20%	20%
1A3b - Road Transportation - other fossil fuels	N_2O	20%	20%
1A3c - Railways - liquid fuels	CO_2	2%	2%
1A3c - Railways - liquid fuels	CH_4	2%	20%
1A3c - Railways - liquid fuels	N_2O	2%	20%
1A3c - Railways - biomass	CH_4	2%	20%
1A3c - Railways - biomass	N_2O	2%	20%
1A3c - Railways - other fossil fuels	CO_2	20%	2%
1A3c - Railways - other fossil fuels	CH_4	20%	20%
1A3c - Railways - other fossil fuels	N_2O	20%	20%
1A3d - Navigation - liquid fuels	CO_2	2%	2%
1A3d - Navigation - liquid fuels	CH_4	2%	20%
1A3d - Navigation - liquid fuels	N_2O	2%	20%
1A3d - Navigation - biomass	CH_4	2%	20%
1A3d - Navigation - biomass	N_2O	2%	20%
1A3d - Navigation - other fossil fuels	CO_2	20%	2%
1A3d - Navigation - other fossil fuels	CH_4	20%	20%
1A3d - Navigation - other fossil fuels	N_2O	20%	20%

The time-series reported under *1A3 - Transportation*, are considered as being consistent. For more specific information on time-series consistency, please refer to the methodological issues as described in the respective sub-categories above.

3.2.9.8 Source-specific QA/QC and verification

Activity data obtained directly from the operators was crosschecked with official statistics, if available, for plausibility.

Consistency and completeness checks have been performed using the tools embedded in CRF Reporter.

3.2.9.9 Category-specific recalculations including changes made in response to the review process

Table 3-80 presents the main revisions and recalculations done since submission 2023v1 relevant to IPCC sub-category *1A3 - Transport*.

For the impact of these recalculations on national total emissions, please refer to Chapter 10.

Table 3-80 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
1A3b/c/d	For several years, the country-specific CO_2 EFs for diesel oil (2017-2020), motor gasoline (2017-2021) and LPG (2016-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	updated CO_2 EF
1A3b/c/d	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-81).	Updated AD
1A3d	Updated AD (liquid fuels, biomass, and other fossil fuels) for leisure boats for 2021 (interpolation between 2020 and 2022) (Table 3-82).	AD

Table 3-81: Activity data recalculations in category 1A3b road transportation

AD changes in GJ	1A3bi Diesel Oil	1A3bi Biomass	1A3bi Other Fossil Fuels	1A3bi Gasoline	1A3bii Gasoline	1A3bii Diesel Oil	1A3bii Biomass	1A3bii Other Fossil Fuels	1A3biii Diesel Oil	1A3biii Biomass	1A3biii Other Fossil Fuels	1A3biv Gasoline	1A3biv Biomass
1990	45.3195	-	-	8.9334	-7.6474	-13.9403	-	-	-59473.4056	-	-	-1.2860	-
1991	36.6918	-	-	8.6947	-6.9609	-15.4538	-	-	-171912.8572	-	-	-1.7339	-
1992	28.9313	-	-	7.8025	-5.7841	-16.8495	-	-	-154236.7522	-	-	-2.0185	-
1993	21.9989	-	-	7.5982	-5.4448	-18.0535	-	-	-158112.1607	-	-	-2.1534	-
1994	25.1328	-	-	6.6031	-4.4004	-20.0339	-	-	-220101.1745	-	-	-2.2027	-
1995	19.4778	-	-	5.6158	-3.5591	-21.6630	-	-	-229346.0850	-	-	-2.0567	-
1996	12.8981	-	-	-7.8188	9.8620	-33.1708	-	-	-238385.5558	-	-	-2.0432	-
1997	18.1566	-	-	12.1997	-10.2430	4.0709	-	-	-176265.1148	-	-	-1.9568	-
1998	45.4287	-	-	85.3699	-84.6763	77.5696	-	-	-79236.5483	-	-	-0.6936	-
1999	40.8230	-	-	83.3169	-82.6145	57.5466	-	-	31494.5407	-	-	-0.7024	-
2000	30.4542	-	-	71.4363	-71.9259	59.9511	-	-	20597.7249	-	-	0.4896	-
2001	26.5787	-	-	65.3676	-65.6979	72.6177	-	-	35078.6853	-	-	0.3303	-
2002	-17.8785	-	-	57.5391	-57.7904	60.5433	-	-	29531.5707	-	-	0.2513	-
2003	-27.2196	-	-	49.3342	-49.6046	54.6835	-	-	19510.9967	-	-	0.2705	-
2004	-42.9165	-1.5873	-0.0906	40.5764	-40.6088	31.1060	-0.1070	-0.0061	20636.2489	1.8772	0.1072	0.0324	-
2005	-81.1894	-1.4340	-0.0819	36.4467	-36.4130	31.5067	-0.0969	-0.0055	20867.9323	1.6846	0.0962	-0.0337	-
2006	-64.6846	-1.1001	-0.0628	67.4581	-67.3411	36.1910	-0.0733	-0.0042	15540.8794	1.2946	0.0739	-0.1170	-
2007	119.9566	-118.7464	-6.7974	114.7493	-114.5951	92.6569	-7.3062	-0.3980	16959.0803	140.9581	8.0462	-0.1542	-0.0004
2008	66.4418	-117.3948	-6.7179	133.6323	-133.4789	112.2810	-6.4349	-0.3507	16352.1319	136.9253	7.8160	-0.1535	-0.0003
2009	-368.4700	209.9679	11.9637	202.0765	-204.5557	130.5908	18.9731	1.1051	-26685.7335	-253.6852	-14.4810	2.4791	0.0047
2010	-143.6759	6.8633	0.3468	243.1618	-246.0028	220.2622	5.3074	0.3149	-1470.3841	-13.3218	-0.7239	2.8410	0.0056
2011	-169.3598	52.1070	2.4650	314.4813	-319.8830	320.1013	5.0375	0.5589	-7818.7298	-62.9374	-3.3249	5.4017	0.0936
2012	-173.4285	11.1763	0.4755	347.1674	-352.5315	318.9535	8.0611	0.4455	-1835.6133	-20.9352	-1.0012	5.3641	0.0191
2013	-199.2528	-69.0714	-3.2740	358.9358	-365.5859	392.9394	6.2825	0.3285	6469.8229	70.6289	3.3140	6.6501	0.0131
2014	-1353.2977	208.5650	10.4115	-12.2072	2.5930	174.6824	27.3296	1.3622	-19143.5919	-269.7530	-13.4582	9.6141	0.0948
2015	-1969.7206	-152.6859	-8.7653	189.9096	-199.6740	369.4083	7.2830	0.6777	5584.4217	153.9138	8.5751	9.7644	0.2387
2016	-3137.5712	-295.7781	-16.6121	223.0522	-232.4378	541.8466	8.0653	0.8392	10676.0080	308.0665	16.9059	9.3855	0.2918
2017	-4619.2366	-506.8432	-28.6951	332.1795	-342.2327	566.1872	10.9358	1.0368	13598.8053	527.2574	29.4201	10.0532	0.2246
2018	-7283.1749	-598.8287	-34.0107	331.7136	-341.4257	592.0733	17.0375	1.5323	12786.8259	601.3308	33.5863	9.7121	0.2957
2019	91316.1137	5961.5821	332.5913	343.9735	-353.0529	564.6917	12.3226	1.6744	-88167.6690	-5962.1968	-333.5854	9.0796	0.4527
2020	-10270.0563	-1083.7087	-48.1196	427.6165	-436.1706	614.0394	26.9786	2.1856	12560.5291	1074.8942	46.7437	8.5542	0.4566
2021	-7444.3312	-698.4069	-25.8086	1459.3353	-476.5031	688.8434	21.3110	1.5936	14581.2161	1098.1121	36.2976	7.9245	0.4473

Table 3-82: Activity data recalculations in categories 1A3c and 1A3d

AD changes in GJ	1A3c liquid	1A3c biomass	1A3c other	1A3d liquid	1A3d biomass	1A3d other
2004	0.0181	-0.0161	-0.0009	0.0014	-0.0013	-0.0001
2005	0.0100	-0.0088	-0.0005	0.0014	-0.0012	-0.0001
2006	0.0056	-0.0049	-0.0003	0.0010	-0.0009	0.0000
2007	0.8169	-0.7232	-0.0413	0.1014	-0.0897	-0.0051
2008	0.8556	-0.7575	-0.0432	0.1048	-0.0928	-0.0053
2009	-1.4771	1.3078	0.0747	-0.1569	0.1390	0.0079
2010	-0.0694	0.0616	0.0033	-0.0075	0.0067	0.0004
2011	-0.3304	0.2937	0.0155	-0.0356	0.0317	0.0017
2012	-0.0844	0.0754	0.0036	-0.0101	0.0091	0.0004
2013	0.3334	-0.2980	-0.0140	0.0397	-0.0355	-0.0017
2014	-1.5672	1.3970	0.0697	-0.1736	0.1548	0.0077
2015	0.2706	-0.2399	-0.0134	0.0384	-0.0340	-0.0019
2016	0.5610	-0.4978	-0.0273	0.0913	-0.0810	-0.0044
2017	0.9040	-0.8014	-0.0447	0.1496	-0.1326	-0.0074
2018	0.5748	-0.5095	-0.0285	0.0864	-0.0766	-0.0043
2019	0.3271	-0.2899	-0.0162	0.0437	-0.0388	-0.0022
2020	0.4921	-0.4414	-0.0192	0.0264	-0.0236	-0.0010
2021	0.6706	-0.6075	-0.0201	-4726.2173	-396.9381	-11.2719

Table 3-83 shows the cumulated effect of all the recalculations listed in Table 3-80 on the total activity data and GHG emissions in category *1A3 - Transport* for the entire time series.

Table 3-83 – Effect of the recalculations in 1A3 – Transport on the activity data and GHG emissions (CO_2 emissions from biomass are excluded) between submissions 2023v1 and 2024v1 for the entire time series.

1A3 - Transport Activity data (AD) of all fuels and related GHG emissions (in Gg CO_2 eq.)						
Year	Submission 2023v1		Submission 2024v1		Difference	
	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.
1990	35 591.01	2 630.97	35 531.57	2 626.66	-59.44	-4.30
1991	43 770.91	3 237.83	43 599.02	3 225.18	-171.89	-12.66
1992	47 520.30	3 530.66	47 366.08	3 519.32	-154.22	-11.34
1993	48 175.96	3 575.94	48 017.85	3 564.31	-158.11	-11.63
1994	49 007.12	3 636.91	48 787.02	3 620.67	-220.10	-16.24
1995	45 760.84	3 395.21	45 531.49	3 378.28	-229.35	-16.93
1996	47 313.84	3 511.93	47 075.43	3 494.34	-238.41	-17.60
1997	50 938.96	3 776.22	50 762.72	3 763.24	-176.24	-12.98
1998	53 471.44	3 963.79	53 392.33	3 958.03	-79.11	-5.76
1999	59 216.64	4 387.61	59 248.24	4 390.07	31.59	2.46
2000	66 407.73	4 917.73	66 428.42	4 919.38	20.69	1.65
2001	69 849.22	5 175.41	69 884.40	5 178.13	35.18	2.72
2002	72 275.34	5 354.98	72 304.91	5 357.28	29.57	2.30
2003	79 529.15	5 893.53	79 548.69	5 895.08	19.54	1.55
2004	92 540.60	6 852.08	92 561.23	6 853.71	20.62	1.63
2005	97 384.88	7 215.04	97 405.70	7 216.69	20.82	1.65
2006	92 663.54	6 868.70	92 679.05	6 869.99	15.51	1.29
2007	90 478.75	6 574.61	90 495.94	6 576.07	17.19	1.46
2008	91 694.64	6 666.67	91 711.18	6 668.14	16.54	1.48
2009	84 317.28	6 129.15	84 290.33	6 127.48	-26.95	-1.66
2010	89 256.82	6 504.84	89 255.43	6 505.17	-1.40	0.33
2011	94 272.35	6 867.26	94 264.68	6 867.24	-7.67	-0.02
2012	90 059.76	6 553.15	90 058.07	6 553.68	-1.69	0.53
2013	88 430.79	6 420.10	88 437.46	6 421.31	6.67	1.21
2014	84 839.49	6 106.05	84 819.13	6 105.29	-20.36	-0.76
2015	79 255.44	5 669.00	79 259.44	5 670.07	3.99	1.07
2016	77 046.75	5 489.57	77 054.85	5 490.96	8.10	1.39
2017	79 784.13	5 628.31	79 793.71	5 629.81	9.58	1.50
2018	85 309.62	6 010.44	85 315.74	6 011.66	6.12	1.22
2019	87 832.94	6 170.15	87 836.67	6 171.19	3.73	1.05
2020	67 446.86	4 618.32	67 449.78	4 618.22	2.92	-0.10
2021	71 398.40	4 919.04	71 402.52	4 919.20	4.12	0.16

3.2.9.10 Category-specific planned improvements including those in response to the review process

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-84 will be explored.

Table 3-84 – Planned improvements for IPCC Sub-category 1A3 – Transport

GHG source & sink category	Planned improvement
1A3 - Transportation	No planned improvements

3.2.10 Other Sectors (1.A.4)

3.2.10.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in the category *1A4 - Other sectors* and covers combustion activities from stationary combustion and mobile combustion in sub-categories:

- *1A4a – Commercial/Institutional*
- *1A4b – Residential*
- *1A4c - Agriculture/Forestry/Fishing*

In 2022, category *1A4 - Other sectors* was responsible for 20.61% of GHG emissions from fuel combustion activities (this share was 13.25% in 1990) and represented around 17.31% of the total GHG emissions excluding LULUCF (10.69% in 1990).

Compared to 2021, emissions decreased by 13.75%, to attain the level of 1418.03 Gg CO_2 eq. Compared to 1990 emissions increased by 4.20%, mainly due to the steady increase in population and economic activity over the last two decades.

1A4 – Other Sectors is a key category regarding CO_2 emissions from gaseous and liquid fuels. It has been a key category for gaseous and liquid fuels without interruption since 1990, see Table 3-6 in Section 3.2.

Table 3-85 – GHG emission trends for category *1A4 – Other Sectors*: 1990-2022

1A4 - Other Sectors — GHG emissions by source & sink category excluding CO_2 emissions from biomass (Gg)												
Year	1A4a - Commercial/Institutional				1A4b - Residential				1A4c - Agriculture/Forestry/Fisheries			
	Total CO_2 eq.	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total CO_2 eq.	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total CO_2 eq.	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	642.21	639.00	0.08	0.004	682.13	669.92	0.37	0.007	36.57	34.04	0.006	0.009
1991	772.45	768.54	0.09	0.005	817.16	803.85	0.40	0.008	37.41	34.92	0.006	0.009
1992	712.33	708.77	0.09	0.004	750.70	738.28	0.37	0.007	35.67	33.33	0.006	0.008
1993	704.69	701.22	0.08	0.004	745.27	732.76	0.38	0.007	33.55	31.27	0.006	0.008
1994	679.22	675.89	0.08	0.004	709.71	698.16	0.35	0.007	35.96	33.57	0.006	0.008
1995	684.67	681.35	0.08	0.004	719.64	707.82	0.36	0.007	34.24	31.84	0.006	0.008
1996	763.98	760.31	0.09	0.004	789.51	778.06	0.34	0.007	35.87	33.41	0.006	0.009
1997	740.61	736.99	0.09	0.004	765.01	753.72	0.33	0.007	37.32	34.83	0.006	0.009
1998	774.65	770.88	0.09	0.005	795.41	784.29	0.33	0.007	38.04	35.46	0.006	0.009
1999	694.13	690.82	0.08	0.004	714.23	703.63	0.31	0.007	55.44	52.73	0.008	0.009
2000	549.35	547.13	0.06	0.002	1 082.26	1 070.14	0.35	0.009	27.44	24.83	0.004	0.009
2001	499.78	497.52	0.06	0.002	1 174.93	1 162.01	0.37	0.010	24.27	21.94	0.004	0.008
2002	501.72	499.38	0.06	0.002	1 118.23	1 106.23	0.34	0.009	25.85	23.40	0.004	0.009
2003	498.17	496.03	0.06	0.002	1 161.10	1 148.90	0.35	0.009	26.12	23.71	0.004	0.009
2004	463.76	461.78	0.05	0.002	1 241.41	1 228.50	0.37	0.010	27.49	25.07	0.004	0.009
2005	418.98	417.19	0.05	0.002	1 215.54	1 203.09	0.36	0.009	26.85	24.61	0.004	0.008
2006	395.82	394.33	0.04	0.001	1 203.58	1 191.14	0.35	0.009	27.35	25.17	0.004	0.008
2007	349.01	347.67	0.04	0.001	1 163.74	1 152.25	0.33	0.009	26.19	24.14	0.004	0.007
2008	377.71	376.33	0.04	0.001	1 196.56	1 184.47	0.34	0.009	28.35	26.20	0.004	0.008
2009	381.71	380.30	0.04	0.001	1 183.29	1 170.63	0.36	0.009	28.42	26.36	0.004	0.007
2010	502.53	500.56	0.05	0.002	1 161.18	1 148.62	0.36	0.009	28.57	26.62	0.004	0.007
2011	305.05	303.80	0.03	0.001	1 063.88	1 053.37	0.30	0.008	27.19	25.43	0.004	0.006
2012	409.62	407.97	0.04	0.002	1 083.21	1 071.13	0.35	0.009	27.22	25.54	0.004	0.006
2013	437.46	435.55	0.05	0.002	1 075.85	1 063.14	0.37	0.009	23.20	21.81	0.004	0.005
2014	381.77	379.99	0.05	0.002	973.03	960.09	0.38	0.008	23.59	22.23	0.003	0.005
2015	486.62	484.45	0.06	0.002	1 086.19	1 072.17	0.41	0.009	24.02	22.71	0.003	0.005
2016	511.16	508.82	0.06	0.002	1 119.40	1 104.17	0.45	0.010	23.76	22.54	0.003	0.004
2017	548.00	545.46	0.06	0.003	1 139.30	1 125.27	0.42	0.009	23.44	22.26	0.003	0.004
2018	569.31	566.70	0.07	0.003	1 042.55	1 028.45	0.42	0.009	24.27	23.10	0.003	0.004
2019	657.28	654.21	0.08	0.004	951.08	940.88	0.30	0.007	23.45	22.36	0.003	0.004
2020	546.88	544.22	0.07	0.003	1 040.02	1 029.43	0.31	0.007	22.88	21.83	0.003	0.004
2021	624.40	621.57	0.07	0.003	997.02	986.29	0.32	0.007	22.74	21.75	0.003	0.003
2022	475.52	473.33	0.06	0.002	919.25	906.50	0.38	0.008	23.26	22.25	0.003	0.003
Trend 1990-2022	-25.96%	-25.93%	-28.36%	-38.30%	34.76%	35.32%	3.13%	11.54%	-36.41%	-34.64%	-49.98%	-60.91%
Trend 2021-2022	-23.84%	-23.85%	-22.77%	-22.14%	-7.80%	-8.09%	20.70%	10.18%	2.27%	2.29%	15.07%	0.60%

Source: Environment Agency

Notes:

CO_2 emissions do not include CO_2 emissions from biomass which are reported under Memo Items.

CH_4 emissions are converted in CO_2e by multiplying the emissions by 28, *i.e.* the global warming potential (*GWP*) value for methane based on the effects of GHG over a 100-year time horizon.

N_2O emissions are converted in CO_2e by multiplying the emissions by 265, *i.e.* the global warming potential (*GWP*) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

3.2.10.2 Commercial/Institutional (1.A.4.a)

3.2.10.2.1 Source category description

In 2022, fuel combustion activities from the commercial and institutional sector were responsible for 6.91% of GHG emissions from fuel combustion activities (this share was 6.25% in 1990). With regard to total GHG emissions excluding LULUCF, *1A4a – Commercial/Institutional* covered 5.80% in 2022 and 5.05% in 1990. Compared to 2021, GHG emissions have decreased by 23.84% to reach the level of 475.52 Gg CO_2 eq. in 2022. This strong decrease is due to reduced energy consumption as a consequence of high global energy prices and national energy saving efforts. Compared to 1990, emissions in this sub-category decreased by 25.96%.

3.2.10.2.2 Methodological issues & time-series consistency

3.2.10.2.2.1 Activity data

Under *1A4a – Commercial/Institutional*, emissions from non-industrial commercial and institutional combustion plants (<50 MW) are accounted, thus covering numerous small combustion units, mainly for the heating purpose of buildings. No specific bottom-up data are available, so that emission estimates solely rely on top-down data from the national energy balance.

However, for the period 1990-1999, fuel consumption data are only reported under the so-called "*domestic sector"* by the national energy balance, covering consumption data for commercial and institutional as well as for residential combustion units. Consequently, data were distributed arbitrarily, *i.e.* 50% are reported under *1A4a - Commercial/Institutional* and 50% under *1A4b - Residential*. From 2000 onwards, the consumption data reported by the national energy balance are properly split between the two categories *1A4a* and *1A4b*.

The total activity rate of category *1A4a* has been relatively constant in recent years (Table 3-86), with sharp decreases in 2007, 2011 and 2014, probably due to relatively mild winters.

Table 3-86 – Activity data for category *1A4a – Commercial/Institutional*

1A4a - Commercial/Institutional Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Gas Oil, LPG	Gaseous Natural Gas	Biomass Biogas, Wood & Wood Wastes	Other
1990	9 296 234	NO	6 359 553	2 936 681	NO	NO
1991	11 122 560	NO	7 822 330	3 300 231	NO	NO
1992	10 323 786	NO	6 985 232	3 338 554	NO	NO
1993	10 259 447	NO	6 708 868	3 550 579	NO	NO
1994	9 898 224	NO	6 406 937	3 491 287	NO	NO
1995	10 042 374	NO	6 223 973	3 818 401	NO	NO
1996	11 278 090	NO	6 794 806	4 483 284	NO	NO
1997	10 906 999	NO	6 718 170	4 188 829	NO	NO
1998	11 463 250	NO	6 954 434	4 506 816	2 000	NO
1999	10 387 398	NO	5 942 758	4 441 640	3 000	NO
2000	8 915 370	NO	2 673 823	6 220 885	20 662	NO
2001	7 837 822	NO	3 312 877	4 491 584	33 361	NO
2002	7 957 180	NO	3 009 270	4 902 833	45 078	NO
2003	7 974 408	NO	2 693 297	5 243 119	37 993	NO
2004	7 357 752	NO	2 685 214	4 642 785	29 753	NO
2005	6 615 090	NO	2 495 701	4 091 000	28 389	NO
2006	6 505 067	NO	1 498 922	4 977 905	28 240	NO
2007	5 730 623	NO	1 383 477	4 319 537	27 609	NO
2008	6 344 565	NO	1 090 665	5 220 321	33 579	NO
2009	6 397 614	NO	1 079 899	5 275 683	42 033	NO
2010	8 175 626	NO	2 428 020	5 710 750	36 856	NO
2011	4 853 677	NO	1 927 682	2 883 496	42 499	NO
2012	6 669 545	NO	2 112 874	4 487 880	68 791	NO
2013	7 054 527	NO	2 531 362	4 437 823	85 342	NO
2014	6 142 035	NO	2 307 949	3 742 627	91 459	NO
2015	7 672 687	NO	3 285 685	4 301 932	85 070	NO
2016	8 182 788	NO	3 213 441	4 850 245	119 101	NO
2017	8 359 671	NO	4 568 878	3 711 297	79 496	NO
2018	8 765 997	NO	4 529 937	4 160 463	75 598	NO
2019	10 029 547	NO	5 494 764	4 465 689	69 094	NO
2020	8 181 169	NO	4 999 213	3 118 489	63 466	NO
2021	9 596 777	NO	4 786 782	4 778 259	31 737	NO
2022	7 338 077	NO	3 737 051	3 541 702	59 323	NO
Trend 1990-2022	-21.06%	NA	-41.24%	20.60%	NA	NA
Trend 2021-2022	-23.54%	NA	-21.93%	-25.88%	86.92%	NA

Source: Environment Agency

3.2.10.2.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2 for all fuels except for biomass (biogas, wood & wood wastes) for which a Tier 1 approach was used. For CH_4 and N_2O, the 2006 IPCC Guidelines Tier 1 approach was used.

3.2.10.2.2.3 Emission factors

Default CH_4 and N_2O emission factors have been applied for all fuels. For biomass (biogas, wood & wood wastes) the IPCC default EFs were applied. For gas oil, LPG, and natural gas, country-specific CO_2 emission factors were used (Table 3-87).

Table 3-87 – Emission factors for category *1A4a – Commercial/Institutional*

1A4a - Commercial/Institutional Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	64 957	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 037	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 386	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Biogas	biomass	54 600	D	5.00	D	0.10	D	2006 IPCC GL
Wood & Wood Wastes	biomass	112 000	D	300.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

Table 3-88 gives an overview of the evolution of the implied emission factors per fuel type. The slight fluctuations for the CH_4 and NO_2 IEFs for liquid fuels are due to fluctuations in the fuel mix (gas oil and LPG).

Table 3-88 – Implied emission factors for IPCC sub-category 1A4a – Commercial/Institutional

1A4a - Commercial/Institutional Implied Emission Factors (kg/TJ)									
Year	Liquid			Gaseous			Biomass		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	73 810	9.79	0.58	57 755	5.00	0.10	NO	NO	NO
1991	73 887	9.84	0.58	57 743	5.00	0.10	NO	NO	NO
1992	73 820	9.82	0.58	57 848	5.00	0.10	NO	NO	NO
1993	73 882	9.83	0.58	57 894	5.00	0.10	NO	NO	NO
1994	73 920	9.84	0.58	57 940	5.00	0.10	NO	NO	NO
1995	73 933	9.85	0.58	57 929	5.00	0.10	NO	NO	NO
1996	73 926	9.85	0.59	57 546	5.00	0.10	NO	NO	NO
1997	74 033	9.92	0.59	57 205	5.00	0.10	NO	NO	NO
1998	73 997	9.90	0.59	56 863	5.00	0.10	54 600	5.00	0.10
1999	74 000	9.90	0.59	56 522	5.00	0.10	54 600	5.00	0.10
2000	73 823	9.78	0.58	56 221	5.00	0.10	64 673	56.77	0.78
2001	73 904	9.83	0.58	56 258	5.00	0.10	70 298	85.68	1.17
2002	74 065	9.91	0.59	56 396	5.00	0.10	82 520	148.49	2.00
2003	74 115	9.96	0.60	56 533	5.00	0.10	69 387	81.00	1.10
2004	73 985	9.90	0.59	56 671	5.00	0.10	61 886	42.45	0.60
2005	73 875	9.85	0.59	56 910	5.00	0.10	60 977	37.78	0.53
2006	73 752	9.78	0.58	57 008	5.00	0.10	57 239	18.56	0.28
2007	73 979	9.91	0.59	56 793	5.00	0.10	57 558	20.20	0.30
2008	73 825	9.85	0.59	56 665	5.00	0.10	61 151	38.67	0.55
2009	73 420	9.63	0.56	57 056	5.00	0.10	65 362	60.31	0.83
2010	72 770	9.24	0.52	56 712	5.00	0.10	63 650	51.51	0.71
2011	72 352	9.02	0.50	56 988	5.00	0.10	58 329	24.16	0.35
2012	72 455	9.07	0.51	56 793	5.00	0.10	61 618	41.07	0.58
2013	72 693	9.20	0.52	56 680	5.00	0.10	66 287	65.07	0.89
2014	72 607	9.19	0.52	56 756	5.00	0.10	69 903	83.65	1.14
2015	73 127	9.45	0.54	56 760	5.00	0.10	61 330	39.59	0.56
2016	72 971	9.35	0.53	56 561	5.00	0.10	65 610	61.58	0.85
2017	73 429	9.59	0.56	56 577	5.00	0.10	55 168	7.92	0.14
2018	73 476	9.63	0.56	56 209	5.00	0.10	55 425	9.24	0.16
2019	73 475	9.65	0.56	56 091	5.00	0.10	55 059	7.36	0.13
2020	73 628	9.70	0.57	56 482	5.00	0.10	56 459	14.56	0.23
2021	73 287	9.53	0.55	56 664	5.00	0.10	65 101	58.97	0.81
2022	73 220	9.55	0.56	56 386	5.00	0.10	59 297	29.14	0.42

Source: Environment Agency

3.2.10.3 Residential (1A4b)

3.2.10.3.1 Source category description

In 2022, fuel combustion activities in the residential sector were responsible for 13.36% of GHG emissions from fuel combustion activities (6.64% in 1990). With regard to total GHG emissions excluding LULUCF emissions from *1A4b – Residential* reached 11.22% in 2022 and 5.36% in 1990. Compared to 2021, GHG emissions decreased by 7.80% and compared to 1990, they increased by 34.76%. Similarly to category 1A4a, a reduced consumption due to high global energy prices and national energy saving efforts is at the origin of the decrease in GHG emissions in 2022.

3.2.10.3.2 Methodological issues & time-series consistency

3.2.10.3.2.1 Activity data

Under *1A4b – Residential*, the following activities have been classified:

- *Non-industrial residential combustion plants < 50 MW*: This source category covers numerous smaller combustion units, mainly for heating purposes. No specific bottom-up data are available, so that emission estimates solely rely on top-down data provided by the national statistics institute. The consumption of coke, hard coal (other bituminous coal), lignite briquettes (brown coal briquettes), patent fuels, wood, biogas, gas oil, LPG and natural gas was obtained from the national statistics institute.
  However, for 1990-1999, the consumptions of gas oil and natural gas are reported under the so-called "*domestic sector"* by the national statistics institute, covering consumptions both from commercial and institutional as well as from residential combustion. Consequently, data were distributed arbitrarily, *i.e.* 50% was allocated to *1A4a - Commercial/Institutional* and 50% to *1A4b - Residential*. From 2000 onwards, the consumptions reported by the national statistics institute are properly split between the two sub-categories *1A4a* and *1A4b*.

- *Household and gardening:* Gasoline consumption was allocated to this sub-category. An average of 0.57 motorised gardening tools per household was assumed *(Komobile, FVT, 2017)*.

In order to verify the potential off-road fuel use by commuters (e.g. export in jerrycans for household and gardening use) to estimate the quantity of fuel sold to trans-border commuters and likely used for non-transport purposes such as motorized gardening equipment and off-road vehicles, publicly available statistics and literature on socio-economic behaviors of commuters have been reviewed (e.g. publications from Luxembourg's Institute of Socio-Economic Research). However, no information has been found on the potential off-road fuel export by commuters working in Luxembourg. Hence, estimating the amount of fuel exported for household/gardening applications would be a challenging task, and the uncertainty of the resulting emissions would be extremely high. In this context, Luxembourg calculated a "worst-case scenario" in which commuters use as much fuel for gardening tools and leisure boats per capita as residents and fuel them exclusively with fuel purchased in Luxembourg. This allows determining the maximum amount of fuel that could possibly be reallocated from passenger cars to off-road applications, and the resulting change in CH_4 and N_2O emissions due to different emission factors. Based on activity data and implied emission factors from Luxembourg's submission from April 2018, the resulting change in total emissions for the different inventory years would range between +0.0028 and +0.0168 Gg CO_2eq, and between 0.00002% and 0.00015% of Luxembourg's national total emissions of the respective years. Even an extremely conservative assumption would thus lead to an emission difference that is several orders of magnitude below the threshold of significance.

Activity data for both stationary and mobile sources, as described above, are listed in Table 3-89.

Table 3-89 – Activity data for category *1A4b – Residential*

1A4b - Residential Fuel consumption by fuel type (GJ)						
		Solid	Liquid	Gaseous	Biomass	Other
Year	Activity Total	Coke Oven Coke, Brown Coal Briquettes, Other Bituminous Coal, Patent Fuels	Gas Oil, LPG, Gasoline	Natural Gas	Biogas, Wood & Wood Wastes, Biogasoline	
1990	10 275 362	268 741	6 424 941	2 936 681	645 000	NO
1991	12 146 433	313 244	7 887 958	3 300 231	645 000	NO
1992	11 287 958	253 192	7 051 213	3 338 554	645 000	NO
1993	11 242 098	271 499	6 775 019	3 550 579	645 000	NO
1994	10 788 381	179 141	6 472 954	3 491 287	645 000	NO
1995	10 967 218	214 226	6 289 591	3 818 401	645 000	NO
1996	12 121 944	133 647	6 860 013	4 483 284	645 000	NO
1997	11 740 355	123 577	6 782 948	4 188 829	645 000	NO
1998	12 260 340	89 753	7 018 771	4 506 816	645 000	NO
1999	11 177 449	83 642	6 007 167	4 441 640	645 000	NO
2000	16 638 275	63 651	9 381 726	6 560 642	632 256	NO
2001	18 091 122	51 351	10 115 894	7 241 170	682 708	NO
2002	17 288 806	40 632	9 297 011	7 320 304	630 859	NO
2003	17 994 330	29 511	9 464 176	7 856 398	644 245	NO
2004	19 260 074	27 390	10 029 871	8 516 240	686 572	NO
2005	18 869 146	30 074	9 645 126	8 536 993	656 953	NO
2006	18 551 460	25 786	9 967 133	7 899 632	658 908	NO
2007	17 966 144	21 523	9 495 267	7 861 031	588 323	NO
2008	18 608 979	19 861	9 535 831	8 407 485	645 803	NO
2009	18 413 650	21 702	9 448 553	8 226 956	716 440	NO
2010	18 497 972	25 322	8 127 713	9 602 707	742 230	NO
2011	16 886 289	22 774	7 246 177	9 027 820	589 519	NO
2012	17 165 414	18 751	8 056 453	8 315 615	774 595	NO
2013	17 260 067	26 584	7 582 062	8 797 046	854 376	NO
2014	15 879 023	20 855	6 468 259	8 443 674	946 234	NO
2015	17 626 875	25 796	7 391 936	9 195 335	1 013 809	NO
2016	18 339 858	24 557	7 401 544	9 781 925	1 131 832	NO
2017	18 877 016	15 951	6 598 718	11 216 019	1 046 328	NO
2018	17 412 272	9 964	6 165 122	10 152 875	1 084 311	NO
2019	15 895 783	10 421	4 914 495	10 271 325	699 542	NO
2020	17 172 935	11 148	5 709 311	10 716 604	735 872	NO
2021	16 396 687	14 581	5 640 855	10 001 857	739 393	NO
2022	15 335 155	20 989	5 437 222	8 903 941	973 003	NO
Trend 1990-2022	49.24%	-92.19%	-15.37%	203.20%	50.85%	NA
Trend 2021-2022	-6.47%	43.94%	-3.61%	-10.98%	31.59%	NA

Source: Environment Agency

3.2.10.3.2.2 Methodology

For stationary sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the Tier 1 approach was used for CH_4 and N_2O.

For mobile sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the method used for CH_4 and N_2O is based on the GEORG model which conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. The methodology is described in section 3.2.7.7.2.2.

3.2.10.3.2.3 Emission factors

For stationary combustion sources, country-specific CO_2 emission factors and default CH_4 and N_2O emission factors from the 2006 IPCC Guidelines were used for the main fuels: see Table 3-90.

For mobile machinery (gardening equipment), the country-specific CO_2 EF for gasoline as described in section 3.2.5.3 was used (Tier 2). For biogasoline, the European CO_2 implied emission factor[82] for gasoline (71270 g/GJ) was applied. CH_4 and N_2O emissions were determined with the GEORG model (Table 3-90). N_2O emission factors are based on (Hausberger, 2006), while CH_4 emission factors are based on the EMEP/EEA 2023 Guidebook (section 1.A.4 Non-road mobile machinery[83], p.39, Tier 3 emission factors for 2-stroke and 4-stroke engines). These values are based on recent European measurements and are thus considered to be applicable to Luxembourg.

Table 3-90 – Emission factors for IPCC sub-category 1A4b – Residential

1A4b - Residential Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Coke Oven Coke	solid	107 000	D	300.00	D	1.50	D	2006 IPCC GL
Brown Coal Briquettes	solid	97 500	D	300.00	D	1.50	D	2006 IPCC GL
Other Bituminous Coal	solid	94 600	D	300.00	D	1.50	D	2006 IPCC GL
Patent Fuels	solid	97 500	D	300.00	D	1.50	D	2006 IPCC GL
LPG	liquid	64 957	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 037	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Gasoline	liquid	72 883	CS	89.65	CS	1.15	CS	AEV
Natural Gas	gaseous	56 386	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Biogas	biomass	54 600	D	5.00	D	0.10	D	2006 IPCC GL
Wood and Wood Wastes	biomass	112 000	D	300.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

Table 3-91 gives an overview of the evolution of the implied emission factors per fuel type.

82 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

83 https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-non-road/view

Table 3-91 – Implied emission factors for IPCC sub-category 1A4b – Residential

1A4b - Residential Implied Emission Factors (kg/TJ)												
Year	Solid			Liquid			Gaseous			Biomass		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	97 464	300	1.50	73 793	12.58	0.58	57 755	5.00	0.10	112 000	300.00	4.00
1991	97 593	300	1.50	73 874	12.12	0.59	57 743	5.00	0.10	112 000	300.00	4.00
1992	97 515	300	1.50	73 812	12.38	0.59	57 848	5.00	0.10	112 000	300.00	4.00
1993	98 441	300	1.50	73 871	12.51	0.59	57 894	5.00	0.10	112 000	300.00	4.00
1994	97 530	300	1.50	73 908	12.59	0.59	57 940	5.00	0.10	112 000	300.00	4.00
1995	101 287	300	1.50	73 920	12.57	0.59	57 929	5.00	0.10	112 000	300.00	4.00
1996	97 350	300	1.50	73 915	12.25	0.59	57 546	5.00	0.10	112 000	300.00	4.00
1997	97 367	300	1.50	74 020	12.25	0.60	57 205	5.00	0.10	112 000	300.00	4.00
1998	97 365	300	1.50	73 985	12.05	0.60	56 863	5.00	0.10	112 000	300.00	4.00
1999	97 303	300	1.50	73 986	12.32	0.60	56 522	5.00	0.10	112 000	300.00	4.00
2000	97 500	300	1.50	74 089	11.43	0.60	56 221	5.00	0.10	112 000	300.00	4.00
2001	97 500	300	1.50	74 104	11.30	0.60	56 258	5.00	0.10	112 000	300.00	4.00
2002	97 500	300	1.50	74 157	11.41	0.60	56 396	5.00	0.10	112 000	300.00	4.00
2003	97 500	300	1.50	74 162	11.39	0.60	56 533	5.00	0.10	112 000	300.00	4.00
2004	97 500	300	1.50	74 099	11.23	0.60	56 671	5.00	0.10	112 000	300.00	4.00
2005	97 500	300	1.50	74 060	11.15	0.60	56 910	5.00	0.10	112 000	300.00	4.00
2006	97 500	300	1.50	74 072	11.00	0.60	57 008	5.00	0.10	112 000	300.00	4.00
2007	97 500	300	1.50	74 111	10.94	0.60	56 793	5.00	0.10	111 988	299.96	4.00
2008	97 500	300	1.50	74 049	10.80	0.60	56 665	5.00	0.10	111 992	299.97	4.00
2009	97 500	300	1.50	73 992	10.67	0.60	57 056	5.00	0.10	111 994	299.97	4.00
2010	97 500	300	1.50	74 014	10.65	0.60	56 712	5.00	0.10	111 994	299.97	4.00
2011	97 500	300	1.50	74 063	10.66	0.60	56 988	5.00	0.10	111 006	294.91	3.93
2012	97 500	300	1.50	74 107	10.55	0.60	56 793	5.00	0.10	108 316	281.07	3.75
2013	97 500	300	1.50	74 112	10.55	0.60	56 680	5.00	0.10	108 249	280.72	3.75
2014	97 500	300	1.50	74 028	10.64	0.60	56 756	5.00	0.10	108 302	281.00	3.75
2015	97 500	300	1.50	74 098	10.55	0.60	56 760	5.00	0.10	107 786	278.34	3.71
2016	97 500	300	1.50	74 106	10.54	0.60	56 561	5.00	0.10	108 256	280.75	3.75
2017	97 500	300	1.50	74 128	10.62	0.60	56 577	5.00	0.10	106 752	273.03	3.64
2018	97 500	300	1.50	74 093	10.65	0.60	56 209	5.00	0.10	107 672	277.75	3.71
2019	97 500	300	1.50	74 012	10.79	0.60	56 091	5.00	0.10	107 720	278.00	3.71
2020	97 500	300	1.50	74 098	10.68	0.60	56 482	5.00	0.10	104 635	262.14	3.50
2021	97 500	300	1.50	74 125	10.70	0.60	56 664	5.00	0.10	106 547	271.97	3.63
2022	97 500	300	1.50	74 009	10.72	0.60	56 386	5.00	0.10	108 039	279.64	3.73

Source: Environment Agency

3.2.10.4 Agriculture/Forestry/Fishing (1A4c)

3.2.10.4.1 Source category description

Luxembourg reports emissions for the following sub-categories:

- *Stationary (1A4c.i)*
- *Off-road vehicles and other machinery (1A4c.ii)*

Sub-category *1A4c.iii Fishing* (mobile combustion) does not exist in Luxembourg.

In 2022, fuel combustion activities in agriculture and forestry were responsible for 0.34% of GHG emissions from fuel combustion activities (0.36% in 1990). With regard to total GHG emissions excluding LULUCF, emissions from *1A4c – Agriculture/Forestry/ Fishing* reached 0.28% in 2022 and 0.29% in 1990. Compared to 2021, GHG emissions increased by 2.27% and compared to 1990, they decreased by 36.41%.

Emissions of *1A4c - Agriculture/Forestry/Fishing* are shown in Table 3-85 at the beginning of this section.

3.2.10.4.2 Methodological issues & time-series consistency

3.2.10.4.2.1 Activity data

Under *1A4c – Agriculture/Forestry/Fishing*, the following activities have been classified:

- *Non-industrial combustion plants in agriculture, forestry and aquaculture*: the fuel consumption data of this activity are derived from the national energy balance. However, only the consumption of gas oil is reported for the entire time-series. Natural gas is only reported from 2000-2010 and from 2014-2020, and for 2022, but its consumption is very small (around 178 GJ for 2022). Biogas has been reported since 1998 and is currently the main fuel for heating purposes. Other fuels might be included elsewhere by the national energy balance.
- *Mobile machinery used in forestry and agriculture*: Diesel oil and gasoline consumption was attributed to mobile machinery used in forestry and agriculture (i.e. tractors, harvesters, chainsaws, etc.) based on stock data and economic indicators *(Komobile, FVT, 2017)*.

Activity data from both stationary and mobile sources, as described above, are listed in Table 3-92.

Table 3-92 – Activity data for category *1A4c – Agriculture/Forestry/Fishing*

1A4c - Agriculture/Forestry/Fishing Fuel consumption by fuel type (GJ)						
		Solid	Liquid	Gaseous	Biomass	Other
Year	Activity Total		Gas Oil, Gasoline, Diesel Oil	Natural Gas	Biogas, Biodiesel, Biogasoline	Fossil part of biodiesel
1990	459 028	NO	459 028	NO	NO	NO
1991	471 085	NO	471 085	NO	NO	NO
1992	449 696	NO	449 696	NO	NO	NO
1993	421 635	NO	421 635	NO	NO	NO
1994	452 523	NO	452 523	NO	NO	NO
1995	429 144	NO	429 144	NO	NO	NO
1996	450 451	NO	450 451	NO	NO	NO
1997	469 600	NO	469 600	NO	NO	NO
1998	479 152	NO	478 152	NO	1 000	NO
1999	714 026	NO	711 026	NO	3 000	NO
2000	343 312	NO	333 926	1 045	8 342	NO
2001	317 388	NO	295 172	693	21 523	NO
2002	343 210	NO	314 918	676	27 616	NO
2003	376 361	NO	318 854	1 125	56 381	NO
2004	426 316	NO	337 246	1 183	87 881	6
2005	459 370	NO	331 233	1 068	127 064	5
2006	495 320	NO	338 502	1 399	155 413	5
2007	512 473	NO	324 332	1 133	186 545	463
2008	577 985	NO	352 400	1 187	223 909	490
2009	629 073	NO	354 619	1 117	272 836	501
2010	575 553	NO	357 779	1 344	215 989	442
2011	538 016	NO	342 790	NO	194 849	377
2012	542 391	NO	344 133	NO	197 836	421
2013	470 366	NO	293 849	NO	176 107	410
2014	431 796	NO	299 626	21	131 571	577
2015	439 059	NO	305 663	24	132 579	793
2016	467 250	NO	303 195	42	163 169	845
2017	479 795	NO	299 117	32	179 545	1 101
2018	480 472	NO	310 557	11	168 764	1 140
2019	430 635	NO	300 790	34	128 717	1 094
2020	394 917	NO	293 192	37	100 428	1 260
2021	336 748	NO	292 500	NO	43 377	871
2022	425 417	NO	299 327	178	124 814	1 098
Trend 1990-2022	-7.32%	NA	-34.79%	NA	NA	NA
Trend 2021-2022	26.33%	NA	2.33%	NA	187.74%	26.04%

Source: Environment Agency

3.2.10.4.2.2 Methodological issues

For stationary sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the Tier 1 approach was used for CH_4 and N_2O.

For mobile sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the method used for CH_4 and N_2O is based on the GEORG model which conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. The methodology is described in section 3.2.7.7.2.2.

3.2.10.4.2.3 Emission factors

Country-specific CO_2 emission factors have been applied for natural gas, gas oil and diesel oil. For stationary sources, default 2006 IPCC emission factors were used for CH_4, N_2O and CO_2 from biomass. For mobile sources, the country-specific CO_2 EFs for diesel oil and gasoline as described in section 3.2.5.3 were used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-93). The CH_4 emission factors are based on the EMEP/EEA 2023 Guidebook (Tier 3 factors for 2-stroke and 4-stroke non-road engines, tables 3-7 and 3-8 in chapter "1.A.4 Non road mobile machinery"[84]). Luxembourg has opted for these emission factors from the EMEP/EEA Guidebook 2023 because these factors are grouped according to engine size classifications used in the EU. N_2O emission factors are based on (Hausberger, 2006). For biogasoline, biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 255 for details), the European CO_2 implied emission factors[85] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied (Table 3-93).

Table 3-93 – Emission factors for category *1A4c – Agriculture/Forestry/Fishing*

1A4c - Agriculture/Forestry/Fishing Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 037	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 037	CS	0.52	CS	10.69	CS	AEV
Gasoline	liquid	72 883	CS	556.04	CS	0.60	CS	AEV
Biogas	biomass	54 600	D	5.00	D	0.10	D	2006 IPCC GL
Natural Gas	gaseous	56 386	CS	5.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

An overview of the evolution of the implied emission factors per fuel type is given in Table 3-94.

84 https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-non-road/view

85 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-94 – Implied emission factors for IPCC sub-category 1A4c – Agriculture/Forestry/Fishing

1A4c - Agriculture/Forestry/Fishing Implied Emission Factors (kg/TJ)												
Year	Liquid			Gaseous			Biomass			Other		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	74 149	12.61	19.49	NO	NO	NO	NO	NO	NO	NO	NO	NO
1991	74 137	12.65	18.55	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	74 117	13.03	18.25	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	74 156	13.31	19.04	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	74 181	12.87	18.55	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	74 184	12.89	19.79	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	74 176	12.58	19.27	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	74 163	12.36	18.69	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	74 155	12.02	19.14	NO	NO	NO	54 600	5.00	0.10	NO	NO	NO
1999	74 164	11.22	13.21	NO	NO	NO	54 600	5.00	0.10	NO	NO	NO
2000	74 187	12.22	28.22	56 221	5.00	0.10	54 600	5.00	0.10	NO	NO	NO
2001	74 191	13.04	28.37	56 258	5.00	0.10	54 600	5.00	0.10	NO	NO	NO
2002	74 193	11.99	27.99	56 396	5.00	0.10	54 600	5.00	0.10	NO	NO	NO
2003	74 172	11.35	27.20	56 533	5.00	0.10	54 600	5.00	0.10	NO	NO	NO
2004	74 132	10.38	25.80	56 671	5.00	0.10	54 621	5.00	0.13	73 450	2.68	26.14
2005	74 117	10.07	24.17	56 910	5.00	0.10	54 613	5.00	0.12	73 450	2.41	24.50
2006	74 119	9.54	22.95	57 008	5.00	0.10	54 611	5.00	0.11	73 450	2.21	23.25
2007	74 122	9.54	21.95	56 793	5.00	0.10	55 421	4.91	1.06	73 450	2.05	22.25
2008	74 068	8.71	21.07	56 665	5.00	0.10	55 323	4.90	0.91	73 450	1.91	21.32
2009	74 055	8.45	20.05	57 056	5.00	0.10	55 207	4.91	0.75	73 450	1.77	20.29
2010	74 109	8.16	18.83	56 712	5.00	0.10	55 310	4.89	0.81	73 450	1.61	19.05
2011	74 094	8.15	17.75	NO	NO	NO	55 296	5.07	0.75	73 450	1.47	17.96
2012	74 114	8.05	16.77	NO	NO	NO	55 441	4.88	0.85	73 450	1.34	16.98
2013	74 122	9.08	16.06	NO	NO	NO	55 535	4.84	0.90	73 450	1.25	16.29
2014	74 050	8.74	15.28	56 756	5.00	0.10	56 262	4.83	1.45	73 450	1.15	15.49
2015	74 118	8.31	14.20	56 760	5.00	0.10	56 637	4.98	1.63	73 450	1.00	14.39
2016	74 126	8.19	13.31	56 561	5.00	0.10	56 392	5.03	1.36	73 450	0.89	13.49
2017	74 143	8.26	12.76	56 577	5.00	0.10	56 680	4.81	1.51	73 450	0.81	12.93
2018	74 116	7.84	12.21	56 209	5.00	0.10	56 891	4.88	1.58	73 450	0.74	12.37
2019	74 066	7.85	11.76	56 091	5.00	0.10	57 488	5.17	1.89	73 450	0.68	11.90
2020	74 130	7.94	11.33	56 482	5.00	0.10	60 071	4.87	3.38	73 450	0.63	11.48
2021	74 135	7.85	10.85	NO	NO	NO	66 133	5.06	6.72	73 450	0.56	10.99
2022	74 022	7.59	10.56	56 386	5.00	0.10	59 060	4.99	2.59	73 450	0.52	10.69

Source: Environment Agency

3.2.10.5 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A4 – Other Sectors* are presented in Table 3-95.

Table 3-95: uncertainties for activity data and emission factors used for IPCC category 1A4 – Other Sectors.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A4 - Gaseous Fuels	CO_2	2%	0.5%
1A4 - Gaseous Fuels	CH_4	2%	50%
1A4 - Gaseous Fuels	N_2O	2%	50%
1A4 - Liquid Fuels	CO_2	2%	0.5%
1A4 - Liquid Fuels	CH_4	2%	50%
1A4 - Liquid Fuels	N_2O	2%	50%
1A4 - Biomass	CH_4	7%	50%
1A4 - Biomass	N_2O	7%	60%
1A4 - Solid Fuels	CO_2	1%	3%
1A4 - Solid Fuels	CH_4	1%	50%
1A4 - Solid Fuels	N_2O	1%	50%

The time series reported under *1A4 - Other Sectors*, are considered to be consistent, to the best of data availability. Further investigations will be needed, in collaboration with the national statistics institute, to see whether, for the years 1990-1999, the arbitrary 50/50 split between 1A4a and 1A4b could be replaced by a more accurate split.

3.2.10.6 Source-specific QA/QC and verification

Standard QA/QC procedures (including consistency and completeness checks) were executed according to the QA/QC policy.

3.2.10.7 Category-specific recalculations including changes made in response to the review process

Table 3-96 presents the main revisions and recalculations relevant to category *1A4 – Other Sectors* since the last submission to the UNFCCC. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 3-96 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
1A4	Revision of the liquid petroleum gas and biogas activity data due to changes in the national energy balance for 2021 (-47 GJ for LPG and +39 TJ for biogas compared to the previous submission). The effects on the greenhouse gas emissions are marginal (< 10^{-3} Gg CO_2 eq.).	AD
1A4	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-2} Gg CO_2 for any given year).	CO_2 EF
1A4	Revision of the country-specific CO_2 emission factor for LPG for 2016-2021. The effects on the GHG emissions are marginal (less than 0.1 Gg CO_2 for any given year).	CO_2 EF
1A4cii	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-97).	AD
1A4bii/1A4cii	For several years, the country-specific CO2 EFs for diesel oil (2017-2020) and motor gasoline (2017-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	CO_2 EF
1A4	In the latest national energy balance, changes were made to the allocation method of natural gas to the different sectors for the year 2021. While significant differences are observed for each sub-category, the total amount of natural gas consumed by the energy sector in 2021 decreases only by 155GJ (corresponding to -0.060 Gg CO2eq). The affected sectors and the respective recalculations are shown in Table 3-62.	AD

Table 3-97 – Activity data changes in category 1A4cii since submission 2023v1

AD changes in GJ	1A4cii liquid	1A4cii biomass	1A4cii other
2004	0.0320	-0.0283	-0.0016
2005	0.0272	-0.0241	-0.0014
2006	0.0209	-0.0185	-0.0011
2007	2.1139	-1.8716	-0.1068
2008	2.0954	-1.8553	-0.1059
2009	-3.7826	3.3491	0.1912
2010	-0.1662	0.1475	0.0080
2011	-0.7555	0.6716	0.0355
2012	-0.2140	0.1911	0.0091
2013	0.8366	-0.7479	-0.0351
2014	-3.5241	3.1416	0.1567
2015	0.9129	-0.8093	-0.0451
2016	2.0524	-1.8210	-0.0999
2017	3.0080	-2.6665	-0.1488
2018	1.8689	-1.6566	-0.0925
2019	1.0655	-0.9444	-0.0528
2020	1.5614	-1.4005	-0.0609
2021	1.9276	-1.7464	-0.0577

Table 3-98 shows the effect of all the recalculations listed in Table 3-96 on the total activity data and GHG emissions for the entire time series.

Table 3-98 – Effect of the recalculations in 1A4 – Other sectors on the activity data and GHG emissions (CO_2 emissions from biomass are excluded) between submissions 2023v1 and 2024v1 for the entire time series.

1A4 - Other Sectors Activity data (AD) of all fuels and related GHG emissions (in Gg CO_2 eq.)						
Year	Submission 2023v1		Submission 2024v1		Difference	
	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.
1990	20 030.62	1 360.91	20 030.62	1 360.91	0.00	0.00
1991	23 740.08	1 627.02	23 740.08	1 627.02	0.00	0.00
1992	22 061.44	1 498.70	22 061.44	1 498.70	0.00	0.00
1993	21 923.18	1 483.51	21 923.18	1 483.51	0.00	0.00
1994	21 139.13	1 424.89	21 139.13	1 424.89	0.00	0.00
1995	21 438.74	1 438.54	21 438.74	1 438.54	0.00	0.00
1996	23 850.48	1 589.37	23 850.48	1 589.37	0.00	0.00
1997	23 116.95	1 542.93	23 116.95	1 542.93	0.00	0.00
1998	24 202.74	1 608.10	24 202.74	1 608.10	0.00	0.00
1999	22 278.87	1 463.81	22 278.87	1 463.81	0.00	0.00
2000	25 896.96	1 659.05	25 896.96	1 659.05	0.00	0.00
2001	26 246.33	1 698.98	26 246.33	1 698.98	0.00	0.00
2002	25 589.20	1 645.80	25 589.20	1 645.80	0.00	0.00
2003	26 345.10	1 685.39	26 345.10	1 685.39	0.00	0.00
2004	27 044.14	1 732.65	27 044.14	1 732.65	0.00	0.00
2005	25 943.61	1 661.37	25 943.61	1 661.37	0.00	0.00
2006	25 551.85	1 626.74	25 551.85	1 626.74	0.00	0.00
2007	24 209.24	1 538.94	24 209.24	1 538.94	0.00	0.00
2008	25 531.53	1 602.61	25 531.53	1 602.61	0.00	0.00
2009	25 440.34	1 593.42	25 440.34	1 593.42	0.00	0.00
2010	27 249.15	1 692.28	27 249.15	1 692.28	0.00	0.00
2011	22 277.98	1 396.12	22 277.98	1 396.12	0.00	0.00
2012	24 377.35	1 520.05	24 377.35	1 520.05	0.00	0.00
2013	24 784.96	1 536.52	24 784.96	1 536.52	0.00	0.00
2014	22 452.85	1 378.38	22 452.85	1 378.38	0.00	0.00
2015	25 738.62	1 596.83	25 738.62	1 596.83	0.00	0.00
2016	26 989.90	1 654.35	26 989.90	1 654.32	0.00	-0.03
2017	27 716.48	1 710.76	27 716.48	1 710.74	0.00	-0.02
2018	26 658.74	1 636.16	26 658.74	1 636.14	0.00	-0.02
2019	26 355.96	1 631.84	26 355.96	1 631.81	0.00	-0.02
2020	25 749.02	1 609.80	25 749.02	1 609.78	0.00	-0.02
2021	26 852.27	1 670.22	26 330.21	1 644.16	-522.06	-26.06

3.2.10.8 Category-specific planned improvements including those in response to the review process

Considering the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-99 will be explored.

Table 3-99 – Planned improvements for category *1A4 – Other Sectors*

GHG source & sink category	Planned improvement
1A4a – Commercial/Institutional, 1A4b – Residential	collecting information helping to refine the fuel consumption split between the commercial/institutional sectors, on the one hand, and the residential sector, on the other hand.

3.2.12 Other (1.A.5.)

3.2.12.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in category *1A5 – Other*. It covers combustion activities from stationary combustion and mobile combustion in sub-categories:

- *1A5a – Stationary*: Building and Plant Site Fuel Powered Machinery
- *1A5b – Mobile*: Military Vehicles

In 2022, category 1A5 - Other was responsible for 0.002% of GHG emissions from fuel combustion activities (this share was 0.03% in 1990) and represented around 0.001% of the total GHG emissions excluding LULUCF (0.02% in 1990).

Compared to 2021, emissions decreased by 0.95%, to attain the level of 0.11 Gg CO2e. Compared to 1990 emissions decreased by 96.39%.

1A5 - Other related CO_2 emissions from liquid fuels have been identified as a key category only for the year 1999.

Table 3-100 summarizes GHG emissions for category *1A5 – Other*.

Table 3-100 – GHG emission trends in CO_2e for category 1A5 – Other: 1990-2022

1A5 - Other GHG emissions by source & sink category (Gg)												
Year	1A5a - Stationary				1A5b - Mobile				1A5 - Other			
	Total CO_2 eq.	CO_2	CH_4	N_2O	Total CO_2 eq.	CO_2	CH_4	N_2O	Total CO_2 eq.	CO_2	CH_4	N_2O
1990	3.00	3.00	0.0002	0.0000	0.14	0.13	0.000006	0.000	3.14	3.12	0.000	0.000
1991	3.01	3.00	0.0002	0.0000	0.14	0.13	0.000006	0.000	3.15	3.13	0.000	0.000
1992	26.76	26.61	0.0034	0.0002	0.14	0.13	0.000006	0.000	26.90	26.74	0.003	0.000
1993	23.62	23.49	0.0030	0.0002	0.14	0.13	0.000006	0.000	23.76	23.62	0.003	0.000
1994	22.03	21.91	0.0028	0.0002	0.14	0.13	0.000006	0.000	22.17	22.04	0.003	0.000
1995	10.70	10.64	0.0013	0.0001	0.14	0.13	0.000005	0.000	10.83	10.77	0.001	0.000
1996	18.49	18.39	0.0023	0.0001	0.14	0.12	0.000005	0.000	18.62	18.51	0.002	0.000
1997	22.99	22.88	0.0027	0.0001	0.14	0.12	0.000005	0.000	23.13	23.01	0.003	0.000
1998	34.11	33.94	0.0041	0.0002	0.14	0.12	0.000005	0.000	34.24	34.06	0.004	0.000
1999	63.20	62.87	0.0078	0.0004	0.13	0.12	0.000005	0.000	63.33	62.99	0.008	0.000
2000	12.13	12.10	0.0009	0.0000	0.13	0.12	0.000005	0.0000	12.26	12.22	0.001	0.000
2001	24.21	24.15	0.0019	0.0000	0.13	0.12	0.000005	0.0000	24.34	24.27	0.002	0.000
2002	13.47	13.43	0.0010	0.0000	0.13	0.12	0.000004	0.0000	13.60	13.55	0.001	0.000
2003	3.15	3.14	0.0002	0.0000	0.13	0.12	0.000004	0.0000	3.28	3.26	0.000	0.000
2004	NO	NO	NO	NO	0.13	0.12	0.000004	0.0000	0.13	0.12	0.0000	0.0000
2005	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2006	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2007	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2008	NO	NO	NO	NO	0.13	0.12	0.000002	0.0000	0.13	0.12	0.0000	0.0000
2009	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2010	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2011	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2012	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2013	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2014	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2015	NO	NO	NO	NO	0.12	0.12	0.000001	0.0000	0.12	0.12	0.0000	0.0000
2016	NO	NO	NO	NO	0.12	0.12	0.000001	0.0000	0.12	0.12	0.0000	0.0000
2017	NO	NO	NO	NO	0.12	0.11	0.000001	0.0000	0.12	0.11	0.0000	0.0000
2018	NO	NO	NO	NO	0.12	0.11	0.000001	0.0000	0.12	0.11	0.0000	0.0000
2019	NO	NO	NO	NO	0.12	0.11	0.000001	0.0000	0.12	0.11	0.0000	0.0000
2020	NO	NO	NO	NO	0.11	0.11	0.000001	0.0000	0.11	0.11	0.0000	0.0000
2021	NO	NO	NO	NO	0.11	0.11	0.000001	0.0000	0.11	0.11	0.0000	0.0000
2022	NO	NO	NO	NO	0.11	0.11	0.000001	0.0000	0.11	0.11	0.0000	0.0000
Trend 1990-2022	NA	NA	NA	NA	-18.65%	-13.63%	-85.10%	-70.66%	-96.39%	-96.48%	-99.63%	-73.34%
Trend 2021-2022	NA	NA	NA	NA	-0.95%	-0.91%	-2.54%	-2.13%	-0.95%	-0.91%	-2.54%	-2.13%

Source: Environment Agency

Notes:

CO_2 emissions do not include CO_2 emissions from biomass which are reported under Memo Items.

CH_4 emissions are converted in CO_2e by multiplying the emissions by 28, *i.e.* the global warming potential (*GWP*) value for methane based on the effects of GHG over a 100-year time horizon.

N_2O emissions are converted in CO_2e by multiplying the emissions by 265, *i.e.* the global warming potential (*GWP*) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

3.2.12.2 Stationary (1A5a)

3.2.12.2.1 Source category description

In 2022, no emissions from fuel combustion activities from *1A5a - Stationary* were reported (notation key NO). In 1990, this category was responsible for 0.03% of GHG emissions from fuel combustion activities. With regard to total GHG emissions excluding LULUCF, the share was 0.02% in 1990.

3.2.12.2.2 Methodological issues & time-series consistency

3.2.12.2.2.1 Activity data

Fuel consumption data (gas oil, LPG) are obtained from the national statistics institute and were attributed to this sub-category based on expert judgement. Activity data are listed in Table 3-101.

3.2.12.2.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied to CO_2, whereas the Tier 1 approach was applied to CH_4 and N_2O.

Table 3-101 – Activity data for category *1A5 – Other*

1A5 - Other Activity Data (GJ)					
	1A5a - Stationary	1A5b - Mobile			
Year	Liquid Gas Oil, LPG	Liquid Diesel Oil	Biomass Biodiesel	Other Fossil part of biodiesel	Activity Total
1990	45 728	1 715	NO	NO	47 443
1991	45 728	1 712	NO	NO	47 440
1992	364 308	1 710	NO	NO	366 017
1993	321 934	1 707	NO	NO	323 642
1994	300 654	1 699	NO	NO	302 353
1995	148 456	1 686	NO	NO	150 142
1996	252 683	1 675	NO	NO	254 358
1997	321 685	1 664	NO	NO	323 349
1998	473 779	1 653	NO	NO	475 431
1999	869 847	1 643	NO	NO	871 490
2000	185 497	1 636	NO	NO	187 133
2001	370 223	1 631	NO	NO	371 854
2002	205 847	1 626	NO	NO	207 473
2003	48 158	1 620	NO	NO	49 779
2004	NO	1 619	0.47	0.03	1 619
2005	NO	1 621	0.45	0.03	1 621
2006	NO	1 623	0.44	0.02	1 624
2007	NO	1 581	40.09	2.29	1 624
2008	NO	1 586	39.09	2.23	1 628
2009	NO	1 590	39.84	2.27	1 632
2010	NO	1 596	36.70	1.99	1 634
2011	NO	1 600	33.72	1.78	1 636
2012	NO	1 593	41.31	1.98	1 636
2013	NO	1 586	47.83	2.24	1 636
2014	NO	1 571	61.49	3.07	1 635
2015	NO	1 557	73.50	4.09	1 635
2016	NO	1 550	79.79	4.38	1 634
2017	NO	1 525	102.02	5.69	1 633
2018	NO	1 526	101.58	5.67	1 633
2019	NO	1 527	100.58	5.63	1 634
2020	NO	1 476	147.81	6.43	1 631
2021	NO	1 491	136.11	4.50	1 632
2022	NO	1 479	146.75	5.49	1 631
Trend 1990-2022	NA	-13.79%	NA	NA	-96.56%
Trend 2021-2022	NA	-0.83%	7.82%	22.09%	-0.04%

Source: Environment Agency

3.2.12.2.2.3 Emission factors

Country-specific CO_2 emission factors were applied to gas oil and LPG, whereas for CH_4 and N_2O, default 2006 IPCC emission factors were used (Table 3-102). For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 244 for details), the European CO_2 implied emission factor for diesel oil (73450 g/GJ) was applied.

Table 3-102 – Emission factors for category *1A5 – Other*

1A5 - Other Emission Factors for 2022 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	64 957	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 037	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 037	CS	0.53	CS	8.19	CS	AEV

Source: Environment Agency

An overview of the evolution of the implied emission factors per fuel type is given in Table 3-103.

Table 3-103 – Implied emission factors for IPCC sub-category 1A5 – Other

1A5 - Other Implied Emission Factors (kg/TJ)												
Year	1A5a - Stationary Liquid (Gas Oil, LPG)			1A5b - Mobile Liquid (Diesel Oil)			Biomass (Biodiesel)			Other (Fossil part of biodiesel)		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	65 536	5.00	0.10	74171	3.40	26.53	NO	NO	NO	NO	NO	NO
1991	65 604	5.00	0.10	74157	3.39	26.57	NO	NO	NO	NO	NO	NO
1992	73 054	9.37	0.54	74130	3.37	26.62	NO	NO	NO	NO	NO	NO
1993	72 961	9.29	0.53	74172	3.35	26.66	NO	NO	NO	NO	NO	NO
1994	72 872	9.24	0.52	74197	3.29	27.00	NO	NO	NO	NO	NO	NO
1995	71 693	8.58	0.46	74202	3.20	27.57	NO	NO	NO	NO	NO	NO
1996	72 761	9.19	0.52	74192	3.11	28.10	NO	NO	NO	NO	NO	NO
1997	71 136	8.30	0.43	74179	3.03	28.63	NO	NO	NO	NO	NO	NO
1998	71 630	8.59	0.46	74170	2.94	29.17	NO	NO	NO	NO	NO	NO
1999	72 273	8.91	0.49	74174	2.86	29.68	NO	NO	NO	NO	NO	NO
2000	65 215	5.00	0.10	74213	2.81	30.02	NO	NO	NO	NO	NO	NO
2001	65 224	5.00	0.10	74218	2.77	30.25	NO	NO	NO	NO	NO	NO
2002	65 256	5.00	0.10	74219	2.63	29.78	NO	NO	NO	NO	NO	NO
2003	65 266	5.00	0.10	74195	2.40	28.67	NO	NO	NO	NO	NO	NO
2004	NO	NO	NO	74156	2.19	26.84	73450	2.19	26.84	73450	2.19	26.84
2005	NO	NO	NO	74140	1.99	24.40	73450	1.99	24.40	73450	1.99	24.40
2006	NO	NO	NO	74140	1.79	21.92	73450	1.79	21.92	73450	1.79	21.92
2007	NO	NO	NO	74146	1.62	19.37	73450	1.62	19.37	73450	1.62	19.37
2008	NO	NO	NO	74090	1.51	16.99	73450	1.51	16.99	73450	1.51	16.99
2009	NO	NO	NO	74077	1.44	15.02	73450	1.44	15.02	73450	1.44	15.02
2010	NO	NO	NO	74131	1.39	13.55	73450	1.39	13.55	73450	1.39	13.55
2011	NO	NO	NO	74116	1.35	12.45	73450	1.35	12.45	73450	1.35	12.45
2012	NO	NO	NO	74137	1.27	11.58	73450	1.27	11.58	73450	1.27	11.58
2013	NO	NO	NO	74146	1.14	10.95	73450	1.14	10.95	73450	1.14	10.95
2014	NO	NO	NO	74073	1.02	10.47	73450	1.02	10.47	73450	1.02	10.47
2015	NO	NO	NO	74132	0.90	10.04	73450	0.90	10.04	73450	0.90	10.04
2016	NO	NO	NO	74140	0.79	9.67	73450	0.79	9.67	73450	0.79	9.67
2017	NO	NO	NO	74156	0.69	9.35	73450	0.69	9.35	73450	0.69	9.35
2018	NO	NO	NO	74130	0.63	9.06	73450	0.63	9.06	73450	0.63	9.06
2019	NO	NO	NO	74077	0.59	8.79	73450	0.59	8.79	73450	0.59	8.79
2020	NO	NO	NO	74145	0.57	8.57	73450	0.57	8.57	73450	0.57	8.57
2021	NO	NO	NO	74151	0.55	8.36	73450	0.55	8.36	73450	0.55	8.36
2022	NO	NO	NO	74037	0.53	8.19	73450	0.53	8.19	73450	0.53	8.19
Trend 1990-2022	NA	NA	NA	-0.18%	-84.33%	-69.14%	NA	NA	NA	NA	NA	NA
Trend 2021-2022	NA	NA	NA	-0.15%	-2.50%	-2.09%	0.00%	-2.50%	-2.09%	0.00%	-2.50%	-2.09%

Source: Environment Agency

3.2.12.3 Mobile (1A5b)

3.2.12.3.1 Source category description

In 2022, fuel combustion activities in 1A5b – Mobile were responsible for 0.002% of GHG emissions from fuel combustion activities (0.001% in 1990). With regard to total GHG emissions excluding LULUCF emissions from 1A5b – Mobile reached 0.001% in 2022 and 0.001% in 1990. Compared to 2021, GHG emissions decreased by 0.95% and compared to 1990, they decreased by 18.65%.

3.2.12.3.2 Methodological issues & time-series consistency

3.2.12.3.2.1 Activity data

Fuel consumption data (diesel oil, biodiesel, fossil part of biodiesel) from military vehicles was attributed to this sub-category based on expert judgement (Komobile, FVT, 2017). Activity data is listed in Table 3-101.

3.2.12.3.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the method used for CH_4 and N_2O is based on the GEORG model which conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. The methodology is described in section 3.2.7.7.2.2.

3.2.12.3.2.3 Emission factors

The country specific CO_2 EF for diesel oil as described in section 3.2.5.3 was used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-102). The CH_4 emission factors are based on the EMEP/EEA 2023 Guidebook (Tier 3) while N_2O emission factors are based on (Hausberger, 2006).

For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to 255 for details), the European CO_2 implied emission factor for diesel oil (73450 g/GJ) was applied.

3.2.12.4 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A5 – Other* are presented in Table 3-104.

Table 3-104 - Uncertainties for activity data and emission factors used for IPCC category 1A5 – Other.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A5 - Gaseous Fuels	CO2	2%	0.5%
1A5 - Gaseous Fuels	CH4	2%	50%
1A5 - Gaseous Fuels	N2O	2%	50%

The time series reported under *1A5 - Other* are considered to be consistent.

3.2.12.5 Source-specific QA/QC and verification

Standard QA/QC procedures (including consistency and completeness checks) were executed according to the QA/QC policy.

3.2.12.6 Category-specific recalculations including changes made in response to the review process.

Table 3-105 presents the main revisions and recalculations relevant to category *1A5 – Other* since the last submission to the UNFCCC.

Table 3-105 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
1A5b	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-106).	AD
1A5b	For several years, the country-specific CO2 EFs for diesel oil (2017-2020) and motor gasoline (2017-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	CO_2 EF

Table 3-106 – Activity data changes in category 1A5b since submission 2023v1

AD changes in GJ	1A5b liquid	1A5b biomass	1A5b other	1D1d liquid
2004	0.0002	-0.0001	0.0000	0.0001
2005	0.0001	-0.0001	0.0000	0.0002
2006	0.0001	-0.0001	0.0000	0.0001
2007	0.0104	-0.0093	-0.0005	0.0107
2008	0.0096	-0.0085	-0.0005	0.0108
2009	-0.0172	0.0152	0.0009	-0.0148
2010	-0.0008	0.0007	0.0000	-0.0007
2011	-0.0036	0.0032	0.0002	-0.0027
2012	-0.0010	0.0009	0.0000	-0.0006
2013	0.0046	-0.0041	-0.0002	0.0022
2014	-0.0187	0.0167	0.0008	-0.0101
2015	0.0047	-0.0042	-0.0002	0.0025
2016	0.0106	-0.0094	-0.0005	0.0059
2017	0.0156	-0.0138	-0.0008	0.0099
2018	0.0093	-0.0082	-0.0005	0.0054
2019	0.0055	-0.0049	-0.0003	0.0028
2020	0.0080	-0.0071	-0.0003	0.0009
2021	0.0100	-0.0090	-0.0003	0.0011

Table 3-107 shows the effect of all the recalculations in Table 3-105 on the total activity data (very marginal) and GHG emissions.

Table 3-107 - Effect of the recalculations in 1A5 – Other on the activity data and GHG emissions (CO_2 emissions from biomass are excluded) between submissions 2023v1 and 2024v1 for the entire time series.

1A5 - Other Activity data (AD) of all fuels and related GHG emissions (in Gg CO_2 eq.)						
Year	Submission 2023v1		Submission 2024v1		Difference	
	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.	AD (TJ)	Gg CO_2 eq.
1990	47.44	3.14	47.44	3.14	0.00	0.00
1991	47.44	3.15	47.44	3.15	0.00	0.00
1992	366.02	26.90	366.02	26.90	0.00	0.00
1993	323.64	23.76	323.64	23.76	0.00	0.00
1994	302.35	22.17	302.35	22.17	0.00	0.00
1995	150.14	10.83	150.14	10.83	0.00	0.00
1996	254.36	18.62	254.36	18.62	0.00	0.00
1997	323.35	23.13	323.35	23.13	0.00	0.00
1998	475.43	34.24	475.43	34.24	0.00	0.00
1999	871.49	63.33	871.49	63.33	0.00	0.00
2000	187.13	12.26	187.13	12.26	0.00	0.00
2001	371.85	24.34	371.85	24.34	0.00	0.00
2002	207.47	13.60	207.47	13.60	0.00	0.00
2003	49.78	3.28	49.78	3.28	0.00	0.00
2004	1.62	0.13	1.62	0.13	0.00	0.00
2005	1.62	0.13	1.62	0.13	0.00	0.00
2006	1.62	0.13	1.62	0.13	0.00	0.00
2007	1.62	0.13	1.62	0.13	0.00	0.00
2008	1.63	0.13	1.63	0.13	0.00	0.00
2009	1.63	0.12	1.63	0.12	0.00	0.00
2010	1.63	0.12	1.63	0.12	0.00	0.00
2011	1.64	0.12	1.64	0.12	0.00	0.00
2012	1.64	0.12	1.64	0.12	0.00	0.00
2013	1.64	0.12	1.64	0.12	0.00	0.00
2014	1.64	0.12	1.64	0.12	0.00	0.00
2015	1.63	0.12	1.63	0.12	0.00	0.00
2016	1.63	0.12	1.63	0.12	0.00	0.00
2017	1.63	0.12	1.63	0.12	0.00	0.00
2018	1.63	0.12	1.63	0.12	0.00	0.00
2019	1.63	0.12	1.63	0.12	0.00	0.00
2020	1.63	0.11	1.63	0.11	0.00	0.00
2021	1.63	0.11	1.63	0.11	0.00	0.00

3.2.12.7 Category-specific planned improvements including those in response to the review process

No further improvements are planned.

3.3 Fugitive Emissions from Fuels (1.B)

3.3.1 Solid Fuels (1.B.1)

This category does not exist in Luxembourg.

3.3.2 Oil and natural gas and other emissions from energy production (1.B.2)

3.3.2.1 Source category description

In Luxembourg, fugitive emissions only occur from natural gas transmission and storage and distribution (sub-categories *1B2b3 – Transmission and Storage* and *1B2b4 – Distribution*) as well as from natural gas venting of transmission and distribution networks (sub-category *1B2c – Venting*). Other fugitive emissions – because they are closely linked to production, processing or exploration – are not occurring in Luxembourg.

Fugitive emissions from the distribution of refined oil products (category 1B2a5) are reported with notation key *NA* in the CRF tables, as only NMVOC emissions occur.

In 2022, fugitive emissions from category *1B2 – Oil and natural gas and other emissions from energy production* were responsible for 0.38% of GHG emissions from the energy sector (0.21% in 1990) and represented 0.32% of the total GHG emissions excluding LULUCF (0.17% in 1990). Compared to 2021, fugitive GHG emissions decreased by 22.17% and compared to 1990, they decreased by 7.52%. Both decreases are due to the very low natural gas consumption in 2022 following the high global energy prices.

Category *1B2 - Oil and natural gas and other emissions from energy production* has not been identified as key category.

Table 3-108 – GHG emission trends in CO_2 eq. for category *1B2 – Oil and natural gas and other emissions from energy production*: 1990-2022

Year	1B2 - Oil and Natural Gas GHG emissions (Gg CO_2 eq.) — 1B2a - Oil				1B2b - Natural Gas				1B2c - Venting & Flaring				1B2d - Other			
	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	NA	NA	NA	NO	21.71	0.03	21.69	NO,NA	0.24	0.00	0.24	NO	NA	NA	NA	NA
1991	NA	NA	NA	NO	22.52	0.03	22.50	NO,NA	0.25	0.00	0.25	NO	NA	NA	NA	NA
1992	NA	NA	NA	NO	23.50	0.03	23.48	NO,NA	0.26	0.00	0.26	NO	NA	NA	NA	NA
1993	NA	NA	NA	NO	24.40	0.03	24.37	NO,NA	0.27	0.00	0.27	NO	NA	NA	NA	NA
1994	NA	NA	NA	NO	24.57	0.03	24.54	NO,NA	0.27	0.00	0.27	NO	NA	NA	NA	NA
1995	NA	NA	NA	NO	28.01	0.03	27.98	NO,NA	0.30	0.00	0.30	NO	NA	NA	NA	NA
1996	NA	NA	NA	NO	30.64	0.04	30.61	NO,NA	0.34	0.00	0.33	NO	NA	NA	NA	NA
1997	NA	NA	NA	NO	31.34	0.04	31.30	NO,NA	0.34	0.00	0.34	NO	NA	NA	NA	NA
1998	NA	NA	NA	NO	31.58	0.04	31.55	NO,NA	0.35	0.00	0.35	NO	NA	NA	NA	NA
1999	NA	NA	NA	NO	32.70	0.04	32.66	NO,NA	0.36	0.00	0.36	NO	NA	NA	NA	NA
2000	NA	NA	NA	NO	33.57	0.04	33.53	NO,NA	0.37	0.00	0.37	NO	NA	NA	NA	NA
2001	NA	NA	NA	NO	37.31	0.04	37.27	NO,NA	0.42	0.00	0.42	NO	NA	NA	NA	NA
2002	NA	NA	NA	NO	53.44	0.06	53.38	NO,NA	0.60	0.00	0.60	NO	NA	NA	NA	NA
2003	NA	NA	NA	NO	54.16	0.06	54.10	NO,NA	0.61	0.00	0.60	NO	NA	NA	NA	NA
2004	NA	NA	NA	NO	60.11	0.07	60.04	NO,NA	0.67	0.00	0.67	NO	NA	NA	NA	NA
2005	NA	NA	NA	NO	59.20	0.07	59.13	NO,NA	0.66	0.00	0.66	NO	NA	NA	NA	NA
2006	NA	NA	NA	NO	62.13	0.07	62.06	NO,NA	0.69	0.00	0.69	NO	NA	NA	NA	NA
2007	NA	NA	NA	NO	58.13	0.07	58.06	NO,NA	0.65	0.00	0.65	NO	NA	NA	NA	NA
2008	NA	NA	NA	NO	55.58	0.07	55.52	NO,NA	0.63	0.00	0.63	NO	NA	NA	NA	NA
2009	NA	NA	NA	NO	56.19	0.07	56.13	NO,NA	0.63	0.00	0.63	NO	NA	NA	NA	NA
2010	NA	NA	NA	NO	60.43	0.07	60.36	NO,NA	0.68	0.00	0.68	NO	NA	NA	NA	NA
2011	NA	NA	NA	NO	52.38	0.06	52.32	NO,NA	0.59	0.00	0.59	NO	NA	NA	NA	NA
2012	NA	NA	NA	NO	53.59	0.06	53.52	NO,NA	0.60	0.00	0.60	NO	NA	NA	NA	NA
2013	NA	NA	NA	NO	45.63	0.05	45.57	NO,NA	0.52	0.00	0.52	NO	NA	NA	NA	NA
2014	NA	NA	NA	NO	43.09	0.05	43.04	NO,NA	0.49	0.00	0.49	NO	NA	NA	NA	NA
2015	NA	NA	NA	NO	38.75	0.05	38.70	NO,NA	0.44	0.00	0.44	NO	NA	NA	NA	NA
2016	NA	NA	NA	NO	35.61	0.04	35.56	NO,NA	0.41	0.00	0.41	NO	NA	NA	NA	NA
2017	NA	NA	NA	NO	35.07	0.04	35.03	NO,NA	0.40	0.00	0.40	NO	NA	NA	NA	NA
2018	NA	NA	NA	NO	34.48	0.04	34.44	NO,NA	0.40	0.00	0.40	NO	NA	NA	NA	NA
2019	NA	NA	NA	NO	34.52	0.04	34.48	NO,NA	0.40	0.00	0.40	NO	NA	NA	NA	NA
2020	NA	NA	NA	NO	31.16	0.04	31.12	NO,NA	0.36	0.00	0.36	NO	NA	NA	NA	NA
2021	NA	NA	NA	NO	33.52	0.04	33.48	NO,NA	0.38	0.00	0.38	NO	NA	NA	NA	NA
2022	NA	NA	NA	NO	26.09	0.03	26.06	NO,NA	0.30	0.00	0.30	NO	NA	NA	NA	NA
Trend 1990-2022	NA	NA	NA	NA	20.15%	20.15%	20.15%	NA	26.89%	-32.69%	26.99%	NA	NA	NA	NA	NA
Trend 2021-2022	NA	NA	NA	NA	-22.17%	-22.17%	-22.17%	NA	-21.81%	-55.32%	-21.76%	NA	NA	NA	NA	NA

Source: Environment Agency

Notes: CH_4 emissions are converted in CO_2e by multiplying the emissions by 25, *i.e.* the global warming potential (*GWP*) value for methane based on the effects of GHG over a 100-year time horizon.

3.3.2.2 Methodological issues

3.3.2.2.1 Activity data

Activity data on national natural gas consumption are obtained from the national statistics institute and are listed in Table 3-109.

Table 3-109 – Activity data for category *1B2 – Oil and natural gas and other emissions from energy production*: 1990-2022

Natural Gas Consumption (GJ)										
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
17933319	18646146	19434015	20184363	20334429	23237685	25491951	26121114	26375112	27358065	28119435
2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
31177039	44596356	45132516	50018454	49248164	51513517	48083276	45774534	46592327	50108059	43235365
2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
44010941	37284498	35310029	32201184	29685081	29283800	28621878	28667601	26013711	28035090.18	22021951.9

Source: STATEC: national energy balance.

3.3.2.2.2 Methodology

For sub-categories *1B2b3 – Transmission and Storage* and *1B2b4 – Distribution* the 2006 IPCC Guidelines Tier 1 approach has been applied.

For sub-category *1B2c – Venting*, a Tier 3 approach was applied. According to Luxembourg's natural gas network operator, 2016 was a typical year with regard to venting (no major works in the gas network) with a vented volume of approximately 2'000 Nm^3. In 2017, 40'000 Nm^3 were vented due to major works (in that specific year). Unfortunately, the operator was not able to provide annual activity data on venting activities for the other years of the time series, and, hence, extrapolation of vented volumes was challenging due to the high variability that is apparent for 2016 and 2017. In order to circumvent this problem, the ratio of the average vented quantity between 2016 and 2017 (approx. 22000 Nm^3) and the corresponding annual consumption was taken and extrapolated (as a constant) over the entire time series. Hence, by multiplying this ratio with the annual natural gas consumption an annual quantity of vented natural gas for the entire time series was obtained. Using the annual natural gas composition, and in particular the methane and carbon dioxide content as obtained by the operator, the vented quantities of methane and CO_2 could thus be calculated. The method used is comparable to the Tier 3 approach according to 2006 IPCC Guidelines (Vol. 2, Chap. 4, p. 4.66).

3.3.2.2.3 Emission factors

For sub-categories *1B2b3 – Transmission and Storage* and *1B2b4 – Distribution,* the 2006 IPCC Guidelines default emission factors have been applied:

- Natural Gas Transmission - CO_2: .... $8.8 \cdot 10^{-7}$ Gg/10^6 m^3
- Natural Gas Distribution - CO_2: .... $5.1 \cdot 10^{-5}$ Gg/10^6 m^3
- Natural Gas Transmission - CH_4: .... $4.8 \cdot 10^{-4}$ Gg/10^6 m^3
- Natural Gas Distribution - CH_4: .... $1.1 \cdot 10^{-3}$ Gg/10^6 m^3

Emission factors from the 2006 IPCC Guidelines were selected as these best reflect the modern and regularly serviced transmission and distribution natural gas networks in Luxembourg.

3.3.2.3 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1B2 - Oil and natural gas and other emissions from energy production* are presented in Table 3-110.

Table 3-110: uncertainties for activity data and emission factors used for IPCC category 1B2 - Oil and natural gas and other emissions from energy production.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1B2 – Natural Gas	CO_2	2%	100%
1B2 – Natural Gas	CH_4	2%	100%

The time series reported under *1B2 - Oil and natural gas and other emissions from energy production* are considered to be consistent. Fluctuations in the time series occur due to maintenance stops of large industrial plants such as the 350 MWe CHP gas turbine (Twinerg, closed in 2016), the closure of iron and steel facilities (2012 - ArcelorMittal Schifflange) or more heat demand due to colder winters. Although the population grows rapidly in Luxembourg, this does not necessarily induce a growth in natural gas demand as buildings become more and more energy efficient through better insulation.

3.3.2.4 Source-specific QA/QC and verification

Standard QA/QC procedures were followed.

Consistency and completeness checks have been performed using the tools embedded in CRF Reporter.

3.3.2.5 Category-specific recalculations including changes made in response to the review process

Table 3-111 presents the main revisions and recalculations relevant to category *1B2 – Oil and natural gas and other emissions from energy production* since the last submission to the UNFCCC.

Table 3-111 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
1B2biii5 – Transmission of natural gas	An error correction was made which slightly changes the CO_2 emissions for the entire timeseries (Table 3-112).	CO_2 emissions

Table 3-112 – Recalculation of CO_2 emissions from category 1B2biii5 since submission 2023v1

	CO2 emissions from 1B2biii5 - Transmission of natural gas (Gg)		
	subm. 2024v1	subm. 2023v1	recalculation
1990	0.02500	0.02543	-0.00043
1991	0.02593	0.02638	-0.00045
1992	0.02706	0.02753	-0.00047
1993	0.02809	0.02858	-0.00048
1994	0.02829	0.02877	-0.00049
1995	0.03225	0.03281	-0.00056
1996	0.03528	0.03589	-0.00061
1997	0.03608	0.03671	-0.00062
1998	0.03637	0.03699	-0.00063
1999	0.03765	0.03830	-0.00065
2000	0.03866	0.03932	-0.00067
2001	0.04296	0.04370	-0.00074
2002	0.06154	0.06260	-0.00106
2003	0.06236	0.06344	-0.00108
2004	0.06921	0.07040	-0.00119
2005	0.06817	0.06934	-0.00118
2006	0.07154	0.07278	-0.00123
2007	0.06693	0.06809	-0.00115
2008	0.06400	0.06511	-0.00110
2009	0.06470	0.06582	-0.00112
2010	0.06958	0.07078	-0.00120
2011	0.06032	0.06136	-0.00104
2012	0.06170	0.06277	-0.00106
2013	0.05254	0.05344	-0.00091
2014	0.04961	0.05047	-0.00086
2015	0.04461	0.04538	-0.00077
2016	0.04100	0.04171	-0.00071
2017	0.04038	0.04108	-0.00070
2018	0.03970	0.04039	-0.00069
2019	0.03975	0.04043	-0.00069
2020	0.03588	0.03650	-0.00062
2021	0.03859	0.03926	-0.00067

3.3.2.6 Category-specific planned improvements including those in response to the review process

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-113 will be explored.

Table 3-113 – Planned improvements for category *1B2 – Oil and natural gas and other emissions from energy production*

GHG source & sink category	Planned improvement
1B2a5 - Distribution of refined oil products	Assess whether these emissions occur and, if appropriate, estimate and report fugitive emissions from the infrastructure supporting the transport, distribution, storage and sale of refined fuel oils.

4 Industrial Processes (CRF sector 2)

4.1 Sector Overview

Chapter 4.1 includes information on and description of methodologies used for estimating GHG emissions as well as references to activity data and emission factors reported under CRF Sector *2 – Industrial Processes* for the period 1990 to 2022.

Emissions from this sector comprise emissions from the following categories: mineral products (2A), metal production (2C) and consumption of halocarbons (2F), SF_6 and N_2O (2G). For more details on categories where emissions are not occurring and categories that are not estimated or included elsewhere, see Table 4-3 and Table 4-4.

Only process related emissions are considered in this sector. Emissions due to fuel combustion in manufacturing industries are allocated to IPCC Sub-category *1A2 – Fuel Combustion Activities – Manufacturing Industries and Construction* (see section 3.2.6).

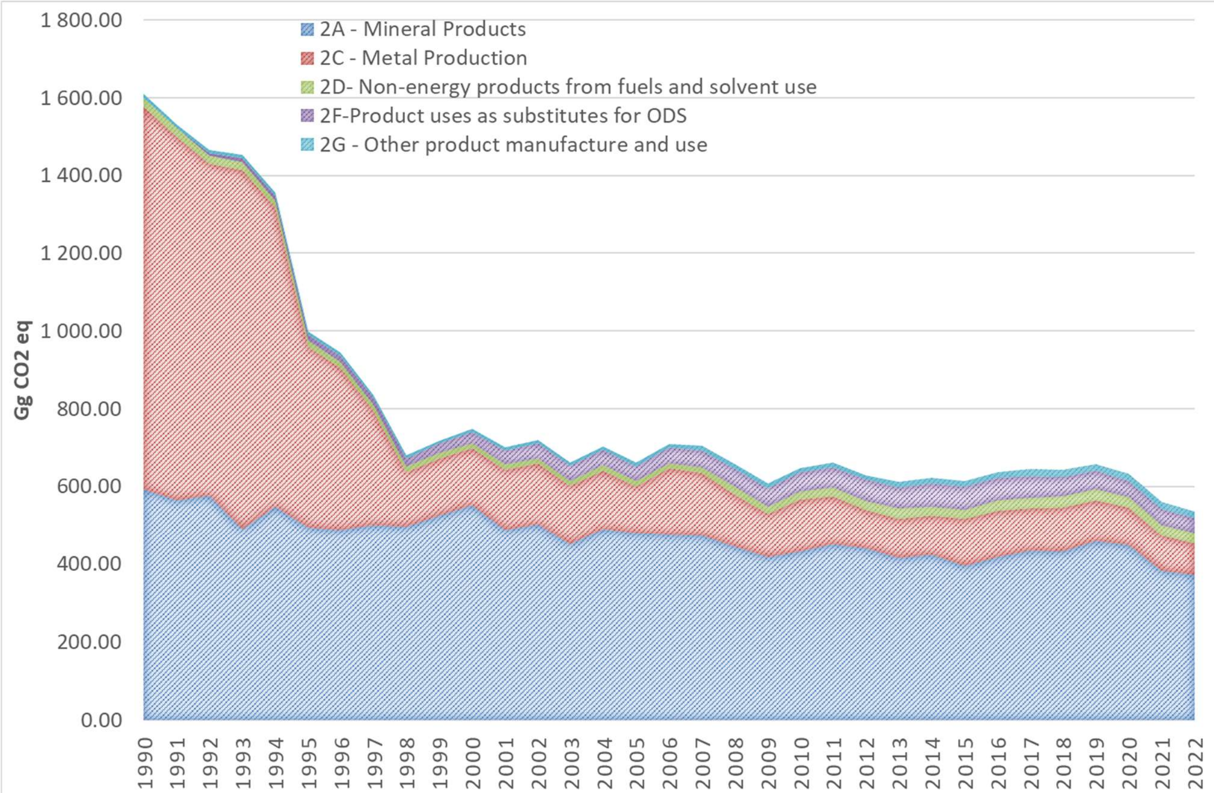
4.1.1 Emission Trends

This section briefly describes the emission trends from 1990 to 2022 for each of the IPCC categories under CRF Sector 2 for which GHG emissions are reported – *i.e.* categories *2A – Mineral Products*, *2C – Metal Production, 2D-Non-energy products from fuels and solvent use*, *2F-Product uses as substitutes for ODS, and 2G- Other product manufacture and use.*

Industrial process emissions include emissions from industrial installations and from consumption of halocarbons and SF_6 (the fluorinated gases (HFCs and SF_6) or F-gases), while PFCs are not in use in Luxembourg. The most important emitting activities are clinker, flat glass and iron and steel productions. With regard to F-gases, increasing emissions are mainly due to a growing use of air conditioning, high-voltage electrical equipment, and noise reduction windows (see Section 4.7).

As shown in Figure 4-1 and Table 4-1, emissions of GHG due to industrial processes have decreased by about 66.74% between 1990 and 2022 (-70.08% for carbon dioxide). The observed rise in F-gas emissions is associated with the low usage rate of F-gas during the early and mid-90s. Indeed, the switch from CFC to F-gases took several years to complete. In addition, a rise in the number of F-gas applications, such as air conditioning systems in cars, is also linked to the growing emissions of F-gases. It is for the IPCC Category *2C – Metal Production* that CO_2 emissions have decreased the most over the same period: 91.74%. For IPCC Category 2A – Mineral Products the decline is limited to 37.38% for CO_2 emissions.

Figure 4-1 – GHG emission trends for CRF Sector 2 – Industrial Processes: 1990-2022



The trend observed for the iron and steel production units is, of course, linked to the dramatic change that occurred in the 1990s with regard to the production process: move from blast furnaces to electrical arc furnaces. This technological change has already been developed in previous chapters (see, *e.g.*, Chapter 2.4) and will not be detailed once again here.

The striking increase of F-gas emissions is the consequence of supposedly growing use in the country of air conditioning, high-voltage electrical equipment, and noise reduction windows - but also of the hypothesis made for their estimation: see Section 4.7. The increasing use of these devices is mainly due to an increase in the number of residents (see Figure 2-15) and of the workforce (see Figure 2-16). The inhabitants and foreign commuters occupy more and more residential, institutional, and commercial buildings, which leads to a greater need for air conditioning (HFC) as well as high-voltage electrical devices (SF_6).

Figure 4-2, Figure 4-3, and Figure 4-4 provide a quick overview on industrial processes related emission trends between 1990 and 2022. More explanations are presented in the subsequent sections detailing each of the sector source sub-categories.

Table 4-1 – GHG emission trends in CO_2e for CRF Sector 2 – Industrial Processes: 1990-2022

Year	2 - Industrial Processes *GHG emissions by source & sink category (Gg CO_2 eq)* 2A - Mineral Products				2C - Metal Production				2D- Non-energy products from fuels and solvent use			
	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	592.93	592.93	NO	NO	984.91	984.91	NO	NO	22.65	22.65	NO	NO
1991	563.63	563.63	NO	NO	937.74	937.74	NO	NO	21.79	21.79	NO	NO
1992	577.72	577.72	NO	NO	853.29	853.29	NO	NO	20.38	20.38	NO	NO
1993	490.59	490.59	NO	NO	923.19	923.19	NO	NO	19.78	19.78	NO	NO
1994	547.82	547.82	NO	NO	770.83	770.83	NO	NO	16.90	16.90	NO	NO
1995	494.58	494.58	NO	NO	465.38	465.38	NO	NO	16.54	16.54	NO	NO
1996	487.94	487.94	NO	NO	416.60	416.60	NO	NO	16.04	16.04	NO	NO
1997	501.01	501.01	NO	NO	294.10	294.10	NO	NO	14.55	14.55	NO	NO
1998	495.24	495.24	NO	NO	140.69	140.69	NO	NO	15.01	15.01	NO	NO
1999	525.08	525.08	NO	NO	147.70	147.70	NO	NO	13.91	13.91	NO	NO
2000	552.01	552.01	NO	NO	146.05	146.05	NO	NO	13.50	13.50	NO	NO
2001	488.96	488.96	NO	NO	154.76	154.76	NO	NO	13.98	13.98	NO	NO
2002	503.35	503.35	NO	NO	155.40	155.40	NO	NO	13.89	13.89	NO	NO
2003	449.75	449.75	NO	NO	151.94	151.94	NO	NO	12.59	12.59	NO	NO
2004	489.32	489.32	NO	NO	152.45	152.45	NO	NO	14.18	14.18	NO	NO
2005	480.22	480.22	NO	NO	119.13	119.13	NO	NO	15.03	15.03	NO	NO
2006	475.74	475.74	NO	NO	170.49	170.49	NO	NO	14.17	14.17	NO	NO
2007	472.92	472.92	NO	NO	162.22	162.22	NO	NO	14.57	14.57	NO	NO
2008	444.54	444.54	NO	NO	134.69	134.69	NO	NO	19.62	19.62	NO	NO
2009	416.93	416.93	NO	NO	112.66	112.66	NO	NO	18.91	18.91	NO	NO
2010	432.75	432.75	NO	NO	133.61	133.61	NO	NO	21.16	21.16	NO	NO
2011	450.03	450.03	NO	NO	123.86	123.86	NO	NO	23.84	23.84	NO	NO
2012	439.59	439.59	NO	NO	100.23	100.23	NO	NO	23.52	23.52	NO	NO
2013	415.33	415.33	NO	NO	101.59	101.59	NO	NO	25.79	25.79	NO	NO
2014	423.23	423.23	NO	NO	102.46	102.46	NO	NO	22.61	22.61	NO	NO
2015	394.35	394.35	NO	NO	122.80	122.80	NO	NO	22.31	22.31	NO	NO
2016	416.70	416.70	NO	NO	121.66	121.66	NO	NO	25.86	25.86	NO	NO
2017	434.60	434.60	NO	NO	109.48	109.48	NO	NO	26.30	26.30	NO	NO
2018	432.15	432.15	NO	NO	114.39	114.39	NO	NO	27.34	27.34	NO	NO
2019	458.77	458.77	NO	NO	105.99	105.99	NO	NO	29.27	29.27	NO	NO
2020	449.68	449.68	NO	NO	96.79	96.79	NO	NO	25.22	25.22	NO	NO
2021	382.02	382.02	NO	NO	91.53	91.53	NO	NO	26.91	26.91	NO	NO
2022	371.30	371.30	NO	NO	81.36	81.36	NO	NO	26.17	26.17	NO	NO
Trend 2021-2022	-2.81%	-2.81%	NA	NA	-11.11%	-11.11%	NA	NA	-2.75%	-2.75%	NA	NA
Trend 1990-2022	-37.38%	-37.38%	NA	NA	-91.74%	0.00%	NA	NA	15.54%	15.54%	NA	NA

Source: Environment Agency

2 - Industrial Processes													
GHG emissions by source & sink category (Gg CO_2 eq)													
Year	2F-Product uses as substitutes for ODS			2G - Other product manufacture and use					2 - Industrial Processes				
	Total	*HFCs*	*PFC*	Total	*HFC*	*PFC*	*SF6*	*N_2O*	Total	*CO_2*	*CH_4*	*N_2O*	*F-gases*
1990	0.00	0.00	NO	8.71	NO	NO	0.34	8.37	1 609.20	1 600.49	NO	8.37	0.34
1991	0.00	0.00	NO	8.45	NO	NO	0.36	8.09	1 531.62	1 523.17	NO	8.09	0.36
1992	4.99	4.99	NO	8.17	NO	NO	0.39	7.78	1 464.55	1 451.39	NO	7.78	5.37
1993	11.76	11.76	NO	7.92	NO	NO	0.41	7.51	1 453.25	1 433.56	NO	7.51	12.18
1994	12.91	12.91	NO	7.68	NO	NO	0.44	7.24	1 356.15	1 335.56	NO	7.24	13.35
1995	13.81	13.81	NO	8.40	NO	NO	1.43	6.96	998.71	976.50	NO	6.96	15.24
1996	15.80	15.80	NO	8.28	NO	NO	1.61	6.68	944.66	920.58	NO	6.68	17.40
1997	18.31	18.31	NO	8.14	NO	NO	1.75	6.39	836.11	809.65	NO	6.39	20.06
1998	20.92	20.92	NO	7.90	NO	NO	1.79	6.10	679.76	650.94	NO	6.10	22.71
1999	23.89	23.89	NO	7.69	NO	NO	1.88	5.81	718.26	686.68	NO	5.81	25.77
2000	28.33	28.33	NO	7.48	NO	NO	1.98	5.49	747.37	711.56	NO	5.49	30.32
2001	34.86	34.86	NO	7.82	NO	NO	2.66	5.16	700.38	657.70	NO	5.16	37.52
2002	37.84	37.84	NO	8.48	NO	NO	3.28	5.21	718.98	672.65	NO	5.21	41.12
2003	38.09	38.09	NO	8.94	NO	NO	3.88	5.06	661.31	614.28	NO	5.06	41.96
2004	38.26	38.26	NO	9.09	NO	NO	4.45	4.64	703.30	655.95	NO	4.64	42.71
2005	36.95	36.95	NO	9.38	NO	NO	5.03	4.35	660.71	614.38	NO	4.35	41.99
2006	39.61	39.61	NO	10.08	NO	NO	5.46	4.62	710.09	660.40	NO	4.62	45.08
2007	43.77	43.77	NO	10.81	NO	NO	5.90	4.91	704.29	649.71	NO	4.91	49.67
2008	46.09	46.09	NO	11.64	NO	NO	6.32	5.32	656.58	598.85	NO	5.32	52.41
2009	47.16	47.16	NO	11.49	NO	NO	6.73	4.76	607.14	548.50	NO	4.76	53.88
2010	49.25	49.25	NO	10.90	NO	NO	7.11	3.79	647.67	587.52	NO	3.79	56.36
2011	51.87	51.87	NO	11.22	NO	NO	7.57	3.65	660.82	597.73	NO	3.65	59.43
2012	54.03	54.03	NO	11.50	NO	NO	7.95	3.55	628.88	563.34	NO	3.55	61.99
2013	54.91	54.91	NO	14.15	2.58	NO	8.33	3.24	611.78	542.72	NO	3.24	65.82
2014	59.83	59.83	NO	13.87	1.72	NO	8.72	3.43	622.00	548.30	NO	3.43	70.27
2015	59.38	59.38	NO	14.52	2.00	NO	9.19	3.33	613.36	539.46	NO	3.33	70.57
2016	57.76	57.76	NO	15.47	2.04	NO	9.55	3.89	637.45	564.22	NO	3.89	69.35
2017	57.00	57.00	NO	18.61	4.92	NO	9.73	3.96	646.00	570.38	NO	3.96	71.65
2018	50.37	50.37	NO	18.76	4.58	NO	10.03	4.15	643.02	573.88	NO	4.15	64.99
2019	47.56	47.56	NO	16.55	1.89	NO	10.26	4.40	658.13	594.03	NO	4.40	59.71
2020	43.30	43.30	NO	17.01	2.41	NO	9.91	4.68	632.00	571.69	NO	4.68	55.63
2021	40.50	40.50	NO	18.32	3.58	NO	9.92	4.83	559.29	500.46	NO	4.83	54.00
2022	39.29	39.29	NO	17.17	2.90	NO	9.18	5.08	535.30	478.83	NO	5.08	51.38
Trend 2021-2022	-2.98%	-2.98%	NA	-6.31%	-18.99%	NA	-7.40%	5.34%	-4.29%	-4.32%	NA	5.34%	-4.86%
Trend 1990-2022	60452229.97%	60452229.97%	NA	97.14%	NA	NA	2627.10%	-39.27%	-66.74%	-70.08%	NA	-39.27%	15153.40%

Source: Environment Agency

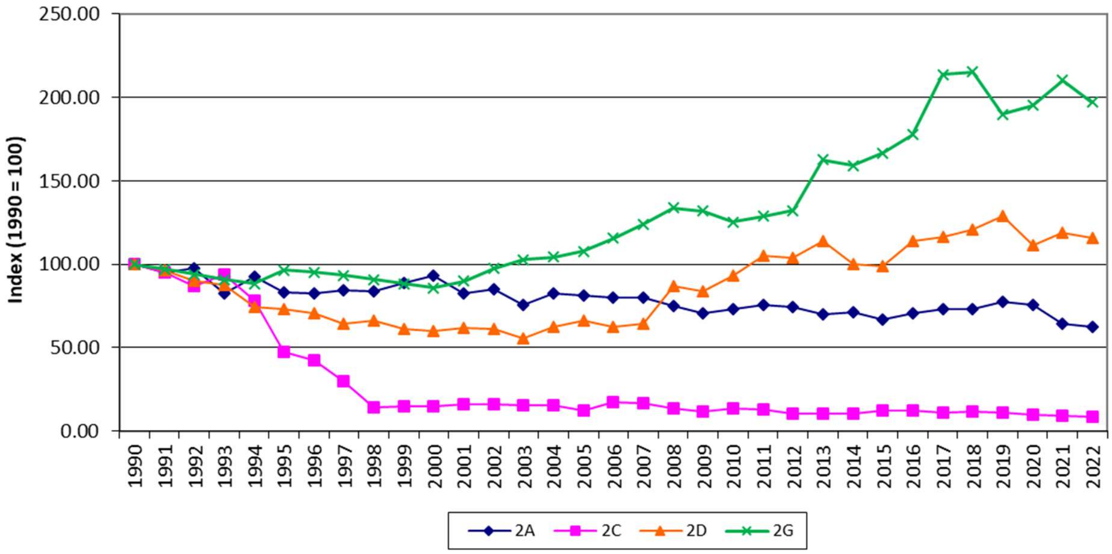
Notes:

CH_4 emissions are converted in CO_2e by multiplying the emissions by 28, *i.e.* the global warming potential (*GWP*) value for methane based on the effects of GHG over a 100-year time horizon.

N_2O emissions are converted in CO_2e by multiplying the emissions by 265, *i.e.* the global warming potential (*GWP*) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

The F-gases are those not covered by the Montreal Protocol, i.e. HFCs, PFCs and SF6 expressed in CO2e using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Figure 4-2 – GHG emission trends – indexes – for CRF Sector 2 – Industrial Processes: 1990-2022



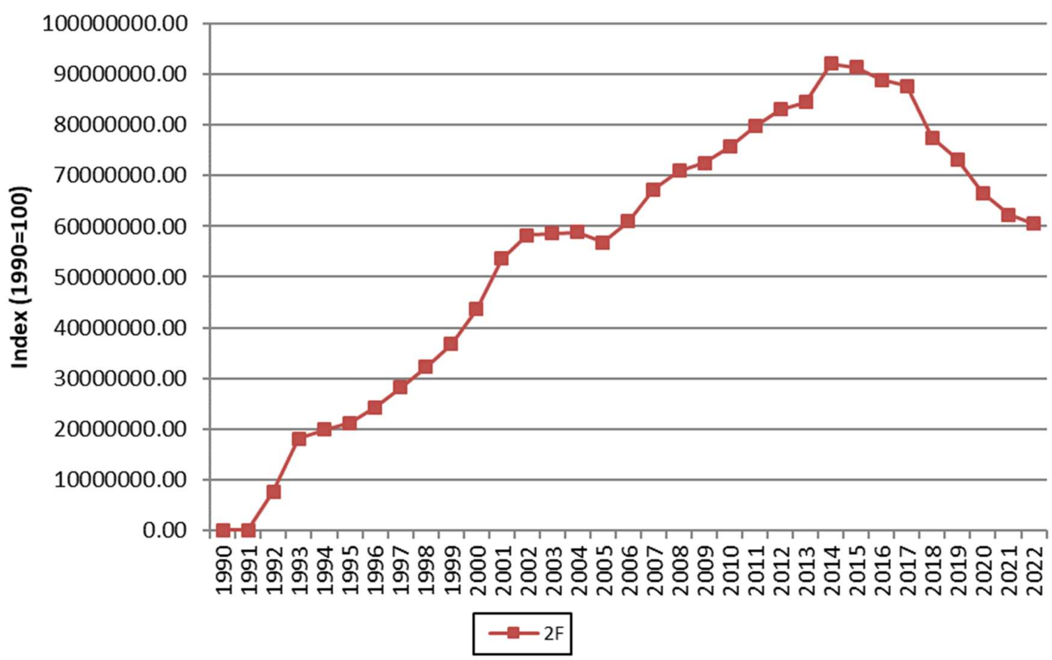
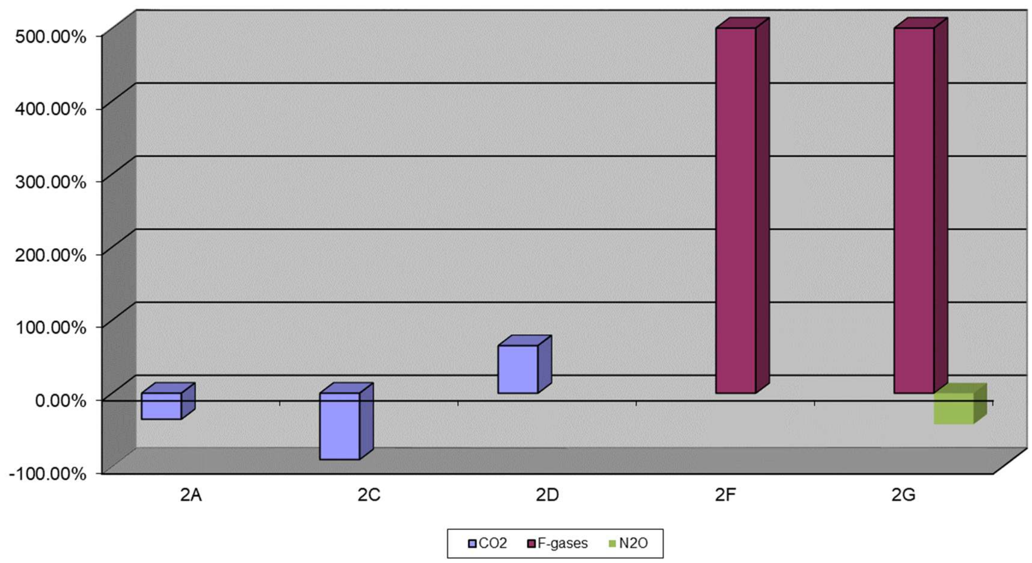
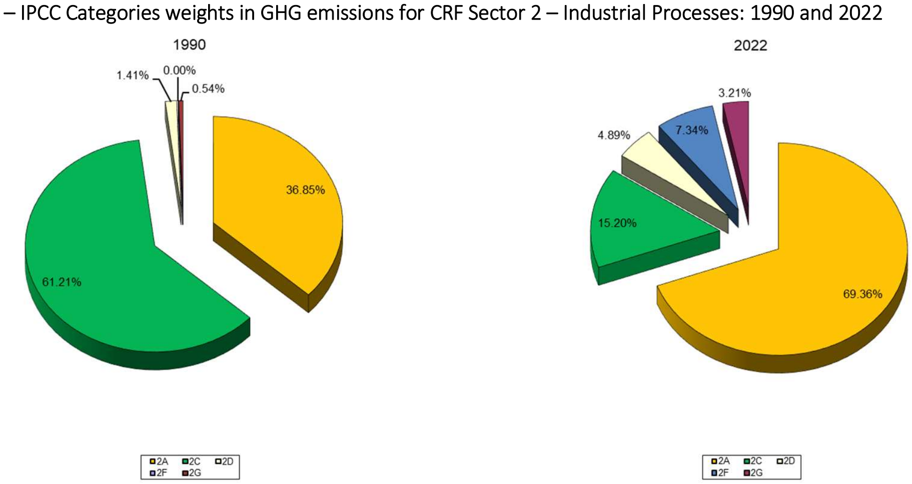


Figure 4-3 – GHG emission trends in % for CRF Sector 2 – Industrial Processes: 1990-2022



The emission trends briefly described above led to a significant change in the composition of industrial processes' GHG emissions, as shown in Figure 4-4.

Figure 4-4 – IPCC Categories weights in GHG emissions for CRF Sector 2 – Industrial Processes: 1990 and 2022



4.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 1.4. Table 4-2 presents the key source categories of IPCC Category 2 Industrial processes.

Table 4-2 – Key sources of IPCC category 2 - Industrial processes

2 - Industrial Processes and Product Use

Key sources

IPCC Category	Category Name	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
2A1	Cement Production	CO_2	90-22	90-22		
2A3	Glass Production	CO_2	15	95-01, 03, 07, 10, 14-20	X	X
2C1	Iron & Steel Production	CO_2	90-22	90-22	X	X

Source: Environment Agency
Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
TA = Trend Assessment 2022 (Tier 1) including respectively excluding LULUCF, for F-gases 1995 is used as the base year

4.1.3 Completeness

Table 4-3 and Table 4-4 give an overview of the IPCC categories included under CRF Sector 2 and provide information on the status of emission estimates of all sub-categories.

Table 4-3 – Overview of sub-categories of CRF Sector 2 – Industrial Processes: status of emission estimates for CO_2, CH_4 and N_2O

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
2.A.1	mineral products - cement production	X		
2.A.2	mineral products - lime production	NO		
2.A.3	mineral products - glass production	X		
2.A.4	mineral products - other process uses of carbonates	NO		
2.A.4.a	Ceramics	NO		
2.A.4.b	Other uses of soda ash	NO		
2.A.4.c	Non-metallurgical magnesium production	NO		
2.A.4.d	Other	NO		
2.B.1	chemical industry - ammonia production	NO	NO	NO
2.B.2	chemical industry - nitric acid production			NO
2.B.3	chemical industry - adipic acid production	NO		NO
2.B.4	chemical industry - carbide production	NO	NO	
2.B.5	chemical industry - other	NO	NO	NO
2.B.4	chemical industry - caprolactam, glyoxal and glyoxylic acid production	NO	NO	NO
2.B.5	chemical industry - carbide production	NO	NO	NO

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
2.B.6	chemical industry - titanium dioxide production	NO	NO	NO
2.B.7	chemical industry - soda ash production	NO	NO	NO
2.B.8	chemical industry - petrochemical and carbon black production	NO	NO	NO
2.B.9	chemical industry - fluorochemical production	NO	NO	NO
2.B.10	chemical industry - other	NO	NO	NO
2.C.1	metal production - iron and steel production	X	NO	NO
2.C.1.a	Steel	X	NO	NO
2.C.1.b	Pig iron	NO	NO	NO
2.C.1.c	Direct reduced iron	NO	NO	NO
2.C.1.d	Sinter	NO	NO	NO
2.C.1.e	Pellet	NO	NO	NO
2.C.1.f	Other (please specify)	NO	NO	NO
2.C.2	metal production - ferroalloys production	NO	NO	NO
2.C.3	metal production - aluminium production	NO	NO	NO
2.C.4	metal production - magnesium production	NO	NO	NO
2.C.5	metal production - lead production	NO	NA	NA
2.C.6	metal production - zink production	NO	NO	NO
2.C.7	metal production - other	X	NO	NO
2.D.1	non-energy products from fuels and solvent us - lubricant use	X		
2.D.2	non-energy products from fuels and solvent us - paraffin wax use	X		
2.D.3	non-energy products from fuels and solvent us - other	X		
2.D.3	solvent use	X	NO	NO
2.D.3	road paving with asphalt	NO	NO	NO
2.D.3	asphalt roofing	NO	NO	NO
2.D.3	other (please specify) Urea-based catalysts	X	NO	NO
2.G	other product manufacture and use	NO	NO	X
2.G.3	other product manufacture and use - N2O from product uses	NO	NO	X
2.G.3.a	Medical applications	NO	NO	X
2.G.3.b	other	NO	NO	X
	propellant for pressure and aerosol products	NO	NO	X
	other (please specify)	NO	NO	NO
2.H.1	other - pulp and paper	NO	NO	NO
2.H.2	other - food and beverages industry	NO	NO	NO
2.H.3	other - other (please specify)	NO	NO	NO

Note: A X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

Table 4-4 – Overview of subcategories of CRF Sector 2 – Industrial Processes: status of emission estimates for halocarbons, SF_6 and NF_3

GHG source & sink category	Description	Status			
		HFCs	PFCs	SF_6	NF_3
2.B	chemical industry	NO	NO	NO	NO

2.B.9	fluorochemical production	NO	NO	NO	NO
	by-product emissions	NO	NO	NO	NO
	fugitive emissions	NO	NO	NO	NO
2.B.10	other	NO	NO	NO	NO
2.C	metal industry	NO	NO	NO	NO
2.C.3	aluminium production	NO	NO	NO	NO
2.C.4	magnesium production	NO	NO	NO	NO
2.C.7	other	NO	NO	NO	NO
2.E	electronics industry	NO	NO	NO	NO
2.E.1	integrated circuit or semiconductor	NO	NO	NO	NO
2.E.2	TFT flat panel display	NO	NO	NO	NO
2.E.3	photovoltaics	NO	NO	NO	NO
2.E.4	heat transfer fluid	NO	NO	NO	NO
2.E.5	other	NO	NO	NO	NO
2.F	product uses as substitutes for ODS	X	NO	X	NO
2.F.1	refrigeration and air conditioning	X	NO	NO	NO
2.F.2	foam blowing agents	X	NO	NO	NO
2.F.3	fire protection	NO	NO	NO	NO
2.F.4	aerosols	X	NO	NO	NO
2.F.5	solvents	NO	NO	NO	NO
2.F.6	other applications	NO	NO	NO	NO
2.G	other product manufacture and use	X	NO	X	NO
2.G.1	electrical equipment	NO	NO	X	NO
2.G.2	SF6 and PFCs from other product use	NO	NO	X	NO
2.G.4	other	X	NO	NO	NO
2.H.1	other - pulp and paper	NO	NO	NO	NO
2.H.2	other - food and beverages industry	NO	NO	NO	NO
2.H.3	other - other (please specify)	NO	NO	NO	NO

Note: a X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

4.2 Mineral Products (2.A.)

This section describes the estimation of carbon dioxide emissions resulting from industrial processes used in clinker works and flat glass production installations. In 2022, this source category was responsible for 69.36% of GHG emissions in CO_2e from industrial processes – but only 36.84% in 1990. It represented 4.50% of the total GHG emissions in CO_2e (excluding LULUCF) in 2022 and 4.66% in 1990. Compared to 2021, emissions decreased by 2.81 % to attain the level of 371.30 Gg CO_2 in 2022. Compared to 1990, emissions decreased by 37.38%.

4.2.1 Cement Production (2.A.1.)

4.2.1.1 Source category description

In 2022, clinker production was responsible for 68.92% of GHG emissions in CO_2e from industrial processes – but only 33.55% in 1990. It represented 4.50% of the total GHG emissions in CO_2e (excluding LULUCF) in 2022 and 4.24% in 1990. Compared to 2021, emissions increased by 5.24% to attain the level of 368.94 Gg CO_2 in 2022. Compared to 1990, emissions decreased by 31.60%.

2A1 - Cement Production is a key source with regard to CO_2 emissions. It has been a key source without interruption since 1990: see Table 4-2.

4.2.1.2 Methodological issues

4.2.1.2.1 Activity data

In Luxembourg, one clinker production plant is operating. During the production of clinker, limestone, which is mainly calcium carbonate ($CaCO_3$), is calcined to produce lime (CaO) and CO_2 as a by-product.

Activity data, *i.e.* clinker production, is obtained annually from the plant operator (Table 4-6).

4.2.1.2.2 Methodology

1990-2013: For the estimation of CO_2 emissions, the ETS 2007 method using clinker production data is applied:

$$CO_2\ Emissions = EF_{clinker} \bullet CF_{clinker} \bullet Clinker\ Production$$

The conversion factor ($CF_{clinker}$) takes into account the amount of (non-carbonate) CaO and MgO in the raw materials. According to the operator of the plant, there is no calcined Cement Kiln Dust (*CKD*) to be lost from the system.

According to 2007 ETS Tier 3 method, the emission factor is based on the CaO and MgO content of the clinker:

$$EF_{clinker} = 0.785 \bullet CaO\ Content + 1.092 \bullet MgO\ Content\ (Weight\ Fraction\ in\ Clinker)$$

The CaO and MgO contents for the years for which no CaO and no MgO contents are available, are estimated by a linear interpolation (Table 4-6).

Starting 2014, emissions associated to dust in the production ovens have been determined by the operating company. Similar to previous years, the previously described approach according to ETS guidelines is applied and the following fluxes are considered:

-fluxes resulting from process generated dusts in the rotatif oven

-fluxes associated with used powders in the rotatif oven

For the years 1990-2013, these fluxes haven been extrapolated, based on the year 2014, and added to the emissions.

4.2.1.2.3 Emission factor

Emission estimates from the Tier 2 method, as well as activity data and IEFs, are summarized in

Table 4-5.

Table 4-5 - CO_2 emissions trend, activity data and IEFs for IPCC sub-category 2A1 – Cement Production: 1990-2022

2A1 - Clinker Production			
Activity data, emissions and implied emission factors			
Year	**AD**	**CO_2**	**IEF**
	t	***Gg***	***kg CO_2 / t clinker***
1990	1048 000	*539.36*	*514.65*
1991	1001 637	*514.96*	*514.12*
1992	1013 452	*520.45*	*513.54*
1993	842 855	*432.35*	*512.95*
1994	950 854	*487.19*	*512.37*
1995	848 455	*434.23*	*511.79*
1996	837 518	*428.20*	*511.27*
1997	865 659	*442.13*	*510.75*
1998	870 053	*443.92*	*510.23*
1999	913 265	*465.50*	*509.71*
2000	965 369	*491.55*	*509.19*
2001	843 608	*428.56*	*508.00*
2002	874 577	*443.25*	*506.82*
2003	769 754	*389.22*	*505.64*
2004	847 389	*427.47*	*504.45*
2005	833 798	*419.63*	*503.27*
2006	826 131	*415.40*	*502.83*
2007	816 688	*410.29*	*502.38*
2008	761 816	*382.39*	*501.94*
2009	708 048	*357.91*	*505.49*
2010	736 019	*370.66*	*503.60*
2011	770 232	*389.22*	*505.32*
2012	758 241	*381.12*	*502.64*
2013	743 260	*371.56*	*499.91*
2014	731 076	*359.82*	*492.18*
2015	677 731	*329.48*	*486.15*
2016	750 566	*351.37*	*468.14*
2017	761 255	*370.70*	*486.96*
2018	746 704	*369.49*	*494.83*
2019	802 488	*394.79*	*491.96*
2020	783 885	*399.14*	*509.18*
2021	717 074	*350.57*	*488.89*
2022	776 875	*368.94*	*474.90*
Trend 2021-2022	*8.34%*	*5.24%*	*-2.86%*
Trend 1990-2022	*-25.87%*	*-31.60%*	*-7.73%*
Sources: AD: plant operator ; CO2 and IEF: Environment Agency			

Sources: AD: plant operator: CO_2 and IEF: Environment Agency

Table 4-6 – Effective and interpolated CaO content in % and EFs: 1990-2022

2A1 - Cement Production						
CaO content & emission factors						
Year	CaO (%)	CaO (%)	MgO (%)	MgO (%)	EF	CF
	operator	*interpolation*	*operator*	*interpolation*	*kg CO_2 / t clinker*	-
1990	67.72	67.72	1.12	1.12	514.65	0.93
1991		67.67		1.10	514.12	0.93
1992		67.62		1.08	513.54	0.93
1993		67.56		1.06	512.95	0.93
1994		67.51		1.04	512.37	0.93
1995	67.46	67.46	1.02	1.02	511.79	0.93
1996		67.40		1.01	511.27	0.93
1997		67.34		1.00	510.75	0.93
1998		67.28		1.00	510.23	0.93
1999		67.22		0.99	509.71	0.93
2000	67.16	67.16	0.98	0.98	509.19	0.93
2001		67.03		0.96	508.00	0.93
2002		66.89		0.94	506.82	0.93
2003		66.76		0.92	505.64	0.93
2004		66.62		0.90	504.45	0.93
2005	66.49	66.49	0.88	0.88	503.27	0.93
2006		66.42		0.89	502.83	0.93
2007		66.35		0.89	502.38	0.93
2008	66.28	66.28	0.90	0.90	501.94	0.93
2009	66.78	66.78	0.89	0.89	505.49	0.93
2010	66.59	66.59	0.84	0.84	503.60	0.93
2011	66.84	66.84	0.83	0.83	505.32	0.93
2012	65.93	65.93	1.22	1.22	502.64	0.93
2013	65.93	65.93	1.22	1.22	499.91	0.93
2014	67.11	67.11	1.43	1.43	492.18	0.89
2015	67.17	67.17	1.86	1.86	486.15	0.87
2016	65.58	65.58	1.36	1.36	468.14	0.87
2017	66.23	66.23	1.19	1.19	486.96	0.90
2018	66.22	66.22	1.21	1.21	494.83	0.91
2019	66.27	66.27	1.17	1.17	491.96	0.91
2020	66.69	66.69	1.12	1.12	509.18	0.94
2021	66.12	66.12	1.11	1.11	488.89	0.91
2022	66.06	66.06	1.19	1.19	474.90	0.87
Sources: plant operator and Environment Agency						

Sources: plant operator and Environment Agency

4.2.1.2.4 Conversion factor (CF)

In 2012, the estimation method of raw material composition was changed. Before 2012, the operating company assumed that all the CaO and MgO came from carbonated source (CaCO3 and MgCO3), the amounts of which were known. Since 2012, the company started to measure and determine the actual content of carbon, organic carbon, CaO and MgO content in the different raw materials, because raw material contained some decarbonated materials (such as blast furnace slacks). To take into account the amount of (non-carbonate) CaO and MgO in the raw material and according to 2007 ETS method, the conversion factor (CF) is based on measurements twice a month of total carbon, organic carbon, CaO and MgO content in the raw material. As such, for the values prior to 2012, the conversion factors are based on the 2012 value of the conversion factor. The rational is that the amount of already decarbonated CaO and MgO should be rather constant, due to the fact that the primary raw material comes from one single quarry, and that secondary raw materials (blast furnace slack) come from historical slack depots within the country, which one could assume to also possess constant CaO and MgO contents. Since 2014, the CF varies a little more as Luxembourg's blast furnace slack depots are almost exhausted, and other secondary raw materials need to be imported with varying decarbonated CaO and MgO contents.

4.2.1.3 Uncertainties and time-series consistency

Table 4-7 gives the error values which are assumed on the various calculation parameters for the uncertainty assessment.

Table 4-7 – Error values (%) for uncertainty assessment

Step	Error (%) IPCC GPG 2000 Table 3.1 (Tier 2)	Error (%) Plant-specific estimation
1) Production data	1-2	1.5
2) Assume 100% carbonate source from $CaCO_3$	1-3	2
3) CaO chemical analysis	1-2	1.5

Combined resulting errors (uncertain quantities are to be combined by multiplication):

- Activity data uncertainty ....1.5 %
- Emission factor uncertainty ....2.5 %
- Emissions uncertainty ....2.9 %

4.2.1.4 Source-specific QA/QC and verification

The calculated plant-specific emission factors are consistent with the 2004 ETS Tier 1 Guidelines default emission factor of 525 kg CO_2/t clinker.

4.2.1.5 Category-specific recalculations including changes made in response to the review process

No recalculations were made.

4.2.1.6 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.A.1.

4.2.2 Lime Production (2.A.2)

This source category does not exist in Luxembourg.

4.2.3 Glass Production (2.A.3)

4.2.3.1 Source category description

In 2022, glass production was responsible for 0.44% of GHG emissions in CO_2e from industrial processes – and only 3.33% in 1990. It represented 0.03% of the total GHG emissions in CO_2e (excluding LULUCF) in 2022 and 0.42% in 1990. Compared to 2021, emissions decreased by 92.48% to attain the level of 2.36 Gg CO_2 in 2022. Compared to 1990, emissions decreased by 95.59%. The observed decrease is due to the fact that the operator has shut down one of the two active production sites in Luxembourg. Similarly in 2022, the second oven was switched off beginning of February.

2.A.3 - Glass Production has been a key source since for several years: see Table 4-2 in Section 4.1.2.

4.2.3.2 Methodological issues

4.2.3.2.1 Activity data

In Luxembourg, one company runs two flat glass production plants. CO_2 is released during melting in the kiln, from carbonates contained in mineral input materials (limestone, dolomite and soda ash).

Activity data, *i.e.* flat glass production, is obtained annually from the plant operators (Table 4-8).

4.2.3.2.2 Methodology

A country specific (CS) methodology is applied:

$$CO_2 \text{ emissions} = EF_{glass} \bullet \text{Glass Production}$$

Estimates from the CS method, as well as activity data and IEFs, are summarized in Table 4-8.

Table 4-8 – CO_2 emission trend, activity data and IEFs for IPCC sub-category 2.A.3 – Other – Glass Production: 1990-2022

2A3 - Glass Production			
Activity data, emissions and implied emission factors			
Year	**AD**	**CO_2**	**IEF**
	t	***Gg***	***kg CO_2 / t glass***
1990	377 240	*53.57*	*142.00*
1991	342 745	*48.67*	*142.00*
1992	403 328	*57.27*	*142.00*
1993	410 176	*58.24*	*142.00*
1994	426 991	*60.63*	*142.00*
1995	425 026	*60.35*	*142.00*
1996	420 750	*59.75*	*142.00*
1997	414 616	*58.88*	*142.00*
1998	361 401	*51.32*	*142.00*
1999	419 579	*59.58*	*142.00*
2000	425 751	*60.46*	*142.00*
2001	425 391	*60.41*	*142.00*
2002	423 240	*60.10*	*142.00*
2003	426 299	*60.53*	*142.00*
2004	435 595	*61.85*	*142.00*
2005	435 073	*60.60*	*139.28*
2006	435 806	*60.34*	*138.45*
2007	443 094	*62.63*	*141.34*
2008	440 538	*62.15*	*141.09*
2009	437 319	*59.02*	*134.95*
2010	430 140	*62.10*	*144.36*
2011	433 676	*60.82*	*140.23*
2012	423 081	*58.47*	*138.20*
2013	304 453	*43.77*	*143.76*
2014	430 098	*63.41*	*147.42*
2015	420 703	*64.87*	*154.20*
2016	430 103	*65.34*	*151.91*
2017	433 178	*63.90*	*147.52*
2018	422 078	*62.66*	*148.45*
2019	403 425	*63.98*	*158.58*
2020	287 230	*50.54*	*175.95*
2021	218 569	*31.45*	*143.87*
2022	15 502	*2.36*	*152.53*
Trend 2021-2022	*-92.91%*	*-92.48%*	*6.02%*
Trend 1990-2022	*-95.89%*	*-95.59%*	*7.42%*

Sources: AD: plant operator; CO_2 and IEF: Environment Agency

The use of soda ash for glass production is accounted for in 2A3. The amount of soda ash used in 2020 in the glass production was 40671.85 t (Source: verified ETS data). In 2021, the use of soda ash amounted to 38212.50 t.

4.2.3.2.3 Emission factors

The emission factor is based on the loss of ignition of the batch composition. Recycled glass is included in the calculation of the emission factor. The background data and the calculation of the emission factor are provided by the operator. The batch is composed of 1 t dry raw material and 0.25 t recycled glass. The loss of ignition of the dry raw material is 15.5%. Accordingly, the production of 1 t glass consumes 0.9132 t dry raw material and releases 141.5 kg CO_2 as loss of ignition. For each year, the plant-specific EF's of the two operating plants were determined based on the carbonate contents in the raw materials and the activity data for plant 1 and plant 2. The employed EF corresponds to the average EF of the two plants.

As no data is available for the years 1990-2004, an average EF of 142 kg CO_2/ t glass, based on the years 2005-2013, has been applied for those years. There is no indication of any change in product quality or batch composition over time, hence favouring the approach of an average emission factor that is kept constant for the whole time span from 1990-2004.

4.2.3.3 Uncertainties and time-series consistency

Estimations of uncertainties are based on the following study: W. Winiwarter, T. Köther, Austrian Research Centers, "Uncertainty related to Luxembourg's national greenhouse gas inventory", June 2008, ARC-sys-0162, as well as consultations with the producer

- Activity data uncertainty ....2.0 %
- Emission factor uncertainty ....5.0 %
- Cumulative emission uncertainty ....5.4 %

4.2.3.4 Source-specific QA/QC and verification

The calculated CO_2 emission is consistent with the calculated value according to the ETS methodology.

Concerning the use of soda ash in glass production, import and export values for Soda ash, provided by STATEC, have been compared to the use of soda ash in Glass Production to check for equivalence and exclude any other application.

4.2.3.5 Category-specific recalculations including changes made in response to the review process

Emissions have been revised for the year 2020. As such emission data for the year 2020 has increased by 47.3996% (34.287 Gg CO2eq -> 50.53891722 Gg CO2eq).

4.2.4 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.A.3.

4.2.5 Other Process Uses of Carbonates (2.A.4)

This source category does not exist in Luxembourg.

4.2.5.1 Ceramics (2.A.4.a)

This source category does not exist in Luxembourg.

4.2.5.2 Other Uses of Soda ash (2.A.4.b)

The use of soda ash is accounted for in IPCC sub-category *2A3 –Glass Production*. There is no other soda ash use in Luxembourg.

4.2.5.3 Source-specific QA/QC and verification

Import and Export values for Soda ash, provided by STATEC, have been compared to the use of soda ash in IPCC sub-category 2A3 – lass Production to check for equivalence.

4.2.5.4 Non Metallurgical Magnesia Production (2.A.4.c)

This source category does not exist in Luxembourg.

4.2.5.5 Other (2.A.4.d)

This source category does not exist in Luxembourg.

4.2.6 Asphalt Roofing (2.A.5)

This source category does not exist in Luxembourg.

4.2.7 Road Paving with Asphalt (2.A.6)

This source category does not exist in Luxembourg.

4.3 Chemical Industry (2.B)

There are no emissions to be reported for the chemical industry for Luxembourg.

CRF	Description	Notation key
2.B.1	Ammonia production	NO
2.B.2	Nitric acid production	NO
2.B.3	Adipic acid production	NO
2.B.4	Caprolactam, glyoxal and glyoxylic acid production	NO
2.B.5	Carbide production	NO
2.B.6	Titanium dioxide production	NO
2.B.7	Soda ash production	NO
2.B.8	Petrochemical and carbon black production	NO
2.B.9	Fluorochemical production	NO
2.B.10	Other	NO

4.4 Metal Production (2.C)

This section describes the estimation of carbon dioxide emissions resulting from industrial processes relating to iron and steel production (IPCC Sub-category 2C1). As a matter of fact, steel production combines process and energy related emissions. For pragmatic reasons (and to be as close as reasonable to the real situation), gaseous fuels have been considered causing energy related emissions[86] (this includes blast furnace gas derived from solid fuels), and solid fuels (coke, anthracite, residue oil and – for electric arc furnaces – carbon electrodes) process related emissions.

No other IPCC sub-categories under IPCC category *2C* are reporting GHG emissions, hence IPCC category *2C* = IPCC sub-category *2C1 – Iron and Steel Production*.

4.4.1 Iron and Steel Production (2.C.1)

4.4.1.1 Source category description

In 2022, iron and steel production was responsible for 14.84% of GHG emissions in CO_2e from industrial processes – but 61.22% in 1990. It represented 0.97% of the total GHG emissions in CO_2e (excluding LULUCF) in 2022 and 7.74% in 1990. Compared to 2021, emissions decreased by 11.62% to attain the level of 79.44 Gg CO_2 in 2022. Compared to 1990, emissions decreased by 91.93% due to the technological shift from blast furnaces to electric arc furnaces operated in the mid-1990s. Furthermore, one of three electric furnaces stopped production in the year 2012.

An overview of the iron and steel related CO_2 emissions is provided in Table 4-9.

86 Accounted for under IPCC Category 1A – Fuel Combustion Activities. See also Section 4.4.1.3 below.

Table 4-9 – CO_2 emissions trend, activity data and IEFs for IPCC sub-category 2C1 – Iron and Steel Production: 1990-2022

2C1 - Iron & Steel Production					
	Steel Production (t)				Filter Dust (t)
Year	SP	BF	BOF	EAF	Primus
1990	4 804 000	2 645 200	3 506 230	NO	NO
1991	4 567 000	2 463 000	3 379 440	NO	NO
1992	4 152 000	2 255 200	3 068 463	NO	NO
1993	4 561 000	2 412 000	3 288 847	4 095	NO
1994	3 747 000	1 926 890	2 627 278	445 990	NO
1995	1 977 700	1 028 230	1 410 469	1 202 668	NO
1996	1 810 970	829 010	1 168 070	1 333 758	NO
1997	1 002 815	438 030	597 814	1 982 405	NO
1998	NO	NO	NO	2 476 909	NO
1999	NO	NO	NO	2 600 324	NO
2000	NO	NO	NO	2 571 243	NO
2001	NO	NO	NO	2 724 679	NO
2002	NO	NO	NO	2 736 000	NO
2003	NO	NO	NO	2 675 000	NO
2004	NO	NO	NO	2 684 000	NO
2005	NO	NO	NO	2 194 485	29 263
2006	NO	NO	NO	2 802 049	38 942
2007	NO	NO	NO	2 845 872	46 446
2008	NO	NO	NO	2 584 341	35 717
2009	NO	NO	NO	2 103 281	16 514
2010	NO	NO	NO	2 633 613	NO
2011	NO	NO	NO	2 525 697	NO
2012	NO	NO	NO	2 208 000	NO
2013	NO	NO	NO	2 089 000	NO
2014	NO	NO	NO	2 192 999	NO
2015	NO	NO	NO	2126283	NO
2016	NO	NO	NO	2175409	NO
2017	NO	NO	NO	2171696	NO
2018	NO	NO	NO	2227951	NO
2019	NO	NO	NO	2103583	NO
2020	NO	NO	NO	1887003	NO
2021	NO	NO	NO	2077543	NO
2022	NO	NO	NO	1874792	NO

Sources: AD: plant operator; Statec

Note: SATEC's 1990 value for BOF replaced by TÜV Rheinland 1992-1993 study reported value

2C1 - Iron & Steel Production CO2 Emissions						
Year	Total (Gg)	Pig Iron	Steel			Sinter
		BF (Gg)	BOF (Gg)	EAF (Gg)	Primus (Gg)	SP (Gg)
1990	984.91	200.00	404.48	NO	NO	380.43
1991	937.74	186.23	389.85	NO	NO	361.66
1992	853.29	170.52	353.98	NO	NO	328.80
1993	923.19	182.37	379.40	0.23	NO	361.19
1994	770.83	145.69	303.08	25.33	NO	296.72
1995	465.38	77.74	162.71	68.31	NO	156.61
1996	416.60	62.68	134.75	75.76	NO	143.41
1997	294.10	33.12	68.96	112.60	NO	79.41
1998	140.69	NO	NO	140.69	NO	NO
1999	147.70	NO	NO	147.70	NO	NO
2000	146.05	NO	NO	146.05	NO	NO
2001	154.76	NO	NO	154.76	NO	NO
2002	155.40	NO	NO	155.40	NO	NO
2003	158.94	NO	NO	151.94	7.00	NO
2004	172.45	NO	NO	152.45	20.00	NO
2005	152.92	NO	NO	119.13	33.79	NO
2006	209.79	NO	NO	170.49	39.30	NO
2007	203.49	NO	NO	162.22	41.27	NO
2008	169.30	NO	NO	134.69	34.61	NO
2009	128.66	NO	NO	112.66	16.00	NO
2010	133.61	NO	NO	133.61	NO	NO
2011	123.86	NO	NO	123.86	NO	NO
2012	100.23	NO	NO	100.23	NO	NO
2013	101.59	NO	NO	101.59	NO	NO
2014	102.46	NO	NO	102.46	NO	NO
2015	122.80	NO	NO	122.80	NO	NO
2016	119.33	NO	NO	119.33	NO	NO
2017	107.43	NO	NO	107.43	NO	NO
2018	112.14	NO	NO	112.14	NO	NO
2019	103.70	NO	NO	103.70	NO	NO
2020	96.15	NO	NO	96.15	NO	NO
2021	89.88	NO	NO	89.88	NO	NO
2022	79.44	NO	NO	79.44	NO	NO
Trend 2021-2022	-11.62%	NA	NA	-11.62%	NA	NA
Trend 1990-2022	-91.93%	NA	NA	NA	NA	NA

Sources: AD: plant operator; Statec

Note: SATEC's 1990 value for BOF replaced by TÜV Rheinland 1992-1993 study reported value.

2C1 – Iron and Steel Production is a key source with regard to CO_2 emissions. It has been a key source since 1990: see Table 4-2 in Section 4.1.2.

4.4.1.2 Methodological issues

4.4.1.2.1 Activity data

One sinter plant, two blast furnaces and three basic oxygen furnace steel plants (*BOF*) were operated in Luxembourg in 1990. The shift from BOF steel production to the EAF steel production occurred between 1993 and 1997 (see Figure 4-5). Three electric arc furnaces were operated between 1998 and 2011. One advanced multiple-heath furnace followed by a specially designed electric arc furnace (PRIMUS process) was operated between 2003 and 2009. Since 2013 , only two of the three electric arc furnaces (*EAF*) are in operation.

A simplified country-specific methodology is used for the years 1993 to 2003 (as the first EAF was only introduced in 1993). It is important to mention that the base year 1990 is not concerned by this simplified methodology. In 1990, only blast furnaces were operated. Concerning time-series consistency, it is not possible to improve time-series consistency without losing the quality of the data. Indeed, the production processes changed over time and also more detailed methodologies were introduced over time which required a more detailed data collection. The required data for the time before the new methodologies do not exist, and cannot be extrapolated based on surrogates, without considerably increasing the uncertainties. Thus, it was opted to use the most detailed and verified data available to assess the emissions over time. In that sense, Luxembourg considers that the time series are constituent in an overall manner, as the carbon mass balance method was used for every technology used over time.

Concerning carbon mass balance, the NIR clearly indicates that for all production processes (BF, EAF, PRIMUS) a carbon mass balance is applied over the production process (see section 4.4.1.2.2). For the example of the electric arc furnace production, the carbon mass balance is the following:

E= (CCarbon+CAnthracite) * 3.664 + EElectrodes+EPig iron+EPetroleum coke+ECaC2+Eflux

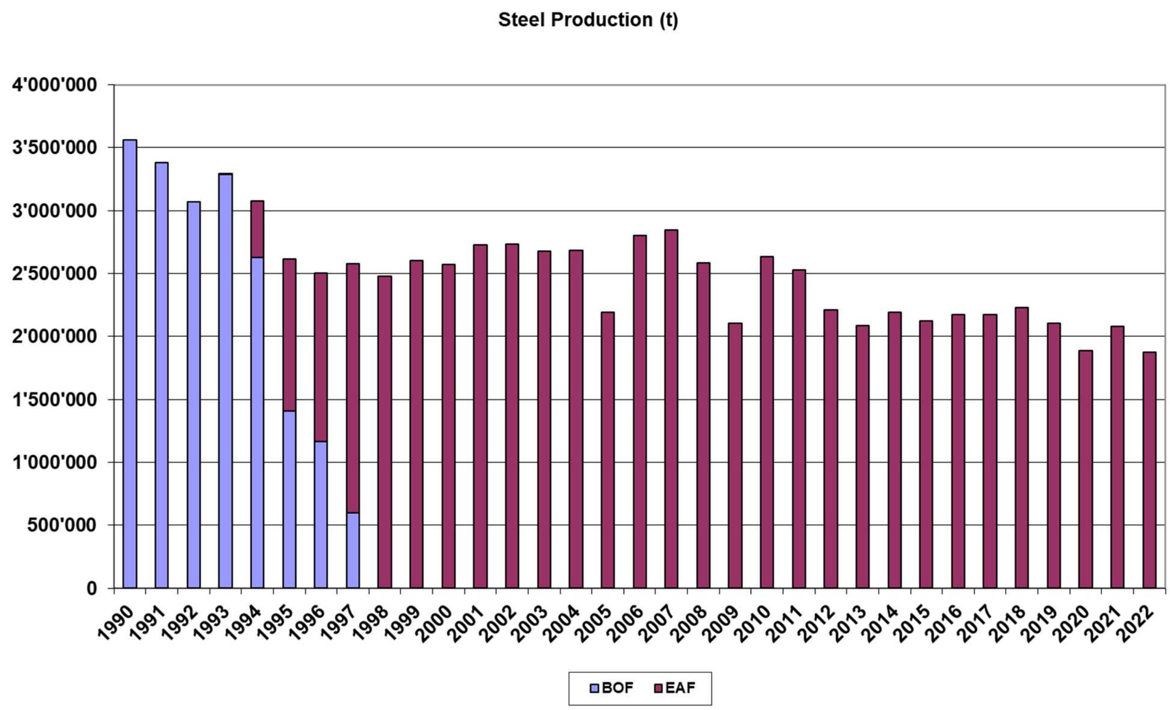
Ei= ADi * EFi with i= electrodes, pig iron, petroleum coke, CaC2, fluxes

All materials introduced in the furnace and containing carbon are considered (carbon, anthracite, electrodes, pig iron, petroleum coke, CaC2 and scrap) and it is assumed that the carbon content of the steel output equals to the scrap input.

Limestone and dolomite were not used as such in Luxembourg's BF and BOF steel production. In the sinter plant, the sinter was produced from two types of iron ore, "Minettes calcaires", i.e. iron ore containing carbonates and "Minettes silicieuses", i.e. siliceous iron ore. The carbon content of the iron ore is displayed in Table 4-11. The use of carbonate containing iron ore, and mixing it with siliceous ore, was advantageous in the sense that no limestone needed to be added to reach the optimal basicity of the final ore. Hence, decarbonisation of the ore is considered in the sinter plant and neither limestone nor dolomite was added to the ore to produce the agglomerate.

In the BF and BOF steel production, again neither limestone nor dolomite was added to the production process. Only burnt lime is used in the BOF steel production, for instance, to favour the slagging. All the C input is detailed in the methodological description.

Figure 4-5 – Steel production according to BOF and EAF: 1990-2022



Several plants are considered:

Sinter Plant (SP)

In the sinter plant iron ore and other iron-containing materials are agglomerated prior to the introduction into the blast furnace. Process emissions occur from the oxidation of the carbonates in the iron ore.

Blast furnace (BF)

Mainly sinter (iron oxides), coke and other fuels are supplied to the blast furnace. CO_2 process emissions are associated with the use of carbon to convert iron oxide to pig iron. Coke and other fuels serve not only as reducing agent but also to produce blast furnace gas as energy source which is recovered and used as fuel within the plant and in other steel industry processes and in a power station.

An energy balance serves to exclude double-counting of carbon from the consumption as reducing agent if this is already accounted for as fuel consumption in IPCC category *1A – Fuel Combustion Activities*.

Basic oxygen furnace steel production (BOF)

In the basic oxygen furnace, pig iron (4% C) is transformed to steel (0.13% C). During the process, the reduced carbon is released as CO_2.

Electric arc furnace steel production (EAF)

In the electric arc furnaces anthracite and carbon, including the consumption of the electrodes, are used as reducing agent with the result of CO_2 process emissions. The consumption of natural gas in the EAF is accounted for as energy consumption and, consequently, reported under IPCC Sub-category *1A2a – Iron and Steel*.

PRIMUS® process (PRIMUS)

The PRIMUS process consists of a combination of an advanced multiple-heath furnace and a specially designed electric arc furnace. Steelmaking dust is transformed into iron. Process emissions occur from raw material (steelmaking dust) and reducing agents (anthracite, carbon and the consumption of the electrodes).

Activity data for iron production (*BF*) and steel production (*BOF & EAF*) are collected from STATEC's Statistical Yearbook. They have been supplemented by information received directly from the operator. This is the case for sinter production (*SP*) and for the steel production breakdown between BOF & EAF between 1993 and 1997.

The activity data for the PRIMUS® process is based on the introduced filter dust.

The production data for the steel production in 1990 (*BOF*) was corrected based on detailed information from the TÜV Rheinland 1992-1993 study. It is assumed that the 1990 value of 3 560 290 tonnes for BOF in STATEC's Statistical Yearbook is a typing error.

Table 4-10 summarizes iron and steel production by process.

Table 4-10 – Iron and steel production by process: 1990-2022

2C1 - Iron & Steel Production CO2 Emissions						
Year	Total (Gg)	Pig Iron	Steel			Sinter
		BF (Gg)	BOF (Gg)	EAF (Gg)	Primus (Gg)	SP (Gg)
1990	984.91	200.00	404.48	NO	NO	380.43
1991	937.74	186.23	389.85	NO	NO	361.66
1992	853.29	170.52	353.98	NO	NO	328.80
1993	923.19	182.37	379.40	0.23	NO	361.19
1994	770.83	145.69	303.08	25.33	NO	296.72
1995	465.38	77.74	162.71	68.31	NO	156.61
1996	416.60	62.68	134.75	75.76	NO	143.41
1997	294.10	33.12	68.96	112.60	NO	79.41
1998	140.69	NO	NO	140.69	NO	NO
1999	147.70	NO	NO	147.70	NO	NO
2000	146.05	NO	NO	146.05	NO	NO
2001	154.76	NO	NO	154.76	NO	NO
2002	155.40	NO	NO	155.40	NO	NO
2003	158.94	NO	NO	151.94	7.00	NO
2004	172.45	NO	NO	152.45	20.00	NO
2005	152.92	NO	NO	119.13	33.79	NO
2006	209.79	NO	NO	170.49	39.30	NO
2007	203.49	NO	NO	162.22	41.27	NO
2008	169.30	NO	NO	134.69	34.61	NO
2009	128.66	NO	NO	112.66	16.00	NO
2010	133.61	NO	NO	133.61	NO	NO
2011	123.86	NO	NO	123.86	NO	NO
2012	100.23	NO	NO	100.23	NO	NO
2013	101.59	NO	NO	101.59	NO	NO
2014	102.46	NO	NO	102.46	NO	NO
2015	122.80	NO	NO	122.80	NO	NO
2016	119.33	NO	NO	119.33	NO	NO
2017	107.43	NO	NO	107.43	NO	NO
2018	112.14	NO	NO	112.14	NO	NO
2019	103.70	NO	NO	103.70	NO	NO
2020	96.15	NO	NO	96.15	NO	NO
2021	89.88	NO	NO	89.88	NO	NO
2022	79.44	NO	NO	79.44	NO	NO
Trend 2021-2022	-11.62%	NA	NA	-11.62%	NA	NA
Trend 1990-2022	-91.93%	NA	NA	NA	NA	NA

Sources: AD: plant operator ; Statec
Note: STATEC's 1990 value for BOF replaced by TÜV Rheinland 1992-1993 study reported value.

4.4.1.2.2 Methodology

Sinter Plant (SP)

The emissions in 1990 are calculated from the mass of carbon in the ore. It is therefore a country specific methodology. The data were collected directly from the operator.

Table 4-11 – Background data for the calculation of CO_2 emissions – Sinter Plant

Raw material	Tonnes (dry)	% C	Gg CO_2
Minettes calcaires	2 043 408	4.38	328.16
Minettes silicieuses	908 957	1.57	52.27
Total	2 952 365	NA	380.43

A country specific methodology has been applied for the years 1991 to 1997 based on the emission factor determined for the year 1990:

$$CO_2\ Emissions_{SP} = EF_{SP} \bullet Sinter\ Production$$

Blast furnace (BF) and basic oxygen furnace steel production (BOF)

The 2000 IPCC-GPG Tier 2 methodology is applied for calculating the emissions in 1990.

The emissions from iron production in BF and from steel production in BOF are calculated separately based on a carbon balance over the production processes.

$$Emissions_{BF} = E_{Iron} = (C_{Reducing\ Agent} + C_{Ore} - C_{Iron}) \bullet 44/12$$

$$Emissions_{BOF} = E_{Steel} = (C_{Iron} + C_{Scrap} + C_{AddBOF} - C_{Steel}) \bullet 44/12$$

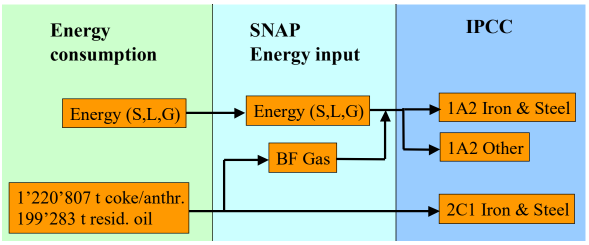
With:

$C_{Reducing\ Agent}$	= carbon serving as reducing agent: calculated from the energy balance over the iron and steel production, see below
C_{Ore}	= additional C-input from Iron ore and Iron scrap into the BF: 3 841 t iron ore (1.57% C, plant specific) + 6 222 t iron scrap (4% C, IPCC default)
C_{Iron}	= 2 645 200 t Iron (4% C, IPCC default)
C_{Scrap}	= 1 296 470 t Steel Scrap (0.4%, ETS default)
C_{AddBOF}	= Additional C-input in BOF: 19 532 t Ferromangan (4% C, plant specific), 1 688 t Carbon 95 (95% C, plant specific), 2 671 t Carbon 98 (98% C, plant specific)
C_{Steel}	= 5 506 230 t Steel (0.13% C, plant specific)

Activity data, as indicated above, were collected from the operator [TÜV Rheinland, 1992-1993].

The carbon accounted for reducing agent ($C_{Reducing\ Agent}$) in the blast furnace is determined from the energy balance over the iron and steel industry.

Figure 4-6 – Energy balance iron and steel industry – flow chart



In 1990, the overall energy consumption in the iron and steel industry was compared with the energy input into the different SNAP categories reported in the CORINAIR inventory. 1 180 646 t coke, 40 027 t anthracite and 199 283 t residual oil are accounted to be transformed partly into blast furnace gas which is then fed with the remaining solid, liquid and gaseous fuels into the CORINAIR SNAP categories and further on into the different IPCC Energy sub-categories 1A2a and 1A2f. The remaining part of the blast furnace gas carbon serves as reducing agent that is reported under IPCC sub-category 2C1:

$$C_{Reducing\ Agent} = C_{2C1} = C_{(1\ 220\ 807\ t\ coke/anthracite\ +\ 199\ 283\ t\ residual\ oil)} - C_{BFGas}$$

From the 1990 energy balance (Table 4-12), 160.05 Gg carbon (*C*) serves as reducing agent in the blast furnace.

Table 4-12 – Energy balance iron and steel industry: 1990

Energy	tonnes	% C		Gg C
Coke	1 180 646	90.33		1066.48
Anthracite	40 027	95.00		38.03
Oil	199 283	85.75		170.88
Energy	GJ	kg CO_2/ GJ	kg C/ GJ	Gg C
BFGas	15 851 000	258.00	70.36	1115.33
				Gg C
C Reducing Agent				160.05

Therefore, the resulting carbon dioxide emissions for the iron and steel production in 1990 equal:

$$CO_2\ Emissions_{BF} = 200.00\ Gg\ CO_2$$

$$CO_2\ Emissions_{BOF} = 404.48\ Gg\ CO_2$$

For the subsequent years (1991 to 1997), a country specific methodology has been applied based on the emission factor determined for the year 1990:

$$CO_2\ Emissions_{BF} = EF_{BF} \bullet Pig\ Iron\ Production$$

$$CO_2\ Emissions_{BOF} = EF_{BOF} \bullet Steel\ Production$$

Electric arc furnace steel production (EAF)

The mass balance approach according to 2007 ETS guidelines is applied for calculating the emissions for the years 2004 to 2014.

The emissions are calculated based on a carbon balance over the production process.

$$E= (C_{Carbon}+C_{Anthracite}) \bullet 3.664 + E_{Electrodes}+E_{Pig\ iron}+E_{Petroleum\ coke}+E_{CaC2}+E_{Scrap}- E_{Steel}$$

$$E_i= AD_i \bullet EF_i \quad \text{with } i= \text{electrodes, pig iron, petroleum coke, CaC2}$$

It is assumed that E_{Scrap} equals E_{Steel}.

The activity data (C_{Carbon} , $C_{Anthracite}$, AD_i) are collected from the individual EAF (consumption of carbon, anthracite, electrodes, pig iron, petroleum coke and calcium carbide with their respective carbon contents).

The emission factors (EF) for electrodes, pig iron, petroleum coke and calcium carbide are taken from the 2007 guidelines - Tier1.

Starting 2015, better data collection allowed for a more specific approach regarding the calculations of EAF associate emissions. Similar to previous years, the mass balance approach, according to 2007 ETS guidelines, is applied, while the carbon balance over the production process has been expanded on:

$$E= (C_{Carbon}+C_{Anthracite}) \bullet 3.664 + E_{Electrodes}+E_{Pig\ iron}+E_{Petroleum\ coke}+E_{CaC2}+E_{flux}$$

Where E_{flux} corresponds to: $E_{flux}= E_{elements\ of\ fine\ alloying}+E_{scrap\ high\ in\ Carbon}+E_{scrap\ low\ in\ Carbon}+E_{actif\ carbon}+E_{forge\ carbon}-E_{steel}-E_{process\ residues}$

All emission factors are taken from the 2007 guidelines- Tier 1.

Regarding previous years, a lack of data doesn't make it possible to apply this new approach to the years preceding 2015.

The resulting emissions for the steel production are:

2022 – CO2 EmissionsEAF = 79.44 Gg CO2

2021 – CO2 EmissionsEAF = 89.88 Gg CO2

2020 – CO2 EmissionsEAF = 96.15 Gg CO2

2019 – CO2 $Emissions_{EAF}$ = 103.70 Gg CO2

2018 – CO2 $Emissions_{EAF}$ = 112.14 Gg CO2

2017 – CO_2 $Emissions_{EAF}$ = 107.43 Gg CO2

2016 – CO_2 $Emissions_{EAF}$ = 119.33 Gg CO2

2015 – CO_2 $Emissions_{EAF}$ = 122.80 Gg CO2

2014 – CO_2 $Emissions_{EAF}$ = 102.46 Gg CO2

2013 – CO_2 $Emissions_{EAF}$ = 101.59 Gg CO_2

$$2012 - CO_2\ Emissions_{EAF} = 100.23\ Gg\ CO_2$$

$$2011 - CO_2\ Emissions_{EAF} = 123.86\ Gg\ CO_2$$

$$2010 - CO_2\ Emissions_{EAF} = 133.61\ Gg\ CO_2$$

$$2009 - CO_2\ Emissions_{EAF} = 112.66\ Gg\ CO_2$$

$$2008 - CO_2\ Emissions_{EAF} = 134.69\ Gg\ CO_2$$

$$2007 - CO_2\ Emissions_{EAF} = 162.22\ Gg\ CO_2$$

$$2006 - CO_2\ Emissions_{EAF} = 170.49\ Gg\ CO_2$$

$$2005 - CO_2\ Emissions_{EAF} = 119.13\ Gg\ CO_2$$

$$2004 - CO_2\ Emissions_{EAF} = 152.45\ Gg\ CO_2$$

For the previous years (1993 to 2003), for which detailed data are not available, a simplified methodology has been applied based on the emission factor determined for the year 2004:

$$CO_2\ Emissions_{EAF} = EF_{EAF} \bullet Steel\ Production$$

It is assumed that the calculated emission factor for the year 2004 is the same for the previous years (1993 to 2003).

<u>PRIMUS® process (PRIMUS)</u>

The PRIMUS process was shut down in 2009. The ETS 2004 guidelines are applied for calculating the emissions in 2009.

$$E_{Primus} = (C_{Raw\ materials} + C_{Electrodes} + C_{Carbon} + C_{Anthracite} - C_{Products}) \times 44/12$$

It is assumed that $C_{Products}$ equals zero (Source: ETS declaration).

The activity data are collected from the operator (consumption of electrodes, carbon and anthracite with their respective carbon contents).

The resulting emissions in 2009 are:

$$Emissions_{PRIMUS} = 16.00\ Gg\ CO_2$$

The same methodology is applied for the years 2005 to 2009.

The emissions for the years 2003 and 2004 are estimated based on the relative carbon consumption (Table 4-13) and the average ratio of the CO_2 emissions per carbon consumption for the years 2005-2008.

Table 4-13 – Carbon consumption of the Primus process

Year	Carbon consumption (t)
2003	2'376
2004	6'592
2005	11'781
2006	12'850
2007	13'302
2008	10'683
2009	NA
2010	NO
2011	NO
2012	NO
2013	NO
2014	NO
2015	NO
2016	NO
2017	NO
2018	NO
2019	NO
2020	NO
2021	NO
2022	NO

Source: plant operator
Note: Facility shut down in 2009

4.4.1.2.3 Emission factors

For SP, BF and BOF, EFs are calculated from the determined CO_2 emissions and the production data in 1990. The EF is kept constant for the subsequent years 1991 to 1997: see Table 4-14.

Table 4-14 – EFs for SP, BF and BOF

Production (1990)	Emissions (1990)	EF
4 804 000 t sinter	380.44 Gg CO_2	EF_{SP} = 79.19 kg CO_2 / t sinter
2 645 200 t iron	200.00 Gg CO_2	EF_{BF} = 75.61 kg CO_2 / t iron
3 506 230 t steel	404.48 Gg CO_2	EF_{BOF} = 115.36 kg CO_2 / t steel

For EAF, the EF_{EAF} is calculated from the determined CO_2 emissions and the production data. For the period from 1993 to 2004, the EF is equal to the one determined for the year 2004. For the years 2005 and 2006, EFs are recalculated for each year: see Table 4-15.

Table 4-15 – EFs for EAF

	Production (2004)	Emissions (2004)	EF
	2 684 000 t steel	152.45 Gg CO2	EF_{EAF} = 56.80 kg CO2 / t
Year	**Production t steel**	**Emissions Gg CO2**	**EF_{EAF} *(kg CO_2 / t steel)***
2005	2 194 485	119.13	54.29
2006	2 802 049	170.49	60.85
2007	2'845'872	162.22	57.00
2008	2'584'341	134.69	52.12
2009	2'103'281	112.66	53.56
2010	2'633'613	133.61	50.73
2011	2'525'697	123.86	49.04
2012	2'208'000	100.23	45.39
2013	2'089'000	101.59	48.63
2014	2'192'999	102.46	46.72
2015	2'126'283	122.8	57.75
2016	2'175'409	119.33	54.86
2017	2'171'696	107.43	49.47
2018	2'227'951	112.14	50.33
2019	2'103'583	103.70	49.30
2020	1'887'003	96.15	50.95
2021	2'077'543	89.88	43.26
2022	1'874'792	79.44	42.37

The calculated emission factor for steel production in 2004 (EF_{EAF} = 56.80 kg CO_2 / t steel) and also applied for the previous years (1993 to 2003) is consistent with the calculated emission factors for the subsequent years (2005 to 2021).

For the PRIMUS® process, the implied emission factors $EF_{PRIMUS,}$ for the years 2005-2009, are calculated from the determined CO_2 emissions and the introduced filter dust (Table 4-16).

Table 4-16 – AD, emissions and IEF for Primus

Year	Filter dust (t)	Emissions (Gg CO2)	EF PRIMUS (Mg CO2 / t dust)
2005	29'263	33.79	1.15
2006	38'942	39.30	1.01
2007	46'446	41.27	0.89
2008	35'717	34.61	0.97
2009	16'514	16.00	0.97
2010	NO	NO	NA
2011	NO	NO	NA
2012	NO	NO	NA
2013	NO	NO	NA
2014	NO	NO	NA
2015	NO	NO	NA
2016	NO	NO	NA
2017	NO	NO	NA
2018	NO	NO	NA
2019	NO	NO	NA
2020	NO	NO	NA
2021	NO	NO	NA
2022	NO	NO	NA
Note: Facility shut down in 2009			

4.4.1.3 Uncertainties and time-series consistency

Table 4-17 gives the error values which are assumed on the various calculation parameters for the uncertainty assessment.

Table 4-17 – Error values (%) for uncertainty assessment

Step	Error (%) IPCC GPG 2000 Chap. 3.1.3.1	Error (%) Plant-specific estimation
1) Amount of reducing agent for iron production	5	5
2) Pig iron activity data / Steel activity data	a few	2
3) Carbon content of pig iron and iron ore (plant-specific data are available)	5	5
4) emission factors uncertainties	5	5

Combined resulting errors (uncertain quantities are to be combined by multiplication):

- Emissions uncertainty (1990: 1), 2), 3), 4)) .. 8.9 %
- Emissions uncertainty (2004: 2), 4) ....5.4 %

4.4.1.4 Source-specific QA/QC and verification

Activity and energy data for 1990 have been cross-checked with the activity data available in STATEC's Statistical Yearbook as well as with those provided by the operator directly or through the TÜV Rheinland 1992-1993 study. The iron and steel IPCC Sub-categories 1A2a (fuel combustion) and 2C1 (process emissions) have been cross-checked to avoid double counting.

The calculated emission factor for steel production in 2004 (EF_{EAF} = 56.80 kg CO_2 / t steel) and also applied for the previous years (1993 to 2003) is consistent with the calculated emission factors for the subsequent years.

4.4.1.5 Category-specific recalculations including changes made in response to the review process

No changes were made since the last submission.

4.4.1.6 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.C.1.

4.4.2 Ferroalloys Production (2.C.2)

There are no dedicated plants for producing ferroalloys in Luxembourg.

4.4.3 Aluminium Production (2.C.3)

Aluminium production in Luxembourg is made out of aluminium scraps. There is, therefore, no primary aluminium production. The production from aluminium scraps is generating only fuel combustion emissions – hence, no process emissions – and is, therefore, reported under IPCC Sub-category *1.A.2.b – Non-Ferrous Metals*.

4.4.4 Magnesium production (2.C.4)

This source category does not exist in Luxembourg.

4.4.5 Lead production (2.C.5)

This source category does not exist in Luxembourg.

4.4.6 Zinc production (2.C.6)

This source category does not exist in Luxembourg.

4.4.7 Other (as specified in table 2(I).A-H) (2.C.7)

Secondary aluminium production

In Luxembourg, one manufacturer is carrying activities belonging to the category 2.G.4. Activity data is directly obtained from the manufacturer. The data is limited to the one manufacturer and is considered confidential, thus the here described information is restricted to the activity data, which concerns CO_2 emissions related to the processing of lacquered or coated aluminium. Starting 2016, these emissions are estimated to equal 2.3231 kt, 2.0492 kt in 2017, 2.2473 kt in 2018, 2.2834 kt in 2019, 0.6416 kt in 2020 ,1.6567 kt in 2021 and 1.9278 kt in 2022

4.4.7.1.1 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 0.4%, based on ETS reporting
- Emission factor uncertainty 50%, emission factor estimation was based on a single analysis campaign.

4.4.7.1.2 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.5) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.4.7.2 Category-specific recalculations including changes made in response to the review process

No revisions and recalculations have been done since the last submission.

4.4.7.3 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.4

4.5 Non-energy products from fuels and solvent use (2.D)

This section describes the estimation of carbon dioxide emissions resulting from non-energy products like lubricants or waxes. In 2022, this source category was responsible for 4.89% of CO_2e emissions from industrial processes – but only 1.41% in 1990. It represented 0.32% of the total GHG emissions in CO_2e (excluding LULUCF) in 2022 and 0.18% in 1990. Compared to 2021, emissions decreased by 2.75% to attain the level of 26.17 Gg CO_2 in 2022. Compared to 1990, emissions increased by 15.54%.

4.5.1 Lubricant use (2.D.1)

4.5.1.1 Source category description

No manufacturing of lubricants does occur in Luxembourg. Lubricants are either used in road transportation (motor oil and greases) or in the manufacturing and construction industry (mainly greases). Incineration of lubricants (waste oil) does not occur in Luxembourg. Waste oil is either recycled or exported.

Luxembourg reports emissions from lubricants exclusively under category 2.D.1. The activity data obtained from the national statistics institute (Statec) does not allow for a disaggregation of the lubricants consumption between 2-stroke engines and other applications. Furthermore, the number of 2-stroke engines in Luxembourg is very low; the gasoline consumption by this vehicle category in 2019 was 10 tonnes. Assuming a mixture of 1:50 as suggested by the IPCC 2006 Guidelines, the lubricant consumption of 2-stroke engines is about 0.2 tonnes, and the associated CO_2 emissions are 0.0006 kt CO_2 emissions, which is below the threshold of significance.

In 2022, this source category was responsible for 0.86% of CO_2e emissions from industrial processes – but only 0.39% in 1990. It represented 0.06% of the total GHG emissions in CO_2e (excluding LULUCF) in 2022 and 0.05% in 1990. Compared to 2021, emissions increased by 18.15% to attain the level of 4.59 Gg CO_2 in 2022. Compared to 1990, emissions decreased by 26.07%.

An overview of the lubricant related CO_2 emissions, as well as of the amount of associated carbon stored is provided in Table 4-18.

Table 4-18 Emissions from 2.D.1 Lubricant Use

2D1 - Lubricant Use Activity data, emissions				
Year	AD t	CO_2 Gg	Fraction of carbon stored	Carbon stored Gg C
1990	10'524	6.205	0.800	6.769
1991	10'696	6.306	0.800	6.880
1992	10'199	6.013	0.800	6.560
1993	9'655	5.693	0.800	6.210
1994	10'004	5.898	0.800	6.435
1995	10'223	6.027	0.800	6.575
1996	10'175	5.999	0.800	6.545
1997	9'038	5.329	0.800	5.813
1998	9'061	5.342	0.800	5.828
1999	7'648	4.509	0.800	4.919
2000	7'102	4.187	0.800	4.568
2001	6'745	3.977	0.800	4.338
2002	7'067	4.167	0.800	4.545
2003	6'645	3.918	0.800	4.274
2004	5'040	2.972	0.800	3.242
2005	6'153	3.628	0.800	3.958
2006	4'961	2.925	0.800	3.191
2007	4'825	2.845	0.800	3.103
2008	10'218	6.025	0.800	6.572
2009	8'207	4.839	0.800	5.279
2010	9'425	5.557	0.800	6.062
2011	8'568	5.052	0.800	5.511
2012	8'058	4.751	0.800	5.183
2013	7'853	4.630	0.800	5.051
2014	7'446	4.390	0.800	4.789
2015	7'736	4.561	0.800	4.976
2016	8'770	5.171	0.800	5.641
2017	7'923	4.671	0.800	5.096
2018	9'131	5.384	0.800	5.873
2019	7'954	4.690	0.800	5.116
2020	6'254	3.687	0.800	4.023
2021	6'585	3.883	0.800	4.235
2022	7'780	4.587	0.800	5.004
Trend 2021-2022	18.15%	18.15%	0.00%	18.15%
2005-2022	26.44%	26.44%	0.00%	26.44%
1990-2022	-26.07%	-26.07%	0.00%	-26.07%

Sources: AD: STATEC; CO2: Environment Agency

4.5.1.2 Methodology

Generally speaking, lubricant emissions estimations in Luxembourg are based on the Tier 1 (Chap5, Tab.5.2, p5.7) methods described in the 2006 IPCC Guidelines for National Greenhouse Gas inventories. Activity data (import/export) for the years 1990 to 2021 were obtained from STATEC.

4.5.1.3 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 5%
- Emission factor uncertainty 50%

4.5.1.4 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.5) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.5.1.5 Category-specific recalculations including changes made in response to the review process

Emissions have been revised for the year 2021. As such emission data for the year 2021 has decreased by -36.6583% (6.1294816 Gg CO_2eq -> 3.882516 Gg CO_2eq).

4.5.1.6 Category-specific planned improvements including those in response to the review process

There are no planned improvements for this category.

4.5.2 Paraffin wax use (2.D.2)

4.5.2.1 Source category description

No manufacturing of products from the paraffin wax category occurs in Luxembourg, as such all used products are imported. In 2022, this source category was responsible for 0.54% of CO_2e emissions from industrial processes – but only 0.01% in 1990. It represented 0.03% of the total GHG emissions in CO_2e (excluding LULUCF) in 2021 and 0.002% in 1990. Compared to 2021, emissions increased by 54.81% to attain the level of 2.87 Gg CO_2 in 2022. Compared to 1990, emissions increased by 1264.54%. Starting 2010, activity data for paraffin wax strongly increases, which is due to the implementation of a new company. Similarly, the increase in 2012/2013 is also linked to the activity of the same company.

An overview of the paraffin wax related CO_2 emissions is provided in Table 4-19.

Table 4-19 Emissions from 2.D.2 Paraffin Wax Use

Activity data, emissions			
Year	AD t	CO_2 Gg	IEF kg CO2 / kg wax
1990	357.16	0.21	0.59
1991	361.99	0.21	0.59
1992	366.82	0.22	0.59
1993	371.84	0.22	0.59
1994	376.95	0.22	0.59
1995	382.43	0.23	0.59
1996	387.36	0.23	0.59
1997	392.19	0.23	0.59
1998	397.11	0.23	0.59
1999	371.51	0.22	0.59
2000	413.31	0.24	0.59
2001	396.54	0.23	0.59
2002	397.54	0.23	0.59
2003	469.48	0.28	0.59
2004	441.56	0.26	0.59
2005	439.36	0.26	0.59
2006	295.88	0.17	0.59
2007	283.61	0.17	0.59
2008	424.01	0.25	0.59
2009	213.16	0.13	0.59
2010	2177.23	1.28	0.59
2011	1268.85	0.75	0.59
2012	1135.95	0.67	0.59
2013	4526.83	2.67	0.59
2014	2883.55	1.70	0.59
2015	2609.31	1.54	0.59
2016	4480.71	2.64	0.59
2017	4343.01	2.56	0.59
2018	3801.70	2.24	0.59
2019	4439.66	2.62	0.59
2020	5324.51	3.14	0.59
2021	3148.06	1.86	0.59
2022	4873.60	2.87	0.59
Trend 1990-2022	1264.54%	1264.54%	0.00%
Trend 2005-2022	1009.26%	1009.26%	0.00%
Trend 2021-2022	54.81%	54.81%	0.00%
Sources: AD: STATEC ; CO2 and IEF: Environment Agency			

Sources: AD: STATEC ; CO2: Environment Agency

4.5.2.2 Methodology

The emissions of paraffin wax in Luxembourg were assessed in 2014 in order to assure compliance with the 2006 IPCC reporting guidelines.

Generally speaking, paraffin wax emissions estimations in Luxembourg are based on the Tier 1 (Chap5, Tab.5.3., p5.11) methods described in the 2006 IPCC Guidelines for National Greenhouse Gas inventories. Activity data (import/export) for the years 1999 to 2020 were obtained from STATEC. For the years 1990 to 1998, the data was extrapolated based population data and on the average import/export data for the years 1999-2005.

4.5.2.3 Uncertainties and time-series consistency

The error values were taken from the 2006 IPCC Guidelines for National Greenhouse Gas inventories (paraffin wax chapter) and are as follows:

- Activity data uncertainty 5%
- Emission factor uncertainty 100%

4.5.2.4 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which mportant elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.5.2.5 Category-specific recalculations including changes made in response to the review process

No recalculations were done since the last submission.

4.5.2.6 Category-specific planned improvements including those in response to the review process

Obtaining country specific data for the years 1990 to 1998, alternatively improvements to the estimations of the activity data and emissions concerning those years will be performed.

4.5.3 Other (2.D.3)

4.5.3.1 Solvent use (2.D.3.1)

4.5.3.1.1 Sector Overview

Solvents are chemical compounds, which are used to dissolve substances as paint, glues, ink, rubber, plastic, pesticides or for cleaning purposes (degreasing). Solvents used in products such as coatings, inks, and consumer products generally emit substances classified as VOCs (Volatile Organic Compounds). Because solvents consist mainly of (non-methane) VOCs (NMVOC), solvent use is a major source for anthropogenic NMVOC emissions in Luxembourg. Once released into the atmosphere, NMVOCs react with reactive molecules (mainly HO-radicals) or high energetic light to finally form CO_2.

For more details on categories where emissions are not occurring and categories that are not estimated or included elsewhere, see Table 4-3.

4.5.3.1.2 Emission Trends

In 2022, this source category was responsible for 1.43% of the total CO_2e emissions of the industrial processes sector estimated for Luxembourg (1.01% in 1990). Furthermore, in 2022, 0.09% of total GHG emissions (excluding LULUCF) in Luxembourg originated from Solvent and Other Product Use, compared to 0.13% in 1990. Compared to 2021, GHG emissions from Solvent and Other Product Use decreased by 4.04 % in 2022. Compared to 1990, emissions decreased by 52.83%.

Figure 4-7 and Table 4-20 present the trend in total greenhouse gas emissions by subcategories.

Figure 4-7 - Emissions and trend from 1990 – 2022 by Sub-Categories of 2.D.3.1 - Solvent and Other Product Use.

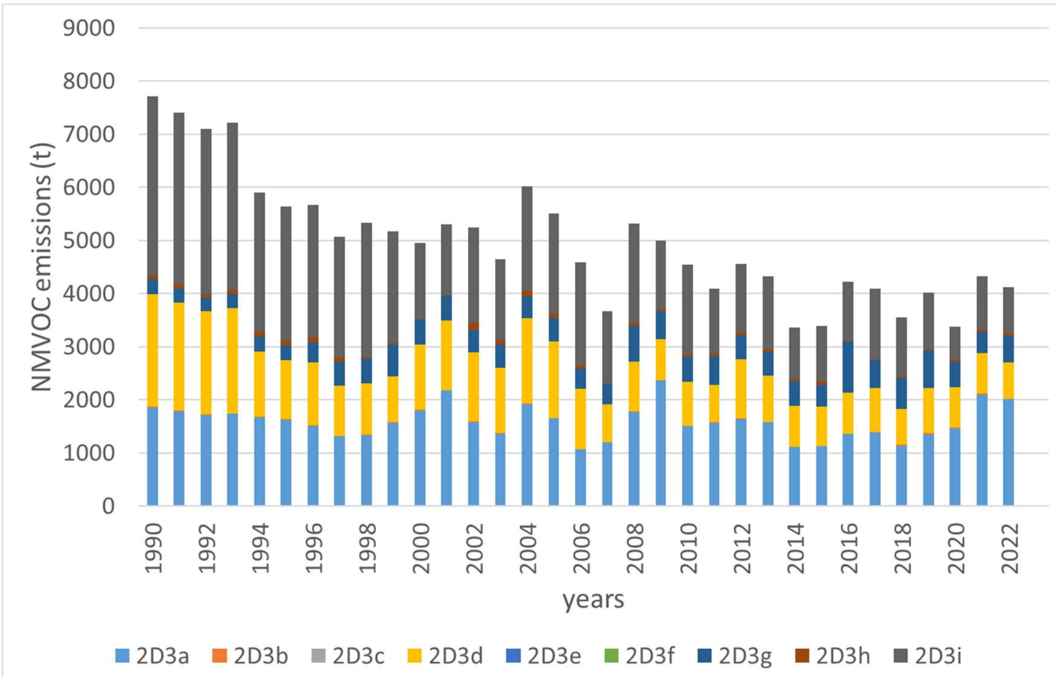


Table 4-20 - Emissions and trend from 1990 – 2022 by Sub-Categories of 2.D.3.1 - Solvent and Other Product Use.

2D3 - Solvent and Product Use										
CO2 emissions (Gg)										
Year	2D3 TOTAL	2D3a Dometics solvent use including fungicides	2D3b Road paving with asphalt	2D3c Asphalt roofing	2D3d Coating applications	2D3e Degreasing	2D3f Dry cleaning	2D3g Chemical products	2D3h Printing	2D3i Other solvent use
1990	16.23	3.73	N/A	N/A	5.12	0.00	0.00	0.52	0.14	6.71
1991	15.27	3.67	N/A	N/A	4.68	0.00	0.00	0.48	0.13	6.31
1992	14.15	3.51	N/A	N/A	4.23	0.00	0.00	0.42	0.12	5.86
1993	13.87	3.52	N/A	N/A	4.05	0.00	0.00	0.44	0.11	5.75
1994	10.78	3.28	N/A	N/A	2.36	0.00	0.00	0.43	0.14	4.57
1995	10.29	3.21	N/A	N/A	2.09	0.00	0.00	0.49	0.12	4.38
1996	9.82	2.86	N/A	N/A	2.11	0.00	0.00	0.62	0.13	4.09
1997	8.99	2.55	N/A	N/A	1.71	0.00	0.00	0.78	0.13	3.82
1998	9.44	2.61	N/A	N/A	1.74	0.00	0.00	0.80	0.03	4.25
1999	9.18	3.08	N/A	N/A	1.54	0.00	0.00	0.97	0.05	3.54
2000	9.07	3.56	N/A	N/A	2.23	0.00	0.00	0.80	0.03	2.45
2001	9.77	4.31	N/A	N/A	2.36	0.00	0.00	0.81	0.03	2.26
2002	9.49	3.14	N/A	N/A	2.35	0.00	0.00	0.74	0.18	3.07
2003	8.39	2.70	N/A	N/A	2.21	0.00	0.00	0.76	0.12	2.61
2004	10.95	3.81	N/A	N/A	2.90	0.00	0.00	0.73	0.14	3.37
2005	9.98	3.28	N/A	N/A	2.61	0.00	0.00	0.77	0.10	3.22
2006	8.22	2.12	N/A	N/A	2.05	0.00	0.00	0.67	0.09	3.30
2007	6.68	2.38	N/A	N/A	1.27	0.00	0.00	0.66	0.01	2.35
2008	9.66	3.52	N/A	N/A	1.69	0.00	0.00	1.18	0.07	3.20
2009	9.27	4.69	N/A	N/A	1.38	0.00	0.00	0.93	0.06	2.20
2010	8.26	2.98	N/A	N/A	1.50	0.00	0.00	0.83	0.05	2.91
2011	7.48	3.12	N/A	N/A	1.27	0.00	0.00	0.93	0.07	2.10
2012	8.34	3.26	N/A	N/A	2.01	0.00	0.00	0.80	0.07	2.21
2013	7.90	3.12	N/A	N/A	1.57	0.00	0.00	0.78	0.07	2.35
2014	6.11	2.19	N/A	N/A	1.41	0.00	0.00	0.80	0.07	1.65
2015	6.15	2.23	N/A	N/A	1.35	0.00	0.00	0.70	0.08	1.79
2016	7.68	2.70	N/A	N/A	1.39	0.00	0.00	1.69	0.03	1.88
2017	7.45	2.76	N/A	N/A	1.49	0.00	0.00	0.93	0.02	2.25
2018	6.42	2.25	N/A	N/A	1.20	0.00	0.00	1.03	0.03	1.91
2019	7.28	2.67	N/A	N/A	1.54	0.00	0.00	1.22	0.03	1.82
2020	6.21	2.90	N/A	N/A	1.36	0.00	0.00	0.85	0.06	1.05
2021	7.98	4.14	N/A	N/A	1.37	0.00	0.00	0.70	0.06	1.71
2022	7.66	3.99	N/A	N/A	1.24	0.00	0.00	0.89	0.05	1.49
Trend 1990-2022	-52.83%	6.87%	NA	NA	-75.83%	NA	NA	69.61%	-65.70%	-77.77%
2005-2022	-23.24%	21.76%	NA	NA	-52.58%	NA	NA	15.96%	-52.31%	-53.65%
2021-2022	-3.99%	-3.75%	NA	NA	-9.65%	NA	NA	27.72%	-10.81%	-12.72%

Greenhouse gas emissions in this sector decreased by 52.83% between 1990 and 2022, due to the positive impact of the enforced laws and regulations in Luxembourg:

- Solvent Ordinance: for limitation of emission of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products in order to combat acidification and ground-level ozone[87];
- Ordinance for paint finishing system (surface technology systems): for limitation of emission of volatile organic compounds due to the use of organic solvents by activities such as surface coating, painting or varnishing of different materials and products along the entire chain in the painting process in order to combat acidification and ground-level ozone[88]
- Ordinance for industrial facilities and installations applying chlorinated hydrocarbon: for limitation of emission of chlorinated organic solvents from industrial facilities and installations applying chlorinated hydrocarbon;
- Convention on Long-range Transboundary Air Pollution (LRTAP)[89], extended by eight protocols from which the following have relevance:
  - The 1988 Protocol concerning the Control of Nitrogen Oxides or their Transboundary Fluxes;[90]
  - The 1991 Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes;[91]
  - The 1998 Protocol on Persistent Organic Pollutants (POPs);[92]
  - The 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone; 21 Parties.[93]
- Ordinance for volatile organic compounds (VOC) due to the use of organic solvents in certain activities and installations;[94]
- European Council Directive 1999/13/EC of March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations;
- European Council Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC;
- Regulation on the limitation of emission during the use of solvents containing lightly volatile halogenated hydrocarbons in industrial facilities and installations.[95]

4.5.3.1.3 Completeness

Table 4-21 gives an overview of the IPCC categories included in this chapter and presents the transformation matrix from SNAP categories. It also provides information on the status of emission estimates of all subcategories. A "✓" indicates that emissions from this sub-category have been estimated.

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87 Règlement grand-ducal du 7 avril 2011 remplaçant l'annexe III du règlement grand-ducal modifié du 25 janvier 2006 relatif à la réduction des émissions de composés organiques volatils dues à l'utilisation de solvants organiques dans certains vernis et peintures et dans les produits de retouche de véhicules. (implementation of European Council Directive 2004/42/CE and European Council Directive 2010/79/EC).

88 Règlement grand-ducal du 20 décembre 1995 relatif à certaines modalités d'application et à la sanction du règlement CE N° 3093/94 du Conseil du 15 décembre 1994 relatif à des substances qui appauvrissent la couche d'ozone.

89 Loi du 18 juin 1981 portant approbation de la Convention sur la pollution atmosphérique transfrontière à longue distance, en date à Genève, du 13 novembre 1979. (Convention entered into force 16 March 1983; ratified by Luxembourg 15 July 1982)

90 Loi du 31 juillet 1990 portant approbation du Protocole à la Convention sur la pollution atmosphérique transfrontière à longue distance de 1979, relatif à la lutte contre les émissions d'oxydes d'azote ou leurs flux transfrontières, fait à Sofia, le 31 octobre 1988. (Protocol entered into force 14 February 1991; ratified by Luxembourg 4 October 1990)

91 Loi du 29 juillet 1993 portant approbation du Protocole à la Convention sur la pollution atmosphérique transfrontière à longue distance, de 1979, relatif à la lutte contre les émissions de composés organiques volatils ou de leurs flux transfrontières, fait à Genève, le 18 novembre 1991. (Protocol entered into force 29 September 1997; ratified by Luxembourg 11.11.1993)

92 Loi du 24 décembre 1999 portant approbation du Protocole à la Convention sur la pollution atmosphérique transfrontière à longue distance, de 1979, relatif aux polluants organiques persistants, fait à Aarhus (Danemark), le 24 juin 1998. (Protocol entered into force on 23 October 2003; ratified by Luxembourg 01.05.2000)

93 Loi du 14 juin 2001 portant approbation du Protocole à la Convention de 1979 sur la pollution atmosphérique transfrontière à longue distance, relatif à la réduction de l'acidification, de l'eutrophisation et de l'ozone troposphérique, fait à Göteborg, le 30 novembre 1999. (Protocol entered into force on 17 May 2005; ratified by Luxembourg 07.08.2001)

94 Règlement grand-ducal du 3 décembre 2010 modifiant le règlement grand-ducal modifié du 4 juin 2001 portant - application de la directive 1999/13/CE du Conseil du 11 mars 1999 relative à la réduction des émissions de composés organiques volatils dues à l'utilisation de solvants organiques dans certaines activités et installations; - modification du règlement grand-ducal modifié du 16 juillet 1999 portant nomenclature et classification des établissements classes;.

95 Règlement grand-ducal du 12 juillet 1995, relatif aux générateurs d'aérosols.

Table 4-21 - Overview of subcategories of IPCC Category 2.D.3.1 - Solvents and Other Product Use: correlation with SNAP codes and status of estimation.

IPCC Category		SNAP		CO2	N2O
3.A	Paint application	0601	Paint application	✓	NA
3.B	Degreasing and Dry Cleaning	0602	Degreasing, dry cleaning and electronics	✓	NA
3.C	Chemical Products, Manufacture and Processing	0603	Chemical products manufacturing and processing	✓	NA
3.D	Other	0604	Other use of solvents and related activities	✓	NA

4.5.3.1.4 CO2 Emissions from Solvent and Other Product Use

4.5.3.1.4.1 Methodology Overview

NMVOC emissions from solvent containing substances and products are calculated as follows:

a) The starting point is the import statistics of solvent-containing substances and products provided by the national statistics office. Approximately 500 different products and substances are listed according to their combined nomenclature (CN) code.

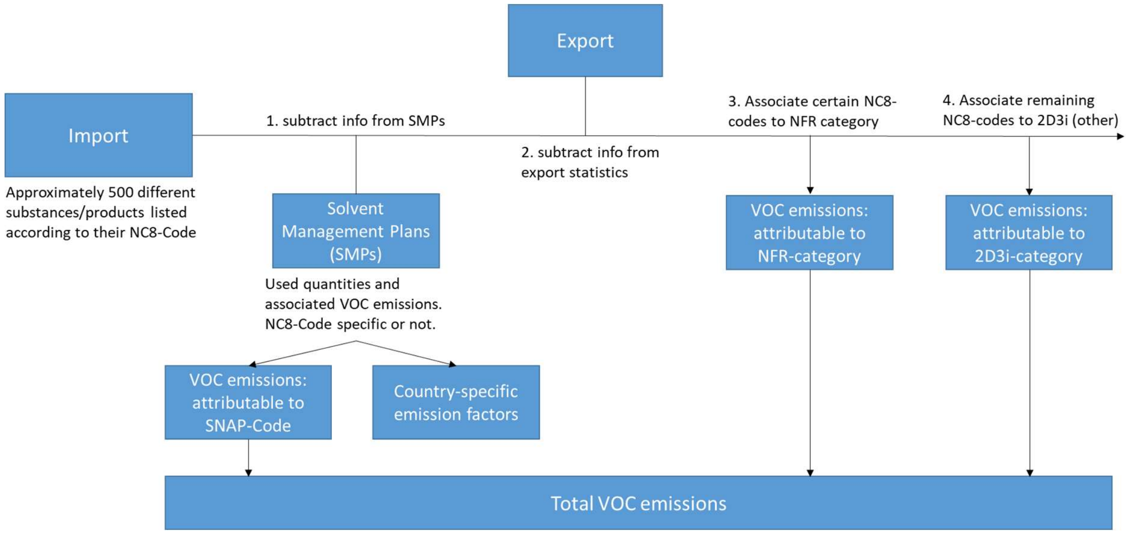
b) Next, solvent management plans (SMPs) from companies are analyzed, which are yearly submitted to the Environmental Administration according to the Directive 2010/75/EU of the European parliament and of the council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). SMPs provide information about the consumption of certain solvent-containing substances and products as well as the resulting NMVOC emissions. Thus, country specific emission factors (kg NMVOC / kg substance/product) can be determined for the utilized substances/products. Finally, the quantities are subtracted from the import statistics.

c) Then, the export statistics are used to account for the exported quantities. However, quantities are set to 0 in case that quantities become negative after subtraction.

d) Subsequently, certain substances and products are linked to be used under certain NFR categories. This attribution links the emissions, calculated in the next step, to a certain NFR category as well.

e) Finally, NMVOC emissions for all remaining CN-code specific quantities are calculated. Emission factors are used based on the former model of Luxembourg, which itself is based on the Austrian inventory calculations. Emissions are attributed to previously attributed NFR-categories. In case that a certain substance or product cannot be attributed to a NFR-category, emissions are allocated under category 2D3i (Other solvent and product use).

It is noted that the SMPs are first account for prior to subtracting the export statistics. The reasoning is that these quantities are judged to be more accurate.



The approach is motivated as follows:

- Data from the European Solvents Industry Group (ESIG) is not available solely for Luxembourg due to confidentially reasons and is thus only available in aggregated form with the Belgian statistics.
- No other federations exist in Luxembourg, who gather statistics covering solvent-containing products.
- Thus, the only source of activity data is the national statistics on import and export of solvent-containing substances and products, which are disaggregated according to their CN-code provided by the national statistics agency.
- Additional data is gathered from solvent management plans (SMPs). Only a few sufficiently large companies exist in Luxembourg. However, the SMPs cover already a large portion of the imported solvent-containing products and substances. The reported emissions can directly by associated with a SNAP code and thus a NFR category.

It is noted that no statistics are available, which cover the production of solvent-containing substances and products. However, as Luxembourg is a small country and a major contribution to NMVOC emissions arises from a few international companies, the error is assumed to be small when treating the production within the export statistics.

The following issues arise for the approach described above.

- Some SMPs do not give details about which substances/products are used, but only specify the quantity of NMVOC input. In these cases, quantities and emissions cannot be associated to a specific CN-code. Nevertheless, the information of the SNAP-code is used, which is attributed to the company. Consequently, the emissions can also be attributed to that SNAP-Code. Thus, the emissions are subtracted from the previously calculated category 2D3i and added to the NFR-category corresponding to the given SNAP-code of the company.

- SMPs are not available for the entire timeline starting from 1990. Thus, for each company the NC8-code specific information is extrapolated towards the past until the year where the company is founded. If T is the year of the earliest available SMP for a certain company, the relative amount $p_{SMP,NC\ ,T}$ with respect to the total import $IMP_{NC\ ,T}$ is calculated. For earlier years $T - x$, the used quantities by this company are determined by $q_{PGS,NC\ ,T-x} = IMP_{NC\ ,T-x}\, p_{PGS,NC\ ,T}$.

In case that a subset of the used quantities cannot be related to a CN-code in the earliest available SMP, extrapolation is still performed for these quantities. In that case, extrapolation is carried out after the extrapolation of items with a CN-code is completed according to:

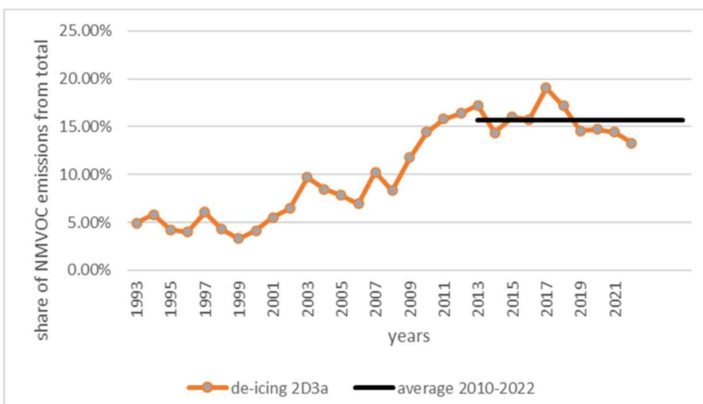
$$q_{NC8=None,T-x} = q_{NC8=None,T} \times \frac{q_{NC\ ,T-x}}{q_{NC8,T}}$$

Thus, these quantities without a NC8-code scale the same way as the quantities having a NC8-code.

In case that no quantities of a company's SMP can be related to a NC8-code, no extrapolation is carried out.

4.5.3.1.4.2 De-icing products

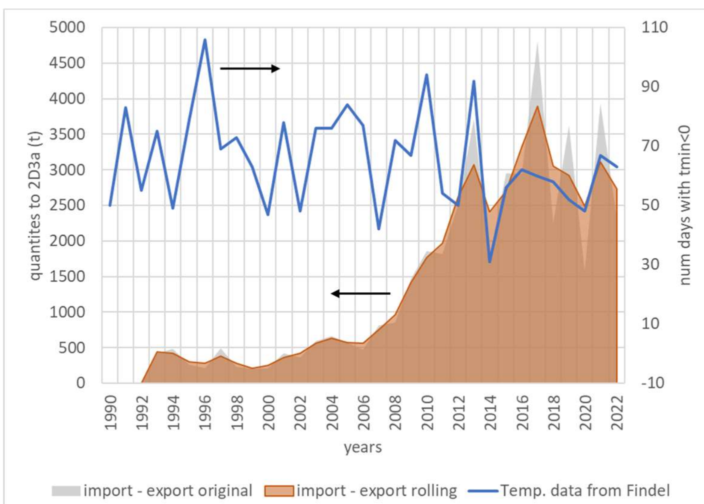
As can be seen below, a major contribution to the national NMVOC emissions in the category 2D3 are de-icing products allocated to the 2D3a (domestic solvent use including fungicides) category. Between 2010 and 2022, emissions of de-icing products in the category 2D3a amount to an average of 15.7 % of the total 2D3 emissions.



In order to account for emissions from de-icing products in general, the following steps are taken:

- De-icing products (single CN-code) are split into two categories with allocations to the NFR categories 2D3a and 2D3i. According to the EMEP guidebook (2.D.3.a Domestic solvent use including fungicides), 50 % of the total de-icing products should be allocated to each of these two NFR categories. However, in Luxembourg the transport sector has a major contribution due to the relatively large amount of commuters, suggesting that a larger portion than 50 % should be allocated to the category 2D3a. Second, in Luxembourg only a single airport exists from which the amount of used de-icing quantities are available to the Environment Administration. Consequently, the quantities provided by the Luxembourgish Airport are allocated to 2D3i, whereas the rest of the de-icing products are allocated to 2D3a.

- Second, the year-to-year import statistic of de-icing products varies significantly. Those products are generally utilized in the winter months, i.e. at a time where the statistics for one year are concluded and the statistics for the next year commence. However, stockage is not taken into account in the statistics. Therefore, a rolling average is calculated for the import of de-icing products, which are allocated to the 2D3a category. For the rolling average, the window-size is 3, the center-point is weighted with 100 %, whereas the neighbouring points are weighted with 35 %. With these parameters, the shape of the import is maintained, while the peaks flatten slightly. Indeed, the Figure below shows a decent correlation between the amount of de-icing products allocated to 2D3a and the temperatures - more precisely the number of days where temperatures fall between 0 °C. In particular, a better match is observed when using the rolling average (red area) instead of the original data (gray area).
- In addition, a strong increase in de-icing products allocated to 2D3a is observed since 2007. It is assumed that the solvent-content of de-icing products is reduced over time, so that ready-to-use solutions are directly available to the consumers and no additional dilution is necessaire (i.e. de-icing fluids with a freezing point of -10 or -5 °C). Consequently, the emission factor (kg NMVOC / kg product) is reduced from 50% in 2007 to 20 % in 2014. The year 2014 is chosen because since then the quantity of de-icing products allocated to 2D3a does not show a trend anymore but only fluctuations.



4.5.3.1.4.3 Rolling average for other products

A relatively strong variation in import and export is also observed for some other products allocated to the 2D3a category. For those items, a rolling average is calculated the same way as for de-icing products described above. Table xy gives an overview of all products, for which such a rolling average is calculated.

CN-Code	Short description
38200000998	domestic_Préparations antigel et liquides préparés…
33072000	Personal deodorants and antiperspirants
33074900	Preparations for perfuming or deodorising rooms, i…
33053000	Hair lacquers
33071000	Shaving preparations, incl. pre-shave and aftersha…
34029090	Washing preparations, incl. auxiliary washing prep…

4.5.3.1.4.4 Items allocated to NFR categories

The items listed in Table xy are allocated to NRF categories. It is noted that the NC8-code 38140090 is split to be allocated to category 2D3d and 2D3a with a share of 70 % and 30 % respectively. Therefore, the NC8-code is extended to distinguish between these two in the calculations. Similarly, de-icing products are split. Here, only the de-icing products allocated to 2D3a are listed, while the de-icing products used by the airport are contained in the information of the SMPs (thus not listed in Table xy. It is noted that all items starting with the NC8-code 3808 are allocated to 2D3a as well and in the calculations an emission factor (kg NMVOC / kg product) of 0.15 is used according to the guidebook (2.D.3.a Domestic solvent use including fungicides).

CN-Code	NRF category	Abbreviated description
32064970	2D3g	Matières colorantes inorganiques ou minérales, n.d…
32081090	2D3d	Paints and varnishes, incl. enamels and lacquers, …
32082090	2D3d	Paints and varnishes, incl. enamels and lacquers, …
32089091	2D3d	Paints and varnishes, incl. enamels and lacquers, …
32089099	2D3d	Paints and varnishes, incl. enamels and lacquers, …
32091000	2D3d	Paints and varnishes, incl. enamels and lacquers, …
32099000	2D3d	Paints and varnishes, incl. enamels and lacquers, …
32100010	2D3d	Oil paints and varnishes, incl. enamels and lacque…
32100090	2D3d	Paints and varnishes, incl. enamels, lacquers and …

32141090	2D3d	Painter's fillings
32151100	2D3h	Black printing ink, whether or not concentrated or…
32151900	2D3h	Printing ink, whether or not concentrated or solid…
32159020	2D3a	Cartouches d'encre pour imprimantes/photocopieurs,…
33030010	2D3a	Perfumes (excl. aftershave lotions and personal de…
33030090	2D3a	Toilet waters (excl. aftershave lotions, deodorant…
33049900	2D3a	Beauty or make-up preparations and preparations fo…
33052000	2D3a	Preparations for permanent waving or straightening…
33053000	2D3a	Hair lacquers
33059000	2D3a	Preparations for use on the hair (excl. shampoos, …
33059010	2D3a	Hair lotions
33059090	2D3a	Preparations for use on the hair (excl. shampoos, …
33071000	2D3a	Shaving preparations, incl. pre-shave and aftersha…
33072000	2D3a	Personal deodorants and antiperspirants
33074900	2D3a	Preparations for perfuming or deodorising rooms, i…
33079000	2D3a	Depilatories and other perfumery, toilet or cosmet…
34029090	2D3a	Washing preparations, incl. auxiliary washing prep…
34051000	2D3a	Polishes, creams and similar preparations, for foo…
34052000	2D3a	Polishes, creams and similar preparations, for the…
34053000	2D3a	Polishes and similar preparations for coachwork, w…
34059010	2D3a	Metal polishes, whether or not in the form of pape…
38063000	2D3g	Ester gums
3808*	2D3a	Pesticides
38140090998	2D3d	2D3d_Organic composite solvents and thinners and p…
38140090999	2D3a	2D3a_Organic composite solvents and thinners and p…

38200000998	2D3a	domestic_Anti-freezing preparations and prepared d...

4.5.3.1.4.5 Activity data and implied emission factors

Finally, combining the information from the SMPs and the import and export statistics, the following activity and NMVOC emissions per NFR category is obtained

2D3 - Solvent and Product Use										
Activity Data (Gg)										
Year	2D3 TOTAL	2D3a Dometics solvent use including fungicides	2D3b Road paving with asphalt	2D3c Asphalt roofing	2D3d Coating applications	2D3e Degreasing	2D3f Dry cleaning	2D3g Chemical products	2D3h Printing	2D3i Other solvent use
1990	68.08	8.76	N/A	NO	5.92	IE	IE	3.14	1.25	49.01
1991	65.40	8.42	N/A	NO	5.69	IE	IE	3.01	1.20	47.08
1992	62.72	8.07	N/A	NO	5.45	IE	IE	2.89	1.15	45.16
1993	63.69	8.20	N/A	NO	5.54	IE	IE	2.94	1.16	45.86
1994	84.31	8.31	N/A	NO	4.10	IE	IE	3.80	1.46	66.64
1995	71.27	8.47	N/A	NO	3.99	IE	IE	4.06	1.33	53.43
1996	55.72	6.19	N/A	NO	4.62	IE	IE	7.72	1.54	35.65
1997	60.76	6.89	N/A	NO	3.67	IE	IE	9.79	1.54	38.87
1998	47.62	7.35	N/A	NO	3.58	IE	IE	9.62	0.44	26.63
1999	74.17	9.45	N/A	NO	3.63	IE	IE	13.66	0.57	46.86
2000	79.96	10.95	N/A	NO	3.83	IE	IE	11.44	0.27	53.47
2001	70.51	13.31	N/A	NO	3.46	IE	IE	13.31	0.27	40.15
2002	71.14	9.16	N/A	NO	5.09	IE	IE	13.45	2.56	40.88
2003	70.97	8.21	N/A	NO	4.98	IE	IE	15.16	1.72	40.91
2004	80.43	7.24	N/A	NO	7.08	IE	IE	21.31	2.22	42.58
2005	79.01	5.92	N/A	NO	7.50	IE	IE	24.94	1.72	38.92
2006	73.98	7.15	N/A	NO	8.07	IE	IE	23.33	1.55	33.88
2007	66.08	8.82	N/A	NO	4.53	IE	IE	23.41	0.16	29.16
2008	81.23	11.24	N/A	NO	7.70	IE	IE	28.40	1.34	32.56
2009	68.07	12.11	N/A	NO	6.91	IE	IE	26.62	1.12	21.30
2010	65.19	9.04	N/A	NO	7.51	IE	IE	19.45	1.00	28.18
2011	79.01	9.50	N/A	NO	8.24	IE	IE	31.06	1.52	28.69
2012	77.47	10.33	N/A	NO	8.56	IE	IE	28.95	1.72	27.91
2013	83.35	11.12	N/A	NO	8.25	IE	IE	32.49	1.85	29.64
2014	76.00	8.95	N/A	NO	7.60	IE	IE	31.32	1.97	26.17
2015	79.09	8.43	N/A	NO	8.31	IE	IE	34.15	2.59	25.60
2016	78.57	9.11	N/A	NO	7.77	IE	IE	36.64	0.92	24.13
2017	92.60	9.91	N/A	NO	8.51	IE	IE	47.59	0.81	25.78
2018	88.07	8.67	N/A	NO	7.74	IE	IE	47.01	0.92	23.74
2019	96.61	9.50	N/A	NO	7.31	IE	IE	46.53	1.02	32.26
2020	94.41	9.79	N/A	NO	6.94	IE	IE	48.79	1.12	27.77
2021	107.32	10.74	N/A	NO	8.53	IE	IE	51.96	1.19	34.90
2022	100.92	9.62	N/A	NO	8.19	IE	IE	49.32	0.82	32.97
Trend 1990-2022	48.25%	9.77%	NA	NA	38.43%	NA	NA	1471.88%	-34.09%	-32.74%
2005-2022	27.74%	62.45%	NA	NA	9.19%	NA	NA	97.77%	-52.29%	-15.30%
2021-2022	-5.97%	-10.45%	NA	NA	-3.90%	NA	NA	-5.08%	-31.06%	-5.55%

2D3 - Solvent and Product Use										
NMVOC emissions (Gg)										
Year	2D3 TOTAL	2D3a Dometics solvent use including fungicides	2D3b Road paving with asphalt	2D3c Asphalt roofing	2D3d Coating applications	2D3e Degreasing	2D3f Dry cleaning	2D3g Chemical products	2D3h Printing	2D3i Other solvent use
1990	7.71	1.86	0.01	NO	2.12	IE	IE	0.28	0.07	3.38
1991	7.41	1.78	0.01	NO	2.03	IE	IE	0.27	0.07	3.24
1992	7.10	1.71	0.01	NO	1.95	IE	IE	0.26	0.07	3.11
1993	7.21	1.74	0.01	NO	1.98	IE	IE	0.26	0.07	3.16
1994	5.90	1.67	0.01	NO	1.23	IE	IE	0.27	0.09	2.63
1995	5.65	1.63	0.01	NO	1.11	IE	IE	0.28	0.08	2.54
1996	5.66	1.51	0.01	NO	1.18	IE	IE	0.38	0.10	2.48
1997	5.07	1.31	0.01	NO	0.95	IE	IE	0.45	0.09	2.27
1998	5.33	1.33	0.01	NO	0.96	IE	IE	0.48	0.02	2.52
1999	5.17	1.57	0.01	NO	0.86	IE	IE	0.60	0.03	2.10
2000	4.96	1.79	0.01	NO	1.24	IE	IE	0.46	0.02	1.44
2001	5.30	2.17	0.01	NO	1.31	IE	IE	0.46	0.02	1.33
2002	5.25	1.59	0.01	NO	1.30	IE	IE	0.42	0.13	1.80
2003	4.65	1.36	0.02	NO	1.22	IE	IE	0.44	0.08	1.53
2004	6.02	1.92	0.00	NO	1.60	IE	IE	0.42	0.10	1.97
2005	5.50	1.65	0.00	NO	1.45	IE	IE	0.44	0.07	1.89
2006	4.59	1.07	0.00	NO	1.13	IE	IE	0.38	0.06	1.94
2007	3.67	1.20	0.00	NO	0.71	IE	IE	0.38	0.01	1.38
2008	5.32	1.78	0.00	NO	0.94	IE	IE	0.67	0.05	1.87
2009	5.00	2.37	0.00	NO	0.77	IE	IE	0.53	0.04	1.29
2010	4.55	1.50	0.00	NO	0.83	IE	IE	0.47	0.03	1.70
2011	4.09	1.57	0.00	NO	0.70	IE	IE	0.53	0.05	1.23
2012	4.56	1.64	0.00	NO	1.11	IE	IE	0.46	0.05	1.29
2013	4.33	1.58	0.00	NO	0.87	IE	IE	0.45	0.05	1.38
2014	3.36	1.11	0.01	NO	0.78	IE	IE	0.45	0.05	0.96
2015	3.38	1.12	0.00	NO	0.75	IE	IE	0.40	0.06	1.05
2016	4.22	1.36	0.00	NO	0.77	IE	IE	0.96	0.02	1.10
2017	4.09	1.39	0.00	NO	0.83	IE	IE	0.53	0.02	1.32
2018	3.56	1.13	0.03	NO	0.67	IE	IE	0.59	0.02	1.12
2019	4.01	1.34	0.03	NO	0.85	IE	IE	0.70	0.02	1.07
2020	3.38	1.46	0.02	NO	0.75	IE	IE	0.49	0.04	0.62
2021	4.32	2.09	0.03	NO	0.76	IE	IE	0.40	0.04	1.00
2022	4.14	2.01	0.03	NO	0.69	IE	IE	0.51	0.04	0.87
Trend 1990-2022	-46.25%	8.36%	228.77%	NA	-67.62%	NA	NA	81.21%	-51.56%	-74.10%
2005-2022	-24.66%	21.76%	533.51%	NA	-52.58%	NA	NA	15.96%	-52.31%	-53.65%
2021-2022	-4.03%	-3.75%	-3.14%	NA	-9.65%	NA	NA	27.72%	-10.81%	-12.72%

From this data, the following implied emission factors (g NMVOC / kg product or substance) are obtained

2D3 - Solvent and Product Use										
Implied Emission Factors (g NMVOC / kg product or substance)										
Year	2D3 AVERAGE	2D3a Dometics solvent use including fungicides	2D3b Road paving with asphalt	2D3c Asphalt roofing	2D3d Coating applications	2D3e Degreasing	2D3f Dry cleaning	2D3g Chemical products	2D3h Printing	2D3i Other solvent use
1990	113.28	211.87	N/A	N/A	357.79	N/A	N/A	89.33	58.55	68.86
1991	113.26	211.87	N/A	N/A	357.79	N/A	N/A	89.33	58.55	68.86
1992	113.28	211.87	N/A	N/A	357.79	N/A	N/A	89.33	58.55	68.86
1993	113.25	211.87	N/A	N/A	357.79	N/A	N/A	89.33	58.55	68.86
1994	69.98	200.82	N/A	N/A	300.22	N/A	N/A	70.59	62.38	39.42
1995	79.21	192.22	N/A	N/A	279.41	N/A	N/A	68.87	61.12	47.46
1996	101.65	244.17	N/A	N/A	256.29	N/A	N/A	49.01	61.70	69.70
1997	83.50	190.53	N/A	N/A	257.67	N/A	N/A	45.73	57.31	58.41
1998	111.84	181.68	N/A	N/A	269.30	N/A	N/A	49.39	54.26	94.63
1999	69.72	166.17	N/A	N/A	236.72	N/A	N/A	43.58	59.84	44.81
2000	62.00	163.82	N/A	N/A	323.01	N/A	N/A	40.10	68.58	26.87
2001	75.16	163.15	N/A	N/A	377.63	N/A	N/A	34.80	65.43	33.06
2002	73.81	173.20	N/A	N/A	256.10	N/A	N/A	31.36	49.50	44.08
2003	65.51	165.70	N/A	N/A	245.87	N/A	N/A	28.76	47.95	37.37
2004	74.87	265.13	N/A	N/A	226.77	N/A	N/A	19.57	45.48	46.37
2005	69.63	279.02	N/A	N/A	192.72	N/A	N/A	17.56	43.04	48.46
2006	62.01	149.58	N/A	N/A	140.40	N/A	N/A	16.33	40.65	57.14
2007	55.59	136.13	N/A	N/A	155.87	N/A	N/A	16.10	49.18	47.24
2008	65.44	158.03	N/A	N/A	121.76	N/A	N/A	23.72	37.49	57.58
2009	73.47	195.29	N/A	N/A	110.85	N/A	N/A	20.06	36.53	60.60
2010	69.77	166.15	N/A	N/A	110.42	N/A	N/A	24.41	34.19	60.49
2011	51.76	165.39	N/A	N/A	85.50	N/A	N/A	17.19	30.88	42.83
2012	58.85	159.08	N/A	N/A	130.01	N/A	N/A	15.76	28.87	46.32
2013	51.91	141.66	N/A	N/A	105.52	N/A	N/A	13.79	27.41	46.51
2014	44.22	123.61	N/A	N/A	102.86	N/A	N/A	14.50	25.05	36.86
2015	42.79	133.09	N/A	N/A	90.03	N/A	N/A	11.73	22.60	41.03
2016	53.70	149.37	N/A	N/A	98.83	N/A	N/A	26.32	21.73	45.67
2017	44.13	140.36	N/A	N/A	96.99	N/A	N/A	11.13	21.13	51.16
2018	40.38	130.66	N/A	N/A	86.08	N/A	N/A	12.56	23.88	47.15
2019	41.54	141.62	N/A	N/A	116.50	N/A	N/A	15.03	23.28	33.02
2020	35.77	149.17	N/A	N/A	108.19	N/A	N/A	9.97	36.41	22.19
2021	40.24	194.56	N/A	N/A	89.02	N/A	N/A	7.65	33.26	28.69
2022	41.07	209.13	N/A	N/A	83.70	N/A	N/A	10.30	43.03	26.51
Trend 1990-2022	-63.74%	-1.29%	NA	NA	-76.61%	NA	NA	-88.47%	-26.50%	-61.50%
!005-2022	-41.02%	-25.05%	NA	NA	-56.57%	NA	NA	-41.37%	-0.03%	-45.28%
!021-2022	2.06%	7.49%	NA	NA	-5.99%	NA	NA	34.56%	29.38%	-7.59%

4.5.3.1.4.6 Calculation of CO_2 emissions from Solvent Emissions

The basis for the calculation of the carbon dioxide emissions were the quantities of solvent emissions differentiated by the 15 groups of substances (acetone, methanol, propanol, solvent naphtha, paraffins, alcohols, glycols, ester, aromates, ketones, aldehydes, amines, organic acids, cyclic hydrocarbons, and others). Substance specific carbon dioxide factors for these 15 substance groups have been created in Austria (see Table 4-22) on the basis of the carbon content and the stoichiometrically formed CO_2.

Table 4-22 - Substance specific carbon dioxide emission factors

Substances	CO_2 factor [kg CO_2/kg substance]	Substances	CO_2 factor [kg CO_2/kg substance]
Acetone	2.28	Glycols	1.82
Aldehydes	2.44	Ketones	2.45
Alcohols	1.91	Methanol	1.38
Alcohols/Propanols	2.20	Paraffins	3.14
Aromates	3.33	Residuals	0.92
Cydic Hydrocarbons	3.14	Solvent naphta	3.14
Ester	2.16	Glycols	1.82

In Austria the amount of carbon dioxide emissions was disaggregated to SNAP level 3 according to the share of solvents used and solvent emissions that were calculated in the context of the bottom up approach (as used in the Austrian Inventory Report). For the CO2 emissions resulting from NMVOC emissions in Luxembourg, an emission factor (t CO2 / t NMVOC) is calculated for each NFR category if emissions occure due to solvent use in Luxemoburg. The calculation is based on the average emission factor of the SNAP for each NFR category. The table below lists these emission factors

emission factors (t CO2 / t NMVOC)										
years		2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
1990		2.01	N/A	N/A	2.42	2.12	1.10	1.87	1.98	1.99
1991		2.06	N/A	N/A	2.30	1.99	1.18	1.78	1.88	1.95
1992		2.05	N/A	N/A	2.17	1.85	1.25	1.64	1.77	1.88
1993		2.03	N/A	N/A	2.04	1.70	1.29	1.66	1.66	1.82
1994		1.97	N/A	N/A	1.91	1.54	1.31	1.62	1.54	1.74
1995		1.97	N/A	N/A	1.88	1.44	1.38	1.75	1.49	1.73
1996		1.89	N/A	N/A	1.78	1.35	1.34	1.65	1.41	1.65
1997		1.94	N/A	N/A	1.81	1.36	1.39	1.75	1.43	1.68
1998		1.96	N/A	N/A	1.81	1.34	1.42	1.68	1.42	1.69
1999		1.96	N/A	N/A	1.80	1.31	1.44	1.63	1.40	1.69
2000		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2001		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2002		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2003		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2004		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2005		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2006		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2007		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2008		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2009		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2010		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2011		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2012		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2013		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2014		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2015		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2016		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2017		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2018		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2019		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2020		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2021		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71
2022		1.98	N/A	N/A	1.81	1.30	1.47	1.75	1.40	1.71

4.5.3.1.5 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 50%
- Emission factor uncertainty 50%

4.5.3.1.6 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.5) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

Source-specific elements of QA/QC for Solvent and Other Product Use include:

Input data and emission factors:

- check for the plausibility of the activity data and their trend and check for plausibility of the emission factors as well as the related input data and their trends
- check documentation of the most important reasons for changes and non-changes of activity data
- check if these changes or non-changes of activity data fit to trends of underlying conditions
- if checks do not allow any explanation, further check of the used statistics and their estimates and/or communication with the data providers
- check of input data for completeness
- Comparison of the used activity data with those from other statistics: STATEC publication and EUROSTAT database.
- Comparison of the used activity data with those from relevant plant operators and SMPs
-

Emissions:

- check the correctness of all equations in the calculation files
- check the correctness of all intermediate results
- check the plausibility of the results and their trends related to activity data and emission factors
- check the correctness of the transfer of all data and results
- Comparison of the used emission factors and underlying input data with those of other data sources (*e.g.* from literature, results in NIRs of other comparable regions, IPCC default values).

4.5.3.1.7 Category-specific recalculations including changes made in response to the review process

No recalculations were made.

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision

4.5.3.1.8 Category-specific planned improvements including those in response to the review process

A detailed revaluation of the solvent model is planned for the next submission to IPCC sub-category 2.D.3.1.

4.5.3.2 Road Paving with Asphalt (2D3b)

Previously, emissions from road paving with asphalt were reported in 1A2gviii, and have now been moved to 2.D.3.1. An overview of road paving with asphalt related NMVOC emissions is provided in the following table:

Road Paving with Asphalt			
year	Activity Data (kt) Asphalt produced	Emissions (t) NMVOC	Implied Emission Factors (kg NMVOC/t asphalt)
1990	608.880	0.009	15.000
1991	529.120	0.008	15.000
1992	583.052	0.009	15.000
1993	455.934	0.007	15.000
1994	864.349	0.013	15.000
1995	452.471	0.007	15.000
1996	684.634	0.010	15.000
1997	623.154	0.009	15.000
1998	555.976	0.008	15.000
1999	859.039	0.013	15.000
2000	827.880	0.012	15.000
2001	740.321	0.011	15.000
2002	722.684	0.011	15.000
2003	1200.022	0.018	15.000
2004	539.700	0.004	8.259
2005	560.490	0.005	8.457
2006	564.883	0.005	8.249
2007	630.567	0.005	7.211
2008	606.886	0.004	7.076
2009	688.418	0.003	4.197
2010	627.093	0.003	4.281
2011	783.181	0.005	5.836
2012	703.165	0.004	6.217
2013	607.814	0.004	6.208
2014	690.515	0.005	7.377
2015	607.760	0.004	6.832
2016	768.686	0.005	6.086
2017	685.024	0.005	6.639
2018	671.173	0.026	39.003
2019	642.210	0.028	43.426
2020	626.732	0.020	31.540
2021	711.414	0.031	44.214
2022	631.074	0.030	47.581
Trend 2021-2022	-11.29%	-4.54%	7.62%
2005-2022	12.59%	533.51%	462.66%
1990-2022	3.65%	228.77%	217.21%

As CO emissions are considered negligible (IPCC guidelines 2006, Volume 3 Industrial Processes and Product Use, 5.4 Asphalt Production And Use) they were not estimated.

4.5.3.3 Asphalt Roofing (2D3c)

This source category does not exist in Luxembourg.

5.1.1.1 Urea-based catalysts (2.D.3.2)

1.1.1.1.1 Source category description

In 2022, CO_2 emissions resulting from the use of urea-based catalysts in SCR-equipped vehicles was responsible for 2.06% of GHG emissions CO_2e from industrial processes and product use and for 0.13% of the total GHG emissions in CO_2e (excluding LULUCF). Compared to 2021, emissions decreased by 16.29% to reach 11.05 Gg CO_2 in 2022. An overview of the related CO_2 emissions is provided in Table 4-23.

Urea-based catalysts is not a key source with regard to CO_2 emissions.

Table 4-23 - CO_2 emissions trend, activity data and IEFs for IPCC sub-category 2.D.3.2 – Urea-based catalysts: 1990-2022

2D3 - Urea-based catalysts			
Year	**activity data (t)**	**CO_2 emissions (Gg)**	**implied emission factor (t CO_2/t)**
1990	NO	NO	*NA*
1991	NO	NO	*NA*
1992	NO	NO	*NA*
1993	NO	NO	*NA*
1994	NO	NO	*NA*
1995	NO	NO	*NA*
1996	NO	NO	*NA*
1997	NO	NO	*NA*
1998	NO	NO	*NA*
1999	NO	NO	*NA*
2000	NO	NO	*NA*
2001	NO	NO	*NA*
2002	NO	NO	*NA*
2003	NO	NO	*NA*
2004	NO	NO	*NA*
2005	4'888	1.16	*0.238*
2006	11'931	2.84	*0.238*
2007	20'481	4.88	*0.238*
2008	30'599	7.29	*0.238*
2009	31'462	7.50	*0.238*
2010	39'491	9.41	*0.238*
2011	43'892	10.46	*0.238*
2012	42'152	10.05	*0.238*
2013	44'436	10.59	*0.238*
2014	43'733	10.42	*0.238*
2015	42'223	10.06	*0.238*
2016	43'496	10.37	*0.238*
2017	48'748	11.62	*0.238*
2018	55'790	13.30	*0.238*
2019	61'605	14.68	*0.238*
2020	51'113	12.18	*0.238*
2021	55'366	13.20	*0.238*
2022	46'371	11.05	*0.238*
Trend 1990-2022	NA	NA	NA
Trend 2005-2022	126.41%	126.41%	0.00%
Trend 2021-2022	-16.25%	-16.25%	0.00%

Total sales volumes or import/export data for urea-based catalysts are not available for Luxembourg. Therefore the NEMO model (details in Chapter 3.2.9.3.2.2) was used to estimate the consumption of AdBlue® by SCR-equipped vehicles (domestic and transiting/commuting fleet). Urea-based catalysts have been consumed by heavy duty vehicles since 2005 (EURO IV and higher) and since 2013 also by passenger cars (EURO 6).

1.1.1.1.1.1 Methodology

CO_2 emissions from urea-based catalysts used in SCR-equipped vehicles are calculated separately by the NEMO model (described in chapter 3.2.9.3.2.2.). This approach considers the specific operating condition of the SCR exhaust gas after-treatment system in any driving condition[96]. The calculation is based on the assumption that one mole of urea generates one mole of CO_2 and converts 0.9 mole of NO_x as illustrated by Equation 4-1.

Equation 4-1: Formula used by the NEMO model to determine CO_2 emissions from the use of AdBlue® in SCR-equipped vehicles.

$$\mathbf{CO_2}\,[g] = \frac{(\mathbf{NO_{x,EO}} - \mathbf{NO_{x,TP}})[g]}{\underbrace{46\left[\frac{g}{mol}\right]}_{\text{molar mass } NO_2}} \cdot \left(\frac{1}{1 - \mathbf{s_{NH3,loss}}}\right) \underbrace{\frac{1}{2}}_{CO_2\,/\,NH_3 \text{ mole ratio}} \underbrace{44\left[\frac{g}{mol}\right]}_{\text{molar mass } CO_2}$$

With:

$NO_{x,EO}$: NO_x emissions (in NO_2 mass equivalent) at engine out

$NO_{x,TP}$: NO_x emissions (in NO_2 mass equivalent) at tailpipe

$s_{NH3,loss}$: share of NH_3 losses caused by NH_3 slip through SCR catalyst without NO_x conversion and by NH_3 not generated from urea. The value used for $s_{NH3,loss}$ is 10% (expert judgment by IVT Graz).

1.1.1.1.1.2 Emission factors

The CO_2 implied emission factor for urea-based catalysts is 0.238 t/t for the entire timeseries. This is equivalent to the default emission factor proposed in the IPCC guidelines[97].

1.1.1.1.2 Uncertainties and time-series consistency

The uncertainty for activity data is estimated to be +/−20% (expert judgement by TU Graz, 2015). The timeseries is considered to be consistent.

1.1.1.1.3 Source-specific QA/QC and verification

There are no statistical recordings of activity data for AdBlue®.

The emission factor used by the NEMO model was compared to the default value proposed in the IPCC guidelines.

96 Rexeis M., Schwingshackl M., Dippold M., Hausberger S.: Emissionen aus Kalt- und Kühlstarts sowie aus AdBlue-Verwendung in SCR-Katalysatoren von Lkw, LNF, 2-Rädern sowie von mobilen Maschinen. Erstellt im Auftrag des Umweltbundesamtes GmbH. Bericht Nr.: I-24/201313/Rex Em 11/2013-679 vom 16.9.2013

97 2006 IPCC Guidelines, Volume 2, Chapter 3, p. 3.12

1.1.1.1.4 Category-specific recalculations including changes made in response to the review process

An error has been corrected. As such the emission values from 2005 to 2021 changed. The variations are given in the following table:

2.D.3.2 Urea-based catalysts			
year	submission 2023 (Gg CO2 e)	submission 2024 (Gg CO2 e)	variation(%)
2005	1.1578	1.164952743	0.6155%
2006	2.8220	2.843527727	0.7628%
2007	4.8541	4.881316347	0.5599%
2008	7.2330	7.292800485	0.8270%
2009	7.4322	7.498504887	0.8915%
2010	9.3347	9.411958626	0.8280%
2011	10.3791	10.4608214	0.7872%
2012	9.9590	10.04617591	0.8755%
2013	10.5021	10.5905439	0.8421%
2014	10.33248917	10.42309388	0.8769%
2015	9.982429582	10.06303799	0.8075%
2016	10.26429254	10.36648331	0.9956%
2017	11.49649234	11.61823045	1.0589%
2018	13.17095588	13.29655121	0.9536%
2019	14.64497588	14.68261336	0.2570%
2020	12.07774772	12.18202706	0.8634%
2021	13.04924398	13.1956291	1.1218%

1.1.1.1.5 Category-specific planned improvements including those in response to the review process

There are currently no planned improvements to IPCC sub-category 2.D.3.2.

4.6 Electronics industry (2.E)

4.6.1 Integrated circuit or semiconductor (2.E.1)

This source category does not exist in Luxembourg.

4.6.2 TFT flat panel display (2.E.2)

This source category does not exist in Luxembourg.

4.6.3 Photovoltaics (2.E.3)

This source category does not exist in Luxembourg.

4.6.4 Heat transfer fluid (2.E.4)

This source category does not exist in Luxembourg.

4.6.5 Other (as specified in table 2(II)) (2.E.5)

4.7 Product uses as substitutes for ODS (2.F)

Consumption of Halocarbons and SF_6 (2F)

The following sources have been identified:

- Refrigeration and air-conditioning (2.F.1)
    - Commercial refrigeration
    - Domestic refrigeration
    - Industrial refrigeration
    - Transport refrigeration
    - Mobile air-conditioning
    - Stationary air-conditioning
- Foam blowing agents (2.F.2)
    - Closed cells
    - Open cells
- Fire protection (2.F.3)
- Aerosols (2.F.4)
    - Metered dose inhalers
    - Other (please specify - one row per substance)
- Solvents (2.F.5)
- Other applications(9) (2.F.6)
    - Emissive
    - Contained

4.7.1 Source category description

This section describes the estimation of products uses as substitutes for ODS resulting from industrial processes (production, consumption). In 2022, this category represented 7.34% of the GHG emissions in CO_2e from industrial processes and 0.48% of the total GHG emissions in CO_2e (excluding LULUCF). This percentage was only 1.38% in 1995. As shown in Figure 4-8, the related emissions experienced an increase between 1995 and 2022 (+184.50%). Compared to 2021, emissions decreased by 2.98 % to attain the level of 39.29 Gg CO_2 in 2022. This reduction is mainly due to the Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. The regulation restricts and banes the usage of various F-gases popularly used in stationary refrigeration and air conditioning, as such the amount of F-gases on the market was reduced and prices increased strongly. The impact of these restrictions becomes visible in 2014 and 2015, which show increases due to stock increasment and system refillments being done before the entry into force of the restirctions. These is followed by a decline. Both observations are corroborate with the general observations made by the European Environmental Agency in their F-gas report No 20/2017. The decrease will gradually continue as suppliers are in possession of ample stocks and prices continue to increase. Furthermore, the Directive 2006/40/EC of the European parliament and of the council of 17 May 2006 prohibites new passenger vehicles to use air-conditioning system designed to contain fluorinated greenhouse gases with a global warming potential higher than 150. As such, most manufactures have switched from R134a (GWP=1300) to R1234yf (GWP=4), and as mobile air condition from passenger vehicles represents the biggest source of emissions in 2.F, a decline in emissions can be observed starting in the year 2016.

F-gas emission estimates are presented in Table 4-24.

Figure 4-8 – GHG emission trends for CRF Sector 2F – HFCs: 1990-2022

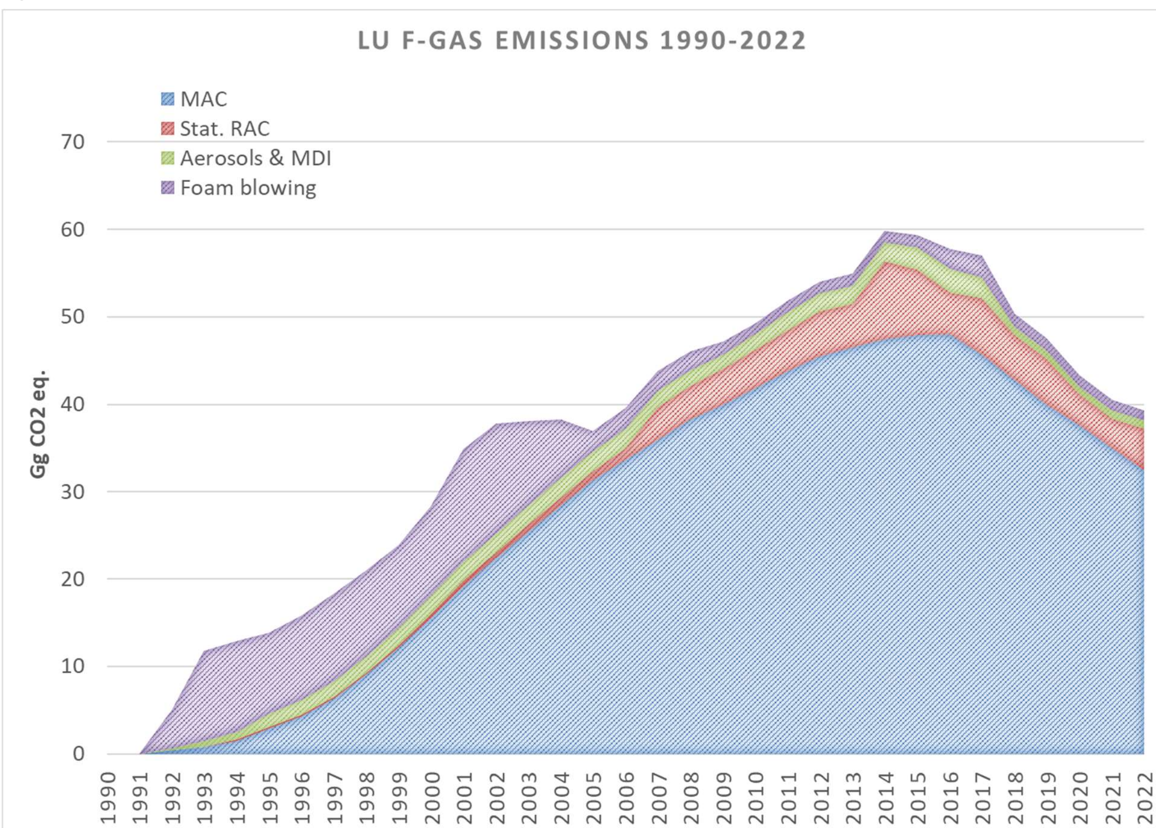


Table 4-24 – Estimated emissions of HFCs: 1990-2022

Year	2F -Product uses as substitutes for ODS	2F1 - Refrigeration and Air Conditioning Equipment (HFC)	2F1 - Stationary refrigeration and air conditioning	2F1 - Mobile refrigeration and air conditioning	2F2 - Foam Blowing (HFC)	2 F4 - Aerosols/ Metered Dose Inhalers (HFC)
	Gg CO_2 e					
1990	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00
1992	4.99	0.43	0.02	0.41	4.36	0.21
1993	11.76	0.82	0.03	0.79	10.31	0.63
1994	12.91	1.61	0.15	1.46	10.41	0.90
1995	13.81	3.02	0.17	2.85	9.29	1.50
1996	15.80	4.50	0.21	4.29	9.66	1.64
1997	18.31	6.54	0.23	6.31	10.02	1.75
1998	20.92	9.25	0.26	9.00	9.81	1.86
1999	23.89	12.45	0.36	12.09	9.48	1.96
2000	28.33	15.94	0.41	15.52	10.33	2.06
2001	34.86	19.79	0.62	19.17	12.92	2.15
2002	37.84	23.07	0.67	22.39	12.59	2.19
2003	38.09	26.24	0.84	25.40	9.61	2.24
2004	38.26	29.39	0.92	28.46	6.69	2.19
2005	36.95	32.36	1.05	31.31	2.36	2.24
2006	39.61	35.03	1.32	33.71	2.35	2.23
2007	43.77	39.65	3.72	35.93	2.19	1.93
2008	46.09	42.14	3.91	38.23	2.20	1.75
2009	47.16	44.10	4.16	39.94	1.48	1.58
2010	49.25	46.26	4.42	41.85	1.20	1.79
2011	51.87	48.51	4.70	43.81	1.29	2.07
2012	54.03	50.66	5.22	45.44	1.36	2.02
2013	54.91	51.44	4.94	46.50	1.33	2.13
2014	59.83	56.35	8.86	47.49	1.37	2.11
2015	59.38	55.37	7.47	47.90	1.46	2.55
2016	57.76	52.77	4.72	48.05	2.28	2.72
2017	57.00	52.09	6.43	45.66	2.54	2.37
2018	50.37	47.93	5.17	42.76	1.49	0.94
2019	47.56	45.21	5.27	39.94	1.41	0.94
2020	43.30	41.16	3.59	37.57	1.27	0.87
2021	40.50	38.41	3.45	34.96	1.21	0.89
2022	39.29	37.27	4.78	32.49	1.12	0.91
Trend 1995-2022	185%	1134%	2683%	1040%	-88%	-40%
Trend 2021-2022	-2.98%	-2.97%	38.59%	-7.07%	-7.09%	2.04%

Source: Environment Agency

2F1 – Refrigeration and air conditioning is not a key source.

Finally, although Luxembourg now reports emissions from 1990 onwards, it should be highlighted that 1995 was chosen as the base year for HFCs.

4.7.1.1 Methodology

The emissions of fluorinated greenhouse gases in Luxembourg were thoroughly re-assessed in 2014 in order to assure compliance with the 2006 IPCC reporting guidelines, to streamline data acquisition and processing, to include previously neglected applications and sub-applications, and to increase transparency of emissions estimations.

Generally speaking, the estimations of emissions in Luxembourg are based onemission-factor approaches. Due to highly incomplete records of chemical sales data (Econotec consultants 2010, importers inquiry 2014), mass-balance approaches are mostly inapplicable. Emission factors are predominantly derived from regional to global estimates. In some cases, it was possible to calculate country-specific emission factors. Activity data consisted in direct emission records (e.g. refrigeration manufacturing, industrial and commercial refrigeration), country-specific life-cycle approach data (e.g. mobile air conditioning) or, in the absence of country-specific records, regionally derived data (e.g. aerosols).For the first time, emissions from fluorinated ethers used as anaesthetics are estimated for Luxembourg as complementary information. Note, however, that fluorinated ethers are not among the mandatory sources of greenhouse gas emissions to be reported under the 2006 IPCC Reporting Guidelines, and were thus excluded from Luxembourg halocarbon and SF_6 emissions compilations. In the medical applications considered here, fluorinated ethers are completely emitted after use. Thus, consumption of fluorinated ethers was considered equal to emission. The used Tier method for each application is given in the following table:

Application sub-application subdivision **Sub-application** **Subdivision**	**Method**
Refrigeration and air conditioning	Tier2a/3
Mobile air conditioning (MAC)	Tier 2a
Car MACs	Tier 2a
Bus and coach MACs	Tier 2a
Truck MACs	Tier 2a
Tractor and engine MACs	Tier 2a
Rail vehicle MACs	Tier 2a
Refrigerated transport	Tier 2a
Stationary refrigeration and air conditioning	Tier 2a/3
Fridge production	Tier 2a
Commercial and industrial refrigeration	Tier 2a/3
Residential and commercial air conditioning	Tier 2a/3
Aerosols	Tier 2a
Metered dose inhalers (MDI)	Tier 2a
Other aerosols	Tier 2a
Foam blowing	Tier 1
Electrical switchgear	Tier2a
Particleaccelerator	Tier 1
Manufacture solvents	Tier 3
Soundproof windows	Tier 2a

4.7.1.1.1 Refrigeration and air-conditioning (2.F.1)

The following sub-applications have been identified:

- Fridge production
- Commercial and industrial refrigeration
- Stationary air conditioning
- Refrigerated transport
- Mobile air conditioning:
  - cars
  - buses
  - trucks
  - trains
  - agricultural and construction engines

Domestic refrigeration plays no significant role here. In fact, , the share of domestic fridges containing fluorinated greenhouse gases has been very low in Luxembourg since 1995, and considering an average refrigerant charge of 0,1 kg and an operation emission factor of 0,3% (Schwarz 2005), emissions from the domestic refrigeration sub-application are, indeed, negligible and therefore omitted here.

Fridge production: A single fridge production plant, run by Dometic S.à.r.l., is currently being exploited in Luxembourg. The equipment produced is predominantly used for medical and other non-domestic purposes. Almost the entire production (99.5%) is exported. Thus, the only relevant emissions to be considered are those occurring during manufacture.

On the basis of a six month emissions survey by Dometic in 2006, a manufacture emission of 2 kg of R134a was calculated for 2006. The manufacture emission factor was reinvestigated with the producer in 2018, after which it was determined to be equal to the value of 2006, thus amounting to 2kg, based on the activity data. The resulting manufacture emissions factor was extrapolated to the years before and after 2006. Discussions with the frdidge manufacturer revealed that an additional source of emission are accidental releases, which for 2017, as an example, amounted to a total of 1.4kg, as measured by the manufacturer. These emissions are accounted for in the total emission resulting from fridge production. The manufacturer employs a recovery system that is based on leak detectors. As such the fill and storage facilities are equipped with such detectors that depending on the measured concentration of the f- gas in questions activates a ventiallation system that sucks out and recovers the emitted gases. The previously described accidental emissions are not covered by the recovery systems.

Commercial and industrial refrigeration: As part of the obligations introduced by Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases, leak checks are to be performed regularly for all equipment containing at least 3 kg of fluorinated greenhouse gases (The regulation No 842/2006 has meanwhile been replaced by the regulation 517/2014, which continues to impose leak checks). Luxembourgian legislation requires the reports of the leak checks to be transmitted to the authorities at the Luxembourg Environmental Agency. Since almost all non-domestic refrigeration and air conditioning devices contain more than 3 kg of refrigerant, the leak tightness reports contribute to an extensive database covering almost the entire sector. This database was used as a basis for the emissions estimations. In order to account for the refrigeration devices containing less than 3 kg of refrigerant and thus not covered by the leak detection database, all emission values were increased by 10%, which was assumed to adequately represent the share of the devices in question taking into account their low individual charges.

Given the nature of the information provided by the leak detection reports, stand-alone commercial refrigeration, medium and large commercial refrigeration and industrial refrigeration were lumped as commercial and industrial refrigeration.

In previous years, the record of leak detection reports was too patchy to be used as source of evidence. Significant efforts were made since to achieve a more thorough enforcement of the reporting obligation, with the result that a much more complete database is available. In order to test for the exhaustiveness of the reports, the retail refrigeration sector was chosen as a model system. In fact, the number of supermarkets and retail stores can be easily monitored, in contrast to the number of buildings equipped with air conditioning for example. Comparison with the leak detection coverage of the retail sector then provides an estimation of the database completeness.

A total of 65,8% of the retail sector existing at the end of 2013 (except for small shops at service stations which mostly lack devices containing more than 3 kg of refrigerant) are covered by a leak detection report for 2013. Subtracting supermarkets equipped with refrigeration devices exclusively using natural refrigerants, accounting for an estimated 18% of the Luxembourgian retail sector, a completeness of 72% can be assumed. The remaining 28% are extrapolated in the present emissions estimations. The 72% completeness quota is extended to all other refrigeration and air conditioning sub-applications covered by the leak inspection database, provided that the retail sector is representative in terms of reports exhaustiveness. Completeness has been revaluated for the years 2014 (80%), 2015 (89%), 2016 (95%) and 2017 (100%).

Assuming a life span of 20 years per device (Schwarz 2005), the evolution of the refrigeration equipment population could be approximated rather faithfully. All equipment constructed before 1993 is assumed to have been converted to hydrofluorocarbon (HFC) refrigerants in 1993 (which approximates the time of introduction of the HFCs as alternatives to the ozone depleting refrigerants), and the respective HFC charges to have entered the population in 1993. The charges of the devices for which the leak inspection reports provided no year of construction were totalled, divided by the number of years since the first appearance of the respective refrigerant in the Luxembourgian refrigeration population and added to the charges of the years in question. These measures are deemed temporary awaiting improvement of the reporting accuracy.

The non-domestic refrigeration sector presents an overwhelming span of refrigerant charges, ranging from a few kilograms to more than half a metric ton. Thanks to the leak inspection reports which indicate the charge of the device checked, the total amount of refrigerant being used in a particular year can be directly monitored rather than approximated on the basis of average refrigerant charges. In combination with the year of manufacture as indicated by the tightness reports and an assumed 20 years life span, the total amount of refrigerant entering the Luxembourgian refrigeration device population per year can be directly monitored as well.

Leak inspection reporting precisely indicates the amount of refrigerant emitted per device. As a result, operation emissions could be directly monitored rather than implied through application of an emission factor, at least since 2012 when the database attained satisfying completeness. On the basis of the total amount of refrigerant used per year and the total amount of refrigerant emitted during operation in the same year, implied emission factor were calculated for individual refrigerants and applied to the respective pre-2012 stocks.

Emissions during manufacture and decommissioning: Most of the non-domestic refrigeration devices are assembled (or at least filled with refrigerant for the first time) and decommissioned in Luxembourg.

Unfortunately, the leak inspection reports provide no insights on emissions during manufacture and decommissioning. In line with the default emission factors of the 2006 IPCC reporting guidelines for developed countries, and assuming a conservative 100 % rate of manufacture and decommissioning of equipment in Luxembourg, a manufacture emission factor of 0,5 % and a decommissioning emission factor of 30 % were adopted based on the opinion of representatives from a Luxembourgish formation center for refrigeration/air conditioning technicians and representatives of the two biggest companies in the sector. Furthermore, decommissioned domestic equipment is exported to neighbouring countries, as such a part of the decommissioning process does not take place in Luxembourg..

Stationary air conditioning: Since data on residential and commercial air conditioning are extracted from the same leak inspection database as the data on commercial and industrial refrigeration, the approaches employed were the same. In line with the default emission factors of the 2006 IPCC reporting guidelines for developed countries, and following an analysis by various experts from the field, representatives from a Luxembourgish formation center for refrigeration/air conditioning technicians and representatives of the two biggest companies in the sector, a manufacture emission factor of 0,2 % and a decommissioning emission factor of 20 % were adopted. Furthermore, a part of the decommissioned equipment is exported to neighbouring countries, as such a part of the decommissioning process does not take place in Luxembourg. For 2012 to 2013 a decrease from 1078.74t to 782.70t is observed for stationary air conditioning (2.F.1.f), this deacrease is linked to reduced amounts of operating emissions linked to R134a. As such, among other yearly variations, half the amount of gas was refilled during 2013 (103.24 kg) in comparison to 2012 (208 kg). Such amounts might not play a big role in larger countires, but in Luxembourg where the amount of large air conditioning system is comparatively small, the refilling , addition or decommissioning of few such systems during one year can visibly impact the yearly values of such a subsector.

Refrigerated transport (RT): As a result of the recent re-assessment of fluorinated greenhouse gas emissions, annual registration figures of RT vehicles for the years 1995-2016 were acquired. No data exist for the years 1990-1994, as such the data was extrapolated based on the data of the years 1995-2014. The here-employed approach is based on the weight-class-specific characteristics used by Schwarz (2005) for the German model combined with Luxembourg-specific registration figures and the relative shares of the weight classes. In order to comply with this model, relative shares of weight classes in the Luxembourgian general truck and van population were applied to annual RT vehicle registrations data. The average life span of a RT vehicle is assumed to equal seven years.

Manufacture and decommissioning of RT equipment does occur in Luxembourg but at a very low level compared to importations and exportations (Carrosserie Comes & Cie 2014). Corresponding emissions are thus considered negligible.

Evolution of the RT vehicle population: are undifferentiated in terms of weight class. by Schwarz (2005), who subdivided German RT vehicles into the classes < 2 - 5 t, 5 - 9 t, 9 - 22 t and > 22 t,. These shares are assumed to approximate the composition of the Luxembourgian RT vehicle population. As for the truck MAC model,

Refrigerant type and average charge per RT vehicle: Schwarz (2005) elaborated a model taking into account the average charge per vehicle for each weight class and the respective shares of the predominantly used refrigerants (R134a, R404A and, since 1997, R410A):

Refrigerant type, average charge and share in RT equipment for the different weight classes

Weight class	< 2 - 5 t	5 - 9 t		9 - 22 t			> 22 t		
Refrigerant	134a	134a	404A	134a	404A	410A	410A	134a	404A

Average charge (kg)	2,0	2,5	2,5	5	4	4	9	6,75	6,75
Share	100 %	50 %	50 %	10 %	10 %	80 %	10 %	5 %	85 %

Since no country-specific data in this respect were available and since there was no reason to assume that the Luxembourgian situation significantly deviates from the German one, the model by Schwarz (2005) was applied to the Luxembourgian RT vehicle population.

Given the exclusively commercial use of RT vehicles and the often highly temperature-sensitive freight, thorough and regular technical maintenance is assumed, implying a 100 % filling level. RT vehicles were assumed to leave the population with a filling of 85 %, in line with the annual loss through operation emission of 15 % (Schwarz 2005).

Mobile air conditioning (MAC):

Car MACs: In spite of relatively low average refrigerant charges (generally less than 1 kg), car MACs count among the most important sources of fluorinated greenhouse gas emissions. Luxembourg is no exception in this respect, considering its large and comparatively modern and thus well-equipped car population. A noteworthy particularity, however, is the lack of car manufacture and decommissioning facilities. All new cars are imported and almost all used cars are exported before scrapping. As a result, the only emissions to take into account for the Luxembourg car MAC sector are operation emissions.

The number of newly entering cars is provided as the number of new registrations by the STATEC records. The mean lifespan of a car in Luxembourg was found to be approximately 7 years by Econotec consultants (2010). Given the similarity between the Luxembourgian and the German car populations, the evolution of the MAC share suggested by Schwarz and Fischer (2009) is adopted here and considered to have reached saturation at 96% since 2005.

Schwarz (1996, 2005) traced a continuous decrease in the average refrigerant charge per car between 1992 until 2002, as a result of an increasing number of smaller cars being equipped with MAC but also a as a result of technical progress. For the trend beyond 2002, the data provided by Clodic (2006) was used and extrapolated. Here, advantage is taken of the brand-specific STATEC record of new registrations for the years 2005 until 2012, combined with the Behr Hella Service GmbH (2012) record of refrigerant charges per car model. Individual charges were averaged per brand, considering the models manufactured between 2005 and 2012. The average refrigerant charge per brand was then used in combination with the share of the individual brands in the Luxembourgian car population to calculate the average refrigerant charge per car of the Luxembourgian population for each year from 2005 to 2012.

The country specific results document a slight decrease from 654 g per car in 2005 to 647 g in 2009, followed by a slight increase to 652 g per car in 2012. These values are well in line with the trend from 1992 to 2002 (Schwarz 1996, 2005) and a population with a high share of large, high-capacity cars. Unless significant shifts in the brand-specific composition of the population occur, the 2012 value of 652 g per car was here considered to hold true for 2013, at least preliminarily (see below).

During the first two years following manufacture, annual refilling of car ACs was assumed for guarantee service reasons. During the following years, car ACs were assumed to be only refilled when considered necessary, i.e. upon tangibly reduced performance. As shown by Clodic (2006), car AC performance only drops after the loss of approximately half of the refrigerant. With an annual regular emission rate of 8,8 % (see below), and a mean life span of seven years, cars in Luxembourg can be assumed to be exported before refilling after the two years guarantee is deemed necessary. In order to take this refilling pattern into account, an average filling level of 81 % is assumed, resulting from two years of 100 % filling, followed by five years of continuous loss without refilling. For the same reason, cars leaving the population after seven years are assumed to contain 59 % of the original refrigerant charge.

Schwarz (2007) used an operation emission factor of 10 %, resulting from an empirically determined factor of 8,8 % for intact ACs taking into account leakage from defective systems. Since there is no reason to assume that the Luxembourgian car population significantly differs from the car population used to determine the operation emission factor, the 10 % value is adopted here.

As a result of the EU MAC Directive (Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles and amending Council Directive 70/156/EEC) banning refrigerants with a GWP exceeding 150 for ACs of newly registered car types, with a temporary exemption until 31 December 2012 (European Commission 2012), 5 % of all newly registered cars with an AC in 2013 were assumed to use a refrigerant other than R134a (such as R1234yf) and were thus excluded from the emissions estimations. The 5 % assumption results from expert judgment implying an average 10 years life span of a car type and taking into account the resilience of certain car manufacturers to abandon R134a. This population was estimated to have increased over time as such values correspond to 15% for 2014, 25% for 2015, 55% for 2016, 94% for 2017 and, staring in 2018, 100%.

Bus and coach MACs: Emissions estimations for bus and coach MACs are basically similar to those of car MACs, with a few exceptions. As for cars, no manufacturing or decommissioning activities take place in Luxembourg. Accordingly, no manufacturing or decommissioning emissions are to be taken into account. The average life span of buses and coaches in Luxembourg was found to evolve around 7 years, as suggested by expert judgment from bus company representatives.

The bus operating companies furthermore confirmed that the vast majority of buses and coaches operated since 1995 have been equipped with MAC. One operator reached the 100 % MAC quota for his bus population in 1997, starting with 25 % in 1995, and a second one had no bus with MAC in 1995, reaching the 100 % quota only in 2007. As a result, a MAC quota of 70 % is assumed for the Luxembourg bus and coach population in 1995, increasing to 80 % in 1997 and then gradually increasing to 100 % in 2007. In order to account for the rise of R134a since its introduction in the bus MAC domain in 1993 (Schwarz 2005), an extrapolated quota evolution of 0 % in 1992, 30 % in 1993 and 70% in 1994 was adopted.

Bus and coach MACs contain much higher amounts of refrigerant than car MACs, owing to the much longer pipes. Individual charges, however, vary considerably, depending on the size and the type of the bus. Minibuses generally contain around 2 kg of refrigerant per vehicle, while the large high standard coaches require 15 kg of refrigerant. According to the information provided by the bus companies in Luxembourg, however, even within the same type of standard 14 m coach, charges range from 4,9 kg to 15 kg per vehicle, depending on technical specificities. Buses with separate conductor air conditioning for example generally contain more refrigerant.

In order to account for the high diversity of refrigerant charges per vehicle, an average value of 10 kg is adopted here, in line with the estimated average provided by the bus companies. Minibuses were assumed to range among the bus and coach figures rather than the car estimations. Although this is likely to result in overestimated emission values, a conservative approach is warranted in the absence of a more type-specific bus and coach population survey.

According to the bus company representatives, MACs of buses and coaches are generally refilled every year. In some cases, annual refilling is even part of maintenance obligations imposed by the manufacturers. This implies a 100 % filling level from registration to removal from service. Buses are assumed to leave the population with a 86 % filling level, in line with an annual loss of 14 %.

Figures of refrigerant consumption for maintenance provided by the bus companies suggest annual operation emission factors between 10 and 14 %. Ökorecherche (2007) found operation emission rates of 15 % for older buses and 13,7 % for younger ones (registered after 2000). An emission factor of 14 % is therefore adopted here to account for both the published figures and the empirical data provided by operators.

Truck MACs: Truck MACs follow the same principles of emissions estimations as car and bus/coach MACs. Again, only operation emissions are relevant in the case of Luxembourg. Estimations were based on a subdivision in three weight classes (vans, small trucks, large trucks) with individual MAC quota, refrigerant charge and operation emission factor figures respectively, following the model employed by Schwarz (2005).

Data on new weight-class specific truck registrations are extracted from the STATEC database. For the years since 1997, registration figures are subdivided into several weight classes. For the years before 1997, the trend of the relative shares in new registrations of the three weight classes of Schwarz (2005) is extrapolated to the weight-unspecific truck and van registrations of the respective years. In the absence of specific data, an average life span of seven years is assumed for trucks, in analogy to the car and bus/coach models.

Schwarz (2005) provided MAC quota figures for all three truck weight classes in Germany for the years 1993-2002. For the large trucks, the trend seems to meaningfully reflect the situation in Luxembourg and is therefore applied here in the absence of country-specific data. MAC quota figures after 2002 are extrapolated to attain a hypothetical saturation value of 90 % in 2005.

Since the equipment standard of the Luxembourgian vehicle population is generally above the European average, MAC quota figures for smaller trucks and vans provided by Schwarz (2005) seem too low. Country-specific data could not be collected because the presence or absence of a MAC is not recorded upon registration (SNCT pers. comm.). It was assumed that the MAC quota evolution of smaller trucks in Luxembourg was best reflected by that of the larger trucks. In the case of the vans, in contrast, the same trend as for cars was assumed.

According to Schwarz (2005), refrigerant charges have remained at constant values of 1 kg for small trucks and 1,2 kg for large trucks since 1993. Van MACs, in contrast, have undergone a decrease in refrigerant charge from 1,2 kg in 1993 to 0,85 kg in 2002. In line with the Behr Hella Service GmbH (2012) refrigerant charge data for various vehicle types, a further decrease to 0,8 kg per van by 2013 was adopted. Intermediate values between 2002 and 2013 were interpolated. A truck is assumed to leave the population with an average filling level of 86,5 %, in line with a combined average operation emission factor of 13,5 %.

Due to the predominantly commercial use of trucks, a more thorough and regular technical maintenance than for cars was assumed, resulting in an annual refilling of MACs and thus an effective charge of 100%, except for the last year before leaving the population.

Again, in the absence of country-specific data on refrigerant loss during operation, the emission factors determined by Schwarz (2005) on the basis of a survey on the German truck population were adopted. Vans were assumed to have the same operation emission factor as cars (10 %), as a result of technical similarity. Truck MACs, in contrast, are confronted with longer operation times and higher mechanical stress, and are thus assigned an emission factor of 15 %.

Tractor and engine MACs: Emissions estimations for MACs of tractors and engines (e.g. harvesters) are basically similar to those of truck MACs, with two different categories (tractors and engines) each with individual MAC quotas, refrigerant charges and emission factors. A similar approach to that of truck MACs, including calculation of combined variables, is therefore proposed.

All data on newly registered tractors and engines are extracted from the STATEC database. In the absence of specific data, an average life span of seven years is assumed for tractors and engines, in analogy to the car and bus/coach models.

Data on MAC quota were adopted from Schwarz (2005), who found a very steep rise since the introduction of R134a in the MAC sector to 75 % in 1994 and eventually 95 % in 2002 for engines, and a more gentle and gradual rise to 70 % in 2002 for tractors. These trends were assumed to hold true for the Luxembourgian tractor and engine populations, with pre-1994 data extrapolated to 0 % in 1992 in line with an introduction of R134a as standard MAC refrigerant in 1993 (Schwarz 2005), and post-2002 data assumed constant at 95 % for engines and extrapolated to reach 95 % in 2005 for tractors.

The average refrigerant charges of 1,44 kg per tractor and 1,6 kg per engine provided by Schwarz (2005) were adopted in the absence of country-specific data. Due to the largely commercial use of tractors and engines and the strong seasonal concentration of operation time, technical maintenance was assumed to be more thorough and regular than for cars, resulting in an annual refrigerant refilling and thus a 100 % filling level. Tractors and engines were assumed to leave the population with a filling level of 83 %, in line with an average operation emission factor of 17 % for the combined tractor and engine sector.

No country-specific data on operation emission factors were available, which is why the figures for the German tractor and engine populations provided by Schwarz (2005) (15 % for tractors and 25 % for engines) were adopted.

Rail vehicle MACs: Detailed annual data on rail vehicles with MAC entering and leaving the population, indicating individual refrigerant charges, were provided by the sole national railway operator as well as Luxtram

It is assumed that all rail vehicles are subject to regular technical maintenance and thus refilled at least annually, implying a filling level of 100 %.

No construction or dismantling of rail vehicles takes place in Luxembourg. As a result, only emissions during operation are relevant. No country-specific data were available for operation emission factors. Schwarz (2005) used 15 % for German rail vehicles. Since there was no reason to assume a different operation emission factor for Luxembourgian rail vehicles, the 15 % value is adopted.

4.7.1.1.2 Foam blowing agents (2.F.2)

In spite of significant efforts to collect country-specific data, no improvement in the estimation of fluorinated greenhouse gas emissions related to foam blowing could be achieved. In fact, in the absence of a local producer, sales data are the most promising source of data but have remained unavailable by the end of the last re-assessment of emissions estimations. Waste treatment data, including an analysis of household garbage to search for erroneously disposed polyurethane (PU) cans, resulted in unrealistically low consumption figures for PU cans (approximately half the figures of the neighbouring countries). Therefore, as in the previous reports, the PU spray emissions (HFC 134a, HFC 152a) and the extruded polystyrene (XPS) emissions (HFC 134a) are estimated using the reported quantities used per habitant and year in Belgium, Germany as well as France, and their average HFC content, expressed per capita with the relative population in Luxembourg. The aformenetined 3 countires are neigbouring Luxembourg and as the socioeconomical situation of the the 4 countires are similar it is assumed that this approach is best suited to estimate the emissions related to 2.F.2.

4.7.1.1.3 1.8.1.1. Fire extinguisher (2.F.3)

This source category does not exist in Luxembourg.

4.7.1.1.4 Aerosols (2.F.4)

Metered Dose Inhalers (MDI)

Emissions from MDIs were estimated on the basis of country specific data provided by IMS Health for the years 2001 to 2005, indicating the number of doses sold in Luxembourgian pharmacies. The share of doses sold in hospitals was assumed to amount to 5 %, in line with Belgian hospital sales. It was furthermore assumed that R134a was the only fluorinated greenhouse gas used in MDIs sold in Luxembourg, and that each dose contained 75 mg of R134a. For the years before 2001, a gradual ingression of R134a-using MDIs, from the first appearance in 1996 onwards, was assumed, in line with the German MDI evolution (Schwarz 2005). In order to estimate the total number of MDIs sold before 2001 and after 2005 (the period covered by IMS Health data), per capita MDI dose sales for 2001 and 2005 were extrapolated to the pre-2001 and the post-2005 years respectively on the basis of the population evolution. This approach admittedly neglected possible effects of dry powder injection (DPI) as an alternative to MDIs, and of population-independent variations in the number of asthmatic patients. In the absence of robust evidence, however, these factors could not be accounted for in the here-employed model.

In line with the 2006 IPCC reporting guidelines, emissions of MDIs sold in year x are assumed to be emitted at 50 % in the course of year x and at 50 % in the course of the following year x+1.

Other aerosols

No country-specific data on emissions from aerosols other than MDIs could be collected owing to the absence of aerosol manufacturing plants and the unavailability of importation data. As a result, the German per capita aerosol emissions were applied to Luxembourg.

4.7.1.1.5 Solvents (2.F.5)

This source category does not exist in Luxembourg.

4.7.1.2 Uncertainties and time-series consistency

The uncertainties estimated for activity data and emission factors for the different sub-categories are presented in table xx.

Sub-category	AD uncertainty	Explanation/source	EF uncertainty	Explanation/source
2.F.1.a - Commercial refrigeration	25%	AD are taken from AEV's Leak database, uncertainty is based on expert judgement from the administrator of the database	25%	EFs are derived from AEV Leak database, uncertainty is based on expert judgement from the administrator of the database
2.F.1.b - Domestic refrigeration	1%	Data directly received from the only fridge manufacturer.	1%	Data directly received from the only fridge manufacturer.
2.F.1.d - Transport refrigeration	2%	Expert judgement from data provider (SNCA)	25%	Uncertainty expected to be „high" according to Schwarz (2005)
2.F.1.e - Mobile air-conditioning	2%	Expert judgement from data provider (Statec)	25%	Germany's GHG inventory 2020
2.F.1.f - Stationary air-conditioning	25%	AD are taken from AEV's Leak database, uncertainty is based on expert judgement from the administrator of the database	25%	EFs are derived from AEV Leak database, uncertainty is based on expert

				judgement from the administrator of the database
2.F.2 - Foam blowing agents	25%	Belgium's GHG inventory 2020	5%	Belgium's GHG inventory 2020
2.F.4.a - Meter dose inhalers	25%	Relatively high uncertainty because data are extrapolated from neighbouring countries	0%	IPCC 2006 Guidelines (EF=100%)
2.F.4.b - Other	25%	Relatively high uncertainty because of different varieties available and because data are extrapolated from neighbouring countries	0%	IPCC 2006 Guidelines (EF=100%)

4.7.1.3 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.5) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.7.1.4 Category-specific recalculations including changes made in response to the review process

2.F.1 *Stationary refrigeration and air conditioning*

Activity data has been update as such the emissions for 2020 and 2021 have been revised. The variations are given in the following table:

2.F.1 Stationary refrigeration and air conditioning CO2 emissions

year	submission 2023 (Gg CO2 e)	submission 2024 (Gg CO2 e)	variation(%)
2020	4.21412806	4.21239518	-0.0411%
2021	4.10434269	3.87924161	-5.4845%

2.F.2 Foam Blowing

Activity data has been update as such the emissions for 2020 and 2021 have been revisied. The variations are given in the following table:

2F2 - Foam Blowing (HFC)			
year	submission 2023 (Gg CO2 e)	submission 2024 (Gg CO2 e)	variation(%)
2020	0.911812325	1.271536736	39.4516%
2021	0.420578365	1.208309062	187.2970%

4.7.1.5 Category-specific planned improvements including those in response to the review process

The following improvements to category *2F - Product uses as substitutes for ODS* are planned, or will be explored for the next submission depending on the availability of data and resources (Table 4-25).

Table 4-25 – Planned improvements for IPCC Category 2F – Product uses as substitutes for ODS

GHG source & sink category	Planned improvement	Recommendation
2F2 – Foam blowing	continue the quest for country-specific data	
2F4 – Aerosols	continue the quest for country-specific data	

4.8 Other product manufacture and use (2.G)

4.8.1 Source category description

This section describes the estimation of F-gas emissions resulting from the category *2.G - Other product manufacture and use* from industrial processes (production, consumption). In 2022, the category 2.G represented 3.21% of the GHG emissions in CO_2e from industrial processes and 0.21% of the total GHG emissions in CO_2e (excluding LULUCF). This percentage was 0.07% in 1990. As shown in Figure 4-9, emissions from category 2.G experienced an increase of 105% between 1990 and 2022. Compared to 2021, emissions decreased by 6.31% to attain the level of 17.17 Gg CO_2 in 2022.

F-gas emission estimates are presented in Table 4-26

Figure 4-9 - GHG emission trends for CRF Sector 2G : 1990-2022

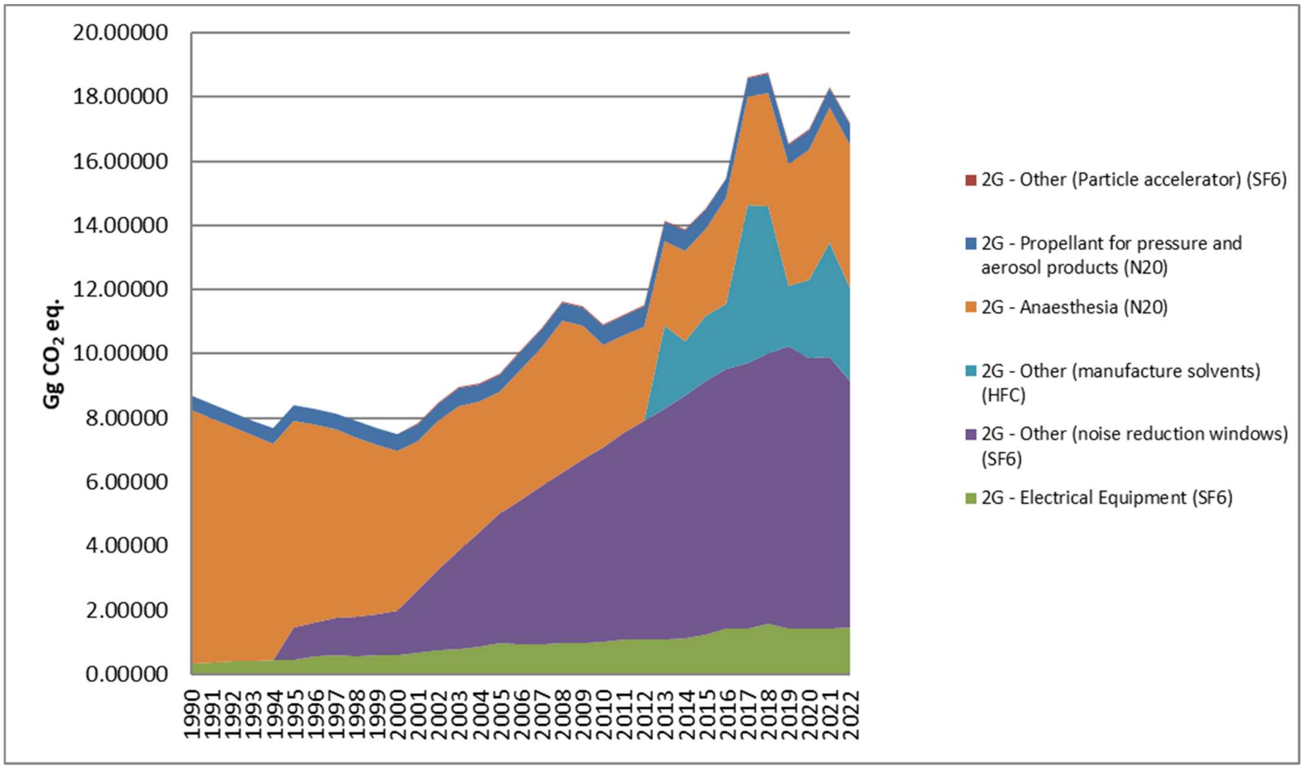

20.00000
18.00000
16.00000
14.00000
12.00000
10.00000
8.00000
6.00000
4.00000
2.00000
0.00000
Gg CO2 eq.
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2G - Other (Particle accelerator) (SF6)
2G - Propellant for pressure and aerosol products (N20)
2G - Anaesthesia (N20)
2G - Other (manufacture solvents) (HFC)
2G - Other (noise reduction windows) (SF6)
2G - Electrical Equipment (SF6)

Table 4-26 - Estimated emissions for CRF Sector 2G: 1990-2022

Year	2G - Other product manufacture and use	2G - Electrical Equipment (SF6)	2G - Other Particle accelerator) (SF6)	2G - Other (noise reduction windows) (SF6)	2G - Other (manufacture solvents) (HFC)	2G - Anaesthesia (N_20)	2G - Propellant for pressure and aerosol products (N_20)
	Gg CO_2 e						
1990	8.70895	0.33677	NO	NO	NO	7.919065	0.453116
1991	8.44881	0.36032	NO	NO	NO	7.629317	0.45917
1992	8.16873	0.38534	NO	NO	NO	7.318049	0.465339
1993	7.91816	0.41213	NO	NO	NO	7.034301	0.47173
1994	7.67908	0.44083	NO	NO	NO	6.760033	0.478215
1995	8.39508	0.44598	NO	0.98614	NO	6.477756	0.485201
1996	8.28135	0.53280	NO	1.07264	NO	6.184544	0.491367
1997	8.13967	0.58984	NO	1.15939	NO	5.892924	0.497521
1998	7.89664	0.55799	NO	1.23647	NO	5.598368	0.503809
1999	7.68806	0.57596	NO	1.30637	NO	5.294677	0.511055
2000	7.47752	0.59468	NO	1.39016	NO	4.97528	0.517404
2001	7.81677	0.66085	0.03262	1.96154	NO	4.638464	0.523287
2002	8.48478	0.72663	0.03262	2.51922	NO	4.677882	0.528426
2003	8.94332	0.79103	0.03262	3.05559	NO	4.52779	0.536287
2004	9.08681	0.84248	0.03262	3.57142	NO	4.096635	0.54366
2005	9.38231	0.95482	0.03262	4.04746	NO	3.794535	0.552869
2006	10.07992	0.93551	0.03262	4.49620	NO	4.054235	0.561355
2007	10.81352	0.94302	0.03262	4.92377	NO	4.34388	0.570223
2008	11.63807	0.95387	0.03262	5.32978	NO	4.740055	0.581743
2009	11.48798	0.97985	0.03262	5.71443	NO	4.169245	0.59183
2010	10.90032	0.98629	0.03262	6.09525	NO	3.182915	0.603251
2011	11.21728	1.06066	0.03262	6.47225	NO	3.03584	0.615905
2012	11.50080	1.07337	0.03422	6.84549	NO	2.91818	0.629552
2013	14.15294	1.08317	0.03422	7.21499	2.57895	2.64364	0.597971
2014	13.86893	1.10650	0.03422	7.58080	1.71600	2.816155	0.615267
2015	14.52154	1.21362	0.03422	7.94445	1.99980	2.71996	0.60949
2016	15.47225	1.41051	0.03422	8.10594	2.03610	3.286795	0.598686
2017	18.61395	1.43167	0.03422	8.26581	4.91865	3.376895	0.586709
2018	18.76318	1.57274	0.03422	8.42409	4.58370	3.549834	0.598595
2019	16.54536	1.41103	0.03422	8.81153	1.89090	3.787216	0.610467
2020	17.00672	1.42302	0.03422	8.45520	2.41230	4.063405	0.618582
2021	18.32498	1.42687	0.03422	8.45687	3.58050	4.201891	0.624626
2022	17.16919	1.46179	0.03422	7.68802	2.90070	4.444917	0.639542
Trend 1995-2022	*105%*	*228%*	*NA*	*680%*	*NA*	*-31%*	*32%*
Trend 2021-2022	*-6.31%*	*2.45%*	*0.00%*	*-9.09%*	*-18.99%*	*5.78%*	*2.39%*

4.8.1.1 Methodology

The emissions of fluorinated greenhouse gases in Luxembourg were thoroughly re-assessed in 2014 in order to assure compliance with the 2006 IPCC reporting guidelines, to streamline data acquisition and processing, to include previously neglected applications and sub-applications, and to increase transparency of emissions estimations.

Generally speaking, emissions estimations in Luxembourg are based on emission-factor approaches. Due to highly incomplete records of chemical sales data (Econotec consultants 2010, importers inquiry 2014), mass-balance approaches are mostly inapplicable. Emission factors are predominantly derived from regional to global estimates. In some cases, it was possible to calculate country-specific emission factors.

4.8.1.2 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 30%
- Emission factor uncertainty 20%

4.8.1.3 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.5) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.8.1.4 Category-specific recalculations including changes made in response to the review process

4.8.1.5 **No recalculations were done for this submission.**Category-specific planned improvements including those in response to the review process

No improvements are planned for category *2G – Other product manufacture and use*.

4.8.2 Electrical equipment (2.G.1)

One of the major applications of fluorinated greenhouse gases outside the ODS substitute sector (air conditioning and refrigeration, aerosols, etc.) is sulphur hexafluoride (SF6) used as insulator in electrical switchgears. There are different types of switchgear, in particular depending on the voltage (20 kV, 65 kV and 220 kV), with a high diversity of SF6 charges per device. In terms of emissions estimation modalities the switchgear can be divided into medium voltage (MV), for 20kV switchgears, and high voltage (HV) devices (65 kV and 220 kV).

In Luxembourg, there is one main operator of electrical switchgear devices (Creos), covering an estimated 80 % of the equipment, and a few smaller operators, four of which provided data on their equipment. As such the data are obtained directly from the operators and cover all HV devices. In order to account for possibly unreported MV equipment, 2 % were added to the reported stock of SF6 MV equipment.

Individual charges typically vary between less than 1 kg of SF6 in MV devices to several 100 kg in HV equipment. Data on type-specific charges were provided by the equipment operators.

MV equipment is pre-filled in the manufacture plant, which is not occurring in Luxembourg since all MV devices are imported. HV equipment, in contrast, is filled on site which entails manufacture or initial emissions that are relevant for Luxembourg. Since no reports on the amounts of SF6 emitted during such operations are available, the figures provided by Schwarz (2005) documenting the evolution of on-site filling emissions of HV equipment in Germany from 1997 to 2002 were used to calculate initial emission factors for Luxembourg for the period in question. The initial emission factors of 1997 and 2002 are extended to the preceding and the following years respectively.

Operation emissions are not reported by the equipment operators, which is why, again, regionally derived factors in line with the 2006 IPCC reporting guidelines and the recommendations of the VDN, VIK, ZVEI and Solvay (2003) report are used. For the MV devices, an operation emission factor of 0,1 % is assumed. For the HV equipment, operation emissions vary depending on the year of manufacture: 0,9 % for devices installed before 1997, 0,8 % for devices installed between 1997 and 2003, and 0,5 % for those installed since 2004. No refilling is assumed to occur over the equipment lifetime.

Emissions at decommissioning are assumed to be relevant only for the HV equipment, and are assumed to amount for 2 % of the initial charge (2006 IPCC reporting guidelines, Schwarz 2005).

4.8.2.1 SF6 and HFCs from other product use (2.G.2)

Particle accelerators (2.G.2.b)

In Luxembourg, four particle accelerators are used in radiation therapy since 2001 , each using 10 liters of SF6. Furthermore, since 2012, one electron microscope a used in a research facility, which has a storage tank of 220 litres of SF6. The corresponding data is obtained immediately from the operators. The resulting emissions in 2022 correspond to 0.033199536 Gg CO_2-eq.

Noise reduction windows (2.G.2.C)

A life-cycle approach is applied:

$$Emissions = EF \bullet AR + D$$

The activity rate (*AR*) is the calculated SF_6 stock on the basis of the estimated installed noise reduction windows, based on imported double glassed windows into Luxembourg with noise reduction fraction from Germany. The annual leakage rate of SF_6 is assumed to be 1% (EF=1%) and the lifespan 25 years. Disposal emissions (D) of the remaining SF_6 stock occur after a lifetime of 25 years. The resulting emissions in 2022 are 7.69 Gg CO_2-eq.

4.8.3 N_2O from product uses (2.G.3)

4.8.3.1 Medical applications (2.G.3.a)

N_2O emissions from Anaesthesia

In 2022, 0.05% of total GHG emissions (excluding LULUCF) in Luxembourg originated from *2G3 - N_2O emissions from anaesthesia*, compared to 0.07% in 1990. Compared to 2021, N_2O emissions from anaesthesia for the year 2022 increased by 5.78% and decreased by 43.87% compared to 1990.

It was assumed that all the N_2O used for anaesthesia is completely released to the atmosphere. Emissions are shown in Table 4-27 and Figure 4-10 – N_2O emissions and N_2O consumption for anaesthesia per capita and trend: 1990–2022.

For the period 1990-2002, no data from the hospitals on the consumption of N_2O could be obtained. Hence, N_2O emissions from anaesthesia usage were estimated by combining reported emissions in Germany with the relative population in Luxembourg. From 2003 to 2022, the use of N_2O in hospitals for anaesthesia was directly obtained from the “Entente des hôpitaux luxembourgeois”. Thus, country-specific data was used. The data obtained covers the use of N_2O for anaesthesia in all hospitals of Luxembourg. The revised data from Germany (CRF 2015) for N_2O use in anaesthesia have been implemented and taken into account for the comparison.

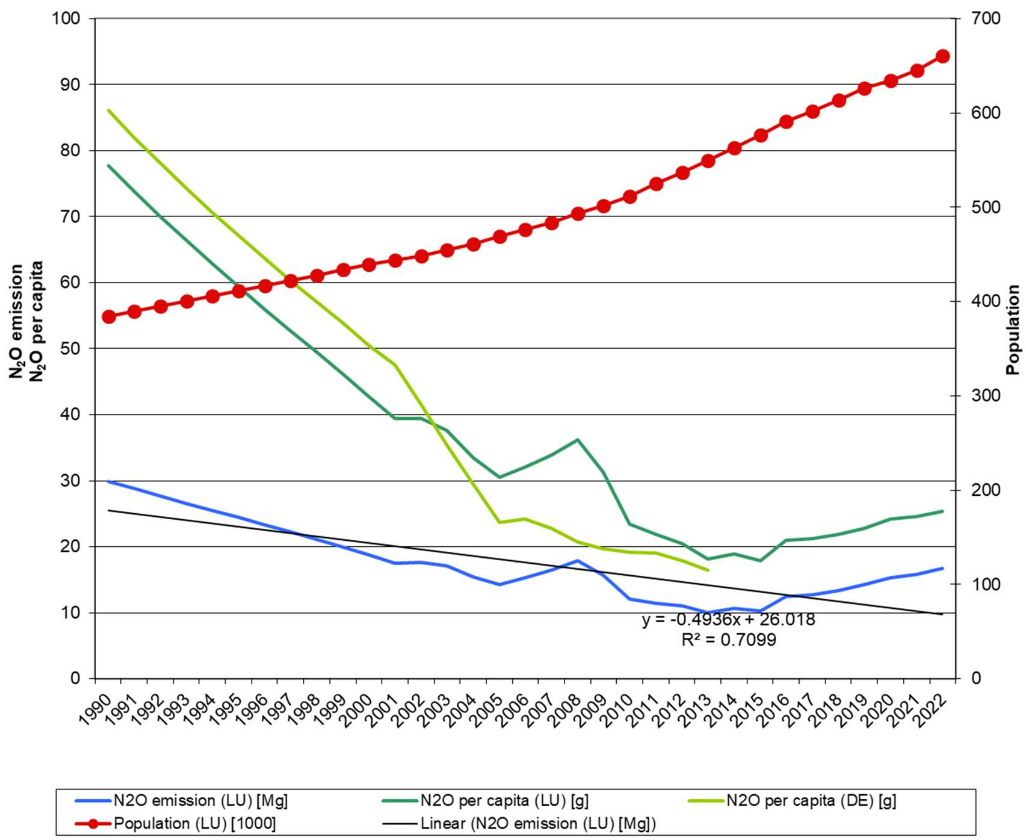
Although two different methods for the estimation of N_2O from anaesthesia are used over the time period (1990-2002 and 2003-2022), it is estimated that the time-series consistency is ensured. Indeed, when comparing the 2002 and 2003 values of emissions per capita of Germany with Luxembourg's value, these are relatively similar (Table 4-25). From 2004 onwards, the German per capita emissions seem to decrease much more rapidly than Luxembourg's values thus avoiding a potential underestimation by applying a country-specific method. However, the general trend of decreasing emissions is consistent between the German and Luxembourgish figures thus ensuring time-series consistency. As such, direct comparison between German and Luxembourgish figures are only carried out until 2013.

Based on data provided by the “Lëtzebuerger Associatioun vun de Klengdéierepraktiker”, which is an association representing all the veterinaries active in Luxembourg, no N_2O is used as anaesthesia in veterinary cabinets or clinics in Luxembourg.

Table 4-27 – 2.G.3.a - Use of N_2O for Anaesthesia: 1990–2022.

	Luxembourg			Germany
	N_2O emission (LU) [Mg]	Population (LU) [1000]	N_2O per capita (LU) [g]	N_2O per capita (DE) [g]
1990	29.88	384.4	77.74	86.07
1991	28.79	389.6	73.90	82.03
1992	27.62	394.8	69.95	78.17
1993	26.54	400.2	66.33	74.19
1994	25.51	405.7	62.88	70.58
1995	24.44	411.6	59.39	67.12
1996	23.34	416.9	55.98	63.68
1997	22.24	422.1	52.68	60.32
1998	21.13	427.4	49.43	57.07
1999	19.98	433.6	46.08	53.86
2000	18.77	439.0	42.77	50.55
2001	17.50	444.0	39.42	47.48
2002	17.65	448.3	39.38	41.45
2003	17.09	455.0	37.55	35.47
2004	15.46	461.2	33.52	29.55
2005	14.32	469.1	30.52	23.62
2006	15.30	476.2	32.13	24.17
2007	16.39	483.8	33.88	22.73
2008	17.89	493.5	36.25	20.69
2009	15.73	502.1	31.33	19.71
2010	12.01	511.8	23.47	19.15
2011	11.46	524.9	21.83	19.07
2012	11.01	537.0	20.51	17.83
2013	9.98	549.7	18.15	16.49
2014	10.63	563.0	18.88	15.55
2015	10.26	576.2	17.81	14.23
2016	12.40	590.7	21.00	12.98
2017	12.74	602.0	21.17	11.88
2018	13.40	613.9	21.82	10.70
2019	14.29	626.1	22.83	9.62
2020	15.33	634.7	24.16	8.51
2021	15.86	645.4	24.57	7.42
2022	16.77	660.8	25.38	6.34

Figure 4-10 – N_2O emissions and N_2O consumption for anaesthesia per capita and trend: 1990–2022



4.8.3.1.1 Uncertainties and time-series consistency

Direct use of N_2O has been specifically collected from the hospitals in Luxembourg. According to Winiwarter (2008) pursuant to Ramirez *et al.* 2006, an uncertainty of 20% for the amount of N_2O is used Table 4-28. In contrast to Ramirez, it is assumed that virtually all of the N_2O actually used is also fully released, thus no additional uncertainty is applied.

Table 4-28 - Uncertainties for category 2.G.3.a - N_2O emissions from anaesthesia.

IPCC Source category	Gas	AD	EF	Combined
			Uncertainty [%]	
2G3a - N_2O emissions from anaesthesia	N_2O	20.0	0	20.0

4.8.3.1.3 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.8.3.2 Category-specific recalculations including changes made in response to the review process

No changes have been made.

4.8.3.3 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.3.a.

4.8.3.4 Other (2.G.3.b)

Propellant for pressure and aerosol products

For the period 1990-2022, no data regarding exclusively the consumption of food aerosol cans, and the related N_2O emission in Luxembourg, could be obtained. Hence, N_2O emissions from propellant for pressure and aerosol products usage were estimated by combining reported emissions in Belgium with the relative population in Luxembourg. In 2022, 0.01% of total GHG emissions (excluding LULUCF) in Luxembourg originated from 2.G.3.b - Propellant for pressure and aerosol products compared to 0.004% in 1990. Compared to 2021, N_2O emissions from Propellant for pressure and aerosol products, for the year 2022, increased by 2.39% and by 41.14% compared to 1990 (Table 4-29).

Table 4-29- 2.G.3.b - Use of N2O for Propellant for pressure and aerosol products: 1990–2022.

1.8.4.2 Other (2.G.3.b) Propellant for pressure and aerosol products		
	N_2O emission [Gg]	Population (LU) [1000]
1990	0.001710	384.4
1991	0.001733	389.6
1992	0.001756	394.8
1993	0.001780	400.2
1994	0.001805	405.7
1995	0.001831	411.6
1996	0.001854	416.9
1997	0.001877	422.1
1998	0.001901	427.4
1999	0.001929	433.6
2000	0.001952	439.0
2001	0.001975	444.0
2002	0.001994	448.3
2003	0.002024	455.0
2004	0.002052	461.2
2005	0.002086	469.1
2006	0.002118	476.2
2007	0.002152	483.8
2008	0.002195	493.5
2009	0.002233	502.1
2010	0.002276	511.8
2011	0.002324	524.9
2012	0.002376	537.0
2013	0.002256	549.7
2014	0.002322	563.0
2015	0.002300	576.2
2016	0.002259	590.7
2017	0.002214	602.0
2018	0.002259	613.9
2019	0.002304	626.1
2020	0.002334	634.7
2021	0.002357	645.4
2022	0.002413	660.8

4.8.3.4.1 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 30%
- Emission factor uncertainty 20%

4.8.3.4.2 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.8.3.4.3 Category-specific recalculations including changes made in response to the review process

Emissions have been revised for the years 2017 to 2021 and are shown in the following table:

2.G.3.b Propellant for pressure and aerosol products			
year	submission 2023 (Gg CO2 e)	submission 2024 (Gg CO2 e)	variation(%)
2017	0.610138781	0.586708944	-3.8401%
2018	0.622199664	0.598594598	-3.7938%
2019	0.634572711	0.610466797	-3.7988%
2020	0.643321412	0.618581639	-3.8456%
2021	0.65412249	0.624626322	-4.5093%

4.8.3.4.4 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.3.b

4.8.3.5 Other (2.G.4)

In Luxembourg, one manufacturer is producing solvents belonging to the category 2.G.4. The aforementioned production started in 2013. Activity data is directly obtained from the manufacturer. The data is limited to the one manufacturer and is considered confidential, thus the here described information is restricted to the activity data.

4.8.3.5.1 Uncertainties and time-series consistency

The error values were obtained from the manufacturer and are the following:

- Activity data uncertainty 6.6%
- Emission factor uncertainty 6.6%

4.8.3.5.2 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.5) of which important elements include:

- Are the correct values used (check for transcription errors, …)?
- Check of plausibility of input data (time-series, order of magnitude, …)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, …)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, …
- Are all references clearly made?
- Are all assumptions documented?

4.8.3.5.3 Category-specific recalculations including changes made in response to the review process

No revisions and recalculations have been done since the last submission.

4.8.3.5.4 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.4

4.9 Other (2.H)

This source category exists in Luxembourg, but no emissions associated with the national inventories are produced. N2O emissions coupled to certain processes used in the beverage and food industry are not occurring in Luxembourg.

5 Agriculture (CRF Sector 3)

5.1 Sector Overview

This chapter gives information about the estimation of greenhouse gas (GHG) emissions from agriculture activities (CRF Sector 3 - Agriculture) in Luxembourg for the period 1990-2022.

Emissions from the agriculture sector comprise emissions from the following categories:

- Methane emissions from enteric fermentation (CRF 3A)
- Methane emissions from manure management (CRF 3Ba)
- N_2O emissions from manure management (CRF 3Bb)
- N_2O emissions from managed soils (CRF 3D)
- CO_2 emissions from liming (CRF 3G)
- CO_2 emissions from urea applicationLiming (CRF 3H)
- CO_2 emissions from other carbon containing fertilizer (CRF 3I)

For categories where emissions are not occurring, not estimated or included elsewhere, see Table 5-4 below. More details are presented under each source category in the following sections.

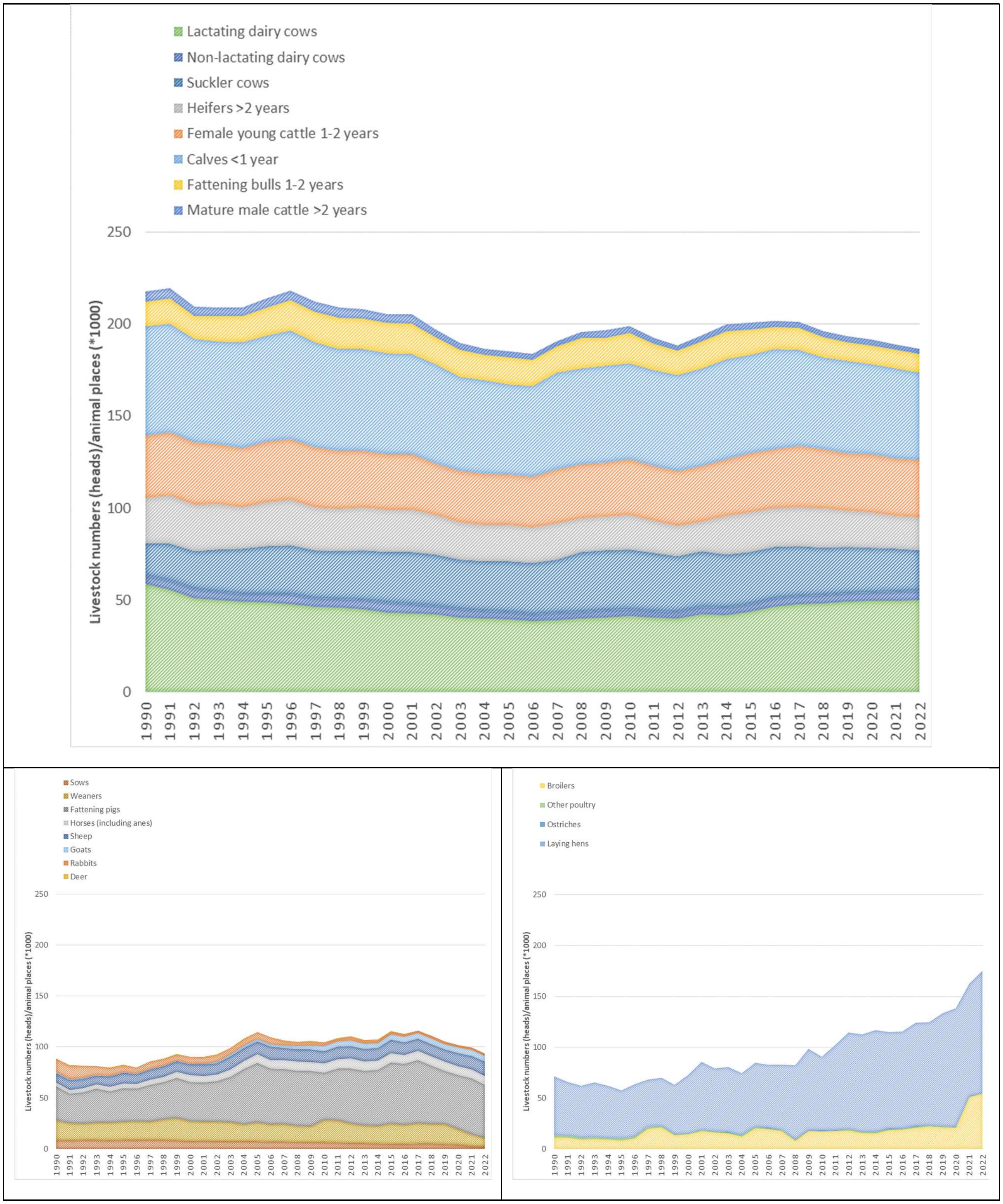
Hereafter a short overview of the Luxemburgish agricultural sector.

The country of Luxembourg is lying in a cool climate region, with both moderate winters and summers. More than 50% of the used agriculture surface in Luxembourg is permanent grassland, see Figure 5-2. Cattle, and in particularly dairy cattle, was and is therefore the most important livestock sector in Luxembourg. With the introduction of the milk quota system in 1983 in the European Union (i.e. a restriction on milk production), and an increasing milk yield per dairy cow over time, the number of dairy cows had decreased over the years, although partly compensated by a parallel increase in the number of suckler cows. However, this trend has changed with the abolishment of the milk quota system in Europe in spring 2015, and the number of dairy cows is increasing since then, with an accelerated increase in the first 2-3 years, and is slowing down in the last years. Suckler cows and fattening bulls have decreased since then, see Figure 5-1.

Swine and poultry are in Luxembourg of far less importance than cattle, and are now-a-days for the majority of the production in the hands of a few professional farmers. Although, in recent years, cattle farmers tend to install mobile laying hen stables, resulting in a sharp increase of laying hens (Note: the produced eggs are sold on a deficitary local market). Furthermore the market introduction of a new label resulted in a significant increase of broilers in 2021. Sheep, goats and other livestock is in Luxembourg a niche production, respectively are backyard animals (Figure 5-1).

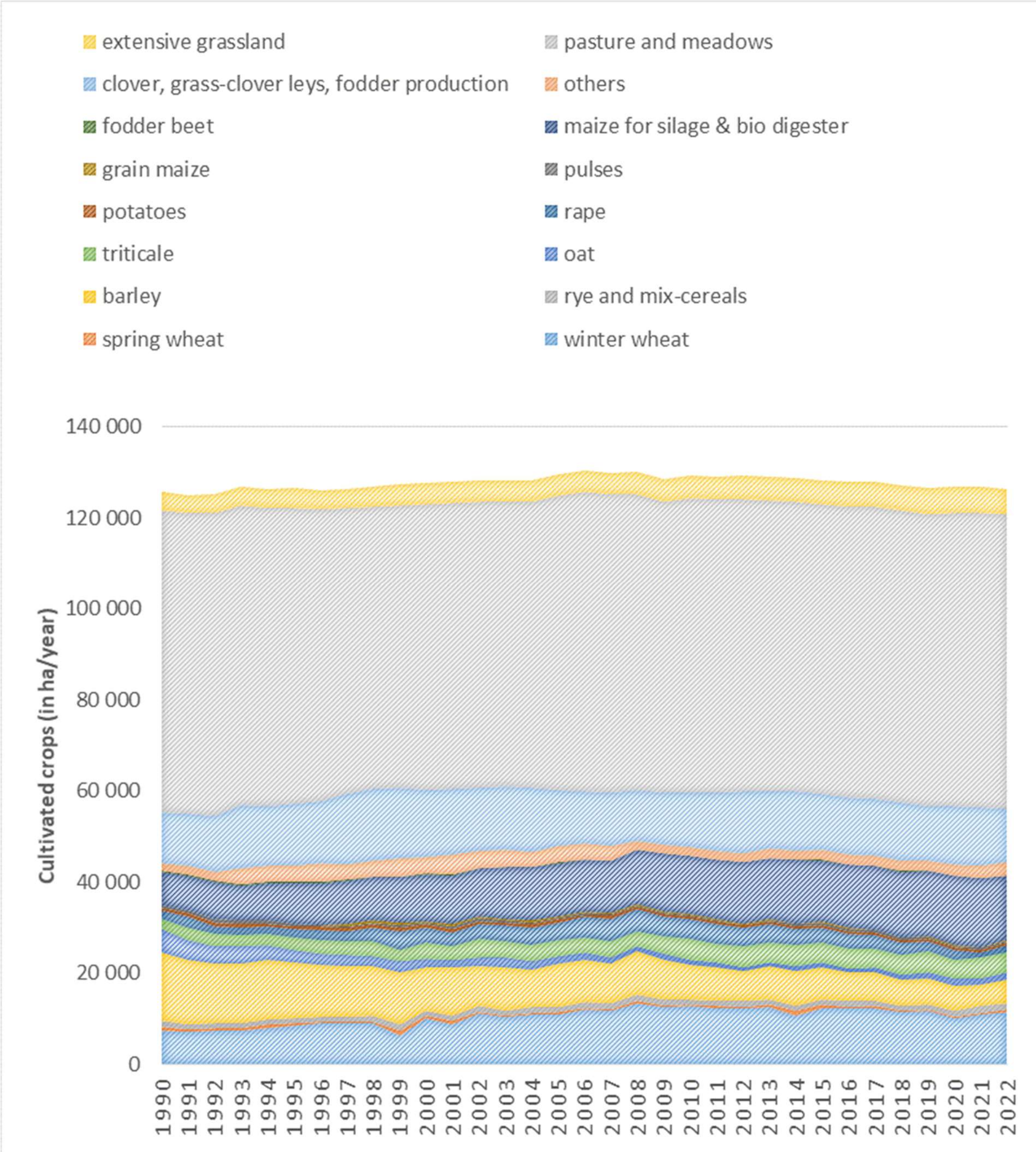
Permanent grassland is with more than 50% of the used agriculture surface predominant in Luxembourg. Grass, cover-grass and maize for silage (whole plant) are and were the main forage crops grown in Luxembourg, see Figure 5-2. Grains such as wheat, barley and triticale, but also rapeseed were the major cash crops cultivated in Luxembourg. In particularly the cultivated area for wheat and maize increased over the years, whereas barley and oat decreased.

Figure 5-1 – Average animal population (heads/animal places) per year for the different livestock categories for the period 1990-2022



Source : Compiled by SER using data by STATEC (published data) and SER (unpublished data).
https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CEntreprises%23D%23%7CAgriculture%20et%20foresterie%23D2%23&pg=0&fc=Th%C3%A8mes&df[ds]=release&df[id]=DF_D2107&df[ag]=LU1&pd=1990%2C2021&dq=.A .

Figure 5-2 – Cultivated crops (ha/year) for the period 1990-2022

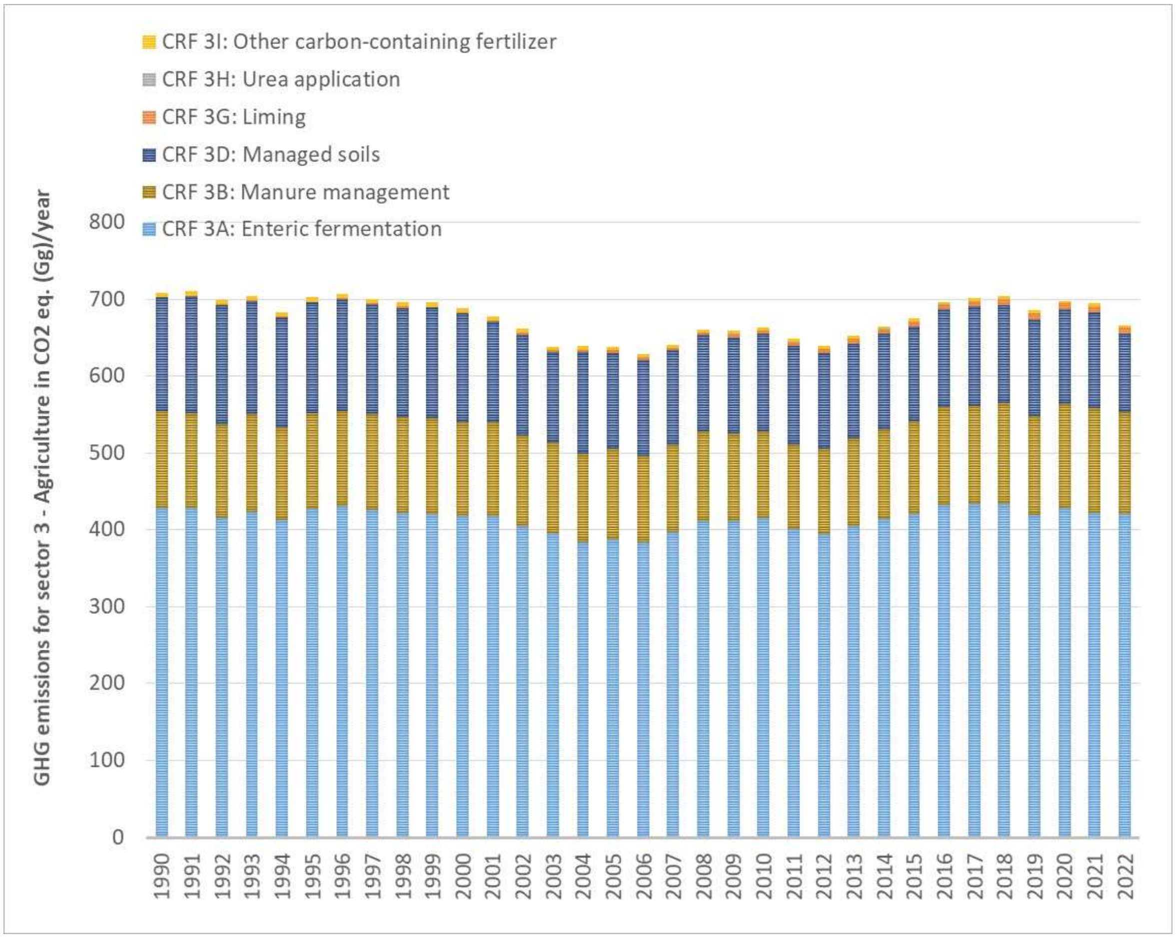


Source : Compiled by SER using data by STATEC (published data) and SER (unpublished data). More details in Annex 3 C.

1.1.2 Emission Trends

In 2022, the agricultural sector contributed 8.07% to the total of Luxembourgish greenhouse gas emissions without LULUCF. The GHG emissions for agriculture decreased by 6.08% when comparing 1990 to 2022 (see Figure 5-3 and Table 5-1, Table 5-2).

Figure 5-3 – Emissions from Agriculture, total and per category (CO_2 eq.): 1990 - 2022



The overall trend in greenhouse gas emissions from agriculture, which used to decrease over time, was reversed in 2013 until 2017, and tends to decline lately, see Figure 5-3. The main drivers for this trend are i) the livestock numbers, in particularly dairy cows (see Figure 5-1), and ii) lower amounts of N-fertilizers applied on agricultural soils (see emissions in Figure 5-3). With the introduction of the milk quota system in 1983 in the European Union (i.e. a restriction on milk production), and an increasing milk yield per dairy cow over time, the number of dairy cows decreased over the years, although partly compensated by a parallel increase in the number of suckler cows. However, this trend has changed with the abolishment of the milk quota system in Europe in spring 2015, and the number of dairy cows is increasing since then, with an accelerated increase in the first 2-3 years, and is slowing down in the last two years, see Figure 5-1. Suckler cows and fattening bulls have decreased since then.

Fluctuations which can be seen for agricultural soils (in particular CRF 3D & CRF 3I (see Table 5-1)) resulted mostly from the variability of mineral fertilizer use, either because of high prices (so for example 2022, but also in earlier years) and/or due to weather conditions hampering their application. Fluctuations which can be seen for enteric fermentation and manure management are partly the result of bad weather conditions hampering the growth and/or the harvest of forages, with consequently a shortage in forage, initiating an increased selling of cattle, followed by a temporary reduction of the cattle population, but also affecting the offered feed diet with consequently higher milk urea than in average years; and in a smaller part also the volatility of either piglet prices and/or pork prices that might result in mostly in a temporary reduction/increase of the pig production. Although recently, a long-lasting period of low swine prices resulted in a reorientation, respectively the closure of pig farms and hence a declining sow and other swine population.

The increase of CO_2 emissions over the years is mainly due to an increase of CO_2 emissions from liming (see Table 5-1). A consequence of the closure of blast furnaces and the re-structurture of the iron industry in Luxembourg in the eighties/nineties, and the replacement of Thomas slag by other types of liming fertilizers.

Table 5-1– GHG emission trends in Gg CO2 eq. for CRF Sector 3 – Agriculture (without LULUCF): 1990-2022

3 - Agricultural Sector

GHG emissions by source & sink category (Gg CO_2 eq)

Year	3A - Enteric fermentation				3B -Manure management				3D - Agricultural soils (without LULUCF)				3G- Liming				3H - Urea application				3I - Carbon-containing fertilizer			
	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	428.6	NA	428.6	NA	126.2	NA	87.5	38.7	147.8	NA	NA	147.8	0.23	0.23	NA	NA	NO	NO	NA	NA	5.82	5.82	NA	NA
1991	429.5	NA	429.5	NA	123.2	NA	84.6	38.6	151.5	NA	NA	151.5	0.41	0.41	NA	NA	NO	NO	NA	NA	6.07	6.07	NA	NA
1992	415.7	NA	415.7	NA	122.4	NA	85.7	36.7	154.6	NA	NA	154.6	0.59	0.59	NA	NA	NO	NO	NA	NA	6.55	6.55	NA	NA
1993	424.3	NA	424.3	NA	126.1	NA	89.3	36.8	147.8	NA	NA	147.8	0.92	0.92	NA	NA	NO	NO	NA	NA	5.97	5.97	NA	NA
1994	413.7	NA	413.7	NA	119.9	NA	83.5	36.3	143.0	NA	NA	143.0	1.34	1.34	NA	NA	NO	NO	NA	NA	5.67	5.67	NA	NA
1995	428.2	NA	428.2	NA	124.0	NA	86.6	37.4	144.0	NA	NA	144.0	1.09	1.09	NA	NA	NO	NO	NA	NA	5.56	5.56	NA	NA
1996	431.6	NA	431.6	NA	123.6	NA	85.7	37.9	145.4	NA	NA	145.4	0.97	0.97	NA	NA	NO	NO	NA	NA	5.59	5.59	NA	NA
1997	426.5	NA	426.5	NA	124.3	NA	87.0	37.3	143.0	NA	NA	143.0	1.43	1.43	NA	NA	NO	NO	NA	NA	5.50	5.50	NA	NA
1998	422.6	NA	422.6	NA	124.8	NA	88.9	35.8	141.5	NA	NA	141.5	1.97	1.97	NA	NA	NO	NO	NA	NA	5.39	5.39	NA	NA
1999	421.3	NA	421.3	NA	124.1	NA	88.3	35.8	144.0	NA	NA	144.0	1.10	1.10	NA	NA	NO	NO	NA	NA	5.56	5.56	NA	NA
2000	417.9	NA	417.9	NA	122.1	NA	87.1	34.9	141.5	NA	NA	141.5	1.84	1.84	NA	NA	NO	NO	NA	NA	5.49	5.49	NA	NA
2001	419.0	NA	419.0	NA	121.6	NA	86.7	34.9	130.5	NA	NA	130.5	2.23	2.23	NA	NA	NO	NO	NA	NA	4.68	4.68	NA	NA
2002	405.2	NA	405.2	NA	118.4	NA	84.6	33.8	130.9	NA	NA	130.9	2.83	2.83	NA	NA	NO	NO	NA	NA	4.88	4.88	NA	NA
2003	395.8	NA	395.8	NA	118.4	NA	85.1	33.3	117.9	NA	NA	117.9	2.75	2.75	NA	NA	NO	NO	NA	NA	3.98	3.98	NA	NA
2004	384.3	NA	384.3	NA	114.5	NA	80.8	33.7	133.2	NA	NA	133.2	2.36	2.36	NA	NA	NO	NO	NA	NA	5.04	5.04	NA	NA
2005	388.5	NA	388.5	NA	116.9	NA	84.4	32.5	125.1	NA	NA	125.1	3.81	3.81	NA	NA	0.42	0.42	NA	NA	4.17	4.17	NA	NA
2006	384.3	NA	384.3	NA	112.7	NA	80.4	32.3	124.4	NA	NA	124.4	2.97	2.97	NA	NA	0.42	0.42	NA	NA	4.15	4.15	NA	NA
2007	396.9	NA	396.9	NA	114.2	NA	81.0	33.2	123.0	NA	NA	123.0	3.00	3.00	NA	NA	0.39	0.39	NA	NA	3.86	3.86	NA	NA
2008	412.2	NA	412.2	NA	116.2	NA	81.9	34.3	125.5	NA	NA	125.5	2.79	2.79	NA	NA	0.39	0.39	NA	NA	3.88	3.88	NA	NA
2009	412.2	NA	412.2	NA	113.8	NA	79.5	34.3	124.8	NA	NA	124.8	3.97	3.97	NA	NA	0.39	0.39	NA	NA	3.84	3.84	NA	NA
2010	416.4	NA	416.4	NA	112.0	NA	78.4	33.7	127.1	NA	NA	127.1	3.43	3.43	NA	NA	0.37	0.37	NA	NA	3.82	3.82	NA	NA
2011	401.3	NA	401.3	NA	110.0	NA	77.1	32.9	128.1	NA	NA	128.1	4.76	4.76	NA	NA	0.35	0.35	NA	NA	4.00	4.00	NA	NA
2012	394.7	NA	394.7	NA	111.3	NA	79.2	32.1	124.2	NA	NA	124.2	4.93	4.93	NA	NA	0.29	0.29	NA	NA	3.79	3.79	NA	NA
2013	404.6	NA	404.6	NA	114.3	NA	81.6	32.7	123.7	NA	NA	123.7	5.66	5.66	NA	NA	0.25	0.25	NA	NA	3.71	3.71	NA	NA
2014	414.7	NA	414.7	NA	116.7	NA	82.8	33.9	124.0	NA	NA	124.0	6.00	6.00	NA	NA	0.21	0.21	NA	NA	3.53	3.53	NA	NA
2015	421.8	NA	421.8	NA	119.6	NA	85.4	34.2	123.9	NA	NA	123.9	6.09	6.09	NA	NA	0.18	0.18	NA	NA	3.64	3.64	NA	NA
2016	433.6	NA	433.6	NA	126.0	NA	91.3	34.6	128.0	NA	NA	128.0	5.53	5.53	NA	NA	0.16	0.16	NA	NA	3.92	3.92	NA	NA
2017	433.8	NA	433.8	NA	127.7	NA	92.4	35.3	129.7	NA	NA	129.7	6.64	6.64	NA	NA	0.12	0.12	NA	NA	3.85	3.85	NA	NA
2018	434.3	NA	434.3	NA	131.3	NA	96.1	35.2	126.8	NA	NA	126.8	8.27	8.27	NA	NA	0.08	0.08	NA	NA	3.56	3.56	NA	NA
2019	419.4	NA	419.4	NA	128.4	NA	93.7	34.7	126.6	NA	NA	126.6	7.84	7.84	NA	NA	0.05	0.05	NA	NA	3.83	3.83	NA	NA
2020	428.5	NA	428.5	NA	135.1	NA	100.5	34.6	123.2	NA	NA	123.2	7.96	7.96	NA	NA	0.06	0.06	NA	NA	3.56	3.56	NA	NA
2021	422.7	NA	422.7	NA	135.6	NA	101.4	34.2	125.2	NA	NA	125.2	7.45	7.45	NA	NA	0.07	0.07	NA	NA	3.70	3.70	NA	NA
2022	420.7	NA	420.7	NA	133.1	NA	99.6	33.5	101.7	NA	NA	101.7	7.90	7.90	NA	NA	0.05	0.05	NA	NA	2.16	2.16	NA	NA
Trend 1990 -2022	-1.9%	NA	-1.9%	NA	5.5%	NA	13.8%	-13.4%	-31.2%	NA	NA	-31.2%	3332%	3332%	NA	NA	NA	NA	NA	NA	-62.9%	-63%	NA	NA
Trend 2021 -2022	-0.5%	NA	-0.5%	NA	-3.4%	NA	-1.8%	-2.0%	-18.8%	NA	NA	-18.8%	6.1%	6.1%	NA	NA	-17.9%	-17.9%	NA	NA	-41.6%	-41.6%	NA	NA

Note: CH_4 emissions were converted in CO_2-eq. by multiplying the emissions by 28 and N_2O emissions were converted in CO_2-eq. by multiplying the emissions by 265.

Table 5-2– GHG emission trends in Gg CO2 eq. for CRF Sector 3 – Agriculture without and without LULUCF

Year	Agriculture (without LULUCF) Total	CO_2	CH_4	N_2O	Agriculture (with LULUCF) Total	CO_2	CH_4	N_2O
1990	708.65	6.05	516.1	186.5	708.7	6.05	516.1	186.5
1991	710.65	6.48	514.1	190.0	710.7	6.48	514.1	190.1
1992	699.89	7.14	501.4	191.3	699.9	7.14	501.4	191.4
1993	705.10	6.89	513.6	184.6	705.1	6.89	513.6	184.7
1994	683.57	7.01	497.2	179.4	683.6	7.01	497.2	179.4
1995	702.81	6.66	514.7	181.4	702.8	6.66	514.7	181.4
1996	707.21	6.55	517.3	183.3	707.2	6.55	517.3	183.4
1997	700.75	6.93	513.5	180.4	700.8	6.93	513.5	180.4
1998	696.19	7.36	511.5	177.3	696.2	7.36	511.5	177.4
1999	696.06	6.66	509.6	179.8	696.1	6.66	509.6	179.8
2000	688.77	7.33	505.0	176.4	688.8	7.33	505.0	176.4
2001	677.98	6.91	505.6	165.4	678.0	6.91	505.6	165.4
2002	662.24	7.71	489.8	164.7	662.3	7.71	489.8	164.8
2003	638.75	6.72	480.8	151.2	638.8	6.72	480.8	151.2
2004	639.45	7.40	465.1	166.9	639.5	7.40	465.1	166.9
2005	638.88	8.41	472.9	157.6	638.9	8.41	472.9	157.6
2006	628.99	7.54	464.8	156.7	629.0	7.54	464.8	156.7
2007	641.33	7.25	477.9	156.2	641.4	7.25	477.9	156.2
2008	660.96	7.06	494.1	159.8	661.0	7.06	494.1	159.8
2009	659.01	8.20	491.7	159.1	659.1	8.20	491.7	159.1
2010	663.14	7.62	494.8	160.7	663.2	7.62	494.8	160.8
2011	648.53	9.11	478.4	161.0	648.6	9.11	478.4	161.0
2012	639.17	9.02	473.9	156.3	639.2	9.02	473.9	156.3
2013	652.24	9.63	486.2	156.4	652.3	9.63	486.2	156.4
2014	665.07	9.75	497.5	157.8	665.1	9.75	497.5	157.9
2015	675.21	9.91	507.2	158.1	675.2	9.91	507.2	158.1
2016	697.24	9.60	525.0	162.6	697.3	9.60	525.0	162.7
2017	701.75	10.61	526.2	165.0	701.8	10.61	526.2	165.0
2018	704.25	11.91	530.4	161.9	704.3	11.91	530.4	161.9
2019	686.13	11.73	513.1	161.3	686.1	11.73	513.1	161.3
2020	698.34	11.58	529.0	157.8	698.4	11.58	529.0	157.8
2021	694.74	11.21	524.1	159.4	694.8	11.21	524.1	159.4
2022	665.58	10.11	520.2	135.2	665.59	10.11	520.2	135.2
Trend 1990 -2022	-6.1%	67%	1%	-27%	-6.1%	67%	1%	-27%
Trend 2021 -2022	-4.2%	-10%	-0.7%	-15%	-4.2%	-10%	-0.7%	-15%

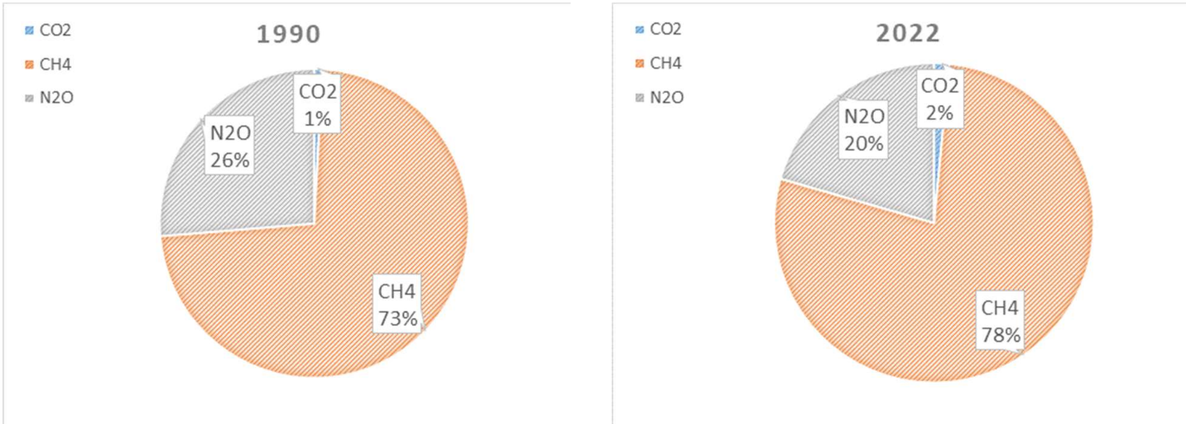
(Table title: 3 - Agricultural Sector, GHG emissions (Gg CO_2 eq))

5.1.1.1 Emission trends per gas

From 1990 to 2022 CO_2 emissions from agriculture increased by 67%, although they account for <2% of the emissions from agriculture in 2022. CH_4 emissions from agriculture increased by 1% from 1990 to 2022, whereas N_2O emissions decreased in the same time by 27%. The trends are presented in Table 5-1 without LULUCF, and in Table 5-2 with and without LULUCF.

The share of gases has slightly changed over time (see Figure 5-4). In 2022 about 78% of emissions from agriculture originate from CH_4 (in 1990 73%), 20% from N_2O (in 1990 26%) and roughly 2% from CO_2 (in 1990 1%).

Figure 5-4 – Share of gases from Agriculture (CO_2 eq.): 1990 and 2022

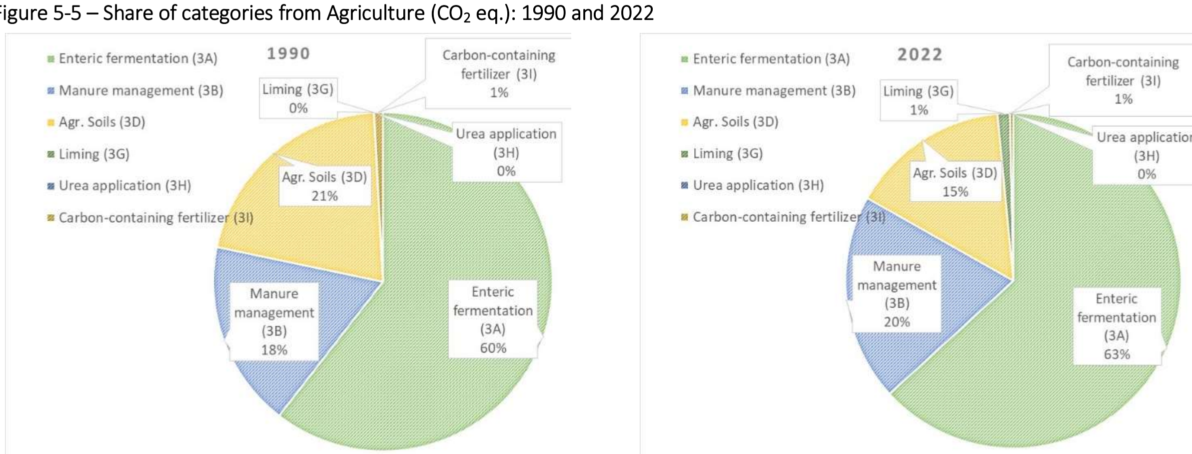


5.1.1.2 Emission trends per subcategory

GHG emissions by subcategories are presented in Figure 5-3 and Table 5-1. Important categories were 3A enteric fermentation (Trend 1990-2022: -1.9%) and by 3.B manure management (Trend 1990-2022: +5.5%) followed by 3.D agricultural soils (Trend 1990-2022: -31%). Although of less importance, liming (3 G) associated CO_2 emissions were increasing since 1990 to 2022 by 3332%. Note this artifact was a consequence of the closure of blast furnaces and the re-structurture of the iron industry in Luxembourg in the eighties/nineties, and the replacement of Thomas slag by other types of liming fertilizers. Whereas carbon-containing fertilizer (3I) associated CO_2 emissions were decreasing (-63%). Urea application (3H) associated CO_2 emissions were/are insignificant (i.e. representing <0.07% of the emissions from agriculture sector (CRF 3) at any moment in time).

Enteric fermentation (3A) emissions are responsible for 63% of the emissions from agriculture in 2022 (in 1990 60%). In 2022 was, due to the drastic drop of synthetic N fertilizer, N_2O emissions from manure management (3B) on second place (20% versus 18% in 1990), followed by N_2O emissions from agricultural soils (3D) (15% versus 21% in 1990), see Figure 5-5. Liming- associated emissions (3G) are responsible for 1.2% of the emissions from agriculture in 2022 (in 1990 0.03%). Carbon-containing (3I) associated CO_2 emissions are responsible for 03% of the emissions from agriculture in 2022 (in 1990 0.8%). Urea application (3H) associated CO_2 emissions are only marginal (<0.01% in 2022).

Figure 5-5 – Share of categories from Agriculture (CO_2 eq.): 1990 and 2022



5.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 1.4. Table 5-3 presents the key source categories of Sector 3 – Agriculture.

Table 5-3 – Key sources of IPCC Sector 3 – Agriculture

3 - Agriculture Key sources						
IPCC Category	**Category Name**	**GHG**	**LA excl. LULUCF**	**LA incl. LULUCF**	**TA excl. LULUCF**	**TA incl. LULUCF**
3A	Enteric Fermentation	CH_4	90-22	90-22	X	X
3B	Manure Management	CH_4	95-02, 08-22	95-22		
3D1	Direct N_2O Emissions from Managed Soils	N_2O	90-22	90-22		

Source: Environment Agency
Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
TA = Trend Assessment 2022 (Tier 1) including respectively excluding LULUCF

5.1.3 Completeness

Table 5-4 gives an overview of the IPCC categories included under CRF Sector 3 and provides information on the status of emission estimates of all subcategories.

Table 5-4 –Overview of subcategories of CRF 3 – Agriculture: Status

CRF source category		CO_2		CH_4		N_2O	
		Method	EF	Method	EF	Method	EF
3. Agriculture							
A.	Enteric fermentation	NA	NA	T1, T2	D, CS	NA	NA
B.	Manure management	NA	NA	T1, T2	D, CS	T2	D
C.	Rice cultivation	NA	NA	NO	NO	NA	NA
D.	Agricultural soils	NA	NA	NA	NA	T1, T2	D, CS
E.	Prescribed burning of savannahs	NO	NO	NA	NA	NA	NA
F.	Field burning of agricultural residues	NO	NO	NA	NA	NA	NA
G.	Liming	T1	D	NA	NA	NA	NA
H.	Urea application	T1	D	NA	NA	NA	NA
I.	Other carbon-containing fertilizers	T1	D	NA	NA	NA	NA
J.	Other	NO	NO	NA	NA	NA	NA

Used abbreviations: NA = not applicable; NO=not occurring. T1=IPCC Tier 1; T2=IPCC Tier 2; D=IPCC default; CS=Country-specific.

5.2 General aspects

Animal categories, livestock numbers, manure management system (MMS), N excretion (N.ex) and the N flows in the manure management system are used in several categories in the emission calculations and were therefore described in this chapter. Other required information are presented under each source category review.

5.2.1 Animal categories

Cattle was and is the major livestock in Luxemburg. In the emission calculations seven categories were distinguished, all of them assumed to be kept in high productivity systems:

Calves	Comprising calves <1 year, from both dairy and suckler herds. Where necessary, further distinguishing between male and female calves.
Female young cattle 1-2 years	Comprising 1-2 years old female cattle from both dairy and suckler herds
Fattening bulls 1-2 years	Comprising 1-2 year old male cattle, from both dairy and suckler herds. In the majority fattening bulls kept and fed inside stables. The remaining animals were growing breeding males and young oxes, but for simplicity reasons treated in the agricultural emission calculations as being 100% fattening bulls.
Heifers >2 years	Comprising heifers >2 years from both dairy and suckler herds. Most of the heifers were kept for breeding purposes. Heifers for slaughtering were/are raised, fed, and kept in the same way as breeding heifers, why no further distinction was made.
Mature male cattle >2 years	Comprising male cattle >2 years from both dairy and suckler herds. Mostly breeding animals; a few fattening bulls who took longer than the useable 20-24 months for finishing; and a few fattening oxes. For simplicity all animals in this category were treated as being mature male breeding cattle.
Lactating dairy cows	Comprising *only* lactating dairy cows. In the census up to the year 2007 were three “cow” categories distinguished, namely dairy cows comprising only “lactating dairy cows”; “non-lactating dairy cow”s kept for fattening purposes and “suckler cows”. Since 2008, however, both lactating and non-lactating dairy cows are reported together in one single category. For 1990-2007 non-lactating dairy cows accounted on average for 9.15% (range 7.1%-10.8%) of the total consisting of lactating dairy cows and non-lactating dairy cows ($P_{cull\ cows}$) (STATEC 2019c). Assuming the same distribution of lactating and non-lactating dairy cows for the year 2008 and onwards, the number of lactating dairy cows ($N_{lactating\ dairy\ cows} = N_{dairy\ cows\ (total)} – N_{non-lactating\ dairy\ cows}$) and the number of non-lactating dairy cows ($N_{non-lactating\ dairy\ cows} = [N_{dairy\ cows\ (total)} * P_{non-lactating\ dairy\ cows}]$) was estimated.

Non-lactating dairy cows	Comprising *only* non-lactating dairy cows kept for fattening purposes (i.e. cull cows) Numbers of non-lactating dairy cows were partly based on statistics (1990-2007), partly estimated (2008-and onwards), for more details see livestock category “lactating dairy cows”.
Suckler cows	Comprising suckler cows.

Note in the CRF tables female calves and male calves were summarized and reported as one category, namely “calves”; female young cattle 1-2 years and heifers >2 years were summarized and reported as one category, namely “young cattle”; and non-lactating dairy cows and suckler cows were summarized and reported as one category, namely “other cows”.

For sheep the distinction was made between mature sheep and sheep lambs. Further was assumed that sheep kept on agricultural holdings would in general be livestock kept in high productivity systems, whereas sheep kept off-farms, which are in general backyard animals kept for leisure or landscape maintenance, were considered as being low productivity systems:

Mature sheep	Comprising all sheep ≥1 year; in the majority breeding females (~90%) (STATEC 2019c). The remaining animals are other mature sheep, but for simplicity reasons treated in the agricultural emission calculations as being 100% female breeding animals.
Sheep lambs	Comprising only lambs <1 year. Sheep lambs are born in early spring. The majority of them are fattened and slaughtered at the age of 5-7 months, (Kirchgessner M. , 2014c) and remaining animals are raised as replacement stock. Approximately 80% (range 75%-85% (Vaessen Personal communication; December 2018)) of the fattening lambs were assumed to be slaughtered at the age of 6 months. The average animal population was corrected following IPCC guidelines (Gavrilo, et al., 2019)[98].

For swine we distinguished between sows, fattening pigs and weaners, , all of them assumed to be kept in high productivity systems.

Sows	Comprising mated sows, sows with piglets and mated young sows.
Weaners	Comprising piglets with a weight between 10-30 kg, i.e. weaners.
Fattening pigs	Comprising fattening pigs >30 kg (>90%) (STATEC 2019c) and growing not mated female breeding swines >30 kg and all male breeding swines >30 kg. For simplicity reason, these swine’s’ are treated in the emission calculations as being fattening pigs.

Note: Emissions from piglets <10 kg were considered within the “sow” category, respectively “breeding pigs” in the CRF tables.

For poultry (reported in the CRF tables as one category) we distinguish between laying hens, broilers and other poultry, all of them assumed to be kept in high productivity systems:

Laying hens	Comprising laying hens and chicks up to 6 months

98 Annual average population = (Number of lambs raised * 20%) + ((6*30) * ((Number of lambs raised * 80%)/365)). Note the number of sheep lambs raised was derived from the number of mature sheep.

Broilers	Comprising only broilers
Other poultry	Comprising all other poultry categories, but subtracting ostriches, which were considered in a separate category.

For goats (reported in the CRF tables as one category) we distinguished between mature goats and goat kits. Further was assumed that dairy goats are in general livestock kept in high productivity systems, whereas all other goats, independent if kept on or off-farms are backyard animals, kept for leisure or landscapre maintenance, and therefore considered as being kept in low productivity systems:

Mature goats	Comprising all goats ≥1 year, in the majority goat ewes (STATEC 2019c). The remaining animals are other mature goats, but for simplicity reasons treated in the agricultural emission calculations as being 100% goat ewes.
Goat kits	Comprising goat kids <1 year. Goat kids are born in early spring. Male dairy goats kits (assumption to be 50%) are fattened and slaughtered at the age of 5-7 weeks. Female goat kits are raised as replacement stock (own survey)[99]. It was therefore assumed that ~50% of the dairy goat kits would be slaughtered at the age of 6 weeks, and adapted the average animal population following IPCC guidelines (IPCC, 2019 Refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Chapter 10 Emissions from Livestock and Manure Management., 2019a)[100].

Horses, including mules and asses:

Horses	Comprising horses, mules and asses. For horses, it was further distinguished, between heavy agriculture horses, riding horses and ponies. Mules and asses were considered together with the ponies.

Note emissions from mules and asses were considered together with horses, why using in the CRF tables the notation key "IE".

For rabbits (reported in the CRF tables as one category) we distinguished between breeding female animals and other rabbits:

Breeding female animals	Comprising breeding female animals. Estimated emissions include the raising of young stock, but no fattening.
Other rabbits	Comprising all other rabbits, mainly fattening rabbits

Other animal categories considered were deer and ostriches:

Deer	All other registered animals are considered in this category, the majority (>90%) were deer's.
Ostriches	Comprising only ostriches

99 Own survey conducted in November 2018 between goat famers keeping in 2017 approximately 70% of the goat ewes in Luxembourg, and confirmed by unpublished data collected by the "landwirtschaftliche Testbetriebsnetz " (LTBN), i.e. the Luxemburgish Farm accounting data network (FADN)-partner (Pers. communication Marc Schmit and Paul Jacqué, SER - Comptabilité, December 2018). For more details on the LTBN see: https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html, and on the FADN see http://ec.europa.eu/agriculture/rica/.

100 Annual average population = (Number of goat kits raised * 50%) + ((6*7) * ((Number of kits reaised * 50%)/365)). Note the number of goat kits raised was derived from the number of mature goats.

5.2.2 Activity data

5.2.2.1 Livestock numbers - General

Activity data on animals numbers are summarized in Table 5-5. Activity data were in general based on the agricultural census conducted annually in spring[101] by STATEC (Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg)[102] in later years in collaboration with SER (Service d'Economie Rurale) (STATEC 2018) [103], and since 2017 only by SER. In the Agriculture census, all farms situated in Luxemburg with either ≥10 horses, or ≥10 cattle, or ≥20 small ruminants, or ≥50 fattening pigs, or ≥10 breeding female pigs (>50 kg), or ≥1000 poultry birds or ≥ 1000 rabbits were taken into account. The response rate was ~95%. The number of animals as counted on the reference data in spring was assumed to represent the animal numbers at any other possible reference data in the same year, except for:

- cattle from 2014 onwards;
- swine from 2020 onwards;
- laying hens from 2020 onwards.

In addition, were adjustement made to account for the fact that some animals are kept outside agricultural holdings, and hence not covered by the agricultural census. This was done for equidae and for small ruminants.

Cattle

Agriculture census data was used for the period 1990-2013, and from 2014 onwards were average numbers as extracted from the "SANITEL" database used. In Luxemburg each single cattle must be registered and is followed from birth or import until end of life (slaughter or natural death) or export, whatever comes first. All those movements are registered in the "SANITEL" database[104], hence a 100% coverage of the cattle population and their evaluation throughout the year.

Swine

Agriculture census data was used for the period 1990-2019; and from 2020 onwards were data from the agricultural census in spring and the swine census on the 1st of December[105] used for estimating the "average population".

Laying hens

Agriculture census data was used for the period 1990-2019, and from 2020 onwards were data from the agricultural census in spring and a laying hens survey on the 31th December, and on 31th December from previous year[106] used. The median of this three data

101 Reference date: Until 2010 15th Max; 2011-2021: 1st April and from 2022 onwards 1st February

102 https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CEntreprises%23D%23%7CAgriculture%20et%20foresterie%23D2%23&pg=0&fc=Th%C3%A8mes&df[ds]=release&df[id]=DF_D2107&df[ag]=LU1&pd=1990%2C2021&dq=.A

103 A short description of the underlying legislation and other details can be found on: https://statistiques.public.lu/en/methodology/methodes/enterprises/Agriculture/agriculture/index.html accessed on 24-02-2019

104 ALVA, 2023, Identifizierung und Rückverfolgbarkeit – Rinder, Administration luxembourgeoise vétérinaire et alimentaire (ALVA). https://agriculture.public.lu/de/tierhaltung/nutztiere/identifizierung-ruckverfolgbarkeit/rinder.html Accessed on. 23-01-2023

105 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale), Division des statistiques agricoles, des relations extérieures et des marchés agricoles. Data is available on : https://agriculture.public.lu/de/agrarstatistik/production-animale/animaux/tiere-jahr.html.

106 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agricoles, des relations extérieures et des marchés agricoles.

points was used to obtain the "average population" in year *x*. For all other poultry categories was the agriculture census data the only data source used.

Horses, mules and anes

In the agricultural census in spring was data collected on the number of horses, mules and anes ***kept on agricultural holdings***. However, the data collection had changed over the years, and adjustement were necessary for:

- the number of horses in pension on agricultural holdings were missing for the period 1990-1998, a trend estimate based on the years 1999-2021 was used;
- the number of mules and anes kept on agricultural holdings were missing for the years 1990-2004, a trend estimate based on the years 2005-2009 was used;
- and further were heavy horses, riding horses and ponys not always collected as separate categories, hence a splitting of the collected data was required for some years, using the observed trend of the following years.

There were no data available on the number of equidae ***kept off-farms***. Presuming that half of the equidae in Luxembourg would be kept on agricultural holdings, the number of equidae kept on agricultural holdings was multiplied by two to obtain the total equidae population in Luxemburg.

Small ruminants

In the agricultural census were data collected on sheep and on goats ***kept on agricultural holdings***. Due to large fluctuations of the number of sheep lambs and goat kits over the years, was the number of sheep lambs and goat kits born and raised estimated assuming 1.165 sheep lambs raised per sheep ewe for non-dairy breeds, 1.5 sheep lambs raised per sheep ewe for dairy breeds and 0.81 goat kits raised per goat ewe.[107]

Data on the number of small ruminants kept off-farms were missing. In 2020-2021 the veterinary authority counted roughly 1000 small ruminant holders. The agricultural census however counted <400 holders, hence roughly 600 holders keeping small ruminants off-farms. Assuming that agricultural holdings with less than 50 small ruminants would be comparable to small ruminants' herds off-farms (i.e. median was 7 small ruminants including lambs and kits in 2020), estimates of the number of sheep and goats kept off-farms were made for 2020. And for all other years (1990-2019 and 2021-2022), it was assumed that the number of small ruminants kept off-farms were comparable to 2020.

107 Estimates were based on farms within the LTBN (Source: SER) and validated by comparing the so estimated numbers of lambs/kits with the agricultural census data. They were considered as being valid, as the estimates would have been in all the years (1990-2021) higher than the census data.

Table 5-5 – Average animal numbers (heads/animal places) per year per livestock category for the period 1990-2022

3 - Agriculture

Activity data - annual average population (heads/animal places per year (* 1000))

Year	Calves < 1 year	Female young cattle 1-2 years[a]	Heifers >2 years[a]	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows[b]	Non lactating dairy cows[b,c]	Suckler cows[c]	Sows	Fattening pigs[d]	Weaners[d,e]	Sheep[f,g]	Goats [f,h]	Horses[i,j]	Broilers	Laying hens[k]	Other poultry [l]	Ostriches [l]	Rabbits[m]	Deer
1990	59.6	34.0	24.6	13.0	5.4	58.8	4.5	17.6	9.0	33.2	19.2	9.3	0.7	3.6	11.2	57.8	2.26	0.00	13.5	0.09
1991	59.3	34.4	25.7	13.6	5.6	55.6	5.1	20.2	8.5	28.4	17.0	9.6	0.8	3.8	10.9	52.7	2.06	0.00	13.6	0.16
1992	56.2	33.8	25.0	12.7	4.7	51.1	4.8	20.9	8.6	30.6	16.4	9.5	0.7	3.8	9.5	50.8	1.82	0.00	12.0	0.13
1993	55.7	32.3	25.0	13.7	4.7	50.2	4.3	23.0	8.6	33.6	16.9	8.7	0.7	4.0	9.9	53.6	1.62	0.00	8.6	0.13
1994	58.0	31.9	22.6	14.1	4.2	49.0	4.3	24.6	8.6	30.9	17.0	10.1	0.6	4.4	9.3	51.1	1.52	0.00	7.7	0.18
1995	57.6	33.0	23.7	15.3	4.9	48.6	4.8	26.0	8.9	33.0	17.8	10.3	0.5	4.5	8.5	47.1	1.80	0.00	7.2	0.18
1996	59.1	33.0	24.6	16.2	5.1	48.0	5.1	26.8	8.6	31.6	18.7	9.7	0.4	4.6	10.3	51.6	1.59	0.00	5.9	0.14
1997	57.0	32.7	23.2	16.7	5.6	46.3	4.7	26.2	8.7	36.1	18.1	10.1	0.5	4.8	19.6	46.7	1.94	0.00	7.2	0.17
1998	55.3	31.4	23.0	17.1	5.3	46.0	4.7	26.0	8.7	36.6	20.3	10.6	0.4	4.9	21.3	47.1	1.39	0.00	6.8	0.28
1999	55.4	30.8	23.1	16.6	4.8	45.1	5.1	27.0	8.3	39.2	22.0	10.7	0.3	5.9	13.5	48.6	0.98	0.00	6.1	0.33
2000	54.8	30.6	22.6	16.4	4.4	43.3	5.3	27.6	7.6	38.5	19.7	10.7	0.4	6.6	14.2	57.6	0.85	0.00	6.6	0.38
2001	54.3	30.3	22.7	16.7	4.8	42.9	5.0	28.4	7.8	38.4	18.9	11.4	0.4	6.5	17.6	66.7	1.00	0.00	6.5	0.34
2002	53.7	28.1	21.4	15.0	4.2	42.1	4.9	27.9	7.6	39.7	19.1	11.1	1.1	6.5	16.0	61.9	0.96	0.00	7.0	0.32
2003	51.3	28.0	20.1	14.3	3.8	40.6	4.4	27.1	7.4	44.4	18.9	12.8	1.8	7.2	15.3	64.0	1.01	0.20	6.5	0.24
2004	50.8	27.7	19.8	13.8	3.6	39.9	4.1	27.1	7.2	54.7	16.6	12.7	2.3	7.7	12.2	60.9	1.08	0.27	6.6	0.29
2005	49.2	27.6	19.6	14.5	3.4	39.3	4.1	27.6	7.4	58.0	18.9	12.3	2.3	9.0	20.3	63.1	1.12	0.21	6.5	0.25
2006	49.5	27.8	19.0	14.0	3.2	38.6	3.6	28.0	7.1	54.7	16.9	13.1	2.1	8.6	19.3	62.0	1.15	0.17	6.8	0.25
2007	52.7	29.1	20.0	14.4	2.8	39.0	4.0	28.9	6.9	54.2	17.4	11.9	2.4	8.5	17.5	64.4	0.81	0.18	4.8	0.19
2008	52.1	29.3	18.4	16.5	3.2	40.0	3.6	32.6	6.6	54.0	16.0	11.9	3.2	8.9	8.1	73.3	0.63	0.21	4.1	0.34
2009	52.4	29.4	18.3	15.4	3.8	40.6	3.7	32.8	6.6	54.2	15.7	12.3	3.5	9.0	17.3	80.1	0.83	0.23	4.1	0.34
2010	52.2	30.3	18.6	16.5	3.7	41.3	3.7	32.5	6.5	46.2	21.9	12.1	5.0	9.1	17.2	72.4	0.54	0.20	3.5	0.33
2011	52.3	29.7	17.2	14.3	3.2	40.5	3.7	31.7	6.0	50.8	22.2	12.3	5.0	9.1	17.5	84.1	0.68	0.33	2.8	0.43
2012	52.5	29.8	16.3	13.1	2.8	39.8	3.6	30.5	5.7	54.3	19.1	12.0	5.7	9.7	17.8	95.0	1.54	0.21	3.6	0.38
2013	53.3	30.2	16.3	14.4	3.1	42.1	4.1	30.2	5.4	53.7	17.5	12.2	4.8	9.3	15.6	95.7	0.85	0.34	3.4	0.27
2014	54.1	31.0	20.9	15.4	3.3	41.9	4.1	28.8	5.3	54.8	17.4	12.4	4.5	9.3	15.4	100.1	1.01	0.18	3.0	0.27
2015	53.6	32.0	21.8	13.9	3.5	43.4	4.3	28.4	4.9	60.0	19.9	13.0	5.3	9.3	18.4	95.3	0.96	0.26	2.7	0.24
2016	54.4	32.0	21.0	12.2	3.1	46.5	4.6	27.9	4.9	60.0	18.5	12.4	5.2	9.0	18.9	95.3	0.87	0.25	2.8	0.17
2017	52.3	33.1	21.1	12.0	3.1	47.6	4.7	27.2	5.3	61.8	19.9	12.0	5.2	9.3	20.9	101.7	1.26	0.20	2.4	0.12
2018	49.9	31.9	21.8	11.2	3.1	48.0	4.7	25.6	5.2	57.1	19.2	12.0	5.4	9.3	22.1	101.4	0.77	0.21	2.8	0.15
2019	50.2	31.0	19.8	10.3	3.0	49.0	4.8	25.1	4.5	51.9	20.0	11.9	5.1	9.3	21.4	110.7	0.60	0.24	2.4	0.05
2020	49.4	31.6	18.9	10.1	2.9	49.5	4.9	24.3	4.0	53.0	15.2	13.0	5.5	8.8	20.9	116.5	0.55	0.22	2.1	0.04
2021	49.1	31.1	18.1	9.7	2.8	49.7	4.9	23.3	3.1	55.2	11.1	13.5	5.8	8.5	51.1	110.6	0.61	0.20	2.2	0.04
2022	47.7	31.4	17.7	9.9	2.9	50.0	4.9	22.3	2.4	52.5	8.2	13.9	5.8	8.7	54.1	120.3	0.58	0.13	2.1	0.04
Trend 1990 -2022	-20%	-8%	-28%	-24%	-48%	-15%	9%	27%	-74%	58%	-57%	49%	709%	142%	382%	108%	-75%	NA	-84%	-53%
Trend 2021 -2022	-3%	1%	-2%	2%	2%	1%	1%	-4%	-23%	-5%	-26%	3%	1%	2%	6%	9%	-5%	-35%	-6%	16%

Explication notes for Table 5-5:

a) In the CRF Tables were female young cattle 1-2 years and heifers >2 years reported as one category, namely "young cattle".

b) Up to 2007 were dairy cows registered in two categories, i) lactating dairy cows, and ii) non-lactating dairy cows with the purpose to be fattened and slaughtered, but since 2008 there was no further distinction made. From 1990-2007, did non-lactating dairy cows on average account for 9.15% of the total dairy cow population (range 7.1%-10.8%). Assuming that the percentage of non-lactating dairy cows remained the same, the number of non-lactating dairy cows were estimated for the years 2008 and onwards and subtracted from the total number of dairy cows in order to obtain the number of "lactating dairy cows". Non-lactating dairy cows were considered together with suckler cows in the animal category "other cows".

c) Suckler cows and non-lactating dairy cows were considered together in the animal category “other cows”.
d) For the period 1990-2009 there was a subcategory of fattening pigs from 20 kg-50 kg. To suit our animal categories, this category was split up, whereby assuming that 2/3 would have been fattening pigs >30 kg and 1/3 would have been weaners. From 2010 onwards, statistics were collected accordingly to the live weights used in the current inventory, i.e. fattening pigs >30 kg and weaners 10-30 kg. Note the number of pig farmers and the number of pigs is relatively low in Luxemburg compared to our neighboring countries. This fact together with a strong reorientation of the sector in the whole period, and the fact that some of the pig famers work on contract basis - in particularly those raising weaners and fattening pigs – is an explication for the observed fluctuations between years.
e) Piglets staying with the sow up to 10 kg weight were not considered as a separate category in the emission calculation - a category also registered in the census. Since 2010 were those registered as a separate category. For the time period 1990-2009, it was assumed that 50% of the piglets <20 kg would be weaners, and the other 50% would be newborn piglets <10 kg staying with the sows. The total for swine from the inventory differs therefore from the one reported by STATEC and other international statistical institutes such as EUROSTAT.
f) The total of sheep and goats reported in this inventory varies from the one reported by STATEC, and other international statistical institutes because a) including also small rumiants kept off-farms; and b) the majority of sheep lambs and goat kids were fattened and sold previous to one year of age. Following the IPPC guidelines the average number of animals were corrected; and is the number of lambs and kits born and raised derived from the number of ewes.
g) In the inventory the distinction is made between mature sheep and lambs; and further between high productivity systems (i.e. assumed to be sheep kept on farms), and low productivity systems (i.e. backyard animals kept off farms). For average annual population data see Table A3- 1 in Annex 3 A. Note in the CRF table mature sheep (high and low productivity systems) lambs (high and low productivity systems) are reported as one category.
h) In the inventory the distinction is made between mature goats and goat kits; and further between high productivity systems (i.e. dairy does and kits) and low productivity systems (i.e. other goats). For average annual population data see Table A3- 1 in Annex 3 A. Note in the CRF table goats are reported as one category.
i) The total of horses reported in this inventory varies from the one reported by STATEC, and other international statistical institutes because a) including also horses kept off-farms; and b) due to adjustment made to correct for adapted data collection over time.
j) Mules and asses are included in the category “horses”.
k) There were two categories, namely laying hens and chicks older than 6 months up to 2004. Since 2005, however are chicks older than 6 months and laying hens considered as one category.
l) In the published statistics were ostriches included in “other poultry”. Ostriches were considered as a separate category and therefore subtracted from this category.
m) In the CRF tables reported as one category, but for the emission calculations the distinction is made between breeding female animals and other rabbits (i.e. fattening rabbits). For average annual population data see Table A3- 1 in Annex 3 A.

5.2.2.2 Temporary export and import of grazing animals over the summer months

A part of the utilized agriculture surface cultivated by luxemburgish farmers were situated in neighbouring countries. During summer months were the animals grazing on these fields "temporary" exported to neighbouring countries, see Table 5-6. The same applied the other way around, so were grazing animals from German, Belgium or France imported, see Table 5-6 for grazing in Luxemburg on fields cultivated by German, Belgium and/or French farmers. In the inventories were only animals grazing in Luxemburg considered.

The temporary transfers had to be notified to the Luxemburgish animal health authorities, who published since 2001 annually the number of transferred animals.[108] The majority of these transfers were cattle. Transfers from other animal categories were rather seldom and included only very few animals, why ignored in the inventories. Having no data for the period 1990-2000, the observed trend for the years 2001-2006 was taken. The number of exported and imported animals is reported in Table 5-6, as well as the applied correction factor used in divers calculations.

Detailed information on the age of the exported and imported livestock were not available, but as mostly female cattle was the assumption made that 50% of the cattle would have been young female cattle 1-2 years old and 50% would have been heifers >2 years old.

Table 5-6 – Temporary net exported grazing cattle (heads/year) and applied correction factor for the period 1990-2022

3 - Agriculture					
	Activity data - Temporary exported and imported grazing cattle (head/year)			Activity data - Correction factor for net exported grazing livestock category *i* (i.e. percentage of net exported animals in comparison to average number of animals in livestock category *i*)	
Year	Exported number of cattle	Imported number of cattle	Net export of cattle	Female young cattle 1-2 years	Heifers >2 years
	heads	heads	heads	%	%
1990	*5 451*	*649*	*4 803*	*0.07*	*0.10*
1991	*5 383*	*610*	*4 772*	*0.07*	*0.09*
1992	*5 314*	*572*	*4 742*	*0.07*	*0.09*
1993	*5 245*	*533*	*4 712*	*0.07*	*0.09*
1994	*5 176*	*494*	*4 682*	*0.07*	*0.10*
1995	*5 107*	*456*	*4 652*	*0.07*	*0.10*
1996	*5 039*	*417*	*4 622*	*0.07*	*0.09*
1997	*4 970*	*378*	*4 591*	*0.07*	*0.10*
1998	*4 901*	*340*	*4 561*	*0.07*	*0.10*
1999	*4 832*	*301*	*4 531*	*0.07*	*0.10*
2000	*4 763*	*263*	*4 501*	*0.07*	*0.10*
2001	4 800	108	4 692	0.08	0.10
2002	4 423	318	4 105	0.07	0.10
2003	4 401	98	4 303	0.08	0.11
2004	4 740	240	4 500	0.08	0.11
2005	4 669	-	4 669	0.08	0.12
2006	4 103	-	4 103	0.07	0.11
2007	3 776	12	3 764	0.06	0.09
2008	4 191	59	4 132	0.07	0.11
2009	4 297	28	4 269	0.07	0.12
2010	4 102	39	4 063	0.07	0.11
2011	4 818	8	4 810	0.08	0.14
2012	5 421	90	5 331	0.09	0.16
2013	5 359	44	5 315	0.09	0.16
2014	4 497	120	4 377	0.07	0.10
2015	4 637	507	4 130	0.06	0.09
2016	4 668	151	4 517	0.07	0.11
2017	4 312	741	3 571	0.05	0.08
2018	4 460	629	3 831	0.06	0.09
2019	3 932	25	3 907	0.06	0.10
2020	3 735	-	3 735	0.06	0.10
2021	5 725	386	5 339	0.09	0.15
2022	3 558	817	2 741	0.04	0.08

Source: For 2001 and onwards: annual reports of the Ministry of Agriculture.
Note: In Italic estimations for the years 1990-2000.

108 Publication in the annual activity reports ("Rapport d'activité") from the ministry of agriculture later years are available online at https://agriculture.public.lu/de.html .

5.2.3 Manure management system

5.2.3.1 General

For the emission calculations were for the different animal categories information required on:

- the fraction (or proportion) of the year that animal *i* spend in:
    - grazing ($x_{grazing\ (i)}$);
    - on yards (i.e. not occurring in Luxemburg);
    - and buildings ($x_{build(i)} = (1 - x_{grazing(i)})$)[109]
- the proportion of livestock manure handled as:
    - slurry ($x_{slurry\ (i)}$), whereby, depending on animal category different housing systems were further distinguished (for more details see 5.1.1.2);
    - and as solid ($x_{solid(i)}) = (1 - x_{slurry(i)}$), whereby, depending on animal category different housing systems were further distinguished (for more details see 5.1.1.2);
- for slurry further was required, what proportion of slurry[110]:
    - was spread directly ($x_{spread\_direct\_slurry(i)}$) (Not occurring);
    - was used as feedstocks in biogas facilities ($x_{feed\_slurry(i)}$);
    - was stored before application ($x_{store\_slurry(i)} = (1 - x_{feed\_slurry(i)}$). Please note, in the inventories a further distinction was made on how slurry was stored (for more details see 5.1.1.4.1).
- for solid manure was further required, what proportion of solid manure[111]:
    - was spread directly ($x_{spread\_direct\_solid(i)}$) (Not occurring in Luxemburg);
    - was used as feedstocks in biogas facilities ($x_{feed\_solid(i)}$);
    - was stored before application ($x_{store\_solid(i)} = (1 - x_{feed\_solid(i)})$). Please note, in the inventories a further distinction was made on how solid manure was stored (for more details see 5.1.1.4.2).

Please note that

- yards are uncommon in Luxembourg, and where then existing, integrated in the building with similar liquid/slurry management system as the rest of the housing. Yards were therefore not considered in the emission calculations as a separate category, but as building;
- direct spreading of slurry is not occurring in Luxembourg;
- direct spreading of solid manure is not occurring in Luxembourg.

The different manure management systems (MMS) were then calculated using the following formulas:

109 Note: Yards, where than existing, are integrated in the building, and therefore not considered in the emission calculations as a separate category, but in xbuild.

110 Note: Slurry is either stored on the farm or used as feedstocks. Direct spreading of slurry is not occurring in Luxemburg.

111 Note: Solid manure is stored on the farm before spreading. Direct spreading is not occurring in Luxemburg. Also is it not common practice to use solid manure as feedstocks, why assumed to be zero.

- MMS- pasture$_{(i)}$ = $x_{grazing\ i}$; i.e. the proportion of excreta deposited during grazing for animal category *i*, see Table 5-7 including livestock grazing in neighbouring countries;
- MMS-feed_slurry$_{(i)}$ = ($x_{digester\_slurry\ i}$ / ($x_{building\ i}$)); i.e.the proportion of excreta deposited during housing in stables with a liquid/slurry management system, whereby slurry is used as feeding material for bio digester, see Table 5-8;
- MMS-liquid$_{(i)}$ = ($x_{store\_slurry\ i}$ / ($x_{building\ i}$)). i.e. the proportion of excreta deposited during housing in stables with a liquid/slurry management system, whereby slurry is stored on the farm, see Table 5-9;
- MMS-feed_solid$_{(i)}$ = ($x_{digester\_solid\ i}$ / ($x_{building\ i}$)). i.e.the proportion of excreta deposited during housing in stables with livestock *i* kept on solid manure, whereby solid manure is used as feeding material for bio digester, see Table 5-10;
- MMS-solid$_{(i)}$ = ($x_{store\_solid\ i}$ / ($x_{building\ i}$)). i.e. the proportion of excreta deposited during housing in stables with livestock *i* kept on solid manure and solid manure is stored on the farm, see Table 5-11;
- with *i* = for animal category *i*.

Table 5-7 – Manure management system pasture (MMS-pasture) for all animal categories: 1990-2022.

3 -Agriculture

Manure management system - pasture (MMS-pasture) for animal category *i*
(i.e. the proportion of excreta deposited during grazing)

Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	37%	49%	49%	0%	16%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1991	37%	49%	49%	1%	17%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1992	37%	49%	49%	1%	18%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1993	37%	49%	49%	1%	19%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1994	37%	49%	49%	2%	20%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1995	37%	49%	49%	2%	20%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1996	37%	49%	49%	2%	21%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1997	37%	49%	49%	4%	19%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1998	37%	49%	49%	3%	22%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
1999	37%	49%	49%	3%	21%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
2000	37%	49%	49%	3%	23%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
2001	37%	49%	49%	3%	23%	25%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	NO	0%	75%
2002	37%	49%	49%	3%	26%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	NO	0%	75%
2003	37%	49%	49%	3%	27%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2004	37%	49%	49%	2%	30%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2005	37%	49%	49%	3%	29%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2006	37%	49%	49%	3%	32%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2007	37%	49%	49%	8%	35%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2008	37%	49%	49%	8%	35%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2009	37%	49%	49%	8%	33%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2010	37%	49%	49%	10%	36%	25%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2011	36%	49%	49%	8%	32%	24%	24%	50%	0%	0%	0%	75%	0%	51%	0%	0%	0%	76%	0%	73%
2012	34%	49%	49%	8%	36%	23%	23%	51%	0%	0%	0%	75%	0%	52%	0%	0%	0%	76%	0%	72%
2013	33%	48%	49%	9%	40%	23%	23%	52%	0%	0%	0%	75%	0%	54%	0%	0%	0%	76%	0%	70%
2014	32%	48%	48%	10%	37%	22%	22%	53%	0%	0%	0%	75%	0%	55%	0%	0%	0%	77%	0%	68%
2015	30%	48%	48%	10%	37%	21%	21%	54%	0%	0%	0%	75%	0%	56%	0%	0%	0%	77%	0%	66%
2016	29%	47%	48%	9%	38%	20%	20%	55%	0%	0%	0%	75%	0%	58%	0%	0%	0%	77%	0%	64%
2017	28%	47%	48%	9%	41%	19%	19%	55%	0%	0%	0%	76%	4%	56%	0%	0%	0%	78%	0%	62%
2018	26%	47%	47%	9%	38%	18%	18%	54%	0%	0%	0%	77%	7%	54%	0%	0%	0%	78%	0%	60%
2019	25%	46%	47%	8%	42%	17%	17%	54%	0%	0%	0%	78%	10%	52%	0%	0%	0%	78%	0%	58%
2020	23%	46%	47%	8%	41%	16%	16%	54%	0%	0%	0%	79%	14%	50%	0%	0%	0%	79%	0%	56%
2021	23%	46%	47%	8%	41%	16%	16%	54%	0%	0%	0%	79%	14%	50%	0%	0%	0%	79%	0%	56%
2022	23%	46%	47%	8%	41%	16%	16%	54%	0%	0%	0%	79%	14%	50%	0%	0%	0%	79%	0%	56%

Table 5-8 – Manure management system – digester-slurry (MMS-digester-liquid) for all animal categories: 1990-2022.

3 -Agriculture

Manure management system - digester-liquid (MMS-digester-liquid) for animal category *i*
(i.e. the proportion of excreta deposited during housing in stables with a liquid/slurry management system and slurry being used as feeding material for bio digesters)

Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1991	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1992	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1993	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1994	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1995	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1997	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1998	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1999	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2000	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2001	0%	0%	0%	0%	0%	0%	0%	0%	2%	2%	2%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2002	0%	0%	0%	0%	0%	0%	0%	0%	2%	3%	2%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2003	0%	0%	0%	1%	0%	1%	1%	0%	3%	4%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2004	1%	1%	1%	2%	1%	2%	2%	0%	9%	10%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2005	1%	2%	2%	3%	1%	4%	4%	1%	14%	16%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2006	1%	2%	2%	4%	1%	5%	5%	1%	18%	20%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2007	2%	3%	2%	4%	1%	5%	5%	1%	21%	23%	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2008	2%	3%	3%	5%	2%	6%	6%	1%	21%	24%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2009	2%	3%	3%	5%	2%	7%	7%	1%	22%	25%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2010	2%	4%	4%	5%	2%	8%	8%	1%	25%	29%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2011	2%	4%	4%	6%	2%	9%	9%	1%	23%	26%	26%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	2%	4%	4%	6%	2%	9%	9%	1%	21%	24%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013	2%	5%	4%	6%	2%	10%	10%	1%	21%	25%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2014	3%	5%	4%	6%	2%	10%	10%	1%	20%	24%	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2015	3%	5%	5%	6%	3%	11%	11%	1%	19%	22%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2016	3%	6%	5%	6%	3%	13%	13%	1%	20%	24%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2017	3%	6%	5%	6%	3%	13%	13%	1%	16%	19%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2018	3%	6%	6%	7%	3%	14%	14%	1%	14%	17%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2019	3%	6%	6%	6%	3%	14%	14%	1%	14%	16%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	3%	6%	6%	6%	3%	14%	14%	1%	16%	19%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2021	3%	6%	6%	6%	3%	15%	15%	1%	12%	14%	14%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2022	3%	6%	5%	5%	2%	13%	13%	1%	15%	18%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 5-9 – Manure management system – liquid (MMS-liquid) for all animal categories: 1990-2022.

3 -Agriculture

Manure management system - liquid (MMS-liquid) for animal category *i*
(i.e. the proportion of excreta deposited during housing in stables with a liquid/slurry management system and manure being stored on the farm)

Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	19%	27%	22%	56%	19%	52%	52%	12%	78%	78%	74%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1991	19%	27%	22%	56%	19%	52%	52%	12%	78%	79%	74%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1992	19%	27%	22%	55%	18%	52%	52%	12%	78%	80%	75%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1993	19%	27%	22%	55%	18%	52%	52%	12%	78%	80%	76%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1994	19%	27%	22%	55%	18%	51%	51%	12%	78%	81%	77%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1995	19%	27%	22%	55%	18%	51%	51%	12%	78%	82%	78%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1996	19%	27%	22%	55%	17%	51%	51%	12%	79%	82%	78%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1997	19%	27%	22%	53%	18%	51%	51%	12%	79%	83%	79%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1998	19%	29%	24%	52%	19%	56%	56%	12%	79%	83%	80%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1999	19%	29%	24%	52%	19%	56%	56%	12%	79%	84%	80%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2000	19%	29%	24%	51%	19%	57%	57%	12%	78%	84%	80%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2001	19%	29%	24%	51%	19%	56%	56%	11%	78%	84%	81%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2002	19%	29%	24%	50%	17%	56%	56%	11%	77%	84%	81%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2003	19%	28%	24%	50%	17%	55%	55%	11%	76%	83%	81%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2004	18%	28%	23%	48%	16%	54%	54%	11%	70%	77%	75%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2005	17%	28%	24%	47%	17%	56%	56%	10%	65%	72%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2006	17%	28%	24%	45%	16%	55%	55%	10%	62%	69%	67%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2007	16%	27%	23%	42%	14%	53%	53%	10%	59%	66%	65%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2008	16%	26%	23%	41%	14%	52%	52%	9%	59%	66%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2009	15%	26%	22%	40%	14%	51%	51%	9%	58%	65%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2010	15%	26%	24%	35%	14%	55%	55%	8%	55%	63%	62%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2011	15%	26%	24%	34%	14%	56%	56%	7%	57%	65%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	14%	27%	24%	34%	14%	56%	56%	7%	60%	68%	67%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013	14%	27%	24%	32%	13%	57%	57%	6%	59%	69%	68%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2014	14%	27%	24%	31%	13%	57%	57%	6%	60%	70%	69%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2015	14%	27%	24%	30%	13%	57%	57%	6%	62%	73%	72%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2016	13%	26%	23%	29%	13%	57%	57%	5%	61%	71%	71%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2017	13%	26%	23%	28%	12%	57%	57%	5%	65%	77%	76%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2018	13%	26%	23%	27%	12%	58%	58%	5%	67%	80%	79%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2019	13%	26%	24%	27%	12%	59%	59%	4%	68%	81%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	12%	27%	24%	26%	12%	60%	60%	4%	66%	79%	79%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2021	12%	27%	24%	26%	12%	60%	60%	4%	69%	83%	83%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2022	13%	27%	25%	27%	12%	62%	62%	4%	66%	79%	79%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 5-10 – Manure management system – digester-solid (MMS-digester-solid) for all animal categories: 1990-2022.

3 -Agriculture

Manure management system - digester-solid (MMS-digester-solid) for animal category *i*

(i.e. the proportion of excreta deposited during housing in stables with a solid manure management system and solid manure being used as feeding material for bio digesters)

Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1991	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1992	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1993	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1994	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1995	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1997	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1998	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
1999	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2001	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2002	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	NO	0%	0%
2003	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2004	1%	0%	0%	1%	1%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2005	1%	0%	1%	1%	1%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	46%	0%	0%	0%	0%
2006	1%	1%	1%	1%	2%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	40%	0%	0%	0%	0%
2007	2%	1%	1%	2%	2%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	48%	0%	0%	0%	0%
2008	2%	1%	1%	2%	2%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	42%	0%	0%	0%	0%
2009	2%	1%	1%	2%	2%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%	45%	0%	0%	0%	0%
2010	2%	1%	1%	2%	2%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%	66%	0%	0%	0%	0%
2011	2%	1%	1%	3%	3%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%	57%	0%	0%	0%	0%
2012	3%	1%	1%	3%	3%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%	51%	0%	0%	0%	0%
2013	3%	1%	1%	3%	3%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%
2014	3%	1%	1%	3%	2%	1%	1%	2%	0%	0%	0%	0%	0%	0%	0%	48%	0%	0%	0%	0%
2015	4%	1%	2%	4%	3%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%
2016	4%	1%	2%	4%	3%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	47%	0%	0%	0%	0%
2017	4%	2%	2%	4%	3%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	44%	0%	0%	0%	0%
2018	5%	2%	2%	5%	4%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	44%	0%	0%	0%	0%
2019	5%	2%	2%	4%	3%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%
2020	5%	2%	2%	5%	4%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	39%	0%	0%	0%	0%
2021	5%	2%	2%	5%	3%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%
2022	5%	2%	2%	5%	4%	1%	1%	3%	0%	0%	0%	0%	0%	0%	0%	37%	0%	0%	0%	0%

Table 5-11 – Manure management system solid (MMS-solid) for all animal categories: 1990-2022.

3 -Agriculture

Manure management system - solid (MMS-solid) for animal category *i*

(i.e. the proportion of excreta deposited during housing in stables with livestock kept on solid manure and manure being stored on the farm)

Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	44%	23%	29%	44%	66%	24%	24%	38%	22%	22%	26%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1991	44%	23%	29%	44%	65%	24%	24%	38%	22%	21%	26%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1992	44%	23%	29%	44%	64%	24%	24%	38%	22%	20%	25%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1993	44%	23%	29%	43%	63%	24%	24%	38%	22%	20%	24%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1994	44%	23%	29%	43%	63%	24%	24%	38%	22%	19%	23%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1995	44%	23%	29%	43%	62%	24%	24%	38%	22%	18%	22%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1996	44%	23%	29%	43%	61%	24%	24%	38%	21%	18%	22%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1997	44%	23%	29%	42%	63%	24%	24%	38%	21%	17%	21%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1998	44%	22%	27%	45%	59%	20%	20%	39%	21%	16%	20%	25%	25%	51%	100%	100%	100%	NO	100%	25%
1999	44%	22%	26%	45%	60%	20%	20%	39%	21%	16%	19%	25%	25%	51%	100%	100%	100%	NO	100%	25%
2000	44%	21%	26%	46%	58%	19%	19%	39%	21%	15%	18%	25%	25%	51%	100%	100%	100%	NO	100%	25%
2001	44%	22%	26%	46%	59%	19%	19%	39%	21%	15%	18%	25%	25%	51%	100%	100%	100%	NO	100%	25%
2002	44%	22%	26%	46%	56%	19%	19%	39%	21%	14%	17%	25%	100%	51%	100%	100%	100%	NO	100%	25%
2003	44%	22%	26%	47%	56%	19%	19%	39%	21%	13%	16%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2004	44%	22%	26%	47%	53%	19%	19%	39%	20%	13%	15%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2005	44%	20%	24%	47%	52%	15%	15%	39%	20%	12%	14%	25%	100%	51%	100%	54%	100%	25%	100%	25%
2006	44%	20%	24%	47%	50%	16%	16%	39%	20%	11%	14%	25%	100%	51%	100%	60%	100%	25%	100%	25%
2007	44%	20%	24%	45%	47%	16%	16%	39%	20%	11%	13%	25%	100%	51%	100%	52%	100%	25%	100%	25%
2008	44%	20%	24%	45%	47%	16%	16%	39%	20%	10%	12%	25%	100%	51%	100%	58%	100%	25%	100%	25%
2009	44%	21%	25%	45%	49%	17%	17%	39%	20%	9%	11%	25%	100%	51%	100%	55%	100%	25%	100%	25%
2010	44%	19%	22%	48%	46%	11%	11%	40%	20%	9%	10%	25%	100%	51%	100%	34%	100%	25%	100%	25%
2011	45%	19%	22%	49%	48%	11%	11%	39%	20%	8%	10%	25%	100%	49%	100%	43%	100%	24%	100%	27%
2012	46%	19%	22%	50%	46%	11%	11%	39%	19%	7%	9%	25%	100%	48%	100%	49%	100%	24%	100%	28%
2013	48%	19%	22%	50%	43%	10%	10%	38%	19%	7%	8%	25%	100%	46%	100%	50%	100%	24%	100%	30%
2014	49%	19%	22%	51%	45%	10%	10%	38%	19%	6%	7%	25%	100%	45%	100%	52%	100%	23%	100%	32%
2015	50%	19%	22%	51%	45%	10%	10%	37%	19%	5%	6%	25%	100%	44%	100%	50%	100%	23%	100%	34%
2016	51%	19%	22%	52%	43%	10%	10%	36%	19%	5%	6%	25%	100%	42%	100%	53%	100%	23%	100%	36%
2017	52%	19%	22%	52%	41%	10%	10%	37%	19%	4%	5%	24%	96%	44%	100%	56%	100%	22%	100%	38%
2018	53%	19%	22%	52%	43%	9%	9%	37%	19%	4%	4%	23%	93%	46%	100%	56%	100%	22%	100%	40%
2019	55%	19%	22%	54%	41%	9%	9%	37%	19%	3%	3%	22%	90%	48%	100%	59%	100%	22%	100%	42%
2020	56%	19%	22%	55%	41%	9%	9%	38%	18%	2%	2%	21%	86%	50%	100%	61%	100%	21%	100%	44%
2021	57%	19%	22%	55%	41%	9%	9%	38%	18%	2%	2%	21%	86%	50%	100%	59%	100%	21%	100%	44%
2022	56%	19%	22%	55%	41%	9%	9%	38%	18%	2%	2%	21%	86%	50%	100%	63%	100%	21%	100%	44%

5.1.1.1 Grazing

Data on the length of the grazing period were available from surveys on agricultural production methods for the years 2010 (Gargano, L., Zangerlé G., Haupert J., & Hoffmann J.-P., 2014), 2016 and 2020[112]. For the ninties estimates based on expert judgment (Administration des service technique de l'agriculture (ASTA) 19 June 2007), whereby assuming that grazing animals are in general 6 months/year on pasture. Interpolated manure management system for the years 2000-2011 were produced by using the shares as derived from the 2010 SAPM (Gargano, L., Zangerlé G., Haupert J., & Hoffmann J.-P., 2014). In 2016 data on animal grazing was collected for dairy cows, for suckler cows, for horses and for small ruminants (i.e. sheep and goats) and linked at the level of individual herd sizes[113] to estimate average grazing time (MMS-pasture$_i$) for animal category *i* in year 2016. Based on the results, interpolated MMS-pasture for dairy cows, suckler cows, horses and sheep were estimated for the years 2011-2015, assuming a linear decrease/increase between 2010 and 2016. For goats, it was for simplicity reason assumed that the 2016 data would apply from 2002 onwards (i.e. MMS- pasture being 0.3%) corresponding with the installation of the first professional dairy farmer with a few hundred dairy goats in 2001/2002 and a few additional farmers to follow.

In 2020 data on animal grazing was collected for all animal categories in the agriculture census[114] and linked at the level of individual herd sizes to estimate average grazing time (MMS-pasture$_i$) for animal category *i* in the year 2020. An interpolation was applied for the period between the last two available measurements (i.e. 2016 for dairy cows, suckler cows, horses, goats and sheep; and 2010 for calves, female youngstock, including heifers >2 years and other grazing animals).

MMS pasture for 1-2 year old young bulls were based on the 2020 agricultural census observation on animal grazing and additional data allowing to distinguish for both animal categories between “animals kept for fattening purpose” and “other males”[115] (more details were presented in the NIR 2022 in Annex 3:B).

Without new data, the 2020 data were adopted in the following years.

The proportion of excreta deposited during grazing ($x_{grazing(i)}$), also referred as manure management system (MMS) – pasture (MMS-pasture$_{(ij)}$) for animal category *i* are summarized in Table 5-6 for the whole period.

5.1.1.2 Housing systems

5.1.1.2.1 Cattle

In the emissions calculations, the distinction is made between eight housing systems, whereof four housing systems with predominantly liquid manure, and four housing systems with predominantly solid manure.

The four housing systems with slurry were:

- Tied systems, predominantly slurry based;

112 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agri-coles, des relations extérieures et des marchés agricoles.

113 Opposite to EUROSTAT where data are linked to the agricultural holding https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Farm_structure_survey_(FSS)

114 Provisional data. Source: Service d’économie rurale (SER) – Division des statistiques agricoles, des relations extérieures et des marches agricoles. Institute responsable for data collection and data analyses

115 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agri-coles, des relations extérieures et des marchés agricoles. Institute responsable for data collection and data analyses

- Cubicle housing, predominantly slurry based
- Loose housing systems, predominantly slurry based
- Others

The four housing systems with solid manure were:

- Tied systems, predominantly solid manure based;
- Deep beeding system;
- Sloped floor systems with bedding;
- Others.

Frequency distributions of housing systems expressed in animal places for different cattle categories were available from surveys on agricultural production methods for the yearsin 1998 (STATEC, Le recensement agricole 1998, 1999), 2000 (STATEC, Le recensement agricoles 2000, 2001) , 2005 (STATEC, Le recensement agricole en 2005, 2006), 2010 (Gargano, L., Zangerlé G., Haupert J., & Hoffmann J.-P., 2014) and 2020[116]. For 1998, 2000 and 2005 frequency distributions were only available for cattle in general. For 2010, frequency distribution was available for calves <6 months; fattening bulls >8 months; male cattle >2 years; dairy cows; suckler cows; and for female cattle >6 months including also young male cattle 6-8 months: For 2020 frequency distribution were available for all cattle catego-ries, namely calves <1 year; female youngstock 1-2 years; heifers>2 years; young bulls 1-2 years; male cattle >2 years; dairy cows and suckler cows. In case of missing information, the splitting of categories was derived from existing frequency distibutions of 2020, and where available of 2010. For 1990 a trend estimate was made, and compared with published data on housing systems, expressed as number of stables (STATEC, Le recensement de l'agriculture 1989, 1990). The frequencies of cattle were estimated for the years 1990, 1998, 2000, 2005, 2010 and 2020, see Table 5-12, and by linear interpolation between those years. Without new data, the 2020 data were adopted in the following years.

In addition in 2020 it was stated whether the animals had adcess to an exercise yard or not. This information is not used for the time being.

116 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agri-coles, des relations extérieures et des marchés agricoles.

Table 5-12 – Frequency distributions of housing systems for cattle category *i*

3 -Agriculture Housing system$_{(j)}$ for cattle category *i*														
		Slurry based systems							Solid manure based systems					
Animal category		1990	1998	2000	2005	2010	2020		1990	1998	2000	2005	2010	2020
Calves < 1 year														
	Tied systems	21%	15%	14%	10%	2%	1%	Tied systems	31%	23%	21%	14%	7%	2%
	Cubicle loose housing	55%	59%	60%	62%	60%	64%	Deep bedding	67%	68%	65%	70%	54%	62%
	Fully slatted floor	25%	26%	27%	28%	17%	24%	Sloped floor	2%	10%	14%	16%	33%	32%
	Others	0%	0%	0%	0%	20%	10%	Others	0%	0%	0%	0%	6%	5%
Female young cattle 1-2 years														
	Tied systems	24%	17%	16%	11%	5%	2%	Tied systems	73%	61%	57%	44%	18%	8%
	Cubicle loose housing	56%	60%	61%	65%	70%	71%	Deep bedding	25%	29%	28%	36%	32%	39%
	Fully slatted floor	21%	22%	23%	24%	21%	23%	Sloped floor	1%	10%	15%	20%	44%	47%
	Others	0%	0%	0%	0%	5%	4%	Others	0%	0%	0%	0%	6%	6%
Heifers > 2 years														
	Tied systems	21%	15%	14%	10%	4%	2%	Tied systems	77%	66%	62%	50%	22%	10%
	Cubicle loose housing	62%	66%	67%	70%	75%	77%	Deep bedding	22%	26%	25%	33%	34%	42%
	Fully slatted floor	17%	19%	19%	20%	16%	18%	Sloped floor	1%	8%	13%	17%	40%	45%
	Others	0%	0%	0%	0%	5%	3%	Others	0%	0%	0%	0%	3%	3%
Fattening bulls 1-2 years														
	Tied systems	15%	10%	9%	7%	3%	4%	Tied systems	36%	24%	20%	13%	4%	3%
	Cubicle loose housing	17%	17%	18%	18%	19%	19%	Deep bedding	60%	54%	49%	52%	31%	32%
	Fully slatted floor	69%	72%	73%	75%	75%	74%	Sloped floor	4%	22%	31%	35%	55%	57%
	Others	0%	0%	0%	0%	3%	4%	Others	0%	0%	0%	0%	10%	8%
Mature male cattle > 2 years														
	Tied systems	5%	3%	3%	2%	1%	0%	Tied systems	61%	47%	43%	31%	11%	5%
	Cubicle loose housing	56%	57%	58%	58%	59%	58%	Deep bedding	37%	40%	37%	44%	38%	37%
	Fully slatted floor	39%	39%	40%	40%	35%	38%	Sloped floor	2%	14%	20%	25%	47%	54%
	Others	0%	0%	0%	0%	5%	4%	Others	0%	0%	0%	0%	4%	4%
Dairy cows														
	Tied systems	10%	7%	6%	4%	2%	1%	Tied systems	83%	76%	74%	63%	36%	13%
	Cubicle loose housing	83%	86%	86%	88%	91%	92%	Deep bedding	17%	22%	22%	30%	23%	38%
	Fully slatted floor	7%	7%	8%	8%	5%	5%	Sloped floor	0%	3%	4%	6%	19%	31%
	Others	0%	0%	0%	0%	3%	2%	Others	0%	0%	0%	0%	22%	19%
Suckler cows														
	Tied systems	67%	58%	55%	46%	24%	11%	Tied systems	71%	59%	54%	42%	17%	5%
	Cubicle loose housing	20%	26%	28%	33%	47%	57%	Deep bedding	27%	31%	30%	37%	31%	37%
	Fully slatted floor	13%	16%	17%	21%	17%	21%	Sloped floor	1%	10%	16%	21%	44%	52%
	Others	0%	0%	0%	0%	12%	12%	Others	0%	0%	0%	0%	8%	5%

Note: In Italic estimates

5.1.1.2.2 Swine

In the emissions calculations, the distinction is made between four housing systems, namely:.

- Fully slatted floors (slurry-based system);
- Partly slatted floors (slurry-based system);
- Non-slatted floors (predominantly slurry-based system);
- Deep bedding (i.e. the only solid manure-based system).

Frequency distributions of housing systems expressed in animal places for the three swine categories were available from surveys on agricultural production methods for the years 2010 (Gargano, L., Zangerlé G., Haupert J., & Hoffmann J.-P., 2014) and 2020[117]. For 1990 a trend estimate was made, and compared with published data on housing systems, expressed as number of stables (STATEC, Le recensement de l'agriculture 1989, 1990). Deep bedding was assumed to be the only solid manure-based system. For the frequency distribution of the slurry-based housing system for swine category *i,* see Table 5-13. The frequencies of swine were estimated for the years 1990, 2010 and 2020, and by linear interpolation between those years. Without new data, the 2020 data were adopted in the following years.

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Table 5-13 – Frequency distributions of slurry based housing systems for swine category *i*

3 -Agriculture				
Slurry based housing system$_{(i)}$ for swine category *i*				
		Slurry based systems		
Animal category		1990	2010	2020
Sows				
	Fully slatted floor	*22%*	54%	70%
	Partly slatted floor	*78%*	43%	28%
	Non-slatted floor		2%	2%
Fattening pigs				
	Fully slatted floor	*48%*	82%	99%
	Partly slatted floor	*52%*	18%	1%
	Non-slatted floor		0%	0%
Weaners				
	Fully slatted floor	*62%*	80%	89%
	Partly slatted floor	*38%*	20%	11%
	Non-slatted floor		0%	0%

Note: In Italic estimates

5.1.1.2.3 Poultry

Laying hens

In the emission calculation is the distinction for laying hens made between three housing systems, namely:

- Aviary/cages;
- Floor management (i.e. deep beeding) without outdoor access (hereafter referred to as “Deep beeding”);
- Floor management (i.e. deep beeding) with outdoor access/free range (hereafter referred to as “Free range”).

Frequency distributions of housing systems expressed in bird places for laying hens were available from surveys on price statistic for the year 2005[118] and on agricultural production methods for the years 2010 (Gargano, L., Zangerlé G., Haupert J., & Hoffmann J.-P., 2014) and 2020[119], see Table 5-14. The 2005 data were assumed to apply also for the period 1990-2004, whereby it cannot be excluded that the 13% of laying hens kept in aviaries in 2005 might have been in earlier years kept in cages. The frequencies of laying hens were estimated for the years 2005, 2010 and 2020 by linear interpolation between those years. Without new data, the 2020 data were adopted in the following years.

Table 5-14 – Frequency distributions of housing systems for poultry category *i*

3 -Agriculture Housing system$_{(j)}$ for poultry *i*						
Poultry category		1990	2005	2010	2020	2021
Laying hens						
	Aviary/cage	*13%*	13%	14%	40%	
	Deep beeding	*78%*	78%	73%	25%	
	Free range	*9%*	9%	14%	35%	
Broilers						
	Deep beeding	*80%*	80%	36%	25%	54%
	Free range	*20%*	20%	64%	75%	46%

Note: In Italic estimates

Broilers

In the emissions calculations the distinction is made between floor management without outdoor access, and floor management with outdoor access. Frequency distributions of housing systems expressed in bird places for laying hens were available from surveys on price statistic for the year 2005, 2010, 2020 and 2021[120], see Table 5-14. The 2005 data were assumed to apply also for the period 1990-2004. The frequencies of broilers were estimated for the years 2005, 2010 and 2020 by linear interpolation between those years. The large difference between 2020 and 2021 is due to the initiative of offering a new product/brand at the national market and hence a tripling of the broiler population within one year. Without new data, the 2021 data were adopted in the following years.

Other poultry and ostriches

In the emissions calculations the distinction is made between floor management without outdoor access and floor management with outdoor access.

118 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agri-coles, des relations extérieures et des marchés agricoles.

119 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agri-coles, des relations extérieures et des marchés agricoles.

120 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agri-coles, des relations extérieures et des marchés agricoles.

Frequency distributions of housing systems expressed in bird places for turekys, ostriches and other poultry were available from surveys on agricultural production methods for the year 2020[121]. The 2020 data were assumed to apply also for the period 1990-2019. Without new data, the 2020 data were adopted in the following years.

5.1.1.2.4 All other animals

No data was collected for other animal categories. Deep bedding (i.e. solid manure system) was the common housing system used.

5.1.1.3 Use of manure as feedstock in digester

5.1.1.3.1 Use of locally produced manure as feedstock in digester

National annual quantities of locally produced slurry and solid manure were compared with quantities of slurry and solid manure used in biogas facilities and locally produced in order to obtain the percentage of slurry and solid manure used in biogas facilities. The same livestock numbers and the same housing systems as used in the inventories were used for estimating national annual quantities of locally produced slurry and solid manure. The quantities of slurry and solid manure used as feed in biogas facilities and locally produced was derived by compiling annual individual plant reports describing the feedstock input and submitted to AEV, and in recent years completed using data provided by ASTA. Unpublished plant individual electricity or gas production, available since 1993 from the Institute Luxembourgeois de Régulation (ILR)[122], were used to impute missing information on the use of manure. The imputed value was based on previous/following self-reported data on used manure but corrected for the ratio observed between electricity / gas production for the year with known data and the year with missing data. The so-obtained MMS are summarized in Table 5-8 and Table 5-10.

5.1.1.3.2 Use of imported manure as feedstock in digester

In addition to the locally produced manure were also manure imported for being used as feedstock in biogas facilities. This occurred for the first time in 2016. The quantities of imported slurry and solid manure (expressed as kg N) for use as feedstock in biogas facilities is summarized in Table 5-15 and was derived by compiling annual individual plant reports describing the feedstock input and submitted to AEV. The percentage of TAN in the imported manure was assumed to be like locally produced manure when entering storage. The mix of separated swine manure and poultry manure was assumed to be 50% swine manure and the remainder would be poultry manure. For simplification it was assumed that poultry manure would originate 100% from laying hens; swine manure would originate 100% from fattening pigs and cattle manure would originate 100% from female young stock >1 year.

121 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agricoles, des relations extérieures et des marchés agricoles.
122 Institute Luxembourgeois de Régulation (ILR); Christian Meyers ; personal communication October 2021 and following years.

Table 5-15 – Imported quantities of manure to be used as feedstock in biogas facilities

3 - Agriculture

Activity data - Imported quantities of manure to be used as feedstock in biogas facilities (kg N/year)

Year	Poultry manure	Separated swine manure & dry poultry manure	Separated cattle slurry / cattle manure	Separated swine manure
1990	NO	NO	NO	NO
1991	NO	NO	NO	NO
1992	NO	NO	NO	NO
1993	NO	NO	NO	NO
1994	NO	NO	NO	NO
1995	NO	NO	NO	NO
1996	NO	NO	NO	NO
1997	NO	NO	NO	NO
1998	NO	NO	NO	NO
1999	NO	NO	NO	NO
2000	NO	NO	NO	NO
2001	NO	NO	NO	NO
2002	NO	NO	NO	NO
2003	NO	NO	NO	NO
2004	NO	NO	NO	NO
2005	NO	NO	NO	NO
2006	NO	NO	NO	NO
2007	NO	NO	NO	NO
2008	NO	NO	NO	NO
2009	NO	NO	NO	NO
2010	NO	NO	NO	NO
2011	NO	NO	NO	NO
2012	NO	NO	NO	NO
2013	NO	NO	NO	NO
2014	NO	NO	NO	NO
2015	NO	NO	NO	NO
2016	57 065	0	14 045	0
2017	93 362	17 549	22 375	0
2018	194 891	4 780	21 824	0
2019	189 128	0	20 342	3 152
2020	157 482	4 249	2 453	39 543
2021	144 126	19 018	809	36 031
2022	68 857	22 666	0	4 219

5.1.1.4 Storage system

5.1.1.4.1 Liquid manure storage system

In the emissions calculations, the distinction is made between four slurry storage systems, namely:

- Open tanks without cover;
- Open tanks with floating cover (for example straw);
- Closed tanks with cover (plastic film or solid cover);
- Liquid manure stored underneath slatted floor.

The available data was collected in surveys on agricultural production methods in 2010 (Gargano, L., Zangerlé G., Haupert J., & Hoffmann J.-P., 2014) and in 2020[123]. In 2010 10.8% of the liquid manure was stored in tanks without cover; 14.8% in tanks with cover (plastic film or solid cover), and 74.4% of the liquid manure was stored underneath slatted floor (Gargano, L., Zangerlé G., Haupert J.,

123 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agricoles, des relations extérieures et des marchés agricoles.

& Hoffmann J.-P., 2014) . In 2020 14.5% of liquid manure was stored in open tanks without cover; 2.8% was stored in open tanks with a floating cover such as straw; 6.1% in open tanks with a fixed cover and 76.6% was stored underneath slatted floor. The frequencies apply to the cattle and pig liquid manure. It was therefore assumed that cattle liquid manure stored in tanks without cover would have in 50% a natural crust and in 50% no natural crust. Whereas swine liquid manure stored in tanks without cover would have no natural crust.

Based on expert judgment, it was assumed that in earlier years, the frequency distributions would have been similar to the one found in 2010. An interpolation was applied for the period between the last two available measurements (i.e. 2010 and 2020). Without new data, the 2020 data were adopted in the following years.

5.1.1.4.2 Solid manure storage system

In the emissions calculations, the distinction is made, except for poultry, between two solid manure storage systems, namely:

- Solid manure stored in heaps;
- In-house deep litter/deep bedding.

The available data was collected in a survey on agricultural production methods in 2020[124]. In 2020 78% of the solid manure was stored in heaps and 22.4% in-house deep litter. Having no other information, it was assumed that in earlier years, the frequency distributions would have been similar to the one found in 2020. Without no data, the 2020 data were adopted in the following years.

For poultry the distinction is made between:

- Poultry manure with litter;
- Poultry manure without litter.

Based on housing systems (see section 5.1.1.2.3) poultry manure from broilers and other poultry was assumed to be 100% with litter. Whereas for laying hens in 1990, 2010 and 2020 poultry manure with litter was equal to 87.5%, 86.4% and 60%, respectively. The remaining was poultry manure without litter. Interpolation was applied for the periods between two measurements. Without new data, the 2020 data were adopted in the following years.

5.1.1.4.3 Digestate storage system

In the emissions calculations, the distinction is made between three digestate storage systems, namely:

- Open tanks without cover;
- Open tanks with floating cover;
- Closed tanks.

The available data was collected in a survey on agricultural production methods in 2020. In 2020 18% of the digestate was stored in closed tanks; and the remaining digestate was stored in open tanks. Based on expert judgment, it was assumed that in earlier years, the frequency distributions would have been like the one found in 2020. A fact that could be confirmed when control-ling ortho-photos from earlier years. Without new data, the 2020 data were adopted in the following years.

124 Ministère de l'Agriculture, de la Viticulture et du Développement rural, Service d'économie rurale, Division des statistiques agricoles, des relations extérieures et des marchés agricoles.

5.1.2 Nitrogen excretion

5.1.2.1 Dairy cows

For dairy cows the Nitrogen excretion (N.ex) per cow per year was calculated according to the following equation (DLG., 2008) that was based on Bannink and Hindle, 2003:

$$N.ex = \left(320 * \left(124 + \left(1320 * milk\ urea\ N[\frac{g}{day}]\right) + \left(1.87 * milk\ N[\frac{g}{day}]\right) - (6.9 * daily\ milk\ yield))\right)\right) + (45 * 256)$$

with

- assuming that an average dairy cow is 320 days on lactation and 45 days dry;
- using country-specific data for milk urea, see Table 5-16.
- assuming an N-ratio in urea of 46% (DLG., 2008) ;
- using country-specific milk protein, see Table 5-16.
- dividing milk protein by 6.38 to obtain N (DLG., 2008);
- using a country-specific daily milk yield, see Table 5-16, which is calculated by dividing the annual milk production by the number of lactating dairy cows.

The annual milk production, see Table 5-16, consist of i) the official amount of milk delivered from the farms to dairy industries (>90%)[125]; ii) the amount of milk and milk products sold by the farmers and iii) estimates on milk used at the farm for the farmers family and for feeding the calves (SER 2019).

Data on milk urea were obtained from the Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait. ASTA is the only organization in Luxembourg responsible to test the milk collected by the dairy industry. There were no data on milk urea for the years 1990-2000, why using the average as observed for the years 2001-2005 (Engel, 26-11-2019). For the years 2001-2005 only average of the tested milk samples were available and used as such, and for the years 2006-2018 weighted averages were used, i.e. weighted by the delivered amount of milk, and representing >80% of produced and delivered milk in Luxemburg (Engel, 26-11-2019). For the year 2019 and onwards published weighted averages as derived by ASTA were used[126].

The estimated N.ex per lactating dairy cow and per year for the different years is summarized in Table 5-16.

125 The dairy industry reports on a monthly basis the amount of milk collected at farm-gate, the milk fat and milk protein contain and the farm gate price to the SER – Statistiques agricoles, marches agricoles et relations extérieures on a monthly basis. Annual data are published at https://agriculture.public.lu/content/dam/agriculture/statistiques/production-animale/lait/milch-jahr-portail.pdf.

126 Publication in the annual activity reports ("Rapport d'activité") from the ministry of agriculture available online at https://agriculture.public.lu/de.html .

Table 5-16 – Annual milk production (*1000 tons), milk fat, milk protein, milk urea, daily milk yield and N.ex in kg N per dairy cow per year

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Annual milk production (*1000 tons), milk fat, milk protein, milk urea, daily milk yield and N.ex in kg N per lactating dairy cow per year

Year	Annual milk production[a] (* 1000 tons)[a]	Milk fat (%)[a]	Milk protein (%)[a]	Milk urea (ppm)[b]	Daily milk yield (kg/day)[c]	N.ex (kg N per head per year[d])
1990	281.7	4.09	3.26	235	15.0	110.2
1991	265.1	4.16	3.33	235	14.9	111.1
1992	260.4	4.16	3.34	235	15.9	112.3
1993	268.2	4.22	3.35	235	16.7	113.1
1994	261.6	4.16	3.34	235	16.7	113.0
1995	268.6	4.20	3.35	235	17.3	113.8
1996	265.5	4.25	3.38	235	17.3	114.2
1997	263.9	4.23	3.36	235	17.8	114.4
1998	264.0	4.25	3.37	235	18.0	114.7
1999	266.6	4.20	3.38	235	18.5	115.4
2000	264.5	4.19	3.36	235	19.1	115.7
2001	269.7	4.17	3.37	219	19.7	113.2
2002	270.7	4.18	3.37	221	20.1	114.3
2003	267.1	4.20	3.38	237	20.6	118.0
2004	268.5	4.20	3.39	262	21.0	123.5
2005	269.7	4.19	3.40	237	21.4	119.1
2006	268.1	4.21	3.40	250	21.7	121.9
2007	274.2	4.19	3.41	257	22.0	123.9
2008	277.7	4.21	3.40	254	21.7	122.7
2009	283.9	4.18	3.37	231	21.8	117.8
2010	295.3	4.18	3.40	246	22.4	121.8
2011	292.2	4.15	3.37	252	22.6	122.5
2012	289.4	4.16	3.39	234	22.7	119.7
2013	295.9	4.13	3.36	222	22.0	116.0
2014	317.0	4.09	3.38	219	23.6	117.3
2015	346.3	4.11	3.37	211	24.9	116.9
2016	376.2	4.12	3.39	218	25.3	119.1
2017	387.2	4.11	3.41	226	25.4	121.4
2018	407.6	4.12	3.43	232	26.5	124.1
2019	421.3	4.16	3.44	221	26.8	122.7
2020	447.3	4.17	3.45	209	28.2	122.0
2021	443.3	4.22	3.46	213	27.9	122.7
2022	449.0	4.15	3.41	203	28.1	119.6

a) Source: SER. Note: Since 1977 the annual milk production consist of i) the official amount of milk delivered by the producers to the dairy industry (>90% (Source: Fränk Steichen, personal communication December 2018; SER - Statistiques agricoles, marches agricoles et relations extérieures)); ii) the amount of milk and milk products sold by the farmers and iii) milk consumed at the farm by the farmers family and/or used for its animals as derived from unpublished LTBN data (Source: Fränk Steichen, personal communication December 2018; SER - Statistiques agricoles, marches agricoles et relations extérieures).
b) Note: There were no data for the years 1990-2000, why using the average as observed for the years 2001-2005. For the years 2001-2005 only the average of all tested milk samples were available, and for the years 2006 and onwards weighted averages were used. ASTA is in Luxemburg the only institute responsible for testing milk that is delivered to dairy industries in Luxemburg and also for the majority of the milk delivered to dairy industries in Neighbouring countries. In 2017, ~95% of all delivered milk that was produced in Luxemburg was tested by ASTA. For >80% of the delivered milk was also the delivered quantity per tested sample known, allowing to estimate a weighted average representing >80% of the delivered milk in 2017. Urea data: Source: Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait (Engel, 26-11-2019) delivered quantities: Source: SER - Statistiques agricoles, marches agricoles et relations extérieures; Fränk Steichen, personal communication 11th January 2019.
c) Calculated by dividing the milk production by the number of lactating dairy cows and assuming 320 days in lactation
d) Calculated according to the equation shown above.

5.1.2.2 Other livestock categories than dairy cows

Having no own measurements, and having no information on feed diet for all other livestock categories that would allow to estimate the N.ex based on an N-balance, the N.ex data were taken from the technical literature from Germany, Belgium, the Netherlands and France and were summarized in Table 5-17.

Belgium, Germany and France (here in particular the Northern part) have direct borders with Luxembourg (Figure 2-1), and similar climate condition, feeding systems and animal husbandry systems as the one found in Luxembourg. And although the Netherlands does not have a direct border to Luxembourg, the distance between Wemperhardt (village in the North of Luxembourg) and Eijsden (village in the Sought of the Netherlands) is less than 100 km, and in particularly in the south-east of the Netherlands are climate condition, feeding systems and animal husbandry systems for certain livestock categories like the one found in Luxembourg.

The starting point for this technical literature review were the corresponding emission inventories (NIR, IIR or both), respectively the underlying methodology reports (Lagerwerf, et al., 2019), (CITEPA, 2019), (Rösemann, et al., 2019), (Wever, 2019), (Ruyssenaars, 2019), (Anonymous, Informative Inventory Report about Belgiums' air emissions submitted under the Convention on Long Range Transboundary Air Pollution CLRTAP and National Emission Ceiling Directive NECD., 2019a). According to the snowball methodology additional relevant literature were retrieved. Relevant findings were summarized in an Excel-file (available on request). Using this excel-file, the final selection was made by two animal specialist (RB and MJJM). A detailed description of the choices made was provided in Annex 3:A in the NIR 2020 (Schuman, Becker , Hadzic, Mangen, & Mirgain, 2022)

In 2021 was however, the N.ex for suckler cows revised, as the old value had been an underestimation (Haenel H.-D. , et al., 2020), with 90.7 kg N/year per suckler cow, is the N.ex per suckler cow the same as in the German inventory (Haenel H.-D. , et al., 2020).

Table 5-17 – N excretion per head/place per year for the different livestock categories for 1990-2022

	N excretion (kg N per head/animal place per year)	Sources/Notes
Calves < 1 year	Calculated*	Based on the proportion of i) female calves and ii) males calves and the corresponding N.ex*
• Female calves < 1 year*	33	(CBS, 2018), (VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012))
• Male calves < 1 year*	31.5	(CBS, 2018)
Female young female cattle 1-2 years	58	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Heifers > 2 years	77	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); "Other cattle older than 2 years"
Fattening bulls 1-2 years	58	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Mature male cattle > 2 years	77	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); "Other cattle older than 2 years"
Non-lactating dairy cows	77	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); "Other cattle older than 2 years"
Suckler cows	90.7	(Haenel H.-D. , et al., 2020)
Sows	23.5	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Fattening pigs	11.1	(Horlacher, 2018) page 488-489
Weaners	3.6	(Horlacher, 2018) page 488-489
Mature sheep	10.5	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Sheep lambs < 1 year	4.36	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Mature goats	18.7	(CBS 2018)
Goat kids < 1 year	-	Considered with does
Horses	Calculated*	Based on the proportion of i) agriculture horses; ii) riding horses and iii) horses<200 kg, anes and mules and the corresponding N.ex
a) Agr. Horses > 6 months	65	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Horses > 600 kg;
b) Riding horses > 6 months	50	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Horses 200-600 kg;
c) Horses < 200 kg	33	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Ponys; horses < 6 months; mules & anes;
Broilers	0.3	(CITEPA, 2019)
Laying hens	0.81	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Other poultry	0.38	(CITEPA, 2019)
Ostriches	15.6	(Rösemann et al. 2019)
Rabbits - Breeding female animals	3.16	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Breeding female animal, including raising of young stock (but no fattening);
Other rabbits (i.e. fattening rabbits)	0.658	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Fattening rabbits
Deer	16	((Haenel H.-D. , et al., 2018) et al. 2018, Rösemann et al. 2019)

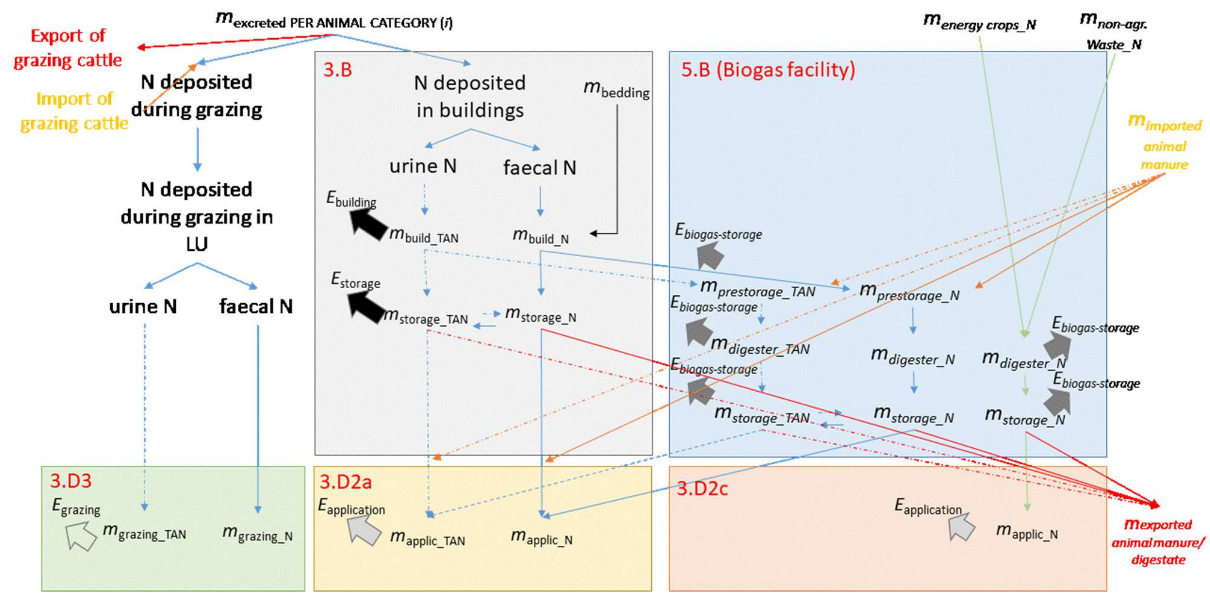
* Using more detailed statistics than the one provided in Table 5-5.

Using the French N.ex for ducks (0.4 kg n/ bird place/year), turkeys (1.0 kg N/bird place/year), geese (1.3 kg N/bird place/year) and broilers (as proxy for all other poultry, i.e. 0.3 kg N/bird place/year), assuming that places for ducks, turkeys and geese would only be occupied for half a year, and using the distribution as observed in 2005 (i.e. 25% ducks, 9% turkeys, 25% geese and 41% others), the N.ex for "other poultry" was calculated to be 0.38 kg N/bird place/year.

5.1.3 N flows in the manure management system

For the calculations of N emissions a Tier 2 technological approach was taken. The Tier 2 uses a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management and is summarized in Figure 5-6.

Figure 5-6 – N flow in the manure management system



Note: *m*: mass from which emissions may occur. Narrow broken arrows: TAN; narrow continuous arrows: organic N. The horizontal arrows denote the process of immobilisation in systems with bedding occurring in the house, and the process of mineralisation during storage. Broad black hatched arrows denote emissions assigned to manure management: *E* emissions of N species ($E_{building}$ NH_3 emissions from buildings; $E_{storage}$ NH_3, N_2O, NO_x and N_2 emissions from storage). Broad grey hatched arrows denote emissions assigned to biogas facility: E emissions of N species ($E_{biogas\text{-}storage}$ NH3 emissions from prestorage, from digester and from biogas storage, and N_2O emissions from digester/biogas storage); Broad white arrows mark emissions from manure application/from soil: ($E_{application}$ NH_3 emissions during and after spreading; N_2O, NO_x and N_2 emissions from soil resulting from manure input; $E_{grazing}$ NH_3, N_2O, NO_x and N_2 emissions during and after grazing).

The Tier 2 uses a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, which was determined following fifteen steps described in the 2023 guidelines (Amon, et al., 2023).

The first step is the definition of livestock subcategories "that are homogeneous with respect to feeding, excretion and age/weight range" (Amon, et al., 2023), see section 5.1.2 for full details.

As second step, is the total annual N.ex for livestock category *i* ($N_{ex(i)}$), expressed in kg N per year per head, respectively per year per animal place determined, with *i* being the ith livestock category. For details see section 5.1.2

In Step 3, the amount of the annual N excreted that is deposited within buildings in which livestock are housed ($m_{build\_N(i)}$) and during grazing ($m_{grazing\_N(i)}$), expressed in kg N per year per head/place for animal category *i*, was determined using the following equations (Amon, et al., 2023):

$$m_{grazing\_N(i)} = x_{grazing(i)} * N_{ex(i)}$$
$$m_{build\_N(i)} = x_{build(i)} * N_{ex(i)}$$

with $x_{grazing(i)}$ and $x_{build(i)}$ being defined in section 5.2.2.2.

Note. Yards, where than existing in Luxembourg, were integrated in the building with same manure management system, and were therefore not considered as a separate category, but as building.

Note. Not all animals owned by luxemburgish farmers were also grazing during the summer months in Luxemburg. Some were temporay exported to fields situated in neighbouring countries on fields cultivated by luxemburgish farmers. Whereas some Belgian, German and/or French owned animals were temporary imported for grazing during summer months in Luxemburg. For more details see section 5.2.2.2 and Table 5-6. In the inventories only animals grazing in Luxemburg were taken into consideration.

In Step 4 the proportion of N excreted as TAN ($x_{TAN(i)}$) expressed as kg TAN per kg $N_{ex(i)}$, was calculated, whereby the amount of TAN deposited in buildings ($m_{build\_TAN(i)}$) and during grazing ($m_{grazing\_TAN(i)}$) was calculated using the following equations (Amon, et al., 2023):

$$m_{grazing\_TAN(i)} = x_{TAN(i)} * m_{grazing\_N(i)}$$
$$m_{build\_TAN(i)} = x_{TAN(i)} * m_{build\_N(i)}$$

No national data was available on the proportion of TAN, why using the default values for $x_{TAN(i)}$ as provided in Table 3.9 in the EMEP guidelines (Amon, et al., 2023) and summarized in Table 5-18.

Table 5-18 – TAN contents (x_{TAN}) used for emission estimates, expressed as kg TAN per kg $N_{ex(i)}$

	$x_{TAN(i)}$	Notes
Calves < 1 year;	0.6	Default value for non-dairy cattle (Table 3.9; (Amon, et al., 2023))
Female young female cattle 1-2 years	0.6	Default value for non-dairy cattle (Table 3.9; (Amon, et al., 2023))
Heifers > 2 years	0.6	Default value for non-dairy cattle (Table 3.9; (Amon, et al., 2023))
Fattening bulls 1-2 years	0.6	Default value for non-dairy cattle (Table 3.9; (Amon, et al., 2023)
Mature male cattle > 2 years	0.6	Default value for non-dairy cattle (Table 3.9; (Amon, et al., 2023))
Dairy cows	0.6	Default value for dairy cattle (Table 3.9; (Amon, et al., 2023))
Suckler cows	0.6	Default value for non-dairy cattle (Table 3.9; (Amon, et al., 2023))
Sows	0.7	Default value for sows and piglets to 8 kg (Table 3.9; (Amon, et al., 2023))
Fattening pigs	0.7	Default value for fattening pigs, 8- 110 kg (Table 3.9; (Amon, et al., 2023))
Weaners	0.7	Default value for fattening pigs, 8-110 kg (Table 3.9; (Amon, et al., 2023))
Sheep (mature sheep and lambs)	0.5	Default value for sheep (Table 3.9; (Amon, et al., 2023))
Goats (mature goats and kids)	0.5	Default value for goats (Table 3.9; (Amon, et al., 2023))
Horses (including assess and mules)	0.6	Default value for horses (Table 3.9; (Amon, et al., 2023))
Broilers	0.7	Default value for broilers (Table 3.9; (Amon, et al., 2023))
Laying hens	0.7	Default value for laying hens (Table 3.9; (Amon, et al., 2023))
Other poultry	0.7	Default values for turkeys, ducks and geese (Table 3.9; (Amon, et al., 2023))
Ostriches	0.7	Default value for geese (Table 3.9; (Amon, et al., 2023)), similar as (Haenel H.-D. , et al., 2018)
Rabbits (breeding female animals and other rabbits)	0.6	Default value for horses (Table 3.9; (Amon, et al., 2023)), similar as (Haenel H.-D. , et al., 2018)
Deer	0.5	Default value for sheep and goats (Table 3.9; (Amon, et al., 2023))

In Step 5 the amounts of TAN and total N deposited in buildings handled as liquid slurry ($m_{build\_slurry\_TAN(i)}$ and $m_{build\_slurry\_N(i)}$) or as solid manure ($m_{build\_solid\_TAN(i)}$ and $m_{build\_solid\_N(i)}$) were calculated using the following equations (Amon, et al., 2023) :

$$m_{build\_slurry\_TAN(i)} = x_{slurry(i)} * m_{build\_TAN(i)}$$

$$m_{build\_slurry\_N(i)} = x_{slurry(i)} * m_{build\_N(i)}$$

$$m_{build\_solid\_TAN(i)} = (1 - x_{slurry(i)}) * m_{build\_TAN(i)}$$

$$m_{build\_solid\_N(i)} = (1 - x_{slurry(i)}) * m_{build\_N(i)}$$

with $x_{slurry(i)}$ being defined in section 5.2.2.2.

In step 6, the NH_3-N losses (in kg NH_3-N per animal per year) from the livestock buildings is calculated, following equation 15 and equation 16 from the EMEP guidelines (Amon, et al., 2023):

$$E_{build\_slurry\_NH3-N(i)} = m_{build\_slurry\_TAN(i)} * EF_{build\_slurry\_NH3-N(i)}$$

$$E_{build\_solid\_NH3-N(i)} = m_{build\_solid\_TAN(i)} * EF_{build\_solid\_NH3-N(i)}$$

with

$E_{build\_slurry\_NH3-N(i)}$	Emissions of NH_3-N from livestock buildings with a liquid manure system;
$E_{build\_solid\_NH3-N(i)}$	Emissions of NH_3-N from livestock buildings with a solid manure system;
$EF_{build\_slurry\_NH3-N(i)}$	Emissions factors for NH_3-N emissions in livestock buildings with a liquid manure system;
$EF_{build\_solid\_NH3-N(i)}$	Emissions factors for NH_3-N emissions from livestock buildings with a solid manure system;

More details are provided in Luxembourg's Informative Inventory Report 2024. The NH_3 emissions are reported in NFR category 3B.

In step 7, the N in animal bedding in litter-based housing systems, an additional N input applicable ***only*** to solid manure, is considered, whereby accounting for the consequent immobilisation of TAN (f_{imm}) in that bedding.

The mass of bedding ($m_{bedding(i)}$), expressed as kg fresh weight per year per head/animal place, and the mass of nitrogen in that bedding ($m_{bedding\_N(i)}$), expressed as kg N added per year per head/animal place were estimated using the figures provided in Table 3.7 in the EMEP guidelines (Amon, et al., 2023) and the country-specific housing period in days ($x_{housing(i)}$) and calculated by multiplying $x_{build(i)}$ with 365 (for $x_{build(i)}$ see section 5.2.2.2.)), and is summarized in Table 5-19.

The estimates for N added straw in animal bedding for livestock category *i* in litter-based housing systems are summarized in Table 5-19. In the emission calculations the N added in straw in animal bedding was only considered for the proportion of animals kept in litter-based housing systems.

Table 5-19 – Estimated N added in straw in animal bedding ($m_{bedding\_N(i)}$) for livestock category *i** (kg N/year/head or place)

3 - Agriculture

Assumed N (kg N/head) in animal bedding for livestock category *i*

Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Deer
1990	1.77	0.94	1.16	1.78	2.66	2.89	0.96	1.55	0.53	0.17	0.21	0.24	0.24	2.05	0.24
1991	1.77	0.94	1.16	1.77	2.63	2.89	0.96	1.55	0.53	0.17	0.20	0.24	0.24	2.05	0.24
1992	1.77	0.94	1.16	1.77	2.60	2.89	0.96	1.55	0.53	0.16	0.20	0.24	0.24	2.05	0.24
1993	1.77	0.94	1.16	1.76	2.57	2.89	0.96	1.55	0.53	0.16	0.19	0.24	0.24	2.05	0.24
1994	1.77	0.94	1.16	1.76	2.54	2.90	0.97	1.55	0.52	0.15	0.19	0.24	0.24	2.05	0.24
1995	1.77	0.94	1.16	1.75	2.51	2.90	0.97	1.55	0.52	0.15	0.18	0.24	0.24	2.05	0.24
1996	1.78	0.94	1.16	1.75	2.48	2.90	0.97	1.55	0.52	0.14	0.17	0.24	0.24	2.05	0.24
1997	1.78	0.94	1.16	1.71	2.55	2.90	0.97	1.55	0.51	0.14	0.17	0.24	0.24	2.05	0.24
1998	1.78	0.88	1.08	1.81	2.40	2.39	0.80	1.57	0.51	0.13	0.16	0.24	0.24	2.05	0.24
1999	1.77	0.88	1.07	1.81	2.42	2.38	0.79	1.57	0.51	0.13	0.15	0.24	0.24	2.05	0.24
2000	1.77	0.87	1.06	1.86	2.35	2.26	0.75	1.58	0.50	0.12	0.15	0.24	0.24	2.05	0.24
2001	1.78	0.88	1.06	1.88	2.38	2.28	0.76	1.59	0.50	0.12	0.14	0.24	0.24	2.05	0.24
2002	1.78	0.88	1.07	1.89	2.28	2.31	0.77	1.59	0.50	0.11	0.13	0.24	0.97	2.05	0.24
2003	1.79	0.89	1.08	1.91	2.28	2.34	0.78	1.60	0.49	0.11	0.13	0.24	0.97	2.05	0.24
2004	1.80	0.89	1.08	1.92	2.19	2.37	0.79	1.60	0.49	0.10	0.12	0.24	0.97	2.05	0.24
2005	1.81	0.83	1.00	1.94	2.16	1.93	0.64	1.61	0.49	0.10	0.12	0.24	0.97	2.05	0.24
2006	1.82	0.84	1.01	1.95	2.08	1.97	0.66	1.62	0.49	0.09	0.11	0.24	0.97	2.05	0.24
2007	1.83	0.85	1.02	1.87	1.99	2.01	0.67	1.62	0.48	0.09	0.10	0.24	0.97	2.05	0.24
2008	1.84	0.86	1.03	1.89	1.99	2.05	0.68	1.63	0.48	0.08	0.10	0.24	0.97	2.05	0.24
2009	1.85	0.87	1.04	1.90	2.08	2.09	0.70	1.64	0.48	0.07	0.09	0.24	0.97	2.05	0.24
2010	1.87	0.82	0.94	2.04	1.97	1.39	0.46	1.69	0.47	0.07	0.08	0.24	0.97	2.05	0.24
2011	1.92	0.82	0.95	2.11	2.07	1.37	0.46	1.67	0.47	0.06	0.08	0.24	0.97	2.00	0.26
2012	1.98	0.82	0.95	2.15	1.97	1.35	0.45	1.66	0.47	0.06	0.07	0.24	0.97	1.94	0.28
2013	2.04	0.83	0.95	2.15	1.84	1.33	0.44	1.64	0.46	0.05	0.06	0.24	0.97	1.88	0.30
2014	2.10	0.83	0.95	2.17	1.92	1.32	0.44	1.62	0.46	0.05	0.06	0.24	0.97	1.83	0.31
2015	2.17	0.83	0.95	2.20	1.94	1.30	0.43	1.60	0.46	0.04	0.05	0.24	0.97	1.77	0.33
2016	2.23	0.84	0.95	2.26	1.89	1.28	0.43	1.58	0.45	0.04	0.04	0.24	0.97	1.71	0.35
2017	2.29	0.84	0.95	2.28	1.79	1.26	0.42	1.60	0.45	0.03	0.04	0.23	0.94	1.79	0.37
2018	2.36	0.84	0.95	2.32	1.89	1.25	0.42	1.62	0.45	0.03	0.03	0.22	0.91	1.87	0.39
2019	2.42	0.84	0.95	2.37	1.78	1.23	0.41	1.64	0.45	0.02	0.03	0.22	0.87	1.96	0.41
2020	2.49	0.85	0.95	2.41	1.80	1.22	0.41	1.66	0.44	0.02	0.02	0.21	0.84	2.04	0.42
2021	2.49	0.85	0.95	2.41	1.80	1.22	0.41	1.66	0.44	0.02	0.02	0.21	0.84	2.04	0.42
2022	2.49	0.85	0.95	2.41	1.80	1.22	0.41	1.66	0.44	0.02	0.02	0.21	0.84	2.04	0.42

*Note : Given the low numbers of poultry, ostriches and rabbits, and given that no data were provided in Table 3.7 in the EMEP Guidelines (Amon, et al., 2023) for these categories, no estimates of additional N in animal bedding in litter-based housing systems were made for poultry, ostriches and rabbits. For deer data provided in Table 3.7 for sheep and goats were used

The amounts of total-N and total-TAN in solid manure that were removed from buildings were calculated ($m_{ex\text{-}build\_solid\_TAN}$ and $m_{ex\text{-}build\_solid\_N}$), whereby following equation 18 and equation 19 from the EMEP guidelines (Amon, et al., 2023) :

$$m_{ex-build\_solid\_TAN(i)} = \left\{m_{build\_solid\_TAN(i)} \quad - \left(E_{build\_solid\_NH3-N(i)} + (m_{bedding_{N(i)}} * f_{imm})\right)\right\}$$

$$m_{ex-build\_solid\_N(i)} = \left\{m_{build\_solid\_N(i)} + m_{bedding\_N(i)} - E_{build\_solid(i)}\right\}$$

with f_{imm} assumed to be 0.0067, according to the EMEP guidelines (Amon, et al., 2023)

In step 8, the amounts of total-N and TAN stored before application to land was estimated. Total manure was corrected for the proportion of manure that was used as feedstock for anaerobic digestions in biogas facilities ($x_{biogas\_slurry\ (i)}$,and $x_{biogas\_solid(i)}$, for details see section 5.2.2.2). Further was assumed that all manure (solid and liquid manure) would be stored before spreading (for details section 5.2.2.2). The remainders, i.e. the proportion of slurry stored on farms ($x_{store\_slurry\ (i)}$) and the proportion of solid manure stored on farms ($x_{store\_solid(i)}$), which were presented in section 5.2.3, were used to estimate the amounts ($m_{storage}$) of total-N and TAN stored before application to land, following equation 20-23 and 26-29, respectively from the EMEP guidelines (Amon, et al., 2023) namely:

whereby for liquid manure:

$$m_{storage\_slurry\_TAN(i)} = \{(m_{build\_slurry\_TAN(i)} - E_{build\_slurry\_NH3-N(i)})\} * x_{store\_slurry(i)}$$
$$m_{storage\_slurry\_N(i)} = \{(m_{build\_slurry\_N(i)} - E_{build\_slur\quad\_NH3-N(i)})\} * x_{store\_slurry(i)}$$

$$m_{biogas\_slurry\_TAN(i)} = \{(m_{build\_slurry\_TAN(i)} - E_{build\_slurry\_NH3-N(i)})\} * x_{biogsas\_slurry(i)}$$
$$m_{biogas\_slurry\_N(i)} = \{(m_{build\_slurry\_N(i)} - E_{build\_slurry\_NH3-N(i)})\} * x_{biogas\_slurry(i)}$$

and for solid manure:

$$m_{storage\_solid\_TAN(i)} = m_{ex-build\_solid\_TAN(i)} * \ x_{store\_solid(i)}$$
$$m_{storage\_solid\_N(i)} = m_{ex-build\_solid\_N(i)} * \ x_{store\_solid(i)}.$$

$$m_{biogas\_solid\_TAN(i)} = m_{ex-build\_solid\_TAN(i)} * \ x_{biogas\_solid(i)}$$
$$m_{biogas\_sol\quad\_N(i)} = m_{ex-build\_solid\_N(i)} * \ x_{biogas\_solid(i)}.$$

The masses of TAN and total N ($m_{biogas\_slurry\_TAN}$ and mbiogas_slurry_N) are used in the Tier 2 methodology for calculating NH_3 emission from anaerobic digestion facilities (biogas production) and reported in NFR Category 5B2.

Step 9 was applied only to liquid manure, with the aim to calculate the amount of TAN from which emissions will occur from liquid manure stores, whereby a fraction of the organic N is mineralised (f_{min}). The modified mass ($mm_{storage\_slurry}$), from which emissions were calculated, was derived following equation 32 from the EMEP guidelines (Amon, et al., 2023) , namely:

$$mm_{storage\_slurry\_TAN(i)} = m_{storage\_slurry\_TAN(i)} + \{(m_{storage\_slurry\_N(i)} - m_{storage\_slurry\_TAN(i)}) * f_{min}\}$$

with f_{min} assumed to be 0.1, according to the EMEP guidelines (Amon, et al., 2023) .

In Step 10, the emissions of NH_3-N, N_2O-N, NO-N and N_2 N were calculated using the corresponding's emission factors (EFs) for storage and the amounts of total TAN stored before application to land, whereby following equation 33 and 34 from the EMEP guidelines (Amon, et al., 2023) , namely:

for liquid manure:

$$E_{storage\_slurry(i)} = E_{storage\_slurry\_NH_3-N(i)} + E_{storage\_slurry\_N_2O-N(i)} + E_{storage\_slurry\_NO-N(i)} + E_{storage\_slurry\_N_2-N(i)}$$

$$= mm_{storage\_slurry\_TAN(i)} * (EF_{storage_{slurry_{NH_3-N(i)}}} + EF_{storage_{slurry_{N_2O}}-N(i)} + EF_{storage_{slurr\ \ NO}-N(i)} + EF_{storage_{slurry_{N_2}}-N(i)})$$

and for solid manure:

$$E_{storage\_solid(i)}$$
$$= E_{storage\_solid\_NH_3-N(i)} + E_{storage\_solid\_N_2O-N(i)} + E_{storage\_solid\_NO-\ \ (i)} + E_{storage\_solid\_N_2-N(i)}$$
$$= m_{stora\ \ \ solid\_TAN(i)} * (EF_{storage_{solid_{NH_3}}-N(i)} + EF_{stora\ \ \ solid_{N_2O}-N(i)} + EF_{stora\ \ \ solid_{NO}-N(i)} + EF_{storage_{solid_{N_2}}-N(i)})$$

Detailed information on the calculations and the used EFs for the N_2O emissions are provided in section 5.4.3 in the current report, and for the other N emissions in section 5.2.3 in Luxembourg's Informative Inventory Report 2024. The N_2O emissions are reported in CRF category 3B, and the NH_3 and NO_x emissions are reported in NFR category 3B.

In Step 11, the total-N and TAN (m_{applic_N} and m_{applic_TAN}) that is applied to the field (expressed in kg TAN and N per year for animal category *i*) was calculated, according to equations 35-38 from the EMEP guidelines (Amon, et al., 2023), namely:

for liquid manure (excluding digestate originating from animal manure):

$$m_{applic\_slurry\_TAN(i)} = \left(mm_{storage\_slurry\_TAN(i)} - E_{storage_{slurry(i)}}\right) * n_i$$
$$m_{applic\_slurry\_N(i)} = \left(mm_{storage\_slurry\_N(i)} - E_{storage\_slurry(i)}\right) * n_i$$

and for solid manure:

$$m_{applic\_solid\_TAN(i)} = \left(m_{storage\_slolid\_TAN(i)} - E_{storage\_solid(i)}\right) * n_i$$
$$m_{applic\_solid\_N(i)} = \left(m_{storage\_solid\_N(i)} - E_{storage\_solid(i)}\right) * n_i$$

with n_i: number of animals/animal places for livestock category *i*

as well as for digestate originating from animal manure, including imported animal manure used as feedstock:

$$m_{applic\_dig\_TAN(i)} = mm_{dig\_TAN(i)} - E_{storage\_dig(i)}$$
$$m_{applic\_dig\_N(i)} = mm_{dig\_N(i)} - E_{storage\_dig(i)}$$

Note 1: the added digestate created by the anaerobic digestion of manure, both liquid and solid manure, ($mm_{dig\_TAN(i)}$ and $mm_{dig\_N(i)}$) is returned from NRF 5.B.2. In some years the digestate returned from NRF 5.B.2. ($mm_{dig\_TAN(i)}$ and $mm_{dig\_N(i)}$) and consisted of digestate originating of national animal manure from livestock category *i* and digestate originating from imported animal manure from livestock category *i*, both used as feedstock in luxemburgish biogas facilities (see section 5.1.1.3.2).

Note 2: some of the national produced manure is exported and applied on fields in neighbouring countries, whereas other manure is imported and applied in Luxemburg (see section 5.1.4.).

The total-N and TAN (m_{applic_N} and m_{applic_TAN}) expressed in kg TAN and N per year for animal category *i* that is applied to the field in Luxembourg was adapted accordingly, namely:

$$m_{applic\_slurry\_TAN\_LU(i)} = m_{applic\_slurry\_TAN(i)} + m_{applic\_slurry\_TAN\_Imported(i)} - m_{applic\_slurry\_TAN\_Exported(i)}$$
$$m_{applic\_slurry\_N\_LU(i)} = m_{applic\_slurry\_N(i)} + m_{applic\_slurry\_N\_Imported(i)} - m_{applic\_slurry\_N\_Exported(i)}$$
$$m_{applic\_dig\_TAN\_LU(i)} = m_{applic\_dig\_TAN(i)} + m_{applic\_dig\_TAN\_Imported(i)} - m_{applic\_dig\_TAN\_Exported(i)}$$
$$m_{applic\_dig\_N\_LU(i)} = m_{applic\_dig\_N(i)} + m_{applic\_dig\_N\_Imported(i)} - m_{applic\_dig\_N\_Exported(i)}$$
$$m_{applic\_solid\_TAN\_LU(i)} = m_{applic\_solid\_TAN(i)} + m_{applic\_solid\_TAN\_Imported(i)} - m_{applic\_solid\_TAN\_Exported(i)}$$
$$m_{applic\_solid\_N\_LU(i)} = m_{applic\_solid\_N(i)} + m_{applic\_solid\_N\_Imported(i)} - m_{applic\_solid\_N\_Exported(i)}$$

In Step 12, the emissions of NH_3-N during and immediately after field application was calculated, according to equation 39 and 40 of the EMEP guidelines (Amon, et al., 2023), namely:

for liquid manure:

$$E_{applic\_slurry\_NH3-N(i)} = m_{applic\_slurry\_TAN\_LU(i)} * EF_{applic\_slurry\_NH3-N(i)}$$

for digestate originating from animal manure:

$$E_{applic\_dig\_NH3-N(i)} = m_{applic\_dig\_TAN\_LU(i)} * EF_{applic\_dig\_NH3-N(i)}$$

and for solid manure:

$$E_{applic\_solid\_NH3-N(i)} = m_{applic\_solid\_TAN\_LU(i)} * EF_{applic\_solid\_NH3-N(i)}$$

Detailed information on the calculations and the used EFs are provided in Luxembourg's Informative Inventory Report 2024. The NH_3 emissions are reported in NFR category 3Da2a.

In Step 13, the net amount of N returned to soil from manure ($m_{returned\_N}$ and $m_{returned\_TAN}$) after losses of NH_3-N were calculated, according to equations 41-44 of the EMEP guidelines (Amon, et al., 2023), namely:

for liquid manure (excluding digestate originating from animal manure):

$$m_{returned\_slurry\_TAN(i)} = m_{applic\_slurry\_TAN\_LU(i)} - E_{applic\_slurry\_NH3-N(i)}$$
$$m_{returned\_slurry\_N(i)} = m_{applic\_slurry\_N\_LU(i)} - E_{applic\_slurry\_NH3-N(i)}$$

for digestate originating from animal manure:

$$m_{returned\_dig\_TAN(i)} = m_{applic\_dig\_TAN\_LU(i)} - E_{applic\_dig\_NH3-N(i)}$$
$$m_{returned\_dig\_N(i)} = m_{applic\_dig\_N\_LU(i)} - E_{applic\_dig\_NH3-N(i)}$$

and for solid manure:

$$m_{returned\_solid\_TAN(i)} = m_{applic\_solid\_TAN\_LU(i)} - E_{applic\_solid\_NH3-N(i)}$$
$$m_{returned\_solid\_N(i)} = m_{applic\_solid\_N\_LU(i)} - E_{applic\_solid\_NH3-N(i)}$$

Note: $m_{returned}$ does not account for NO and N_2O

In Step 14, the NH_3-N emissions from grazing ($E_{grazing\_NH3-N(i)}$) for livestock category *i* were calculated, using $m_{grazing\_TAN(i)}$ as estimated in Step 4 and following equation 45 of the EMEP guidelines (Amon, et al., 2023), however correcting for the fact of temporary imported and exported grazing animals (see section 5.2.2.2) , namely:

$$E_{grazing_{NH3}-N(i)} = \left[m_{grazing_{TAN(i)}} * \left(n_i + n_{TemporaryImportedGrazingAnimals(i)} - n_{TemporaryExportedGrazingAnimals(i)}\right)\right] * EF_{grazing_{NH3}-N(i)}$$

with

n_i	number of animals/ animal places of livestock category *i*;
$n_{TemporaryImportedGrazingAnimals(i)}$	number of temporary imported grazing animals for grazing on fields in Luxemburg for livestock category *i;*
$n_{TemporaryExportedGrazingAnimals(i)}$	number of temporary exported grazing animals for grazing on fields outside Luxemburg for livestock category *i.*

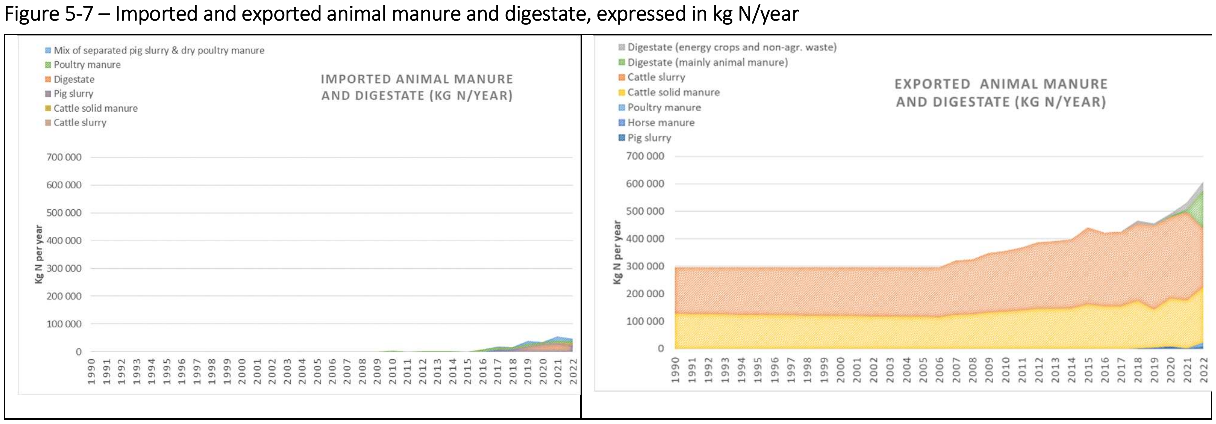
Detailed information on the calculations and the used EFs are in Luxembourg's Informative Inventory Report 2024. The NH_3 emissions are reported in NFR category 3Da3.

And as last step were all the emissions from the manure management system that are to be reported in the NFR category 3B summed and converted to the mass of the relevant compound.

5.1.4 Import and export of animal manure and digestate for application

A part of the utilized agriculture surface cultivated by luxemburgish farmers were situated in neighbouring countries, and animal manure and digestate applied to those fields were exported, see Figure 5-7. But there were also animal manure and digestate imported to be applied on utilized agriculture surfaces in Luxembourg, see Figure 5-7. In the inventories only animal manure and digestate applied to fields in Luxemburg were considered.

Figure 5-7 – Imported and exported animal manure and digestate, expressed in kg N/year



The import of animal manure and digstate for application on utilized agriculture surfaces in Luxembourg, although rather minor, had to be notidifed to Administration des Services techniques de l'Agriculture (ASTA). There were no imports in the years 2008 and 2009 and only minor imports in the years 2010-2015, allowing the assumption that imports were uncommon before 2008 and were therefore assumed to not occur. The percentage of TAN in the imported manure was assumed to be like nationally produced manure / digestate when leaving storage. The imported manure was, according to its origin, added to the specific livestock category *i* (see step 11 in section 5.1.4). Imported digestate was assumed to originate from cattle manure.

The export of animal manure and digestate from Luxembourg to utilized agriculture surfaces in Belgium had to be notified since 2013 to the Belgian authorities before their application[127]. The Beglian authorities transmitted the notified data to ASTA. The online notification to the Belgian authorities by Luxemburgish farmers had however some troughbacks in the early phase (2013-2016), and manure was often exported without notification. Reliable data were only available for 2017 and onwards. For ealier years, an estimate was made by using the median of exported/applied kg N per ha of utilized agricultural surface cultivated in Belgium by Luxemburgish farmers for the years 2017-2021, i.e. 86.7 kg N/ha and multiplied by the utilized agricultural surface cultivated in Belgium by Luxemburgish farmers (more details in Annex 3 C), whereby assuming that only liquid and solid cattle manure would have been exported (both accounted for >99% in the years 2018-2021) whereby using the observed trend for the years 2018-2021. Data on export of manure and digestate to France and Germany were missing (except for one farmer, who had notifed his exports to France to ASTA), and were therefore assumed, except for this one case, not to occur. The percentage of TAN in the exported manure / digestate was assumed to be like nationally produced manure / digestate when leaving storage. The exported manure was, according to its origin, subtracted from the specific livestock category *i* (see step 11 in section 5.1.4). Exported digestate to France was orginating from energy crops and non-agricultural waste, and the quantity of digestate originating from energy crops and non-agricultural waste applied in Luxemburg was corrected accordingly.

5.1.5 Category specific uncertainty

5.1.5.1 General

Monte Carlo simulation techniques were used for simulating the uncertainities w.r.t. CRF 3 and NRF 3. The stochastic model was built in MS Excel, using the add-in software Palisade @Risk 7.5. A probability distribution was chosen for most parameters to manage uncertainty. A value was drawn from such distributions iteratively using Latin Hypercube sampling with 50,000 iterations. The 95% uncertainty interval (95% UI), corresponding to the 2.5th and 97.5th percentiles of the results' distribution was computed to define the uncertainty, for the agriculture sector (i.e. sector 3), as well as for the separate CRF and NRF categories.

A detailed description of the parameters values used for the uncertainty analysis is given hereafter for livestock numbers, temporary import and export of grazing animals, manure management system (MMS), housing systems, use of imported manure as feedstock in digester, storage of manure and digestate, N excretion rates and import and export of manure; in section 5.2.4 for CRF 3 A related parameters; in section 5.3.4 for CRF 3B related parameters; in section 5.5.4 for CRF 3 D related activity data and parameter values; in section 5.8.3 for CRF 3 G related activity data and parameter values; in section 5.9.3 for CRF 3 I related parameters and in section 5.10.3 for CRF 3 H related parameter values.

127 In recent years these notifications are made via the following link http://environnement.wallonie.be/sols, whereby choosing "Je suis Agriculture" (in English: I'm a farmer) and "Mouvements d'effluents".

5.1.5.2 Changes of uncertainty calculations for sector 3 – Agriculture since last submission

The revision of in particularly CRF 3A and CRF 3Ba (methodology and EFs) applied in the current submission, and described in section 5.2 and section 1.1, had an impact on the results of the uncertainty calculation. Some of them impacted the calculation methods, others the used value and other required a change of the uncertainty range.

5.1.5.3 Livestock numbers

Despite the high coverage a certain uncertainty remains when using agricultural census. Uncertainties for cattle were obtained for the years 1990-2013 by comparing average annual "SANITEL" livestock numbers with the one extracted for the agriculture census of 2015-2017. With the use of the "SANITEL" database, i.e. for 2014 and onwards, the uncertainty was considered minimal and was modelled using a pert-distribution with 100% as most likely value, 99.9% as minimum and 100.1% as maximum. For pigs the 1st December census was compared with the spring census. The uncertainty was assumed to decrease by half when using both 1st December and spring census. The same was assumed for laying hens, where the uncertainty was assumed to decrease by half when using the 31st December and spring census. For goats, the reported monthly animal registers as delivered by the farmers within the "landwirtschaftliche Testbetriebsnetz (LTBN)[128]" were consulted.[129]. For all other animal categories, no data was available, and expert judgement[130] was used to determine the uncertainty.

The uncertainty of livestock numbers was simulated by multiplying the livestock numbers as obtained from the census/sanitel database by the uncertainty parameters presented in Table 5-20.

Table 5-20 – Uncertainty in livestock numbers

	Uncertainty			Distribution used	Notes
	Min	ML	Max		
Calves < 1 year[4)]	99%	100%	100%	Pert	The weighted yearly average correspond to 99% of the census data[1)]
Female young female cattle 1-2 years	99%		101%	Uniform	[1)]
Heifers > 2 years	100%		105%	Uniform	[1)]
Fattening bulls 1-2 years	98%	100%	100%	Pert	[1)]
Mature male cattle > 2 years	95%		102%	Uniform	[1)]
Dairy cows[5)]	99%	100%	101%	Pert	[1)]
Suckler cows	98%	100%	100%	Pert	[1)]
Sows	95%		105%	Uniform	[2)]
Fattening pigs	95%		105%	Uniform	[2)]
Weaners	95%		105%	Uniform	[2)]

128 The LTBN is situated in the division «Division de la gestion, de la comptabilité et de l'entraide agricoles», at the Service d'Economie Rurale. This division gets from about 840 farms farm accountancy data https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung.html). Out of these farms, a representative sample of 450 farms are selected (https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html) to form the sample size shared with the FADN (Farm Accountancy data network); for more details see: https://ec.europa.eu/agriculture/rica/.

129 Pers. Communication : Marc Schmit and Paul Jacqué, Service d'Economie Rurale - Division de la gestion, de la comptabilité et de l'entraide agricoles, December 2018.

130 R. Barthelmy and M-J. Mangen; Service d'Economie Rurale – Division des statistiqes agricoles, des relations extérieures et des marchés agricoles, January 2019

Mature sheep kept on agricultural holdings	90%	100%	100%	Pert	3, 6)); Similar as for goats
Sheep lambs < 1 year					Number is estimated based on number of sheep ewes[7)]
Mature goats kept on agricultural holdings	90%	100%	100%	Pert	3, 6)); The maximum of mature goats kept on the farms is reached in spring, i.e. the time when the census is conducted
Goats - kit < 1 year					Number is estimated based on number of goat ewes[8)]
Horses kept on agricultural holdings	95%		105%	Uniform	3,9)
Broilers	95%		105%	Uniform	3)
Laying hens	90%		110%	Uniform	3,10)
Other poultry	90%		110%	Uniform	3)
Ostriches	90%		110%	Uniform	3)
Rabbits - Breeding animals	90%		110%	Uniform	3)
Other rabbits	90%		110%	Uniform	3)
Deer	90%		110%	Uniform	3)

1.) For 1990-2013: Based on SANITEL data, and comparing with census data. With the use of the "SANITEL" database, i.e. for 2014 and onwards, the uncertainty was considered minimal and was modelled using a pert-distribution with 100% as most likely value, 99.9% as minimum and 100.1% as maximum.

2.) For 1990-2019: Comparing December census data with spring census data. The uncertainty was assumed to decrease by half when using both 1st December and spring census (i.e from 2020 onwards).

3.) Expert Judgement (R. Barthelmy & MJ Mangen, Service d'économie rurale – Division des statistiqes agricoles, des relations extérieures et des marchés agricoles; January 2019).

4.) The percentage of female calves was modelled with minimum 64%, most likely 66% and maximum 68%, based on SANITEL data in 2017.

5.) From 2008 onwards was the percentage of non-lactating cows ($P_{non\text{-}lactatingl\ cows}$) modelled as a Pert-distribution with most likely 9.15%, minimum 7.1% and maximum 10.8% of the total consisting of lactating dairy cows and non-lactating dairy cows.

6.) The number of holders keeping small ruminants off-farm were modelled using a pert-distribution, with most likely 600 holders; minum 500 holders and maximum 700 holders. The average number of animals on those premises was modelled as a pert-distribution with most likely 7, minimum 3 and most likely 11, whereby assuming that most likely 59% would be mature animals, with minimum 58% and maximum 60% using a pert-distribution.

7.) The number of lambs raised per ewe was modelled for non-dairy ewes with most likely 1.165, minimum 0.83 and maximum 1.23 using a pert-distribution, and for dairy ewes with most likely 1.5, minimum 1.3 and maximum 1.7, based on FADN data taking extensive race (minimum) and intensive race (maximum). The percentage of fattening lambs being slaughtered was modelled as uniform distribution with minimum 75% and maximum 85%. Slaughter age was 6 months (most likely), with minimum 5 months and maximum 7 months (modelled using a Pert-distribution). Source: Lëtzebuerger Schéifergenossenschaft; Marc Vaessen; personal communication 7-12-2018.

8.) The number of kits raised per goat ewe was modelled for non-dairy goat ewes with most likely 1.165, minimum 0.83 and maximum 1.23 using a pert-distribution (same as for sheep), and for dairy goats with most likely 2.07, minimum 2 and maximum 2.14 in first years when the number of goats were increasing, and with most likely 0.815, minimum 0.76 and maximum 0.87 thereafter using a Pert-distribution (based on FADN data). The percentage of goat kits being slaughtered was modelled as uniform distribution with minimum 45% and maximum 55%. Slaughter age was 1.5 months (most likely), with minimum 1.25 months and maximum 1.75 months (modelled using a Pert-distribution). Source: Own survey in November 2018 between goat farmers (representing ~70% of goat ewes) & confirmed by unpublished FADN data.

9.) The number of horses kept off-farms was modelled by multiplying the number of horses kept on agricultural holdings by most likely 200%, minimum 150% and maximum 250% using a Pert-distribution.

10.) The uncertainty was assumed to decrease by half when using the 31st December census and the spring census (i.e from 2020 onwards).

5.1.5.3.1 Temporary import and export of grazing animals

The number of cattle grazing over the summer months in the neigbouring countries was modelled using a Pert-distribution with most likely 50%, minimum 40% and maximum 60% of female young cattle 1-2 years old (educated guess). The remainder was assumed to be heifers >2 years. The number of cattle grazing over the summer months in the neigbouring countries was modelled using a Pert-distribution with most likely 50%, minimum 40% and maximum 60% of female young cattle 1-2 years old (educated guess). The remainder was assumed to be heifers >2 years. The uncertainty w.r.t. grazing time of these animals in neigbhouring countries was modelled using a Uniform-distribution with minimum 75% and maximum 100% of the average grazing time of livestock category *i*.

5.1.5.4 Manure management systems

The proportion of excreta deposited during grazing ($x_{grazing\ i}$) for animal category *i* (*i* = are all the different animal categories considered in the emission calculations) was multiplied by an uncertainty factor with most likely 100%, minimum 90% and maximum 110%, and modelled using a pert-distribution. The proportion of excreta deposited within buildings ($x_{building\ i}$) was the remaining proportion that animals were not grazing ($x_{building\ i}$ = 100% - $x_{grazing\ i}$).

The proportion of livestock manure handled as slurry for animal category *i* ($x_{slurry\ i}$) was multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and modelled as a pert-distribution. The proportion of livestock manure handled as solid ($x_{solid\ i}$) was calculated using the following formula: $x_{solid\ i}$ = 100% - $x_{slurry\ i}$.

The proportion of liquid livestock manure used to feed bio digester for animal category *i* ($x_{digester\_slurry\ i}$) was multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and was modelled as a pert-distribution. The proportion of liquid livestock manure stored on the farm for animal category *i* ($x_{store\_slurry\ i}$) was calculated: $x_{store\_lurry\ i}$ = 100% - $x_{digester\_slurry\ i}$.

The proportion of solid livestock manure used to feed bio digester for animal category *i* ($x_{digester\_solid\ i}$) was multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and was modelled as a pert-distribution. The proportion of solid livestock manure stored on the farm for animal category *i* ($x_{store\_slolid\ i}$) was calculated: $x_{store\_solid\ i}$ = 100% - $x_{digster\_solid\ i}$.

5.1.5.5 Housing systems

Slurry based housing systems

For animal category *i*, the frequencies as presented in Table 5-12 and Table 5-13 for cattle and swine, respectively, were corrected by multiplying these frequencies with an uncertainty factor, based on 2020 census. The uncertainty factor was most likely 100%, minimum 75% and maximum 125% for the second largest frequency; most likely 100%, minimum 40% and maximum 160% for the third largest frequency, and most likely 100%, minimum 30% and maximum 170% for the smallest frequency. All frequencies were modelled using a pert-distribution. The largest housing category was calculated by subtracting all other slurry based housing systems for animal category *i* from 100%. Same uncertainties were used for earlier years.

Solid based housing systems

For cattle category *i*, the frequencies as presented in Table 5-12, were corrected by multiplying these frequencies with an uncertainty factor, based on 2020 census. The uncertainty factor was most likely 100%, minimum 80% and maximum 120% for the second largest frequency; most likely 100%, minimum 62% and maximum 138% for the third largest frequency, and most likely 100%, minimum 55% and maximum 145% for the smallest frequency. All frequencies were modelled using a pert-distribution. The largest housing category was calculated by subtracting all other slurry based housing systems for cattle category *i* from 100%. Same uncertainties were used for earlier years.

For laying hens, the frequencies as presented in Table 5-14, were corrected by multiplying these frequencies with an uncertainty factor, based on 2020 census and expert judgement. The uncertainty factor was most likely 100%, minimum 50% and maximum 150% for aviary/cage system; most likely 100%, minimum 90% and maximum 110% for floor management with outdoor access. All frequencies were modelled using a pert-distribution. The largest housing category (i.e. floor management without outdoor access) was calculated by subtracting all other housing systems for laying hens from 100%. Same uncertainties were used for earlier years.

For broilers, the uncertainty factor was most likely 100%, minimum 90% and maximum 110% for floor management with outdoor access, and the remainder was floor management without outdoor access. Same uncertainties were used for earlier years.

5.1.5.6 Use of imported manure as feedstock in digester

The imported quantities were corrected by multiplying the quantities with uncertainty factors. The uncertainty factor for the imported quantity was most likely 100%, minimum 90% and maximum 110% using a pert-distribution. The proportion of swine manure in the mix of imported separated swine and poultry manure was assumed to be uniformely distributed with minimum 25% and maximum 75% and the remainder would be poultry manure

5.1.5.7 Storage of manure and digestate

Slurry /liquid manure

For 2020 and based on census, open slurry tanks without swimming cover were assumed to be uniformely distributed with minimum 11% and most likely 18%; open slurry tanks with swimming cover were assumed to be uniformely distributed with minimum 1% and most likely 4%; closed slurry tanks with fixed cover were assumed to be uniformely distributed with minimum 4% and maximum 8%; and the remainder was slurry stored underneath slatted floor. Same uncertainties were used for all other years.

For cattle slurry stored in an open tank, it was assumed that most likely 50%, minimum 30% and maximum 70%, using a pert-distribution, of the stored slurry would be covered with a natural crust (educated guess by experts). The remainder is the percentage of cattle slurry stored in open tank without having a natural crust.

Solid manure

For 2020 and based on census, solid manure, except for poultry, was assumed to be stored in-house in deep litter/deep bedding for most likely 22.4%; minimum 19% and maximum 26%, using a pert-distribution. The remainder was solid manure stored in heaps. Same uncertainties were used for all other years.

Digestate

For 2020 and based on census, closed tanks were assumed to be uniformely distributed with minimum 0% and most likely 38% and the remainder was assumed to be open tanks. Same uncertainties were used for all other years.

5.1.5.8 Nitrogen excretion factor (N.ex)

Except for dairy cows was the assumed $N.ex_i$ per head, respectively per place per year for animal category *i* (*i* = are all the different animal categories considered in the emission calculations, except for lactating dairy cows) multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and modelled using a pert-distribution.

For lactating dairy cows, the calculated daily milk yield, the assumed milk protein and the assumed milk urea, - all factors determining the N.ex per lactating dairy cow per year - were considered to be to some extent uncertain. The daily milk yield was calculated by dividing the national milk production by the number of lactating dairy cows. The national milk production in itself was an estimation, including the quantity delivered to the dairy industry, the quantity directly sold at the farm gate, and quantities of milk used on the farm. The quantity delivered to the dairy industry (i.e. 97% in 2016) [131] was considered to be the minimum of the national milk production; 100% was seen as most likely value and 103%[132] was set as maximum. The uncertainty was modelled using a Pert-distribution. The uncertainty of the urea measurements is ±10% (Source: Tom Engel, pers. communication 9th November 2018; Tom Engel, personal communication Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait) and was therefore modelled as being uniformly distributed with minimum 90% and maximum 110%. The uncertainty range for milk protein and milk fat were assumed to be minimum 99%, most likely 100% and maximum 101%.

5.1.5.9 Import and export of manure

The same uncertainty factors were used for imported manure to be used as fertilizer on fields in Luxemburg, as were used for imported manure to be used as feed in bio-digester (see section 5.1.5.6). The exported quantities were corrected by multiplying the quantities with uncertainty factors. The uncertainty factor for the exported quantity was most likely 100%, minimum 90% and maximum 110% using a pert-distribution.

5.1.6 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly in the model.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.1.7 Category-specific recalculations including changes made in response to the review process

Revisions and recalculations relevant to livestock numbers, manure management systems, N excretion and the N-flows, including imported and exported animals and manure, since submission 2023v1 are described in Table 5-21.

Table 5-21 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
3.A / 3.B.	Error correction of the number of laying hens in 2021; Used in 3.A. & 3.B. and impacting 3.D	Revised AD
3.B	Revision of origin of solid manure to be used as feedstock in biogas facilities from 2005 onwards from laying hens and cattle rather than just cattle. Used in 3.B and impacting 3.D	Revised AD
3.B	Revision of the calculation methodology whereby the imported manure to be used as feedstock was split according to its origin and added to the corresponding livestock categories. Used in 3.B and impacting 3.D	Revised calculation methodology and error correction
3.D.	Having additional data w.r.t. export of digestate originating from energy crops and non-agricultural waste. AD was updated	Revised AD

131 About 3% of the milk production in 2016 was used on farms to fed calves or by the farmers family (Source: unpublished FADN data). These 3% were used to estimate the national milk production. Personal communication: Fränk Steichen; SER – Statistiques agricoles, marches agricoles et relations extérieures; 29-02-2019

132 Assuming that not 3% of the national milk production, but the double would be used on the farm or by the farmers family.

The adapted AD and and the revised/corrected MMS affected 3A, 3Ba, 3Bb and 3D. For recalculations see Table 5-30, Table 5-43, Table 5-44 and see Table 5-53 respectively.

5.1.8 Planned improvement

Planned improvements, as listed in Table 5-22, will be explored, based on available resources and available data.

Table 5-22 – Planned improvements for category – *3- General aspects*

GHG source & sink category	Planned improvement
3.D. - Export of animal manure and digestate	Countine the quest for data on quantities exported of locally produced animal manure and digestate to France and Germany.

5.2 Enteric Fermentation (IPCC Source Category 3.A)

This section describes the estimation of methane emissions resulting from enteric fermentation. In 2022, this source category was responsible for 81% of agricultural methane emissions. It represented 63% of the total GHG emissions from the agriculture sector and 5.14% of the total GHG emissions in CO_2eq (excluding LULUCF).

5.2.1 Key source

With 5.14% of the total GHG emissions in CO_2 eq., excluding LULUCF in 2022, methane emissions from enteric fermentation (IPCC category 3A) is a key source, whether LULUCF is included or excluded (Table 5-3). It has been a key source in both cases without interruption since 1990.

5.2.2 Source category description

Livestock statistics in Luxembourg were detailed enough to go for option C. Cattle, the main livestock category in Luxembourg was split into 8 categories, namely calves <1 year; young female cattle 1-2 years; heifers >2 years; fattening bulls 1-2 years, mature male >2 years, lactating dairy cows, non-lactating dairy cows and suckler cows. For swine the distinction was made between sows, weaners 10-30 kg and fattening pigs >30 kg. Poultry was split in laying hens, broilers and other poultry. Sheep was split in mature animals and lambs, furthermore was the distinction made between high and low producing systems. Mules and asses were included in the category horses. The remaining categories were goats (i.e. dairy goats being a high producing systems and all other goats being a low producing system), ostriches, rabbits and deer (see details in section 5.2.1).

Goats, although a niche production in Luxembourg, have experienced the biggest increase in their population for the whole period 1990-2022 (Table 5-5 and Table A3- 1 in Annex 3 A), and consequently also the biggest increase in methane emission from enteric fermentation for the same time period (1079%), see Table 5-23. However, methane emission from enteric fermentation from goats represent <0.3% of the total methane emission from enteric fermentation in 2022. Cattle as a whole group is over the whole period the main methane emitting animal category with regard to enteric fermentation, and was, in 2022, responsible for 97% of the total methane emission from enteric fermentation (Table 5-23 and Figure 5-8). Dairy cows (lactating and non-lactating) is the subgroup with the highest emission over the whole period (Figure 5-8). In 2022, 50% of the methane emission from enteric fermentation originated from dairy cows (Figure 5-8 and Table 5-23).

On the whole, methane emissions from enteric fermentation decreased by 2% over the period 1990-2022. This results mainly from decreasing emissions from enteric fermentation of cattle (-3%) and swine (-4%), but was partly compensated by increasing emissions of horses (+124%) and small rumiants (+66%). And although emissions of cattle decreased over the period 1990-2022, methane emissions from enteric fermentation of the cows (dairy and suckler) increased by 9%, whereas emissions from all other cattle than cows decreased by 20% in the same period.

With regard to cattle, its total population and its evolution are strongly influenced by changes in agricultural policy and, more precisely, in the Common Agricultural Policy of the EU (CAP). This is the case for dairy cows. Due to a quota system for milk production in place from 1983-31st March 2015, and an increasing milk yield per cow was the population of dairy cows declining over time, and in the majority replaced by suckler cows. But with the abolishment of the milk quota system in Europe in spring 2015, is the number of dairy cows increasing since then, with an accelerated increase in the first 2-3 years, and a slowing down in the later years.

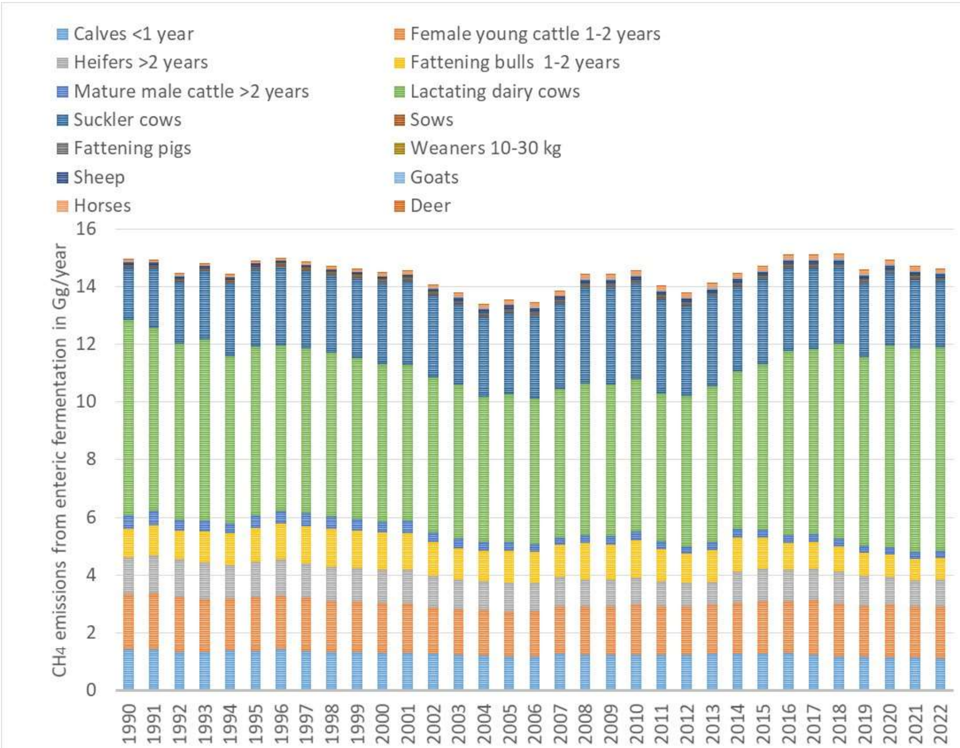
Another factor influencing cattle/livestock population is/was, availability of fodder, respectively high fodder prices, and/or low milk and/or meat prices. As an example, the peak in the non-dairy cattle population observed in 1991 can be explained by a sharp price fall of the bovine meat price that year. This price fall led farmers to postpone slaughtering until early 1992.

Table 5-23 – CH_4 emission trends for IPCC Category 3A – Enteric Fermentation: 1990-2022 (Gg)

Year	3 - Agriculture Sector — CH_4 emissions (Gg) — 3.A - Enteric fermentation																				
	Total	Calves <1 year	Female young cattle 1->2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners 10-30 kg	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	15.31	1.42	1.92	1.28	0.99	0.45	6.80	0.38	1.81	0.037	0.05	0.011	0.09	0.003	0.06	NO	NO	NO	NO	0.003	0.002
1991	15.34	1.42	1.94	1.34	1.04	0.47	6.36	0.43	2.08	0.035	0.04	0.010	0.10	0.004	0.07	NO	NO	NO	NO	0.003	0.003
1992	14.85	1.34	1.91	1.30	0.98	0.39	6.11	0.41	2.15	0.035	0.05	0.009	0.10	0.003	0.07	NO	NO	NO	NO	0.003	0.003
1993	15.15	1.33	1.82	1.30	1.05	0.39	6.27	0.36	2.37	0.035	0.05	0.010	0.09	0.004	0.07	NO	NO	NO	NO	0.002	0.003
1994	14.77	1.39	1.80	1.17	1.08	0.35	5.81	0.36	2.53	0.035	0.05	0.010	0.10	0.003	0.08	NO	NO	NO	NO	0.002	0.004
1995	15.29	1.38	1.86	1.23	1.17	0.41	5.88	0.40	2.67	0.037	0.05	0.010	0.10	0.002	0.08	NO	NO	NO	NO	0.002	0.004
1996	15.42	1.41	1.86	1.28	1.24	0.42	5.72	0.43	2.76	0.035	0.05	0.011	0.10	0.002	0.08	NO	NO	NO	NO	0.001	0.003
1997	15.23	1.36	1.84	1.20	1.29	0.47	5.69	0.39	2.70	0.036	0.06	0.010	0.10	0.002	0.08	NO	NO	NO	NO	0.002	0.003
1998	15.09	1.32	1.76	1.19	1.32	0.44	5.68	0.40	2.68	0.035	0.06	0.012	0.11	0.002	0.08	NO	NO	NO	NO	0.002	0.006
1999	15.05	1.32	1.73	1.20	1.28	0.40	5.58	0.43	2.78	0.034	0.06	0.013	0.11	0.002	0.10	NO	NO	NO	NO	0.001	0.007
2000	14.93	1.31	1.72	1.17	1.26	0.37	5.47	0.44	2.84	0.031	0.06	0.011	0.11	0.002	0.11	NO	NO	NO	NO	0.002	0.008
2001	14.96	1.30	1.70	1.18	1.28	0.41	5.41	0.42	2.93	0.032	0.06	0.011	0.12	0.002	0.11	NO	NO	NO	NO	0.001	0.007
2002	14.47	1.28	1.58	1.11	1.15	0.35	5.37	0.41	2.87	0.031	0.06	0.011	0.11	0.007	0.11	NO	NO	NO	NO	0.002	0.006
2003	14.13	1.23	1.57	1.04	1.10	0.32	5.33	0.37	2.79	0.030	0.07	0.011	0.13	0.012	0.12	NO	NO	NO	0.001	0.001	0.005
2004	13.73	1.21	1.55	1.02	1.06	0.30	5.04	0.34	2.78	0.030	0.08	0.010	0.13	0.015	0.13	NO	NO	NO	0.001	0.001	0.006
2005	13.87	1.18	1.54	1.01	1.11	0.29	5.13	0.34	2.84	0.030	0.09	0.011	0.13	0.016	0.15	NO	NO	NO	0.001	0.001	0.005
2006	13.73	1.18	1.57	0.98	1.07	0.27	5.04	0.30	2.89	0.029	0.08	0.010	0.14	0.014	0.15	NO	NO	NO	0.001	0.001	0.005
2007	14.17	1.26	1.65	1.04	1.11	0.24	5.16	0.33	2.97	0.028	0.08	0.010	0.12	0.016	0.14	NO	NO	NO	0.001	0.001	0.004
2008	14.72	1.24	1.65	0.95	1.27	0.27	5.25	0.30	3.35	0.027	0.08	0.009	0.12	0.022	0.15	NO	NO	NO	0.001	0.001	0.007
2009	14.72	1.25	1.65	0.94	1.19	0.32	5.24	0.31	3.37	0.027	0.08	0.009	0.12	0.024	0.15	NO	NO	NO	0.001	0.001	0.007
2010	14.87	1.25	1.71	0.96	1.28	0.32	5.28	0.31	3.34	0.027	0.07	0.013	0.12	0.034	0.15	NO	NO	NO	0.001	0.001	0.007
2011	14.33	1.25	1.66	0.87	1.10	0.27	5.15	0.31	3.27	0.025	0.08	0.013	0.13	0.036	0.15	NO	NO	NO	0.002	0.001	0.009
2012	14.10	1.25	1.66	0.81	1.01	0.24	5.21	0.30	3.14	0.023	0.08	0.011	0.12	0.041	0.16	NO	NO	NO	0.001	0.001	0.008
2013	14.45	1.27	1.68	0.82	1.11	0.27	5.40	0.35	3.12	0.022	0.08	0.010	0.13	0.035	0.15	NO	NO	NO	0.002	0.001	0.005
2014	14.81	1.29	1.75	1.08	1.19	0.29	5.46	0.35	2.97	0.022	0.08	0.010	0.13	0.033	0.15	NO	NO	NO	0.001	0.001	0.005
2015	15.06	1.27	1.81	1.13	1.07	0.30	5.74	0.36	2.94	0.020	0.09	0.011	0.13	0.037	0.15	NO	NO	NO	0.001	0.001	0.005
2016	15.49	1.29	1.80	1.09	0.94	0.27	6.39	0.38	2.89	0.020	0.09	0.011	0.13	0.037	0.15	NO	NO	NO	0.001	0.001	0.003
2017	15.49	1.24	1.88	1.10	0.93	0.27	6.42	0.39	2.82	0.022	0.10	0.011	0.12	0.038	0.15	NO	NO	NO	0.001	0.001	0.002
2018	15.51	1.18	1.81	1.14	0.86	0.26	6.78	0.39	2.65	0.021	0.09	0.011	0.12	0.039	0.15	NO	NO	NO	0.001	0.001	0.003
2019	14.98	1.18	1.75	1.03	0.79	0.26	6.53	0.40	2.60	0.018	0.08	0.011	0.12	0.036	0.15	NO	NO	NO	0.001	0.001	0.001
2020	15.30	1.16	1.79	0.98	0.78	0.25	7.00	0.41	2.51	0.016	0.08	0.009	0.13	0.038	0.14	NO	NO	NO	0.001	0.000	0.001
2021	15.10	1.16	1.74	0.91	0.75	0.24	7.07	0.41	2.41	0.013	0.09	0.006	0.14	0.041	0.14	NO	NO	NO	0.001	0.001	0.001
2022	15.02	1.12	1.79	0.93	0.76	0.25	7.04	0.41	2.31	0.010	0.08	0.005	0.14	0.041	0.14	NO	NO	NO	0.001	0.000	0.001
Trend 1990 -2022	-2%	-21%	-7%	-28%	-23%	-46%	4%	8%	28%	-74%	58%	-57%	53%	1079%	124%	NO	NO	NO	NO	-84%	-53%
Trend 2021 -2022	0%	-3%	3%	1%	2%	2%	0%	1%	-4%	-23%	-5%	-26%	4%	1%	3%	NO	NO	NO	-35%	-7%	16%

Note: Asses and mules are included in the category horses. Turkey are included in the category other poultry.

Figure 5-8 – Enteric fermentation per animal category: 1990 - 2022



Source: SER.
Note: Asses and mules were included in the category horses.

5.2.3 Methodological issues

The 2019 Refinements of the 2006 IPCC GLs do not provide an EF for poultry, because of “insufficient data” (Gavrilo, et al., 2019). Why not estimated (NE).

An IPCC Tier 2 methodology was used for cattle (96%-98% of all methane emissions from enteric fermentation), whereas an IPCC Tier 1/Tier 1a methodology was applied for all other animal categories.

5.2.3.1 Activity data

Livestock numbers were the activity data for this emission source. Livestock numbers were presented in section 5.2.2.1. Please note, that the enteric emissions during the summer months were corrected for the fact some of the animals were grazing outside the countries, respectively were foreign animals temporarily imported to graze on fields in Luxemburg (see section 5.2.2.2).

5.2.3.2 Emission factors

Emission factors for livestock categories others than cattle

For the Tier 1 methodology, emission factors (EF) for enteric fermentation related methane emissions in kg CH_4 per head per year were derived from Table 10.10 in the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019), by using either directly the default EF or an approximated EF whereby applying the IPCC scaling approach, the so-estimated EF and the live weight for those animal categories are summarized in Table 5-24. For the assumed uncertainties, see section 5.2.4.

Table 5-24 – Emission factors and live weight for livestock categories others than cattle.

Animal category	Weight (kg)				Emission Factors [b] (kg CH_4 / head / year)
	Begin weight (kg)	End weight (kg)	Mature weight (kg)	Average weight [a] (kg)	
Sows			250-300 kg (KTBL 2018f)	275 kg	4.1
Fattening pigs	30 kg	120 kg (KTBL 2018g) (Kirchgessner, 2014f)	-	75 kg	1.5
Weaners	10 kg	30 kg		20 kg	0.57
Mature sheep			75 kg (KTBL 2018b)	75 kg	High :14.4 / Low: 9.7 [c]
Sheep lamp < 1 year	5 (KTBL 2018a, (Kirchgessner, 2014e)	45 kg (slaughtered lambs) / 55 kg (replacement animal) (Kirchgessner, 2014d)	75 kg (KTBL 2018b)	26 kg	High: 6.5 / Low: 4.4 [c]
Mature goats [d]			Dairy goats: 50-55 kg (KTBL 2018g, Weiss 1985) / Other goats: 33 kg	Dairy: 52.5 kg/ Others: 33 kg	Dairy: 9.3 / Others: 5.6
Goat kits [d]	Dairy goats: 3.5-5 kg (KTBL 2018a) Others: 3 kg	Dairy goats: 13 kg (slaughtered kits (own survey)); 52.5 kg [a] (replacement animal) / Others: 33 kg	Dairy goats: 50-55 kg (KTBL 2018b) (Weiss, 1985) / Others: 30 kg	Dairy: 19 kg / Others: 18 kg	Dairy: 4.3 / Others: 3.6
Horses			Heavy horses: 600-800 kg (Anonymous, 2019b) (Kirchgessner, 2014g) / Riding horses: 500-700 kg (Kirchgessner 2014g) / Ponys, anes & mules: 100-400 kg (Kirchgessner 2014g)	Heavy horses: 700 kg / Riding horses: 550 kg / Pony, anes & mules: 250 kg	Heavy horses: 21.6 / Riding horses: 18 / Pony, anes & mules: 10
Laying hens			1.8-2.3 kg (Scholtyssek, 1987)	2.05 kg	NE
Broilers	0.04 kg (KTBL 2018f)	1.5-2 kg (KTBL 2018a, Scholtyssek et al. 1987)		0.9 kg	NE
Other poultry [e]	0.04 -0.2 kg (KTBL 2018a)	3-15 kg (KTBL 2018a)		5 kg	NE
Ostriches	1.5-1.9 kg (Kirchgessner, 2014g) (Kirchgessner M. , 2014h)		90-135 kg	57 kg	5
Rabbits – breeding female			3 kg (Haenel et al. 2018)	3 kg	0.36
Other rabbits	0.1 kg (KTBL 2018a, Kirchgessner 2014f)	2.4-2.7 kg (KTBL 2018a)		1.33 kg	0.20
Deer	4.6-4.9 kg (KTBL 2018a)	42.5-72.5 kg (KTBL 2018a)		31 kg	20

Note: The breeds present in Luxembourg are also very common in Germany. Climate, feeding and housing conditions are similar between Germany and Luxembourg. References to KTBL and Kirchgessner, both standard references for the German agriculture, apply also to the Luxemburgish agriculture.

- The middle of the range is used, respectively the average weight is calculated ((begin weight + end weight) /2) and used as most likely value in the stochastic simulations, and as "the value" for the deterministic calculation.
- Assuming an uncertainty of +- 40%.
- Lower EF for sheep kept off farms as considered to be low productivity systems (i.e. backyard / landscape maintenance); Higher EF for sheep kept by farmers as considered to be high productivity system.

- Higher EF for dairy goats (does and kits) as considered to be high productivity system; Lower EF for all other goats, independent if kept on or off-farms as being considered to be low productivity system.
- The range covers the different other poultry categories considered in this category.

Emission factors for cattle

For cattle a Tier 2 approach was used to calculate country- and year-specific emission factors, see Table 5-28 at the end of this section. The general EF for enteric fermentation related methane emissions in kg CH_4 per head per year was estimated following equation 10.21 from the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$EF\ CH_4\ 3A_i = \left(\frac{GE_{i\_LU} * \left(\frac{Y_{mi}}{100}\right) * 365}{55.65} \right)$$

with:

Y_{mi} : Methane conversation factor for livestock category (i), per cent of gross energy in feed converted to methane

GE_{i_LU} : Gross energy ingested in Luxembourg (MJ/animal/day) for animal category i

Based on the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019), the default value of 6.3% for Y_m for non-dairy cattle was used for all cattle categories, except for calves and lactating dairy cows.

For calves, where the rumen has to develop first, the used Y_m was 5.45; whereby presuming similar as in the German inventory no ruminating in weeks 1-3 (i.e. 0 for Y_m); linear increase from 0 to 0.063 (assumption) for week 4-9 and full ruminating (with an 6.3% for Y_m) from week 10 and onwards. (Vos C. , et al., 2022)

Taking into consideration the annual milk yield, DE% of the diet for dairy cows and the NDF of the diet, and based on the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019), Y_m for lactating dairy cows were assumed to have been 6.5 in 1990-1993; 6.3 in 1994-2003 and 6.0 in 2004 and onwards, but corrected for the dry phase, which was assumed to last for 45 days per year, and where the default value of 6.3% for Y_m for non-dairy cattle was used.

The GE_i in MJ/day/animal is calculated for cattle according to equation 10.16 in the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$GE_i = \left(\frac{\left(\frac{NE_m + NE_a + NE_l + NE_p}{REM}\right) + \left(\frac{NE_g}{REG}\right)}{\frac{DE\%_i}{100}} \right)$$

with:

NE_m = net energy required by the animal for maintenance, MJ/day

NE_a = net energy for animal activity, MJ/day

NE_l = net energy for lactation, MJ/day

NE_p = net energy required for pregnancy, MJ/day

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed

NE_g = net energy needed for growth, MJ/day

REG = ratio of net energy available for growth in a diet to digestible energy consumed

DE% = digestibility energy expressed as a percentage of gross energy.

Note 1. Net energy for work was not considered, as not applicable for cattle in Luxembourg.

As explained in section 5.2.2.2 during summer months some animals from luxemburgish farmers were temporary exported for grazing on fields cultivated outside Luxemburg, and hence the required gross energy were ingested outside the country as were the associated enteric fermentation related methan emissions occurring outside Luxembourg. For livestock category *i* where temporary exports were relevant, GE_i were corrected to represent only the *average* gross energy injested in Luxemburg, expressed as MJ/day/animal, namely,

$$GE_{i\_LU} = \left(GE_i - GE_{i\_TemporaryNETExported_i}\right)$$

whereas for all other livestock categories $GE_i = GE_{i\_LU}$. The so-estimated GE_{i_LU} were summarized in Table 5-27.

$GE_{TemporaryNETExported\_i}$ were calculated using the above equation for GE_i, but considering only the summer months and only the net exported fraction of livestock category *i* (which corresponds to the correction factor shown in Table 5-6).

The net energy for maintenance (NE_m) in MJ/day was calculated according to equation 10.3 of the 2019 Refinement of the 2006 IPCC Guidelines (Gavrilo, et al., 2019):

$$NE_m = Cf_i * (Weight)^{0.75}$$

with:

Cf_i = a coefficient which varies for each animal category, MJ/day/kg

Weight = live-weight of animal, kg

Note the default values provided in Table 10.4 of the 2019 Refinement of the 2006 IPCC Guidelines (Gavrilo, et al., 2019) were used, namely 0.386 for lactating dairy cows; 0.370 for fattening bulls 1-2 years and for mature male cattle >2 years and 0.322 for all other cattle categories.

The used live weights for the different cattle categories are summarized in Table 5-25.

The net energy for animal activity (NE_a) in MJ/day for cattle was calculated according to equation 10.4 of the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019): $NE_a = C_a * NE_m$

with:

C_a = coefficient corresponding to animal's feeding situation.

The C_a according to Table 10.5 from the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019) was 0.17 for the percentage of the year that cattle were grazing ($x_{grazing}$[133]), and 0 for the percentage of the year that cattle were kept in the stall ($x_{stall} = 1 - x_{grazing}$).

133 x.grazing is equal to the proportion of excreta deposited during grazing (MMS – pasture).

Table 5-25 – Cattle: live weight, daily weight gain and digestibility of feed.

Animal category	Weight (kg)				Daily weight gain (kg/day)	Digestible energy (DE%) [d]
	Begin weight	End weight	Live weight	Mature weight		
Calves < 1 year	40 (KTBL 2018a)	325 (KTBL 2018a, Kirchgessner 2014a)	183[a]	794 [c]	0.78 [b]	70% *(68%-72%)*
Female young cattle 1-2 years	End weight of calves <1 year	550 (KTBL 2018a, Kirchgessner 2014a)	438[a]	650 (KTBL 2018a)	0.62 [b]	70% *(68%-72%)*
Heifers > 2 years	End weight of female young cattle	600 (KTBL 2018a, Kirchgessner 2014a)	575[a]	650 (KTBL 2018a)	0.14 [b]	70% *(68%-72%)*
Fattening bulls 1-2 years	430 (Kirchgessner 2014b)	700 (Kirchgessner 2014b, KTBL 2018b)	565 [a]	1075 (KTBL 2018b)	1.33 (KTBL 2018b)	70% *(68%-72%)*
Mature male cattle >2 years	End weight of fattening bulls	900 (KTBL 2018a)	800 [a]	1075 (KTBL 2018b)	0.55 [b]	67% *(65%-69%)*
Lactating dairy cows			650 (KTBL 2018a)	650 (KTBL 2018a)	-	Varies over the years see Figure 5-9
Non-lactating dairy cows	End weight of lactating dairy cows	725 kg	688 [a]	725	0.82[b]	71% *(69%-73%)*
Suckler cows			700 (KTBL 2018a)	700 (KTBL 2018a)	-	66% *(63%-69%)*

Notes:

The dominant breed in dairy cattle in Luxembourg is Holstein, one of the breeds also common in Germany. Climate, feeding and housing conditions are similar between Germany and Luxembourg. References to KTBL and Kirchgessner, both standard references for the German agriculture, apply also to the Luxemburgish agriculture.

a) Calculated: (begin weight + end weight) /2.

b) Calculated: (end weight- begin weight)/365.

c) Weighted average based on mature cows (650 kg) and mature bulls (1075 kg) and assuming that 66% of calves are female calves (STATEC 2018b).

d) In italic the used range in the stochastic simulations.

The net energy for growth (NE_g) in MJ/day for cattle (i.e. all cattle categories except for cows) was calculated according to equation 10.6 of the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$NE_g = 22.02 * \left(\frac{Live - weight}{C * Mature\ weight}\right)^{0.75} * WG^{1.097}$$

with:

C = a coefficient with a value of 0.8 for females and 1.2 for bulls (Gavrilo, et al., 2019).

WG = average daily weight gain in kg/day and as summarized in Table 5-25.

Note: Male calves from dairy cows are often sold and exported at the age of ~10 days for veal production. Consequently ~66% of the calves were female calves (STATEC 2018b).

The net energy for lactation (NE_l) in MJ/day for dairy cows and suckler cows was calculated according to equation 10.8 of the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$NE_l = Milk * (1.47 + 0.4 * Fat)$$

with:

Milk = amount of milk produced in kg per day.

Fat = Fat content of milk in %/kg.

Daily milk yield and fat contents of dairy cows are summarized in Table 5-16.

Daily milk yield for suckler cows varies between 8-14 kg/day ((Kirchgessner M. , 2014a), (KTBL, 2018a) and during 7-10 months (Kirchgessner M. , 2014d). For the emissions calculations an average of 11 kg per day was assumed for a period of 243 days, resulting in 2677 kg milk/suckler cow per year. Having no data, the average fat content as estimated for dairy cows for the years 1990-2018, namely 4.1%, was used as proxy.

The net energy for pregnancy (NE_p) in MJ/day for cattle was calculated according to equation 10.13 of the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$NE_p = C_{pregnancy} * NE_m$$

with:

$C_{pregnancy}$= pregnancy coefficient. The default value, namely 0.10 for cattle was used for cattle (Gavrilo, et al., 2019).

NE_m = net energy required by the animal for maintenance, MJ/day.

NE_p was weighted by the portion of females that would be pregnant in a year. For simplification it was assumed that 100% of lactating dairy cows would be pregnant, 100% of the heifers >2 years and 90% of suckler cows. For female young cattle 1-2 years, it was assumed, similar as Germany, that 30% would be pregnant (Haenel et al. 2018).

The ratio of net energy available in diet for maintenance to digestible energy consumed (REM) was estimated according to equation 10.14 of the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$REM = \left(1.123 - (4.092 * 10^{-3} * DE\%) + [1.126 * 10^{-5} * (DE\%)^2] - \left(\frac{25.4}{DE\%}\right)\right)$$

with:

DE% = digestible energy expressed as a percentage of gross energy.

In the summer, fresh grass was/is the main forage source for grazing cattle other than lactating dairy cows, with average DE% for the years 1990-2022 being 69%. [134] For the winter months, the main roughages are grass silage, hay and corn silage (whole plant), with

134 Based on measurements conducted by the Laboratoire de Contrôle et d'Essais de l'ASTA (Administration des Services Techniques de l'Agriculture), Ettelbruck for the years 2012-2017; Christelle Schmit (head of department), personnel communication (3-10-2018). Feed digestibility is determined in the laboratory. The laboratory is following international recognized norms (for details see https://agriculture.public.lu/de/publications/pflanzen-boden/Labo_Ettelbruck/labo_ettelbruck_analysen.html)

average DE% for the years 1990-2022 being 56%, 70% and 70%, respectively,[135] supplemented with concentrated feed. Feed concentrates in Luxemburg were/are based on fodder cereals, such as barley and wheat, and supplemented with soybean meal and rapeseed meal (both are extruded meals). To estimate the DE% of the diet, the composition of the diet in-house for young bulls were based on the recommandations given by CONVIS, (Feipel, 2016) the major feeding counsellor for young bulls in Luxemburg, whereas for all other cattle categories, except for lactating dairy cows, the diets were derived from German standard recommandations (Kirchgessner, Kirchgessner Tierernährung: Leitfaden für Studium, Beratung und Praxis Vol. 14., neubearbeitete Auflage., 2014f), (Brändle, et al., 2009) and discussed with feed experts. The composition of the diet (in % of the dry matter intake) is summarized for the in-housee period in Table 5-26.

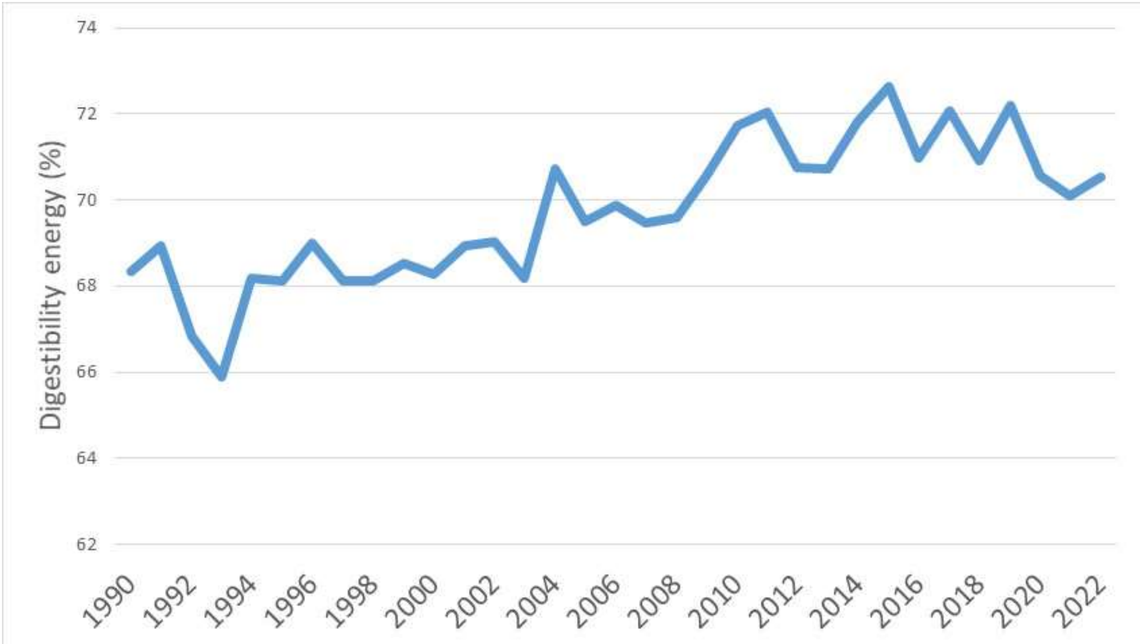
Table 5-26 – Cattle: Diet composition for the housing period (in % of the dry matter intake).

Animal category	Diet composition					
	Straw	Hay	Grassilage	Maize silage (whole plant)	Fodder cereals	Soybean- /rapeseed meal
Calves > 6 months			62%	38%		
Female young stock 1-2 years			67%	33%		
Heifers > 2 years			69%	31%		
Young bulls 1-2 years	4%			51%	36%	9%
Male bulls > 2 years		33%	47%	12%	7%	
Non-lactating dairy cows (fattening period)		6%		67%	10%	17%
Suckler cows			50%	50%		

For lactating dairy cows, grass, grass silage and corn silage were/are the three main roughaghes used, complemented with concentrated feed (see Figure A3- 1 in Annex 3 B). The estimated DE% for the period 1990-2022 is summarized in Figure 5-9, a detailed description is provided in Annex 3 B.

135 Based on measurements conducted by the Laboratoire de Contrôle et d'Essais de l'ASTA (Administration des Services Techniques de l'Agriculture), Ettelbruck for the years 2012-2017; Christelle Schmit (head of department), personnel communication (3-10-2018). Feed digestibility is determined in the laboratory. The laboratory is following international recognized norms (for details see https://agriculture.public.lu/de/publications/pflanzen-boden/Labo_Ettelbruck/labo_ettelbruck_analysen.html)

Figure 5-9 – Estimated digestible energy expressed as a percentage of gross energy (DE %) for lactating dairy cow for 1990-2022



The ratio of net energy available for growth in a diet to digestible energy consumed (REG) is estimated according to equation 10.15 from the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019):

$$REG = \left(1.164 - (5.160 * 10^{-3} * DE\%) + [1.308 * 10^{-5} * (DE\%)^2] - \left(\frac{37.44}{DE\%}\right)\right)$$

Table 5-27 – Estimated gross energy (GE) for cattle categories for the years 1990-2022

3 - Agriculture Activity data - Estimated gross energy (GE)/head/year								
Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows
1990	66.8	136.4	125.6	185.5	201.2	272.0	203.7	249.0
1991	66.8	136.5	126.0	185.6	201.4	269.4	203.7	249.0
1992	66.8	136.4	125.8	185.6	201.7	289.3	203.7	249.0
1993	66.8	136.2	125.9	185.7	202.0	302.5	203.7	249.0
1994	66.8	136.2	125.2	185.8	202.2	287.3	203.7	249.0
1995	66.8	136.4	125.6	185.8	202.5	292.7	203.7	249.0
1996	66.8	136.4	125.9	185.9	202.7	288.8	203.7	249.0
1997	66.8	136.4	125.5	186.3	202.1	297.4	203.7	249.0
1998	66.8	136.2	125.5	186.1	202.8	299.0	203.7	249.0
1999	66.8	136.1	125.6	186.0	202.7	299.7	203.7	249.0
2000	66.8	136.1	125.5	186.0	203.3	305.6	203.7	249.0
2001	66.8	135.9	125.2	186.0	203.0	305.7	203.7	249.0
2002	66.8	136.2	125.7	186.0	204.0	308.6	203.7	249.0
2003	66.8	135.9	125.0	186.0	204.1	318.0	203.7	249.0
2004	66.8	135.6	124.5	185.9	205.0	306.0	203.7	249.0
2005	66.8	135.3	124.1	185.9	204.7	315.8	203.7	249.0
2006	66.8	136.1	124.9	186.1	205.5	316.0	203.7	249.0
2007	66.8	136.8	125.9	187.0	206.4	320.3	203.7	249.0
2008	66.8	136.4	124.6	187.0	206.5	317.9	203.7	249.0
2009	66.8	136.2	124.3	187.1	205.9	312.3	203.7	249.0
2010	66.8	136.6	124.8	187.3	206.6	309.4	203.7	249.0
2011	66.7	135.6	122.7	187.0	205.7	308.4	203.6	249.3
2012	66.6	135.0	121.0	187.0	206.6	316.8	203.5	249.5
2013	66.5	135.1	121.1	187.2	207.7	310.9	203.3	249.7
2014	66.4	136.3	125.1	187.3	207.0	315.4	203.2	250.0
2015	66.3	136.7	125.8	187.4	206.8	320.1	203.0	250.2
2016	66.2	136.3	124.9	187.2	207.2	332.7	202.9	250.5
2017	66.1	137.5	126.4	187.3	208.1	326.6	202.7	250.4
2018	66.0	137.0	126.2	187.2	207.2	341.6	202.4	250.3
2019	65.9	136.8	125.5	187.1	208.2	336.5	202.2	250.3
2020	65.8	137.0	125.5	187.1	208.0	357.1	202.0	250.2
2021	65.8	135.2	122.2	187.1	208.0	358.9	202.0	250.2
2022	65.8	138.1	126.9	187.1	208.0	355.5	202.0	250.2

Note: The here presented gross energy (GE) for female young cattle 1-2 years/head/year and for heifer >2 years/head/year is the one ingested in Luxembourg, hence after correction for temporary net exported animals grazing during summer months outside the country (see section 5.2.2.2).

Table 5-28 – Implied emission factor (IEF) for enteric fermentation related methane emissions in kg CH_4 per head per year for the different cattle categories for the years 1990-2022

3 - Agriculture

Implied emission factor (IEF) - Enteric fermentation related methane emissions (kg CH_4/head/year) for animal category *i*

Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows
1990	23.9	56.3	51.9	76.6	83.1	115.5	84.2	102.9
1991	23.9	56.4	52.0	76.7	83.2	114.4	84.2	102.9
1992	23.9	56.4	52.0	76.7	83.3	119.5	84.2	102.9
1993	23.9	56.3	52.0	76.7	83.4	125.0	84.2	102.9
1994	23.9	56.3	51.7	76.8	83.6	118.7	84.2	102.9
1995	23.9	56.4	51.9	76.8	83.7	121.0	84.2	102.9
1996	23.9	56.4	52.0	76.8	83.8	119.4	84.2	102.9
1997	23.9	56.4	51.9	77.0	83.5	122.9	84.2	102.9
1998	23.9	56.3	51.9	76.9	83.8	123.5	84.2	102.9
1999	23.9	56.3	51.9	76.9	83.8	123.8	84.2	102.9
2000	23.9	56.3	51.9	76.9	84.0	126.3	84.2	102.9
2001	23.9	56.1	51.8	76.8	83.9	126.3	84.2	102.9
2002	23.9	56.3	52.0	76.9	84.3	127.5	84.2	102.9
2003	23.9	56.2	51.6	76.8	84.3	131.4	84.2	102.9
2004	23.9	56.0	51.5	76.8	84.7	126.4	84.2	102.9
2005	23.9	55.9	51.3	76.8	84.6	130.5	84.2	102.9
2006	23.9	56.3	51.6	76.9	84.9	130.6	84.2	102.9
2007	23.9	56.5	52.0	77.3	85.3	132.4	84.2	102.9
2008	23.9	56.4	51.5	77.3	85.3	131.4	84.2	102.9
2009	23.9	56.3	51.4	77.3	85.1	129.0	84.2	102.9
2010	23.9	56.5	51.6	77.4	85.4	127.9	84.2	102.9
2011	23.9	56.0	50.7	77.3	85.0	127.4	84.1	103.0
2012	23.8	55.8	50.0	77.3	85.4	130.9	84.1	103.1
2013	23.8	55.8	50.1	77.3	85.8	128.5	84.0	103.2
2014	23.7	56.3	51.7	77.4	85.5	130.3	84.0	103.3
2015	23.7	56.5	52.0	77.4	85.5	132.2	83.9	103.4
2016	23.7	56.3	51.6	77.3	85.6	137.5	83.8	103.5
2017	23.6	56.8	52.2	77.4	86.0	135.0	83.7	103.5
2018	23.6	56.6	52.2	77.4	85.6	141.1	83.6	103.4
2019	23.6	56.5	51.9	77.3	86.0	133.2	83.5	103.4
2020	23.5	56.6	51.8	77.3	86.0	141.4	83.5	103.4
2021	23.5	55.9	50.5	77.3	86.0	142.1	83.5	103.4
2022	23.5	57.1	52.4	77.3	86.0	140.8	83.5	103.4

These IEFs were multiplied with annual livestock numbers to obtain annual emissions per livestock category, and summarized over all livestock categories to obtain total emissions per year. For the assumed uncertainties, see section 5.2.4.

5.2.4 Category specific uncertainty

Uncertainty was model using Monte-Carlo techniques, see section 5.1.5.1 for full details. The uncertainty w.r.t. livestock numbers and MMS were described in detail in section 5.1.5. The uncertainty w.r.t. used EF for CRF 3 A is described hereafter.

Methane emissions from enteric fermentation for livestock categories other than cattle were estimated using a Tier 1 methodology. The uncertainty range of the enteric methane emission factors (EF) as summarized in Table 5-24, was assumed to be +-40% based on the IPCC guidelines (Gavrilo, et al., 2019) and modelled by multiplying the EF_i by an uncertainty factor that was uniformly distributed with minimum 60% and maximum 140%. In Table 5-24 is the begin weight, end weight, average weight and mature weight summarized, respectively the range presented. Weights are modelled using a pert-distribution, with range minimum and maximum being the minimum and maximum, and the middle of the range the most likely value.

Enteric fermentation for cattle were estimated using a Tier 2 methodology. Whereby the uncertainty for gross energy (GE) for cattle was assumed to be ±20%, and was modelled by multiplying the estimated GE_i by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%. The digestibility energy (DE%) factor for animal category *i* in year *t* was assumed to vary by ±2%, and was modelled as pert-distribution with $DE\%_{i,t}$ – 2% as minimum value; $DE\%_{i,t}$ as most likely value, and $DE\%_{i,t}$ + 2% as maximum value. The methane conversion factor (Y_m) for cattle was assumed to be +-20% based on the IPCC guidelines (Gavrilo, et al., 2019) and modelled by multiplying (Y_{mij}) by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%.

5.2.5 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector. The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.2.6 Category-specific recalculations including changes made in response to the review process

Revision of livestock numbers since submission 2023v1 are described in Table 5-21. Additional revisions and relevant for enteric fermentation emissions are described in Table 5-29.

Table 5-29 – Recalculations done since submission 2022v1

GHG source & sink category	Revisions 2023 ➔ 2024v1	Type of revision
3.A.	Sheep and goats were split into low and high productivity systems; and hence revised mature weights	AD
3.A.	Revising the EFs for enteric fermentation for all livestock categories other than cattle using a Tier 1 approach whereby applying the 2019 Refinement of the 2006 IPCC GLs ; Enteric fermentation for rabits and ostrichs were for the first time considered in the current submission.	EF
3.A.	Revising Y_m for the different cattle categories whereby applying the 2019 Refinement of the 2006 IPCC GLs; For cattle categories other than lactaiting dairy cows, a first attempt of the diet was made, and DE% estimated rather than assuming values from an IPCC table.	EF
3.A	Revised the percentage of pregnancy for suckler cows.	AD

In particularly the revised EFs for all livestock categories other than cattle, and the revised Y_m and DE% for cattle affected 3A. For recalculations see Table 5-30.

The recalculated CH_4 emissions from enteric fermentation, resulted in an average reduction of the methan emissions from entric fermentation of 2.3%, varying over the years from minimum -1.5% to maximum -4.5%, see Table 5-30.

Table 5-30 – Recalcution of methane emission from enteric fermentation in Gg CH_4 and in Gg $CO_{2\text{-eq.}}$ for new and old estimates, respectively

3 - Agriculture Sector CH_4 Emissions (Gg) by source & sink category									
	3A-Cattle Gg CH_4		Impact of recalculation	3A-Other livestock than cattle Gg CH_4		Impact of recalculation	3A - Enteric Fermentation Gg CH_4		Impact of recalculation
Year	New	Old	%	New	Old	%	New	Old	%
1990	15.0	15.3	-1.9	0.26	0.23	14.9	15.3	15.6	-1.6
1991	15.1	15.3	-1.7	0.26	0.23	15.6	15.3	15.6	-1.5
1992	14.6	14.9	-2.3	0.26	0.23	15.1	14.8	15.2	-2.1
1993	14.9	15.2	-2.1	0.26	0.23	13.1	15.2	15.4	-1.9
1994	14.5	14.9	-2.8	0.28	0.24	14.1	14.8	15.1	-2.5
1995	15.0	15.4	-2.6	0.29	0.25	13.9	15.3	15.7	-2.4
1996	15.1	15.6	-2.7	0.28	0.25	12.4	15.4	15.8	-2.4
1997	14.9	15.3	-2.5	0.29	0.26	12.7	15.2	15.6	-2.2
1998	14.8	15.1	-2.3	0.31	0.27	12.2	15.1	15.4	-2.0
1999	14.7	15.1	-2.4	0.32	0.30	9.3	15.0	15.4	-2.2
2000	14.6	15.0	-2.5	0.33	0.30	9.1	14.9	15.3	-2.2
2001	14.6	15.0	-2.4	0.34	0.31	10.1	15.0	15.3	-2.1
2002	14.1	14.5	-2.4	0.34	0.31	9.9	14.5	14.8	-2.2
2003	13.8	14.0	-1.9	0.38	0.34	11.1	14.1	14.4	-1.6
2004	13.3	13.7	-2.6	0.41	0.37	11.3	13.7	14.0	-2.2
2005	13.4	13.7	-2.0	0.43	0.39	9.1	13.9	14.1	-1.7
2006	13.3	13.6	-2.2	0.43	0.38	11.5	13.7	14.0	-1.9
2007	13.8	14.0	-2.0	0.41	0.37	9.9	14.2	14.4	-1.7
2008	14.3	14.6	-1.9	0.42	0.39	9.7	14.7	15.0	-1.6
2009	14.3	14.6	-2.2	0.43	0.39	10.3	14.7	15.0	-1.9
2010	14.4	14.8	-2.4	0.43	0.40	8.3	14.9	15.2	-2.2
2011	13.9	14.3	-2.6	0.44	0.40	8.5	14.3	14.7	-2.3
2012	13.6	14.0	-2.5	0.45	0.42	8.3	14.1	14.4	-2.2
2013	14.0	14.4	-2.5	0.44	0.40	8.9	14.5	14.8	-2.2
2014	14.4	14.8	-2.7	0.44	0.40	8.5	14.8	15.2	-2.4
2015	14.6	15.0	-2.7	0.45	0.42	8.1	15.1	15.4	-2.4
2016	15.0	15.5	-2.8	0.44	0.41	8.3	15.5	15.9	-2.5
2017	15.0	15.5	-2.9	0.45	0.41	7.8	15.5	15.9	-2.6
2018	15.1	15.5	-2.8	0.44	0.41	7.8	15.5	15.9	-2.6
2019	14.6	15.3	-4.7	0.42	0.40	7.2	15.0	15.7	-4.4
2020	14.9	15.6	-4.9	0.43	0.39	9.2	15.3	16.0	-4.5
2021	14.7	15.4	-4.9	0.42	0.38	10.1	15.1	15.8	-4.5
2022	14.6			0.42			15.0		

5.2.7 Planned improvement

Planned improvements, as listed in Table 5-31, will be explored, based on available resources and available data.

Table 5-31 – Planned improvements

GHG source & sink category	Planned improvement
3A – AD	Countine the quest for additional data on feet diet for dairy cows

5.3 Manure Management (IPCC Source Category 3.B)

This section describes the estimation of methane and nitrous oxide emissions resulting from manure management. In 2022, this source category was responsible for 20% of the total GHG emissions from the agriculture sector and represented 1.62% of the total GHG emissions in CO_2e (excluding LULUCF). For each of the two gases reported, excluding LULUCF, in 2022:

- CH_4 represented 74.8% of CRF 3.B emissions and 19.1% of agricultural methane emissions in 2022;
- N_2O represented 25.2% of CRF 3.B emissions and 24.8% of agricultural nitrous oxide emissions in 2022.

5.3.1 Key source

With 1.22% of the total GHG emissions in CO_2e, excluding LULUCF in 2022, methane emissions from manure management are a key source for 2022 and for several other years (see section 1.4.1.1).

5.3.2 Source category description

Livestock statistics in Luxembourg are detailed enough to go for option C. Cattle, the main livestock category in Luxembourg is split into 8 categories, namely calves <1 year; young female cattle 1-2 years; heifers >2years; fattening bulls 1-2 years, mature male >2 years, lactating dairy cows, non-lactating dairy cows and suckler cows. For swine do we distinguish between sows, weaners 10-30 kg and fattening pigs>30 kg. Poultry is split in laying hens, broilers and other poultry. Sheep is split in mature animals and lambs. Mules and asses are included in the category horses. The remaining categories are goats, ostriches, rabbits and deer (see details in section 5.2.1).

Goats, although a niche production in Luxembourg, have experienced the biggest increase in their population for the whole period 1990-2022 (Table 5-5), and consequently also the biggest increase in methane (2 531%) from manure management, see Table 5-32. For N_2O emission the increase was even higher (3 087%), whereby the increase of the goat population was only one factor. The second factor driving those emissions were the husbandry of dairy goats with in-house stabilisation for the whole year around, see Table 5-33. However, methane emission from manure management originating from goats represented only 0.04% of the total methane emission from manure management in 2022 (see Table 5-32 and Figure 5-10), and 1.37% of the total N_2O emission from manure management (Table 5-33 and Figure 5-11).

Cattle as a whole group was over the whole period the main methane emitting animal category with regard to manure management, and was in 2022 responsible for 87% of the total methane emission from manure management (Table 5-32 and Figure 5-10) and for >90% of the total N_2O emission from manure management (Table 5-33 and Figure 5-11). Lactating dairy cows is the subgroup with the highest emission over the whole period for both methane and N_2O emission from manure management (Figure 5-10 and Figure 5-11). In 2022 58% of the methane emission from manure management (Table 5-32 and Figure 5-10) and 33% of the total N_2O emission from manure management (Table 5-33 and Figure 5-11) were from lactating dairy cows.

On the whole, methane emissions from manure management increased by 14% over the period 1990-2022, a result mainly due to raising emission of dairy cows (+34%). Raising emissions of other livestock categories, such as goats (+2531%), broilers (+382%), horses (+118%) and laying hens (+108%) had only a marginal impact on the total methane emissions from manure management.

Direct N_2O emissions from manure management decreased by 19% over the period 1990-2022, see Table 5-33 and Table 5-34. Indirect atmospheric N_2O emissions decreased by 4% (Table 5-34 and Table 5-35).

CRF requires reporting emissions by manure management system categories rather than by livestock, see and Table 5-34. Solid storage is the main source of N_2O. With fewer cattle now-a-days on straw, emissions were decreasing over time. Combining both gases – CH_4 and N_2O (direct and indirect) – manure management related emissions, expressed in CO_2e, show an increase of 5% (Table 5-35).

With regard to cattle, its total population and its evolution are strongly influenced by changes in agricultural policy and, more precisely, in the Common Agricultural Policy of the EU (CAP). This is the case for dairy cows. Due to a quota system for milk production in place from 1983-31st March 2015, and an increasing milk yield per cow was the population of dairy cows declining over time, whereby partly replaced by suckler cows. But with the abolishment of the milk quota system in Europe in spring 2015, is the number of dairy cows increasing since then, with an accelerated increase in the first 2-3 years, and a slowing down in the last two years. Another factor influencing cattle population is/was, availability of fodder, respectively fodder and milk prices.

Table 5-32 – CH_4 emission trends for IPCC Category 3B – Manure Management: 1990-2022 (Gg)

Year	3 - Agriculture Sector CH_4 emissions (Gg) 3.Ba - Manure management																				
	Total	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners 10-30 kg	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	3.12	0.26	0.22	0.13	0.25	0.07	1.55	0.07	0.17	0.109	0.24	0.04	0.001	0.000	0.009	0.000	0.001	0.0002	NO	0.0011	0.0000
1991	3.02	0.26	0.22	0.13	0.26	0.08	1.43	0.07	0.20	0.103	0.21	0.03	0.001	0.000	0.010	0.000	0.001	0.0002	NO	0.0011	0.0000
1992	3.06	0.25	0.22	0.13	0.25	0.06	1.50	0.07	0.21	0.105	0.23	0.03	0.001	0.000	0.010	0.000	0.001	0.0002	NO	0.0010	0.0000
1993	3.19	0.25	0.21	0.13	0.26	0.06	1.58	0.06	0.23	0.106	0.25	0.03	0.001	0.000	0.010	0.000	0.001	0.0002	NO	0.0007	0.0000
1994	2.98	0.26	0.21	0.12	0.27	0.06	1.38	0.06	0.25	0.105	0.23	0.03	0.001	0.000	0.011	0.000	0.001	0.0002	NO	0.0006	0.0000
1995	3.09	0.25	0.22	0.13	0.29	0.06	1.40	0.07	0.26	0.110	0.25	0.03	0.001	0.000	0.011	0.000	0.001	0.0002	NO	0.0006	0.0000
1996	3.06	0.26	0.22	0.13	0.30	0.07	1.33	0.08	0.27	0.106	0.24	0.04	0.001	0.000	0.011	0.000	0.001	0.0002	NO	0.0005	0.0000
1997	3.11	0.25	0.21	0.12	0.31	0.07	1.36	0.07	0.27	0.107	0.28	0.04	0.001	0.000	0.012	0.001	0.001	0.0002	NO	0.0006	0.0000
1998	3.18	0.24	0.21	0.13	0.31	0.07	1.42	0.07	0.27	0.106	0.29	0.04	0.002	0.000	0.012	0.001	0.001	0.0001	NO	0.0005	0.0001
1999	3.15	0.24	0.21	0.13	0.30	0.06	1.39	0.08	0.27	0.102	0.31	0.04	0.001	0.000	0.014	0.000	0.001	0.0001	NO	0.0005	0.0001
2000	3.11	0.24	0.20	0.13	0.29	0.06	1.38	0.08	0.28	0.092	0.30	0.04	0.001	0.000	0.016	0.000	0.001	0.0001	NO	0.0005	0.0001
2001	3.10	0.24	0.20	0.13	0.30	0.06	1.34	0.08	0.29	0.095	0.30	0.04	0.002	0.000	0.016	0.000	0.001	0.0001	NO	0.0005	0.0001
2002	3.02	0.24	0.19	0.12	0.27	0.05	1.33	0.08	0.29	0.091	0.31	0.04	0.002	0.000	0.016	0.000	0.001	0.0001	NO	0.0006	0.0001
2003	3.04	0.23	0.19	0.11	0.25	0.05	1.36	0.07	0.29	0.088	0.35	0.04	0.002	0.000	0.017	0.000	0.001	0.0001	0.001	0.0005	0.0001
2004	2.89	0.22	0.19	0.11	0.24	0.04	1.18	0.06	0.29	0.081	0.40	0.03	0.002	0.001	0.019	0.000	0.001	0.0001	0.002	0.0005	0.0001
2005	3.01	0.22	0.19	0.12	0.26	0.04	1.29	0.07	0.30	0.078	0.40	0.03	0.002	0.001	0.022	0.001	0.001	0.0001	0.001	0.0005	0.0001
2006	2.87	0.21	0.19	0.11	0.24	0.04	1.24	0.06	0.30	0.071	0.36	0.03	0.002	0.001	0.021	0.001	0.001	0.0001	0.001	0.0005	0.0001
2007	2.89	0.22	0.20	0.12	0.23	0.03	1.26	0.06	0.30	0.066	0.35	0.03	0.002	0.001	0.021	0.000	0.001	0.0001	0.001	0.0004	0.0000
2008	2.93	0.21	0.20	0.11	0.26	0.04	1.27	0.06	0.33	0.063	0.34	0.03	0.002	0.001	0.022	0.000	0.002	0.0001	0.001	0.0003	0.0001
2009	2.84	0.21	0.20	0.11	0.23	0.04	1.22	0.06	0.33	0.063	0.34	0.03	0.002	0.001	0.022	0.000	0.002	0.0001	0.001	0.0003	0.0001
2010	2.80	0.20	0.20	0.11	0.23	0.04	1.24	0.06	0.31	0.059	0.28	0.04	0.002	0.001	0.022	0.000	0.001	0.0001	0.001	0.0003	0.0001
2011	2.76	0.20	0.20	0.10	0.20	0.04	1.21	0.06	0.30	0.056	0.32	0.04	0.002	0.001	0.022	0.000	0.002	0.0001	0.002	0.0002	0.0001
2012	2.83	0.21	0.20	0.10	0.18	0.03	1.29	0.06	0.29	0.055	0.36	0.03	0.002	0.002	0.022	0.000	0.002	0.0002	0.001	0.0003	0.0001
2013	2.91	0.21	0.21	0.10	0.19	0.03	1.36	0.07	0.28	0.052	0.35	0.03	0.002	0.001	0.021	0.000	0.002	0.0001	0.002	0.0003	0.0001
2014	2.96	0.22	0.21	0.13	0.20	0.04	1.34	0.07	0.26	0.051	0.37	0.03	0.002	0.001	0.020	0.000	0.002	0.0001	0.001	0.0002	0.0001
2015	3.05	0.22	0.22	0.14	0.18	0.04	1.39	0.07	0.26	0.049	0.42	0.04	0.002	0.001	0.020	0.001	0.002	0.0001	0.001	0.0002	0.0001
2016	3.26	0.23	0.22	0.13	0.16	0.03	1.64	0.08	0.25	0.048	0.41	0.03	0.002	0.002	0.019	0.001	0.002	0.0001	0.001	0.0002	0.0000
2017	3.30	0.23	0.24	0.13	0.16	0.03	1.62	0.08	0.24	0.055	0.45	0.04	0.002	0.001	0.020	0.001	0.002	0.0001	0.001	0.0002	0.0000
2018	3.43	0.22	0.23	0.14	0.14	0.03	1.81	0.08	0.23	0.055	0.43	0.04	0.002	0.001	0.020	0.001	0.002	0.0001	0.001	0.0002	0.0000
2019	3.35	0.23	0.22	0.13	0.13	0.03	1.78	0.09	0.23	0.048	0.39	0.04	0.002	0.001	0.021	0.001	0.002	0.0001	0.001	0.0002	0.0000
2020	3.59	0.23	0.23	0.12	0.13	0.03	2.05	0.09	0.22	0.042	0.39	0.03	0.002	0.001	0.021	0.001	0.002	0.0001	0.001	0.0002	0.0000
2021	3.62	0.23	0.22	0.11	0.12	0.03	2.09	0.09	0.21	0.034	0.43	0.02	0.002	0.001	0.020	0.001	0.002	0.0001	0.001	0.0002	0.0000
2022	3.56	0.22	0.23	0.12	0.13	0.03	2.08	0.09	0.20	0.025	0.39	0.02	0.002	0.001	0.020	0.001	0.002	0.0001	0.001	0.0002	0.0000
Trend 1990 -2022	14%	-16%	6%	-9%	-50%	-60%	34%	36%	18%	-77%	60%	-55%	56%	2531%	118%	382%	108%	-75%	NA	-84%	-53%
Trend 2021 -2022	-2%	-3%	4%	2%	3%	3%	-1%	2%	-4%	-26%	-9%	-29%	3%	0%	3%	6%	9%	-5%	-35%	-6%	16%

Notes: Mules and asses are include with horses

Table 5-33 – N_2O emission trends for IPCC Category 3B – Manure Management: 1990-2022 (Gg)

Year	Total	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners 10-30 kg	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
	3 - Agriculture Sector N_2O emissions (Gg) 3.Bb - Manure management																				
1990	0.09	0.015	0.009	0.010	0.007	0.005	0.037	0.002	0.003	0.001	0.002	0.0005	0.0003	0.000	0.001	0.00001	0.0001	0.00000	NO	0.0002	0.00001
1991	0.09	0.015	0.009	0.011	0.007	0.005	0.036	0.002	0.003	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00001	0.0001	0.00000	NO	0.0002	0.00001
1992	0.09	0.014	0.009	0.010	0.007	0.004	0.033	0.002	0.003	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00000	0.0001	0.00000	NO	0.0002	0.00001
1993	0.09	0.014	0.009	0.010	0.007	0.004	0.033	0.002	0.004	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00000	0.0001	0.00000	NO	0.0001	0.00001
1994	0.09	0.014	0.009	0.009	0.007	0.003	0.032	0.002	0.004	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00000	0.0001	0.00000	NO	0.0001	0.00001
1995	0.09	0.014	0.009	0.010	0.008	0.004	0.032	0.002	0.004	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00000	0.0001	0.00000	NO	0.0001	0.00001
1996	0.09	0.015	0.009	0.010	0.008	0.004	0.032	0.002	0.004	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00000	0.0001	0.00000	NO	0.0001	0.00001
1997	0.09	0.014	0.009	0.010	0.008	0.005	0.031	0.002	0.004	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00001	0.0001	0.00000	NO	0.0001	0.00001
1998	0.08	0.014	0.008	0.009	0.009	0.004	0.028	0.002	0.004	0.001	0.002	0.0004	0.0003	0.000	0.002	0.00001	0.0001	0.00000	NO	0.0001	0.00002
1999	0.08	0.014	0.008	0.009	0.009	0.004	0.027	0.002	0.004	0.001	0.002	0.0005	0.0003	0.000	0.002	0.00001	0.0001	0.00000	NO	0.0001	0.00002
2000	0.08	0.014	0.008	0.009	0.009	0.003	0.026	0.002	0.005	0.001	0.002	0.0004	0.0003	0.000	0.003	0.00001	0.0001	0.00000	NO	0.0001	0.00002
2001	0.08	0.013	0.008	0.009	0.009	0.004	0.025	0.002	0.005	0.001	0.002	0.0004	0.0004	0.000	0.003	0.00001	0.0001	0.00000	NO	0.0001	0.00002
2002	0.08	0.013	0.007	0.008	0.008	0.003	0.025	0.002	0.005	0.001	0.002	0.0004	0.0004	0.000	0.003	0.00001	0.0001	0.00000	NO	0.0001	0.00002
2003	0.08	0.013	0.007	0.008	0.008	0.003	0.025	0.002	0.005	0.001	0.003	0.0004	0.0004	0.000	0.003	0.00001	0.0001	0.00000	0.000001	0.0001	0.00001
2004	0.08	0.013	0.007	0.008	0.008	0.003	0.026	0.002	0.005	0.001	0.003	0.0003	0.0004	0.000	0.003	0.00001	0.0001	0.00000	0.000002	0.0001	0.00002
2005	0.08	0.012	0.007	0.007	0.008	0.002	0.023	0.002	0.005	0.001	0.003	0.0004	0.0004	0.000	0.003	0.00001	0.0001	0.00000	0.000001	0.0001	0.00002
2006	0.07	0.012	0.007	0.007	0.008	0.002	0.023	0.001	0.005	0.001	0.003	0.0003	0.0004	0.000	0.003	0.00001	0.0001	0.00000	0.000001	0.0001	0.00002
2007	0.08	0.013	0.008	0.008	0.008	0.002	0.024	0.002	0.005	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00001	0.0001	0.00000	0.000001	0.0001	0.00001
2008	0.08	0.013	0.008	0.007	0.009	0.002	0.025	0.001	0.005	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00000	0.0001	0.00000	0.000001	0.0001	0.00002
2009	0.08	0.013	0.008	0.007	0.008	0.003	0.024	0.001	0.005	0.001	0.003	0.0003	0.0004	0.001	0.004	0.00001	0.0001	0.00000	0.000001	0.0001	0.00002
2010	0.08	0.013	0.008	0.007	0.009	0.002	0.022	0.001	0.005	0.001	0.002	0.0004	0.0004	0.001	0.003	0.00001	0.0001	0.00000	0.000001	0.0001	0.00002
2011	0.07	0.014	0.008	0.006	0.008	0.002	0.022	0.001	0.005	0.001	0.003	0.0004	0.0004	0.001	0.003	0.00001	0.0001	0.00000	0.000002	0.0001	0.00003
2012	0.07	0.014	0.008	0.006	0.008	0.002	0.021	0.001	0.005	0.001	0.003	0.0003	0.0004	0.001	0.004	0.00001	0.0002	0.00000	0.000001	0.0001	0.00003
2013	0.07	0.015	0.008	0.006	0.008	0.002	0.021	0.001	0.005	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00001	0.0002	0.00000	0.000002	0.0001	0.00002
2014	0.08	0.016	0.008	0.008	0.009	0.002	0.021	0.001	0.005	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00001	0.0002	0.00000	0.000001	0.0001	0.00002
2015	0.08	0.016	0.008	0.008	0.008	0.002	0.022	0.001	0.004	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00001	0.0002	0.00000	0.000001	0.0001	0.00002
2016	0.08	0.017	0.008	0.008	0.007	0.002	0.024	0.001	0.004	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00001	0.0002	0.00000	0.000001	0.0001	0.00002
2017	0.08	0.016	0.009	0.008	0.007	0.002	0.025	0.002	0.004	0.001	0.003	0.0003	0.0004	0.001	0.003	0.00001	0.0003	0.00000	0.000001	0.0000	0.00001
2018	0.08	0.016	0.008	0.008	0.007	0.002	0.025	0.002	0.004	0.001	0.002	0.0002	0.0004	0.001	0.003	0.00001	0.0003	0.00000	0.000001	0.0001	0.00002
2019	0.08	0.017	0.008	0.007	0.006	0.002	0.026	0.002	0.004	0.001	0.002	0.0002	0.0003	0.001	0.003	0.00001	0.0003	0.00000	0.000001	0.0000	0.00001
2020	0.08	0.017	0.008	0.007	0.006	0.002	0.026	0.002	0.004	0.001	0.002	0.0002	0.0004	0.001	0.003	0.00001	0.0003	0.00000	0.000001	0.0000	0.00000
2021	0.08	0.017	0.008	0.007	0.006	0.002	0.026	0.002	0.004	0.000	0.002	0.0001	0.0004	0.001	0.003	0.00002	0.0003	0.00000	0.000001	0.0000	0.00000
2022	0.08	0.016	0.008	0.007	0.006	0.002	0.025	0.002	0.004	0.000	0.002	0.0001	0.0004	0.001	0.003	0.00003	0.0003	0.00000	0.000001	0.0000	0.00000
Trend 1990 -2022	-19%	9%	-12%	-35%	-10%	-64%	-32%	-20%	23%	-77%	-17%	-80%	31%	3087%	127%	382%	251%	-75%	NA	-83%	-15%
Trend 2021 -2022	-3%	-3%	1%	-2%	2%	2%	-2%	0%	-4%	-22%	-5%	-26%	4%	4%	3%	6%	-18%	-5%	-35%	-9%	16%

Notes:

Mules and asses are include with horses

N_2O emissions by livestock category excluding emissions from pasture.

Figure 5-10 – CH_4 emissions from manure management (Gg/year) per animal category: 1990 - 2022

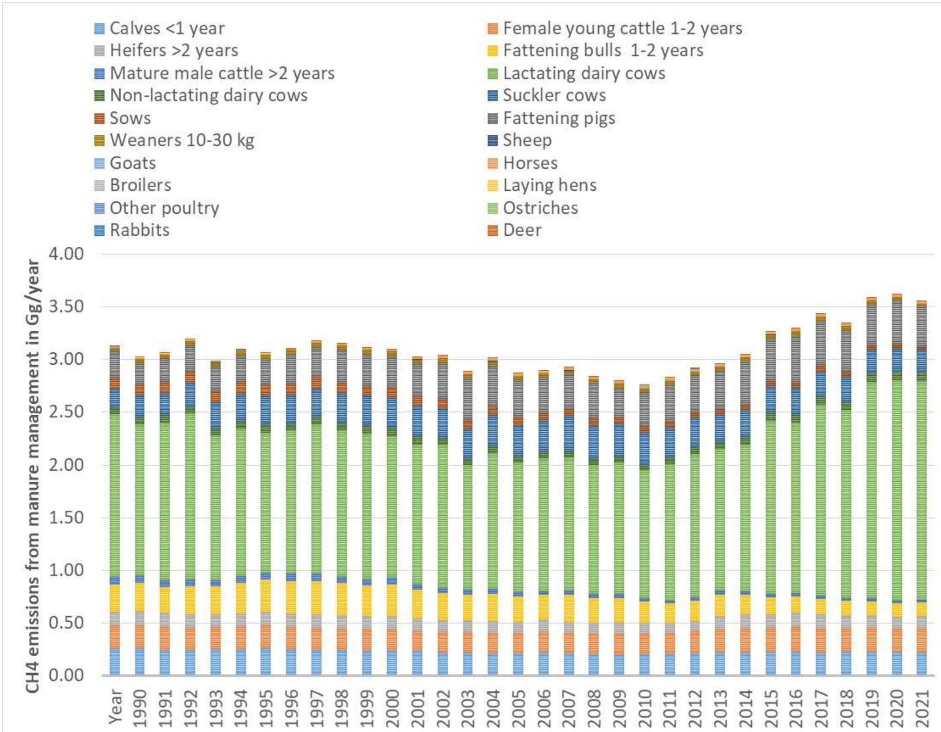


Figure 5-11 – Direct N_2O emissions from manure management (Gg/year) per animal category: 1990 - 2022

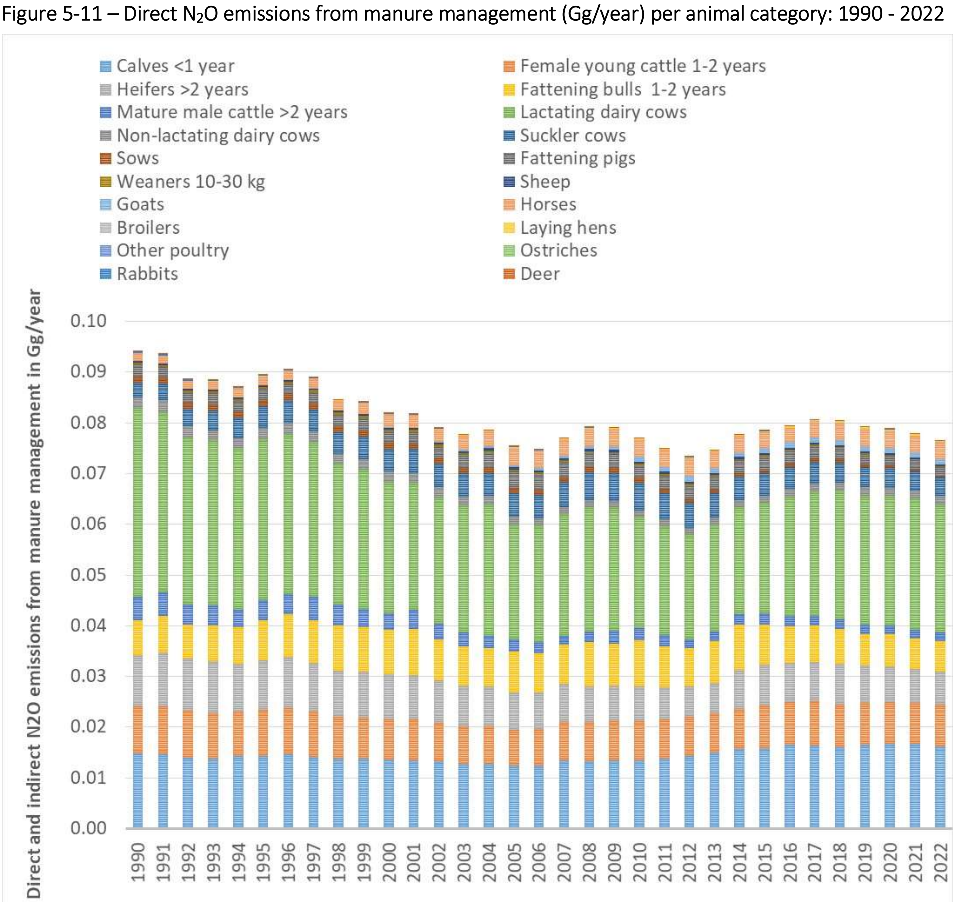


Table 5-34 – N_2O emission trends for IPCC Category 3B – Manure Management: 1990-2022 (Gg)

3 - Agriculture									
N_2O emissions (Gg)									
	3Bb - Manure management								
Year	Direct - Total	Aerobic lagoon	Liquid	Solid	Pature	Digester	Indirect - Total	Atmospheric deposition	Leaching and run-off
1990	0.094	NO	0.024	0.071	IE	NO	0.052	0.052	NO
1991	0.094	NO	0.023	0.070	IE	NO	0.052	0.052	NO
1992	0.089	NO	0.022	0.067	IE	NO	0.050	0.050	NO
1993	0.088	NO	0.022	0.066	IE	NO	0.051	0.051	NO
1994	0.087	NO	0.022	0.065	IE	NO	0.050	0.050	NO
1995	0.089	NO	0.022	0.067	IE	NO	0.052	0.052	NO
1996	0.090	NO	0.022	0.068	IE	NO	0.053	0.053	NO
1997	0.089	NO	0.022	0.067	IE	NO	0.052	0.052	NO
1998	0.085	NO	0.023	0.062	IE	0.000	0.051	0.051	NO
1999	0.084	NO	0.023	0.061	IE	0.000	0.051	0.051	NO
2000	0.082	NO	0.022	0.059	IE	0.000	0.050	0.050	NO
2001	0.082	NO	0.022	0.060	IE	0.000	0.050	0.050	NO
2002	0.079	NO	0.021	0.058	IE	0.000	0.049	0.049	NO
2003	0.078	NO	0.021	0.057	IE	0.000	0.048	0.048	NO
2004	0.079	NO	0.021	0.057	IE	0.000	0.049	0.049	NO
2005	0.075	NO	0.022	0.053	IE	0.000	0.047	0.047	NO
2006	0.075	NO	0.021	0.053	IE	0.001	0.047	0.047	NO
2007	0.077	NO	0.022	0.055	IE	0.001	0.048	0.048	NO
2008	0.079	NO	0.022	0.056	IE	0.001	0.050	0.050	NO
2009	0.079	NO	0.022	0.057	IE	0.001	0.050	0.050	NO
2010	0.077	NO	0.023	0.053	IE	0.001	0.050	0.050	NO
2011	0.075	NO	0.022	0.052	IE	0.001	0.049	0.049	NO
2012	0.073	NO	0.022	0.051	IE	0.001	0.048	0.048	NO
2013	0.075	NO	0.022	0.052	IE	0.001	0.049	0.049	NO
2014	0.078	NO	0.022	0.054	IE	0.001	0.050	0.050	NO
2015	0.078	NO	0.023	0.055	IE	0.001	0.051	0.051	NO
2016	0.079	NO	0.023	0.055	IE	0.001	0.051	0.051	NO
2017	0.081	NO	0.024	0.055	IE	0.001	0.053	0.053	NO
2018	0.080	NO	0.024	0.055	IE	0.002	0.052	0.052	NO
2019	0.079	NO	0.024	0.054	IE	0.002	0.052	0.052	NO
2020	0.079	NO	0.023	0.054	IE	0.002	0.052	0.052	NO
2021	0.078	NO	0.023	0.053	IE	0.002	0.051	0.051	NO
2022	0.076	NO	0.023	0.052	IE	0.001	0.050	0.050	NO
Trend 1990 -2022	-19%	NO	-3%	-26%	IE	NA	-4%	-4%	NO
Trend 2021 -2022	-2%	NO	-2%	-1%	IE	-15%	-2%	-2%	NO

Notes:

N_2O emissions from MMS-pasture are excluded from the total N_2O emissions in IPCC Category 3B since they have to be accounted for in IPCC Sub-category 3D2 – Emissions.

N_2O emissions from MMS-– digester included N_2O emissions from both, national-produced animal manure and from imported animal manure used as feedstock in biogas facilities. N_2O emissions from MMS-– digester associated with imported animal manure were also included in the total.

Table 5-35 – CH_4 & N_2O emission trends for IPCC Category 3B – Manure Management and indirect atmospheric N_2O emissions: 1990-2022

3 - Agriculture

GHG emissions by source & sink category (Gg CO2 eq)

Year	3B - Manure management			
	Total	CH_4	N_2O - direct emissions	Indirect atmospheric N_2O emissions
1990	126.2	87.5	24.9	13.77
1991	123.2	84.6	24.8	13.81
1992	122.4	85.7	23.5	13.24
1993	126.1	89.3	23.4	13.40
1994	119.9	83.5	23.1	13.27
1995	124.0	86.6	23.7	13.73
1996	123.6	85.7	24.0	13.94
1997	124.3	87.0	23.6	13.77
1998	124.8	88.9	22.4	13.42
1999	124.1	88.3	22.3	13.47
2000	122.1	87.1	21.7	13.23
2001	121.6	86.7	21.7	13.26
2002	118.4	84.6	20.9	12.86
2003	118.4	85.1	20.6	12.70
2004	114.5	80.8	20.8	12.87
2005	116.9	84.4	20.0	12.58
2006	112.7	80.4	19.8	12.47
2007	114.2	81.0	20.4	12.83
2008	116.2	81.9	21.0	13.34
2009	113.8	79.5	21.0	13.34
2010	112.0	78.4	20.4	13.26
2011	110.0	77.1	19.9	12.99
2012	111.3	79.2	19.4	12.69
2013	114.3	81.6	19.8	12.88
2014	116.7	82.8	20.6	13.30
2015	119.6	85.4	20.8	13.42
2016	126.0	91.3	21.0	13.61
2017	127.7	92.4	21.4	13.93
2018	131.3	96.1	21.3	13.86
2019	128.4	93.7	21.0	13.73
2020	135.1	100.5	20.9	13.70
2021	135.6	101.4	20.6	13.56
2022	133.1	99.6	20.3	13.24
Trend 1990 -2022	5%	14%	-19%	-4%
Trend 2021 -2022	-2%	-2%	-2%	-2%

Note: CH_4 emissions were converted in CO_2-eq. by multiplying the emissions by 28 and N_2O emissions were converted in CO_2-eq. by multiplying the emissions by 265.

5.3.3 Methodological issues

Table 5-36 gives an overview of the status, the methods and emission factors (EF) used for the IPCC Source Category 3.B.

Table 5-36 –Overview of IPCC Source Category 3.B: Status, methods and EF used

GHG source & sink category	Description	CH_4			N_2O		
		Status	Method	EF	Status	Method[e]	EF
3.B.1 opt. C	Calves < 1 year	x	T2	CS	x	T2	D
3.B.1	Female young cattle 1-2 years	x	T2	CS	x	T2	D
3.B.1	Heifers > 2 years	x	T2	CS	x	T2	D
3.B.1	Fattening bulls 1-2 years	x	T2	CS	x	T2	D
3.B.1	Mature male cattle >2 years	x	T2	CS	x	T2	D
3.B.1	Lactating dairy cows	x	T2	CS	x	T2	D
3.B.1	Suckler cows	x	T2	CS	x	T2	D
3.B.2	Mature sheep	x	T1	CS	x	T2	D
3.B.2	Sheep lamb < 1 year	x	T1	CS	x	T2	D
3.B.3	Sows	x	T1	CS	x	T2	D
3.B.3	Fattening pigs >30 kg	x	T1	CS	x	T2	D
3.B.3	Weaners (10-30 kg)	x	T1	CS	x	T2	D
3.B.4	Horses[a]	x	T1	CS	x	T2	D
3.B.4	Goats[b]	x	T1	CS	x	T2	D
3.B.4	Poultry[c]	x	T1	CS	x	T2	D
3.B.4	Ostrich	x	T1	D	x	T2	D
3.B.4	Rabbits[d]	x	T1	D	x	T2	D
3.B.4	Deer	x	T1	D	x	T2	D
3.B.5	Indirect N_2O emissions	NA			x	T2	D

Notes:

An “x” indicates that emissions from this sub-category have been estimated.

a) Including also ponys, mules and asses. Ponys, mules and asses are pet animals, as are also the majority of the horses (i.e. riding horses).

b) Goats are split in 2 sub-categories: i) mature goats and ii) goat kit for the calculations, but reported in the CRF as one category.

c) Poultry, excluding ostriches are split in 3 sub-categories: i) broilers; ii) laying hens; iii) other poultry for the calculations.

d) Rabbits are split in 2 sub-categories: i) female breeding animals and ii) other rabbits for the calculations but reported in the CRF as one category.

Used abbreviations: CS = country-specific value EF; D = IPCC default EF; NA = not applicable; T1 = IPCC Tier 1; T2 = IPCC Tier 2.

5.3.3.1 Activity data

Livestock numbers and manure management systems (MMS) are the two main types of activity data for estimating methane emissions. Livestock numbers were presented in section 5.2.2.1 and MMS for the different animal categories in section 5.2.2.2.

For direct N_2O emissions, livestock numbers and N.ex per head/place per year are the two main types of activity data. Livestock numbers were presented in section 5.2.2.1 and N.ex. in kg/head, respectively kg/place were discussed in detail in section 5.1.2. An additional source for N_2O emissions were the imported manure used as feedstock in biogas facilities in Luxemburg, see Table 5-15, and annual nitrogen input via co-digestate, see Table 5-37. More details are provided in Luxembourg’s Informative Inventory Report 2024. Livestock numbers and N.ex per head/place are the activity data used for estimating NH_3-N emissions (kg NH_3-N/year) and NO_x-N emissions (kg NO_x-N /year, expressed as nitrogen monoxide) for all defined livestock categories *i* within NFR Category 3B (Manure management). Volatilisation of N from manure management in forms of NH_3 and NO_x are the activity data used to estimate the indirect N_2O emissions from manure management, and are summarized in Table 5-37. Those emissions were estimated following the N-flow model described in section 5.1.3. More details are provided in Luxembourg’s Informative Inventory Report 2024 in section 5.3.3.

Additionally are volatilisation of N from co-digestate in forms of NH3, the activity data used for estimating the indirect N_2O emissions from co-digestate, and summarized in Table 5-37. N_2O emissions from co-digestate are reported in sector *5B2 - Biogenic Waste Treated in Biogas Plants*.

Table 5-37 – Activity data - Volatilisation of N from manure management in forms of NH_3 and NO_x and nitrogen input via co-digestate and volatilisation of N from co-digestate in forms

Year	3 - Agriculture: Activity data - Volatilisation of N from manure management in forms of NH_3 and NO_x (NRF 3B) (kg NH_3-N/year and kg NO-N/year)		5B2 - Biogenic Waste Treated in Biogas Plants: Activity data - Nitrogen input via co-digestate (kg N/year)	Activity data - Volatilisation of N from co-digestate in forms of NH_3 (NRF 5B2) (kg NH_3-N/year)
	NH_3-N Emissions	NO-N Emissions	N Input via co-digestate	NH_3-N Emissions
1990	2 356 011	5 984	-	-
1991	2 362 740	5 951	-	-
1992	2 265 971	5 634	-	-
1993	2 292 624	5 624	-	-
1994	2 271 444	5 539	-	-
1995	2 350 085	5 690	-	-
1996	2 385 300	5 759	-	-
1997	2 355 542	5 659	-	-
1998	2 296 769	5 380	2 465	54
1999	2 304 672	5 356	5 980	130
2000	2 264 047	5 210	9 706	212
2001	2 269 223	5 199	15 113	330
2002	2 200 813	5 021	26 732	583
2003	2 173 680	4 939	43 962	959
2004	2 202 105	4 985	99 926	2 180
2005	2 152 656	4 768	162 346	3 541
2006	2 134 332	4 719	248 800	5 427
2007	2 195 638	4 857	293 174	6 395
2008	2 283 445	4 989	329 400	7 185
2009	2 282 673	4 981	453 075	9 882
2010	2 268 997	4 840	430 015	9 379
2011	2 222 804	4 710	675 854	14 742
2012	2 171 832	4 603	665 271	14 511
2013	2 204 667	4 686	660 667	14 410
2014	2 276 394	4 875	776 700	16 941
2015	2 296 988	4 917	712 009	15 530
2016	2 329 079	4 962	757 725	16 527
2017	2 384 227	5 035	878 056	19 152
2018	2 372 155	5 010	1 014 731	22 133
2019	2 349 428	4 938	792 401	17 284
2020	2 344 846	4 913	749 389	16 346
2021	2 320 406	4 854	686 240	14 968
2022	2 265 757	4 782	609 548	13 295
Trend 1990 -2022	-4%	-20%		
Trend 2021 -2022	-2%	-1%	-11%	-11%

5.3.3.2 Emission factors

5.3.3.2.1 Emission factors - manure management related methane emissions

Emission factors used for the calculation of manure management related methane emissions were estimated using an IPCC Tier 2 for cattle and an IPCC Tier 1 for all other livestock categories and are detailed in the following sections. A simple Tier 1 was used for deer, rabbits and ostrichs, and an advanced Tier 1a methods for swine, sheep, goats, horses and poultry.

Emission factors for deer, rabbits and ostrichs

For deer, rabbits and ostrichs, the default emission factors (EF) for manure management related methane emissions for livestock category *i*, in kg CH_4 per head per year, were derived from Table 10.15 of the 2019 Refinement of the IPCC guidelines (Gavrilo, et al., 2019) and were 0.22, 0.08 and 5.67, respectively. For the assumed uncertainties, see 5.3.4.

Emission factors for swine, sheep, goats, horses and poultry

For swine, sheep, goats, horses and poultry the implied emission factors (IEF) for the calculation of manure management related methane emissions for livestock category *i*, for productivity system *p*, when applicable, expressed in kg CH_4/head/year, were estimated following the updated equation 10.22 of the 2019 Refinement of the IPCC guidelines (Gavrilo, et al., 2019):

$$IEF\ CH_4\ 3B_i = \left[\sum_{j\ (p)} \left(VS_{i,(p)} *\ MMS_{(i,j,(p))} * EF_{i,j,(p)}\right)/1000\right]$$

with:

VS_i	= annual volatile solid (VS) excretion per head/bird for livestock category *i*, for productivity system *p*, when applicable, in kg VS per animal per year
$MMS_{(i,(p),j)}$	= fraction of livestock category *i*'s , and where applicable, for productivity system *p*, manure handled using manure management system *j* in the country
$EF_{i,(p),j}$	= Emission factor for direct CH4 emissions from manure management system j, by livestock category I, in manure management system j, for productivity system *p*, when applicable, in g CH_4 per kg VS

The annual VS excretion for livestock category *i*, for productivity system *p*, when applicable was estimated according to the updated equation 10.22A of the 2019 Refinement of the IPCC guidelines (Gavrilo, et al., 2019):

$$VS_{i(p)} = \left(VS_{rate(i,(p))} * \frac{TAM_{i,(p)}}{1000}\right)$$

whereby using the IPCC default volatile solid excretion rates for Western Europe presented in Table 10.13a (Gavrilo, et al., 2019), namely 2.4, 5.3, 5.3, 8.2, 9, 5.65, 7.2, 16.1, 5.3 and 12.3 for sows, growing pigs, weaners, sheep, goats, horses, mules/anes, broilers, laying hens and other poultry, respectively. The "typical animal mass" (TAM) for livestock population *i,* for productivity system *p*, when applicable, was summarized in Table 5-24 .

The used fraction of livestock category *i*'s manure handled using manure management system *j* were explained in more details in section 5.2.2.2, and are summarized in Table 5-7 to Table 5-11.

The applied methane emission factors for the different manure management system for swine, sheep, goats, horses and poultry are summarized in Table 5-38.

Table 5-38 – Used methane emission factors for the different manure management system for swine, sheep, goats, horses and poultry

3- Agriculture

Methane emission factors by animal category *i,* productivity system j, where applicable, and manure management system *j* (in g CH4 pro kg VS)

Animal category	Pasture	Liquid/Slurry, and Pit storage below animal confinements > 1 month	Solid	Anaerobic Digester
Swine (i.e. sows; fattening pigs & weaners)	NO	63.3	6.0	6.0
Sheep – High productivity	0.6	NO	2.5	NO
Sheep – Low productivity	0.6	NO	1.7	NO
Goats: Dairy goats (High productivity)	0.6	NO	2.4	NO
Goats: Other goats (Low productivity)	0.6	NO	1.7	NO
Horses: Heavy horses (High productivity)	0.6	NO	4.0	NO
Horses: Riding horses (High productivity)	0.6	NO	4.0	NO
Horses: Ponys / Anes & Mules (Low productivity)	0.6	NO	3.5	NO
Broilers	NO	NO	5.2	NO
Laying hens	NO	NO	5.2	5.2
Other poultry	NO	NO	5.2	NO

Emission factors for cattle

For cattle the implied emission factors (IEF) for the calculation of manure management related methane emissions for livestock category *i*, expressed in kg CH_4/head/year, were estimated following equation 10.23 of of the 2019 Refinement of the IPCC guidelines (Gavrilo, et al., 2019):

$$IEF\ CH_4\ 3B_i = (VS_i * 365) * \left[B_{o(i)} * 0.67 * \sum_j \frac{MCF_j}{100} * MMS_{(i,j)}\right]$$

with:

VS_i = Daily volatile solid excreted for livestock category *i*, kg dry matter per animal per day

365 = the basis for calculating annual VS production

$B_{o(i)}$ = maximum methane producing capacity for manure produced by livestock category *i*, m^3 CH_4 kg^{-1} of VS excreted

0.67	= conversation factor of m^3 CH_4 to kilograms CH_4
MCF_j	= methane conversation factors for each manure management system, %
$MMS_{(i,j)}$	= fraction of livestock category *i*'s manure handled using manure management system *j* in the country

The used fraction of livestock category *i*'s manure handled using manure management system *j* were explained in more details in section 5.2.2.2, and are summarized in Table 5-7 to Table 5-11.

Having no country-specific data, but similar conditions, breeds and systems than Germany, the MCF was adapted to better fit local conditions, by using the same values as in the German Inventory (Günther, Gniffke, & Tarakji, 2023) for slurry and solid manure. The used MCF for pasture and anaerobic digester were based on Table 10.17 of the 2019 Refinement of the 2006 IPCC Guidelines, (Gavrilo, et al., 2019), whereby assuming that open storage would have been mostly constructed previous to 2008 (and hence less gastight), whereas covered storage would be equal to more recent constructions with best complete industrial technology. All used MCFs are summarized in Table 5-39.

Table 5-39 – Used methane conversion factors (MCF) for the different manure management system for cattle category *i*

3- Agriculture

Methan conversion factors (MCF) for the different manure management systems for cattle category *i*

Animal category	Pasture	Liquid/Slurry	Solid	Anaerobic Digester
Dairy cattle	0.47% (Gavrilo, et al., 2019) – Table 10.17	10% for natural crust; 17% for open tank without natural crust; Tank with solid or floating cover and underneath a slatted floor > 1 months (Günther, Gniffke, & Tarakji, 2023) – Table 231	17% for deep bedding > 1 months and 2% for heap (Günther, Gniffke, & Tarakji, 2023) – Table 231	12.14% open storage (as mostly constructed previous to 2008); 1% closed storage (Gavrilo, et al., 2019) – Table 10.17
Non-dairy cattle	0.47% (Gavrilo, et al., 2019) – Table 10.17	10% for natural crust; 17% for open tank without natural crust; Tank with solid or floating cover and underneath a slatted floor > 1 months (Günther, Gniffke, & Tarakji, 2023) – Table 231	17% for deep bedding > 1 months and 2% for heap (Günther, Gniffke, & Tarakji, 2023) – Table 231	12.14% open storage (as mostly constructed previous to 2008); 1% closed storage (Gavrilo, et al., 2019) – Table 10.17

There were no country-specific B_o measurement values available. The 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019) default values were used for dairy cattle (i.e 0.24) and for non-dariy cattle (0.18), and according to footnote 2 in Table 10.17 B_o for grazing cattle was assumed to be 0.19.

For the different cattle categories VS_i was estimated following equation 10.24 of the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019)

$$VS_i = \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left[\frac{(1 - ASH)}{18.45}\right]$$

with:

GE	= Gross energy intake, MJ per day (for the values used see Table 5-27)
DE%	= digestibility of the feed in percent (for the values used see Table 5-25)
(UE*GE)	= urinary energy expressed as a fraction of GE.
ASH	= the ash content of manure calculated as a fraction of the dry matter feed intake.
18.45	= conversion factor for dietary GE per kg of dry matter (MJ per kg).

Default values for UE (0.04 (IPCC 2006a) page 10.42) and ash (0.08 (IPCC 2006a) page 10.42) were used.

The so-obtained EF/IEFs for manure management related methane emissions, expressed in kg CH_4/head/year, are summarized for livestock category *i* for the years 1990-2022 in Table 5-40. These EF/ IEFs were multiplied with annual livestock numbers to obtain annual emissions per livestock category, and summarized over all livestock categories to obtain total emissions per year. For the assumed uncertainties, see 5.3.4.

Table 5-40 – Implied emission factors (IEFs) for manure management related methane emissions, in kg CH4/head/year for the years 1990-2022

Implied emission factors (IEF) for manure management related methane emissions, in kg CH_4/head/year for animal category *i*

Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Non-lactating dairy cows	Suckler cows	Sows	Fattening pigs > 30 kg	Weaners 10-30 kg	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	R
1990	4.4	6.4	5.2	19.5	13.4	26.3	14.6	9.9	6.5	3.9	1.0	0.14	0.08	2.6	0.03	0.02	0.11	NO	
1991	4.4	6.4	5.2	19.4	13.3	25.7	14.6	9.9	6.5	4.0	1.0	0.14	0.08	2.6	0.03	0.02	0.11	NO	
1992	4.4	6.5	5.3	19.3	13.3	29.3	14.7	10.0	6.5	4.0	1.0	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1993	4.4	6.5	5.3	19.2	13.2	31.4	14.7	10.0	6.5	4.0	1.0	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1994	4.4	6.5	5.3	19.1	13.1	28.1	14.7	10.1	6.5	4.1	1.0	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1995	4.4	6.5	5.3	18.9	13.1	28.7	14.8	10.2	6.5	4.1	1.0	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1996	4.4	6.5	5.3	18.8	13.0	27.7	14.8	10.2	6.6	4.1	1.1	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1997	4.4	6.5	5.3	18.4	13.3	29.3	14.8	10.3	6.6	4.1	1.1	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1998	4.4	6.7	5.6	18.3	13.2	30.9	15.5	10.2	6.6	4.2	1.1	0.14	0.08	2.5	0.03	0.02	0.11	NO	
1999	4.4	6.7	5.6	18.1	13.2	30.7	15.6	10.2	6.6	4.2	1.1	0.13	0.08	2.4	0.03	0.02	0.11	NO	
2000	4.3	6.7	5.6	17.8	12.7	31.9	15.7	10.1	6.5	4.2	1.1	0.14	0.08	2.5	0.03	0.02	0.11	NO	
2001	4.4	6.7	5.6	17.8	13.0	31.3	15.8	10.2	6.5	4.2	1.1	0.14	0.08	2.4	0.03	0.02	0.11	NO	
2002	4.4	6.8	5.7	17.8	12.7	31.6	15.8	10.4	6.4	4.2	1.1	0.14	0.22	2.4	0.03	0.02	0.11	NO	
2003	4.4	6.8	5.7	17.8	12.8	33.4	15.8	10.5	6.4	4.2	1.1	0.14	0.24	2.4	0.03	0.02	0.11	5.7	
2004	4.4	6.8	5.7	17.8	12.4	29.7	15.7	10.6	6.0	3.9	1.0	0.15	0.26	2.4	0.03	0.02	0.11	5.7	
2005	4.4	6.9	5.9	17.7	13.0	32.7	16.2	10.8	5.6	3.7	1.0	0.14	0.27	2.4	0.03	0.02	0.11	5.7	
2006	4.3	6.9	5.9	17.1	12.3	32.0	16.0	10.6	5.4	3.5	0.9	0.14	0.27	2.5	0.03	0.02	0.11	5.7	
2007	4.2	6.8	5.9	15.9	11.6	32.4	15.8	10.4	5.1	3.4	0.9	0.15	0.26	2.5	0.03	0.02	0.11	5.7	
2008	4.1	6.7	5.8	15.5	11.3	31.8	15.6	10.2	5.1	3.4	0.9	0.15	0.26	2.5	0.03	0.02	0.11	5.7	
2009	3.9	6.7	5.8	14.9	11.4	30.0	15.5	10.0	5.0	3.4	0.9	0.15	0.28	2.5	0.03	0.02	0.11	5.7	
2010	3.8	6.7	6.0	13.8	11.0	30.0	16.2	9.6	4.8	3.3	0.9	0.16	0.28	2.4	0.03	0.02	0.11	5.7	
2011	3.9	6.7	5.9	13.8	11.4	30.0	16.4	9.5	5.0	3.4	0.9	0.16	0.29	2.4	0.03	0.02	0.11	5.7	
2012	4.0	6.8	5.9	13.8	11.0	32.5	16.5	9.4	5.2	3.5	0.9	0.16	0.29	2.3	0.03	0.02	0.11	5.7	
2013	4.0	6.8	5.9	13.5	10.4	32.3	16.7	9.2	5.1	3.5	0.9	0.15	0.30	2.2	0.03	0.02	0.11	5.7	
2014	4.1	6.9	6.2	13.3	10.7	32.0	16.8	9.1	5.2	3.6	0.9	0.15	0.29	2.2	0.03	0.02	0.11	5.7	
2015	4.2	7.0	6.2	13.2	10.8	32.0	17.0	9.0	5.4	3.7	1.0	0.15	0.28	2.1	0.03	0.02	0.11	5.7	
2016	4.3	7.0	6.2	13.2	10.6	35.3	17.0	8.9	5.3	3.6	1.0	0.15	0.29	2.1	0.03	0.02	0.11	5.7	
2017	4.3	7.1	6.3	13.0	10.1	34.1	17.3	8.9	5.6	3.9	1.0	0.15	0.29	2.2	0.03	0.02	0.11	5.7	
2018	4.4	7.1	6.4	12.9	10.6	37.6	17.5	9.0	5.7	4.0	1.1	0.15	0.28	2.2	0.03	0.02	0.11	5.7	
2019	4.5	7.2	6.4	12.9	10.1	36.3	17.8	9.0	5.8	4.1	1.1	0.15	0.26	2.3	0.03	0.02	0.11	5.7	
2020	4.6	7.3	6.5	12.9	10.2	41.4	18.1	9.1	5.6	4.0	1.1	0.15	0.25	2.3	0.03	0.02	0.11	5.7	
2021	4.6	7.2	6.3	12.8	10.1	42.1	18.0	9.1	5.9	4.2	1.1	0.15	0.25	2.3	0.03	0.02	0.11	5.7	
2022	4.6	7.4	6.6	12.9	10.2	41.5	18.2	9.1	5.7	4.0	1.1	0.15	0.25	2.3	0.03	0.02	0.11	5.7	

Note: Mules and asses were recorded together with horses.

5.3.3.2.2 Emission factors – direct N_2O emissions from manure management

The IPCC Tier 2 method has been applied to all animal categories when estimating the N_2O emissions related to manure management, and annual nitrogen input via co-digestate, including imported animal manure.

Direct N_2O emissions from manure management in the country ($N_2O_{D(mm)}$), expressed in kg N_2O per year was obtained by:

$$N_2O_{D(mm)} = N_2O - N_{D(mm)} * \left(\frac{44}{28}\right)$$

with:

$N_2O - N_{D(mm)}$	= direct N_2O-N emissions from manure management in the country, kg N_2O-N/year
44/28	= conversion of $N_2O\text{-}N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

Direct N_2O-N emissions from manure management in the country ($N_2O - N_{D(mm)}$), expressed as kg N_2O-N per year, were estimated following equation 10.25 of the IPCC 2019 Refinements (Gavrilo, et al., 2019):

$$N_2O - N_{D(mm)} = \left[\sum_j \langle\left(\sum_i (n_i * N.ex_{(i)} * MMS_{(ij)})\right) + N_{cdg(j)}\rangle * EF_{dN2O\,(j)}\right]$$

with:

n_i	= number of head/places of livestock category *i*
$N.ex_{(i)}$	= annual average N excretion per head/place of livestock category *i*, in kg N per head/place per year
$MMS_{(i,j)}$	= fraction of livestock category *i*'s manure handled using manure management system *j* in the country
$N_{cdgi,j)}$	= annual nitrogen input via co-digestate, in kg N per year, where the system (j) refers exclusively to anaerobic digestion,
$EF_{dN2O(j)}$	= emission factor for direct N_2O emissions from manure management system *j* in the country, kg N_2O-N/ kg N in manure management system *j*

Yearly nitrogen excretion ($N.ex_{(i)}$)/head, respectively per place for livestock category *i*, as described in section 5.1.2 were used. Livestock numbers were presented in section 5.2.2.1 and manure management system *j* for the different livestock categories were explained in more details in section 5.2.2.2 and are summarized in in Table 5-7 to Table 5-11. Annual nitrogen input via co-digestate were presented in Table 5-37, and nitrogen input from imported animal manure to be used as feedstock in Table 5-15.

Emission factors (EF) default values as provided in Table 10.21 of the 2019 Refinement of the 2006 IPCC Guidelines (Gavrilo, et al., 2019) for the different manure management systems, and the different slurry storage systems were used and are summarized in Table 5-41.

Please note the direct N_2O-N emissions from annual nitrogen input via co-digestate originating from energy crops and non-agricultural waste, were estimated according to the above described equation, but notified under CRF 5B2 (see section 7.3.3).

Table 5-41 – Default EFs for N_2O emissions per selected MMS and livestock categories (Source: IPCC 2019 Refinements (Gavrilo, et al., 2019) – Table 10.21)

	MMS			
	Liquid System	Solid Storage	Pasture	Digester
Cattle	0.005[a,b] 0.002[c] 0[d]	0.005	IE	0.0006
Pigs	0.005[b] 0.002[c] 0[d]	0.005	NO	0.0006
Sheep	NO	0.005	IE	NO
Goats	NO	0.005	IE	NO
Horses	NO	0.005	IE	NO
Poultry	NO	0.001	NO	NO
Ostriches	NO	0.005	IE	NO
Rabbits	NO	0.005	NO	NO
Deer	NO	0.005	IE	NO
Annual nitrogen input via co-digestate				0.0006

Notes: Emissions related to pasture are accounted for under IPCC Category 3D- Agricultural Soils.
a) Cattle slurry stored in an open tank with natural crust cover;
b) Slurry stored in a covered slurry tank;
c) Storage of slurry underneath a slatted floor;
d) Slurry stored in an open slurry tank without natural crust cover.
Abbreviation used: IE = estimated elsewhere. NO=not occurring

5.3.3.2.3 Emission factors – indirect N_2O emissions from manure management

The indirect N_2O emissions due to volatilisation of N from manure management in forms of NH_3 and NO_x in the country, expressed as kg N_2O per year were estimated using an N-flow model (for more details see section 5.1.3 and a schematic representation of the N flows in Figure 5-6).

Indirect N_2O emissions due to volatilisation of N from manure management in the country ($N_2O_{G(mm)}$), expressed in kg N_2O per year was obtained by:

$$N_2O_{G(mm)} = N_2O - N_{G(mm)} * \left(\frac{44}{28}\right)$$

with:

$N_2O - N_{G(mm)}$ = indirect N_2O-N emissions due to volatilization of N from manure management in the country, kg N_2O-N per year

44/28 = conversion of N_2O-$N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

Indirect N_2O-N emissions due to volatilisation of N from manure management in the country ($N_2O - N_{G(mm)}$), expressed as kg N_2O-N per year, were estimated by multiplying the total emissions of NH_3 and NO_x from animal housing and manure management and NH_3 from manure and digestate storage by an emission factor.

$$N_2O - N_{G(mm)} = \{[NH_3 - N\ emissions\ manure\ management + NO_x - N\ emissions\ manure\ management\ ] * EF_{iN_2O-N}\ \}$$

with:

NH_3-N emissions manure management = NH_3-N emissions (kg NH_3-N/year) for all defined livestock categories *i* within NFR Category 3B (Manure management), see Table 5-37, and for NH_3-N emissions (kg NH_3-N/year) from nitrogen input via co-digestate. For additional information see section 5.1.3 and the INFORMATIVE INVENTORY REPORT 2024; Note: n_i= the number of animals in the *i*-th livestock category.

$$= \sum_i [\{E_{build\_slurry\_NH3-N(i)} + E_{build\_solid\_NH3-N(i)} + E_{storage\_slurry\_NH3-N(i)} + E_{storage\_solid\_NH3-N(i)} + E_{storage\_digestate\_NH3-\ \ (i)}\} * n_i]$$

NO_x-N emissions manure management = NO_x-N emissions (kg NO_x-N /year, expressed as nitrogen monoxide) for all defined livestock categories *i* within NFR Category 3B (Manure management), see Table 5-37. For additional information see section 5.1.3 and the INFORMATIVE INVENTORY REPORT 2024. Note: n_i= the number of animals in the *i*-th livestock category.

$$= \sum_i [\{\ E_{storage\_slurry\_NO-N(i)} + E_{storage\_solid\_NO-N(i)}\} * n_i]$$

EF_{iN2O}-N manure management indirect = Nitrous oxide emission factor for indirect emission following atmospheric deposition of NH3 and NOx, here the default IPCC N_2O-N emission factor for indirect emissions from deposition in a wet climate (i.e. (0.014 according to the IPCC 2019 Refinements (Hergoulac'h, et al., 2019), expressed in kg N_2O-N/kg N was used.

Leaching and/or uncontrolled surface runoff from manure management (including management of bio-digester) is, according to the EU Nitrate Directive (EU, 1991) forbidden on grounds of protection of inshore waters (EU, 1991). Hence, no indirect N_2O emissions from leaching and runoff was calculated for the manure management. This was done so for all years since 1990.

Indirect N_2O emissions due to volatilisation of annual nitrogen input via co-digestate originating from energy crops and no-agricultural waste are reported in the Sector 5.B.2, whereas indirect N_2O emissions as a consequence of spreading of manure and digestate are reported in Sector 3.D.

5.3.4 Category specific uncertainty

Uncertainty was model using Monte-Carlo techniques, see section 5.1.5.1 for more details. The uncertainty w.r.t. livestock numbers, manure management system and N.ex were described in detail in section 5.1.5. The uncertainty of the used emission factors for manure management for methane emissions and N_2O emissions, both direct and indirect, are provided hereafter.

5.3.4.1 Methane emissions from manure management (CRF 3Ba) - Emission factors

The uncertainty range of the methane emission factors for manure management for all other livestock categories than cattle, was based on the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019) whereby assuming an uncertainty of ±30%, which was modelled as an uniform-distribution with as a minimum value of (EF_i*0.7) and a maximum value of: (EF_i*1.3). The Tier 1- default VS excretion rate for swine, sheep, goats, horses and poultry were assumed to be uniformely distributed with ±25%,±50%, ±50%, ±50%, ±50% and ±50%, respectively.

For cattle a Tier 2 approach was taken. The uncertainty range for maximum methane producing capacity for manure produced by livestock category *i* ($B_{o(i)}$) was assumed to be +- 15% (Gavrilo, et al., 2019) and modelled as uniformely distributed. The uncertainty for VS_i for lactating dairy cows was assumed to be ±20%, according to Table 10.A4 in the IPCC 2006 guidelines (Hongmin, et al.), and was modelled by multiplying the estimated VS_i by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%. The uncertainty for VS_i for cattle other than dairy cows was assumed to be ±35%, according to Table 10.A5 in the IPCC 2006 guidelines (Hongmin, et al.), and was modelled by multiplying the estimated VS_i by an uncertainty factor that was uniformly distributed with minimum 65% and maximum 135%. And as already indicated in section 5.2.4, the digestibility energy (DE%) was assumed to vary by ±2%.

5.3.4.2 N_2O emissions from manure management (CRF 3Bb)

The uncertainty range of the default emission factors (EF) for direct N_2O emissions from manure management as presented in Table 10.21 from the 2019 Refinement of the 2006 IPCC guidelines (Gavrilo, et al., 2019) were assumed to be a factor 2. Assuming that EFs would be uniformly distributed, the minimum was equal to the default value divided by 2, and the maximum was equal to the default value multiplied by 2.

Methology, used emissions factors, including uncertainty ranges, for estimating NH_3 and NO_X emissions from manure management is described in the Informative inventory report 2024, and determines the uncertainty range of the estimated Nitrogen loss due to volatilization of NH_3 and NO_X. The uncertainty range used for the Emission factor – N volatilization and re-deposition for indirect soil N_2O emissions for a wet climate was based on Table 11.3 of the 2019 Refinement to the 2006 IPCC guidelines (Hergoulac'h, et al., 2019), and modelled as uniformly distributed with minimum 0.011 and maximum 0.017.

5.3.5 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.3.6 Category-specific recalculations including changes made in response to the review process

Revision of livestock numbers and the composition of digestate originating from animal manure since submission 2023v1 are described in Table 5-21 and affected also the emissions from manure management, both methane emissions as N_2O emissions. Additional revisions and relevant for emissions from manure management are described in Table 5-42.

Table 5-42 – Recalculations done since submission 20232v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
3.B.a.	Revision and adaptation of the methodology for methane emissions from manure management: i) for all ivestock categories other than cattle, using a Tier 1 approach according to the 2019 Refinement; and ii) for cattle, using a Tier 2 approach according to the 2019 Refinement.	EF
3.B.b	Revision: Direct and indirect N_2O emissions from N input via co-digestate originating from energy crops and non-agricultural waste was reported in Sector CRF 5B2	Method

The recalculated CH_4 emissions from manure management, resulted in an average increase of the methan emission of 19%, varying over the years from minimum 14% to maximum 22%, see Table 5-43.

The recalculated N_2O emissions from manure management, both direct and indirect, changed only slightly, see Table 5-44.

Table 5-43 – Recalcution of methane emission from manure management in Gg CH_4 emissions

3 - Agriculture Sector

CH_4 Emissions (Gg) by source & sink category

Year	3Ba-Cattle Gg CH_4		Impact of recalculation	3Ba-Other livestock than cattle Gg CH_4		Impact of recalculation	3Ba - Manure management Gg CH_4		Impact of recalculation
	New	Old	%	New	Old	%	New	Old	%
1990	2.7	2.4	13.5	0.40	0.30	34.0	3.1	2.7	15.8
1991	2.7	2.3	14.2	0.36	0.27	33.9	3.0	2.6	16.3
1992	2.7	2.3	15.9	0.38	0.28	35.8	3.1	2.6	18.0
1993	2.8	2.4	16.6	0.41	0.30	36.5	3.2	2.7	18.8
1994	2.6	2.3	15.0	0.39	0.29	35.0	3.0	2.5	17.3
1995	2.7	2.3	15.3	0.41	0.30	35.2	3.1	2.6	17.6
1996	2.7	2.3	15.5	0.40	0.30	32.9	3.1	2.6	17.5
1997	2.7	2.3	16.3	0.44	0.32	35.8	3.1	2.6	18.7
1998	2.7	2.4	15.9	0.45	0.34	33.0	3.2	2.7	18.0
1999	2.7	2.3	14.9	0.47	0.36	31.6	3.2	2.7	17.1
2000	2.7	2.3	13.8	0.45	0.34	32.9	3.1	2.7	16.2
2001	2.6	2.3	15.3	0.45	0.34	33.6	3.1	2.6	17.7
2002	2.6	2.2	16.1	0.46	0.34	33.4	3.0	2.6	18.4
2003	2.5	2.1	19.2	0.50	0.37	34.6	3.0	2.5	21.5
2004	2.3	2.0	18.2	0.54	0.39	37.0	2.9	2.4	21.3
2005	2.5	2.1	19.3	0.54	0.41	32.5	3.0	2.5	21.5
2006	2.4	2.0	18.1	0.49	0.37	31.4	2.9	2.4	20.2
2007	2.4	2.0	18.7	0.47	0.36	28.5	2.9	2.4	20.2
2008	2.5	2.1	18.4	0.46	0.36	29.2	2.9	2.4	19.9
2009	2.4	2.0	16.5	0.46	0.36	28.8	2.8	2.4	18.3
2010	2.4	2.1	13.2	0.40	0.34	18.3	2.8	2.5	13.9
2011	2.3	2.0	14.1	0.44	0.37	20.6	2.8	2.4	15.0
2012	2.4	2.0	15.4	0.47	0.38	26.0	2.8	2.4	17.1
2013	2.5	2.1	15.9	0.46	0.37	27.0	2.9	2.5	17.6
2014	2.5	2.1	16.1	0.48	0.37	28.1	3.0	2.5	17.9
2015	2.5	2.2	17.0	0.53	0.41	28.2	3.1	2.6	18.8
2016	2.7	2.3	17.4	0.52	0.40	28.6	3.3	2.7	19.0
2017	2.7	2.3	17.7	0.57	0.43	31.1	3.3	2.8	19.8
2018	2.9	2.4	18.3	0.55	0.42	32.0	3.4	2.9	20.3
2019	2.8	2.4	19.4	0.51	0.39	29.8	3.3	2.8	20.9
2020	3.1	2.6	19.7	0.49	0.37	34.2	3.6	3.0	21.5
2021	3.1	2.6	19.8	0.52	0.36	41.9	3.6	3.0	22.5
2022	3.1			0.46			3.6		

Table 5-44 – Recalcution of N_2O emissions from manure management in Gg N_2O

3 - Agriculture

N_2O Emissions (Gg) by source & sink category

Year	3Bb - Direct emissions Gg N_2O		Impact of recalculation	3Bb - Indirect emissions Gg N_2O		Impact of recalculation	CRF 3Bb Gg N_2O		Impact of recalculation
	New	Old	%	New	Old	%	New	Old	%
1990	0.09	0.09	0.00	0.05	0.05	0.00	0.15	0.15	0.00
1991	0.09	0.09	0.00	0.05	0.05	0.00	0.15	0.15	0.00
1992	0.09	0.09	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1993	0.09	0.09	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1994	0.09	0.09	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1995	0.09	0.09	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1996	0.09	0.09	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1997	0.09	0.09	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1998	0.08	0.08	0.00	0.05	0.05	0.00	0.14	0.14	0.00
1999	0.08	0.08	-0.01	0.05	0.05	-0.01	0.13	0.13	-0.01
2000	0.08	0.08	-0.01	0.05	0.05	-0.01	0.13	0.13	-0.01
2001	0.08	0.08	-0.02	0.05	0.05	-0.01	0.13	0.13	-0.02
2002	0.08	0.08	-0.03	0.05	0.05	-0.03	0.13	0.13	-0.03
2003	0.08	0.08	-0.05	0.05	0.05	-0.04	0.13	0.13	-0.05
2004	0.08	0.08	-0.11	0.05	0.05	-0.10	0.13	0.13	-0.11
2005	0.08	0.08	-0.17	0.05	0.05	-0.14	0.12	0.12	-0.16
2006	0.07	0.07	-0.28	0.05	0.05	-0.23	0.12	0.12	-0.26
2007	0.08	0.08	-0.31	0.05	0.05	-0.26	0.13	0.13	-0.29
2008	0.08	0.08	-0.35	0.05	0.05	-0.29	0.13	0.13	-0.32
2009	0.08	0.08	-0.48	0.05	0.05	-0.40	0.13	0.13	-0.45
2010	0.08	0.08	-0.46	0.05	0.05	-0.37	0.13	0.13	-0.42
2011	0.07	0.08	-0.76	0.05	0.05	-0.62	0.12	0.12	-0.70
2012	0.07	0.07	-0.76	0.05	0.05	-0.62	0.12	0.12	-0.71
2013	0.07	0.08	-0.74	0.05	0.05	-0.61	0.12	0.12	-0.69
2014	0.08	0.08	-0.84	0.05	0.05	-0.70	0.13	0.13	-0.79
2015	0.08	0.08	-0.76	0.05	0.05	-0.64	0.13	0.13	-0.71
2016	0.08	0.08	-0.73	0.05	0.05	-0.66	0.13	0.13	-0.70
2017	0.08	0.08	-0.85	0.05	0.05	-0.75	0.13	0.13	-0.81
2018	0.08	0.08	-0.97	0.05	0.05	-0.88	0.13	0.13	-0.94
2019	0.08	0.08	-0.88	0.05	0.05	-0.69	0.13	0.13	-0.80
2020	0.08	0.08	-0.79	0.05	0.05	-0.65	0.13	0.13	-0.73
2021	0.08	0.08	-0.67	0.05	0.05	-0.57	0.13	0.13	-0.63
2022	0.08			0.05			0.13		

5.3.7 Planned improvement

No further improvements foreseen.

5.4 Rice Cultivation (IPCC Source Category 3.C)

This source category does not exist in Luxembourg.

5.5 Agricultural Soils (IPCC Source Category 3.D)

This section describes the estimation of nitrous oxide emissions linked to agricultural soils, whether these are direct or indirect emissions originating from crops or from spreading on soils. In 2022 this source category was responsible for 75% of agricultural nitrous oxide emissions. N_2O emissions linked to agricultural soils represented 15% of the total GHG emissions from the agriculture sector and represented 1.24% of the total GHG emissions in CO_2e (excluding LULUCF).

5.5.1 Key source

With 1.01% of the total GHG emissions in CO_2e, excluding LULUCF in 2022, nitrous oxide emissions from agricultural soils (IPCC Category 3D) is a key source, whether LULUCF is included or excluded. It has been a key source in both cases without interruption since 1990 (see Table 5-3 in section 5.1.2).

5.5.2 Source category description

The source category agricultural soils covers:

- direct N_2O soil emissions (IPCC Sub-category 3D1) resulting from animal manure application, including digestate originating from animal manure, grazing, application of mineral fertiliser, sewage sludge, other organic N additions (i.e. compost and digestate originating from energy crops and non-agricultural organic waste) and crop residues.
- and indirect N_2O soil emissions (IPCC Sub-category 3D2) resulting from deposition of reactive nitrogen and via leaching and run-off.

Since 1990, agricultural soil N_2O related emissions declined by 31%, Table 5-45 and Figure 5-12. The largest decline was observed for sewage sludge (-88%), synthetic fertilizer (-58%) and mineralisation (-52%). N_2O emissions from crop residues varies over the years, as depending on growth conditions (i.e. prescipitations and temperature). In 2022 was the most important category in absolute terms animal manure (30%), followed by synthetic fertilizer (27.5%). Synthetic fertilizer used to always the most important source category, but high fertilizer prices in 2022, had resulted in a drastic drop of used synthetic fertilizer, and hence in a drop of the direct N_2O emission from managed soils (Table 5-45 and Figure 5-12).

Figure 5-12 – N_2O emissions from managed soils (Gg/year): 1990 -2022

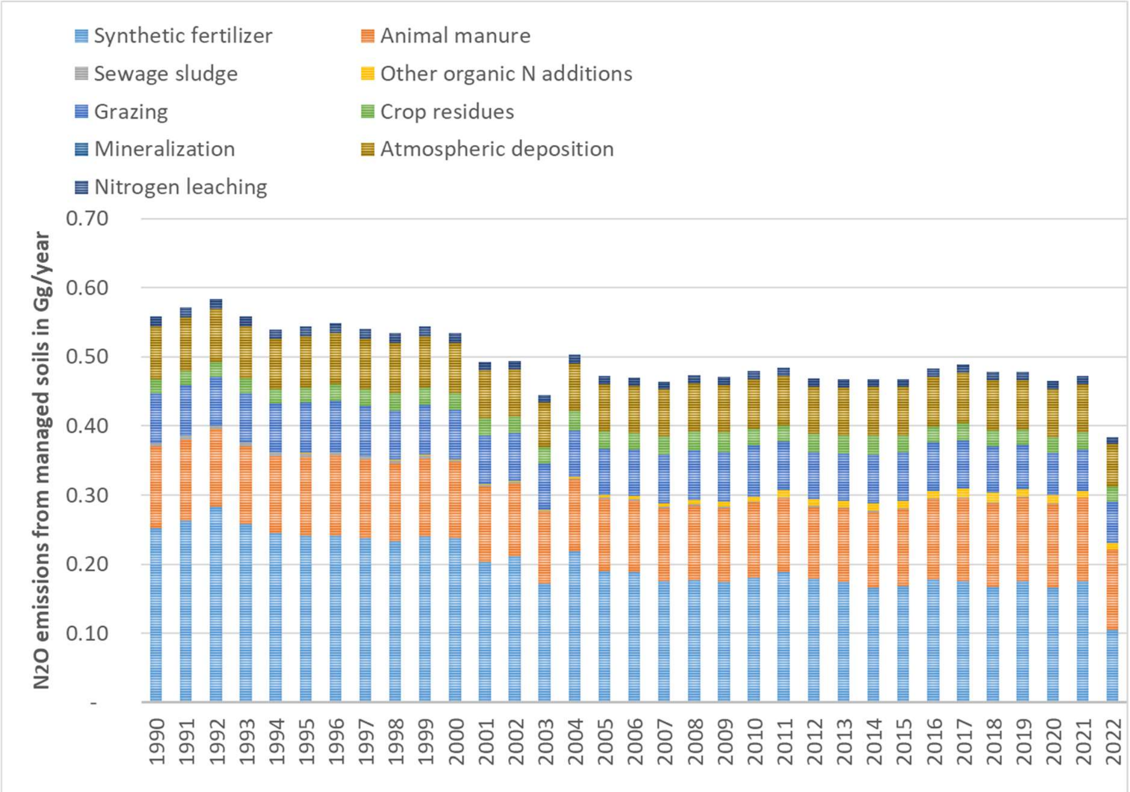


Table 5-45 – N_2O emission trends (Gg) for IPCC Category 3D – Agricultural Soils: 1990-2022

	3 - Agriculture									
	N_2O emissions (Gg)									
	3 D - Agricultural soils									
Year	Total	Synthetic fertilizer	Animal manure	Sewage sludge	Other organic N additions*	Grazing	Crop residues	Mineral-ization	Organic soils	Ot
1990	0.56	0.25	0.12	0.0051	NO	0.07	0.020	0.00011	NO	N
1991	0.57	0.26	0.12	0.0051	NO	0.07	0.021	0.00011	NO	N
1992	0.58	0.28	0.11	0.0052	NO	0.07	0.021	0.00011	NO	N
1993	0.56	0.26	0.11	0.0054	0.000	0.07	0.022	0.00011	NO	N
1994	0.54	0.25	0.11	0.0057	0.000	0.07	0.020	0.00011	NO	N
1995	0.54	0.24	0.11	0.0056	0.000	0.07	0.022	0.00011	NO	N
1996	0.55	0.24	0.12	0.0049	0.000	0.07	0.024	0.00011	NO	N
1997	0.54	0.24	0.11	0.0051	0.000	0.07	0.024	0.00011	NO	N
1998	0.53	0.23	0.11	0.0051	0.001	0.07	0.024	0.00011	NO	N
1999	0.54	0.24	0.11	0.0051	0.001	0.07	0.025	0.00011	NO	N
2000	0.53	0.24	0.11	0.0027	0.0014	0.07	0.024	0.00011	NO	N
2001	0.49	0.20	0.11	0.0025	0.0008	0.07	0.025	0.00011	NO	N
2002	0.49	0.21	0.11	0.0027	0.0011	0.07	0.024	0.00011	NO	N
2003	0.44	0.17	0.10	0.0020	0.0009	0.07	0.024	0.00011	NO	N
2004	0.50	0.22	0.10	0.0017	0.0018	0.07	0.028	0.00011	NO	N
2005	0.47	0.19	0.10	0.0022	0.0034	0.07	0.025	0.00011	NO	N
2006	0.47	0.19	0.10	0.0019	0.0044	0.07	0.025	0.00011	NO	N
2007	0.46	0.18	0.10	0.0023	0.0050	0.07	0.026	0.00011	NO	N
2008	0.47	0.18	0.11	0.0022	0.0057	0.07	0.028	0.00016	NO	N
2009	0.47	0.17	0.11	0.0014	0.0073	0.07	0.028	0.00016	NO	N
2010	0.48	0.18	0.11	0.0014	0.0072	0.07	0.025	0.00016	NO	N
2011	0.48	0.19	0.11	0.0019	0.0101	0.07	0.022	0.00016	NO	N
2012	0.47	0.18	0.10	0.0023	0.0097	0.07	0.026	0.00016	NO	N
2013	0.47	0.17	0.11	0.0018	0.0095	0.07	0.026	0.00006	NO	N
2014	0.47	0.17	0.11	0.0017	0.0112	0.07	0.028	0.00006	NO	N
2015	0.47	0.17	0.11	0.0020	0.0105	0.07	0.024	0.00006	NO	N
2016	0.48	0.18	0.12	0.0011	0.0111	0.07	0.023	0.00007	NO	N
2017	0.49	0.18	0.12	0.0011	0.0129	0.07	0.025	0.00007	NO	N
2018	0.48	0.17	0.12	0.0006	0.0144	0.07	0.023	0.00007	NO	N

* Other organic N additions = compost & digestate originating from energy crops and non-agricultural waste.

5.5.3 Methodological issues

Table 5-46 gives an overview of the status, the methods and emission factors (EF) used for category 3.D – Agricultural Soils.

Table 5-46 – Overview of category 3.D: Status, methods and emission factors (EF) used.

GHG source & sink category	Description	N_2O		
		Status	Method	EF
3.D.1	*Direct soil emissions*			
	Synthetic fertilizers	x	T1	CS
	Animal manure applied to soils, including digestate orginating from animal manure	x	T2	CS
	Sewage sludge	x	T1	CS
	Compost and digestate orginating from energy crops and other waste	x	T1	CS
	Crop Residue	x	T1	CS

	Urine and dung N deposited on pasture by grazing animals	x	T2	CS
	Drainage/management of organic soils	NO	-	-
3.D.2	*Indirect soil emissions*			
	Atmospheric Deposition	x	T2	D
	Nitrogen Leaching & Run-off	x	T1	D

Note: An "x" indicates that emissions from this sub-category has been estimated.
Used abbreviations: D = IPCC default EF; IE= included elsewhere; NO=not occurring; T1 = IPCC Tier 1.

5.5.3.1 Activity data

Activity data used to estimate N_2O estimates for IPCC Category 3D are:

- Synthetic N fertilizer, see Table 5-47.
- Applied organic N fertiliser, including animal manure, sewage sludge and other organic N additions (i.e. compost and digestate originating from energy crops and non-agricultural waste), see Table 5-47.
- Urine and dung N deposited on pasture by grazing animals, see Table 5-47.
- N in crop/forage residues, see Table 5-47.
- Mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils, see Table 5-47.
- Atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge and other organic N additions (i.e. compost and digestate originating from energy crops and non-agricultural waste), see Table 5-47 and Table 5-51.
- N leaching from inorganic N fertilizer, animal manure, compost, sewage sludge and other organic N additions, dung and urine N deposited by grazing animals, N in crop residues and N mineralised in mineral soil, see Table 5-47.

Table 5-47 – Activity data (kg N) for IPCC Category 3D: 1990-2022

3 - Agriculture Activity data - Annual amount of N inputs to soil (kg N/year) from different sources 3D- Crop production and agricultural soils												
Year	Synthetic fertilizer	Animal manure	Sewage sludge	Compost	Digestate (energy crops & non-agr. waste)	Grazing	Crop residues	Mineral-ization	Organic soils	Other	Atmospheric deposition	Nitrogen leaching
1990	18 218 653	8 590 319	371 985	-	-	5 162 269	1 445 881	7 699	NO	NO	3 475 138	8 111 234
1991	18 983 396	8 530 126	372 205	-	-	5 285 211	1 524 344	7 699	NO	NO	3 515 805	8 328 715
1992	20 484 409	8 097 044	376 491	-	-	5 112 247	1 534 309	7 699	NO	NO	3 470 580	8 546 928
1993	18 687 016	8 122 177	391 126	10 513	-	5 138 502	1 570 548	7 699	NO	NO	3 394 937	8 142 620
1994	17 740 897	8 020 890	409 055	11 888	-	5 117 691	1 457 385	7 699	NO	NO	3 323 046	7 863 721
1995	17 407 501	8 235 827	406 178	15 130	-	5 280 713	1 584 870	7 699	NO	NO	3 375 272	7 905 100
1996	17 489 448	8 325 784	352 796	14 408	-	5 374 170	1 707 970	7 699	NO	NO	3 404 991	7 985 346
1997	17 220 060	8 155 938	369 747	29 637	-	5 232 189	1 730 836	7 699	NO	NO	3 338 008	7 859 065
1998	16 873 182	8 103 127	370 828	47 992	2 410	5 157 325	1 768 716	7 699	NO	NO	3 343 217	7 759 507
1999	17 400 520	8 098 349	368 839	49 670	5 846	5 185 761	1 825 360	7 699	NO	NO	3 374 615	7 906 091
2000	17 180 729	7 945 074	193 515	93 077	9 489	5 160 075	1 770 879	7 699	NO	NO	3 319 274	7 766 529
2001	14 655 099	7 884 850	181 353	43 384	14 775	5 138 146	1 780 267	7 699	NO	NO	3 157 154	7 129 338
2002	15 267 722	7 621 168	191 920	49 819	26 133	4 994 835	1 745 014	7 972	NO	NO	3 104 065	7 177 100
2003	12 443 168	7 480 533	146 205	25 282	42 979	4 877 587	1 715 055	7 972	NO	NO	2 915 098	6 417 308
2004	15 769 127	7 568 168	121 081	34 736	97 691	4 884 444	2 021 011	7 972	NO	NO	3 106 609	7 321 015
2005	13 762 308	7 526 856	159 100	84 921	158 714	4 833 017	1 825 602	7 972	NO	NO	3 096 017	6 806 038
2006	13 680 584	7 424 943	139 750	74 971	243 234	4 859 206	1 781 709	7 972	NO	NO	3 080 957	6 770 969
2007	12 722 328	7 588 316	165 609	77 357	286 615	5 089 680	1 867 114	7 972	NO	NO	3 098 721	6 673 198
2008	12 781 284	7 786 424	156 780	87 340	322 030	5 222 545	1 999 399	11 680	NO	NO	3 163 098	6 808 196
2009	12 644 457	7 689 769	103 488	82 833	442 939	5 214 667	2 050 516	11 680	NO	NO	3 127 702	6 777 684
2010	13 058 411	7 850 971	103 729	99 310	420 395	5 326 376	1 781 877	11 680	NO	NO	3 250 587	6 876 660
2011	13 642 135	7 688 187	137 317	70 731	660 733	5 100 221	1 621 660	11 680	NO	NO	3 254 514	6 943 839
2012	12 912 925	7 493 490	165 135	50 606	650 387	4 913 198	1 871 469	11 680	NO	NO	3 132 403	6 736 533
2013	12 628 048	7 655 113	132 854	43 191	645 886	4 943 999	1 902 688	4 513	NO	NO	3 126 773	6 709 510
2014	11 990 249	7 890 958	122 577	48 488	759 323	5 092 512	2 050 299	4 513	NO	NO	3 163 390	6 710 141
2015	12 164 881	8 016 481	144 931	59 767	696 079	5 127 788	1 726 056	4 513	NO	NO	3 168 546	6 705 719
2016	12 875 308	8 364 895	77 569	59 835	740 772	5 095 391	1 679 060	4 772	NO	NO	3 249 500	6 935 425
2017	12 666 185	8 680 694	78 285	72 794	858 412	5 052 824	1 834 096	4 772	NO	NO	3 312 250	7 019 535
2018	12 065 012	8 790 887	46 674	58 868	982 879	4 837 284	1 689 400	4 772	NO	NO	3 310 919	6 834 186
2019	12 679 772	8 765 799	45 038	63 245	766 835	4 609 340	1 623 480	4 772	NO	NO	3 232 482	6 853 988
2020	12 000 433	8 755 672	93 164	75 185	724 598	4 422 077	1 637 029	4 772	NO	NO	3 196 572	6 651 103
2021	12 704 561	8 682 309	38 486	87 125	646 136	4 273 893	1 831 652	4 772	NO	NO	3 175 959	6 784 544
2022	7 618 981	8 341 663	44 936	99 443	565 648	4 282 992	1 605 139	3 662	NO	NO	2 841 167	5 414 992

Sources: SER, MECB, AEV, STATEC

* Other organic N additions = compost & digestate originating from energy crops and waste

5.5.3.1.1 Synthetic N fertilizer

Only nitrogenous fertilizers have been considered as synthetic N fertilizers since these are the ones generating nitrous oxide emissions.

Up to 1998 included, statistics were not recording fertilizer application, but fertilizer sales in Luxembourg. Therefore, for the years prior to 1999, the hypothesis that fertilizers consumption/application equals fertilizer sales (i.e. no stocks and stock changes) has been made. Thereafter, consumption data had been used. Synthetic N fertilizer, expressed in kg N, was based on data collected within the Luxemburgish "landwirtschaftliche Testbetriebsnetz (LTBN)"[136], using a nutrient balance methodology (in German the so-called "Feld – Stall Bilanz") (Weckbecker, 2018). National utilisation was obtained by multipling the weighted average kg N per ha used agriculture surface (STATEC, Consommation d'engrais chimiques - Consommation par ha cultivé (en kg d'élements nutrififs par ha) - Engrais azotes, 2023) by the cultivated agriculture surface in Luxembourg[137].

5.5.3.1.2 Applied organic N fertiliser

Applied organic N fertilizers comprise animal manure, including digestate originating from animal manure, sewage sludge and other organic N additions (i.e. compost and digestate originating from energy crops and non-agricultural organic waste). The total annual amount of organic N fertilizer applied to soils other than by grazing animals (F_{on}), in kg N per year was calculated according to equation 11.3 of the 2019 Refinement to the 2006 IPCC guidelines (Hergoulac'h, et al., 2019)

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{DEC}$$

with:

F_{AM}	= annual amount of animal manure N applied to soils, kg N per year, see Table 5-47
F_{SEW}	= annual amount of total sewage N that is applied to soils, kg N per year, see Table 5-47
F_{COMP}	= annual amount of total compost N applied to soils, kg N per year see Table 5-47.
F_{DEC}	= annual amount of total digestate N originating from energy crops and non-agricultural organic waste applied to soils, kg N per year see Table 5-47.

N in animal manure applied to soil was determined using a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, which was determined following the fifteen steps from the 2023 guidelines (Amon, et al., 2023), which were described in section 5.1.3 and schematically shown in Figure 5-6. Gross amounts are used throughout, i.e. emissions of various N substances from a given source are calculated using the same basic nitrogen amount. Both the N in animal manure stored on the farm and the N in digestate created by the anaerobic digestion of manure and returned from NRF 5.B.2 is taken into consideration. This corresponds to step 11 described in section 5.1.3. Please note that some of the nationally produced manure is

136 Luxemburg has the obligation to collect data from agriculture farms for the Farm Accountancy Data Network (FADN). For details on the FADN see http://ec.europa.eu/agriculture/rica/, for the Luxemburgish "landwirtschaftliche Testbetriebsnetz (LTBN)" see https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html. The LTBN is situated in the division «Division de la gestion, de la comptabilité et de l'entraide agricoles», at the SER. This division gets from about 840 farms farm accountancy data (https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung.html). Out of these farms, a representative sample of 450 farms are selected to form the sample size shared with FADN (https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html).

137 Used agriculture surface as reported by EUROSTAT/STATEC is the used agriculture surface by Luxemburgish farmers in and outside the country. For the emissions estimations, however, only the used agriculture surface in Luxemburg is considered, independent if cultivated by Luxemburgish or non-luxemburgish farmers, why there are differences between EUROSTATEC / STATEC published and the here presented data (for more details see Annex 3:b) in NIR 2023.

exported and applied on fields in neighbouring countries, whereas other manure was imported. In the inventories the N applied to soil in Luxemburg was considered, namely:

$$F_{AM} = \left[\sum_{i} \{ m_{applic\_slurry\_N\_LU(i)} + m_{applic\_dig\_N\_LU(i)} + m_{applic\_solid\_LU(i)} \} \right]$$

with:

$m_{applic\_slurry\_N\_LU(i)}$ the net amount of N applied on fields in Luxemburg from liquid manure and expressed in kg N per year for animal category *i*;

$m_{applic\_dig\_N\_LU(i)}$ the net amount of N applied on field in Luxemburg from digestate originating from animal manure, including imported animal manure used as feedstock for biogas facility and expressed in kg N per year for animal category *i*;

$m_{applic\_solid\_N\_LU(i)}$ the net amount of N applied on field in Luxemburg from solid manure and expressed in kg N per year for animal category *i*.

The annual amount of total sewage N applied to soils (in kg N per year) is summarized in Table 5-47. Sewage sludge data used in the inventory were derived from:

- estimates for the total sewage sludge produced in the various wastewater treatment plant (*WWTP*) of the country. These estimates have been prepared by the MECB-AEV (Environment Agency) with some corrections performed by the MECB for the years 2000 to 2004;
- annual reports on sewage sludge that are regularly issued since 2003.[138] These reports are based on a questionnaire sent to WWTPs with at least 2000 inhabitants-eq., hence not all the WWTPs are interrogated. The questionnaire requests, among other things, to indicate the destination and the use of the sludge, both in Luxembourg and abroad.
- a five-year trend estimate was used for 2022, as data collection was still on-going.

The annual amount of compost N applied to soils (in kg N per year) is summarized in Table 5-47. Compost data used in the invenventory were derived from:

- estimates for the quantities of compost used in agriculture for the years 1993-1999 were derived using individual plant activity data of the total quantiy of compost (see Table 7-15) and presuming the same proportion of produced compost being used in agriculture as the median observed for the years 2001-2003. Further was the N-content in the compost in the years 1993-1999 assumed to be the same as the median observed for the years 2001-2003 using individual plant data;
- annual reports on compost statistics published by AEV for the year 2000 and onwards.[139]

138 See https://data.public.lu/en/datasets/boues-depuration/.

139 See https://data.public.lu/en/datasets/biodechets/#_ .

The annual amount of digestate N originating from energy crops and non-agricultural waste (in kg N/year) as returned from NRF 5.B.2, was corrected for the quantities of digestate exported for application on fields outside Luxemburg (see section 5.1.4), and was summarized in Table 5-47. The annual amount was derived, starting with activity data of the use of energy crops and non-agricultural waste in biogas facilities, and transferred into N_{tot} following the 2023 EMEP guidelines (Trozzi, et al., 2023) schematically shown in Figure 5-6 and described in full detail in Luxembourg's Informative Inventory Report 2024 .

5.5.3.1.3 N in crop/forage residues

The annual amount of N in crop residues (above and below ground), including N-fixing crops and from forage/pasture renewal, returned to soils annually (F_{CR}), expressed in kg N per year is summarized in Table 5-47, and was estimated based on equation 11.6 of the IPCC 2019 Refinements (Hergoulac'h, et al., 2019) :

$$F_{CR} = \sum_{k} \{[AGR_k * N_{AG(k)} * (1 - Frac_{Remove(k)})] + [BGR_k * N_{BG(k)}]\}$$

with:

$$AGR_k = AG_{DM(k)} * Area_k = (Crop_k * R_{AG(k)}) * Area_k$$

$$BGR_k = (Crop_k + AG_{DM(k)}) * RS_k * Area_k * Frac_{Renew(k)}$$

Where:

AGR_k	= annual total amount of above-ground crop residue for crop *k*, kg dry matter per year, with *k* = crop or forage type,
$N_{AG(k)}$	= N content in above ground residues in kg N, see Table 5-50;
$Frac_{Removed(k)}$	= fraction of above-ground residues of crop *k* removed annually for purposes as feed and bedding, see Table 5-50;
BGR_k	= annual total amount of belowground crop residue for crop *k*, kg dry matter per year, with *k* = crop or forage type; $N_{BG(k)}$ = N content in below ground residues in kg N, see Table 5-50.
$AG_{DM(k)}$	= above ground residues dry-matter for crop *k*, kg d.m. per ha
$Crop_k$	= harvested annual dry matter yield for crop *k*, ha d.m. per year
$R_{AG(k)}$	= ratio of aboce-ground residue dry matter to harvested yield for crop *k*, kg d.m. per ha, see Table 5-50
$Area_k$	= total annual area harvested of crop *k*, ha per year
$RS_{(k)}$	= ratio of below-ground root biomass to above-ground shoot biomass for crop *k*, kg d.m. per ha, see Table 5-50
$Frac_{Renew(k)}$	= fraction of total area under crop *k* that is renewed annually, dimensioneless, see Table 5-50

Note: The above equation was slightly adapted as burning of crop residues is forbidden by law in Luxemburg, and therefore assumed to not occur.

The cultivated crop area for 1990-2022 ($Area_k$) is summarized in Table 5-48, and the harvest yield for the different crop cultivated ($Crop_k$) is summarized in Table 5-49. Area data were based on both, published and unpublished data (for details see Annex 3: C). Official statistics were consulted for the harvest yield data (SER, Rapport d'activité 2022 - XV Statistiques agricoles - Tableau 16: Les rendements en grandes cultures et en cultures fourragères, 2023)[140], whereby cash crops were mainly extracted from unpublished LTBN data and forage yields were based on measurements conducted by ASTA in different experimental fields through the country (for example for pasture http://www.grengland.lu/grunland-ticker).

With the exception of clover, grass-clover and pasture and meadows were all crops annually renewed (see Table 5-50). Clover and grass-clover leys were renewed every 3 years, similar to Germany (Haenel H.-D. , et al., 2018). Whereas permanent grassland (i.e. pasture and meadows) is forbidden to plough (GDR, 30 juillet 2015).

The above ground residues dry-matter ($AG_{DM(k)}$) was calculated:

$$AG_{DM(k)} = \left(Crop_k * R_{AG(k)}\right)$$

whereby using the information provided for $R_{AG(k)}$ in Table 11.1A in the the IPCC 2019 Refinements (Hergoulac'h, et al., 2019), if not otherwise indicated, and are summarized in Table 5-50.

Straw from wheat and other cereals would be annually completely removed from the field and used as bedding material. Maize for silage, is a whole plant silage, and accordingly also here would be the whole plant removed from the field during the harvest. Fodder beet, clover, grass-clover, pasture and meadows were used as forage plants, whereby the whole plant would be used, see Table 5-50.

Values used for $N_{AG(k)}$, $RS_{(k)}$ and $N_{BG(k)}$ were taken from Table 11.1A in the the IPCC 2019 Refinements (Hergoulac'h, et al., 2019), if not otherwise indicated, and are summarized in see Table 5-50 .

Grains such as wheat, barley and triticale, but also rapeseed were the major cash crops cultivated in Luxembourg. Grass, cover-grass and maize for silage (whole plant) are and were the main forage crops grown in Luxembourg, see Figure 5-2. In particularly the cultivated area for wheat and maize for silage increased over the years, whereas barley and oat decreased. This change was partly driven by improved plant breeds and an increased proportion of maize in the feed diet of dairy cows and fattening bulls.

Variations in precipitation (see Figure 2-9) and in air temperature (see Figure 2-5 and Figure 2-6) resulted in large fluctuations of the harvest crops between years, and hence impacted also the crop residues.

140 And earlier versions of this annual report published by the Ministry of Agriculture

Table 5-48 – Cash crop plants, fodder plants, pasture and total agricultural area (ha): 1990-2022

3 - Agriculture

Activitiy data - Agriculture surface area, cash crop plants, fodder plants and pasture (in ha)

Year	agricultural area	winter wheat	spring wheat	rye and mix-cereals	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio digester	fodder beet	clover, grass-clover leys, fodder production	pasture and meadows	extensive grassland	others
1990	125 671	7 373	943	1 209	15 120	4 962	2 191	1 881	796	518	NO	7 205	223	11 158	66 362	3 896	1 833
1991	124 927	7 071	599	1 107	14 227	4 338	2 574	2 502	828	570	NO	7 563	237	11 437	66 076	3 952	1 845
1992	125 246	7 303	553	1 067	13 169	3 957	2 620	1 466	912	734	NO	8 365	270	12 292	66 714	4 008	1 817
1993	126 722	7 430	638	891	13 254	3 682	2 570	1 626	804	805	NO	7 666	239	13 911	65 744	4 064	3 399
1994	126 344	8 062	644	1 058	13 078	3 398	2 336	1 605	756	592	NO	8 234	226	13 078	65 589	4 120	3 569
1995	126 497	8 598	403	1 055	12 227	2 690	2 771	1 884	773	457	NO	9 049	213	13 659	65 097	4 176	3 446
1996	126 075	9 025	417	894	11 391	2 502	2 923	2 355	768	390	NO	9 187	172	13 606	64 131	4 232	4 084
1997	126 381	8 966	427	938	11 169	2 427	2 984	2 169	812	406	441	9 665	159	15 500	62 638	4 287	3 392
1998	126 926	9 007	445	1 218	10 952	2 217	3 297	2 759	812	399	487	9 527	124	15 794	62 133	4 343	3 411
1999	127 241	6 392	1 126	1 190	11 461	2 368	2 657	3 923	810	537	484	10 116	102	15 657	62 071	4 399	3 948
2000	127 526	10 211	367	1 283	9 549	1 841	3 505	3 129	799	416	246	10 412	74	14 734	62 939	4 455	3 566
2001	127 870	8 740	733	1 268	10 545	1 663	2 956	2 974	708	668	459	10 839	59	14 628	62 782	4 511	4 338
2002	128 092	11 130	449	1 413	8 669	1 893	3 866	3 367	648	643	314	10 622	49	13 919	62 712	4 567	3 831
2003	128 189	10 353	433	1 097	9 422	2 086	3 591	3 542	601	579	325	11 205	41	14 018	62 506	4 623	3 767
2004	128 164	10 972	328	1 367	8 101	1 839	3 450	4 040	612	489	337	11 844	41	14 138	62 737	4 678	3 189
2005	129 619	10 967	600	1 129	9 499	1 637	3 390	3 956	608	477	221	11 733	61	12 118	64 749	4 734	3 741
2006	130 415	12 019	348	1 384	9 266	1 418	3 358	4 526	528	352	257	11 382	34	11 481	65 719	4 790	3 554
2007	129 943	11 748	291	1 348	8 836	1 347	3 327	5 136	573	350	268	11 518	30	11 793	65 490	4 846	3 041
2008	129 963	13 533	389	1 489	9 305	1 100	3 416	4 963	556	210	274	11 835	24	11 275	64 811	4 902	1 881
2009	128 499	12 563	426	1 238	8 794	1 264	3 854	4 356	535	292	324	12 654	33	11 398	63 949	4 958	1 860
2010	129 379	12 788	321	1 032	7 762	1 039	4 577	4 266	557	324	290	12 894	27	12 021	64 651	5 014	1 815
2011	129 089	12 438	460	1 112	7 354	995	4 106	4 244	582	264	232	13 186	32	12 658	64 500	5 069	1 855
2012	129 288	12 258	405	1 214	6 647	827	4 504	4 021	569	165	195	13 512	54	13 606	64 293	5 125	1 893
2013	128 986	12 663	437	1 075	7 311	990	4 298	4 022	565	253	242	13 432	65	12 544	63 943	5 181	1 964
2014	128 826	10 658	1 117	1 107	7 683	1 086	4 482	3 683	534	351	216	14 023	88	12 911	63 724	5 215	1 949
2015	128 103	12 351	723	1 030	7 143	1 078	4 347	3 388	506	549	153	13 503	129	12 119	63 595	5 225	2 263
2016	127 919	12 273	411	1 192	6 258	1 001	4 313	3 125	536	638	112	13 943	124	12 538	63 852	5 414	2 190
2017	127 821	12 377	439	1 132	6 134	1 129	4 233	2 890	561	581	82	13 927	106	12 505	64 046	5 442	2 236
2018	127 221	11 402	324	1 199	5 544	1 147	4 364	2 804	541	402	92	14 497	67	12 632	64 362	5 475	2 370
2019	126 489	11 722	256	1 285	5 625	1 240	4 653	2 256	501	386	125	14 442	71	11 931	64 241	5 534	2 221
2020	126 692	10 161	347	1 233	5 547	1 440	4 183	2 163	550	365	72	15 249	70	12 735	64 508	5 573	2 495
2021	126 692	10 989	211	1 568	4 766	1 415	4 420	1 285	578	331	63	15 289	89	12 738	64 868	5 581	2 500
2022	126 394	11 437	474	1 359	5 424	1 520	4 264	1 671	546	398	153	14 135	85	11 709	64 839	5 573	2 806

Note: The here presented data reflects the utilized agricultural area in Luxemburg and differ from the one published by STATEC and EUROSTAT, who refer to the utilized agricultural area used by luxemburgish farmers.

For more details see Annex 3:C.

Table 5-49 – Crop harvest (kg/ha): 1990-2022

3 - Agriculture

Activitiy data - Crop harvest (kg/ha)

3D- Crop production and agricultural soils

Year	winter wheat	spring wheat	rye and mix-cereals	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio digester[a,b,c]	fodder beet[a,b]	Clover, grass-clover leys, fodder production[a,b,e]	Pasture and meadows[a,d,f]
1990	5 186	3 941	3 737	4 439	3 645	4 612	2 741	27 800	2 533	NO	14 056	12 030	8 534	5 165
1991	5 630	4 849	4 639	4 980	4 330	4 990	2 562	22 700	3 092	NO	14 056	12 030	8 534	3 920
1992	5 720	4 880	4 181	5 153	4 200	4 946	1 520	28 400	2 870	NO	14 056	12 030	8 534	5 322
1993	5 870	4 985	3 748	4 951	4 480	5 220	2 669	30 760	2 610	NO	14 056	12 030	8 534	5 623
1994	5 130	3 519	3 439	4 415	3 510	4 804	2 160	22 779	2 990	NO	14 056	12 030	8 534	5 079
1995	5 715	4 269	3 665	4 954	4 355	5 077	2 614	28 500	2 911	NO	14 056	12 030	8 534	5 880
1996	6 644	5 129	4 759	5 645	5 117	5 980	3 124	25 400	4 745	NO	14 056	12 030	8 534	5 708
1997	5 904	4 688	4 626	5 454	5 263	4 994	3 496	27 100	3 636	5 000	14 056	12 030	8 534	6 957
1998	6 125	4 680	5 156	5 158	5 086	6 323	3 210	26 500	3 430	8 500	14 056	12 030	8 534	7 767
1999	6 001	5 178	5 303	5 452	4 986	6 282	3 334	30 600	4 141	6 200	14 056	12 030	8 534	5 959
2000	5 599	4 968	4 703	5 080	4 828	5 459	2 580	33 605	2 866	8 000	12 060	11 000	11 460	9 800
2001	5 563	4 730	5 498	4 609	4 521	5 429	2 847	31 022	3 285	9 099	14 050	11 000	9 970	8 530
2002	5 979	5 669	6 642	5 406	5 206	5 747	3 586	29 913	3 486	7 100	13 400	12 650	7 440	6 360
2003	6 178	5 129	6 022	5 343	5 278	5 369	3 412	29 425	3 571	5 649	15 400	12 000	5 020	4 290
2004	6 843	6 199	7 175	5 941	4 959	6 453	3 944	35 010	3 407	10 332	15 368	13 500	8 780	7 510
2005	6 070	5 021	6 582	5 318	4 561	5 433	3 621	31 784	3 184	9 576	15 980	13 770	6 940	5 940
2006	5 982	5 590	5 401	5 263	4 429	5 669	3 398	27 664	3 184	6 520	13 900	12 000	8 410	7 190
2007	5 622	4 762	5 755	4 838	3 905	4 983	3 393	31 828	2 247	7 540	17 110	12 500	8 890	7 600
2008	6 707	5 136	6 607	5 422	4 985	5 966	3 154	36 022	3 462	9 141	15 930	12 100	9 590	8 200
2009	6 575	6 369	6 478	5 806	5 200	6 268	3 917	33 185	3 954	9 289	16 340	10 375	9 120	7 800
2010	5 981	5 062	5 886	5 206	4 214	5 339	3 371	31 739	2 892	8 316	13 480	8 583	8 300	7 100
2011	5 578	4 451	4 910	4 843	3 595	5 138	3 332	30 991	2 328	7 787	12 790	7 610	6 300	5 383
2012	5 906	4 524	5 249	5 306	5 168	4 946	3 337	32 254	2 765	8 255	14 060	11 038	10 200	8 730
2013	6 402	6 062	5 740	5 489	4 898	5 645	3 394	29 594	3 303	8 930	13 460	10 528	10 220	8 739
2014	6 303	4 674	6 603	5 526	4 647	6 282	3 788	31 244	2 773	7 743	15 830	10 528	10 610	9 053
2015	6 324	5 567	6 395	5 754	4 923	5 946	3 482	22 750	2 662	6 578	12 350	8 376	7 200	6 154
2016	5 107	4 066	4 731	4 927	4 834	4 956	3 112	30 447	1 913	6 697	12 680	24 003	9 520	8 130
2017	5 501	4 979	5 035	5 300	4 522	5 242	3 464	34 237	2 593	8 597	16 750	8 231	7 640	6 520
2018	6 075	4 749	5 569	5 773	5 636	5 726	3 227	25 841	3 762	6 225	12 710	8 727	7 900	6 743
2019	6 030	5 000	5 918	5 830	5 000	5 750	3 391	25 503	2 889	5 669	11 810	9 000	8 000	6 832
2020	5 940	6 128	4 747	5 406	5 000	5 597	3 300	26 252	3 409	6 752	13 740	10 440	6 370	5 436
2021	5 957	4 850	4 996	5 439	4 240	5 718	2 700	25 744	2 505	7 871	15 910	13 300	9 840	8 371
2022	6 215	5 200	-	6 020	4 830	6 330	3 550	22 818	3 155	6 309	12 360	14 000	8 020	6 843

Notes: a) In kg/ha dry matter; b) No data were available on the harvest of silage maize, fodder beets, clover and grass-clover for the years 1990-1999. The average as observed for the years 2000-2004 was taken; c) No data were available on the harvest maize used to feed the bio-digester for the years 1990-2001. The same harvest as for maize for silage was taken; d) No data was available on the harvest of pasture and meadows for the year 1990. The average as observed for the years 1991-1995 was take. e) No data were available for others (for example set-a-side), why assuming 25% of harvest of clover, grass-clover leys; f) No data were available for extensive grassland, why assuming 25% of the harvest of pasture and meadows.. Sources: Annual activity reports from the Ministry of Agriculture.

Table 5-50 – Parameters values, and in parentheses uncertainty values,used for $Frac_{RENEW(k)}$, $Frac_{REMOVE(k)}$, $N_{AG(k)}$, $N_{BG(k)}$ $R_{AG(k)}$, $RS_{(k)}$ and Dry $matter_{(k)}$.

	$FRAC_{RENEW}$	$FRAC_{REMOVE}$	N content of above-ground residues ($N_{AG(k)}$)	N content of below-ground resiudes ($N_{BG(k)}$)	Ratio of above-ground residues dry matter to harvested yield ($R_{AG(k)}$)	Ratio of below-ground biomass to above-ground biomass (RS_k)	Dry matter of harvest product (%)[a]
Winter wheat	1	1	0.006 (±75%)	0.009 (±75%)	0.93[b]	0.23 (±41%)	0.86
Spring wheat	1	1	0.006 (±75%)	0.009 (±75%)	0.93[b]	0.28 (±26%)	0.86
Rye and mix-cereals	1	1	0.005 (±75%)	0.011 (±75%)	1.6	0.22[g] (±16%)	0.86
Barley	1	1	0.007 (±75%)	0.014 (±75%)	1.2	0.22 (±33%)	0.86
Oat	1	1	0.007 (±75%)	0.008 (±75%)	1.3	0.25 (±120%)	0.86
Triticale	1	1	0.006[d] (±75%)	0.009[b] (±75%)	1.05[b]	0.22[g] (±16%)	0.86[b]
Rape	1	0	0.008[a] (±75%)	0.010[a] (±75%)	1.91 [b]	0.22[a] (±16%)	0.91
Potatoes	1	0	0.019 (±75%)	0.014 (±75%)	0.2	0.20 (±50%)	0.22
Pulses	1	0	0.008 (±75%)	0.008 (±75%)	0.19	0.19 (±45%)	0.86
Grain maize	1	0	0.006 (±75%)	0.007 (±75%)	0.22	0.22 (±26%)	0.86
Maize for silage	1	1	0.014[a] (±75%)	0.007[a] (±75%)	0.22 [a]	0.22 (±26%)	0.28
Fodder beet	1	1	0.019[e] (±75%)	0.014[e] (±75%)	0.2[e]	0.20[e] (±50%)	0.12
Grass, clover, grass-clover & similar (fodder production)	0.33 [a]	1	0.015[f] (±75%)	0.012[f] (±75%)	0.3[f]	0.54[f] (±50%)	0.2
Pasture and meadows	NO[b]	1	0.015 (±75%)	0.012 (±75%)	0.3	0.8 (±50%)	0.2
All other cultures, including set-a-side [c]	0.33	0	0.008 (±75%) [c]	0.009 (±75%) [c]	1.0 [c]	0.22 (±16%) [c]	0.85 [c]
"Extensive permanent grassland"	NO[b]	1	0.015 (±75%)	0.012 (±75%)	0.3	0.8 (±50%)	0.2

Note: a) Similar as (Vos C. , et al., Submission 2022); b) It is in general forbidden to plough permanent grassland, therefore assumed to no occur; c) for all other cultures, including set-a-side grass production on arable land, the generic value for crops not indicated in Table 11.1A was used to estimate above- and below-ground residues; d) no value in Table 11.1A why value for general grains; e) used values for tubers; f) used values for Non-N-fixing forages as the clover area is only marginal; g) generic grains; ; h) generic value for crops not indicated in Table 11.1A.

5.5.3.1.4 Urine and dung N deposited on pasture by grazing animals

The annual amount of urine and dung N deposited on pasture by grazing animals (F_{PRP}), expressed in kg N per year is summarized in Table 5-47, and was determined using a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, which was determined following the fifteen steps from the 2023 guidelines (Amon, et al., 2023), which were described in section 5.1.3 and schematically shown in Figure 5-6. The annual amount of urine and dung N deposited on pasture by grazing animals is described in step 4 in section 5.1.3.

$$F_{PRP} = \left[\sum_i \left(m_{grazing\_N(i)} * \left[n_i + n_{TemporaryImportedGrazingAnimals(i)} - n_{TemporaryExportedGrazingAnimals(i)}\right]\right)\right]$$

with:

$m_{grazing\_N(i)}$	the amount of the annual N excreted during grazing, expressed in kg N per year per head/place for animal category *i*; $m_{grazing\_N(i)}$ corresponds to step 4 described in section 5.1.3
n_i	the number of animals in livestock category *i* and shown in Table 5-5; please note that these were all animals owned by luxemburgish farmers;
$n_{TemporayImportedGrazingAnimals(i)}$	the number of temporary imported animals in livestock category *i* during the grazing period (see Table 5-6);
$n_{TemporaryExportGrazingAnimals(i)}$	the number of temporary exported animals in livestock category *i* during the grazing period (see Table 5-6).

5.5.3.1.5 Mineralisation associated with loss of soil organic matter from land use changes

The annual release of direct N_2O emissions due to the conversion of land to cropland is summarized in Table 5-47. The methodology is described in section 6.3.4.2.3.

5.5.3.1.6 Atmospheric depositions of nitrogen compounds

Atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x from inorganic N fertilizer, the application of animal manure, including digestate originating from animal manure, grazing, sewage sludge, compost and digestate originating from energy crops and non-agricultral waste, see Table 5-51. The methodology used to determine the NH_3-N and NO_x-N emissions is described in informative inventory report 2024.

Table 5-51 – Activity data: atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x from inorganic N fertilizer, the application of animal manure, including digestate originating from animal manure, grazing, sewage sludge, compost and digestate originating from energy crops and other waste.

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Activity data - atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x (NRF 3D)

Year	Synthetic fertilizer		Animal manure incl. digestate originating from animal manure		Sewage sludge		Compost & digestate originating from energy crops and non-agr. waste		Crop residues	Grazing	
	kg NH_3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year
1990	550 253	340 082	1 838 851	160 353	39 824	6 944	-	-	26 990	442 470	96 362
1991	573 351	354 357	1 830 093	159 229	39 848	6 948	-	-	28 454	453 323	98 657
1992	618 686	382 376	1 736 870	151 145	40 307	7 028	-	-	28 640	438 741	95 429
1993	564 399	348 824	1 742 344	151 614	41 873	7 301	693	196	29 317	441 773	95 919
1994	535 824	331 163	1 717 482	149 723	43 793	7 636	783	222	27 205	440 889	95 530
1995	525 754	324 940	1 765 106	153 735	43 485	7 582	997	282	29 584	454 817	98 573
1996	528 229	326 470	1 785 913	155 415	37 770	6 586	949	269	31 882	463 073	100 318
1997	520 093	321 441	1 745 914	152 244	39 585	6 902	1 953	553	32 309	451 656	97 668
1998	509 617	314 966	1 774 439	151 258	39 700	6 922	3 693	941	33 016	445 411	96 270
1999	525 544	324 810	1 773 657	151 169	39 487	6 885	4 567	1 036	34 073	450 659	96 801
2000	518 905	320 707	1 749 910	148 308	20 717	3 612	8 243	1 915	33 056	450 635	96 321
2001	442 624	273 562	1 719 607	147 184	19 415	3 385	6 051	1 086	33 232	448 328	95 912
2002	461 127	284 997	1 651 656	142 262	20 547	3 583	8 824	1 418	32 574	436 415	93 237
2003	375 818	232 272	1 617 889	139 637	15 653	2 729	10 752	1 274	32 014	428 026	91 048
2004	476 271	294 357	1 633 149	141 272	12 963	2 260	22 553	2 472	37 726	430 135	91 176
2005	475 059	256 896	1 641 079	140 501	17 033	2 970	38 010	4 548	34 078	429 705	90 216
2006	472 238	255 371	1 615 050	138 599	14 961	2 609	54 388	5 940	33 259	431 096	90 705
2007	439 160	237 483	1 644 299	141 649	17 730	3 091	63 234	6 794	34 853	450 273	95 007
2008	441 195	238 584	1 679 370	145 347	16 785	2 927	71 145	7 642	37 322	462 618	97 488
2009	436 472	236 030	1 635 867	143 542	11 079	1 932	93 461	9 814	38 276	462 165	97 340
2010	473 418	243 757	1 702 958	146 551	11 105	1 936	90 248	9 701	33 262	471 487	99 426
2011	491 461	254 653	1 651 204	143 513	14 701	2 563	134 464	13 654	30 271	453 096	95 204
2012	462 239	241 041	1 592 812	139 878	17 679	3 083	130 625	13 085	34 934	440 248	91 713
2013	449 154	235 724	1 608 283	142 895	14 223	2 480	126 843	12 863	35 517	442 020	92 288
2014	423 727	223 818	1 640 170	147 298	13 123	2 288	147 268	15 079	38 272	455 558	95 060
2015	417 957	227 078	1 652 455	149 641	15 516	2 705	134 326	14 109	32 220	459 041	95 719
2016	429 726	240 339	1 709 497	156 145	8 304	1 448	137 804	14 945	31 342	456 179	95 114
2017	422 086	236 435	1 760 273	162 040	8 381	1 461	157 329	17 383	34 236	452 544	94 319
2018	418 844	225 214	1 777 280	164 097	4 997	871	177 052	19 446	30 558	432 823	90 296
2019	424 058	236 689	1 750 742	163 628	4 822	841	137 432	15 495	34 191	412 734	86 041
2020	413 585	224 008	1 763 665	163 439	9 974	1 739	128 709	14 929	29 963	393 978	82 545
2021	449 899	237 152	1 724 938	162 070	4 120	718	123 522	13 688	31 072	380 073	79 779
2022	280 183	142 221	1 669 998	155 711	4 811	839	113 600	12 415	31 122	381 440	79 949

*Other organic fertilizer = compost and digestate originating from energy crops and other waste.

5.5.3.2 Emission factors

5.5.3.2.1 Emission factors – direct N_2O emissions from managed soil

Direct N_2O emissions from managed soil (N_2O_{Direct}) , expressed as kg N_2O per year were estimated using a Tier 2 method. The used emission factor is the same as used in the German Inventory for "South-Eastern Germany" (Vos C. , et al., 2022). Similar as in the German inventory is there no distinction between synthetic fertilizers and other nitrogen inputs, as according to (Mathivanan, Evsholdt, Zinnbauer, Rösemann, & Fuss, 2021) not significant in Germany, and hence most likely also not significant in Luxemburg, given similar soil types, climat and agriculture practices.

The following equation was used:

$$N_2O_{Direct} = \left[N_2O_{N\ inputs}\right]$$

whereby

$$N_2O_{N\ inputs} = \left[(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * EF_{N_2O-N,inputs}\right] * \left(\frac{44}{28}\right)$$

with:

$N_2O_{N\ inputs}$	= annual direct N_2O emissions from N inputs to managed soils, kg N_2O per year
F_{SN}	= annual amount of synthetic fertilizer N applied to soils, kg N per year, see Table 5-47
F_{ON}	= annual amount of organic N applied to soils from animal manure including digestate orginating from animal manure; sewage sludge; compost and digestate orginating from energy crops and other waste; kg N per year, see Table 5-47 and for the calculations see also section 5.5.3.1.2
F_{PRP}	= annual amount of urine and dung deposited by grazing animals on pasture, kg N per year, see Table 5-47 and for the calculations see also section 5.5.3.1.4.
F_{CR}	= annual amount of N in crop residues, including N-fixing crops and from forage/pasture renewal, returned to soils, kg N per year, see Table 5-47 and for the calculations see also section 5.5.3.1.3
F_{SOM}	= annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N per year, see Table 5-47
$EF_{N2O-N,,inputs}$	= emission factor for N_2O inputs, kg N_2O-N. The emission factors for direct N_2O-emission from agricultural mineral soils in the region "South-Eastern Germany" in Table 11-4 in (Vos C. , et al., 2022) namely 0.0088 (Uncertainty interval 0.0038-0.0143) was used. The South-Eastern Germany region reflects best the soil properties in Luxemburg, has same climate conditions and in general similar agriculture practices. The derived emissions factor for "South-Eastern Germany" was, according to (Vos C. , et al., 2022), derived from emission factors from (Mathivanan, Evsholdt, Zinnbauer, Rösemann, & Fuss, 2021), a meta-analysis with 71 studies, including 676 field measurements at 43 locations in Germany over at least 150 days.
44/28	= conversion of $N_2O\text{-}N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

Direct N_2O emissions from managed organic soils are not occurring, and where therefore not considered in the above equation.

5.5.3.2.2 Emission factors – indirect N2O emissions from managed soil

The indirect N_2O emissions from managed soils consist of a) N_2O emissions from atmospheric deposition of N volatilised from managed soils and b) N_2O emissions from leaching and runoff.

The indirect N_2O emissions occurring after atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge, compost and digestate originating from energy crops and other waste (all attributed to agricultural soils) were calculated using the following formula:

$$indirect\ soil\ N_2O\ emissions = \{[E_{NH3-}\ +\ E_{NO-N}]_{fert} + [E_{NH3-N} + E_{NO-}\ ]_{SAM} + [E_{NH3-N} + E_{NO-N}]_{SSS} + [E_{NH3-N} + E_{NO-N}]_{Comp} + [E_{NH3-}\ +\ E_{NO-N}]_{DEC} + [E_{NH3-N} + E_{NO-N}]_{graz} + [\,E_{NO-N}]_{CR}\} * EF_{N_2O-N\ indirect\ soil} * \left(\frac{44}{28}\right)$$

Where:

- Indirect N_2O emissions resulting from the deposition of NH_3 and NO_x emitted from agricultural soils, in Gg/year
- $[E_{NH3-N} + E_{NO-N}]_{fert}$: NH_3-N and NO-N emissions from mineral fertilizer, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{SAM}$: NH_3-N and NO-N emissions from spreading of animal manure, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{SSS}$: NH_3-N and NO-N emissions from spreading of sewage sludge, in Gg/year.
- $[E_{NH3-}\ +\ E_{NO-N}]_{Comp}$: NH_3-N and NO-N emissions from spreading of compost, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{DEC}$: NH_3-N and NO-N emissions from spreading of digestate originating from energy crops and other waste, in Gg/year.
- $[E_{NH3-}\ +\ E_{NO-}\ ]_{graz}$: NH_3-N and NO-N emissions from grazing, Gg/year.
- $[E_{NO-N}]_{CR}$: NO-N emissions from crop residues, Gg/year.
- $EF_{N2O\text{-}N\ indirect\ soil}$: Default IPCC N_2O-N emission factor for indirect emissions from deposition in a wet climate (i.e. (0.014 according to the IPCC 2019 Refinements (Hergoulac'h, et al., 2019), expressed in kg N_2O-N/kg N
- 44/28 : Conversion factor from kg N_2O-N to kg N_2O

And consequently the fraction of synthetic fertilizer N ($Frac_{GASF}$) that volatilizes as NH_3 and NO_x, was calculated by using the following formula:

$$Frac_{GASF} = {[E_{NH3-}\ +\ E_{NO-N}]_{fert}}\Big/{F_{SN}}$$

Where:

- F_{SN}: annual amount of synthetic fertilizer N applied to soil, in Gg/year

Also is the fraction of applied organic N fertilizer materials and of urine and dung N deposited by grazing animals ($Frac_{GASM}$) that volatiles as NH_3 and NO_x, calculated by using the following formula:

$$Frac_{GASM} = \left[\frac{\{[E_{NH3-N}+E_{NO-}\ ]_{SAM}+[E_{NH3-N}+E_{NO-N}]_{SSS}+[E_{NH3-}\ +E_{NO-N}]_{Comp}+[E_{NH3-}\ +E_{NO-N}]_{DEC}+[E_{NH3-N}+E_{NO-N}]_{graz}+[\,E_{NO-N}]_{CR}\}}{\{F_{ON}+F_{PRP}\}}\right]$$

Where:

- F_{ON}: annual amount of managed animal manure, including digestate originating from animal manure, of sewage sludge, of compost, of digestate originating from energy crops and other waste and crop residues, in Gg/year

- F_{PRP}: annual amount of urine and dung N deposited by grazing animals on pasture, in Gg/year

For nitrogen from synthetic fertilizers, from organic fertilizers, from urine and dung deposited by grazing animals, from crop residues and from mineralization that were lost through leaching and run-off, N_2O emissions had been estimated using equation 11.10 in the the IPCC 2019 Refinements (Hergoulac'h, et al., 2019) :

$$N_2O_L = \{[(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * Frac_{LEAC\quad(H)}] * EF_5\} * \left(\frac{44}{28}\right)$$

with:

F_{SN}	= annual amount of synthetic fertilizer N applied to soils, kg N per year, see Table 5-47
F_{ON}	= annual amount of animal manure, including digestate originating from animal manure, sewage sludge, compost and digestate originating from energy crops and other waste, all organic N additions applied to soils, kg per year, see Table 5-47 and for the calculations see also section 5.5.3.1.2
F_{PRP}	= annual amount of urine and dung deposited by grazing animals on pasture, kg N per year, see Table 5-47
F_{CR}	= annual amount of N in crop residues, including N-fixing crops and from forage/pasture renewal, returned to soils, kg N per year, see Table 5-47.
F_{SOM}	= annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N per year, see Table 5-47
$Frac_{LEACH-(H)}$	= fraction of all N added to/mineralised in managed soils in regions where leacing/runoff occurs that is lost through leaching and runoff, kg N per year. The default value from Table 11.3 in the IPCC 2019 Refinements (Hergoulac'h, et al., 2019), i.e. 0.24 was used.
EF_5	= emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N. For the emissions calculations the default values provided in Table 11.3 in the IPCC 2019 Refinements (Hergoulac'h, et al., 2019), namely 0.0011 was used.
44/28	= conversion of N_2O-$N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

5.5.4 Category specific uncertainty

Uncertainty was model using Monte-Carlo techniques, see section 5.1.5 for more details. A detailed description of the assumed uncertainties for activity data and the used emission factors is provided hereafter.

5.5.4.1 Activity data for direct N_2O emissions from managed soils

The uncertainty w.r.t. the activity data of the N in animal manure applied to soil and the N in urine and dung deposited to soils were both determined using a mass-flow approach (see section 5.1.3) and were described in section 5.1.5, in section 5.3.4 and in the informative inventory report 2024 (section 5.3.4 and 6.4.3).

For 1990-2004 were areas of cultivated crops derived from the Agricultural census, i.e. self-reported data from the farmers collected on the 15th of May of each year by STATEC (Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg). For 2005 data and onwards were the data extracted from the database hold by the Ministry of Agriculture and used for applying for e.g. direct payments and other subsidies, respective for the compulsory accident insurance, implying divers administrative and other controls. The uncertainty of annual area for the different cultivated crops was for both databases assumed to be uniformly distributed by ±1%. Extensive grassland not cultivated by farmers, although for 2014 and onwards also derived from a database from the Ministry of Agriculture, was not controlled, why assuming to be uniformly distributed by ±10%.

The uncertainty of the harvest annual dry matter yield for winter wheat, barley, oats, triticale and rapeseed was assumed to be uniformly distributed by ± 10%. For those crops, large quantities were sold at farm-gate with high quality data collected within the Luxemburgish LTBN, the source used to estimate annual harvest yields (Fränk Steichen, December 2018; Personal communication; Service d'economie rurale – Division des statistiques agricoles, des relations extérieures et des marchés agricoles). For all other crops, the uncertainty of the harvest annual dry matter yield was assumed to be uniformly distributed with a range of ± 20%.

The uncertainty range for the N content of above-ground residues; for the N content of below-ground residues and for the ratio of below-ground biomass to above-ground biomass was based on the values provided in Table 11.1A in the 2019 Refinement to the 2006 IPCC Guidelines (Hergoulac'h, et al., 2019), and are summarized in Table 5-50. The uncertainty was modelled using a Pert-distribution with the deterministic value set as most likely value and the range defining the minimum and maximum value.

The uncertainty for the total quantity of N from synthetic fertilizers was modelled as uniformely distributed by +- 10%. When reallocating the total N quantiy to the different synthetic N fertilizers, an uncertainty range of +-10% was assumed, except for Calcium ammonium nitrate (CAN). The estimated quantities of CAN were calculated by subtracting all other N-fertilizer from the total quantity of of N from synthetic fertilizer. Total quantity per ha of utilised agriculture area and the different synthetic N-fertilizers, both were derived from the Luxemburgish LTBN data.

Activity data for sewage sludge and compost were based on annual reports with information on produced quantities and average N-content, as well as quantities (or proportion) delivered to the agriculture sector. The uncertainty on the quantities of N applied from sewage sludge and N applied from compost was therefore assumed to be +- 25% (Hergoulac'h, et al., 2019).

A similar uncertainty was assumed for the quantities of mineralisation of N in soil (+- 25%).

For activity data on quantities of waste and energy crops used in biodigestate, and later applied as other organic N fertilizer on managed soils an uncertainty of +- 25% was assumed for the used quantities as feedstock, and in addition an uncertainty of +- 10%, modelled as Pert-distribution for the N-content of the different energy crops and non-agricultural waste categories (for more details see informative inventory report 2024 (section 6.4.3).

5.5.4.2 Emission factors for direct N_2O Emissions from managed soils

The uncertainty range of the emission factor (EF) for N inputs was 0.0038-0.0143, i.e. the same as for "South-Eastern Germany (Vos C. , et al., 2022), with most likely 0.0088 and modelled as a Pert-distribution. Similar as in the German inventory is there no distinction between synthetic fertilizers and other nitrogen inputs, as according to (Mathivanan, Evsholdt, Zinnbauer, Rösemann, & Fuss, 2021) not significant in Germany, and hence most likely not significant in Luxemburg, given similar soil properties, climat and agriculture practices.

5.5.4.3 Indirect N_2O emissions from managed soils - Activity data

The assumed uncertainty range around the estimated Nitrogen loss due to volatilization of NH_3 and NO_X is described in the informative inventory report 2024.

The uncertain range of the fraction of all N added to/mineralized in managed soils ($Frac_{Leach}$) was based on Table 11.3 in the 2019 Refinement to the 2006 IPCC Guidelines (Hergoulac'h, et al., 2019) and modelled as Pert-distribution with most likely 0.24; minimum 0.01 and maximum 0.73.

5.5.4.4 Indirect N_2O emissions from managed soils - Emission factors

The uncertainty range for the EF for indirect N_2O emissions originating from atmospheric deposition of N volatilised from managed soils was based on Table 11.3 in the 2019 Refinement to the 2006 IPCC Guidelines (Hergoulac'h, et al., 2019) for a wet climate, and was modelled as Pert-distribution with most likely 0.014; minimum 0.011 and maximum 0.017.

The uncertainty range used for the EF for indirect N_2O emissions originating from leaching and runoff from managed soils was based on Table 11.3 of the 2019 Refinement to the 2006 IPCC guidelines (Hergoulac'h, et al., 2019) and modelled as Pert-distribution with most likely 0.011; minimum 0.0000 and maximum 0.020.

5.5.5 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.5.6 Category-specific recalculations including changes made in response to the review process

Revisions and recalculations relevant to animal categories and livestock numbers and the manure management systems since submission 2023v1 impacting also N_2O emissions from managed soil, although only marginal, are described in Table 5-21. Additional revisions and relevant for N2O emissions from managed soils are described in Table 5-52.

Table 5-52 – Recalculations done since submission 2022v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
3.D.1	The provisional activity data for sewage sludge for the year 2021 was replaced by published data	AD
3.D.1	Revision of the 2021 data on the application of slurry, digestate and solid manure. Provisional data were replaced.	AD / N emissions
3.D.2	Revision of N volatilised from managed soils because of new EF for NH_3-emissions from synthetic fertilizer by using updated EF of the 2023 EMEP/EEA guidelines, and hence revised N volatilised from managed soils;	AD

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
3.D.2	Error correction: The consideration of NO-N emissions from crop residues in N volatilised from managed soils	AD

The recalculated N_2O emissions from managed soils, resulted in an average increase of 1.1% N_2O emissions, varying over the years from minimum 0.8% to maximum 1.3%, see Table 5-53. In particularly the indirect N_2O emissions had increased by 6.7%, what is mainly the result of the updated EF for NH3-emissons from synthetic fertilizer, and hence increased N volatised from managed soils.

Table 5-53 – Recalcution of N_2O emissions from managed soils (CRF 3D)

3 - Agriculture N_2O Emissions (Gg) by source & sink category									
	3D -Direct emissions Gg N_2O		Impact of recalculation	3D- Indirect emissions Gg N_2O		Impact of recalculation	3D - Managed soil (total) Gg N_2O		Impact of recalculation
Year	New	Old	%	New	Old	%	New	Old	%
1990	0.47	0.47	0.0	0.09	0.08	8.1	0.56	0.55	1.2
1991	0.48	0.48	0.0	0.09	0.08	8.3	0.57	0.56	1.2
1992	0.49	0.49	0.0	0.09	0.08	9.1	0.58	0.58	1.3
1993	0.47	0.47	0.0	0.09	0.08	8.4	0.56	0.55	1.3
1994	0.45	0.45	0.0	0.09	0.08	8.2	0.54	0.53	1.2
1995	0.46	0.46	0.0	0.09	0.08	7.9	0.54	0.54	1.2
1996	0.46	0.46	0.0	0.09	0.08	7.9	0.55	0.54	1.2
1997	0.45	0.45	0.0	0.09	0.08	7.9	0.54	0.53	1.2
1998	0.45	0.45	0.0	0.09	0.08	7.7	0.53	0.53	1.2
1999	0.46	0.46	0.0	0.09	0.08	7.9	0.54	0.54	1.2
2000	0.45	0.45	0.0	0.09	0.08	7.9	0.53	0.53	1.2
2001	0.41	0.41	0.0	0.08	0.08	7.1	0.49	0.49	1.1
2002	0.41	0.41	0.0	0.08	0.08	7.5	0.49	0.49	1.2
2003	0.37	0.37	0.0	0.08	0.07	6.5	0.44	0.44	1.0
2004	0.42	0.42	0.0	0.08	0.08	7.8	0.50	0.50	1.2
2005	0.39	0.39	0.0	0.08	0.08	6.4	0.47	0.47	1.0
2006	0.39	0.39	0.0	0.08	0.07	6.4	0.47	0.46	1.0
2007	0.38	0.38	0.0	0.08	0.08	5.9	0.46	0.46	1.0
2008	0.39	0.39	0.0	0.08	0.08	5.8	0.47	0.47	1.0
2009	0.39	0.39	0.0	0.08	0.08	5.8	0.47	0.47	0.9
2010	0.40	0.40	0.0	0.08	0.08	5.6	0.48	0.48	0.9
2011	0.40	0.40	0.0	0.08	0.08	5.8	0.48	0.48	1.0
2012	0.39	0.39	0.0	0.08	0.08	5.7	0.47	0.46	0.9
2013	0.39	0.39	0.0	0.08	0.08	5.5	0.47	0.46	0.9
2014	0.39	0.39	0.0	0.08	0.08	5.2	0.47	0.46	0.9
2015	0.39	0.39	0.0	0.08	0.08	5.3	0.47	0.46	0.9
2016	0.40	0.40	0.0	0.08	0.08	5.5	0.48	0.48	0.9
2017	0.40	0.40	0.0	0.09	0.08	5.2	0.49	0.49	0.9
2018	0.39	0.39	0.0	0.08	0.08	4.8	0.48	0.47	0.8
2019	0.39	0.40	0.0	0.08	0.08	5.4	0.48	0.47	0.9
2020	0.38	0.38	-0.1	0.08	0.08	5.4	0.47	0.46	0.8
2021	0.39	0.39	0.1	0.08	0.08	5.7	0.47	0.47	1.0
2022	0.31			0.07			0.38		

5.5.7 Planned improvement

Planned improvements, as listed in Table 5-54, will be explored, based on available resources and available data.

Table 5-54 – Planned improvements

GHG source & sink category	Planned improvement
Export of animal manure and digestate	Countine the quest for data on quantities exported of locally produced animal manure and digestate to France and Germany.

5.6 Prescribed Burning of Savannahs (IPCC Source Category 3.E)

This source category does not exist in Luxembourg.

5.7 Field Burning of Agricultural Residues (IPCC Source Category 3.F)

Article 14, indent 2 of the Law of August, 11 1982 concerning the protection of nature and natural resources (Climat & Environnement, 1982), later abrogated by (Climat & Environnement, 2004) (Climat & Environnement, 2018) forbids clearing and burning (in French "essartement") of fields, meadows, grasslands, roadsides, forests between the 1st of March and the 30th of September. According to this law, the clearing and burning of agricultural residues (such as straw) is not strictly forbidden. However, for economic reasons (residues can be used as litter, as feeding stuff for animals or can be sold), field burning is not practiced in Luxembourg and, therefore, emission estimates have been recorded as not occurring (notation key NO) in the inventory.

5.8 Emissions from Liming (IPCC source Category 3G)

This section describes the estimation of carbon dioxide emissions resulting from liming in agricultural soils. Liming is used to reduce soil acidity and improve plant growth in managed systems, particularly agricultural lands and managed forests. In 2022, this source category was responsible for 1.19% of the total GHG emissions from the agriculture sector.

5.8.1 Source category description

This category consists of emissions resulting from the agricultural use of dolomite and limestone.

Thomas slag as fertilizer was commonly used in Luxembourg until the eighties/ninties, but with the closing of blast furnaces and the re-structuration of the iron industry in Luxembourg, local Thomas slag got scarce, and farmers had to looked for other types of liming fertilizers. Hence the use of lime has significantly increased over time. Note that in 2016 there is a small drop in the use of lime. This drop was related to the weather conditions, hampering the application of lime.

Until 2017 more than 95% of the applied lime was dolomite (Turmes 2018). For simplification reason it was therefore assumed that 100% of the lime would be dolomite and the application of limestone would be zero, hence the notification of "NO" in the CRF table. However, in 2018, a larger quantity of limestone was sold, why since 2018 both dolomite and limestone are considered separately.

Table 5-55 - CO_2 emission trends for IPCC Category 3G – Liming: 1990-2022 (Gg)

3 - Agriculture Sector			
CO2 emissions (Gg)			
	3G - Liming		
Year	Total	Lime	Dolomite
1990	0.23	NO	0.23
1991	0.41	NO	0.41
1992	0.59	NO	0.59
1993	0.92	NO	0.92
1994	1.34	NO	1.34
1995	1.09	NO	1.09
1996	0.97	NO	0.97
1997	1.43	NO	1.43
1998	1.97	NO	1.97
1999	1.10	NO	1.10
2000	1.84	NO	1.84
2001	2.23	NO	2.23
2002	2.83	NO	2.83
2003	2.75	NO	2.75
2004	2.36	NO	2.36
2005	3.81	NO	3.81
2006	2.97	NO	2.97
2007	3.00	NO	3.00
2008	2.79	NO	2.79
2009	3.97	NO	3.97
2010	3.43	NO	3.43
2011	4.76	NO	4.76
2012	4.93	NO	4.93
2013	5.66	NO	5.66
2014	6.00	NO	5.90
2015	6.09	NO	5.89
2016	5.53	NO	5.23
2017	6.64	NO	6.24
2018	8.27	0.61	7.66
2019	7.84	0.53	7.31
2020	7.96	0.64	7.32
2021	7.45	0.81	6.64
2022	7.90	1.61	6.29
Trend 1990 -2022	3332%		2632%
Trend 2021 -2022	6%	99%	-5%

5.8.2 Methodological issues

Tier 1 method has been used to estimate the emissions resulting from liming.

5.8.2.1 Activity data

Activity data for this emission sources is the used amount of carbonate containing lime (confidential data), whereby differentiating between limestone and dolomite and taking into account of the content of calcic limestone, respectively dolomite.

According to Turmes (2018), director of Versis S.A. Luxemburg, more than 95% of the lime used in Luxemburg used to be dolomite. A fact that was confirmed by the data collected by the Luxemburg partner within the LTBN (Karl Weckbecker, Service d'Economie Rurale, Luxemburg; personal communication; October 2018). For simplification reason it was therefore assumed that up to 2017 100% would be dolomite. However, in 2018, a larger quantity of limestone was sold, why since 2018 both dolomite and limestone are considered separately.

There was up to 2012 one main seller for lime in Luxemburg. Since then there are two major lime sellers in Luxemburg (Turmes 2018, (Hess, November 2021), (Palzkill K., November 2019). In 2013, a second seller appeared on the scene, these two sellers were responsible for approximately 100% of all lime selling's in Luxemburg for the years 2013-2017 (Hess, November 2021), (Palzkill K., November 2019). In 2018 two additional sellers entered the market. (Thomé, 2023) (Cremer, 2023)

Selling statistics, collected by Marc Weyland, Administration des Services Techniques de l'Agriculture (ASTA), Luxemburg, were available from 1993-2013. Having no data for the years 1990-1992, a trend estimation was conducted based on the 1993-2003 data. For the years 2014-2022 own investigations at the Service d'Economie Rurale took place[141].

5.8.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO_2 emissions from liming.

CO_2 emissions from liming in tonnes per year were calculated according to equation 11.12 see equation (De Klein, et al., 2006):

$$CO_2\ Emissions = [(M_{Dolomite} * EF_{Dolomite}) + (M_{Limestone} * EF_{Limestone})] * (\frac{44}{12})$$

with,

$M_{Dolomit}$ = the annual amount of dolomite (in tonnes per year).

$EF_{Dolomit}$ = emission factor, the 2006 IPCC default emissions factor for dolomite ($EF_{Dolomite}$), i.e. 0.13 (De Klein, et al., 2006) was used.

$M_{Limestone}$ = the annual amount of limestone (in tonnes per year).

$EF_{Limestone}$ = emission factor, the 2006 IPCC default emissions factor for limestone ($EF_{Limestone}$), i.e. 0.12 (De Klein, et al., 2006) was used.

44/12 = conversion of CO_2-C emissions to CO_2 emissions.

Note, limestone was assumed not to occur in Luxembourg for the years 1990-2017.

5.8.3 Category specific uncertainty

Uncertainty was model using Monte-Carlo techniques, see section 5.1.5.1 for more details. A detailed description of the assumed uncertainties for activity data and for the used EFs for CRF 3G are provided hereafter.

The uncertainty range for the quantities of dolomite and for limestone, both based on data collected by interviews with the main sellers, was assumed to be uniformly distributed by ±20%.

141 2014-2017 data: (Turmes., 2018) ; 2018 & 2019 data: Palzkill, pers. com. 20-11-2019; Hess, pers. com. 22-11-2019; Cremer; pers.l com. 9-11-2023 & Thomé, pers. com. 20-08-2023; 2020 data: Palzkill, pers. com. 10-11-2021; Hess, pers. com. 16-11-2021; Cremer; pers.l com. 9-11-2023 & Thomé, pers. com. 20-08-2023 2021 data: Palzkill, pers. com. 18-07-2022; Hess, pers. com. 9-08-2022; Cremer; pers. com. 9-11-2023 & Thomé, pers. com. 20-08-2023; 2022 data: Cremer; pers. com. 9-11-2023; Hess, pers. com. 26-07-2023; Palzkill, pers. com. 2-08-2023; & Thomé, pers. com. 20-08-2023

The uncertainty range for the EFs for limestone and dolomite was based on the 2006 IPCC guidelines on page 11.27 (De Klein, et al., 2006), with minimum -50%, whereas the default value was used as most likely and maximum value (Pert-distribution).

5.8.4 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.8.5 Category-specific recalculations including changes made in response to the review process

Revisions and recalculations relevant to 3G, since submission 2023v1 are described in Table 5-56 .

Table 5-56 – Recalculations done since submission 2023v2

GHG source & sink category	Revisions 2023v2 ➔ 2024v1	Type of revision
3G	Revision of the quantities used, as for the years 2018-2022 having data of the quantities sold of two additional sellers rather than estimates of the market share of the two main sellers and extrapolating. Revision of the quantities, as having collected information of the composition of the different lime fertilizers on the market in the years 1990-2021	Revised AD

The recalculated $C0_2$ emissions from liming, resulted in an average reduction of the $C0_2$ emissions from liming of 15.8%, see Table 5-57.

Table 5-57 – Recalcution of CO_2 emission for IPCC Category 3G – Liming in Gg $CO_{2\text{-eq.}}$

3 - Agriculture			
CO2 Emissions (Gg) by source & sink category			
	3G-Lime application Gg CO2		Impact of recalculation
Year	New	Old	%
1990	0.23	0.26	-10
1991	0.41	0.46	-10
1992	0.59	0.66	-10
1993	0.92	1.02	-10
1994	1.34	1.49	-10
1995	1.09	1.22	-10
1996	0.97	1.07	-10
1997	1.43	1.59	-10
1998	1.97	2.19	-10
1999	1.10	1.22	-10
2000	1.84	2.04	-10
2001	2.23	2.48	-10
2002	2.83	3.15	-10
2003	2.75	3.05	-10
2004	2.36	2.62	-10
2005	3.81	4.23	-10
2006	2.97	3.30	-10
2007	3.00	3.34	-10
2008	2.79	3.10	-10
2009	3.97	4.41	-10
2010	3.43	3.81	-10
2011	4.76	5.29	-10
2012	4.93	5.48	-10
2013	5.66	6.29	-10
2014	6.00	6.95	-14
2015	6.09	7.36	-17
2016	5.53	6.99	-21
2017	6.64	8.80	-25
2018	8.27	10.97	-25
2019	7.84	10.38	-24
2020	7.96	11.07	-28
2021	7.45	9.85	-24
2022	7.90		

5.8.6 Planned improvement

No further improvements planned.

5.9 Emissions from urea application (IPCC Source Category 3H)

This section describes the estimation of carbon dioxide emissions resulting from urea application in agricultural soils. The use of urea as a synthetic N fertilizer was never a common practice in Luxembourg. In 2022, this source category was responsible for <0.01% of the total GHG emissions from the agriculture sector.

5.9.1 Source category description

This category consists of emissions resulting from the urea application in agricultural managed soils; CO_2 emissions. The use of urea as a synthetic N fertilizer was never a common practice in Luxembourg. Now-a-days just a handvoll of farmers were using urea as a synthetic N fertilizer for certain crops, a few additional farmers just urea as an addition with phytosanitary treatments rather than as a synthetic N fertilizer, see Table 5-58.

Table 5-58 - CO_2 emission trends and activity data for IPCC Category 3H – Urea application: 1990-2022 (Gg)

3 - Agriculture Sector CO_2 emissions (Gg) and Activity data (tonnes utilized urea/year)		
	3H - Urea application	
Year	CO_2 Emissions	Utilized urea (tonnes/year)
1990	NO	NO
1991	NO	NO
1992	NO	NO
1993	NO	NO
1994	NO	NO
1995	NO	NO
1996	NO	NO
1997	NO	NO
1998	NO	NO
1999	NO	NO
2000	NO	NO
2001	NO	NO
2002	NO	NO
2003	NO	NO
2004	NO	NO
2005	0.42	577
2006	0.42	574
2007	0.39	533
2008	0.39	536
2009	0.39	530
2010	0.37	500
2011	0.35	473
2012	0.29	402
2013	0.25	347
2014	0.21	286
2015	0.18	247
2016	0.16	215
2017	0.12	165
2018	0.08	114
2019	0.05	74
2020	0.06	81
2021	0.07	89
2022	0.05	73
Trend 1990 -2022		
Trend 2021 -2022	-18%	-18%

5.9.2 Methodological issues

Tier 1 method has been used to estimate the emissions from the urea application.

5.9.2.1 Activity data

Activity data for this emission sources are data on the utilization of urea. Table 5-58 shows the activity data used for the emission estimations.

The national utilisation of kg N used on agriculture surface (see section 5.5.3.1.1) was the basis for the estimation of the national utilisation of urea. In a first step was the national utilisation of kg N obtained by multiplying the weighted average kg N per ha used agriculture surface (STATEC, Consommation d'engrais chimiques - Consommation par ha cultivé (en kg d'élements nutrififs par ha) - Engrais azotes, 2023) by the used agriculture surface. In a second step were the estimated utilized N redistributed over the different fertilizer in questions, including urea and CAN. The allocation of fertiliser types was based on the consumption of the farmers within the Luxemburgish “landwirtschaftliche Testbestriebsnetz” (LTBN). Since 2000 nearly every year, price statistics had been published on the used fertiliser types, presuming that at least 8 farmers had used them, and that total consumption was minimum 10,000 kg, if solid fertilizer, respectively 25 hl, if liquid fertilizer. Together with the price, was also the quantities published on which prices had been based (i.e. the quantities used by LTBN farmers). (Brücher & Jacqué, Preisstatistik, 2010) (Brücher & Jacqué, Preisstatistik, 2011) (Brücher & Jacqué, Preisstatistik , 2012) (Conter, Preisstatistik 2000, 2001) (Conter, 2002) (Conter, 2003) (Conter, 2004) (Conter, 2005) (Conter, 2006) (Conter, 2007) (Hermes C. , Preisstatistik 2007, 2008) (Hermes C. , 2009) (Majerus, Preisstatistik 2016, 2017) (Majerus, 2018; Majerus, 2019) There were no data for the years 1990-1999. But according to field experts[142] was the distribution of the used synthetic N-fertilizer similar to the one observed for the years 2000-2004, why assuming the same distribution for the years 1990-1999 as observed in 2000-2004. Given that prices are driving annual sales, multiannual sales data were considered to be more appropriate for the allocation of fertilizer type. The years chosen were 2000-2004, 2005-2009, 2010-2012 and 2016-2018. No information was available for the years 2013-2015, why using as proxy for the years 2013 and 2014 the 2010-2012 multiannual sales data and for the year 2015, the 2016-2018 multiannual sales data. For the year 2019 and onwards, information from all LTBN farmers were used, and the allocation was derived directly from the LTBN database[143]. But given that urea utilisation is rather seldom in Luxembourg, and therefore showed only up in the period 2005-2009, and again in the 2019, an interpolation was made for the years 2010-2018 presuming a linear decrease from 1.9% in 2005-2009 to 0.3% in 2019. This correction was applied on the costs of the allocation of CAN, the major synthetic N-fertilizer used in Luxembourg. The amount of N was scaled to the total N use of inorganic fertiliser in Luxembourg. The quantities of utilized urea in kg, were derived by dividing the so-obtained national utilisation of kg N originating from urea by 46%, i.e. the assumed percentage of N per kg N-fertilzer. (https://de.eurochemagro.com/produkte/stickstoff-einzel-duenger/harnstoff/) and are summarized in Table 5-58.

5.9.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO_2 emissions from the urea application.

CO_2 emissions from urea utilization in tonnes per year were calculated according to equation 11.13 see equation (De Klein, et al., 2006):

$$CO_2\ Emissions = [(M_{Urea} * EF_{Urea})] * (\frac{44}{12})$$

with,

M_{Urea} = the annual amount of urea fertilisation (in tonnes fertilzer per year).

EF_{Ureat} = emission factor, the 2006 IPCC default emissions factor for urea (EF_{Urea}), i.e. 0.2 (De Klein, et al., 2006) was used.

44/12 = conversion of CO_2-C emissions to CO_2 emissions.

142 Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l’entraide agricoles; Simone Marx; ASTA, Service de pédologie; personal communications; July 2020

143 2019-2021 :Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l’entraide agricoles, 2019 data: pers. com. 24-11-2020; 2020 data: pers. com. 29-11-2021; 2021 data: pers. com.23-11-2022; 2022 data: Paul Jacqué, pers. com. 27-11-2023

5.9.3 Category specific uncertainty

Uncertainty was model using Monte-Carlo techniques, see section 5.1.5.1 for more details. A detailed description of the assumed uncertainties for activity data and for the used EFs for CRF 3H are provided hereafter.

The quantities of urea was indirectly derived from the estimated total quantity of N from synthetic N fertilizer (see activity data for N_2O emissions from managed soils in section 5.5.4). But to take into consideration that the N-content in urea might vary, the uncertainty of the N-content was assumed to be minimum 45%, most likely 46%[144] and maximum 47% (Pert-distribution).

The same uncertainty range as for liming was assumed for the EF for urea fertilisation (2006 IPCC guidelines on page 11.32 (De Klein, et al., 2006)), with minimum -50% and the default value as most likely and maximum value (using a pert distribution).

5.9.4 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.9.5 Category-specific recalculations including changes made in response to the review process

No revisions and no recalculations relevant to 3H, since submission 2023v1.

5.9.6 Planned improvement

No further improvements planned.

5.10 Other carbon containing fertilizer (IPCC Source Category 3I)

This section describes the estimation of carbon dioxide emissions resulting from the application of carbon-containing fertilizers on agricultural soils. Calcium ammonium nitrate (CAN) is the most common synthetic N fertilizer used in Luxembourg. In 2022, this source category was responsible for 0.32% of the total GHG emissions from the agriculture sector.

5.10.1 Source category description

This category consists of emissions resulting from the use of carbon-containing fertilizer on agricultural managed soils.

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[144] https://de.eurochemagro.com/produkte/stickstoff-einzelduenger/harnstoff/

Synthetic N fertilizer, and hence also the use of CAN, is showing a decreasing trend over the years, see Table 5-59. High prices for synthetic N fertilizer / CAN, such as in 2022, resulted in a drastic drop of the use, and hence in the emissions.

Table 5-59 - CO_2 emission trends and activity data for IPCC Category 3H – Carbon-containg fertilizer: 1990-2022 (Gg)

3 - Agriculture Sector CO_2 emissions (Gg) and Activity data (tonnes $CaCO_3$/year)		
	3I - Carbon-containing fertilizer	
Year	CO_2 Emissions	Calcium ammonium nitrate (tonnes $CaCO_3$ / year)
1990	5.82	13 230
1991	6.07	13 786
1992	6.55	14 876
1993	5.97	13 571
1994	5.67	12 884
1995	5.56	12 641
1996	5.59	12 701
1997	5.50	12 505
1998	5.39	12 253
1999	5.56	12 636
2000	5.49	12 477
2001	4.68	10 643
2002	4.88	11 087
2003	3.98	9 036
2004	5.04	11 452
2005	4.17	9 489
2006	4.15	9 432
2007	3.86	8 771
2008	3.88	8 812
2009	3.84	8 718
2010	3.82	8 678
2011	4.00	9 083
2012	3.79	8 615
2013	3.71	8 442
2014	3.53	8 031
2015	3.64	8 284
2016	3.92	8 912
2017	3.85	8 756
2018	3.56	8 094
2019	3.83	8 710
2020	3.56	8 089
2021	3.70	8 414
2022	2.16	4 915
Trend 1990 -2022	-63%	-63%
Trend 2021 -2022	-42%	-42%

5.10.2 Methodological issues

Tier 1 method has been used to estimate the emissions resulting from liming.

5.10.2.1 Activity data

The national utilisation of kg N used on agriculture surface (see section 5.5.3.1.1) was the basis for the estimation of the national utilisation of calcium ammonium nitrate (CAN). In a first step was the national utilisation of kg N obtained by multiplying the weighted average kg N per ha used agriculture surface (STATEC, Consommation d'engrais chimiques - Consommation par ha cultivé (en kg d'élements nutrififs par ha) - Engrais azotes, 2023) by the used agriculture surface. In a second step were the estimated utilized N redistributed over the different fertilizer in questions, including CAN. The allocation of fertiliser types was based on the consumption of the farmers within the Luxemburgish "landwirtschaftliche Testbestriebsnetz" (LTBN). Since 2000 nearly every year, price statistics had been published on the used fertiliser types, presuming that at least 8 farmers had used them, and that total consumption was minimum 10,000 kg, if solid fertilizer, respectively 25 hl, if liquid fertilizer. Together with the price, was also the quantities published on which prices had been based (i.e. the quantities used by LTBN farmers). (Brücher & Jacqué, Preisstatistik, 2010) (Brücher & Jacqué, Preisstatistik, 2011) (Brücher & Jacqué, Preisstatistik , 2012) (Conter, Preisstatistik 2000, 2001) (Conter, 2002) (Conter, 2003) (Conter, 2004) (Conter, 2005) (Conter, 2006) (Conter, 2007) (Hermes C. , Preisstatistik 2007, 2008) (Hermes C. , 2009) (Majerus, Preisstatistik 2016, 2017) (Majerus, 2018; Majerus, 2019) There were no data for the years 1990-1999. But according to field experts[145] was the distribution of the used synthetic N-fertilizer similar to the one observed for the years 2000-2004, why assuming the same distribution for the years 1990-1999 as observed in 2000-2004. Given that prices are driving annual sales, multiannual sales data were considered to be more appropriate for the allocation of fertilizer type. The years chosen were 2000-2004, 2005-2009, 2010-2012 and 2016-2018. No information was available for the years 2013-2015, why using as proxy for the years 2013 and 2014 the 2010-2012 multiannual sales data and for the year 2015, the 2016-2018 multiannual sales data. For the year 2019 and onwards, information from all LTBN farmers were used, and the allocation was derived directly from the LTBN database[146]. But given that urea utilisation is rather seldom in Luxembourg, and therefore showed only up in the period 2005-2009, and again in the 2019, an interpolation was made for the years 2010-2018 presuming a linear decrease from 1.9% in 2005-2009 to 0.3% in 2019. This correction was applied on the costs of the allocation of CAN, the major synthetic N-fertilizer used in Luxembourg. The amount of N was scaled to the total N use of inorganic fertiliser in Luxembourg.

The quantities of utilized CAN in kg $CaCO_3$ were derived by dividing the national utilisation of kg N originating from CAN first by 27%, i.e. the percentage of N per kg N-fertilizer, (https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV) and in a second step by 21.48%. The majority of applied CAN has a content of 12% CaO, (https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV) which is equivalent to 21.48 % $CaCO_3$. Due to a lack of data, it was assumed that 100% of the carbon in CAN is presented as CaCO3. Table 5-59 shows the quantities of utilized CAN in tonnes $CaCO_3$.

5.10.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO_2 emissions from carbon-containing fertilizer, i.e. CAN.

CO_2 emissions from the quantities of utilized CAN in tonnes $CaCO_3$, per year were calculated according to equation 11.12 see equation (De Klein, et al., 2006):

$$CO_2\ Emissions = [\ (M_{CAN\_CaCO3} * EF_{Limestone})] * (\frac{44}{12})$$

with,

M_{CAN_CaCO3} = the annual amount of utilized CAN (in tonnes $CaCO_3$ per year).

$EF_{Limestone}$ = emission factor, the 2006 IPCC default emissions factor for limestone ($EF_{Limestone}$), i.e. 0.12 (De Klein, et al., 2006) was used.

145 Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles; Simone Marx; ASTA, Service de pédologie; personal communications; July 2020

146 2019-2021 :Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles, 2019 data: pers. com. 24-11-2020; 2020 data: pers. com. 29-11-2021; 2021 data: pers. com.23-11-2022; 2022 data: Paul Jacqué, pers. com. 27-11-2023

44/12 = conversion of CO_2-C emissions to CO_2 emissions.

Note: The current estimations might be an overestimation, as due to a lack of data, it is unclear if 100% of the carbon in CAN is presented as CaCO3.

5.10.3 Category specific uncertainty

Uncertainty was model using Monte-Carlo techniques, see section 5.1.5.1 for more details. A detailed description of the assumed uncertainties for activity data and for the used EFs for CRF 3I are provided hereafter.

The quantities of Calcium ammonium nitrate (CAN) was indirectly derived from the estimated total quantity of N from synthetic N fertilizer (see activity data for N_2O emissions from managed soils in section 5.5.4). But to take into consideration that the N-content in CAN might vary, the uncertainty w.r.t. N-content of CAN was modelled as minimum 22%, most likely 27%[147] and maximum 28% using a Pert-distribution. Furthermore, the CaO content was modelled as minimum 10%, most likely 12%[148] and maximum 14%, using a Pert-distribution.

The uncertainty range for the EFs for other carbon-containing fertilizer was based on the 2006 IPCC guidelines on page 11.27 (De Klein, et al., 2006), with minimum -50%, whereas the default value was used as most likely and maximum value (Pert-distribution).

5.10.4 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.10.5 Category-specific recalculations including changes made in response to the review process

No revisions and no recalculations relevant to 3I, since submission 2023v1.

5.10.6 Planned improvement

Planned improvements, as listed in Table 5-60, will be explored, based on available resources and available data.

Table 5-60 – Planned improvements

GHG source & sink category	Planned improvement
3I	Looking for additional information/data source allowing to eventually confirm, respectively to revise, if not applicable, the assumption that 100% of CAN would be presented as CaCO3

147 https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV

148https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV

5.11 Others (IPCC Source Category 3J)

This source categorie are not used in Luxembourg's GHG inventory.

6 Land Use, Land-Use Change and Forestry (CRF sector 4)

Chapter 6 includes information on and description of methodologies used for estimating GHG emissions as well as references to activity data and emission factors reported under CRF Sector 4 – Land Use, Land-use Change and Forestry – *i.e.* LULUCF – for the period 1990 to 2022.

6.1 Sector Overview

In 2022, *Land Use, Land Use Change and Forestry* was a net sink in Luxembourg (Table 6-1). Net removals from the LULUCF sector amounted to -651.01 Gg CO_2 and 0.011 Gg N_2O. Since 1990, net emissions have decreased by 7318%. The key driver for the fall in emissions is the ongoing increase in net removals in forest land remaining forest land following the recovery from the major disturbance events in the early 1990s. Within the sectors, forest land and grassland resulted in net removals (-651.01 Gg CO_2 and -17.64 Gg CO_2, respectively). All other categories resulted in net emissions: the largest source of emissions was from cropland (36.70 Gg CO_2), followed by settlements (22.60 Gg CO_2), wetlands (0.21 Gg CO_2) and other land (0.17 Gg CO_2).

Table 6-1 - Emissions and Removals from CRF category 4 - LULUCF

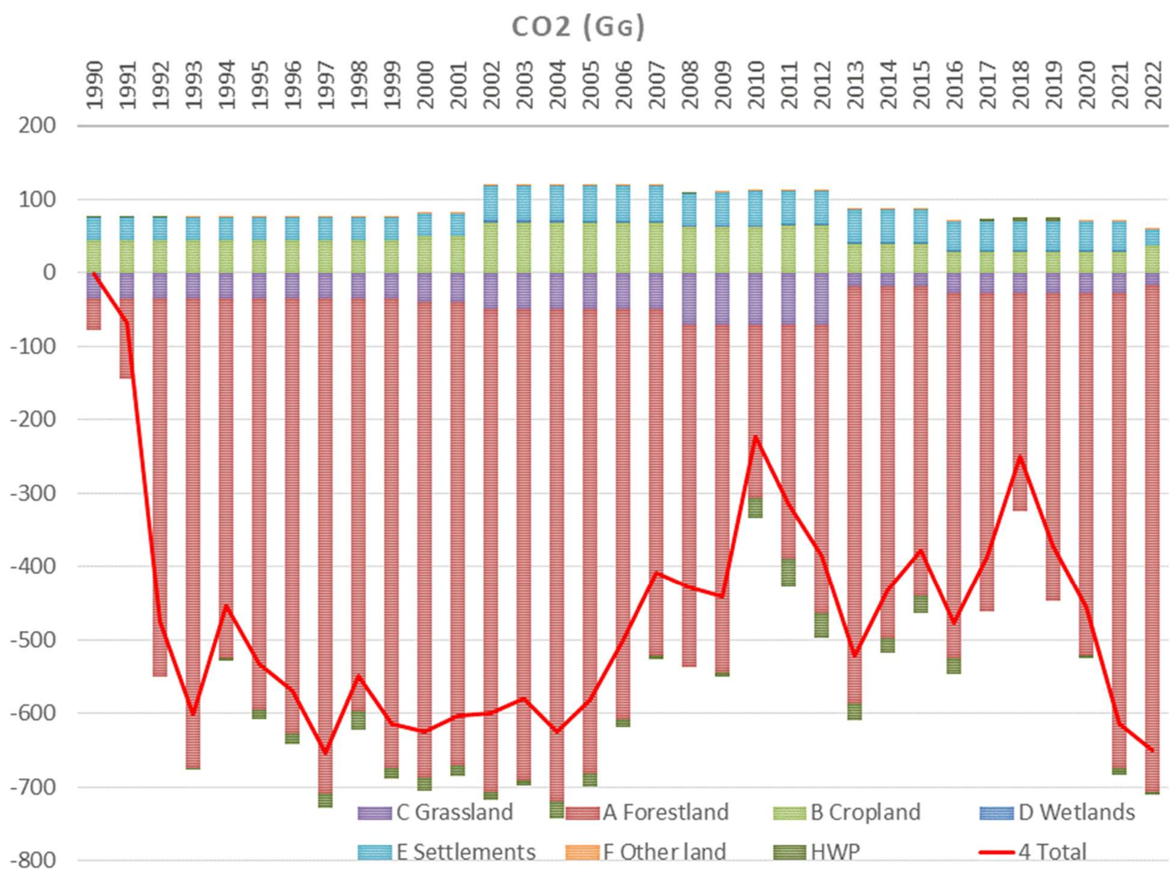
	4 - Land Use, Land Use Change & Forestry										
	Net CO_2 emissions/removals (Gg)								N_2O (Gg)		Total
Year	4 Total	A Forestland	B Cropland	C Grassland	D Wetlands	E Settlements	F Other land	HWP	N_2O	N_2O leaching	CO_2e (Gg)
1990	-1.16	- 42.65	44.77	- 34.81	0.15	29.22	0.05	2.11	0.0227	0.0156	8.98
1991	-69.07	- 110.43	44.77	- 34.79	0.15	29.22	0.05	1.97	0.0227	0.0156	-58.92
1992	-474.67	- 516.31	44.77	- 34.78	0.15	29.23	0.05	2.21	0.0227	0.0156	-464.53
1993	-601.37	- 640.36	44.78	- 34.76	0.15	29.24	0.05	-0.45	0.0227	0.0156	-591.23
1994	-453.59	- 490.82	44.78	- 34.75	0.15	29.24	0.05	-2.23	0.0227	0.0156	-443.44
1995	-532.79	- 559.84	44.78	- 34.74	0.15	29.25	0.05	-12.44	0.0227	0.0156	-522.65
1996	-568.52	- 592.57	44.79	- 34.72	0.15	29.25	0.05	-15.46	0.0227	0.0156	-558.38
1997	-654.46	- 674.70	44.79	- 34.71	0.15	29.26	0.05	-19.29	0.0227	0.0156	-644.32
1998	-548.58	- 562.86	44.79	- 34.69	0.15	29.26	0.05	-25.27	0.0227	0.0156	-538.44
1999	-614.89	- 639.30	44.79	- 34.68	0.15	29.27	0.05	-15.17	0.0227	0.0156	-604.75
2000	-624.91	- 647.52	49.66	- 40.07	0.91	30.50	0.02	-18.40	0.0227	0.0156	-614.76
2001	-603.52	- 630.47	49.45	- 40.06	0.91	30.56	0.02	-13.92	0.0227	0.0156	-593.38
2002	-599.05	- 657.89	68.02	- 49.30	2.91	47.37	0.01	-10.16	0.0363	0.0240	-583.05
2003	-579.32	- 642.09	67.80	- 49.29	2.91	47.43	0.01	-6.08	0.0363	0.0240	-563.32
2004	-625.46	- 671.01	67.59	- 49.29	2.91	47.49	0.01	-23.16	0.0363	0.0240	-609.47
2005	-581.97	- 632.84	67.37	- 49.28	2.91	47.55	0.01	-17.69	0.0363	0.0240	-565.98
2006	-500.98	- 558.54	67.16	- 49.27	2.91	47.61	0.01	-10.86	0.0363	0.0240	-484.99
2007	-408.72	- 472.13	66.95	- 49.26	2.91	47.67	0.01	-4.86	0.0363	0.0240	-392.73
2008	-428.45	- 465.27	61.75	- 71.73	2.23	43.87	0.28	0.42	0.0402	0.0268	-410.69
2009	-440.81	- 473.06	62.25	- 71.73	2.23	44.16	0.28	-4.94	0.0402	0.0268	-423.05
2010	-223.16	- 235.33	62.84	- 71.47	2.23	45.20	0.31	-26.95	0.0402	0.0268	-205.40
2011	-315.92	- 318.99	63.34	- 71.46	2.23	45.49	0.31	-36.85	0.0402	0.0268	-298.17
2012	-385.95	- 392.04	63.84	- 71.46	2.23	45.79	0.31	-34.62	0.0402	0.0268	-368.20
2013	-522.78	- 566.88	39.20	- 18.57	2.20	45.25	0.20	-24.16	0.0212	0.0126	-513.84
2014	-431.53	- 478.78	38.99	- 18.56	2.20	45.26	0.21	-20.84	0.0212	0.0126	-422.59
2015	-378.15	- 422.29	38.79	- 18.56	2.20	45.28	0.21	-23.78	0.0212	0.0126	-369.20
2016	-476.83	- 497.27	28.23	- 28.30	2.06	39.09	0.17	-20.81	0.0210	0.0111	-468.32
2017	-387.94	- 433.55	28.04	- 28.30	2.06	39.23	0.17	4.41	0.0210	0.0111	-379.43
2018	-249.66	- 297.07	27.85	- 28.30	2.06	39.38	0.17	6.26	0.0210	0.0111	-241.15
2019	-372.10	- 418.66	27.65	- 28.30	2.06	39.52	0.17	5.45	0.0210	0.0111	-363.59
2020	-456.15	- 492.48	27.68	- 28.30	2.06	39.61	0.17	-4.90	0.0210	0.0111	-447.65
2021	-613.85	- 646.09	27.70	- 28.29	2.06	39.70	0.17	-9.11	0.0210	0.0111	-605.35
2022	-651.01	- 689.19	36.70	- 17.64	0.21	22.60	0.17	-3.86	0.0075	0.0030	-648.21
Trend 1990-2022	55900.8%	1516.1%	-18.0%	-49.3%	43.4%	-22.6%	258.6%	-283.0%	-66.8%	-80.7%	-7317.9%
Trend 2021-2022	6.1%	6.7%	32.5%	-37.7%	-89.8%	-43.1%	0.1%	-57.6%	-64.1%	-73.0%	7.1%

6.1.1 Emission Trends

In 2022, removals from category forest land corresponded to -7.35% of total GHG in Luxembourg (incl. LULUCF). The net removals have increased from the base year to 2022, mainly due to the fact that in 1990 forestland was less of a carbon sink due to the heavy windfall during the winter 1990/1991, but also due to an increase of the carbon stock in forest land in the years after (Figure 6-1).

The net carbon stock changes in forest biomass (sector 4.A.1) have a major impact on the overall results in sector 4. These changes vary considerable between single years mainly due to fluctuating harvest rates. The harvest rates in their turn are influenced by timber demand and prices, insect infestation or wind throws.

Figure 6-1 - Emissions and Removals from CRF category 4 - LULUCF



6.1.2 Key categories

The methodology and results of the key category analysis are presented in Chapter 1. Table 6-2 presents the key categories of category *4 - LULUCF*.

Table 6-2 - Key categories of category 4 - LULUCF

4 - Land Use, Land-Use Change and Forestry						
Key sources						
IPCC Category	**Category Name**	**GHG**	**LA excl. LULUCF**	**LA incl. LULUCF**	**TA excl. LULUCF**	**TA incl. LULUCF**
4A1	Forest Land remaining Forest Land	CO_2	NA	92-22	NA	X
4B2	Land Converted to Crop Land	CO_2	NA	98, 02-03, 05-12	NA	
4C2	Land Converted to Grassland	CO_2, N_2O	NA	08-12	NA	

Source: Environment Agency
Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
TA = Trend Assessment 2022 (Tier 1) including respectively excluding LULUCF

6.1.3 Methodology

Luxembourg uses approach 3 for land representation (maps) and a tier 2 for reporting accuracy. Approach 3 for land representation is based on geographically explicit land use conversion data, detailed time series and country specific disagregated data based on inventories. The methodologies for estimating emissions from LUC from and to these land use categories are described in detail in the sub chapters 6.1 to 6.8. The following two chapters will focus on the methodology used for calculating the land use changes. The methodology was developed in the study "Support to LULUCF reporting in Luxembourg /Roll out of the LULUCF methodology for the Grand Duchy of Luxembourg" carried out by space4environment sàrl.

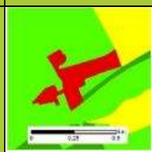
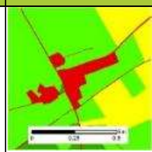
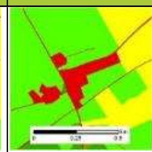
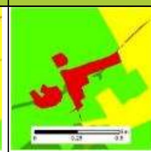
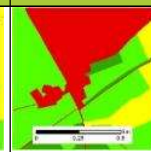
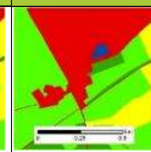
6.1.3.1 Activity data

Over the years, several LU / LC data sets have been produced for Luxembourg, including:

- Occupation Biophysique du Sol (OBS) maps of 1989, 1999 and 2007;
- LULUCF Rapid Eye map of 2012 (LULUCF 2012);
- Land Information System of Luxembourg (LIS-L) – separate Land Use & Land Cover Maps of 2007 and 2015;
- Land Cover map of 2018
- Land Use map of 2018.

The data sets were developed by different providers and using different nomenclatures, different minimum mapping units (MMU), different methods and have different thematic accuracies. Table 6-3 summarizes general information on the Land Use data existing for the country.

Table 6-3 Technical specifications of national Land Use data sets for Luxembourg.

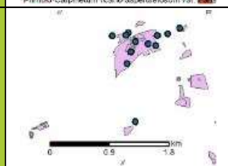
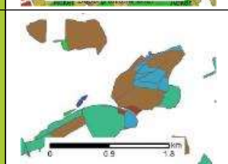
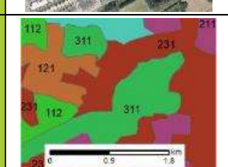
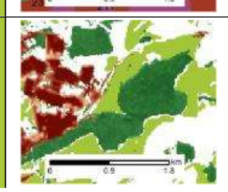
	OBS 1989	OBS 1999	OBS 2007	LU 2012	LIS-L 2015	LU 2018
Visual representation of LU classes						
Input data	In situ campaign, topographic maps	Aerial photographs 1999	Ikonos 2007, Aerial photographs 2007, topographic maps, OBS 1999, FLIK, Digital Height Model, National forest inventory	Rapid Eye 2012 Orthophotos 2007, 2010 (& 2013 if available)	Pleiades 2015, topographic maps, OBS07, FLIK	Orthophotos 2018, topographic maps, LIS-L 2015, FLIK, National forest inventory
Nomenclature / No. of classes	Mix of land cover and land use 181 classes	Mix of land cover and land use 76 classes	Mix of land cover and land use 76 classes	LULUCF categories 11 LU classes	Land use 53 classes	Land use 47 classes
Geodetic reference	LUREF	LUREF	LUREF	LUREF	LUREF	LUREF
Time reference	1989	1999	2007	2012	2015	2018
Target accuracy			Overall accuracy > 85%	Overall accuracy > 85%	Overall accuracy > 90%; Per class accuracy > 85%	Overall accuracy > 90%; Per class accuracy > 90%
Final accuracy of the product			Overall accuracy was estimated at 82.77% at level 4; 86.31% at level 3; 91.17% at level 2; 95.54% at level 1, with an absolute precision of +/- 3% at the 99% confidence level. User's accuracy: 81.76% Producer's accuracy: 85.82%	Overall accuracy was estimated at 98.01%. Producer's accuracy per class ranges between 95%-100% and the user's accuracy between 94%-100%.	Overall accuracy was estimated at 95%, with an absolute precision of +/- 2% at the 95% confidence level.	Overall accuracy was estimated at 96.5%, with an absolute precision of +/- 2% at the 95% confidence level.
Minimum mapping unit		2500m² for surface features 1500m² for objects of specific biologic interest	500m² for changes between 1999-2007 (sliver polygons or errors in 1999 were not removed / changed)	1500m² for changes between 2007-2012	100m² for settlements / standing water 500m² remaining classes	100m² for settlements / standing water 500m² remaining classes
Tree height		6m	6m			3m
Additional information			LU 2007 Change layer 1999-2007 available.	LU 2012 Change layer 2007-2012 available.	LU 2015 Change layer 2007-2015 and updated version of LU 2007 Separate land cover product available for the same year.	LU 2018 Change layer 2015-2018 and updated version of LU 2015 Separate land cover product available for the same year.

Ancillary data are useful when updating or deriving new LU maps, because not all information can be extracted directly from the orthophotomap. There are several additional sources in Luxembourg that can be used to generate high-quality LU maps. These sources are presented in Table 6-4 and listed below:

- National ancillary data:
  - Cartographie phytosociologique des végétations forestières (Phyto);
  - Biotopkataster of the open landscapes;
  - LPIS inventories for the period;
  - National Forest Inventory (NFI);
  - Topographic maps.
- International ancillary data:
  - Corine Land Cover (CLC);
  - Copernicus High Resolution Layers (HRL)149: Imperviousness, Water & Wetness, Forest and Grassland.

149 https://land.copernicus.eu/

Table 6-4 Technical specification of ancillary data.

Data	Visual representation of data	Type of data (raster/vector)	Geodetic reference	Time reference
Cartographie phytosociologique des végétations forestières		vector	LUREF	1994-2002
Biotopkataster of the open landscapes,		vector	LUREF	2014
LPIS inventories		vector	LUREF	2009-2019
National Forest Inventory (NFI)		vector	LUREF	2000, 2010
Topo Map		scanned map	GCS WGS 1984, D WGS 1984	1989 (1:20.000) 1993 (1:50.000) 2000 (1:20.000)
Aerial photographs		GeoTiff /JPG	LUREF	1987 (not georeferenced) 2001, 2004, 2007, 2010, 2013, 2016, 2017, 2018, 2019
Corine Land Cover (CLC)		vector	-	1990, 2000, 2006, 2012, 2018
EC Copernicus HRL 2012 and 2015, including Imperviousness, Water, Forest and Grassland		raster (20×20m) raster (10 x 10m) from 2018	-	2012, 2015, 2018 in production

6.1.3.2 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories (*e.g.* land use and land-use change matrix)

The land use classification system used is in accordance with the 2006 IPCC Good Practice Guidance on LULUCF. The categories are defined as presented in Table 6-5

Table 6-5 Definition of land use categories

Land Use Class	Definition
Forest Land	All forest and wooded land with: • Minimum land area: 0.1 ha (1990-2011) and 0.05ha (2012-today) • tree crown cover >= 10 % • tree height >= 6 m at maturity (1990-2011) and >=3m actual height measured by LIDAR data (2012-today).
Annual Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a yearly changed rhythm including artificial meadows (not permanent) including land temporarily set aside
Permanent Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a permanent manner, *i.e.* not changing in a yearly rhythm
Grassland	All grassland that is not considered as cropland including systems with vegetation or tree cover below the density used in the forest category. This includes all grassland from wild lands, recreational areas as well as agricultural systems. (IPCC GPG definition).
Settlements	All developed land, including transportation and any size of human settlement unless already included under other categories.(IPCC GPG definition)
Wetland	Land that is covered or saturated by water for all or part of the year (*e.g.* peat land) and that does not fall into other categories.
Water	Land that is covered by water for all the year and that does not fall into other categories. This includes reservoirs. (IPCC GPG definition)
Other land	This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

The extraction and verification of permanent changes across different years is difficult based on the comparison of original LU data sets for 1989, 1999, 2007, 2012, 2015, and 2018, as these have different nomenclatures. Therefore, it is necessary to perform a reclassification to a common LULUCF nomenclature to enable a proper comparison.

6.1.3.3 Methodology used to develop the land transition matrix

One shortcoming of establishing a consistent time series of land use change statistics is that – despite all geometric and thematic improvements described in the previous sections – already small deviations on object delineation (i.e. sliver polygons) can cause false changes and thus erroneous change statistics.

An option to address this issue is to use a point-based sampling approach instead of a polygon-based approach to compare the LU change between data sets. The point-based approach allows to generate an evenly spaced point grid that is used to check whether the LU class has changed. This reduces the probability of inclusion of LU change errors that would be kept by considering the datasets in polygon format. Since the grid with a 50m spatial resolution already captures around 95% of the at national level, the improvements achieved with grids of higher resolution do not justify the increase storage space and processing time. Therefore, it was decided to adopt the 50m grid for the final database.

The 50m grid database was filled by allocating the LULUCF category from the respective LULUCF yearly data sets to the grid sample point. The category found at the location of the grid point was taken.

6.1.3.4 Surface statistics according to LULUCF categories

The territory of Luxembourg has an area of 2 586 km^2. In 1990, 90.2% of that area was covered by agriculturally used areas and forests, 9.1% were covered by urban areas and road network. The remaining areas were covered by water and other land (0.6%). In 2021, the respective areas were 87.7%, 11.8% and 0.5%. Thus, Luxembourg has some 93 093 ha of forests, some 133 727 ha of agriculturally used land, and some 30 411 ha covered by buildings and roads. Rivers, lakes, wetlands and other lands cover a surface of some 1 370 ha.

Table 6-6: Land use changes between 1989 and 1999

		1999 (to)								
		SL	ACL	PCL	GL	FL	OL	WL	WT	Totals 1989
1989 (from)	SL	22,958.50	16.25	2.25	256.75	104.00	0.75		0.25	23,338.75
	ACL	901.50	46,309.00	148.25	8,458.25	115.75		1.50	0.25	55,934.50
	PCL	314.25	120.75	3,454.25	1,348.00	103.50				5,340.75
	GL	1,881.50	7,152.50	465.75	69,577.25	238.00		1.00		79,316.00
	FL	164.00	65.25	17.00	415.75	92,355.25	0.50		1.00	93,018.75
	OL	25.50		0.75	6.75	252.25	25.50			310.75
	WL	22.25	1.25		23.75	9.00		219.75		276.00
	WT	1.25	1.25		5.25	1.00		0.50	1,054.00	1,063.25
	Totals 1999	26,268.75	53,666.25	4,088.25	80,091.75	93,178.75	26.75	222.75	1,055.50	258,598.75

Annual rate of change: 2,264 ha

Table 6-7: Land use changes between 1999 and 2007

		2007 (to)								
		SL	ACL	PCL	GL	FL	OL	WL	WT	Totals 1999
1999 (from)	SL	25,568.25	53.00	57.50	502.25	72.75			15.00	26,268.75
	ACL	371.25	51,790.75	83.75	1,344.50	62.00			14.00	53,666.25
	PCL	131.50	34.75	3,725.50	173.50	22.00			1.00	4,088.25
	GL	1,631.25	6,099.25	347.00	71,500.75	446.25			67.25	80,091.75
	FL	162.25	55.50	22.00	193.75	92,736.50		2.25	6.50	93,178.75
	OL	0.50			0.75	1.50	24.00			26.75
	WL	1.50	0.50		8.50	1.00		210.75	0.50	222.75
	WT	13.25	0.25	0.25	18.00	3.75			1,020.00	1,055.50
	Totals 2007	27,879.75	58,034.00	4,236.00	73,742.00	93,345.75	24.00	213.00	1,124.25	258,598.75

Annual rate of change: 1,503 ha

Table 6-8: Land use changes between 2007 and 2012

		2012 (to)								
		SL	**ACL**	**PCL**	**GL**	**FL**	**OL**	**WL**	**WT**	**Totals 2007**
2007 (from)	**SL**	27,869.00	2.75		4.75	3.00			0.25	27,879.75
	ACL	106.25	55,618.25		2,309.00	0.50				58,034.00
	PCL	19.50	49.75	2,583.25	1,578.25	5.25				4,236.00
	GL	322.50	3,053.00	0.25	70,310.50	52.00			3.75	73,742.00
	FL	56.75	4.00	2.75	19.75	93,260.00	2.25		0.25	93,345.75
	OL						24.00			24.00
	WL							213.00		213.00
	WT	0.25							1,124.00	1,124.25
	Totals 2012	28,374.25	58,727.75	2,586.25	74,222.25	93,320.75	26.25	213.00	1,128.25	258,598.75

Annual rate of change: 1,519 ha

Table 6-9: Land use changes between 2012 and 2015

		2015 (to)								
		SL	**ACL**	**PCL**	**GL**	**FL**	**OL**	**WL**	**WT**	**Totals 2012**
2012 (from)	**SL**	28,246.25	17.25	0.75	104.50	4.75	0.50		0.25	28,374.25
	ACL	247.75	56,779.25	19.50	1,679.75	1.25	0.25			58,727.75
	PCL	40.75	7.75	2,498.50	37.00	2.25				2,586.25
	GL	592.00	1,498.50	101.00	71,972.75	56.50	1.25		0.25	74,222.25
	FL	94.75	27.75	2.50	60.25	93,134.50	0.75		0.25	93,320.75
	OL	1.00	1.00		0.50	0.50	23.25			26.25
	WL							213.00		213.00
	WT				2.25				1,126.00	1,128.25
	Totals 2015	29,222.50	58,331.50	2,622.25	73,857.00	93,199.75	26.00	213.00	1,126.75	258,598.75

Annual rate of change: 1,535 ha

Table 6-10: Land use changes between 2015 and 2018

		2018 (to)								
		SL	**ACL**	**PCL**	**GL**	**FL**	**OL**	**WL**	**WT**	**Totals 2015**
2015 (from)	**SL**	29,153.50	2.75	2.25	58.00	2.25			3.75	29,222.50
	ACL	208.00	55,828.50	9.50	2,285.25	0.25				58,331.50
	PCL	8.75	11.00	2,561.25	41.25					2,622.25
	GL	398.50	1,283.00	56.25	72,112.25	6.50		0.25	0.25	73,857.00
	FL	45.00	4.50		13.00	93,136.50	0.75			93,199.75
	OL	1.75				0.75	23.50			26.00
	WL							213.00		213.00
	WT	1.25							1,125.50	1,126.75
	Totals 2018	29,816.75	57,129.75	2,629.25	74,509.75	93,146.25	24.25	213.25	1,129.50	258,598.75

Annual rate of change: 1,481 ha

Table 6-11 – Land Cover surfaces (ha) according to LULUCF categories

4 - Land Use, Land Use Change & Forestry							
Land cover surfaces (kha)							
Year	**A Forestland**	**B Cropland**	**C Grassland**	**D Wetlands**	**E Settlements**	**F Other land**	**Note**
1971	*92.731*	*67.613*	*77.920*	*1.449*	*18.065*	*0.823*	*linear interpolation (from land use changes measured between 89 and 99*
1972	*92.747*	*67.261*	*77.997*	*1.443*	*18.358*	*0.795*	
1973	*92.763*	*66.908*	*78.075*	*1.437*	*18.651*	*0.766*	
1974	*92.779*	*66.556*	*78.152*	*1.431*	*18.944*	*0.738*	
1975	*92.795*	*66.204*	*78.230*	*1.425*	*19.237*	*0.710*	
1976	*92.811*	*65.852*	*78.308*	*1.419*	*19.530*	*0.681*	
1977	*92.827*	*65.500*	*78.385*	*1.412*	*19.823*	*0.653*	
1978	*92.843*	*65.148*	*78.463*	*1.406*	*20.116*	*0.624*	
1979	*92.859*	*64.796*	*78.540*	*1.400*	*20.409*	*0.596*	
1980	*92.875*	*64.444*	*78.618*	*1.394*	*20.702*	*0.568*	
1981	*92.891*	*64.092*	*78.695*	*1.388*	*20.995*	*0.539*	
1982	*92.907*	*63.740*	*78.773*	*1.382*	*21.288*	*0.511*	
1983	*92.923*	*63.388*	*78.851*	*1.376*	*21.581*	*0.482*	
1984	*92.939*	*63.036*	*78.928*	*1.370*	*21.874*	*0.454*	
1985	*92.955*	*62.684*	*79.006*	*1.364*	*22.167*	*0.426*	
1986	*92.971*	*62.331*	*79.083*	*1.358*	*22.460*	*0.397*	
1987	*92.987*	*61.979*	*79.161*	*1.351*	*22.753*	*0.369*	
1988	*93.003*	*61.627*	*79.238*	*1.345*	*23.046*	*0.340*	
1989	*93.019*	*61.275*	*79.316*	*1.339*	*23.339*	*0.312*	*OBS89*
1990	*93.035*	*60.923*	*79.394*	*1.333*	*23.632*	*0.284*	*linear interpolation*
1991	*93.051*	*60.571*	*79.471*	*1.327*	*23.925*	*0.255*	
1992	*93.067*	*60.219*	*79.549*	*1.321*	*24.218*	*0.227*	
1993	*93.083*	*59.867*	*79.626*	*1.315*	*24.511*	*0.198*	
1994	*93.099*	*59.515*	*79.704*	*1.309*	*24.804*	*0.170*	
1995	*93.115*	*59.163*	*79.781*	*1.303*	*25.097*	*0.142*	
1996	*93.131*	*58.811*	*79.859*	*1.297*	*25.390*	*0.113*	
1997	*93.147*	*58.459*	*79.937*	*1.290*	*25.683*	*0.085*	
1998	*93.163*	*58.107*	*80.014*	*1.284*	*25.976*	*0.056*	
1999	*93.179*	*57.755*	*80.092*	*1.278*	*26.269*	*0.028*	*OBS99*
2000	*93.200*	*58.319*	*79.298*	*1.286*	*26.470*	*0.028*	*linear interpolation*
2001	*93.221*	*58.883*	*78.504*	*1.293*	*26.672*	*0.027*	
2002	*93.241*	*59.448*	*77.711*	*1.300*	*26.873*	*0.027*	
2003	*93.262*	*60.012*	*76.917*	*1.308*	*27.074*	*0.027*	
2004	*93.283*	*60.577*	*76.123*	*1.315*	*27.276*	*0.026*	
2005	*93.304*	*61.141*	*75.329*	*1.323*	*27.477*	*0.026*	
2006	*93.325*	*61.706*	*74.536*	*1.330*	*27.678*	*0.026*	
2007	*93.346*	*62.270*	*73.742*	*1.337*	*27.880*	*0.025*	*OBS07*
2008	*93.341*	*62.079*	*73.838*	*1.338*	*27.979*	*0.026*	*linear interpolation*
2009	*93.336*	*61.888*	*73.934*	*1.339*	*28.078*	*0.026*	
2010	*93.331*	*61.696*	*74.030*	*1.340*	*28.176*	*0.027*	
2011	*93.326*	*61.505*	*74.126*	*1.340*	*28.275*	*0.027*	
2012	*93.321*	*61.314*	*74.222*	*1.341*	*28.374*	*0.028*	*LU12*
2013	*93.280*	*61.194*	*74.101*	*1.341*	*28.657*	*0.027*	*linear interpolation*
2014	*93.240*	*61.074*	*73.979*	*1.340*	*28.940*	*0.027*	
2015	*93.200*	*60.954*	*73.857*	*1.340*	*29.223*	*0.027*	*LIS-L_2015*
2016	*93.182*	*60.556*	*74.075*	*1.341*	*29.421*	*0.027*	*linear interpolation*
2017	*93.164*	*60.157*	*74.292*	*1.342*	*29.619*	*0.026*	
2018	*93.146*	*59.759*	*74.510*	*1.343*	*29.817*	*0.026*	*LIS-L_2018*
2019	*93.128*	*59.361*	*74.727*	*1.344*	*30.015*	*0.025*	*linear extrapolation*
2020	*93.111*	*58.963*	*74.945*	*1.345*	*30.213*	*0.024*	
2021	*93.093*	*58.564*	*75.163*	*1.346*	*30.411*	*0.024*	
2022	*93.075*	*58.166*	*75.380*	*1.347*	*30.609*	*0.023*	
Trend 1990-2022	*0.04%*	*-4.53%*	*-5.06%*	*1.02%*	*29.53%*	*-91.83%*	*NA*
Trend 2013-2022	*-0.22%*	*-4.95%*	*1.73%*	*0.45%*	*6.81%*	*-15.50%*	*NA*
Trend 2007-2022	*-0.29%*	*-6.59%*	*2.22%*	*0.71%*	*9.79%*	*-8.25%*	*NA*
Share in 1990	*35.98%*	*23.56%*	*30.70%*	*0.52%*	*9.14%*	*0.11%*	*NA*
Share in 2022	*35.99%*	*22.49%*	*29.15%*	*0.52%*	*11.84%*	*0.01%*	*NA*

Table 6-11 represents the land cover surfaces in ha for the different LULUCF categories, for the period from 1971 to 2022.

The LU maps (based on OBS89, OBS99, OBS07, LU12, LISL-2015 and LISIL-2018) are highlighted in grey. The years in between have been estimated by linear interpolation.

6.1.4 Completeness

Table 6-12 provides an overview of the IPCC categories included under CRF Sector 4 and provides information on the status of emission estimates of all subcategories.

Table 6-12 – Status of emission estimates for category 4 – LULUCF

GHG source & sink category	Description	Status		
		Net CO_2	CH_4	N_2O
4A1	forest land remaining forest land	X	NO	NO
4A2	land converted to forest land	X	NO	NO
4B1	cropland remaining cropland	X	NO	IE*,X
4B2	land converted to cropland	X	NO	X
4C1	grassland remaining grassland	IE**, NA	NO	NO
4C2	land converted to grassland	X	NO	X
4D1	wetlands remaining wetlands	NA	NO	NA
4D2	land converted to wetlands	X	NO	X
4E1	settlements remaining settlements	NA	NE	NA
4E2	land converted to settlements	X	NE	X
4F1	other land remaining other land			
4F2	land converted to other land	X	NO	X
4G	Other (Harvested wood products)	X	NO	NO

Note: a X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

(*) CO_2 emissions from cropland remaining cropland due to land use change from perennial to annual cropland are included in agriculture

(**) CO_2 emissions from lime application on grassland are included in agriculture.

6.2 Forest Land (4A)

Luxembourg has some 93 075 ha of forests, covering about 36% of the country's area. The population is well situated with an average forest area of approximately 0.15 ha per person.

6.2.1 Category description

With regard to forest land, the annual net CO_2 emissions/removals of the reported period 1990-2022 range from -42.65 Gg CO_2 to -689.19 Gg CO_2 (removal). The most important sub-category is forest land remaining forest land (4.A.1), whereas land use changes to forests (4.A.2) and from forests (4.B.2 to 4.F.2) have only minor influence on the net CO_2 balance.

For the reported period 1990 to 2022, the total annual net CO_2 removals (biomass and soil) from land use changes to forest range from about -34.65 Gg CO_2 to -8.91 Gg CO_2 (Table 6-13).

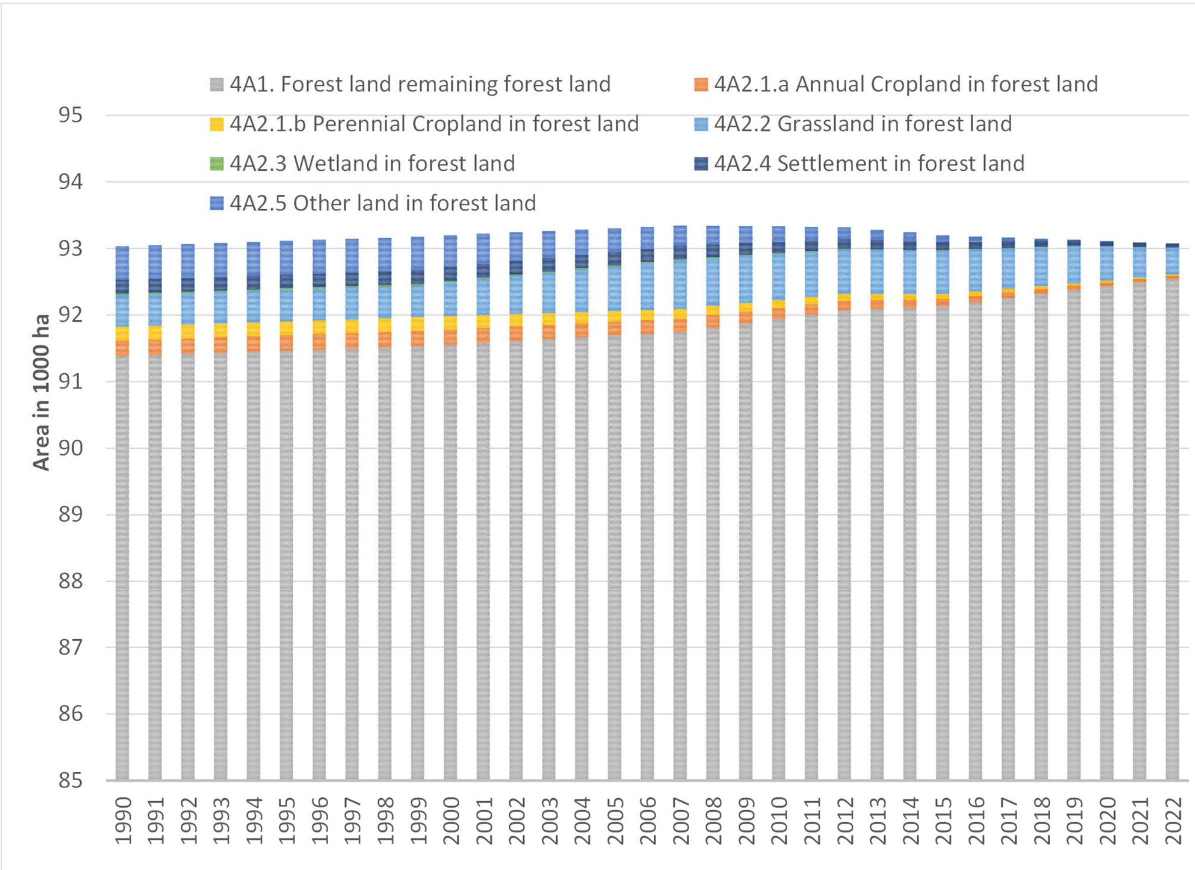
Table 6-13 – CO_2 removals/emissions from category 4A – Forest Land

4A - Forestland									
Net CO_2 emissions/removals (kt)									N_2O (kt)
Year	4A Total Forest Land	4A1 FL - FL	4A2 Land -> FL	4A2.1 CL-FL	4A2.2 GL-FL	4A2.3 WL-FL	4A2.4 SL-FL	4A2.4 OL-FL	N_2O
1990	- 42.65	- 10.10	- 32.55	- 7.62	- 7.47	- 0.51	-3.95	-12.99	NO
1991	- 110.43	- 77.86	- 32.57	- 7.63	- 7.47	- 0.51	-3.96	-13.00	NO
1992	- 516.31	- 483.70	- 32.60	- 7.64	- 7.48	- 0.51	-3.96	-13.01	NO
1993	- 640.36	- 607.73	- 32.63	- 7.64	- 7.49	- 0.51	-3.96	-13.02	NO
1994	- 490.82	- 458.16	- 32.66	- 7.65	- 7.50	- 0.51	-3.97	-13.03	NO
1995	- 559.84	- 527.15	- 32.68	- 7.66	- 7.51	- 0.51	-3.97	-13.04	NO
1996	- 592.57	- 559.85	- 32.71	- 7.67	- 7.51	- 0.51	-3.97	-13.04	NO
1997	- 674.70	- 641.96	- 32.74	- 7.67	- 7.52	- 0.52	-3.98	-13.05	NO
1998	- 562.86	- 530.09	- 32.77	- 7.68	- 7.53	- 0.52	-3.98	-13.06	NO
1999	- 639.30	- 606.50	- 32.80	- 7.69	- 7.54	- 0.52	-3.98	-13.07	NO
2000	- 647.52	- 615.20	- 32.32	- 7.81	- 7.31	- 0.51	-4.00	-12.68	NO
2001	- 630.47	- 598.22	- 32.25	- 7.64	- 7.82	- 0.50	-3.99	-12.29	NO
2002	- 657.89	- 623.35	- 34.54	- 7.91	- 9.56	- 0.51	-4.66	-11.90	NO
2003	- 642.09	- 607.62	- 34.46	- 7.73	- 10.08	- 0.50	-4.64	-11.51	NO
2004	- 671.01	- 636.62	- 34.39	- 7.56	- 10.60	- 0.50	-4.62	-11.12	NO
2005	- 632.84	- 598.52	- 34.32	- 7.38	- 11.12	- 0.49	-4.60	-10.73	NO
2006	- 558.54	- 524.29	- 34.25	- 7.21	- 11.64	- 0.48	-4.59	-10.34	NO
2007	- 472.13	- 437.96	- 34.18	- 7.03	- 12.16	- 0.48	-4.57	-9.94	NO
2008	- 465.27	- 430.62	- 34.65	- 6.89	- 13.11	- 0.46	-4.66	-9.54	NO
2009	- 473.06	- 439.51	- 33.56	- 6.57	- 12.91	- 0.44	-4.50	-9.14	NO
2010	- 235.33	- 202.88	- 32.46	- 6.24	- 12.70	- 0.42	-4.35	-8.74	NO
2011	- 318.99	- 287.63	- 31.36	- 5.91	- 12.50	- 0.41	-4.20	-8.34	NO
2012	- 392.04	- 361.78	- 30.26	- 5.58	- 12.30	- 0.39	-4.04	-7.94	NO
2013	- 566.88	- 545.63	- 21.26	- 4.05	- 11.61	- 0.19	-2.91	-2.49	NO
2014	- 478.78	- 458.48	- 20.31	- 3.72	- 11.54	- 0.18	-2.78	-2.09	NO
2015	- 422.29	- 402.94	- 19.35	- 3.39	- 11.48	- 0.16	-2.64	-1.69	NO
2016	- 497.27	- 478.70	- 18.57	- 3.07	- 11.55	- 0.15	-2.52	-1.29	NO
2017	- 433.55	- 416.24	- 17.31	- 2.72	- 11.21	- 0.13	-2.36	-0.89	NO
2018	- 297.07	- 281.02	- 16.05	- 2.37	- 10.87	- 0.11	-2.21	-0.48	NO
2019	- 418.66	- 403.87	- 14.79	- 2.02	- 10.53	- 0.10	-2.06	-0.08	NO
2020	- 492.48	- 478.86	- 13.62	- 1.85	- 9.68	- 0.09	-1.92	-0.08	NO
2021	- 646.09	- 633.64	- 12.45	- 1.69	- 8.82	- 0.08	-1.79	-0.08	NO
2022	- 689.19	- 680.28	- 8.91	- 1.05	- 6.76	- 0.05	-1.00	-0.06	NO
Trend 1990-2022	1516.07%	6635.89%	-72.63%	-86.28%	-9.46%	-90.60%	-74.73%	-99.57%	NA
Trend 2021-2022	6.67%	7.36%	-28.46%	-37.99%	-23.32%	-39.09%	-44.19%	-31.32%	NA

The net carbon stock changes in forest biomass (sub-category 4.A.1) have a major impact on the overall results in sector 4. These changes vary considerable between single years. The reason is that the figures for annual harvest of forest biomass and to a lesser extend forest area differ significantly year by year. The annual harvest will be analysed in chapter 6.2.4.1.1 (page 523) is influenced by timber demand and prices as well as salvage logging after windfalls. The influence of those factors on the annual variations in the CO_2 net removals of this sector will be explained in the same chapter.

The variation within the time trend for LUCs to forest land is mainly due to the change of LUC areas and its composition of previous land use types across the time series. Figure 6-2 gives an overview of the LUCs to and from forests from 1970 and 1990 on, respectively. LUC areas are in the LUC subcategory for a transition period of 20 years starting 20 years before 1990.

Figure 6-2 – Trend of forest land and LUC to forest land (20 year conversion period)



6.2.2 Information on approaches used for representing land areas and on land-use databases used for the inventory approach

In Luxembourg statistical data about forests are established and updated by the Nature and Forest Administration (Administration de la Nature et des Forêts (ANF)) of the Ministry for the Environment, Climate and Biodiversity. The forest inventory is partly based on aerial photography and partially based on territorial measurements (field-work).

The forest area comprises all territories as described in Table 6-14 and in accordance to the definition provided by FAO 2000.

Table 6-14 - Definition of forest as applied during forest inventory

Total forest area	Forest	Land with tree crown cover (or equivalent stocking level) of more than 10 % and area of more than 0.50 ha. The trees should be able to reach a minimum height of 5 m at maturity in situ. Young natural stands and all plantations established (0.1 – 0.5 ha) for

	forestry purposes which have yet to reach a crown density of 10 % or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest.
Grove	Group or cluster of trees with an area of 0.05 – 0.50 ha with a crown density of 10 % and where tree height potentially reached 5 m at adult stage.
Other wooded land	Land either with a crown cover (or equivalent stocking level) of 5-10 percent of trees able to reach a height of 5 m at maturity in situ; or a crown cover (or equivalent stocking level) of more than 10 percent of trees not able to reach a height of 5 m at maturity in situ (e.g. dwarf or stunted trees); or with shrub or bush cover of more than 10 percent.
Other land in forest areas	Area without tree cover which are enclosed, partially enclosed, or even attached to one side to a forest area and which have a surface area > 0.5 ha (pond, clearing, fallow land…)

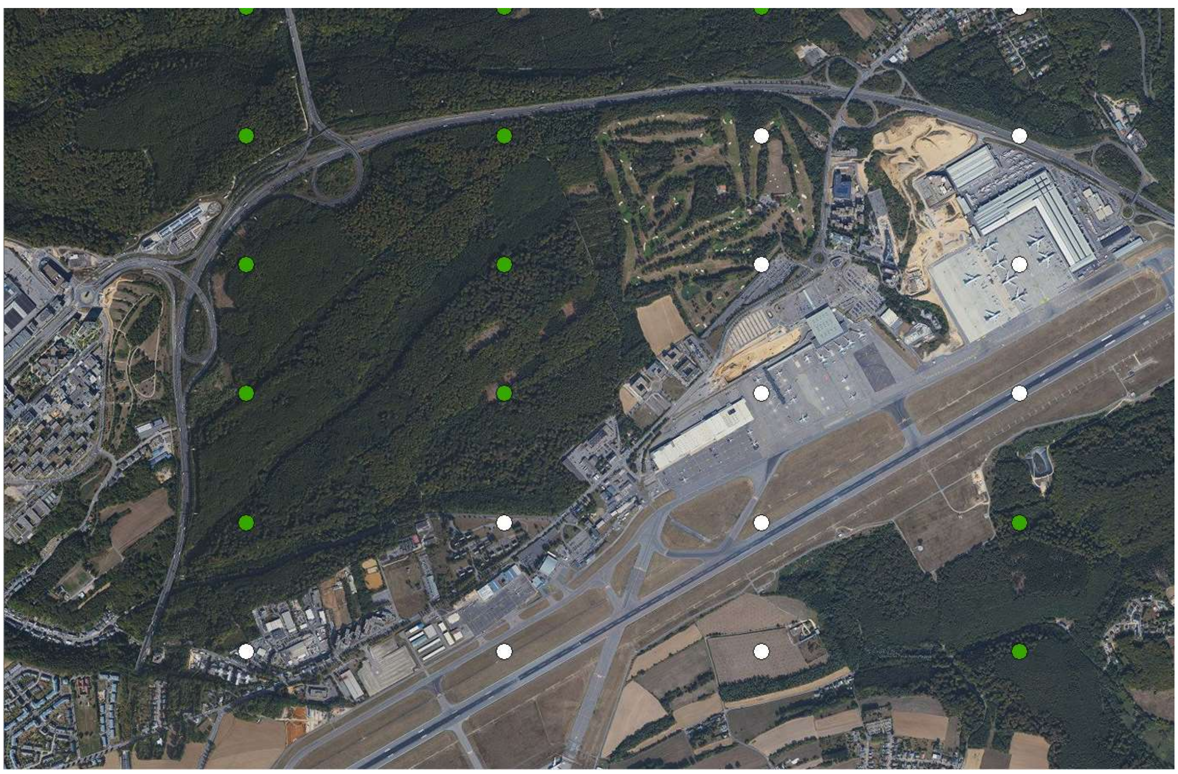
The total forest area estimated during the second forest inventory (NFI 2 2010) for the year 2010 is 92 150 ha and is subdivided in the following types of forests:

1) hardwood forests: 58 050 ha: 63 %
2) coniferous forest (spruce, pin, douglas *etc.*) 27 250 ha: 30 %

other forested (shrubs, forest roads, quarries, clear cuttings, *etc.*) 6 850 ha: 7 %

In 2010, the forest area calculated according to the LUC method (Table 6-11) was estimated at 93.331 ha. The difference with the forest area estimated by the NFI can be explained by the difference in the grid size used.

Figure 6-3 – Example of calculation method of forest area according to forest inventory



The forest inventory is a periodic survey of permanent forest sample plots based on a randomised systematic grid sample design. Each grid has a dimension of 1 000 m * 500 m and this grid density equates to 5 200 points nationally, each representing 50 ha. If a point on the grid is considered as being a forest (use of aerial photography) the equivalent of 50 ha are added to the forest area. In the image shown here above the forest area is estimated at 400 ha (8 points).

Figure 6-4 – Calculation method of forest area according to LUC method

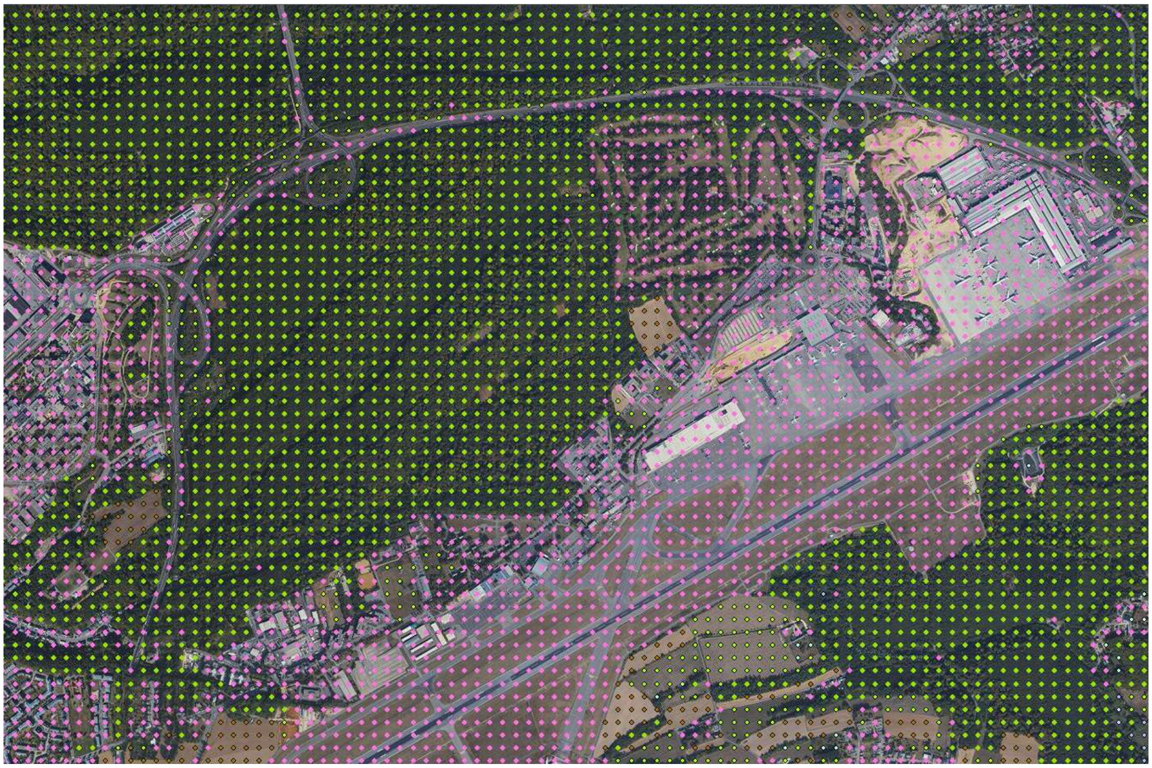


Figure 6-4 shows the same portion of land as Figure 6-3 but with the LUC method grid (50m * 50m) applied and based on land use, land cover data. The increased level of detail of the 50m grid database can be appreciated by comparing both figures.

Data on distribution of deciduous and coniferous forests is taken from the NFI. That means that total forest areas from 50m grid datatbase have been aggregated and redistributed to coniferous forests and deciduous forest according to the percentages of those types of forests from the NFI. Land use changes from and to, either coniferous, deciduous and mixed forests cannot not easily be identified and hence the assumption is taken that land use changes to and from the different forest types are randomly distributed and reflect the species distribution of the NFI. As a result data on tree species distribution is not spatially explicit.

6.2.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The 50m grid database is the main data providers for the greenhouse gas reporting of IPCC category forestland. The National Forest Inventory (NFI) of Luxembourg is the main data provider for the development of carbon stock factors. Consequently and for reason of consistency, the applied forest definition for the reporting follows the definition used within the NFI and the land use maps used to populate the gird database. The selected parameters are:

Land Use Class	Definition
ForestLand	All forest and wooded land with: • Minimum land area: 0.1 ha (1990-2011) and 0.05ha (2012-today) • tree crown cover >= 10 % • tree height >= 6 m at maturity (1990-2011) and >=3m actual height measured by LIDAR data (2012-today).
Conifers:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of coniferous species.
Deciduous:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of broadleaved species
Mixed (coniferous and deciduous):	with > 10 % crown cover and less than 75 % crown cover of one class.

Permanently unstocked basal areas that are directly connected with forest in terms of space and forestry enterprise and contribute directly to its management (such as forest hauling systems, wood storage places, forest glades, forest roads) also represent forests. Areas which are used in short rotation with a rotation period of up to thirty years as well as forest arboretums, forest seed orchards, Christmas tree plantations and plantations of woody plants for the purpose of obtaining fruits such as walnut or sweet chestnut do not account as forests but represent cropland. Rows of trees (except shelter belts for wind protection) and areas with woody plants in a park structure are not forest land.

6.2.4 Methodological issues

6.2.4.1 Forest Land remaining Forest Land (4A1)

6.2.4.1.1 Change of carbon stock in living biomass

For the changes in living biomass, the IPCC Guidelines 2006 Tier 2 approach (biomass gain-loss method) was used with country-specific estimated activity data and emission/removal factors extracted from the national forest inventory.

The calculation of gains in living biomass is mainly based on the results from the two forest inventories carried out in 2000 as well as in 2010. The data extracted from the combination of those two inventories allowed defining country specific values for above- and below-ground biomass growth, wood removal, dead wood as well as country-specific biomass conversion and expansion factors.

The methodology employed to estimate those country-specific values is described by (Alderweireld, 2015). The calculation of biomass volume stock is based on new research (compared to the calculation method described in the official forest inventory publication) and hence the method will be briefly described here below:

The merchantable volume of wood (for standing trees as well as for dead wood) is estimated with the equations of (Dagnelies, Palm, & Rondeux, 2013) which have been defined for 12 tree species. Those equations give the volume of wood from the main trunk and main branches up to a diameter of 7 cm.

The above-ground biomass is calculated with the following formula:

$$G_{W(ag)} = V \cdot BEF_{ag} \cdot WBD$$

where :

$G_{W(ag)}$= average above-ground biomass (excluding leaves) for a specific woody vegetation type (tonnes d.m. ha^{-1})

V = volume of merchantable wood calculated according to (Dagnelies, Palm, & Rondeux, 2013) (m^3 ha^{-1})

BEF_{ag} = biomass expansion factor for above-ground biomass (Deleuze, et al., 2014)

WBD = wood biomass density (tonnes d.m./m^3) (Wagenführ & Schreiber, 1985)

The BEF values were calculated from the work of (Deleuze, et al., 2014), which provides a formula to calculate total above ground biomass depending on height and diameter. The work of (Deleuze, et al., 2014) is based on the work of (Vallet, Dhôte, Le Moguédec, Ravart, & Pignard, 2006).

The volume is calculated with the following formula (Dagnelies, Palm, & Rondeux, 2013) (m^3 ha^{-1}):

$$V = 0.496 \frac{(h_{tot} \cdot c_{130})^2}{4\pi \left(1 - \frac{1.3}{h_{tot}}\right)}$$

where :

V = volume of merchantable wood calculated

h_{tot}= tree height

c_{130} = tree circumference at 130 cm height

The below-ground biomass is calculated with the following formula:

$$G_{W(bg)} = V \cdot BEF_{bg} \cdot WBD$$

where :

$G_{W(bg)}$= average below-ground biomass (excluding leaves) for a specific woody vegetation type (tonnes d.m. ha^{-1})

V = volume of merchantable wood calculated according to (Dagnelies, Palm, & Rondeux, 2013) (m^3 ha^{-1})

BEF_{bg} = biomass expansion factor for below-ground biomass (Vande Walle, et al., 2005)

WBD = wood biomass density (tonnes d.m./m^3) (Wagenführ & Schreiber, 1985)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

With:

$$BEF_{bg} = BEF_{ag} \cdot R$$

where :

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. (Vande Walle, et al., 2005)

BEF_{ag} = biomass expansion factor for above-ground biomass

The IPCC 2006 guidelines only use a biomass expansion factor and a below-ground to above-ground ratio. The study referenced here above introduces a new variable in order to determine below-ground biomass directly from volume of merchantable wood. Essentially the calculations are the same as the one under the IPCC guidelines 2006 but are more suitable to the methods employed by the NFI.

In order to estimate the gain in biomass due to biomass growth for *5A1 - Forest Land Remaining Forest Land*, country specific biomass increment factors have been generated by comparing the biomass increase between the two inventories on the same trees. This methodology has also allowed calculating growth factors for different age categories as can be seen on Figure 6-5. The age categories between 80 and 160 years (mainly for coniferous forests) are however not based on enough samples so that they cannot be seen as statistically reliable. The same applies to the age category 61-80 for deciduous trees which are also underrepresented.

The carbon content used in the calculations is the default value: 0,47 CF = carbon fraction of dry matter, tonnes C (tonne d. m.)$^{-1}$.

Figure 6-5 – Country-specific biomass growth by forest type and by age (source: NFI)

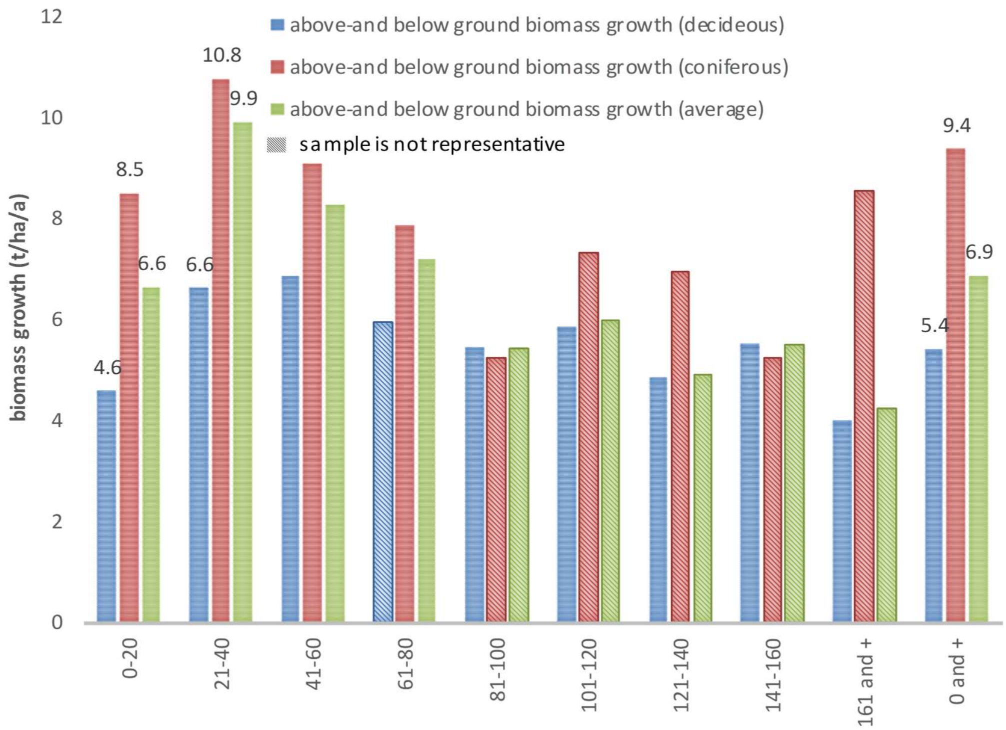


Table 6-15 – Country-specific values for above- and below ground biomass increment factors (tonnes d.m. ha^{-1} yr^{-1})

		above-ground biomass growth	below-ground biomass growth
deciduous	all ages	4.4	1.0
	age 0-20	3.8	0.8
	age 21-40	5.4	1.2
coniferous	all ages	7.8	1.5
	age 0-20	7.1	1.4
	age 21-40	9.0	1.8
average	all ages	5.7	1.2
	age 0-20	5.5	1.1
	age 21-40	8.3	1.6

The growth factors used for the purpose of the inventory are summarised in Table 6-15.

The age category 0-20 includes mainly areas that were clearfelled and to a lesser extend areas which have been afforested. Growth rates for afforested areas have not been separately determined as only 50 sample points have been identified as afforestation, the date of conversion is not known (2001 or 2009) and the previous land use is unknown (no distinction between grassland and cropland).

Table 6-16 – country-specific biomass conversion factor and ratio of below-ground to above-ground biomass used for the calculation of wood removal

	$BCEF_R$	R
Deciduous forests	0.74	0.22
Coniferous forests	0.55	0.20
average	0.68	0.21

In order to estimate the carbon loss due to drain of living biomass (wood and fuelwood removal) stemwood drain data has to be converted in biomass. The data from the forest inventory (Alderweireld, 2015) has been used to define country specific biomass conversion and expansion factors by taking into account the number and type of trees found in coniferous forests as well as deciduous forest.

Data on wood harvest is derived from the statistics of the ANF (Administration de la Nature et des Forêts) as well as from the data extracted from the two consecutive forest inventories. The statistical data collected by the ANF is limited to the wood harvest of public forest and does not include wood harvest of private forests. Furthermore, ANF harvest statistics do not include biomass drain due to mortality (fallen dead trees remaining at site), but the drain according to the forest inventories includes this stemwood loss. In the previous submissions the wood harvest from private forests was simply estimated by using the same harvest rates as public forests and extrapolating it to the forest area of public forests (often with a simple 50/50 ratio). With the completion of the second forest inventory the following data has however become available:

- Stemwood drain from public deciduous forests: 4.8 m^3/ha/a
- Stemwood drain from private deciduous forests: 3.3 m^3/ha/a
- Stemwood drain from public coniferous forests: 8.7 m^3/ha/a
- Stemwood drain from private coniferous forests: 8.7 m^3/ha/a
- Proportion of public deciduous, public coniferous, private deciduous and private coniferous forests for the years 2000 and 2010
- Average annual stemwood drain measured during NFI between 2000 and 2010: 472 866 m^3/a (amended to take into account the higher forest area estimated by the LUC methodology)

Figure 6-6 – Stemwood drain from public forests and estimated stemwood drain from private forests

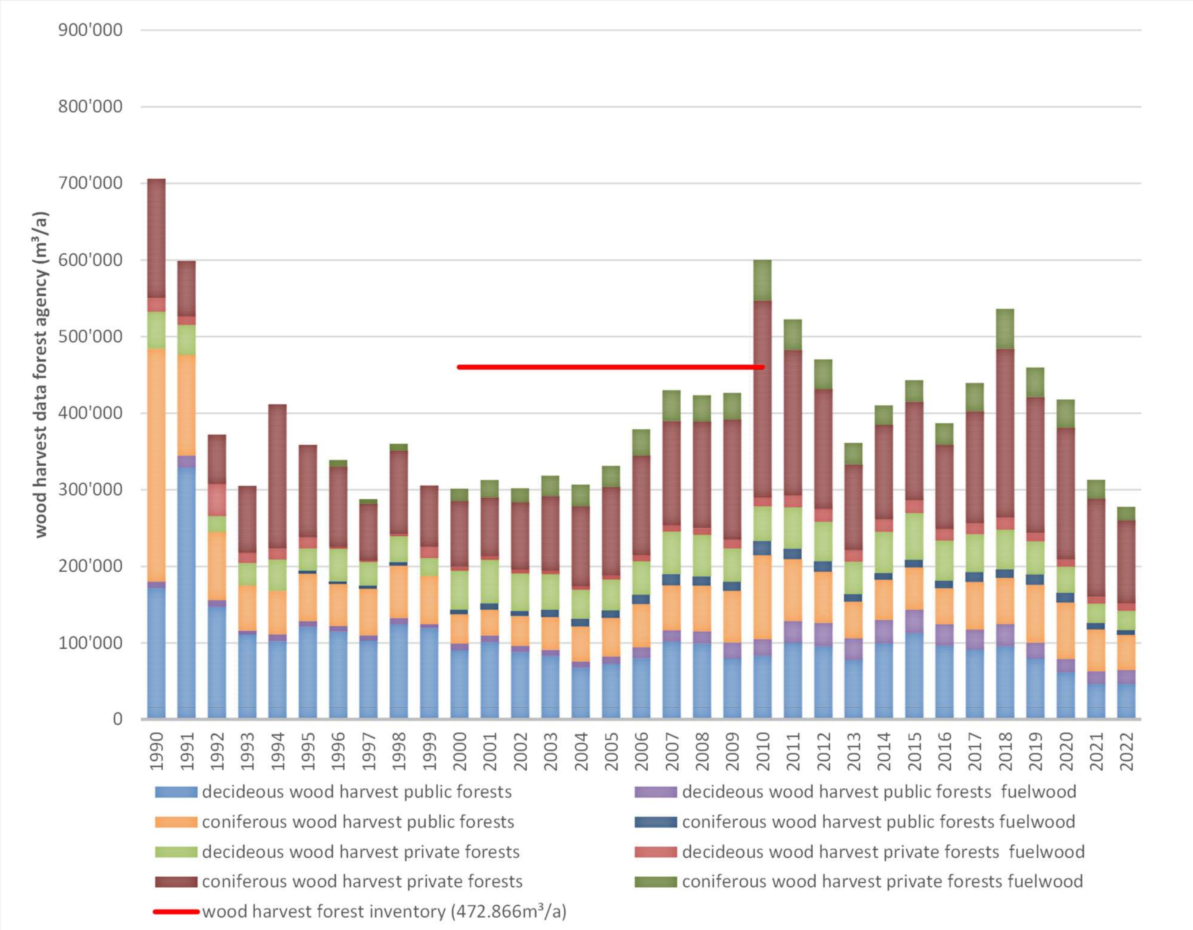


Figure 6-6 shows the yearly wood drain from public forests (marked as *harvest public forests*) as collected by the ANF. The estimated wood drain from private forests (bars marked as *harvest from private forests*) are based on the specific ratios of wood drain and forest distribution as collected during the forest inventory. The peaks 1990 and 1991 and the subsequent fall in wood drain can be explained through the salvage logging after the windstorm of 1990. The peak in 2010 has been traced back to the change of forest practice in one northern commune and also because of salvage logging after the windstorm Xinthia. Considering that this increase was mainly happening in coniferous wood the estimated wood harvest of private forests was strongly affected as the area of private coniferous forest is twice as high as public coniferous forests and the average harvest rate out of coniferous forests is very high (8.7 $m^3/h/a$).

The red line shows the total average wood drain as estimated from the forest inventory. Compared to the average wood drain compiled with the methods described here above it is possible to see that the average wood drain between 2000 and 2010 is lower (377 000 m^3/a) than the average measured during the forest inventory (460 290 m^3/a). The difference is substantial (22 %) but can easily be explained (wood loss during harvest, wood (> 7cm in diameter) remaining as dead wood in forest, different time periods for data collection, estimation of wood harvest from public forests). Hence the whole time series of wood harvest data (1990-2020) was amended (+22%) to match the wood harvest rate of the forest inventory. The reasons to align the data collected from the ANF to the one from the forest inventory are the following:

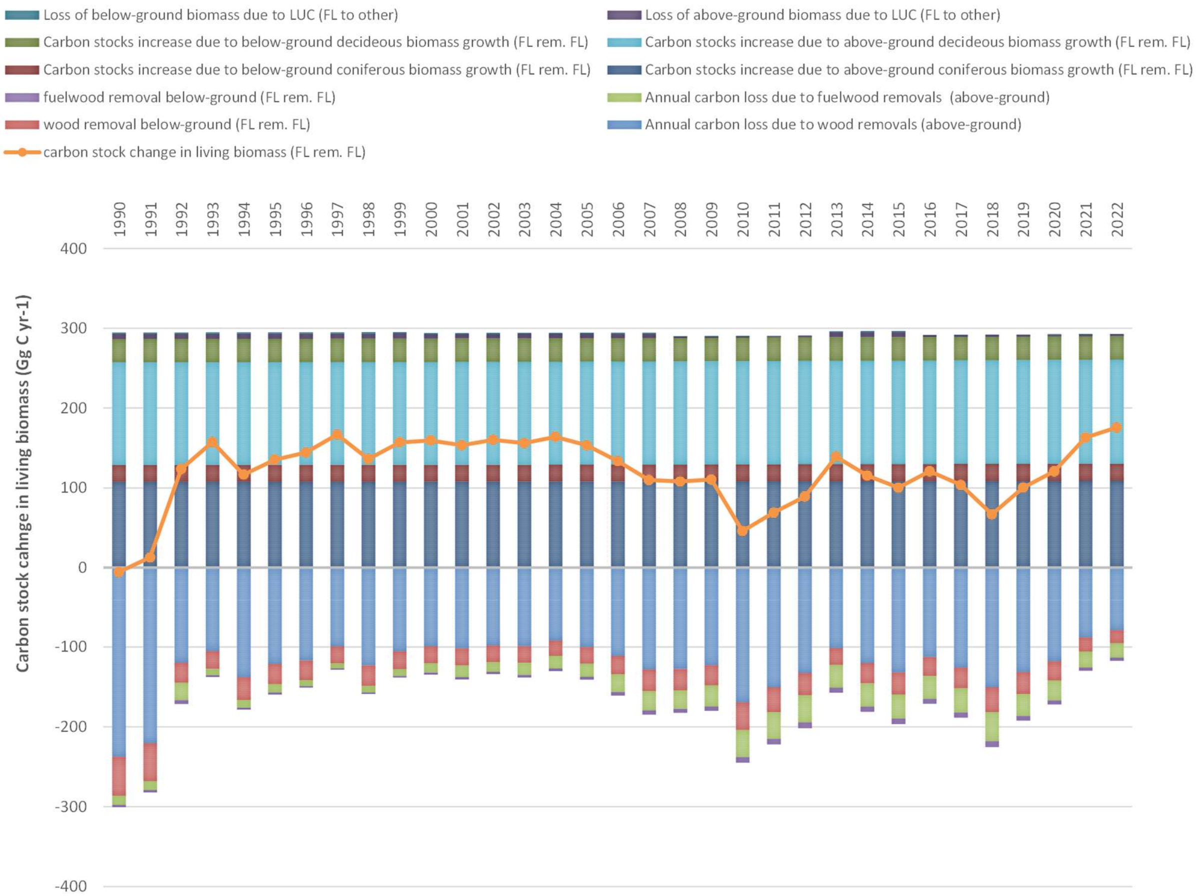
- The data collected from the inventory is more reliable as it is based on a more systematic approach

- The calculation of the total biomass removed is based on country specific biomass expansion and conversion factors (described here above) that are based on the assumption that all wood >7 cm in diameter is removed. Forest practices in public forest limit wood removal to wood with a diameter > 10 cm.

Figure 6-7 – amended time series of wood harvest (alignment with average wood harvest from forest inventory)

It is also important to note that the data on wood harvest shown in Figure 6-7 also includes the biomass removed during conversion of forestland in other land use. According to IPCC Guidelines 2006, Chapter 4.2.1.3, the definition of wood removals and fuelwood removals state clearly that “wood removal from Forest Land Remaining Forest Land and wood removal coming from Forest Land conversion to other uses should be separated”. In order to avoid double counting, the data of carbon loss due to biomass loss from forest land conversion to other land use (from chapters 6.3.4.2.1, 6.4.4.2, 6.5.4.2, 6.6.4.2, 6.7.4.2) has been subtracted from the carbon loss due to wood removal. In Figure 6-8 it is shown as a carbon gain in order to make it visible within the chart.

Figure 6-8 – change of carbon stock living biomass (forestland remaining forestland)



The practice of harvesting tree parts was practiced in the past in order to collect bark which was used in the leather tanning industry. Tree bark has since long been replaced by chemical products and most of these forests have since developed in regular woodlands. Harvest in these woodlands was measured during the the NFI and as annually reported harvest is amended with the data of the forest inventory (see Figure 6-7) harvest of tree parts is also acconted for.

With regards to natural disturbances it is assumed that during previous disturbances all stemwood was removed as part of salvage logging.

6.2.4.1.2 Change of carbon stock in soil

Luxembourg, recognises the dynamic and intricate nature of carbon processes in forest soils and that those processes are challenging to quantify accurately. As a consequence, Luxembourg has adopted the IPCC GPG 2006 Tier 1 approach, which assumes that soil carbon stocks remain in equilibrium. According to this approach, any carbon losses are offset by corresponding carbon gains, leading to a balanced carbon budget.

In order to determine the appropriate tier method to estimate carbon stocks in mineral soil from the category of forest land remaining forestland, the decision tree in figure 2.4 from volume 4, chapter 2 of the IPCC guidelines was used:

- Do you have the data and resources to develop a Tier 3? <u>No</u>, LU only has carbon stocks on forestland that were taken during the NFI in 2010 (Table 6-24). The quality of the data is not comparable to, for example, extensive soil monitoring in agriculatura land. In order to develop a Tier 3 method new and a higher amount of soil samples would need to be taken in forests. Currently LU is lacking the ressources to conduct such an extensive study.

- Do you have country-specific data on soil C stock changes due to land use and management for mineral soils or data to generate countryspecific reference C stocks? No, as mentioned here above carbon stocks in forests are limited to a single measurement in 2010.
- Are changes in C stocks in mineral soils a key category? Possibly. It is not possible to determine if this carbon pool is a key category. However, given that the total carbon stock of mineral soils in forests is very high, even a small variation can already lead to carbon stock changes that exceed the threshold for the category becoming a key category.

To assess carbon changes in this pool, LU would need to implement an extensive and rigorous monitoring plan for carbon stock in mineral soils in forests. However, it's important to recognise that such a comprehensive plan could be both costly and challenging.

6.2.4.1.3 Change of carbon stock in dead wood

Data on dead wood stocks is available at two points in time (NFI 1 – year 2000 and NFI 2 – year 2010). Dead wood with a diameter greater than 7 cm and older than 3 years (unlikely to be harvested) was considered. In order to estimate the biomass for dead wood the biomass expansion factor were not applied which means that small branches of dead wood are not considered. Even though the degree of decomposition influences the quantity of biomass it is not considered in this study as no data on decomposition was collected. Over the last years the forest agency has pursued an active policy to increase the dead wood in public forest. This has led to an increase in dead wood in the forest as can be seen in Table 6-17.

Table 6-17 –values for dead wood by inventory year (tonnes d.m. ha^{-1})

	2000	2010
Dead wood on floor	6.3	7.0
Dead wood standing	3.8	5.0

In the 2021 GHGI the same calculation method of the dead wood was used as the one used during the calculation of the FRL. This means that the evolution of the carbon stock in dead wood is the same in GHGI and the FRL. The following calculation estimates an evolution of the dead carbon stock by considering dynamic age-related characteristics. For the calculation a carbon pool variation module is used to estimate the evolution of this carbon pool. Carbon stock change factors (CSCF) were established according to the same stratification as applied for the calculation of harvest rate. CSCF factors were established according to forest type, ownership and age classes. The stratification according to age class allows taking into account the age class evolution

Table 6-18 – dead wood calculation parameters for coniferous forests under public ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	2.5	6.1	0.36
21-40	10.1	10.3	0.02
41-60	11.3	14.6	0.33
61-80	19.6	12.9	-0.67
80+	0.4	13.1	1.26

Table 6-19 – dead wood calculation parameters for coniferous forests under private ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	5.9	7.5	0.16
21-40	11.0	16.0	0.50

41-60	18.8	14.8	-0.40
61-80	12.8	15.0	0.22
80+	3.9	6.3	0.24

Table 6-20 – dead wood calculation parameters for deciduous forests under private ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	5.7	6.2	0.05
21-40	7.0	9.9	0.30
41-60	13.0	11.0	-0.20
61-80	11.8	13.2	0.14
80+	1.4	3.0	0.15

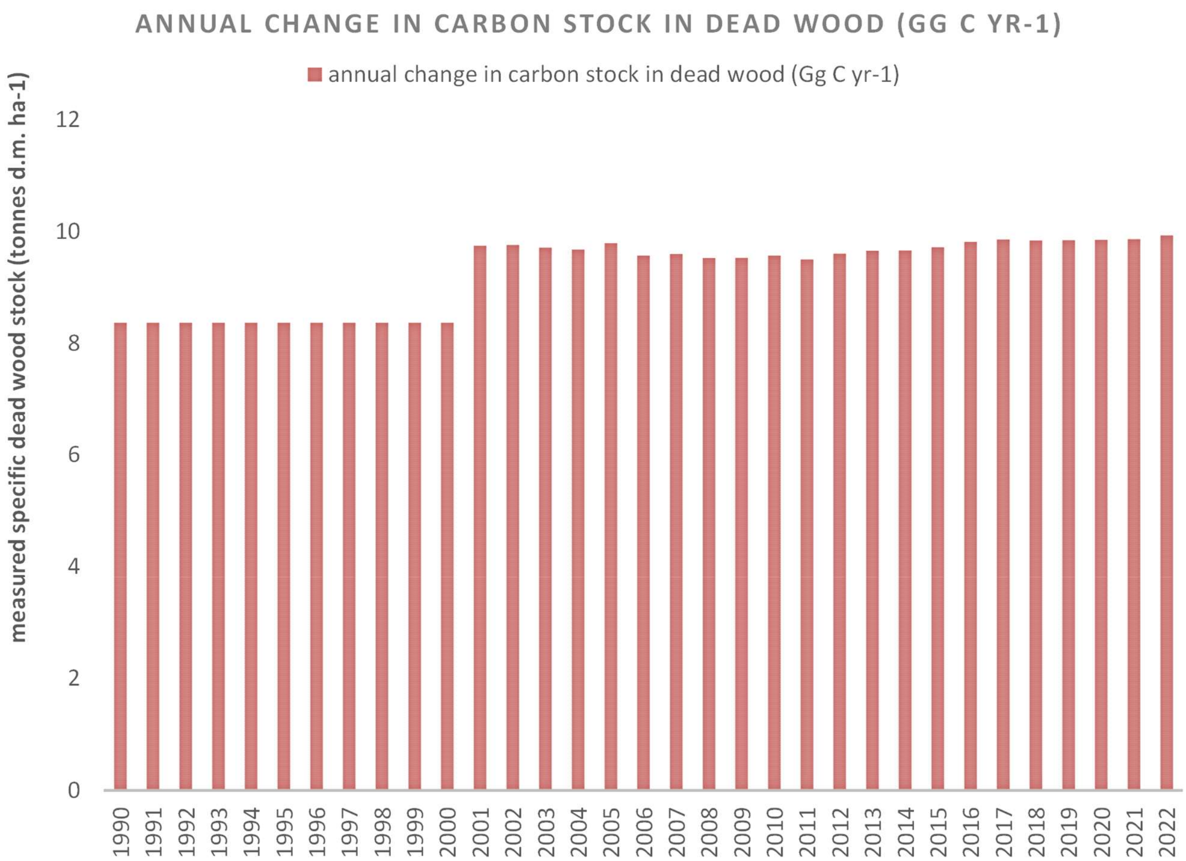
Table 6-21 – dead wood calculation parameters for coniferous forests under private ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	2.6	4.0	0.14
21-40	10.2	17.2	0.71
41-60	21.8	21.6	-0.02
61-80	10.6	10.6	0.00
80+	21.5	40.6	1.91

In order to project the dead wood stock the projected forest areas for each stratum were calculated using the age-structure module.

Those projected areas were then multiplied by the respective CSCFs for each stratum calculated here above.

Figure 6-9 – change of carbon stock in dead wood



A continuous increase can be observed in the years after 2000 due to an increase of the area of forestland remaining forestland. It is important to highlight the importance of carrying out a third forest inventory in order to measure the dead wood stock before 2025. If this is not the case than any real increase of dead wood will not be accounted for in the GHGI.

6.2.4.1.4 Change of carbon stock in litter

For the changes in carbon stock in litter the IPCC GPG Tier 1 approach was used assuming that this carbon pool is in equilibrium and carbon losses are compensated by C gains. Carbon stock changes in litter are very dynamic processes carbon stock changes are most likely changing continuously but no data on litter C stock changes has so far been collected in Luxembourg and hence this carbon pool is not estimated. In order to identify the appropriate tier method to calculate carbon stocks changes in litter from the category forest land remaining forestland the decision tree in figure 2.3 from vol4.chapt 2 of the IPPC guidelines was used:

- Is data on managed area and DOM stocks at two periods of time available to estimate changes in C stocks? No, during the NFI no measurement of the carbon stocks of litter were made.
- Is data on managed area and annual transfer into and out of DOM stocks available? No, there is no data available on the annual transfer into and out of the DOM pool of litter available.
- Are changes in C stocks in the DOM pool of litter a key category? Possibly. It is is not possible to determine if this carbon pool is a key category because there is no data on carbon stocks in litter available. However, given that the total carbon stock of

litter in forests is very high, even a small variation can already lead to carbon stock changes that exceed the threshold for the category becoming a key category.

To assess carbon stock changes in this pool, LU would need to implement an extensive and rigorous monitoring plan in forest. However, it's important to recognise that such a comprehensive plan could be both costly and challenging.

6.2.4.2 Land Use Changes to Forest Land (4A2)

6.2.4.2.1 Change of carbon stock in living biomass of land converted to forest land

The method follows the Tier 2 IPCC GPG approach with default transition periods of 20 years for LUC and country specific data for biomass increase factors. It is assumed that no wood removal occurs in forest less than 20 years old.

For the calculation of annual change in carbon stocks of living biomass of land converted to forestland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (The biomass increment factor for *4.A.2.1 - Land converted to Forestland* is described under § 1.2.4.1. The first age class (0-20) values (Table 6-15) for the annual increment are being used: above-ground biomass growth of 5.5 tonnes d.m. ha-1 yr-1 and below-ground biomass growth 1.1 tonnes d.m. ha-1 yr-1 .)

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock of woody biomass before conversion depending on land use: see Table 6-22 as well as Table 6-23).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

i = type of land use converted to another land-use category

Table 6-22 – Biomass stock for different land use categories (tonnes C ha^{-1})

	Pool	value	Reference
Cropland annual	below-ground	5.0	Table 5.9 IPCC GPG (LULUCF 2006)
Cropland perennial	above-ground	6.4	See below
Forestland	above-ground	98.4	NFI
Forestland	below-ground	21.3	NFI
Grassland	above- and below-ground	6.3	Table 6.4 IPCC GPG (LULUCF 2006)
Wetlands	N/A	0.0	Tier 1
Settlements	above-ground	4.3	section 1.6.4.2
Other land	N/A	0.0	Tier 1

Table 6-18 summarises the biomass stock factors for the different land use categories that are being lost during land use change to forestland. The biomass decrease factor for *4.A.2.1 – Annual cropland converted to Forestland* is 5.0 t C/ha and derives from Table 5.9 of the IPCC GPG (LULUCF 2006, Tier 1 default value). The biomass decrease factor for *4.A.2.2 - Grassland converted to Forestland* is 6.3 t C/ha and derives from Table 6.4 of the IPCC GPG (LULUCF 2006, Tier 1 default value of 13.5 tonnes d.m ha^{-1}). As the distinction between below-and above-ground biomass at this level is not always very clear and in order to simplify the calculations all the biomass stock factors are being considered as above-ground. For wetland and other land the default value for biomass stock is set to 0.

According to the data from ASTA (Administration des Services Techniques de l'Agriculture) vineyards constitute 93 % of the perennial cropland in Luxembourg and it seems justified to calculate a country-specific biomass stock factor for perennial cropland (as was recommended during audit (FCC/ARR/2014/LUX)).

Table 6-23 – Biomass decrease factors for perennial cropland (tonnes C ha^{-1})

	% of perennial cropland	Value	Reference
Vineyards	94	2.64 (2,09 (ag)+ 0.55 bg)	NIR Germany/Switzerland
orchards	6	63.00	IPCC GPG Table 5.1
Perennial cropland (average)	100	6.41	/

The biomass stock factor for perennial cropland used in Luxembourg is a weighted average of vineyards specific values used by neighbouring countries (Germany – NIR 2014: 1.66 Mg C ha^{-1} (above ground biomass (1.22 Mg C ha^{-1}) and below ground biomass (0.44 Mg C ha^{-1}) and Switzerland – NIR 2015: 3.61 Mg C ha^{-1} (above ground biomass (2.96 Mg C ha^{-1}) and below ground biomass (0.65 Mg C ha^{-1})) and the default IPCC GPG value used typically for orchards (63.0 Mg C ha^{-1}). Germany, Switzerland and Luxembourg are all part of Europe's continental region with similar climatic conditions. Furthermore Germany and Switzerland have similar wine industry focussed on white wine production and are hence suitable indicators for biomass stock factors for vineyards in Luxembourg.

6.2.4.2.2 Change of carbon stock in soil of land converted to forest land

In October 2014, ASTA presented two new studies on the carbon content and stocks of different soil types in Luxembourg ("Mapping Topsoil Organic Carbon Content in the Grand-Duchy of Luxembourg" and "Mapping Topsoil Organic Carbon Stocks in the Grand-Duchy of Luxembourg"). While the first study provides detailed information on the carbon content in soils of Luxembourg (covering 90% of the territory and per land use type), the second study assesses the amount of carbon stored in soils of a given area by taking into account the soil density, soil depth (0-30 cm), and the proportion of fine earth to the total soil mass.

According to soil type and geography the country was categorised in 9 different soil association (Figure 6-10). For each category of soil association carbon stock were estimated for cropland, grassland and vineyards (Table 6-24). For land use categories other than cropland, grassland and forest the study did not provide any information and thus were set to zero. Exceptions are settlement areas where the soil carbon stock value was based on the ratio of unsealed surfaces (i.e. grassland 28.9%, bushes 8.3%, trees 15.8%) inside the settlement area in 2018

Figure 6-10 Soil associations

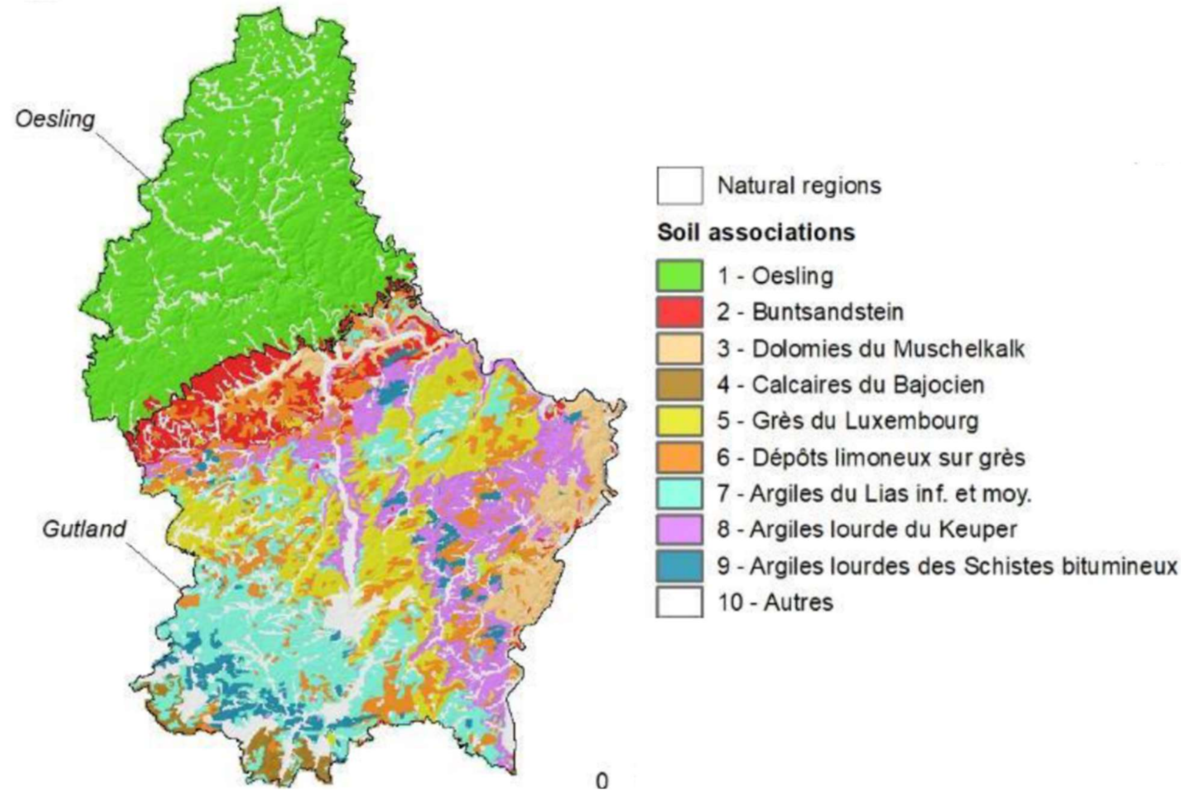


Table 6-24 – Carbon soil stocks per land use and soil type (t C/ha) in Luxembourg

	Carbon soil stocks per land use and soil type (t C/ha)						
Soil type	Cropland (Annual Cropland)	Grassland	Forest land	Vineyard (Perennial cropland)	wetland	settlement	other land
Oesling	91.5	89.2	132.2	71.0	0.0	56.9	0.0
Buntsandstein	66.7	82.8	112.1	73.5	0.0	56.9	0.0
Dolomies du Muschelkalk	85.5	112.1	117.0	77.9	0.0	56.9	0.0
Calcaires du Bajocien	75.2	122.0	111.5	77.7	0.0	56.9	0.0
Grès de Luxembourgs	50.7	83.3	80.6	76.2	0.0	56.9	0.0
Dépôts limoneux sur Grès	58.6	99.4	95.7	75.1	0.0	56.9	0.0
Argiles du Lias inf. et moyen	69.8	121.6	95.2	75.7	0.0	56.9	0.0
Argiles lourdes du Keuper	67.7	121.3	102.6	76.0	0.0	56.9	0.0
Argiles lourdes des schistes bitumineux	88.2	145.7	104.8	NA	0.0	56.9	0.0
Autres	80.7	110.8	126.6	74.9	0.0	56.9	0.0

With the help of the geospatial data set on soil associations in Luxembourg and its land use category, the value of soil organic carbon stock was attached to each grid point in the database. For each point in the grid database with a land use change the carbon stock change was calculated according stock difference

$$\mathrm{IEF}(LUC_j)_{\mathrm{st,i}} = \frac{\mathrm{SOC}(LU_a)_{\mathrm{st,i}} - \mathrm{SOC}(LU_b)_{\mathrm{st,i}}}{\mathrm{transition}_{\mathrm{period}}}$$

$IEF(LUC)_{st,i}$ = yearly emission factor for carbon stock change in soil from land use change j (eg CL->GL) for a soil type i

$SOC(LU_{a,b})_{st,i}$ = soil organic content by land use type a or b and soil type i

$transition_{period}$ = period where the change in carbon stock change is achieved (typically 20 years)

Numerical example first step: calculating the IEF for each land use transition in each soil type (example of Oesling)

$$\mathrm{IEF}_{\mathrm{CL\rightarrow GL\_Oesling}} = \frac{\mathrm{SOC}_{\mathrm{CL_{Oesling}}} - \mathrm{SOC}_{\mathrm{GL_{Oesling}}}}{\mathrm{transition_{period}}} = \frac{91.5 - 89.2}{20} = 0.115\ \mathrm{tC.\,ha^{-1}}.yr^{-1}$$

6.2.4.2.3 Change of carbon stock in dead wood and litter

In order to estimate the increase in dead wood stock the assumption was taken (Tier 1 of IPCC GPG (LULUCF 2006 – Volume 4) that "carbon in dead wood and litter pools in non-forest land are zero, and that carbon in dead organic matter pools increases linearly to the value of mature forests over a specified time period (default = 20 years)".

The EF used for dead wood stock are those described in Figure 6-9 and for litter the default values (Table 2.2, IPCC GPG 2006, Chapter 2) of 16 tonnes C/ha for deciduous and 26 tonnes C/ha for coniferous forests were chosen.

6.3 Cropland (4.B)

6.3.1 Category description

In the category of *4.B Cropland*, the estimation of emissions includes remaining cropland, land converted to cropland, and liming activities. Some management practices (*e.g.* slash and burn, *etc.*) and organic soils do not occur and are prohibited in Luxembourg.

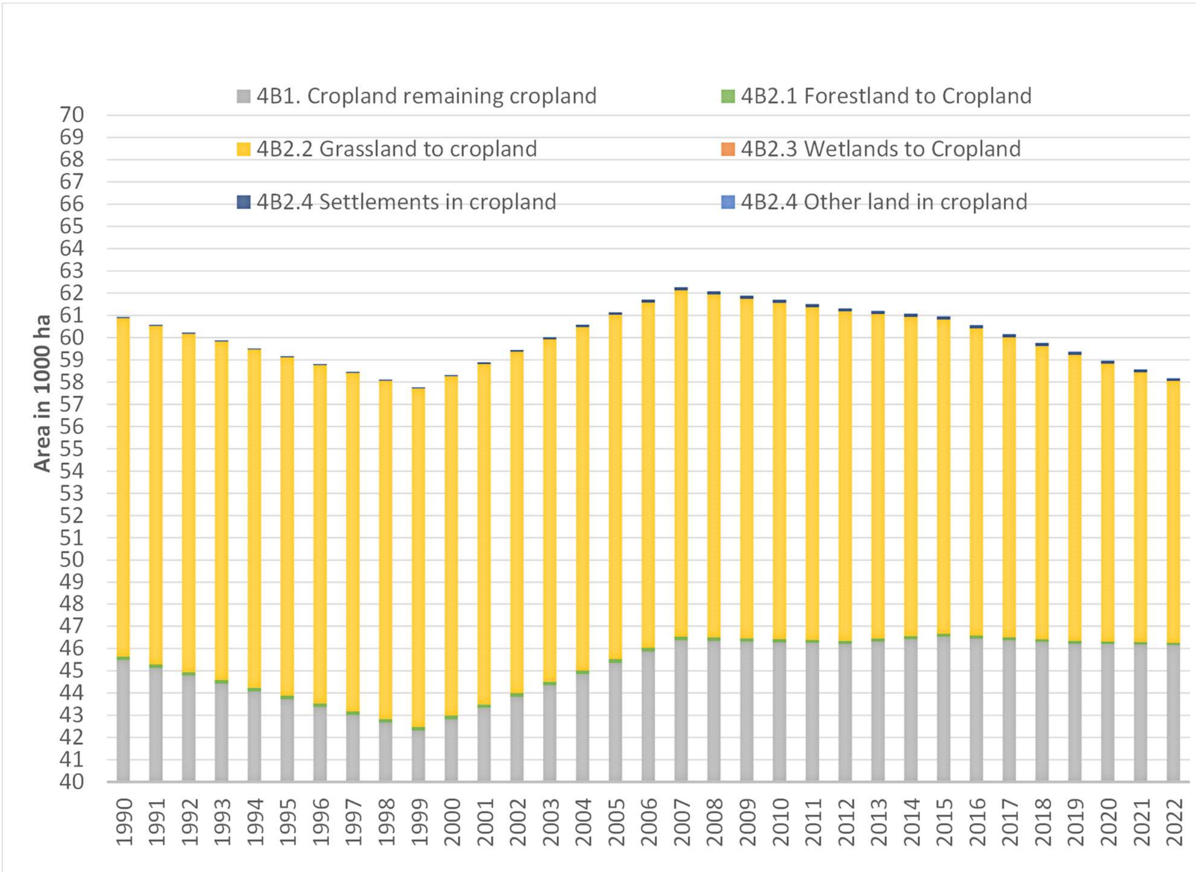
Emissions/Removals were estimated for the sub-categories and related sources/sinks as shown in Table 6-25.

Table 6-25 – Sources (or sinks) considered for cropland management.

Category/source or sink
4B Cropland - total
4B1 Cropland remaining cropland
- carbon stock change in living biomass of perennial cropland and LUC between annual and perennial copland
4B2 Land converted to cropland
4B2.1Forest land converted to cropland
- carbon stock change in living biomass and dead wood of annual/perennial cropland
4B2.2 Grassland converted to cropland
- carbon stock change in living biomass of annual/perennial cropland
- carbon stock change due to changes in organic matter input to cropland soils
4B2.3 Wetland converted to cropland
4B2.4 Settlement converted to cropland
4B2.5 Other land converted to cropland

In 2022, 58 166 ha of Luxembourg were arable land including annual and permanent crops. The land use changes are derived from land transition matrix. The land use changes for a 20 year conversion period are shown in Figure 6-11.

Figure 6-11 – Trend of cropland and LUC to cropland (20 year conversion period)



The annual emissions from 1990-2022 range between 68.02 Gg CO_2 and 27.65 Gg CO_2, and 0.01 and 0.002 GgN2O emissions respectively (Table 6-26). The source is mainly caused by soil C stock changes of land use change areas, particularly by grassland converted to cropland.

Table 6-26 – CO_2 removals/emissions from category 4B – Cropland

4B - Cropland									
Net CO_2 emissions/removals (Gg)									N_2O (Gg)
Year	4B Total Cropland	4B1 CL-CL	4B Land-CL	4B2.1 FL -> CL	4B2.2 GL -> CL	4B2.3 WL -> CL	4B2.4 SL -> CL	4B2.5 OL -> CL	N_2O (*)
1990	44.77	0.00	44.77	4.39	40.49	- 0.04	-0.06	-0.01	0.01
1991	44.77	0.00	44.77	4.39	40.49	- 0.04	-0.06	-0.01	0.01
1992	44.77	0.00	44.77	4.39	40.49	- 0.04	-0.06	-0.01	0.01
1993	44.78	0.00	44.78	4.40	40.49	- 0.04	-0.06	-0.01	0.01
1994	44.78	0.00	44.78	4.40	40.49	- 0.04	-0.06	-0.01	0.01
1995	44.78	0.00	44.78	4.40	40.49	- 0.04	-0.06	-0.01	0.01
1996	44.79	0.00	44.78	4.40	40.49	- 0.04	-0.06	-0.01	0.01
1997	44.79	0.00	44.79	4.41	40.49	- 0.04	-0.06	-0.01	0.01
1998	44.79	0.00	44.79	4.41	40.49	- 0.04	-0.06	-0.01	0.01
1999	44.79	0.00	44.79	4.41	40.49	- 0.04	-0.06	-0.01	0.01
2000	49.66	3.95	45.71	5.13	40.66	- 0.04	-0.02	-0.01	0.01
2001	49.45	3.74	45.71	5.13	40.66	- 0.04	-0.03	-0.01	0.01
2002	68.02	3.28	64.73	5.50	59.68	- 0.04	-0.40	-0.01	0.02
2003	67.80	3.07	64.73	5.50	59.69	- 0.04	-0.41	-0.01	0.02
2004	67.59	2.86	64.72	5.51	59.69	- 0.04	-0.42	-0.01	0.02
2005	67.37	2.65	64.72	5.51	59.70	- 0.04	-0.43	-0.01	0.02
2006	67.16	2.44	64.72	5.51	59.70	- 0.04	-0.44	-0.01	0.02
2007	66.95	2.23	64.71	5.51	59.71	- 0.04	-0.45	-0.01	0.02
2008	61.75	- 4.25	66.00	1.46	65.00	- 0.03	-0.43	0.00	0.02
2009	62.25	- 3.82	66.07	1.46	65.07	- 0.03	-0.43	0.00	0.02
2010	62.84	- 3.40	66.24	1.56	65.14	- 0.03	-0.43	0.00	0.02
2011	63.34	- 2.97	66.31	1.56	65.21	- 0.03	-0.43	0.00	0.02
2012	63.84	- 2.54	66.38	1.56	65.29	- 0.03	-0.43	0.00	0.02
2013	39.20	3.68	35.52	6.11	29.75	- 0.01	-0.32	-0.01	0.01
2014	38.99	3.45	35.55	6.11	29.77	- 0.01	-0.32	-0.01	0.01
2015	38.79	3.22	35.57	6.12	29.79	- 0.01	-0.32	-0.01	0.01
2016	28.23	3.21	25.02	1.43	23.99	- 0.01	-0.40	0.00	0.01
2017	28.04	2.97	25.07	1.44	24.04	- 0.01	-0.40	0.00	0.01
2018	27.85	2.74	25.11	1.44	24.08	- 0.01	-0.40	0.00	0.01
2019	27.65	2.50	25.15	1.44	24.12	- 0.01	-0.40	0.00	0.01
2020	27.68	2.47	25.21	1.45	24.16	- 0.01	-0.39	0.00	0.01
2021	27.70	2.45	25.26	1.45	24.20	- 0.01	-0.38	0.00	0.01
2022	36.70	2.60	34.10	1.06	6.31	0.07	26.67	0.00	0.002
Trend 1990-2022	-18.02%	167988.97%	-23.83%	-75.89%	-84.43%	-263.65%	-44767.44%	-111.07%	-87.57%
Trend 2021-2022	32.48%	6.31%	35.01%	-27.22%	-73.94%	-703.45%	-7096.68%	0.00%	-79.59%

(*) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils.

6.3.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

As described in section 6.1.3.4, land use changes were extracted from the grid database. Land use changes between grassland and cropland are difficult to estimate as they are often based on land cover maps which in turn are based on aerial images. The gridbase approach allowed to introduce data on permanent grassland and cropland from the LPIS system. For all areas that are not covered under the LPIS data is used from the land use and land cover maps.

6.3.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The selected parameters defining annual and perennial cropland are:

Land Use Class	Definition
Annual Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a yearly changed rhythm including artificial meadows (not permanent) including land temporarily set aside
Permanent Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a permanent manner, *i.e.* not changing in a yearly rhythm

6.3.4 Methodological issues

6.3.4.1 Cropland remaining Cropland (4B1)

6.3.4.1.1 Change of carbon stock of annual cropland

a) Changes of carbon stock in biomass of annual cropland remaining annual cropland:

As the biomass of annual crops is harvested every year, there is no change in carbon stock in biomass.

b) Changes of carbon stock in biomass of perennial cropland converted to annual cropland:

For the calculation of annual change in carbon stocks of living biomass of land converted to cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for annual crops carbon accumulation rate is 5 t C $ha^{-1} yr^{-1}$).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock of woody biomass before conversion is 6.4 t C ha^{-1} see section 6.2.4.2.1 and Table 6-22 as well as Table 6-23).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

i = type of land use converted to another land-use category

c) Changes of carbon stock in organic soils:

Organic soils cannot be found in Luxemburg.

d) Changes of carbon stock in mineral soils of annual cropland remaining annual cropland:

Emissions/removals were calculated using country specific values for the soil organic carbon content. The mean organic carbon content of soil per ha in the layer of 0-30 cm depth was determined for the different land uses (annual cropland, perennial cropland, grassland, forest) by using the values of the soil database of ASTA (Administration des Services Techniques de l'Agriculture, Division des Laboratories de Contrôle et d'Essais, Service de Pédologie).

According to expert judgment (EJ_4_01), there were no significant changes in relative stock change factors (tillage factor FMG; land use factor FLU; input factor FI) during the observation period 1990 to 2020 and these factors are set by default equal to 1. Thus there was no change in carbon stocks in annual cropland soils due to management.

<u>e) Changes of carbon stock in mineral soils of perennial cropland converted to annual cropland:</u>

Carbon changes in mineral soild due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2 .

6.3.4.1.2 Change of carbon stock of perennial cropland

<u>a) Changes of carbon stock in biomass of perennial cropland remaining perennial cropland:</u>

According to Tier 1 GPG (2006) for perennial cultures, a steady increase in biomass in the first 20 years is assumed for vineyards and ochards (Table 5.3 (updated). 5.0 % of these cultures are removed and cause emissions. For older cultures the annual increase in biomass is assumed to be equal to the losses by harvesting. For calculating the carbon stock change of living biomass on perennial cropland the following formula was used:

*Annual change in carbon stock in biomass = (area of perennial cropland * carbon accumulation rate) – (area of perennial cropland before 20 years * 0.05 * biomass carbon stock at harvest)*

where:

For the carbon accumulation rate the value of 0.32 t C $ha^{-1}yr^{-1}$ was used (stock at harvest - see below - divided by 20 years rotation cycle).

For the above ground biomass carbon stock at harvest the value of 6.4 t C $ha^{-1}yr^{-1}$ (see Table 6-23) was used.

<u>b) Changes of carbon stock in biomass of annual cropland converted to perennial cropland:</u>

For the calculation of annual change in carbon stocks of living biomass of land converted to cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

Annual change in carbon stock in biomass = $\Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.32 t C $ha^{-1}yr^{-1}$ - see Table 6-22, Table 6-18 as well as Table 6-23 = accumulation of 6.4 tC/ha over 20 years).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock of biomass before conversion is 5 t C ha^{-1} see section 6.2.4.2.1 and Table 6-22).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

i = type of land use converted to another land-use category

c) Changes of carbon stock in mineral soils of annual cropland converted to perennial cropland :

Carbon changes in mineral soild due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.26.2.4.1.2 .

6.3.4.2 Land Use Changes to Cropland (4B2)

6.3.4.2.1 Change of carbon stock of land converted to annual cropland

The method follows the IPCC GPG with a transition period of 20 years for LUC areas and related estimates for the increases and decreases of biomass and soil C stocks. Growth rates for annual crops (annual cropland, grassland) are accounted only once in the year of LUC, while growth rates for perennial crops (perennial cropland, forest land) are accounted for the whole period of transition. In line with the IPCC GPG, a linear soil C stock change due to the LUCs between the average soil C stocks across 20 years was estimated.

a) Changes of carbon stock in biomass of land converted to annual cropland:

For the calculation of annual change in carbon stocks of living biomass of land converted to cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

Annual change in carbon stock in biomass = $\Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for annual crops carbon accumulation rate is 5 t C $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 6.4 t C ha^{-1} for perennial cropland, a dynamic value of 110.7 t C ha^{-1} (previous 2000) and 128.7 t C ha^{-1} (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha^{-1} for grassland, 4.3 t C ha^{-1} for settlements and 0.0 t C ha^{-1} for wetland and other land - see section 6.2.4.2.1 and Table 6-22.

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

b) Changes of carbon stock in dead wood and litter of land converted to cropland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to cropland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

<u>d) Changes of carbon stock in mineral soils of land converted to annual cropland:</u>

Carbon changes in mineral soild due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2 .

6.3.4.2.2 Change of carbon stock of land converted to perennial cropland

The method follows the IPCC GPG with a transition period of 20 years for LUC areas and related estimates for the increases and decreases of biomass and soil C stocks. Growth rates for annual crops (annual cropland, grassland) are accounted only once in the year of LUC, while growth rates for perennial crops (perennial cropland, forest land) are accounted for the whole period of transition. In line with the IPCC GPG, a linear soil C stock change due to the LUCs between the average soil C stocks across 20 years was estimated.

<u>a) Changes of carbon stock in biomass land converted to perennial cropland:</u>

For the calculation of annual change in carbon stocks of living biomass of grassland converted to perennial cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.21 t C $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 5.0 t C ha^{-1} for annual cropland, 119.7 t C ha^{-1} for forestland, 6.3 t C ha^{-1} for grassland, 4.3 t C ha^{-1} for settlements and 0.0 t C ha^{-1} for wetland and other land - see section 6.2.4.2.1 and Table 6-22).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

i = type of land use converted to another land-use category

<u>b) Changes of carbon stock in dead wood and litter of land converted to cropland:</u>

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to cropland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

c) Changes of carbon stock in mineral soils of land converted to perennial cropland:

Carbon changes in mineral soils due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2 .

6.3.4.2.3 N_2O emissions in soils of land converted to cropland

The annual release of direct N_2O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum\nolimits_{LU} \left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

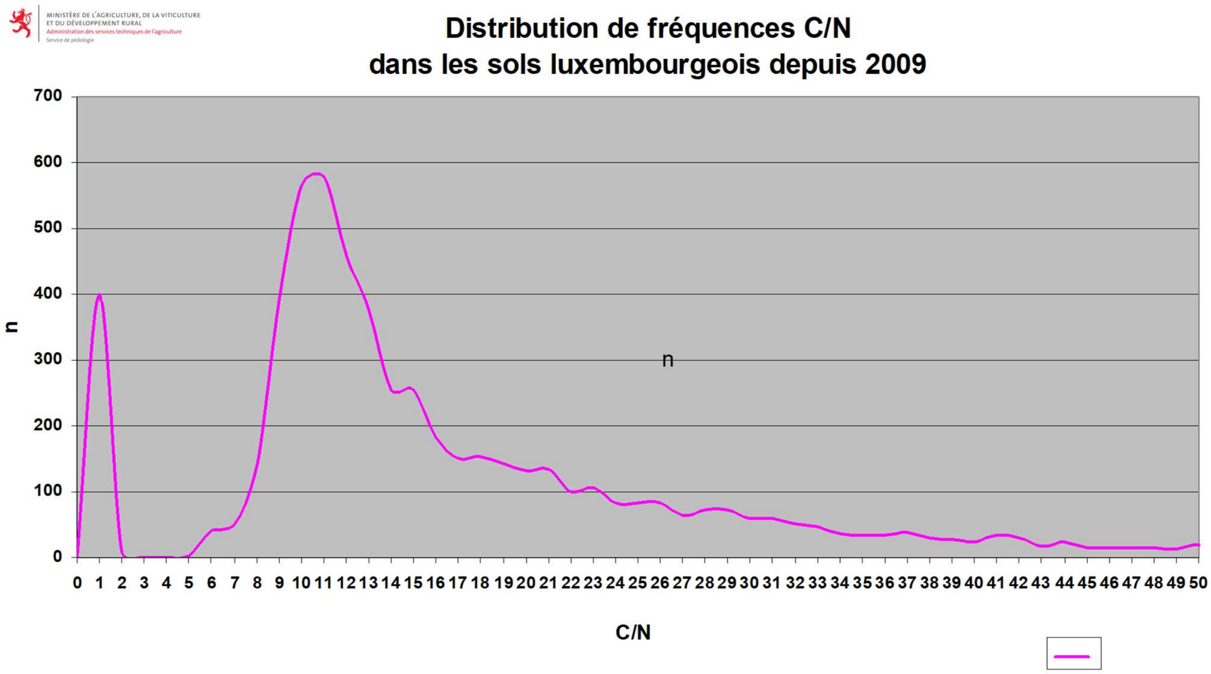
EF_1=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral,LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12. The country-specific C/N was derived from soil analysis done in 2009 (ARR 2011, §107), where C and N content was determined. The distribution curve of C/N ratio (as shown in Figure 6-12) shows a mean C/N ratio of approximately 12. Nevertheless it is important to highlight that the C/N ratio on mineral soils does not have the same significance compared to organic soils in forests. This is due the presence of nitrogen in the form of ammonium fixed in clay minerals. In this case the C/N ratio is however used to determine the potential of mineralisation of nitrogen contained in the organic matter. Separate soil analysis of C/N fraction does not exist for the different soil uses (forestland, grassland etc). According to expert judgement (EJ_4_02) (ASTA) the best available value at this moment in time remains 12.

Figure 6-12 - Frequency distribution of C/N ratio in Luxembourg's soils since 2009



Source: ASTA

The annual release of indirect N_2O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LEACH\ (H)} \cdot EF_5$$

where:

$N_2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN_2O-Nyr^{-1}

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF_5=emission factor for N_2O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$Frac_{LEACH-(H)}$=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)$^{-1}$ (default value = 0.30)

6.4 Grassland (4.C)

6.4.1 Category description

In this category emissions/removals from grassland management (grassland remaining grassland and land converted to grassland) are considered.

Some management practices (*e.g.* slash and burn *etc.*) and organic soils do not occur in Luxembourg. Dead wood and litter are considered in forestland converted to grass land areas but not for the remaining land categories converted to grassland.

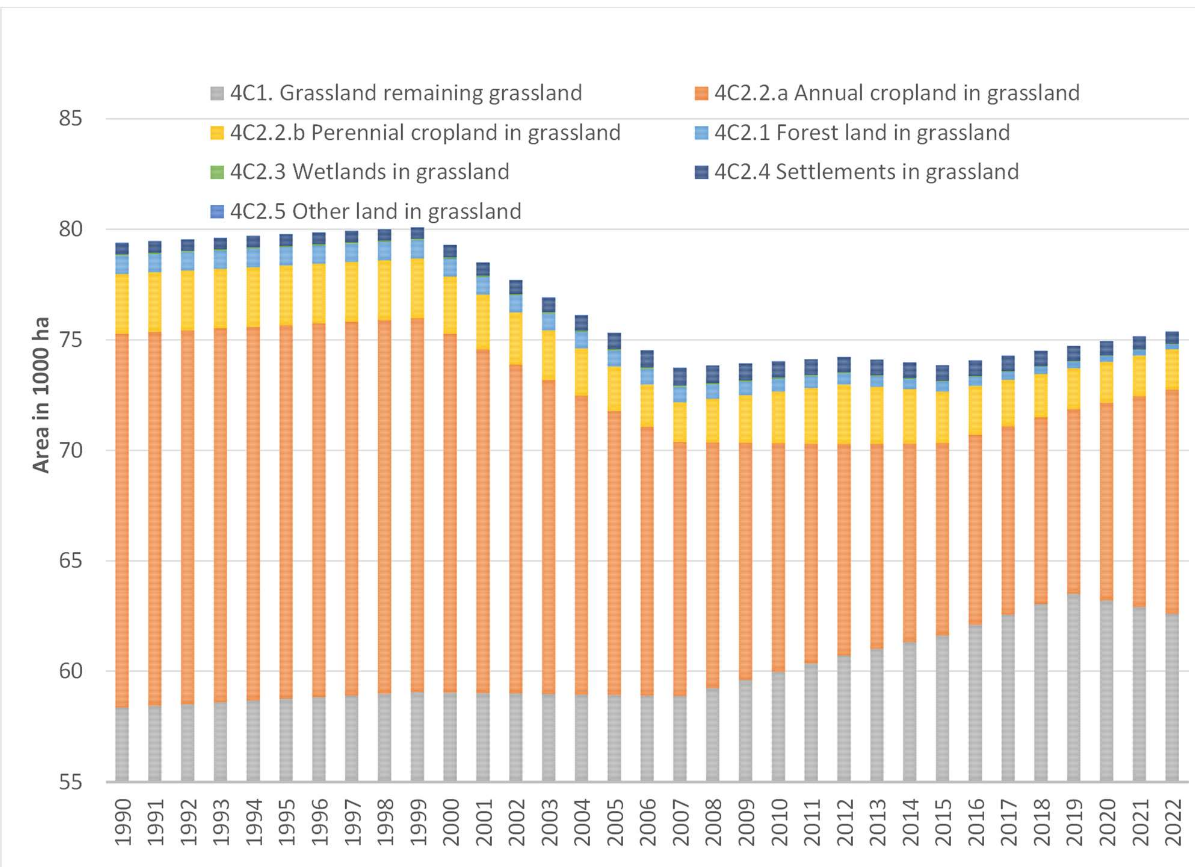
Emissions/Removals were estimated for the following IPCC sub-categories and their related sources/sinks (Table 6-27).

Table 6-27 – Sources (or sinks) considered for grassland management.

Category/source or sink
4C Grassland – total
4C1 Grassland remaining grassland
- carbon stock change due to changes in organic matter input to grassland soils
4C2Land converted to grassland
4C2.1Forest land converted to grassland
4C2.2 Cropland converted to grassland
- carbon stock change in living biomass of grassland
- carbon stock change due to changes in organic matter input (harvest residues) to grassland soils
4C2.3 Wetland converted to grassland
4C2.4 Settlement converted to grassland
4C2.5 Other land converted to grassland

In 2022, 75 380 ha of Luxembourg were grassland (Figure 6-13). Total grassland includes one cut meadows; two and more cut meadows, cultivated pastures, litter meadows, rough pastures and pastures and abandoned grassland.

Figure 6-13 – Trend of grassland and LUC to grassland (20 year conversion period)



The annual emissions of grassland in Luxembourg amounted to -34.81 Gg CO_2 in 1990 and – 17.64 Gg CO_2 in 2022 and 0.0001 and 0.0006 GgN_2O (Table 6-28). The source is mainly caused by soil C stock changes in land use change areas, particularly by forestland converted to grassland.

Table 6-28 – CO_2 removals/emissions for category 4C – grassland

4C - Grassland									
	Net CO_2 emissions/removals (Gg)								N_2O (Gg)
Year	4C Total Grassland	4C1 GL-GL	4C2 Land -> GL	4B2.1 FL -> GL	4B2.2 CL -> GL	4B2.3 WL -> GL	4B2.4 SL -> GL	4B2.5 OL -> GL	N_2O (*)
1990	- 34.81	NA	- 34.81	20.92	- 52.31	- 0.65	-2.62	-0.15	0.00
1991	- 34.79	NA	- 34.79	20.94	- 52.31	- 0.65	-2.62	-0.15	0.00
1992	- 34.78	NA	- 34.78	20.95	- 52.31	- 0.65	-2.62	-0.15	0.00
1993	- 34.76	NA	- 34.76	20.97	- 52.31	- 0.65	-2.62	-0.15	0.00
1994	- 34.75	NA	- 34.75	20.98	- 52.31	- 0.65	-2.62	-0.15	0.00
1995	- 34.74	NA	- 34.74	20.99	- 52.31	- 0.65	-2.62	-0.15	0.00
1996	- 34.72	NA	- 34.72	21.01	- 52.31	- 0.65	-2.62	-0.15	0.00
1997	- 34.71	NA	- 34.71	21.02	- 52.31	- 0.65	-2.62	-0.15	0.00
1998	- 34.69	NA	- 34.69	21.04	- 52.31	- 0.65	-2.62	-0.15	0.00
1999	- 34.68	NA	- 34.68	21.05	- 52.31	- 0.65	-2.62	-0.15	0.00
2000	- 40.07	NA	- 40.07	12.90	- 49.76	- 0.66	-2.42	-0.14	0.00
2001	- 40.06	NA	- 40.06	12.91	- 49.76	- 0.66	-2.42	-0.14	0.00
2002	- 49.30	NA	- 49.30	13.11	- 54.90	- 0.74	-6.68	-0.10	0.00
2003	- 49.29	NA	- 49.29	13.12	- 54.90	- 0.74	-6.68	-0.10	0.00
2004	- 49.29	NA	- 49.29	13.13	- 54.90	- 0.74	-6.68	-0.10	0.00
2005	- 49.28	NA	- 49.28	13.14	- 54.90	- 0.74	-6.68	-0.10	0.00
2006	- 49.27	NA	- 49.27	13.14	- 54.90	- 0.74	-6.68	-0.10	0.00
2007	- 49.26	NA	- 49.26	13.15	- 54.90	- 0.74	-6.68	-0.10	0.00
2008	- 71.73	NA	- 71.73	3.48	- 67.93	- 0.55	-6.67	-0.05	0.00
2009	- 71.73	NA	- 71.73	3.48	- 67.93	- 0.55	-6.67	-0.05	0.00
2010	- 71.47	NA	- 71.47	3.74	- 67.93	- 0.55	-6.67	-0.05	0.00
2011	- 71.46	NA	- 71.46	3.74	- 67.93	- 0.55	-6.67	-0.05	0.00
2012	- 71.46	NA	- 71.46	3.74	- 67.93	- 0.55	-6.67	-0.05	0.00
2013	- 18.57	NA	- 18.57	11.46	- 24.48	- 0.54	-4.99	-0.02	0.00
2014	- 18.56	NA	- 18.56	11.47	- 24.48	- 0.54	-4.99	-0.02	0.00
2015	- 18.56	NA	- 18.56	11.48	- 24.48	- 0.54	-4.99	-0.02	0.00
2016	- 28.30	NA	- 28.30	3.00	- 25.57	- 0.52	-5.20	-0.01	0.00
2017	- 28.30	NA	- 28.30	3.00	- 25.57	- 0.52	-5.20	-0.01	0.00
2018	- 28.30	NA	- 28.30	3.01	- 25.57	- 0.52	-5.20	-0.01	0.00
2019	- 28.30	NA	- 28.30	3.01	- 25.57	- 0.52	-5.20	-0.01	0.00
2020	- 28.30	NA	- 28.30	3.01	- 25.57	- 0.52	-5.20	-0.01	0.00
2021	- 28.29	NA	- 28.29	3.01	- 25.57	- 0.52	-5.20	-0.01	0.00
2022	- 17.64	NA	- 17.64	2.66	- 18.95	- 0.03	-1.32	0.00	0.00
Trend 1990-2022	-49.32%		-49.32%	-87.27%	-63.77%	-94.75%	-49.61%	-99.82%	-79.84%
Trend 2021-2022	-37.65%		-37.65%	-11.52%	-25.89%	-93.41%	-74.65%	-97.80%	-53.31%

(*) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matterresulting from change of land use or management of mineral soils

6.4.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.4.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

Parameters defining grassland:

Land Use Class	Definition
Grassland	All grassland that is not considered as cropland including systems with vegetation or tree cover below the density used in the forest category. This includes all grassland from wild lands, recreational areas as well as agricultural systems. (IPCC GPG definition).

6.4.4 Methodological issues

6.4.4.1 Grassland remaining Grassland (4C1)

6.4.4.1.1 Carbon stock change of grassland

a) Changes in carbon stock in biomass of grassland remaining grassland:

As the biomass of grassland is harvested every year, there is no long term carbon storage in biomass of grassland remaining grassland. Luxembourg uses IPCC tier 1 assumption taken that carbon stock changes are neutral (i.e. net emissions are equal to net removals).

b) Changes in carbon stock in mineral soils of grassland remaining grassland:

Luxembourg uses IPCC tier 1 assumption taken that carbon stock changes are neutral (i.e. net emissions are equal to net removals). Hence it is assumed that there was no change in relative stock change factors (tillage factor FMG; land use factor FLU; input factor FI) during the observation period 1990 to 2020 and these factors are set by default equal to 1. Thus, there was no change in carbon stocks in grassland soils due to management.

Consequently, there are neither emissions nor removals in IPPC Sub-category *5C1 - Grassland remaining Grassland*, due to the fact that the biomass of grassland remaining grassland is harvested every year, and that there is no change in carbon stocks in grassland soils due to management (expert judgement EJ_4_03).

6.4.4.2 Land Use Changes to Grassland (4C2)

The method follows the IPCC GPG with a transition period of 20 years for LUC areas and related estimates for the increases and decreases of biomass and soil C stocks. Growth rates for annual crops (annual cropland, grassland) are accounted only once in the year of LUC, while growth rates for perennial crops (perennial cropland, forest land) are accounted for the whole period of transition. In line with the IPCC GPG, a linear soil C stock change due to the LUCs between the average soil C stocks across 20 years was estimated.

a) Changes in carbon stock in biomass of land converted to grassland:

For the calculation of annual change in carbon stocks of living biomass of land converted to grassland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_{i} \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where:

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for grassland carbon accumulation rate is 6.3 t C $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 6.4 t C ha^{-1} for perennial cropland, a dynamic value of 110.7 t C ha^{-1} (previous 2000) and 128.7 t C ha^{-1} (after 2010) for forestland with linear interpolation between 2000 and 2010, 5.0 t C ha^{-1} for annual cropland, 4.3 t C ha^{-1} for settlements and 0.0 t C ha^{-1} for wetland and other land- see section 6.2.4.2.1 and Table 6-22).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

i = type of land use converted to another land-use category

b) Changes of carbon stock in dead wood and litter of land converted to grassland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to grassland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stock in mineral soil of land converted to grassland:

Carbon changes in mineral soils due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2

6.4.4.2.1 N_2O emissions in soils of land converted to grassland

The annual release of direct N_2O emissions due to the conversion of land to grassland was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF_1=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral,LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N_2O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LEA\quad(H)} \cdot EF_5$$

where:

$N2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF_5=emission factor for N_2O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$Frac_{LEACH-(H)}$=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)$^{-1}$ (default value = 0.30)

6.5 Wetlands (4.D)

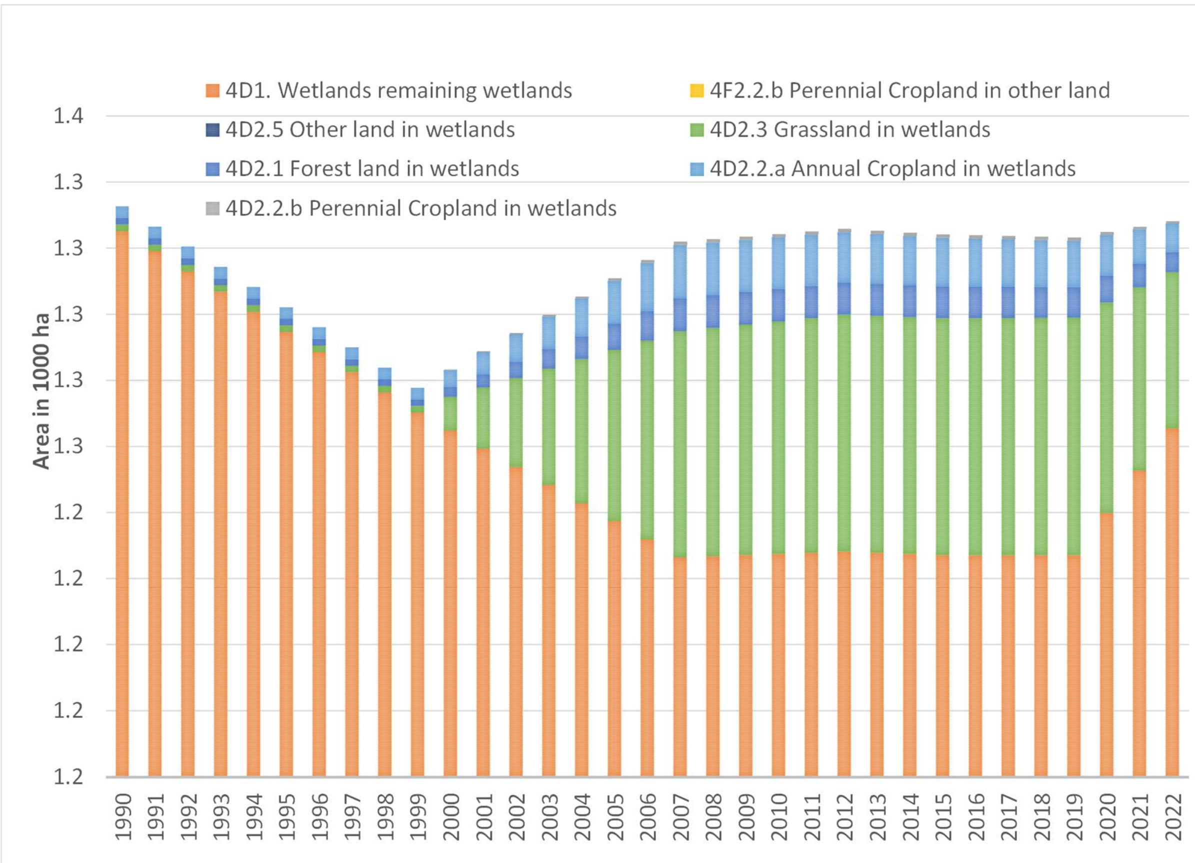
6.5.1 Category description

In this category emissions/removals from land converted to wetland are considered.

Due to the lack of information, it is assumed that the C stock in biomass, dead organic matter and soil of surface waters is zero.

In 2022, 1 347 ha of Luxembourg were wetland (Figure 6-14). Total wetland includes any areas covered by water (rivers, lakes, *etc.*) or saturated by water (marshes, mires, *etc.*). There is no peat land, hence no organic soils in wetlands in Luxembourg.

Figure 6-14 – Trend of wetland and LUC to wetland (20 year conversion period) wetland



The annual emissions from wetland in Luxembourg amounted to 0.15 Gg CO_2 in 1990 and 2.06 Gg CO_2 in 2021 and 0.00002 and 0.0007 GgN_2O (Table 6-29). The source is mainly caused by soil C stock changes in land use change areas, particularly by forestland and grassland converted to wetland.

Table 6-29 – CO_2 removals/emissions for category 4D – Wetland

4D - Wetlands									
	Net CO_2 emissions/removals (Gg)								N_2O (Gg)
Year	4D Total Wetland	4D 1.3 WL -> WL	4D 2.3 Land -> WL	4D 2.3.1 FL -> WL	4D 2.3.2 CL -> WL	4D2.3.3 GL-WL	4D 2.3.4 SL -> WL	4D 2.3.5 OL -> WL	N_2O (*)
1990	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1991	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1992	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1993	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1994	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1995	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1996	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1997	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1998	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
1999	0.15	NA	0.15	0.09	0.03	0.02	0.00	NO	0.00002
2000	0.91	NA	0.91	0.57	0.07	0.21	0.06	NO	0.00003
2001	0.91	NA	0.91	0.57	0.07	0.21	0.06	NO	0.00003
2002	2.91	NA	2.91	0.95	0.25	1.50	0.22	NO	0.00068
2003	2.91	NA	2.91	0.95	0.25	1.50	0.22	NO	0.00068
2004	2.91	NA	2.91	0.95	0.25	1.50	0.22	NO	0.00068
2005	2.91	NA	2.91	0.95	0.25	1.50	0.22	NO	0.00068
2006	2.91	NA	2.91	0.95	0.25	1.50	0.22	NO	0.00068
2007	2.91	NA	2.91	0.95	0.25	1.50	0.22	NO	0.00068
2008	2.23	NA	2.23	0.46	0.21	1.39	0.17	NO	0.00070
2009	2.23	NA	2.23	0.46	0.21	1.39	0.17	NO	0.00070
2010	2.23	NA	2.23	0.46	0.21	1.39	0.17	NO	0.00070
2011	2.23	NA	2.23	0.46	0.21	1.39	0.17	NO	0.00070
2012	2.23	NA	2.23	0.46	0.21	1.39	0.17	NO	0.00070
2013	2.20	NA	2.20	0.45	0.20	1.38	0.17	NO	0.00070
2014	2.20	NA	2.20	0.45	0.20	1.38	0.17	NO	0.00070
2015	2.20	NA	2.20	0.45	0.20	1.38	0.17	NO	0.00070
2016	2.06	NA	2.06	0.20	0.20	1.39	0.27	NO	0.00064
2017	2.06	NA	2.06	0.20	0.20	1.39	0.27	NO	0.00064
2018	2.06	NA	2.06	0.20	0.20	1.39	0.27	NO	0.00064
2019	2.06	NA	2.06	0.20	0.20	1.39	0.27	NO	0.00064
2020	2.06	NA	2.06	0.20	0.20	1.39	0.27	NO	0.00064
2021	2.06	NA	2.06	0.20	0.20	1.39	0.27	NO	0.00064
2022	0.21	NA	0.21	0.01	NO	0.09	0.11	NO	0.00003
Trend 1990-2022	1311.27%	NA	1311.08%	113.65%	612.18%	6472.00%	8170.81%	NA	2474.61%
Trend 2021-2022	0.00%	NA	0.00%	0.00%	0.00%	0.00%	0.00%	NA	0.00%

(*) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matterresulting from change of land use or management of mineral soils

6.5.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.5.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The selected parameters defining wetland are:

Land Use Class	Definition
Wetland	Land that is covered or saturated by water for all or part of the year (*e.g.* peat land) and that does not fall into other categories.
Water	Land that is covered by water for all the year and that does not fall into other categories. This includes reservoirs. (IPCC GPG definition)

6.5.4 Methodological issues

6.5.4.1 Wetlands remaining Wetlands (4D1)

Luxembourg uses IPCC tier 1 assumption taken that carbon stock changes are neutral (i.e. net emissions are equal to net removals).

6.5.4.2 Land Use Changes to Wetlands (4D2)

a) Changes in carbon stock in biomass of land converted to grassland:

For the calculation of the annual change in carbon stocks of living biomass in land converted to wetland the following equation IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for carbon accumulation rate is 0.0 t C $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 6.4 t C ha^{-1} for perennial cropland, a dynamic value of 110.7 t C ha^{-1} (previous 2000) and 128.7 t C ha^{-1} (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha^{-1} for grassland, 4.3 t C ha^{-1} for settlements, 5.0 t C ha^{-1} for annual cropland and 0.0 t C ha^{-1} other land - see section 6.2.4.2.1 and Table 6-22).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

b) Changes of carbon stock in dead wood and litter of land converted to wetland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to wetland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stocks in soil of land converted to wetland

Carbon changes in mineral soils due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2 .

6.5.4.2.1 N_2O emissions in soils of land converted to wetland

The annual release of direct N_2O emissions due to the conversion of land to wetland was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF_1=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral,LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N_2O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LEAC\quad (H)} \cdot EF_5$$

where:

$N2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF_5=emission factor for N_2O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$Frac_{LEACH-(H)}$=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)$^{-1}$ (default value = 0.30)

6.6 Settlements (4.E)

6.6.1 Category description

In this category emissions/removals from land converted to settlements are considered.

In 2022, 30 609 ha of Luxembourg were settlements (Figure 6-15). The area in conversion status from "Land converted to Settlement" causes annual emission due to C stock changes of biomass and soils from 47.67 Gg CO_2 to 22.60 Gg CO_2 and 0.01 and 0.02 GgN2O (Table 6-30).

Annual LUCs to settlement occur from the sub-categories "Forestland", "Cropland", "Grassland", "Wetland" and "Other land".

Figure 6-15 – Trend of settlement and LUC to settlement (20 year conversion period)

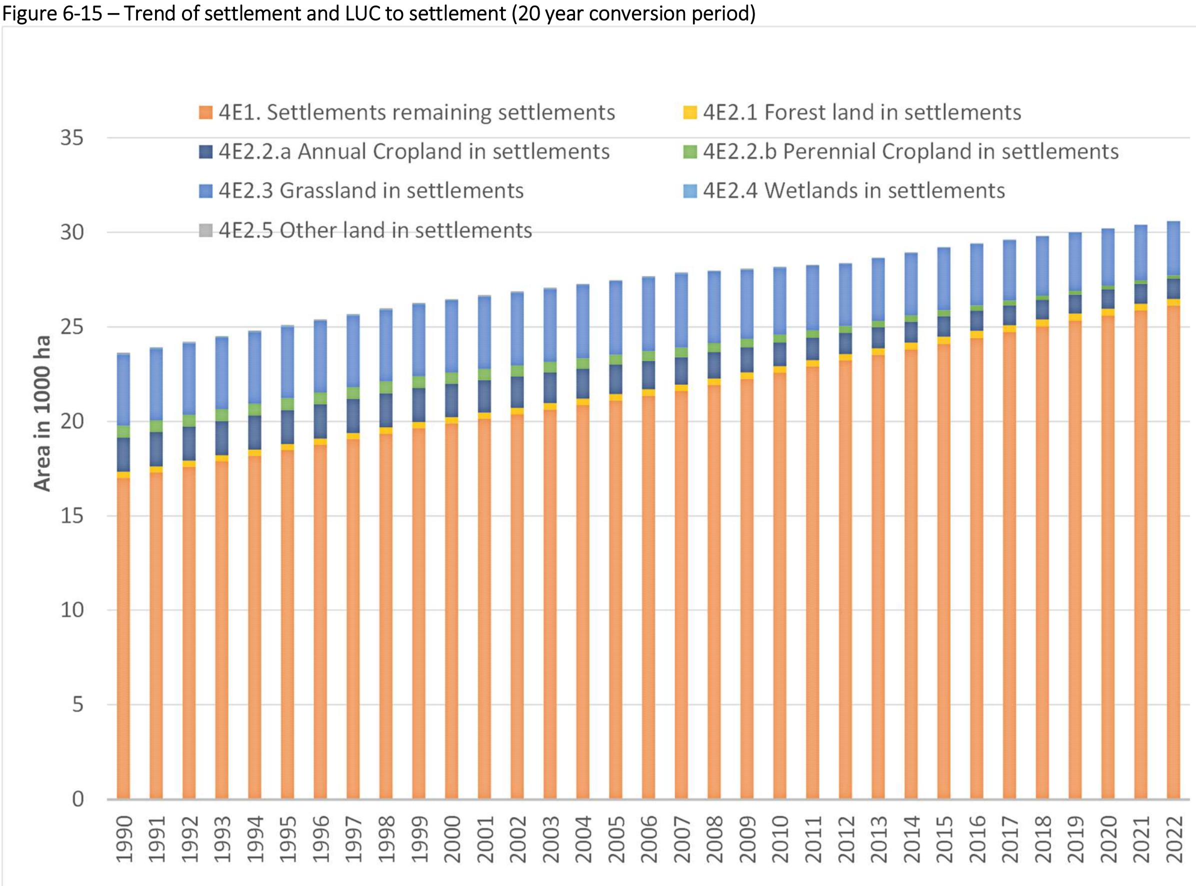


Table 6-30 – CO_2 removals/emissions for category 5E – Settlement

4E - Settlements									
	Net CO_2 emissions/removals (Gg)								N_2O (Gg)
Year	4E Total Settlement	4E1 SL-SL	4E.2 Land -> SL	4E2.1 FL -> SL	4E2.2 CL -> SL	4E2.3 GL -> SL	4E2.4 SL -> WL	4E2.5 OL -> SL	N_2O (*)
1990	29.22	NA	29.22	9.08	3.51	17.28	-0.31	-0.34	0.01
1991	29.22	NA	29.22	9.08	3.51	17.28	-0.31	-0.34	0.01
1992	29.23	NA	29.23	9.09	3.51	17.28	-0.31	-0.34	0.01
1993	29.24	NA	29.24	9.10	3.51	17.28	-0.31	-0.34	0.01
1994	29.24	NA	29.24	9.10	3.51	17.28	-0.31	-0.34	0.01
1995	29.25	NA	29.25	9.11	3.51	17.28	-0.31	-0.34	0.01
1996	29.25	NA	29.25	9.11	3.51	17.28	-0.31	-0.34	0.01
1997	29.26	NA	29.26	9.12	3.51	17.28	-0.31	-0.34	0.01
1998	29.26	NA	29.26	9.12	3.51	17.28	-0.31	-0.34	0.01
1999	29.27	NA	29.27	9.13	3.51	17.28	-0.31	-0.34	0.01
2000	30.50	NA	30.50	11.03	2.53	17.57	-0.31	-0.33	0.01
2001	30.56	NA	30.56	11.03	2.60	17.55	-0.31	-0.32	0.01
2002	47.37	NA	47.37	12.30	4.34	31.43	-0.44	-0.27	0.01
2003	47.43	NA	47.43	12.30	4.42	31.41	-0.44	-0.26	0.01
2004	47.49	NA	47.49	12.30	4.49	31.39	-0.44	-0.26	0.01
2005	47.55	NA	47.55	12.30	4.56	31.37	-0.44	-0.26	0.01
2006	47.61	NA	47.61	12.30	4.64	31.35	-0.44	-0.25	0.01
2007	47.67	NA	47.67	12.31	4.71	31.33	-0.44	-0.25	0.01
2008	43.87	NA	43.87	8.35	4.58	31.61	-0.43	-0.25	0.02
2009	44.16	NA	44.16	8.36	4.70	31.76	-0.43	-0.24	0.02
2010	45.20	NA	45.20	9.13	4.82	31.92	-0.42	-0.24	0.02
2011	45.49	NA	45.49	9.14	4.94	32.07	-0.42	-0.24	0.02
2012	45.79	NA	45.79	9.15	5.06	32.23	-0.42	-0.23	0.02
2013	45.25	NA	45.25	19.91	3.26	22.28	-0.17	-0.03	0.01
2014	45.26	NA	45.26	19.90	3.29	22.26	-0.16	-0.03	0.01
2015	45.28	NA	45.28	19.89	3.32	22.25	-0.16	-0.02	0.01
2016	39.09	NA	39.09	10.88	3.86	24.54	-0.17	-0.01	0.01
2017	39.23	NA	39.23	10.89	3.92	24.61	-0.17	-0.01	0.01
2018	39.38	NA	39.38	10.90	3.98	24.68	-0.17	-0.01	0.01
2019	39.52	NA	39.52	10.91	4.04	24.75	-0.17	-0.01	0.01
2020	39.61	NA	39.61	10.92	4.03	24.84	-0.16	-0.01	0.01
2021	39.70	NA	39.70	10.93	4.02	24.93	-0.16	-0.01	0.01
2022	22.60	NA	22.60	9.54	2.06	11.04	-0.03	-0.01	0.01
Trend 1990-2022	-22.64%	NA	-22.64%	5.14%	-41.23%	-36.14%	-89.55%	-97.95%	-33.65%
Trend 2021-2022	-43.07%	NA	-43.07%	-12.67%	-48.65%	-55.73%	-79.93%	-15.06%	-51.96%

(*) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matterresulting from change of land use or management of mineral soils

6.6.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.6.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The selected parameters defining settlements are:

Land Use Class	Definition
Settlements	All developed land, including transportation and any size of human settlement unless already included under other categories.(IPCC GPG definition)

The settlement area in correspondence to the LULUCF category comprises the following subcategories:

3) building land : sealed, partly sealed and unsealed area,

4) parks and gardens,

5) road, railway, track and excavation area,

6) other, not further differentiated settlement area.

6.6.4 Methodological issues

6.6.4.1 Settlements remaining Settlements (4E1)

Luxembourg uses IPCC tier 1 assumption taken that carbon stock changes are neutral (i.e. net emissions are equal to net removals).

6.6.4.2 Land Use Changes to Settlements (4E2)

<u>a) Changes in carbon stock in biomass of land converted to settlements:</u>

For the estimation of biomass stock and biomass growth in settlements, data from the 2018 land use and land cover maps was used.

Figure 6-16 estimation of trees, bushes and grass cover in settlement areas

Aerial photograph of airport and adjacent golf course

2018 land use map showing different settlements land use areas (pink=airport, blue=golf course, yellow roads etc)

2018 land cover map showing grass cover (light = green, tree = dark green, green = bushes, grey = constructed areas, pink = buildings etc

Since 2018 Luxembourg has also produced land cover maps along land use maps. The figure here above is showing the example of the area around the airport area. The land use maps identify different types of settlement areas. In this case it would be the airport (pink), gollf course (blue) but also roads (yellow), office areas, settlement areas and so forward. The land cover map, on the other hand, provides maps on the different land cover types (buildings, herbaecous areas, trees, bushes, bare soil, water and other contructed areas). The land use map of all settlement areas (country wide) was overlayed with the land cover maps. As a result the following results were obtained for tree, bushes and grassland cover in settlement areas:

- share of grassland inside settlement (2018): 28.9 %
- share of bushes inside settlement (2018): 8.3 %
- share of trees inside settlement (2018): 15.8 %

The share of trees inside the settlement area was multiplied with the default crown cover area-based growth rates (CRW) for urban trees in cold temperate regions as published in the IPCC GPG 2019 (Table 8.1 revised). This resulted in an annual growth of trees in settlement areas of 0.33 t C/ha*y. For shrubs and annual plants, an annual growth rate of 0.125 and 3.2 t C/ha*y, respectively, at unsealed settlement areas was taken. Due to the lack of own data sources, these values were derived from the related estimates for

Austria which are based on a study for the city of Vienna (Dörflinger, Hietz, Maier, Punz, & Fussenegger, 1995). From these values and the percentage of bushes and grassland area per ha settlement the annual C stock growth rate of biomass per settlement area (sealed plus unsealed) was estimated: 0.34 t C/ha*y for perennial plants and 0.92 t C/ha*y for annual plants. These annual biomass growth rates were assumed to be a valid average for settlement areas in Luxembourg and were used for areas of LUCs to settlement and for the 20 years of transition period after LUC (perennial plants) or for the first year after LUC only (annual plants).

For the biomass losses at LUC areas from settlements to other land uses the same data origins were used. The average biomass C stock at these areas was estimated to represent an equivalent of 20 years of growth of the tree and shrub biomass with the annual growth rates above and one biomass of annual plants. This results in a total biomass stock of 7.77 t C/ha to be present per ha settlement area. The rationale, for the 20-year growth period (because at 20 years trees are comparatively small), is that settlement areas with an equal distribution of older and younger biomass stocks are converted. Therefore, from a range of settlement areas with biomass stocks representing 1 year to 40 years of growth that are converted, the biomass stock from this range of land-use change areas is the average one of 20 years.

The methodology and activity data are described in chapter 6.2.4. However, the perennial plants in the settlement areas are estimated with a continued annual growth during the whole LUC transition period of 20 years as described in chapter 6.6.4.2.

For the calculation of the annual change in carbon stocks of living biomass in land converted to settlements the following equation IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where:

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.34 t C $ha^{-1}yr^{-1}$ for perennial plants for a period of 20 years and 0.92 t C $ha^{-1}yr^{-1}$ for annual plants for a period of 1 year.

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 6.4 t C ha^{-1} for perennial cropland, a dynamic value of 110.7 t C ha^{-1} (previous 2000) and 128.7 t C ha^{-1} (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha^{-1} for grassland, 5.0 t C ha^{-1} for annual cropland and 0.0 t C ha^{-1} for wetland and 0.0 t C ha^{-1} other land - see section 6.2.4.2.1 and Table 6-22.

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

<u>b) Changes of carbon stock in dead wood and litter of land converted to settlements:</u>

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to settlements equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stocks in soil of land converted to settlements

The following assumptions were taken to estimate the soil C stock in settlements. Sealed areas were assumed to have a soil C stock of 0 t C/ha. The unsealed settlement area of 53 % (28.9 % share of grassland + 8.3 % share of bushes and 15.8 % share of trees) was assumed to have the same soil C stock as grassland in Luxembourg (107 t C/ha). This resulted for total settlement in a soil C stock of 56.9 t C/ha which was used as initial soil C stock before LUC from settlement to other land uses or as final soil C stock after 20 years of transition after LUC to settlement.

Carbon changes in mineral soils due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2 .

6.6.4.2.1 N_2O emissions in soils of land converted to settlements

The annual release of direct N_2O emissions due to the conversion of land to settlements was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF_1=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral,LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N_2O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LEACH-(H)} \cdot EF_5$$

where:

$N2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF_5=emission factor for N_2O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$Frac_{LEACH-(H)}$=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)$^{-1}$ (default value = 0.30)

6.7 Other Land (4.F)

6.7.1 Category description

In this category emissions/removals from land converted to other land are considered.

In 2022, 23 ha of Luxembourg were considered as other land Figure 6-17. The area in conversion status from “Land converted to Other Land” causes annual emission rates due to C stock changes of biomass and soils from 0.31 Gg CO_2 to 0.01 Gg CO_2 and 0.00001 and 0.00002 GgN_2O (Table 6-31).

Annual LUCs to other land occur in the sub-categories "Forestland", "Cropland", "Grassland", “Settlements” and "Wetland".

Figure 6-17–Trend of Other Land and LUC to Other Land (20 year conversion period)

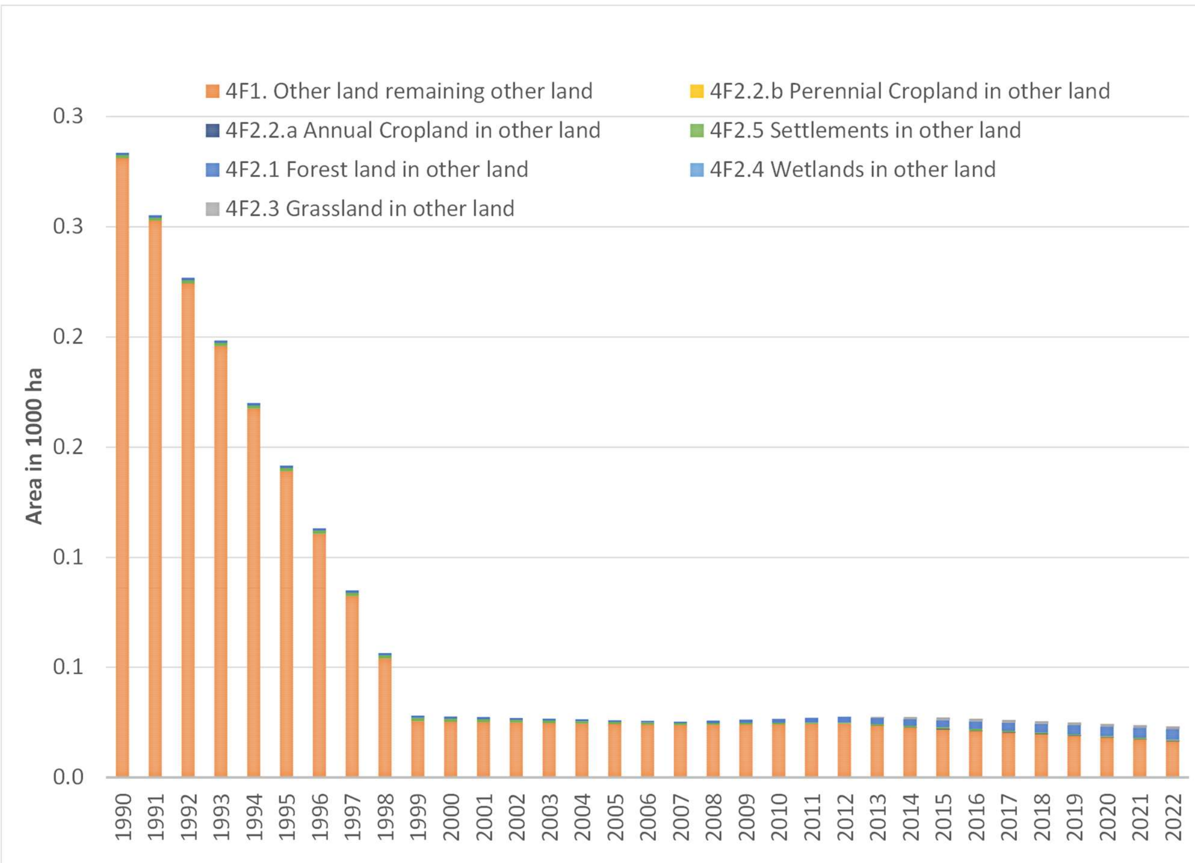


Table 6-31– CO_2 removals/emissions for category 4F – Other land from

4F - Other land									
	Net CO_2 emissions/removals (Gg)								N_2O (Gg)
Year	4F Total other land	4F1 OL-OL	4F2 Land -> OL	4F2.1 FL -> OL	4F2.2 CL -> OL	4F2.3 GL -> OL	4F2.4 WL -> OL	4F2.5 SL -> OL	N_2O (*)
1990	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1991	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1992	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1993	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1994	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1995	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1996	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1997	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1998	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
1999	0.05	NA	0.05	0.04	NO	NO	NO	0.01	0.00
2000	0.02	NA	0.02	0.01	NO	NO	NO	0.01	0.00
2001	0.02	NA	0.02	0.01	NO	NO	NO	0.01	0.00
2002	0.01	NA	0.01	NO	NO	NO	NO	0.01	0.00
2003	0.01	NA	0.01	NO	NO	NO	NO	0.01	0.00
2004	0.01	NA	0.01	NO	NO	NO	NO	0.01	0.00
2005	0.01	NA	0.01	NO	NO	NO	NO	0.01	0.00
2006	0.01	NA	0.01	NO	NO	NO	NO	0.01	0.00
2007	0.01	NA	0.01	NO	NO	NO	NO	0.01	0.00
2008	0.28	NA	0.28	0.28	NO	NO	NO	0.01	0.00
2009	0.28	NA	0.28	0.28	NO	NO	NO	0.01	0.00
2010	0.31	NA	0.31	0.31	NO	NO	NO	0.01	0.00
2011	0.31	NA	0.31	0.31	NO	NO	NO	0.01	0.00
2012	0.31	NA	0.31	0.31	NO	NO	NO	0.01	0.00
2013	0.20	NA	0.20	0.16	0.00	0.02	NO	0.01	0.00
2014	0.21	NA	0.21	0.16	0.00	0.03	NO	0.01	0.00
2015	0.21	NA	0.21	0.16	0.00	0.03	NO	0.01	0.00
2016	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
2017	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
2018	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
2019	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
2020	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
2021	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
2022	0.17	NA	0.17	0.17	NO	NO	NO	NO	0.00
Trend 1990-2022	258.61%			356.55%	NA	NA	NA	NA	NA
Trend 2021-2022	0.06%			0.06%	NA	NA	NA	NA	NA

(*) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matterresulting from change of land use or management of mineral soils

6.7.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.7.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The selected parameters defining other land are:

Land Use Class	Definition
Other land	This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

The other land area in correspondence to the LULUCF category comprises the following subcategories:

7) Rocks and screes
8) Land with no vegetation,
9) Abandoned quarries.

6.7.4 Methodological issues

6.7.4.1 Other Land remaining Other Land (4F1)

Luxembourg uses IPCC tier 1 assumption taken that carbon stock changes are neutral (i.e. net emissions are equal to net removals).

6.7.4.2 Land Use Changes to Other Land (4F2)

6.7.4.2.1 Biomass and soil

According to the land use assessment systems OBS89, OBS99 and OBS07, other land in Luxembourg is constituted by rocks, scree slopes and gravel areas. It is assumed that these areas have no C stock in biomass and soil, so 0 was used as previous or final C stock at areas of LUCs from or to other land, respectively.

For the calculation of the annual change in carbon stocks of living biomass in land converted to wetland the following equation IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.0 t C $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha^{-1} (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 6.4 t C ha^{-1} for perennial cropland, a dynamic value of 110.7 t C ha^{-1} (previous 2000) and 128.7 t C ha^{-1} (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha^{-1} for grassland, 4.3 t C ha^{-1} for settlements, 5.0 t C ha^{-1} for annual cropland and 0.0 t C ha^{-1} other land - see section 6.2.4.2.1 and Table 6-22).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO\_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr^{-1}.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$.

b) Changes of carbon stock in dead wood and litter of land converted to other land:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to other land equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stocks in soil of land converted to other land

Carbon changes in mineral soils due to land use changes between perennial cropland and annual cropland are based on the calculation method described in section 6.2.4.2.2 .

6.7.4.2.2 N_2O emissions in soils of land converted to other land

The annual release of direct N_2O emissions due to the conversion of land to other land was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF_1=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral,LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N_2O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LEA} \quad _{(H)} \cdot EF_5$$

where:

$N2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF_5=emission factor for N_2O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$Frac_{LEACH-(H)}$=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)$^{-1}$ (default value = 0.30)

6.8 Uncertainties and time-series consistency

6.8.1 Uncertainties in relation to the emission factors extracted from the NFI

In order to calculate the uncertainties within the forestland category a study was commissioned in order to estimate the errors related to the individual emission factors extracted from the NFI (Bauwens, 2015) as well as a study to estimate errors relating to activity data from land use changes ((Kleeschulte, Korzeniowska,, & Philipsen, 2021).

There are many sources of uncertainty in forest biomass estimates (section 3.1.5 of the volume1 of the 2006 IPPC guidelines) and many intermediate steps are necessary to estimate the individual parameters (biomass, biomass growth rate, biomass expansion factor etc) extracted from NFI data. An error is associated with each of these intermediate steps. The global uncertainty related to any other parameter combines all those individual uncertainties. Due to the nature of the NFI (sampling method) the “statistical random sampling error” is also part of the whole uncertainty assessment. The error related to the estimations is based on statistical formula relating the standard error of the mean and the t-student variable with a risk of 5 % as recommended by IPCCC guidelines.

$$\boldsymbol{\widehat{SE}_x = \frac{\hat{\sigma}_x}{\sqrt{n}} = \frac{\sum(x-\bar{x})^2}{\sqrt{(n-1)n}}}$$

$$Error\ (\%) = t_{1-\frac{\alpha}{2}} \cdot \frac{\widehat{SE}_x}{\bar{x}}$$

where:

$\widehat{SE}_x$, the estimated standard error of the variable x

$\hat{\sigma}_x$, the estimated standard-deviation of the variable x;

n the total number of sample;

$\bar{x}$ the mean of the variable x;

t the t-student variable with a risk .

In order to estimate carbon stock the NFI used species-specific values for biomass expansion factors, wood density and below-ground to above-ground biomass rations (R). The biomass expansion factors are based on a detailed study by (Dagnelies, Palm, & Rondeux, 2013) and are estimated at ±15%. It seems reasonable to assume that a specific calculated value a smaller error has than the default value of 29%, as found in TABLE 3A.1.10, for temperate coniferuous and broadleaf. The below-ground to above-ground biomass rations (R) are based on a study by (Vande Walle, et al., 2005) which itself is based on a comparison of values used across Europe. Hence the default error values of ±93% for coniferous wood (value R=0.2 [0.12-0.49]) and ±56% for deciduous wood (value R=0.24 [0.17-0.44]) were used. The values of wood density chosen for the NFI are based on (Wagenführ & Schreiber, 1985). Here as well the default value for uncertainty from IPCC guidelines was chosen. The latter one is estimated to be between 10-40% and hence the value was set at ±25%. The uncertainty on the carbon factor is also based on the default value of ±5.3 % (0.47 [0.44-0.49]). For litter the default emission factor and associated uncertainty were extracted from the IPCC guidelines (weighted average of deciduous 16 tC/ha^{-1} (5 tC/ha^{-1} - 31 tC/ha^{-1}) and coniferous 26 tC/ha^{-1} (10 tC/ha^{-1} – 48 tC/ha^{-1}).

Those calculations translated into the following errors for the individual emission factors:

Table 6-32 – Errors linked to emission NFI factors (t C/ha)

emission factor	Sample size	Stedv (sample)	value	error
Above ground biomass growth coniferous trees	415	0.21 t/ha/a	7.83 tC/ha^{-1}	±30%
Above ground biomass growth deciduous trees	219	0.10 t/ha/a	4.40 tC/ha^{-1}	±30%
Below ground biomass growth coniferous trees	415	0.04 t/ha/a	1.54 tC/ha^{-1}	±97.3%
Below ground biomass growth deciduous trees	219	0.02 t/ha/a	1.01 tC/ha^{-1}	±63.8%
Above ground biomass growth trees 0-20y	95	0.39 t/ha/a	5.53 tC/ha^{-1}	±32.7%
Below ground biomass growth trees 0-20y	95	0.08 t/ha/a	1.12 tC/ha^{-1}	±81.2%
Dead wood	1126	0.60 t/ha/a	11.96 tC/ha^{-1}	±36.6%
Litter (default IPPC)			19.20 tC/ha^{-1}	±77.2%
Biomass carbon stocks in forests (above-and below ground)	1576	3.94 t/ha/a	119.7 tC/ha^{-1}	±80.3%

The data on wood harvest is based on data extracted from the NFI as well as from yearly data of wood sales from public forests. The error applied on those figures is the default value of ±20% (IPPC guideline page 4.19).

6.8.2 Uncertainties of activity data in relation to area (activity data)

A thematic validation of several land use changes was carried out to determine the uncertainty associated with particular change types and the years where they have occurred. The uncertainty assessment was carried out by (Kleeschulte, Korzeniowska,, & Philipsen, 2021) and was carried out for the following change types:

- Any land to Forest Land (L-FL) – representing potential afforestation;
- Forest Land to any land (FL-L) – representing potential deforestation;
- Any land to Settlement (L-SL) – representing land take / artificialisation;
- Forest Land remaining Forest Land (FL-FL).

For each of the four change types a set of 400 points has been sampled from the point grid (version 5) for each of the six reference years (1989, 1999, 2007, 2012, 2015 and 2018). This adds up to 400 (points) x 4 (land use transitions) x 5 (temporal transitions) = 8,000 sampling points to be validated with respect to its initial and its final LULUCF category. The following reference data was used;

- 1989: Grayscale monochrome aerial photographs from 1987, not orthorectified, only roughly georeferenced Topographic map of 1989
- 1999: Orthophotos from 2001 and topographic map of 2000
- 2007: Orthophotos from 2007
- 2012: Orthophotos from 2013
- 2015: Orthophotos from 2016
- 2018: Orthophotos from 2018

Table 6-33 Uncertainty assessment and related area values

Time period	Transition	Area (ha)	Lower limit	Upper limit
1989 - 1999	FL-FL	92 357	88 377	91 297
	FL-L	682	287	354
	L-FL	805	488	563
	L-SL	3 323	2 342	2 625
1999 – 2007	FL-FL	97 702	92 702	92 702
	FL-L	460	255	299
	L-FL	617	252	312
	L-SL	2 321	1 891	2 054
2007 – 2012	FL-FL	93 235	93 234	93 235
	FL-L	84	56	66
	L-FL	63	13	20
	L-SL	479	429	454
2012 – 2015	FL-FL	93 098	89 959	92 517
	FL-L	200	148	164
	L-FL	110	46	57
	L-SL	1 011	545	643
2015 – 2018	FL-FL	93 143	91 657	93 232
	FL-L	65	50	56
	L-FL	3	-	-
	L-SL	662	582	619

6.8.3 Uncertainties of emission factors from soil samples

According to the methodology described in 6.3.1 carbon stock changes have been measured for the individual regions and soil covers in Luxembourg. The error computed here represents the standard deviation of the individual sample plots multiplied by two. This is in line with the first footnote of Table 2.3 (IPPC Guidelines – Chapter 2) where “a nominal error estimate of ± 90% (expressed as 2x standard deviations as percent of the mean)” was provided for standard soil organic carbon stocks.

Table 6-34 – Carbon soil stocks and errors per land use and soil type (t C/ha) in Luxembourg

	Carbon soil stocks per land use and soil type (t C/ha) and error (%)			
Soil type	Cropland (Annual Cropland)	Grassland	Forestland	Vineyard (Perennial cropland)
Oesling	91.5 ± 27%	89.2 ± 13%	132.2 ± 20%	71.0 ± 0%
Buntsandstein	66.7 ± 29%	82.8 ± 26%	112.1 ± 41%	73.5 ± 0%
Dolomies du Muschelkalk	85.5 ± 35%	112.1 ± 28%	117.0 ± 20%	77.9 ± 0%
Calcaires du Bajocien	75.2 ± 33%	122.0 ± 16%	111.5 ± 21%	77.7 ± 0%
Grès de Luxembourgs	50.7 ± 25%	83.3 ± 31%	80.6 ± 23%	76.2 ± 0%
Dépôts limoneux sur Grès	58.6 ± 36%	99.4 ± 35%	95.7 ± 25%	75.1 ± 0%
Argiles du Lias inf. et moyen	69.8 ± 35%	121.6 ± 21%	95.2 ± 21%	75.7 ± 0%
Argiles lourdes du Keuper	67.7 ± 40%	121.3 ± 23%	102.6 ± 22%	76.0 ± 0%
Argiles lourdes des schistes bitumineux	88.2 ± 46%	145.7 ± 14%	104.8 ± 17%	NA
Others	80.7 ± 61%	110.8 ± 28%	126.6 ± 55%	74.9 ± 0%
ALL	**76.8 ± 48%**	**107.4 ± 37%**	**110.7 ± 42%**	**73.5 ± 4%**

It is important to highlight that the error on the mean is very low because the amount of soil samples is very high. Hence the confidence interval on the mean value is also very narrow (the probability that the average value measured corresponds to the true average value is hence very high). If the total carbon content was calculated as a total figure for the whole country the error would also be very low. For the purpose of IPPC calculations the carbon soil contents are however used to determine carbon soil changes due to land use change at parcel level. This means that the variability of the samples has to be taken into account. Compared to the error of the mean the variability of the dataset is however very high. Because the variability has to be considered, when calculating carbon stock changes due to land use change, the overall error on carbon stock changes associated with land is very high. This error cannot be reduced by taking more soil samples.

With the help of the geospatial data set on soil associations in Luxembourg (Figure 6-10) and its land use category, the median value of soil organic carbon was attached to each grid point. Carbon stock changes were then computed at grid level. The carbon stock changes and the associated erros were also calculated at grid level. For a land use change in the soil association “Argiles du Lias inf. et moyen” the emission factors and associtated errors from Table 6-36 were used.

Table 6-35 – Land use change matrix for soil carbon emission factors with errors (t C/ha*yr) in "Argiles du Lias inf. et moyen"

from \ to	Forest land	Annual Cropland	Perennial Cropland	Grassland	Wetland	Settlement	Other land
Forest land	0	-1.8 ±176%	-1.2 ±196%	-0.5 ±672%	-5. ±306%	-3.4 ±306%	-5.6 ±306%
Annual Cropland	1.8 ±176%	0	0.5 ±433%	1.3 ±221%	-3.8 ±306%	-1.6 ±306%	-3.8 ±306%
Perennial Cropland	1.2 ±196%	-0.5 ±433%	0	1.5 ±138%	-3.8 ±306%	-1.6 ±306%	-3.8 ±306%
Grassland	0.5 ±672%	-1.3 ±221%	-1.5 ±138%	0	-5.1 ±306%	-2.9 ±306%	-5.1 ±306%
Wetland	5.6 ±306%	3.8 ±306%	3.8 ±306%	5.1 ±306%	0	2.2 ±306%	0.000
Settlement	3.4 ±306%	1.6 ±306%	1.6 ±306%	2.9 ±306%	-2.2 ±306%	0	-2.2 ±306%
Other land	5.6 ±306%	3.8 ±306%	3.8 ±306%	5.1 ±306%	0.0 ±306%	2.2 ±306%	0 ± 27%

Table 6-35 indicates the errors of the emission factors used for calculation of soil carbon stock changes in the soil association "Argiles du Lias inf. et moyen". The errors are calculated by taking into account the individual errors of carbon soil content categories as well as the variability. As the matrix is giving the difference between two levels of carbon soil contents the relative errors (in %) becomes very high. The table was established for all soil assocoitation. For the categories wetland, settlements, grassland and other land the average error of the remaining categories was chosen. Uncertainties of emission factors from biomass carbon stocks

Table 6-36 – Errors linked to emission factors of biomass carbon stock (t C/ha)

emission factor	value	error	origin
biomass carbon stock for perennial cropland (see Table 6-23)	6,3 tC/ha^{-11}	±75%	IPPC default value (Table 5.1)
biomass carbon stock for annual cropland	5,0 tC/ha^{-1}	±75%	IPPC default value (Table 5.9)
biomass carbon stock for grassland	6,3 tC/ha^{-1}	±75%	IPPC default value (Table 6.4)
biomass carbon stock for wetland	0,0 tC/ha^{-1}	±0%	
biomass carbon stock for settlements	4,3 tC/ha^{-1}	±75%	See comment here below
biomass carbon stock for other land	0,0 tC/ha^{-1}	±0%	

The error for N2O emissions is a combination of the error on the C/N ratio (±40%) and the error of the linked calculation of carbon emission. The biomass carbon stock for settlement is not known as is has been estimated by analysing land use maps of settlement areas. For this reason it was assumed that the error is identical to the error proposed by IPPC default value for perennial cropland, annual cropland and grassland.

6.8.4 Overall uncertainty assessment

Compared to the other sectors the LULUCF sector is particular as it does not only cover CO_2 emission but also CO_2 removals. This means that the calculated uncertainties are best evaluated for emissions and removals separately in order to get a good understanding of the quality of the data collected.

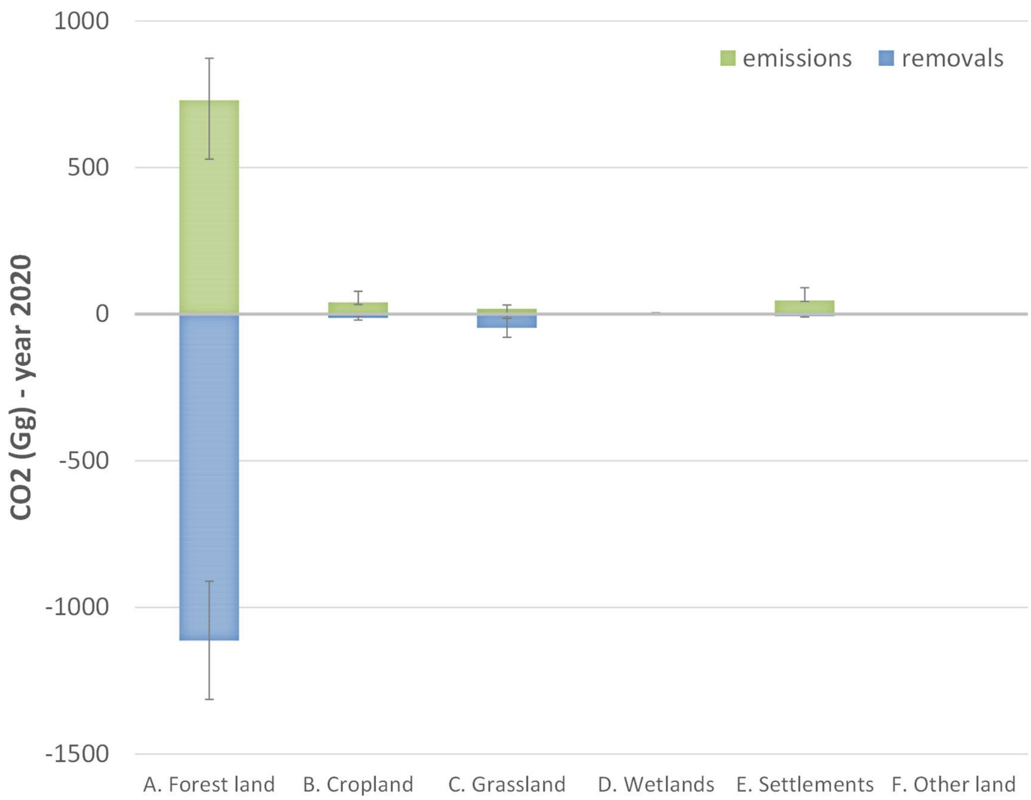
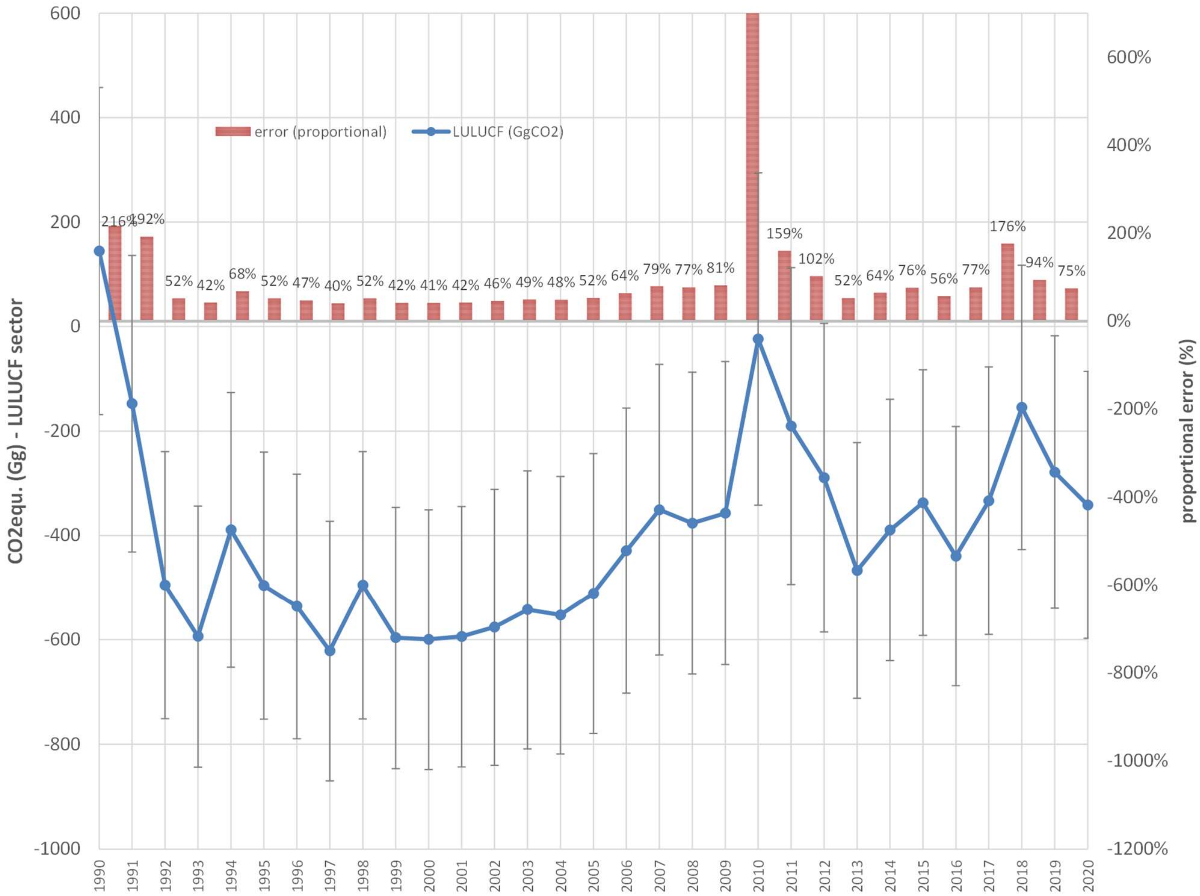


Figure 6-18 – Errors in the LULUCF sector by land use categories and by removals and emissions

Figure 6-18 highlights how the overall LULUCF sector is mainly influenced by emissions and removals in the forest sector. The error on emissions and removals for the forest sector are ±17 % and ±19 %. Considering that the error related to the total forest area is very low (Table 6-33) the uncertainty is mainly influenced by uncertainty from growth factors, carbon stock, dead wood etc (Table 6-32). The other land use and land use change categories contribute a lesser extend to the overall emissions and removals of the LULUCF sector. As a result the uncertainty of those categories (and for example uncertainty in soil carbon -Table 6-34) do hardly influence the overall uncertainty of the LULUCF sector.

Figure 6-19 – Absolute and proportional error in relation to total emissions in LULUCF sector



For the year 2020 the proportional error is 74 %. The proportional error is strongly dependant on the ratio of removals and emissions. The error tends towards infinity as the sum of removals and emissions tends to zero. This is very striking when comparing the year 2010 with any of the years in Figure 6-19. The absolute error is more or less constant but the proportional error is much higher for the year 2010 where the sum of emissions and removals was close to zero. In order to qualify the errors of the LULUCF sector it is hence more useful to assess the error separately for the emissions and removals as it is done in Figure 6-18. The proportional error of the LULUCF sector can only be used to assess the error on the overall result but cannot be used to assess the quality of the underlying data.

6.8.5 Time series consistency

Within the LULUCF land use change matrixes are the most critical type of data when analysing time series consistency. Other emission factors have been used consistently for the entire time series. When, for example new emission factors from the second NFI were being introduced the entire time series was subsequently being updated in order to reflect those new emission factors (e.g. growth rates).

Table 6-3 higlights the specifities of the different geospatial datasets that were used in order to calculate land use change matrixes. The individual maps were not created to calculate land use changes but rather to produce the best land representation for individual yeas. Hence the maps have different minimum mapping units, different land use categories, different representation of road network, interpretation of clearcuts in forests, small deviations on object delineation (leading to sliver polygons when comparing different years. In order to address some issues, LU decided to use a point-based approach where an evenly spaced point grid that is used to check whether the LU class has changed (see Figure 6-4). This reduces the probability of inclusion of LU change errors that would be kept by considering the datasets in polygon format. A 50m grid database was filled by allocating the LULUCF category from the respective LULUCF yearly data sets to the grid sample point. As the 2018 data is geometrically and thematically probably the most accurate data set (based on the use the 20cm orthophotos and LiDAR for its production), it was decided to maintain the LULUCF category from 2018 also to all other observation years, if there was no information coming from one of the change databases that would indicate a change. For agricultural the national Land Parcel Information System (LPIS / FLIK) data was used for the years of 2012, 2015 and 2018. Despite all the actions to make the database as consistent as possible, still a number of points showed some inconsistencies in the time patterns over the six observation years. As a result, thematic correction of LULUCF codes in the grid database were carried out based on a rule set for the correction of grid points based on time series of LULUCF codes. (Eg If one point in the time series is different (not 1989 or 2018) then recode point to 2018)

6.9 Harvested Wood Products (4.G)

LU does unfortunately not have very reliable data on HWP and has in the past not provided estimates on this carbon pool. The lack of reliable data can be partly explained by the small size of the country with high import and export of wood products. LU has addressed certain issues regarding incomplete and inconsistent datasets by using a different range of conservative hypothesis and simplifications.

Emissions from the use and disposal of harvested wood products are estimated using the model described in (Hirashi, et al., 2014). The basis of this model is the first order decay function which simulates total stock volumes depending on the life expectancy of products. The life expectancy of HWP is described by using half-life values. The half-life is the number of years it takes for the quantity of carbon stored in a harvested wood products category to decrease to one half of its initial value. The evolution of stock volumes are calculated using the following equations:

$$C(i+1) = e^{-k} \cdot C(i) + \left[\frac{1-e^{-k}}{k}\right] \cdot Inflow\ (i)$$ (Equation 6-1)

$$\Delta C(i) = C(i+1) - C(i)$$ (Equation 6-2)

where :

i = year

C(i) = the carbon stock in the particular HWP category at the beginning of the year i, (GgC), LU uses a carbon conversion factor of 0.229 Mg C/m³ for sawnwood and a carbon conversion factor for sawnwood of 0.269 Mg C/m³ for wood-based panels (table 2.8.1 of the KP Supplement (p.161).

k = decay constant of first order decay function for each HWP category given in units yr^{-1} (k=ln(2)/HL, where HL is the half-life of the HWP pool in years

Inflow(i) = the inflow to the particular HWP category during the year i (GgC/a)

ΔC(i) = carbon stock change of the HWP category during year i (GgC/a)

The evolution of stock volumes is carried for two different types of products: sawnwood (which has a half-life of 35 years) and wood-based panels (which have a half-life of 25 years).

LU chose to use the production approach which estimates the net change of the proportion of the HWP carbon pool that originates from wood harvested in LU. Hence, imported HWP is not be accounted for. The share of industrial roundwood for the domestic production of HWP originating from domestic forests is calculated for each year is calculated with the following equation (Hirashi, et al., 2014):

$$f_{IRW}(i) = \frac{IRW_P(i) - IRW_{EX}(i)}{IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i)}$$ (Equation 6-3)

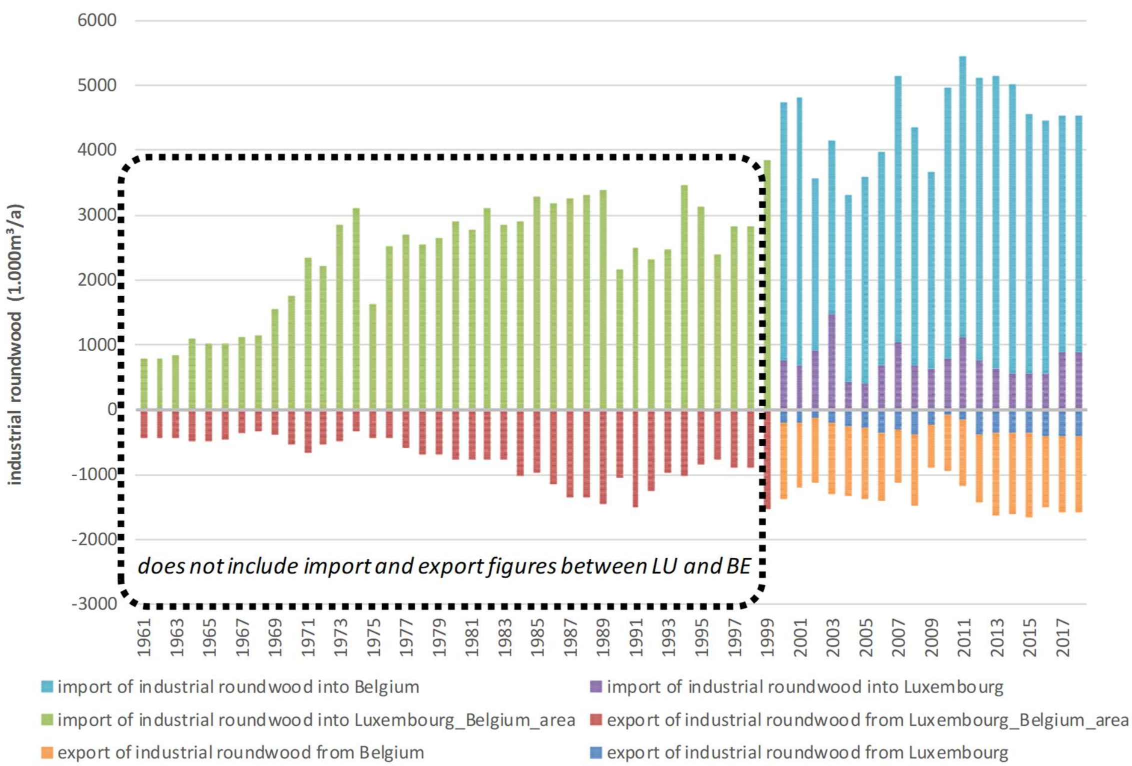
6.9.1.1 Data available in the FAO database

FAOSTAT-Forestry provides annual production and trade estimates for numerous forest products, primarily wood products such as roundwood, sawnwood, wood panels, pulp and paper. For most countries, historical data are available from 1961 onwards. These estimates are provided by countries through an annual survey conducted by FAO (JFSQ questionnaire). In cases where countries have not provided information through the questionnaire, FAO estimates annual production. The LU forest agency is responsible for submitting this questionnaire. For LU the JFSQ questionnaire is often prefilled with import and export data from Eurostat (comex). The comex database does however only include import and export data but not production of HWP. The forest agency only submits data on production data on roundwood (industrial roundwood, sawlogs, and pulpwood). Production data on wood-based panels, sawnwood, wood pulp, paper etc have only submitted occasionally and were based on basic production capacity figures of individual factories rather than actual production figures.

6.9.1.2 Data available on production, imports and exports of industrial roundwood

In order to use the production approach, the share of industrial roundwood, originating from domestic forests, for the domestic production of HWP needs to be calculated. Furthermore, data for the main HWP categories need to date back, ideally, to 1960. For most countries data on HWP categories in the FAO database date back to 1960. For Luxembourg this is unfortunately not the case as all the data on HWP categories only date back to the year 2000. From 1961 until 2000 data is combined for Luxembourg and Belgium who are jointly considered as one region. Figure 6-20 is showing import and export of industrial roundwood retrieved from the FAO database for Luxembourg, Belgium and the Luxembourg-Belgium area.

Figure 6-20 import and export of industrial roundwood in Luxembourg and Belgium (source: FAO)



As Luxembourg and Belgium are considered as one region between 1961 and 2000, fluxes of roundwood between both countries are not available. This is visible in Figure 6-20 as there is a clear jump in combined export and import figures between both countries after 2000. Import and export figures between Luxembourg and Belgium are however considerable in relation to the total production of roundwood in LU. Luxembourg exports a high amount of beech wood to a paper mill in Belgium. This paper mill has been in operation since the seventies. On the other hand, Luxembourg has one of the biggest wood-panel producers in Europe. It is however estimated that only 10% of the wood, needed for the production, originates from Luxembourg. Hence it can be assumed that a vast majority of this wood is imported from Belgium. One reason for the high volume of wood import is that the production of wood-panels requires coniferous wood which is very abundant in Belgium.

Figure 6-21 amended import and export of industrial roundwood in Luxembourg and Belgium

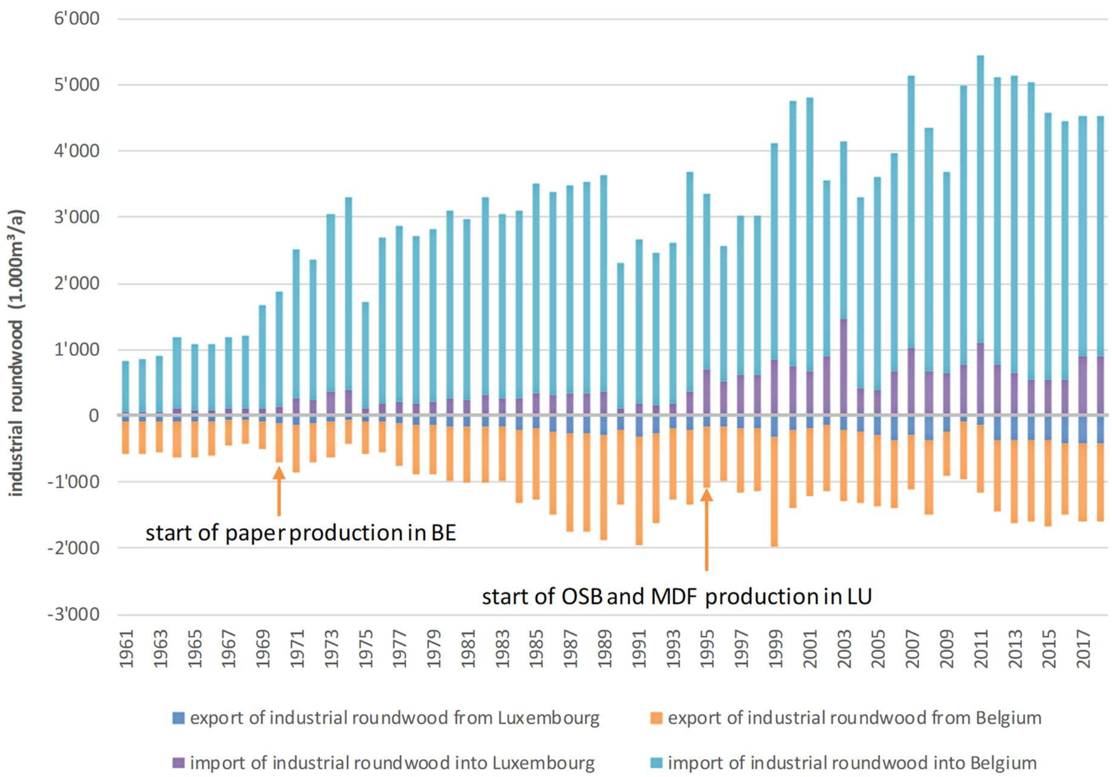
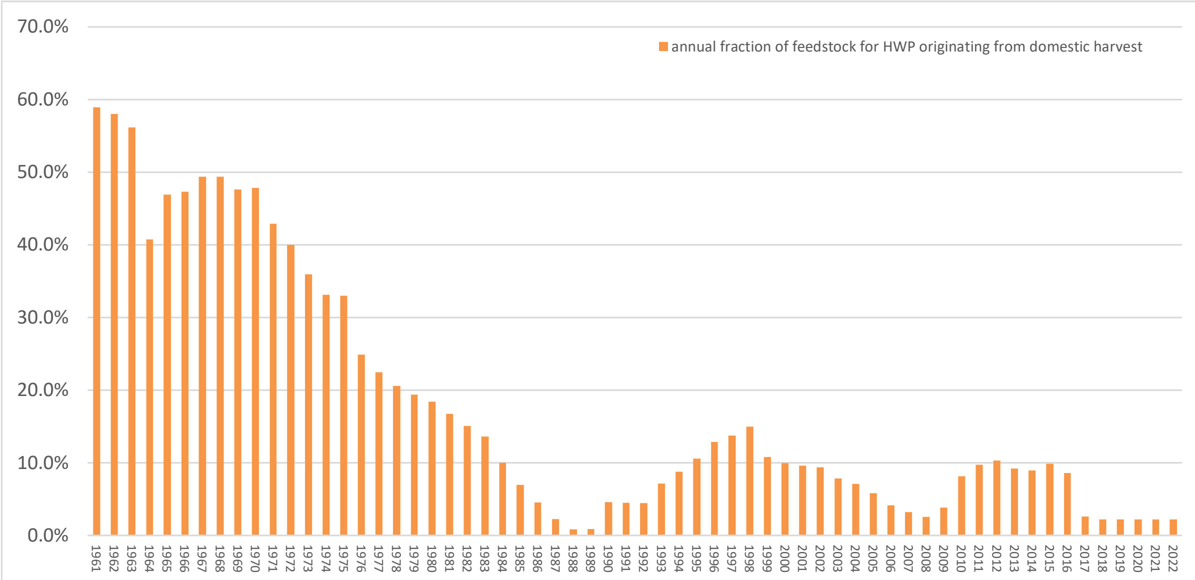


Figure 6-21 illustrates how the import and export of industrial roundwood was amended to take into account import and export figures between LU and BE:

- Increase of combined export of roundwood from Luxembourg and Belgium in order to take into account the export and import figures between those two countries. This was realised by comparing total import and export between 2000 and 1999
- A decrease of industrial roundwood into Luxembourg before the start of the wood-panel production in 1995.

The high annual fluctuations of roundwood import into Luxembourg is probably due to stock fluctuations of roundwood purchased by the HWP producers.

Figure 6-22 annual fraction of feedstock for HWP originating from domestic harvest



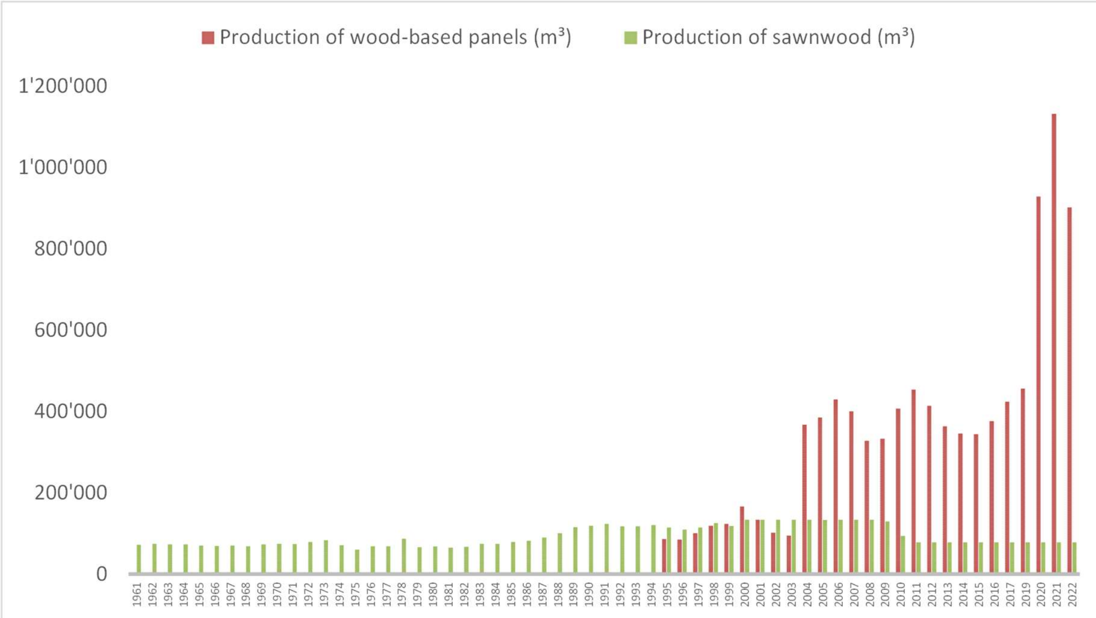
Import and export of industrial roundwood are very high and show strong yearly fluctuations. Those fluctuations can partly be explained by stock changes and bulk purchases by the wood processing industry. Unfortunately, yearly fluctuations of import and export can, on an annual basis, lead to inconsistent results. For this reason, a 10-year moving average (see Figure 6-20) was used in order to calculate the annual fraction of feedstock for HWP originating from domestic harvest (fIRW).

6.9.1.3 Production of wood-based panels and sawnwood

As mentioned in the previous chapters a major wood-panel (mainly OSB and MDF) producer is operating in LU. Unfortunately, no production data is collected in LU. Data on export of wood-based panels is however based on the comex database and are very reliable. Hence the assumption is taken that the production of wood-based panels is equal to the export of wood-based panels. This assumption seems justified as it is a conservative approach and the market for wood-based panels is LU is small compared to the production.

For the production of sawnwood and wood-based panels before 2000 the combined production between LU and BE was split onto both countries by considering the production ratio of both countries for the period between 2000 and 2005 (5-year average). As the production of wood-based panels only started in 1995 the calculation for wood-based panels was considered to be zero before that year.

Figure 6-23 production of wood-based panels and sawnwood in Luxembourg

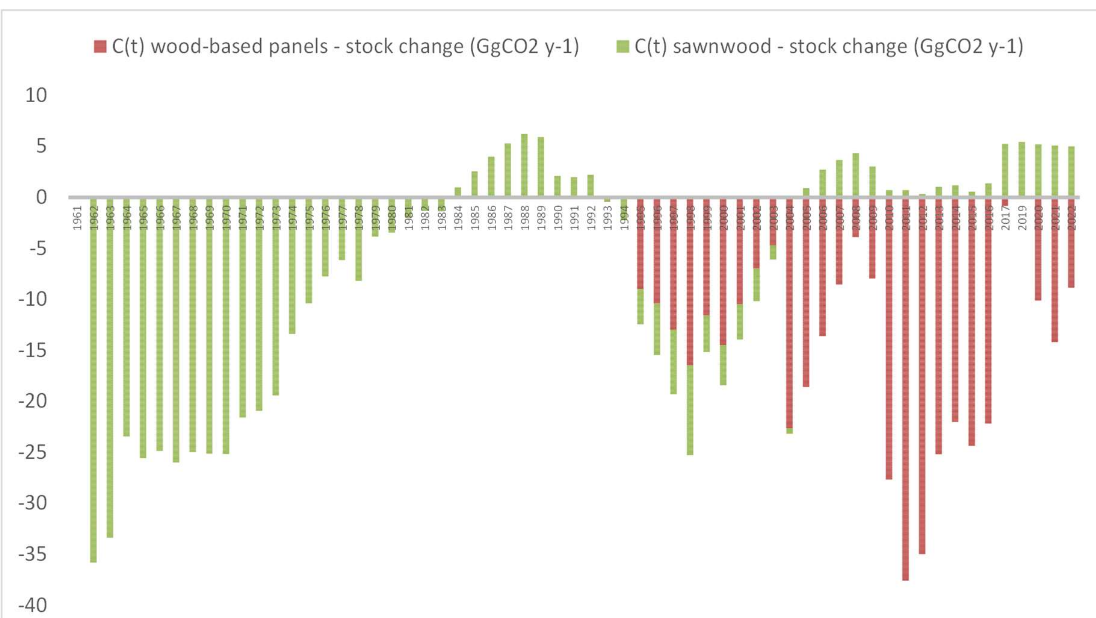


Since 2020 a new production line of OSB panels has been operating in LU.

6.9.1.4 Data available on production, imports and exports of pulpwood

There is no production of paper and paperboard in Luxembourg using pulpwood originating from LU forests.

Figure 6-24 carbon emission and removals in HWP



By 1985 the balance for sawnwood in terms of inflow and outflow has been reached. For wood-panels the production only started in 1995 and hence a balance has not yet been reached.

6.10 Category-specific QA/QC and verification

Forest area calculated by the NFI have been compared to the total forest area from the LULUCF methodology. Both method are illustrated in Figure 6-3 and Figure 6-4. The results Table 6-37 are considered to be in line considering the difference in methodology.

Table 6-37 Forest area according to LULUCF methodology and NFI

	1989	1999	NFI 2000	2007	NFI 2010	2012	2015	2018
Total Forest area	93 018 ha	93 178 ha	92 350 ha	93 345 ha	92 150 ha	93 320 ha	93 199 ha	93 146 ha

6.11 Category-specific recalculations including changes made in response to the review process

No recalculations have occurred in the LULUCF sector compared to the previous submission (2023v2).

However, a minor error was rectified in Sector 4.B.2.5 - Other Land Converted to Cropland. In the previous submission, the emissions arising from mineral soil due to the land use change from other land to cropland were inadvertently omitted in the reporting tables. However, the emissions are very minimal, constituting only -0.1158% in 1990 and -0.0002% in 2021.

A similar error was rectified in Sector 4.F Other land where N2O emissions under the category land converted to other land were inadvertently omitted.

Figure 25: Recalculations with respect to previous submission 2023v2 in category 4.

4. Land use, land-use change and forestry			
year	Submission 2023 v2	Submission 2024 v2	variation (%)
1990	8.99	8.98	-0.1158%
1991	-58.91	-58.92	0.0177%
1992	-464.52	-464.53	0.0022%
1993	-591.22	-591.23	0.0018%
1994	-443.43	-443.44	0.0023%
1995	-522.64	-522.65	0.0020%
1996	-558.37	-558.38	0.0019%
1997	-644.31	-644.32	0.0016%
1998	-538.43	-538.44	0.0019%
1999	-604.74	-604.75	0.0017%
2000	-614.75	-614.76	0.0017%
2001	-593.37	-593.38	0.0018%
2002	-583.05	-583.05	0.0017%
2003	-563.31	-563.32	0.0017%
2004	-609.46	-609.47	0.0016%
2005	-565.97	-565.98	0.0017%
2006	-484.98	-484.99	0.0020%
2007	-392.72	-392.73	0.0025%
2008	-410.69	-410.69	0.0008%
2009	-423.05	-423.05	0.0008%
2010	-205.40	-205.40	0.0017%
2011	-298.17	-298.17	0.0012%
2012	-368.19	-368.20	0.0009%
2013	-513.84	-513.84	-0.0008%
2014	-422.59	-422.59	-0.0009%
2015	-369.21	-369.21	-0.0010%
2016	-468.32	-468.32	-0.0008%
2017	-379.43	-379.43	-0.0010%
2018	-241.15	-241.15	-0.0015%
2019	-363.59	-363.59	-0.0010%
2020	-447.65	-447.65	-0.0008%
2021	-605.35	-605.34	-0.0006%
2022		-648.21	

4.A Forestland:

No recalculations were carried out in this sector.

4.B Cropland:

See descriptions here above.

Figure 26: Recalculations with respect to previous submission 2023v2 in category 4B.

4.B Cropland			
year	Submission 2023 v2	Submission 2024 v2	variation (%)
1990	48.36	48.35	-0.022%
1991	48.36	48.35	-0.022%
1992	48.36	48.35	-0.022%
1993	48.37	48.36	-0.022%
1994	48.37	48.36	-0.022%
1995	48.37	48.36	-0.022%
1996	48.38	48.37	-0.022%
1997	48.38	48.37	-0.022%
1998	48.38	48.37	-0.022%
1999	48.38	48.37	-0.022%
2000	53.25	53.24	-0.020%
2001	53.04	53.03	-0.020%
2002	73.44	73.43	-0.014%
2003	73.23	73.22	-0.014%
2004	73.01	73.00	-0.014%
2005	72.80	72.79	-0.014%
2006	72.58	72.57	-0.014%
2007	72.37	72.36	-0.014%
2008	67.83	67.83	-0.005%
2009	68.33	68.32	-0.005%
2010	68.92	68.91	-0.005%
2011	69.41	69.41	-0.005%
2012	69.91	69.91	-0.005%
2013	41.86	41.86	0.003%
2014	41.66	41.66	0.003%
2015	41.45	41.45	0.003%
2016	30.41	30.41	0.005%
2017	30.22	30.22	0.005%
2018	30.02	30.03	0.005%
2019	29.83	29.83	0.005%
2020	29.86	29.86	0.005%
2021	29.88	29.88	0.005%
2022		37.15	

4.F Other land:

See descriptions here above.

Figure 27: Recalculations with respect to previous submission 2023v2 in category 4F.

4.F Other land			
year	Submission 2023 v2	Submission 2024 v2	variation (%)
1990	0.05	0.05	0.00%
1991	0.05	0.05	0.00%
1992	0.05	0.05	0.00%
1993	0.05	0.05	0.00%
1994	0.05	0.05	0.00%
1995	0.05	0.05	0.00%
1996	0.05	0.05	0.00%
1997	0.05	0.05	0.00%
1998	0.05	0.05	0.00%
1999	0.05	0.05	0.00%
2000	0.02	0.02	0.00%
2001	0.02	0.02	0.00%
2002	0.01	0.01	9.46%
2003	0.01	0.01	9.46%
2004	0.01	0.01	9.46%
2005	0.01	0.01	9.46%
2006	0.01	0.01	9.46%
2007	0.01	0.01	9.46%
2008	0.29	0.29	0.00%
2009	0.29	0.29	0.00%
2010	0.32	0.32	0.00%
2011	0.32	0.32	0.00%
2012	0.32	0.32	0.00%
2013	0.20	0.20	1.23%
2014	0.21	0.21	1.18%
2015	0.21	0.21	1.18%
2016	0.17	0.17	1.39%
2017	0.17	0.17	1.38%
2018	0.17	0.17	1.38%
2019	0.17	0.17	1.38%
2020	0.17	0.17	1.38%
2021	0.17	0.17	1.38%
2022		0.17	

4.G Harvested Wood Products

No recalculations have occurred in this sector.

6.12 Category-specific planned improvements

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented Table 6-38 will be explored.

Table 6-38 – Planned improvements for category 4 – LULUCF

GHG source & sink category	Planned improvement
4A	Luxembourg plans to revise its OBS maps by 2023-2024
4A	Luxembourg plans to carry out a new NFI by 2025

7 Waste (CRF Sector 5)

7.1 Sector Overview

This chapter includes information on and description of methodologies used for estimating GHG emissions, as well as references to activity data and emission factors reported under CRF Sector *5 – Waste* for the period 1990 to 2022. Emissions from this sector comprise emissions for the three main IPCC categories: *5A - Solid Waste Disposal*, *5B - Biological Treatment of Solid Waste* and *5D – Wastewater Treatment and Discharge*.

GHG emissions related to *5C – Incineration and Open Burning of Waste* are allocated to IPCC subcategory *1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production* (see Section 3.2.6) since energy is recovered and injected into the public electricity network from waste burned in the sole incinerator of the country.

7.1.1 Emission Trends

As shown in Figure 7-1 and Table 7-1, that provide a quick overview on *Waste* and *Wastewater Treatment and Discharge* related emission trends between 1990 and 2022, and Table 7-2 depicting the shares of each IPCC category under CRF Sector *5* for both the years 1990 and 2022, total waste related GHG emissions have decreased by 27.26% from 1990 to 2022, and decreased by 5.40% between 2021 and 2022.

Figure 7-1 – GHG Emission Trends for category 5 – Waste: 1990-2022

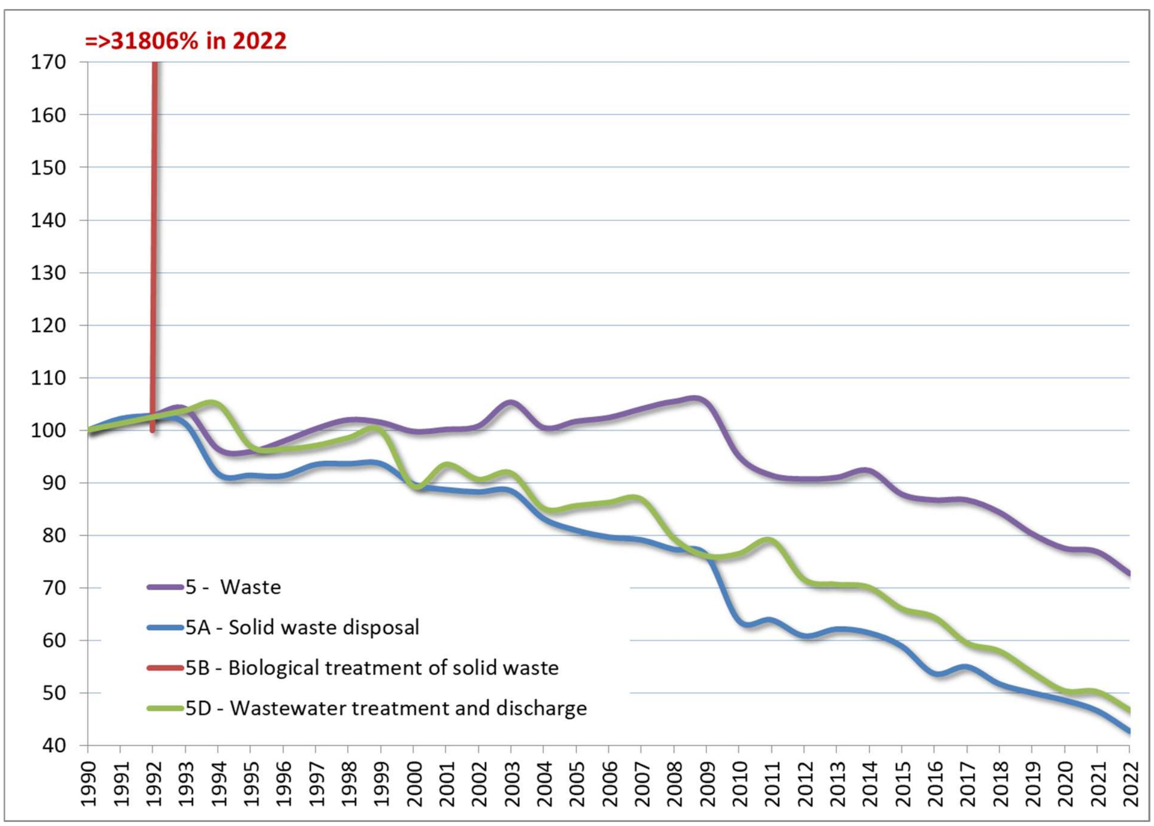
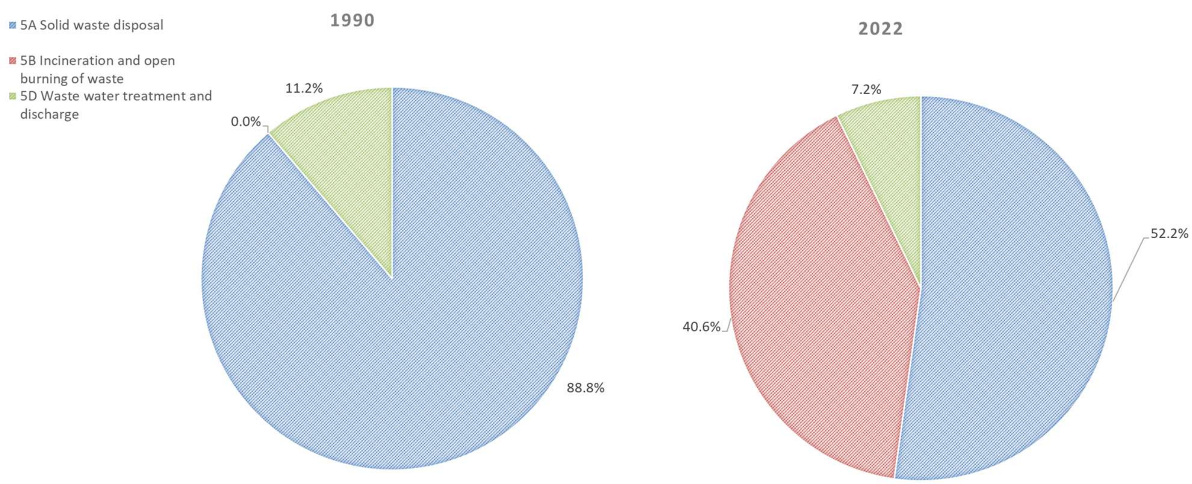


Figure 7-2 – Shares for category 5 – Waste: 1990 and 2022



The above mentioned trend evolution was mainly driven by the fact that, for IPCC category ***5A – Solid Waste Disposal***, methane emissions have been reduced by 57.22% between 1990 and 2022 due to:

a) an increase in aerobic treatment[150] before landfilling;

b) a decrease in the quantity of waste being landfilled, notably through the development of recycling schemes, and the expansion of both the numbers of and the various waste categories collected by recycling centres;

c) the installation of methane recovery systems at waste dumping sites;

d) an increase of waste being incinerated.

No CO_2 emissions derived from non-biological or inorganic waste sources have been identified so far from waste disposal on land.

For category ***5B – Biological Treatment of Solid Waste***, unlike IPCC category *5A*, an increase of emissions is recorded for the years 1992 to 2022 for *5B1*. With regard to compost production as well as aerobic treatment of solid waste, these activities have only started on an "industrial scale" in the early 1990s. The accelerated development of compost production from 1993-2003 explains the very high, and therefore not really exploitable, percentage growths observed for both CH_4 and N_2O. Since 2003, compost production activity has more or less stabilized (Section 7.3). In addition, as Luxembourg has committed itself to an increased share of electricity produced from renewable sources, fugitive CH_4 emissions from the use of biomass in anaerobic digesters in *5B2* have accumulated (since 1992).

For this analysis, IPCC category ***5C – Incineration and Open Burning of Waste*** is excluded since, as indicated above, it is entirely accounted for under IPCC subcategory *1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production*. Consequently, IE is reported for this category in CRF Table *5C*.

150 Aerobic treatment refers to the cold treatment at SIGRE (until 2014), and the mechanical-biological treatment at SIDEC.

Table 7-1 – GHG Emission Trends in CO_2eq for category *5* – Waste: 1990-2022

5 - Waste CO_2 eq emissions (Gg) by source & sink category																
Year	5A - Solid Waste Disposal				5B - Biological Treatment of Solid Waste				5D - Wastewater Treatment and Discharge				5 - Waste			
	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	103.25	NA	103.25	NA	0.00	NO	NO	NO	13.05	NA	8.48	4.56	116.29	NA	111.73	4.56
1991	105.53	NA	105.53	NA	0.00	NO	NO	NO	13.20	NA	8.56	4.64	118.73	NA	114.09	4.64
1992	105.94	NA	105.94	NA	0.29	NO	0.29	NO	13.37	NA	8.64	4.72	119.59	NA	114.87	4.72
1993	104.52	NA	104.52	NA	2.96	NO	2.00	0.97	13.53	NA	8.72	4.81	121.01	NA	115.23	5.78
1994	94.71	NA	94.71	NA	3.70	NO	2.47	1.24	13.68	NA	8.80	4.88	112.09	NA	105.97	6.12
1995	94.40	NA	94.40	NA	4.47	NO	2.97	1.50	12.64	NA	7.77	4.87	111.51	NA	105.14	6.37
1996	94.33	NA	94.33	NA	6.92	NO	4.53	2.39	12.57	NA	7.83	4.74	113.82	NA	106.69	7.13
1997	96.54	NA	96.54	NA	7.38	NO	4.80	2.58	12.66	NA	7.89	4.77	116.58	NA	109.22	7.35
1998	96.67	NA	96.67	NA	9.05	NO	5.84	3.21	12.85	NA	7.94	4.91	118.57	NA	110.45	8.11
1999	96.70	NA	96.70	NA	8.27	NO	5.32	2.95	13.03	NA	8.00	5.03	118.00	NA	110.02	7.98
2000	92.65	NA	92.65	NA	11.69	NO	7.91	3.78	11.65	NA	6.75	4.89	115.99	NA	107.31	8.68
2001	91.60	NA	91.60	NA	12.65	NO	8.88	3.77	12.19	NA	6.78	5.41	116.44	NA	107.26	9.18
2002	91.15	NA	91.15	NA	14.23	NO	9.98	4.25	11.82	NA	6.79	5.03	117.19	NA	107.91	9.28
2003	91.37	NA	91.37	NA	19.10	NO	13.68	5.42	11.97	NA	6.81	5.16	122.45	NA	111.87	10.58
2004	85.90	NA	85.90	NA	19.81	NO	14.64	5.17	11.10	NA	5.83	5.27	116.81	NA	106.38	10.43
2005	83.61	NA	83.61	NA	23.45	NO	17.64	5.82	11.17	NA	5.72	5.44	118.22	NA	106.97	11.26
2006	82.26	NA	82.26	NA	25.55	NO	19.49	6.06	11.25	NA	5.69	5.56	119.06	NA	107.44	11.62
2007	81.72	NA	81.72	NA	27.92	NO	21.39	6.53	11.33	NA	5.70	5.63	120.97	NA	108.82	12.15
2008	79.85	NA	79.85	NA	32.40	NO	24.96	7.44	10.36	NA	5.04	5.31	122.61	NA	109.85	12.75
2009	78.75	NA	78.75	NA	33.73	NO	26.70	7.03	9.92	NA	4.58	5.35	122.40	NA	110.03	12.37
2010	65.82	NA	65.82	NA	34.69	NO	27.57	7.12	9.98	NA	4.45	5.53	110.49	NA	97.84	12.65
2011	66.01	NA	66.01	NA	29.98	NO	24.59	5.39	10.31	NA	4.66	5.65	106.30	NA	95.25	11.04
2012	62.85	NA	62.85	NA	33.29	NO	27.75	5.54	9.34	NA	4.58	4.76	105.47	NA	95.17	10.30
2013	64.19	NA	64.19	NA	32.41	NO	27.10	5.32	9.21	NA	4.43	4.78	105.82	NA	95.72	10.10
2014	63.46	NA	63.46	NA	34.75	NO	29.05	5.71	9.14	NA	4.34	4.80	107.36	NA	96.85	10.51
2015	60.85	NA	60.85	NA	32.66	NO	28.05	4.61	8.61	NA	3.93	4.69	102.12	NA	92.83	9.29
2016	55.45	NA	55.45	NA	36.98	NO	31.88	5.10	8.40	NA	3.65	4.75	100.83	NA	90.98	9.85
2017	56.82	NA	56.82	NA	36.28	NO	31.55	4.73	7.76	NA	3.19	4.57	100.86	NA	91.56	9.30
2018	53.42	NA	53.42	NA	37.14	NO	32.22	4.91	7.56	NA	3.01	4.55	98.12	NA	88.66	9.46
2019	51.69	NA	51.69	NA	34.68	NO	29.83	4.85	7.04	NA	2.41	4.63	93.41	NA	83.94	9.47
2020	50.23	NA	50.23	NA	33.36	NO	28.65	4.70	6.58	NA	2.32	4.26	90.16	NA	81.20	8.96
2021	48.19	NA	48.19	NA	34.67	NO	29.44	5.24	6.56	NA	2.21	4.35	89.42	NA	79.83	9.58
2022	44.17	NA	44.17	NA	34.31	NO	30.04	4.27	6.10	NA	1.91	4.19	84.59	NA	76.13	8.46
Trend 1990-2022	-57.22%	NA	-57.22%	NA	NA	NA	NA	NA	-53.22%	NA	-77.43%	-8.19%	-27.26%	NA	-31.86%	85.47%
Trend 2021-2022	-8.33%	NA	-8.33%	NA	-1.04%	NA	2.05%	-18.41%	-6.93%	NA	-13.38%	-3.65%	-5.40%	NA	-4.64%	-11.71%

For IPCC category ***5D – Wastewater Treatment and Discharge***, emissions decreased by 53.22% in 2022 compared to the base year 1990, and decreased by 6.93% compared to 2021. Wastewater treatment plant (WWTP) capacities expressed in population-equivalents have steadily grown (Section 7.5) over the period 1990 to 2022[151], whereas nitrous oxide emissions (Table 7-1) decreased by 8.19%. With regard to wastewater treatment, technical changes therefore have an unquestionable role, as the evolution of methane emissions (-77.43% from 1990 to 2022) confirms.

7.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 1.4. Table 7-2 presents the key source categories of category 5 – Waste.

151 This increase is notably explained by (i) the significant population growth between 1990 and 2022, and (ii) the increasing number of commuters who are crossing the border each working day (Section 2.1). Percentage growths recorded for these two variables are, as well, largely above the one estimated for N2O emissions from WWTP.

Table 7-2 - Key categories in category 5 – Waste.

5 - Waste

Key sources

IPCC Category	Category Name	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
5A	Solid Waste Disposal	CH_4	95-04, 06-07, 09, 14	90-18, 20-22		

Source: Environment Agency
Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
TA = Trend Assessment

7.1.3 Completeness

Table 7-3 provides more details on the IPCC categories included under CRF Sector *5*, in which emissions are not occurring for activities or processes (*NO*), emissions do not result from activities in the given source category (*NA*), emissions are considered negligible (*NE*) or emissions that are included elsewhere (*IE*) in the inventory.

Table 7-3 – Status of Emission Estimates for CO_2, CH_4 and N_2O in category *5 – Waste*

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
5A - Solid Waste Disposal				
5A1	Managed waste disposal sites	NO	X	
5A2	Unmanaged waste disposal sites	NO	IE*	
5A3	Uncategorized waste disposal sites	NO	NO	
5B - Biological Treatment of Solid Waste				
5B1	Composting		X (1993-2022)	X (1993-2022)
5B1	Pre-treatment of solid waste		X (1993-2022)	X (1993-2022)
5B2	Anaerobic digestion at biogas facilities		X (1992-2022)	X ***
5C - Incineration and Open Burning of Waste				
5C1	Waste incineration	IE **	IE **	IE **
5C2	Open burning of waste	NO	NO	NO
5D - Wastewater Treatment and Discharge				
5D1	Domestic wastewater		X	X
5D2	Industrial wastewater		NO	X
5D3	Other		NO	NO

Note: X indicates that emissions from this subcategory have been estimated.

The grey shaded cells are those also shaded in the CRF tables (AD has not been specified, or cells are blocked for editing).

* = Unmannaged waste disposal sites are recorded under CRF subcategory *5A1* since nowadays all the landfills are considered well-managed.

** = Waste incineration is recorded under CRF subcategory *1A1a* since electricity is produced from incinerated municipal waste residues.

***N2O emissions (both direct and indirect) originating from energy crops and non-agricultural waste were notified under 5B2, whereas N2O emissions originating from animal manure were notified in CRF 3Bb.

7.1.4 Luxembourg's Waste Generation and Management System

The common basis for activity data to estimate emissions from IPCC categories *5A – Solid Waste*, *5B – Biological Treatment of Solid Waste*, and *5C – Incineration and Open Burning of Waste* is the generation of municipal solid waste (MSW). MSW consists of waste collected from households, as well as refuses generated by small industries, retail shops and services (private or institutional). In other words, MSW corresponds to the totality of waste collected by municipalities (Total MSW).

According to the modified Luxembourgish law of March 21, 2012 on waste, the collection of MSW falls within the competence of municipalities. As a result municipalities joined together in different municipal waste management syndicates. There are four inter-municipal syndicates responsible for the management of municipal solid waste:

- SIDA regrouping municipalities in the north of the country (integrated in SIDEC since 1994);
- SIDEC regrouping the municipalities of the North;
- SIDOR regrouping the municipalities of the West, the South and the Center;
- SIGRE regrouping the municipalities of the East.

Unmanaged landfill sites

Before the syndicates started managing different solid waste disposal sites (SWDS), the waste was dumped in local unmanaged dumping sites within the municipalities. In 1980, the first law on waste was voted in Luxembourg. Between 1981 and 1982, around 110 permits were issued for unmanaged landfill sites. When the new waste legislation came into force in 1994, all private and municipal unmanaged landfills had to be closed. These areas were cleaned and covered in plantation in order to fit into the surrounding landscape. A cadastre was set up, with all landfill sites that could be contaminated.

Since 1994, inspections were systematically performed by the Environment Agency at 616 former landfills. The Environment Agency oversaw the work that lasted until 2005. No abnormal behaviour of these closed sites has been detected and no corrective actions were required.

An example for a successful closing procedure is the former landfill site in Bettembourg next to the leisure park "*Parc Merveilleux*", visited by lots of families during the summer months. About 500 000 m^3 MSW had been deposited at this site in the 1980s, and after closure, the site was equipped with a drainage system and covered with a one meter thick layer of earth. Specific analysis showed that the anaerobic fermentation process was finished, and no methane emissions stemming from the site could be detected. Hence, it was decided that these sites could be annexed to the leisure park, to host larger compounds for animals (such as a deer park).

The managed landfill sites of SIDEC and SIGRE opened in 1972 and 1979, respectively. Table 7-4 summarizes the situation for each waste management syndicate.

Table 7-4 – Municipal Solid Waste Management in Luxembourg

Syndicate	Waste Elimination Scheme	Operating Years with Regard to the GHG Inventory
SIDA	Landfill	till 1993
SIDEC	Landfill	1972-2014
	+ Methane recovery system	*2002-2022*
	+ Biological treatment	*2007-2022*
SIDOR	Incineration	1976-2022
SIGRE	Landfill	1979-2022
	+ Aerobic treatment	*1993-2014*
	+ Methane recovery system	*2000-2022*

Notes: SIDEC (www.sidec.lu), SIDOR (www.sidor.lu), and SIGRE (www.sigre.lu)

The waste management syndicates, listed in Table 7-4, exist since 1990 and have been managing their own dumping or incineration site. In 1994 the syndicate SIDA merged with SIDEC and its dumping site was subsequently closed. In 2014 there were two controlled landfill sites (one managed by SIDEC and one managed by SIGRE) and one incinerator (managed by SIDOR) in operation in Luxembourg. In 2015, the syndicates decided to use only one controlled landfill site in Muertendall, managed by SIGRE. The landfill site managed by SIDEC was subsequently closed.

A **methane recovery system** has been in operation at the SIGRE site since 2000, and at the SIDEC site since 2002. The **aerobic treatment** in heaps has been performed at SIGRE from 1993 to 2014. Also, pre-treatment of solid waste prior landfilling of waste in tunnels has been fully operational since 2007 at SIDEC.

Figure 7-3 – Waste flow in Luxembourg before 2015

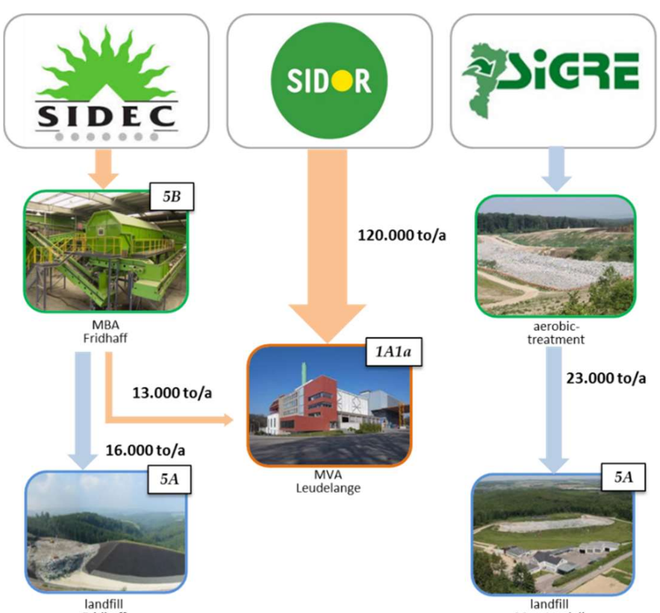
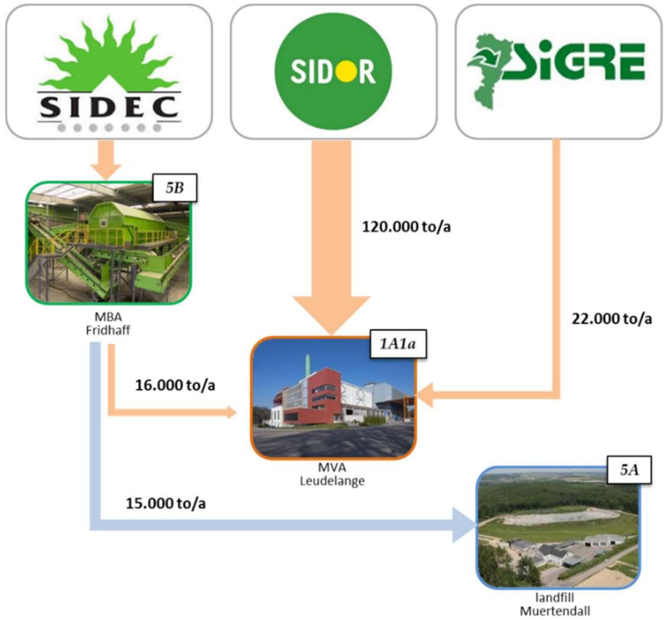


Figure 7-4 – Waste flow in Luxembourg after 2015



The total municipal solid waste (Total MSW, municipal waste from households and similar household waste excluding recycling), accounted for in the inventory is – upon collection – partly:

- landfilled – accounted under IPCC category *5A* either directly[152] or indirectly after treatment (emissions occurring during biological treatment are accounted under IPCC category *5B*), or
- incinerated (solid waste to be accounted for under IPCC category *1A1a* as energy is recovered from incineration).

7.1.5 Legislation

The most important legislative and regulatory measures, which have reduced the waste-related emissions from Luxembourg, are included in the

- EU Waste Framework Directive 2008/98/EC;
- Landfill Directive 1999/31/EC;
- Industrial Emissions Directive 2010/75/EU.

The Waste Framework Directive mandates waste management as a priority to prevention (non-waste), re-use, recycling and recovery. The latter directive, which also has introduced the "*polluter pays principle*", has been transposed on the national level by the modified Luxembourgish law of March 21, 2012.

The modern requirements for disposal sites, in order to reduce methane generation, of the Landfill Directive have been transposed into national legislation through the Grand-Ducal regulation of February 24, 2003.

The aim of the Industrial Emissions Directive, transposed by the law of May 9, 2014, is to prevent or to reduce emissions caused by the

152 Direct landfilling of waste concerns waste with or without mechanical sorting. Direct landfilling was completely abandoned in 2015.

incineration of waste. This is to be achieved through the application of operational conditions, technical requirements, and emission limit values for incineration plants within the EU.

Even though the uncontrolled management of waste was already included in the law of 17 June 1994 ("Loi modifiée du 17 juin 1994 relative à la prévention et à la gestion des déchets (abrogée)") the article 42 of the modified national law of March 21, 2012 states clearly that the abandonment, dumping or uncontrolled management of waste is prohibited. This statement includes the prohibition of open burning of waste, which is considered as an uncontrolled management of waste. This includes the ban on burning of green waste, household and non-domestic waste in the open air. Waste fines imposed for non-compliance with this provision are fixed in the Grand-Ducal regulation of December 9, 2022. Many municipalities have also implemented this prohibition in their respective municipal regulations.

7.2 Solid Waste Disposal (5A)

7.2.1 Source Category Description

The following section describes GHG emissions resulting from solid waste disposal on land (SWDL), which originates from waste disposal sites in Luxembourg. As there are no longer unmanaged waste disposal sites (Chapter 7.1.4 Box "*Unmanaged Landfill Sites*"), emissions from IPCC category *5A – Solid Waste Disposal* are equal to the one deriving from IPCC subcategory *5A1 – Managed Waste Disposal Sites*.

Municipal waste is indirectly landfilled after treatment. Indirectly landfilled waste undergoes mechanical and biological pre-treatment prior landfilling. However, the emissions deriving from the treatment processes of waste are addressed under CRF subcategory *5B1* (see Figure 7-3 and Figure 7-4).

In 2022, the source category *5A* was responsible for 52.22% of emissions related to waste treatment under Section *5*, and for 6.81% of the total methane emissions estimated for Luxembourg (15.14% in 1990). It represented 0.54% of the total GHG emissions (excluding LULUCF) in 2022 (0.81% in 1990). Neither CO_2 (biogenic origin), nor N_2O emissions (not significant) derived from non-biological or inorganic waste sources have been identified so far.

The source category *5A – Solid Waste Disposal* has been identified as a key category for CH_4 for several years (level assessment excluding and including LULUCF, please refer to Table 7-2).

7.2.2 Methodological Issues

7.2.2.1 Data Origin

The syndicates responsible for the MSW management submit an annual report, in which all the waste delivered to their landfill site or incineration plant is reported. The reduction of waste due to rotting losses occurring at the SIDEC site is based on measurements. The rotting losses due to the pre-treatment until 2014 at the SIGRE site have been estimated.

The IPCC category *5A* covers all waste disposal which is organised *via* regional disposal districts (as listed in Table 7-5) as well as industrial waste deposited at Ronnebierg (Box "*Industrial Waste Disposal Site Ronnebierg*"). Today, Muertendall (managed by SIGRE in the Eastern district) is the only active landfill site.

Industrial Waste Disposal Site Ronnebierg

The deposit of industrial waste in Ronnebierg was in operation from approximately 1962 until 1994. At the end of 1994 Luxembourg's only industrial waste disposal site was closed and subsequently sanitised between 1997 and 2000. The landfill site was sealed and a drainage system was installed.

According to a study from 1995 the following information is available for this site:

- 1962 start of operation
- 1960-1972: estimated volume deposited 92.000m³
- 1973 landfill site official handover to waste contractor
- 1974: authorisation for sludge and residues from septic tanks
- 1976 disposal of incineration slag from waste incineration plant
- 1978 disposal of industrial inert waste: mainly polyester and polypropylene
- 1981 authorisation for municipal waste was revoked (except in case of problems with the incineration plant)
- 1972-1984: estimated volume deposited 356.000 m³
- 1983 detailed analysis of yearly waste composition: 65 891 t collected between 1/8/1982 and 31/8/1983:
    - 66,7% incineration slag;
    - 8,9% demolition waste;
    - 6,7% shredder waste;
    - 5,9% plastic, paper and cardboard;
    - 4,2% glass;
    - 3,2% sludge;
    - 1,6% grease from restaurants;
    - 1,4% waste from septic tanks;
    - 0,5% dry sludge;
    - 0,9% other.
- 1986 – 1994:

Total waste (t)	Ronnebierg I	Monticule	Ronnebierg II
1986	83.600		
1987	112.000		
1988	130.200		
1989	140.700		
1990	270.100		
1991	12.800	68.700	
1992		59.300	
1993		17.000	3.000
1994			20.000
Total 1986-1994	**749.400**	**145.000**	**23.000**

- Separate study focusing on incineration slag estimates that 472.298 t of slag were deposited between 1976 and 1988, and a further 196.472 t between 1989 and 1993.
- In conclusion of the study the composition of the total volume deposited is as follows:
    - Household waste: 20 %
    - Incineration slag: 50 %
    - Demolition waste: 6 %
    - Shredder, plastic, cardboard and glass: 15 %
    - Different types of sludge: 7 %
    - Other: 2 %

In the framework of the rehabilitation of the landfill, regular controls of the landfill condition, as well as measurements of emissions, have been performed since 2000 (except for 2001). These measurements are annually reported to the Environment Agency and used for estimating emissions. For the years before 2000, the emissions have been extrapolated based on the historic information available. The emissions from the closed landfill site for industrial waste, Ronnebierg, have been included in the category *5A* (see Table 7-9).

Table 7-5 – Total Municipal Solid Waste generated in Luxembourg by syndicates

Total MSW generated by syndicats							
Year	**Total MSW** *Gg*	***SIDOR*** *Gg*	**SIDEC** *Gg*	**SIGRE** *Gg*	**SIDA** *Gg*	**Population** #	**MSW / capita** *kg / hab.*
1990	223.60	135.97	58.23	18.40	11.00	*379 300*	*589.51*
1991	216.80	142.26	39.34	24.60	10.60	*384 400*	*564.00*
1992	195.52	141.85	38.11	5.46	10.10	*389 600*	*501.86*
1993	200.98	134.95	39.52	13.45	13.06	*394 800*	*509.06*
1994	196.10	132.03	45.96	18.12		*400 200*	*490.01*
1995	194.76	126.09	46.98	21.69		*405 700*	*480.06*
1996	191.62	97.55	50.90	43.16		*411 600*	*465.54*
1997	192.58	115.56	42.03	34.99		*416 900*	*461.94*
1998	189.02	113.28	41.83	33.90		*422 100*	*447.80*
1999	196.81	129.69	40.43	26.69		*427 400*	*460.48*
2000	187.72	125.99	41.77	19.95		*433 600*	*432.93*
2001	190.03	124.40	42.67	22.96		*439 000*	*432.87*
2002	192.34	126.32	42.59	23.43		*444 000*	*433.19*
2003	191.18	122.86	42.18	26.14		*448 300*	*426.45*
2004	193.65	125.79	43.94	23.92		*455 000*	*425.61*
2005	196.06	121.14	42.68	32.23		*461 200*	*425.10*
2006	192.51	124.03	38.31	30.17		*469 100*	*410.39*
2007	193.48	127.69	39.40	26.40		*476 200*	*406.31*
2008	193.82	127.54	39.57	26.71		*483 800*	*400.61*
2009	194.04	126.72	39.21	28.11		*493 500*	*393.19*
2010	191.15	117.06	39.32	34.76		*502 100*	*380.70*
2011	192.09	125.36	39.39	27.34		*511 800*	*375.32*
2012	190.83	123.03	39.70	28.10		*524 900*	*363.56*
2013	185.48	119.04	39.19	27.25		*537 000*	*345.41*
2014	187.70	118.19	39.39	30.13		*549 700*	*341.46*
2015	182.41	123.47	37.47	21.48		*563 000*	*324.00*
2016	189.50	130.23	37.92	21.34		*576 200*	*328.88*
2017	189.19	130.63	37.88	20.68		*590 700*	*320.28*
2018	194.54	133.10	38.00	23.44		*602 005*	*323.15*
2019	195.65	136.64	37.72	21.30		*613 894*	*318.71*
2020	186.39	130.48	35.32	20.60		*626 108*	*297.70*
2021	192.05	136.02	31.43	24.59		*634 730*	*302.57*
2022	186.07	136.26	30.02	19.79		*645 397*	*288.30*
Trend 1990-2022	*-16.79%*	*0.21%*	*-48.45%*	*7.54%*	*-100.00%*	*70.15%*	*-51.10%*
Trend 2021-2022	*-3.12%*	*0.17%*	*-4.49%*	*-19.55%*	*NA*	*1.68%*	*-4.72%*

Sources: Annual reports submitted by syndicates

In order to evaluate the generation of MSW in Luxembourg Table 7-5 illustrates the production of MSW by syndicates. There are however important waste streams between the incineration plant and the two landfill sites which are not visible in this table (see Figure 7-4). With the closure of the landfill site in Fridhaff (SIDEC) in 2014 the waste from the pre-treated waste is being landfilled in the landfill site in Muertendall. The waste from the SIGRE communes is either directly transported to the SIDOR incineration plant (and reported under SIDOR) or first deposited at the SIGRE site and subsequently transported to the SIDOR site (but still reported under SIGRE). This explains the dip in the SIGRE category from 2015 and the increase in the SIDOR category. The decrease of total waste between 2014 and 2015 is a reduction of demolition waste (to specialised landfill site) and a reduction of bulk waste (separate collection and partly recycled). To sum up, this table can only be analysed for the total generated MSW per captia (excluding recycling).

7.2.2.2 Methodology

Table 7-6 lists the amount of MSW managed by the solid waste disposal sites. The table is split in MSW directly deposited and indirectly deposited. The table shows waste flows including the reduction in waste due to biological treatment (rotting losses) as well as the high calorific fraction of waste (HWF="Heizwertfraktion") separated by mechanical treatment and subsequently eliminated in the incineration plant and addressed under *1A1a*.

Table 7-6 - Amounts of managed waste deposited at SWDS sites

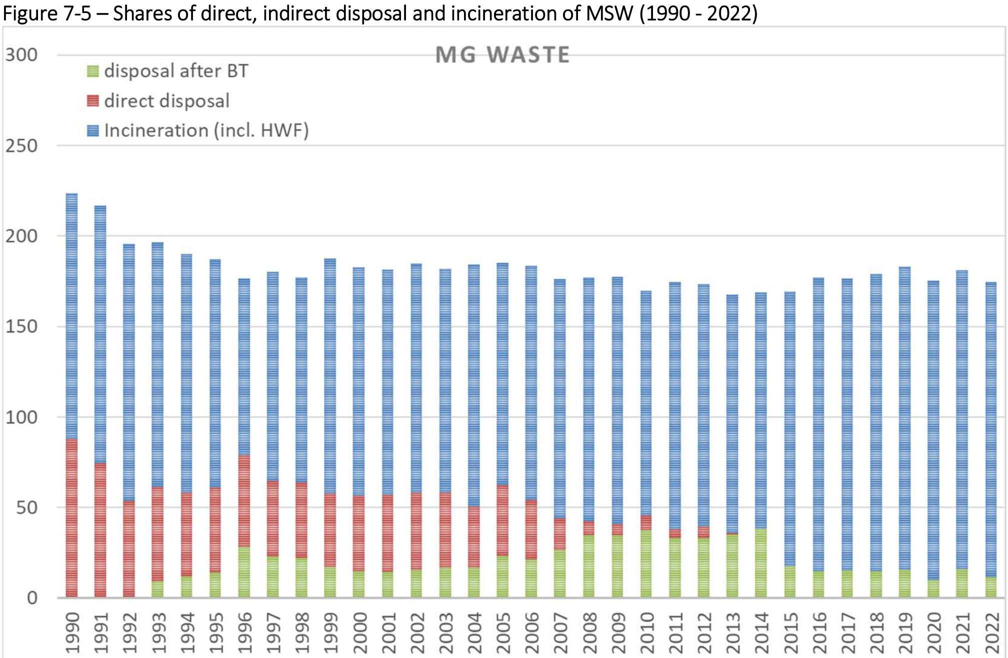
	Incineration (incl. HWF)	**SIDA total**	**SIGRE - Muertendall**					**SIDEC - Fridhaff**											
Year			Total	const. waste	rotting losses	to SIDOR	disposal after BT	Total	inert. Waste & metal	disposal before MS	disposal after MS	to SIDOR	disposal before BT	rotting losses	disposal to SIGRE	disposal after BT	direct disposal	direct disposal	disposal after BT
1990	136.0	11.0	18.4		0.0			58.2									58.2	87.6	
1991	142.3	10.6	24.6		0.0			39.3									39.3	74.5	
1992	141.9	10.1	5.5		0.0			38.1									38.1	53.7	
1993	134.9	13.1	13.5		-4.5		8.9	39.5									39.5	52.6	8.9
1994	132.0		18.1		-6.0		12.1	46.0									46.0	46.0	12.1
1995	126.1		21.7		-7.8		13.9	47.0									47.0	47.0	13.9
1996	97.6		43.2		-15.2		28.0	50.9									50.9	50.9	28.0
1997	115.6		35.0		-12.2		22.8	42.0									42.0	42.0	22.8
1998	113.3		33.9		-11.9		22.0	41.8									41.8	41.8	22.0
1999	129.7		26.7		-9.4		17.3	40.4									40.4	40.4	17.3
2000	126.0		20.0		-5.0		15.0	41.8									41.8	41.8	15.0
2001	124.4		23.0		-8.6		14.4	42.7									42.7	42.7	14.4
2002	126.3		23.4		-7.7		15.7	42.6									42.6	42.6	15.7
2003	123.8		26.1		-9.3		16.8	42.2	0.0			-1.0					41.2	41.2	16.8
2004	133.8		25.1	-1.2	-6.9		17.0	43.9	-2.4	3.1	0.0	-8.0	30.4				*33.5*	33.5	17.0
2005	122.7		35.0	-2.7	-9.1		23.1	42.7	-2.0	2.2	0.0	-1.5	37.0				*39.2*	39.2	23.1
2006	129.3		32.3	-2.2	-8.8		21.4	38.3	-0.4	1.2	0.0	-5.3	31.4				*32.7*	32.7	21.4
2007	132.4		31.1	-4.7	-6.8		19.6	39.4	-2.0	0.7	1.2	-4.7	15.5	*-8.3*		*7.0*	*17.4*	17.4	26.6
2008	134.8		30.4	-3.7	-7.3		19.4	39.6	-2.0	0.4	3.1	-7.2	4.2	*-7.5*		*15.2*	*7.7*	7.7	34.7
2009	136.5		33.0	-4.9	-7.4		20.7	39.2	-1.7	0.1	0.4	-9.8	5.6	*-7.6*		*14.0*	*6.1*	6.1	34.7
2010	124.1		38.5	-3.8	-10.0		24.7	39.3	-1.6	0.2	1.2	-7.0	6.7	*-9.9*		*12.6*	*8.1*	8.1	37.3
2011	136.7		31.3	-4.0	-7.4		19.9	39.4	-2.0	0.1	0.1	-11.3	4.4	*-8.3*		*13.2*	*4.6*	4.6	33.1
2012	134.2		33.2	-5.1	-7.2		20.9	39.7	-2.1	0.0	0.0	-11.1	6.2	*-8.0*		*12.2*	*6.2*	6.2	33.2
2013	132.0		31.4	-4.2	-7.1		20.1	39.2	-2.0	0.0	0.0	-13.0	0.7	*-8.6*		*14.9*	*0.7*	0.7	35.1
2014	130.6		35.8	-5.7	-7.4		22.7	39.4	-2.0		0.0	-12.4	0.0	*-9.2*		*15.8*	*0.0*		38.5
2015	151.6		36.5	-3.5		-15.3	*17.8*	39.5	-2.0			-12.9		*-9.1*	*-15.4*	*0.0*			17.8
2016	162.1		35.7	-5.3		-15.6	*14.8*	39.3	-1.9			-16.3		*-7.1*	*-14.1*	*0.0*			14.8
2017	161.4		35.1	-5.0		-15.0	*15.1*	37.9	-0.2			-15.8		*-7.2*	*-14.7*	*0.0*			15.1
2018	164.4		36.9	-7.1		-15.2	14.6	38.0	-0.2			-16.2		*-7.6*	*-14.1*	*0.0*			14.6
2019	167.5		35.2	-5.8		-13.8	15.5	37.7	-0.2			-17.1		*-6.6*	*-13.9*				15.5
2020	165.6		27.7	-5.7		-12.1	10.0	35.3	-0.1			-23.0		*-5.1*	*-7.1*				10.0
2021	165.1		36.2	-7.3		-12.9	16.0	31.4	-0.1			-16.1		*-3.5*	*-11.7*				16.0
2022	163.0		29.7	-6.3		-11.8	11.6	30.0	-0.1			-14.9		*-5.1*	*-10.0*				11.6
Trend 1990-2022	*19.88%*		*61.62%*				*NA*	*-48.45%*									*-100.00%*	*-100.00%*	*NA*
Trend 2021-2022	*-1.26%*		*-17.96%*				*-27.72%*	*-4.49%*									*NA*	*NA*	*-27.72%*

Sources: Annual reports submitted by syndicates

Figure 7-5 illustrates the evolution of the shares of the direct, indirectly deposited and incinerated MSW for Luxembourg.

- The sudden drop in total waste between 1992 and 1993 can be explained by the opening of one major composting facility Minett-Kompost and multiple recycling centres.
- The drop in share of direct disposal in 1995/1996 can be explained by an increased amount of waste being treated in the mechanical-biological pre-treatment at SIGRE.
- The second sudden drop in share of direct disposal in 2006/2007 is due to the biological pre-treatment of solid waste prior to landfilling at SIDEC.
- During a short period in 2020, due to the sanitary crisis, all MSW from SIDEC was temporarily sent for incineration to SIDOR and not to biological treatment and further to SIGRE for landfill. This explains the drop in quantities deposited in the SIGRE landfill.

Figure 7-5 – Shares of direct, indirect disposal and incineration of MSW (1990 - 2022)



From 2014 onwards no more waste has been landfilled without pre-treatment (due to the Landfill Directive, see Section7.1.5).

7.2.2.2.1 Directly Deposited Waste (SIDEC)

Up to 1990 total amounts of waste and waste composition have been estimated. From 1990 onwards waste amounts are known and categorised according to the European Waste Catalogue (CED 2nd version Classification Européenne des Déchets). The fractions of waste listed are listed in Table 7-7.

The waste composition of both, residual (CED 200301 and 200399) and bulky waste (CED 200307) is analysed in a 3-year or 5-year cycle respectively. The results of the waste composition analysis are used to calculate emissions for directly deposited waste. For other waste fractions (190801, 190802, …) degradable organic carbon (DOC) contents are estimated (Table 7-7).

Table 7-7 – Waste Fractions and Estimated Degradable Organic Carbon for directly deposited waste

CED	*Description*	*Estimated DOC*
200301	Mixed municipal waste	Residual waste composition
200399	Municipal waste, not otherwise specified	
200307	Bulky waste	Bulky waste composition
190801 (1)	Wastes from wastewater treatment plants – screenings	90 %
190802 (2)	Wastes from wastewater treatment plants – waste from de-sanding	50 %
200303 (3)	Street-cleaning residues	20 %
200201	Garden and park waste, biodegradable waste	100 %

Note: (1) Sächsisches Landesamt für Umwelt und Geologie 2006: Klärschlammkonzeption

(2) Hitzler Andreas: Beurteilung und Optimierung von Sandwaschanlagen im Einsatz auf Kläranlagen; Dissertation Universität Fridericiana zu Karlsruhe (TH), 2002

(3) Bayerisches Landesamt für Umwelt Infoblatt Abfallwirtschaft, Straßenkehrricht Mai 2010

Emissions are estimated by the using of a *multiphase model* ***(three phase model)***, an approach with which several organic element groups can be distinguished in the waste through their half-lives.

The spreadsheet based on the First Order Decay (FOD) method implementing the Tier 1 methodology from the IPCC 2006 Guidelines for national GHG inventories has been used to estimate CH_4 emissions from SWDS. The method takes into account the decomposable degradable organic carbon ($DDOC_m$) accumulated (IPCC 2006, Chapter 3, Equation 3.4) and the $DDOC_m$ decomposed (IPCC 2006, Chapter 3, Equation 3.5) under anaerobic conditions in the SWDS at the end of a given year. According to K.-U. Heyer, the anaerobic degradation proceeds relatively intensively with a higher gas production rate (K.-U. Heyer, 2013) during the first years of disposal.

7.2.2.2.2 Indirectly Deposited Waste (after biological pre-treatment)

The pre-treatment of municipal waste before disposal leads to a substantial aerobic decay of the organic component. As a consequence, the behaviour of the decay in terms of reduction of the total mass and DOC_m is changing substantially.

Since the pre-treatment (until 2014) of waste at the SWDS site Muertendall (managed by SIGRE) has been performed directly on the landfill site, the reduction of the total mass is not known and has been estimated. The resulting mass loss (Table 7-6) during the six-month rotting process is estimated to correspond to 50% of the mass of degradable organic compounds (DOC).

The waste at the site in Fridhaff (SIDEC) is weighed before and after treatment and hence the reduction in mass (rotting losses) is known. However the composition of the remaining waste and its fraction of degradable organic carbon content is not known. Landfill operators have determined the respiration activity of waste after mechanical and biological treatment as a parameter of biologic reactivity and the rotting state of waste under aerobic conditions. The AT_4 parameter indicates the amount of O_2 consumed during the decomposition of the organic fraction of waste. SIDEC reported that AT_4 was reduced from 90 mg O_2/g TS (untreated waste) to 17 mg O_2/g TS (pre-treated waste). This analysis is however not sufficient in order to figure out the exact fraction of degradable organic carbon content post rotting process. Hence the emissions have been calculated according to the IPCC ***single-phase model*** based on bulk waste. This approach is also justified because, even though the waste has been partly decomposed, the water loss also means that the concentration of biodegradable elements in the residual waste is higher. The oxidation factor (0,1) has been based on the study by

(Kühle-Weidemeyer & Bogon, Dezember 2008). The value is justified by the fact that solid waste disposal sites in Luxembourg are operated by gradually covering different parts of the site with a layer of soil. According to the guidelines the default methane generation rate for bulk waste analysis ranges between 0.08-0.1. It can reasonably be argued that after the rotting process the remaining waste is predominantly constituted with materials that have a longer half-time value and hence the lower value of the allowed range was chosen.

7.2.2.3 Activity Data

As there are no national data on amounts of municipal waste generation available for the years 1950 to 1989, data on waste *per* capita from Germany (Prof. Dr. Dr. B.-M. Wilke, 2009) was used from 1950 (200 kg *per capita*) and 1975 (385 kg *per capita*). The first available data on waste generation is the year 1990 (590 kg MSW produced *per* capita (Table 7-5). The quantities of waste generated between 1950 and 1975 as well as between 1975 and 1990 were interpolated.

Municipal waste was completely landfilled until 1975 after which the incinerator of SIDOR started operating. The fraction of waste incinerated was attributed in relation to the population living in the SIDOR municipalities. After 1990 the exact proportion of waste going into landfill or being incinerated is known.

7.2.2.3.1 Directly Deposited Waste (SIDEC)

An overview of the composition trends of waste destined to direct disposal is given in Table 7-8.

Table 7-8 – Composition Trends of Waste destined to Direct Disposal

Year	Food	Garden	Paper	Wood	Textile	Nappies	Plastics, other inert	Total
1950-1974	20%	0%	25%	5%	0%	0%	50%	100%
1975-1980	24%	1%	25%	11%	1%	1%	37%	100%
1981-1984	24%	1%	24%	11%	1%	2%	37%	100%
1985-1991	29%	4%	20%	11%	1%	2%	33%	100%
1992 – 2003	39%	8%	16%	1%	1%	5%	30%	100%
2004	19%	6%	12%	28%	6%	3%	25%	100%
2005	17%	5%	13%	26%	6%	3%	29%	100%
2006	28%	5%	16%	13%	4%	4%	30%	100%
2007	24%	6%	16%	12%	5%	4%	33%	100%
2008	17%	7%	17%	13%	8%	4%	36%	100%
2009	28%	3%	14%	13%	4%	5%	33%	100%
2010	33%	6%	11%	12%	2%	3%	33%	100%
2011	42%	5%	10%	10%	1%	3%	29%	100%
2012	44%	5%	12%	6%	1%	4%	29%	100%
2013	46%	5%	9%	5%	1%	5%	30%	100%
since 2014	0%	0%	0%	0%	0%	0%	0%	0%

Note: Percentages of waste fractions refer to the Managed MSW to SWDS.

The following points can be highlighted with regards to this table:

(i) Waste composition for the period 1950-1974 has been oriented on the IPCC default values but it was assumed that the fractions "*food*", "*paper*" and "*wood*" landfilled were lower in the after WW2 period. The difference was allocated to the fraction "*plastics, other inert*".

(ii) For the period 1975-1991 the default IPPC values for waste composition were used. The values were however gradually adapted to take into account the appearance of nappies in the waste streams. The remaining fractions were modified accordingly.

(iii) Waste composition is exactly known since 1990 and is determined by periodical sampling.

(iv) Between 1992 and 2004, the amount of directly deposited waste corresponds to the waste deposited at the SIDEC site where the total amount of waste is directly deposited without pre-treatment. Hence the composition of deposited waste was considered to correspond to the residual waste composition analysis.

(v) In 2003 the MBA from SIDEC was put in service and hence the amount of directly deposited waste was strongly reduced as the majority of waste was undergoing a biological treatment. The amount of directly deposited correspond to individual fractions of waste which have been separated by mechanical sorting. Hence the proportion of wood is much higher as in previous year. The composition of waste is mainly influenced by the proportion of general waste to bulky waste. The drop in wood content observed between 2005 and 2006 is due to the fact that amount of bulky waste arriving at the SIDEC plant was halved.

(vi) Since 2014 there is no more direct disposal in Luxembourg. The deposited waste undergoes a biological treatment before being deposited.

7.2.2.3.2 Deposited Waste after Biological Treatment

During mechanical sorting, the high calorific fraction[153] and metals are separated from the waste:

- The separated high calorific fraction of in average 13.0 Gg is destined to waste incineration at SIDOR. This is clearly made visible when looking at the time-series of waste amounts being incinerated and being landfilled (year 2007 in Figure 7-5). In 1996 the sharp increase of solid waste disposed at SIGRE and to a smaller extent at SIDEC can be explained by a sharp decrease of waste incinerated at SIDOR (shut-down for 3 months due to a fire [154]).
- In 2015 the waste produced by the municipalities of SIGRE are no longer landfilled but are instead being directly incinerated in the SIDOR facilities without any pre-treatment.
- During a short period in 2020, due to the sanitary crisis, all MSW from SIDEC was temporarily sent for incineration to SIDOR and not to biological treatment and further to SIGRE for landfill. This explains the drop in quantities deposited in the SIGRE landfill.

Biological pre-treatment of municipal waste leads to a substantial aerobic decay of the organic component and as a consequence, the behaviour of the decay (in terms of reduction of the total mass and DOC_m) is changing substantially. The practical reductions depend on the type and duration of MBT in question:

– At SIDEC, waste fractions are cycling every two weeks in heaps and are mixed with remaining lixiviate collected from the landfill site. Pre-treatment of waste induces a reduction of the organic pollution of lixiviate in total organic carbon (TOC). The remaining weight of waste after biological treatment is measured and hence the reduction of waste (rotting losses) is known.

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153 The deriving high calorific (combustible) fraction (> 150mm) is incinerated (addressed under CRF subcategory 1A1a) at the municipal waste incinerator SIDOR. with energy generation for electronic power supply

154 De Journal, N.200, p.7, "SIDOR: Feiern in der Zeit des Umbruchs"

– Until 2014, the aerobic treatment at the SIGRE landfill Muertendall was performed using forced aerated windrows of 36 tons in which large streams of waste undergo a systematic six-month-rotting process. The resulting waste was then installed directly without weighing in the landfill. The resulting mass loss is estimated to amount up to 50% of the mass of DOC in the deliveries where the DOC is estimated according to the waste composition (Table 7-7).

The amount of MB-treated MSW finally deposited in the landfills is listed as a residue of biological treatment in Table 7-6. The drop after 2014 can be explained by the fact that solid waste generated by the SIGRE municipalities is incinerated at the SIDOR plant. The pre-treated waste from the MBA plant in SIDEC is however being landfilled in the last remaining landfill in Luxembourg, Muertendall.

The emissions deriving from the pre-treatment of solid waste prior to landfilling starting from 1993 are addressed under CRF subcategory *5B1*.

7.2.2.4 Parameters and emissions

Table 7-9 illustrates *(i)* the methane emissions from solid waste disposal, as well as *(ii)* the implied emission factor.

Table 7-9 – CH_4 emissions from *5A1 - Managed Waste Disposal Sites*

CH_4 emissions from 5A1 - Managed Waste Disposal Sites

Year	Total [Gg]	SIDEC, SIGRE, SIDA [Gg]		Ronnebierg [Gg]	IEF kg / t MSW
		direct	indirect		
1990	3.69	3.53	NO	0.15	42.08
1991	3.77	3.63	NO	0.14	50.56
1992	3.78	3.65	NO	0.13	70.49
1993	3.73	3.61	0.00	0.12	56.53
1994	3.38	3.23	0.04	0.11	52.79
1995	3.37	3.18	0.09	0.10	49.10
1996	3.37	3.13	0.14	0.09	35.81
1997	3.45	3.11	0.25	0.08	44.76
1998	3.45	3.04	0.34	0.07	45.58
1999	3.45	2.98	0.41	0.06	51.46
2000	3.31	2.78	0.45	0.07	53.61
2001	3.27	2.73	0.48	0.06	49.85
2002	3.26	2.70	0.51	0.04	49.31
2003	3.26	2.69	0.54	0.03	47.77
2004	3.07	2.47	0.57	0.03	45.21
2005	2.99	2.35	0.60	0.03	39.86
2006	2.94	2.25	0.66	0.03	42.90
2007	2.92	2.20	0.70	0.02	44.36
2008	2.85	2.08	0.76	0.01	43.03
2009	2.81	1.95	0.86	0.01	41.78
2010	2.35	1.40	0.94	0.01	31.73
2011	2.36	1.32	1.03	0.01	35.33
2012	2.24	1.14	1.10	0.01	33.11
2013	2.29	1.13	1.16	0.01	34.51
2014	2.27	1.04	1.22	0.01	32.61
2015	2.17	0.86	1.30	0.01	36.87
2016	1.98	0.71	1.26	0.01	33.42
2017	2.03	0.79	1.23	0.01	34.65
2018	1.91	0.70	1.20	0.01	31.05
2019	1.85	0.67	1.17	0.01	31.28
2020	1.79	0.65	1.14	0.00	32.08
2021	1.72	0.64	1.08	0.00	30.72
2022	1.58	0.53	1.05	0.00	31.67
Trend 1990-2022	-57%	-85%	NA	-97%	-25%
Trend 2021-2022	-8%	-18%	-3%	1%	3%

Note: The amount of MSW deposited is the amount of MSW containing degradable organic carbon and thus excludes inert waste such as plastics, glass, *etc.* Emissions from unmanaged landfill sites (closed in 1992) are also included in reporting table 5A1.

Table 7-10 gives an overview of the parameters used for the estimation of emissions from solid waste disposal on land.

Table 7-10 – Parameters used for the Calculation of Emissions

	Directly Deposited Waste	*Deposited Waste after Biological Treatment*
DOC (Degradable Organic Carbon) *(weight fraction, wet basis)*	"*waste by composition*"	"*bulk waste data only*"
Food	0.15	
Garden	0.2	
Paper	0.4	
Wood	0.43	
Textile	0.24	
Nappies	0.24	
Bulk MSW		0.19
DOC_f (fraction of DOC dissimilated)	0.5	
Methane Generation Rate Constant (k) ($years^{-1}$)		
Food	0.185	
Garden	0.1	
Paper	0.06	
Wood	0.03	
Textile	0.06	
Nappies	0.1	
Bulk MSW		0.08
Delay Time (months)	6	
Fraction of Methane (F) in generated landfill gas	0.5 (for 1950-2009) 0.4037 (after 2010)	0.5
Conversion Factor, C to CH_4	1.33	

The kinetics of waste degradation under anaerobic conditions are dependent on the different climate zones. The climate zone for *Western Europe, Luxembourg* has been selected. While the option "*waste by composition*" has been selected for waste destined for direct disposal, the option of "*bulk waste data only*" has been chosen for waste after biological treatment.

Under the assumption that the SWDS environment is anaerobic and the DOC values include lignin (Oonk and Boom, 1995), the default value for DOC_f in mechanical-biological pre-treated waste applied is 0.5 (IPCC 2006, Chapter 2, Table 2.4).

For the years 1990-2009, the default setting of the IPCC was used for the fraction of methane in generated landfill gas (F= 0.5). It was adjusted from 2010 on, as from that point onwards the data on the proportion of methane in the captured landfill gas were available. The adjusted value from 2010 corresponds to the average methane content of the years 2010 - 2014.

Since the pre-treatment before disposal to solid waste disposal sites leads to substantial decay (aerobic) of organic components, including rapidly degradable waste components, a methane generation rate of 0.08 is chosen for estimating CH_4 emissions from indirectly deposited waste.

7.2.2.4.1 Methane Correction Factor (MCF)

From 1950 till the opening of SIDEC in 1972, municipal waste was deposited in unmanaged local landfills. Due to a lack of information, it was assumed that 50% were brought to unmanaged, shallow and 50% to unmanaged, deep landfills: the MCF of 0.4 and 0.8 have been applied to the activity data.

The controlled landfill of SIDEC was installed in 1972 and took over up to 20% of the total waste. When SIGRE landfill site was opened in 1979, up to 80% of the total waste was managed by the two controlled landfill sites under anaerobic conditions. The MCF of 1 (IPCC 2006, Table 3.1) was applied to this share of activity data.

Since 1993, all collected waste is accepted at SIDEC (until 2014) and SIGRE landfill sites which both underwent several modernization procedures (*i.e.* leachate drainage system, regulating pondage, gas ventilation system at SIDEC) over time. Independently on whether waste is *(i)* landfilled directly or *(ii)* pre-treated, the MCF of 1 is applicable to managed anaerobic landfills.

No activity data was attributed to the type "*Uncategorized*", *"Managed, active-aeration"* and "*Managed, semi-aerobic*". Table 7-11 gives an overview of the evolution of the MCF with regard to the waste management type.

Table 7-11 – Methane Correction Factors and Waste Distribution by Waste Management Type

	Methane Correction Factor					
	Un-managed, shallow	*Un-managed, deep*	*Managed*	*Managed, semi-aerobic*	*Managed, active-aeration*	*Uncategorized*
Year	0.4	0.8	1	0.5/0.7	0.4/0.7	0.6
1950-1971	50%	50%	0%	0%		0%
SIDEC opened						
1972	45%	45%	10%	0%	0%	0%
1973-1978	40%	40%	20%	0%	0%	0%
SIGRE opened						
1979-1992	10%	10%	80%	0%	0%	0%
SIDA closed						
1993-2022	0%	0%	100%	0%	0%	0%

Note: If parameters shown as "country-specific values" are identical to the IPCC default values, this means that the IPCC default value was used.

7.2.2.4.2 Methane Oxidation Factor

The methane oxidation factor (OX) indicates the fraction of emitted methane, which is oxidized in the surface layers of landfills. The default value of the methane oxidation factor, an OX of 0, has been used for the waste disposal from 1950 to 1993. Since 1993, all landfill sites (since 2014 only the SIGRE site is operational) are considered as well-managed SWDS, and the OX has been fixed to 0.1 according to the expertise of KÜHLE-WEIDEMEIER and BOGON (Kühle-Weidemeyer & Bogon, Dezember 2008). The value is justified by the fact that solid waste disposal sites in Luxembourg are operated by gradually covering different parts of the site with a layer of soil. As the MBT residues are not placed in a separate landfill but in a section which is in connection with the existing landfill or on top of raw waste, the pre-treated waste is considered as CH_4 oxidising material (similar to compost or soil), following a recommendation by the TERT during the EU ESD review. The OX factor was applied after subtraction of CH_4 recovered.

7.2.2.5 CH_4 Recovery

The methane recovery systems have been installed at the individual landfills Muertendall (managed by SIGRE) and Fridhaff (managed by SIDEC) in the years 2000 and 2002, respectively. Since then, the individual landfills report the quantity of the captured landfill gas as well as the methane content to the Environment Agency in accordance to their permits, see Table 7-12. These detected quantities are included in the reported CH_4 recovery in the GHG inventory.

Table 7-12 – CH_4 Recovery from *5A1 – Managed Waste Disposal Sites*

CH_4 Recovery from 5A1 - Managed Waste Disposal Sites

Year	Total *Gg*	SIDEC, SIGRE *Gg*	Ronnebierg *Gg*
1990	NO	NO	*NO*
1991	NO	NO	*NO*
1992	NO	NO	*NO*
1993	NO	NO	*NO*
1994	NO	NO	*NO*
1995	NO	NO	*NO*
1996	NO	NO	*NO*
1997	NO	NO	*NO*
1998	NO	NO	*NO*
1999	NO	NO	*NO*
2000	0.15	0.15	*NO*
2001	0.15	0.15	*NO*
2002	0.14	0.14	*NO*
2003	0.10	0.10	*NO*
2004	0.30	0.30	*NO*
2005	0.31	0.31	*NO*
2006	0.34	0.34	*NO*
2007	0.32	0.32	*NO*
2008	0.31	0.31	*NO*
2009	0.27	0.27	*NO*
2010	0.28	0.28	*NO*
2011	0.26	0.26	*NO*
2012	0.34	0.34	*NO*
2013	0.27	0.27	*NO*
2014	0.26	0.26	*NO*
2015	0.35	0.35	*NO*
2016	0.43	0.43	*NO*
2017	0.26	0.26	*NO*
2018	0.28	0.28	*NO*
2019	0.25	0.25	*NO*
2020	0.21	0.21	*NO*
2021	0.17	0.17	*NO*
2022	0.24	0.24	*NO*
Trend 1990-2022	*NA*	*NA*	*NA*
Trend 2021-2022	*42%*	*42%*	*NA*

While the recovered CH_4 was used for the production of electricity at the SIGRE landfill Muertendall (> 50% methane), recovered gas was flared at the SIDEC landfill Fridhaff (35-40% methane). Methane emissions that are recovered by the systems installed at the SWDS sites, have already been subtracted from the estimated emissions in Table 7-9.

7.2.3 Uncertainties and Time-Series Consistency

Uncertainties from Activity Data

The information on activity data, composition and handling of solid waste on landfills in Luxembourg resembles the situation of Austria. The uncertainty assessment is originally based on an Austrian national study (Winiwarter, 2007), and was improved and revised by expert judgement:

- In the legal framework of the EU Directive 2008/98/EC and the Landfill Directive 1999/31/EC, Luxembourg has elaborated also a similar Waste Strategy to Austria by setting up a waste national action plan[155];
- The advanced waste collection system, often with waste collection charges, allows the evaluation of annual quantities of municipal waste;
- The activity data of the collected amount of waste is considered to be complete;
- The type and composition of waste is also characterized by lack of hazardous waste, introduction of aerobic pre-treatment prior landfilling and high recycling. Regularly performed residual waste and bulky waste analysis as well as inspection activity on landfill according to ISO 17020 and ISO 17025 underlines the high quality of activity data available in Luxembourg.

An overall uncertainty from activity data has been assumed of ± 8%.

Uncertainties from EFs and Methodology Applied

Under the uncertainty of the model methodology are considered:

- Uncertainty of DOC: ± 20% (Table 3.5, IPCC 2006)
  - Uncertainty for MCF : -10% to 0% (Table 3.5, IPCC 2006)
  - Uncertainty for fraction of CH_4 in generated landfill gas: ± 5% (Table 3.5, IPCC 2006)
  - Uncertainty for CH_4 recovery known for SIDEC and SIGRE:
    (Uncertainty of oxidation factor included) ± 10% (Table 3.5, IPCC 2006)
- Uncertainty for half-time $t_{1/2}$: ± 15% (Table 3.4, IPCC 2006)
- Uncertainty for delay period over 50 years: ± 30%

According to expert judgment, a combined uncertainty for the solid waste disposal sector (which includes the uncertainty deriving from the waste deposited, the MCF, the DOC content in the directly deposited and pre-treated waste, the CH_4 generation rate as well as the delay time) sums up to approximatively 42%.

7.2.4 Category-Specific QA/QC and Verification

Category-specific QA/QC and verification include:

– Internal verifications and plausibility checks when compiling aggregated activity data on waste from the waste disposal sites;

155 Plan national de gestion des déchets 2017

- QA/QC procedures described under the different Waste Directives in the context of reporting on waste data. Indeed, the same aggregated data used for the inventory is also used for reporting to Eurostat;
- Use of the tools embedded in CRF Reporter.

7.2.5 Category-Specific Recalculations Including Changes Made in Response to the Review Process

Table 7-13 presents the main revisions and recalculations relevant to category 5A – Solid waste disposal since the last submission to the UNFCCC. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 7-13 – Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
5A	No recaclulations	-

7.2.6 Category-Specific Planned Improvements including those in Response to the Review Process

No improvements are planned in this moment in time.

7.3 Biological Treatment of Solid Waste (5B)

7.3.1 Source Category Description

Under the IPCC category *5B – Biological Treatment of Solid Waste*, GHG emissions originate from composting and biological pre-treatment of solid waste prior to landfill (*5B1 - Biogenic waste composted at centralised composting plants*), as well as from anaerobic treatment (*5B2 - Biogenic waste treated in biogas plants and sewage treatment plants*).

In 2022, this source category was responsible for 40.56% of the total GHG emissions from the waste sector and it represented 0.42% of the total GHG emissions in CO_2e (excluding LULUCF). For each of the gases reported in 2022:

- CH_4 represented 39.46% of waste treatment methane related emissions and 4.63% of the total methane emissions estimated for Luxembourg;
- N_2O represented 50.50% of waste treatment nitrous oxide related emissions and 1.98% of the total nitrous oxide emissions estimated for Luxembourg.

Neither CO_2 (biogenic origin), nor N_2O emissions (negligible) derived from non-biological or inorganic waste sources have been identified so far.

The CRF category *5B - Biological Treatment of Solid Waste* has not been identified as a key category.

7.3.1.1 Biogenic Waste Composted at Centralised Composting Plants (*5B1*)

Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into CO_2, water and heat. CH_4 is only formed in oxygen-deprived sections of the compost, and can be oxidized during aerobic treatment.

Composting also produces N_2O emissions, depending on the initial nitrogen content of the material. These are reported under subcategory *5B1a - Municipal Solid Waste.*

Biological pre-treatment of solid waste prior landfilling, during which air is forcedly blown through the bulk waste to speed up its decomposition, has been systematically performed since SIGRE has first introduced aerobic treatment processes for the managed waste in 1993. Since 2015, this process is not in operation anymore at the SIGRE site. At SIDEC, a mechanical-biological treatment (MBT) plant has been installed treating mixed waste since 2007. Disposal of waste and its residues after treatment are reported under CRF category *5A*, while the CH_4 and N_2O emissions generated during the rotting process are considered under subcategory *5B1b Other – MBA treated MSW*.

7.3.1.2 Biogenic Waste Treated in Biogas Plants (*5B2*)

Anaerobic digestion of organic waste results in CH_4 generation which is used to produce heat or electricity, wherefore reporting of emissions from the process is usually done in the Energy Sector (see Section 3.2.6) according to IPCC Guidelines. Emissions of CH_4 from biogas plants due to unintentional leakages during process disturbances or other unexpected events are estimated to be between 0 and 10 % of the amount of CH_4 generated (Volume 5, Chapter 4, Paragraph 4.1, IPCC 2006).

Table 7-14 – CH_4 & N_2O Emission Trends for Category *5B – Biological Treatment of Solid Waste*

***5B* - Biological Treatment of Solid Waste**

Year	Emissions (Gg) CO_2	CH_4	N_2O	Total in CO_2e
1990	NO	NO	NO	NO
1991	NO	NO	NO	NO
1992	NO	0.01	NO	0.29
1993	NO	0.07	0.00	2.96
1994	NO	0.09	0.00	3.70
1995	NO	0.11	0.01	4.47
1996	NO	0.16	0.01	6.92
1997	NO	0.17	0.01	7.38
1998	NO	0.21	0.01	9.05
1999	NO	0.19	0.01	8.27
2000	NO	0.28	0.01	11.69
2001	NO	0.32	0.01	12.65
2002	NO	0.36	0.02	14.23
2003	NO	0.49	0.02	19.10
2004	NO	0.52	0.02	19.81
2005	NO	0.63	0.02	23.45
2006	NO	0.70	0.02	25.55
2007	NO	0.76	0.02	27.92
2008	NO	0.89	0.03	32.40
2009	NO	0.95	0.03	33.73
2010	NO	0.98	0.03	34.69
2011	NO	0.88	0.02	29.98
2012	NO	0.99	0.02	33.29
2013	NO	0.97	0.02	32.41
2014	NO	1.04	0.02	34.75
2015	NO	1.00	0.02	32.66
2016	NO	1.14	0.02	36.98
2017	NO	1.13	0.02	36.28
2018	NO	1.15	0.02	37.14
2019	NO	1.07	0.02	34.68
2020	NO	1.02	0.02	33.36
2021	NO	1.05	0.02	34.67
2022	NO	1.07	0.02	34.31
Trend 1993-2022	NA	1405.75%	341.32%	1058.00%
Trend 2021-2022	NA	2.05%	-18.41%	-1.04%

Table 7-14 shows that CH_4 and N_2O emissions, generated by *5B – Biological Treatment of Solid Waste* increased over time as a result of the increasing amount of waste composted and undergoing biological pre-treatment prior landfilling (since 1993). In addition, as Luxembourg has committed itself to an increased share of electricity produced from renewable sources, fugitive CH_4 emissions from the use of biomass in anaerobic digesters have increased (since 1992).

7.3.2 Biogenic Waste Composted at Centralised Composting Plants (*5B1*)

7.3.2.1 Methodological Issues

7.3.2.1.1 Data Origin

Composting

In the CRF subcategory *5B1*, composting covers six composting installations that exist in Luxembourg, plus one that co-composts sewage sludge[156]:

- Various local municipalities (*e.g.* Mondercange, Mamer, Hesperange) operate their own composting installation and all households are covered by a collection scheme for biodegradable waste which is included in the activity data for *5B1 – Composting*. These composting installations operate in part under anaerobic conditions, with a residence time in the composter of a few weeks.
- Table 7-15 lists the amount of compostable waste collected from households and commercial activities and shows that the majority of green waste is collected in the composting installation MINETT-Kompost in Mondercange.
- Soil-Concept is a plant which co-composts sewage sludge and different organic fractions.

Activity data for compost production are taken from:

- STATEC, *Statistical Yearbook*, Table A.3306 (prepared by the Environment Agency based on annual reports from 1993-2015) for the composting installations;
- Annual reports transmitted to the Environment Agency for the Soil-Concept installation;
- Annual reports transmitted to the Environment Agency for the composting installations from 2016 on.

Soil-Concept [157]

Since 1996, Soil-Concept has been working on a project with the inter-municipal syndicate SIDEN. The objective of this project was to find the most appropriate solution for upgrading sewage sludge in Luxembourg. In 2001, the culmination of the project was the identification of a process of co-composting sewage sludge with structuring organic plant waste (crushed bark and green waste). Soil-Concept aims at reducing direct spreading of sludge on agricultural lands thanks to the spreading of certified compost for soil improvement in agriculture, horticulture and viticulture. The Soil-Concept site has an acceptance capacity of 11.5 Gg of sludge and

156 Sewage sludge is allocated to the CRF Sector 3D - Agriculture.

157 http://www.soil-concept.lu

17.7 Gg of green waste. Associated emissions are recorded in IPCC category *5B1* since these are "process" and not "spreading" emissions.

Pre-Treatment of Solid Waste Prior Landfilling

According to the national implementation of the Landfill Directive 1999/31/EC, large streams of waste undergo aerobic treatment procedures prior landfilling. The subcategory *5B1* covers the CH_4 and N_2O emissions generated during the rotting process from waste entering the pre-treatment procedure prior landfilling. By doing this, the activity data has been based on the quantity of solid waste from CRF *5A* undergoing the pre-treatment procedures starting from 1993, as reported by the operators.

7.3.2.1.2 Methodology

The IPCC Tier 1 method has been applied to estimate methane and nitrous oxide emissions from compost production as well as pre-treatment of solid waste prior landfilling. CH_4 and N_2O emissions are estimated using the default method given in the following equations:

$$CH_4 emissions = \sum_i (M_i \bullet EF_i) \bullet 10^{-3} - R$$

$$N_2O emissions = \sum_i (M_i \bullet EF_i) \bullet 10^{-3}$$

Where:

CH_4 emissions	=	Total CH_4 emissions in inventory year [Gg CH_4]
N_2O emissions	=	Total N_2O emissions in inventory year [Gg N_2O]
M_i	=	Mass of organic waste treated by biological treatment type i [Gg]
EF_i	=	Emission factor for biological treatment type i
i	=	Composting
R	=	Total amount of CH_4 recovered in inventory year [Gg CH_4][158]

7.3.2.1.3 Activity Data

Composting

Legal Framework for Composting:

Article 20 of the modified waste legislation of 21 March 2012 stipulates that the management of waste on the territory of the municipalities is under their responsibility. Selective collection of biogenic waste from households is done through door-to-door pick-up (currently up to 100%). Green waste can also be brought in bulk to municipal and intercommunal collection points, composting facilities or container parks.

In spring season 2018, the Environment Agency was working in collaboration with stakeholders (municipalities, syndicates, operators of interim storage facilities, treatment plants, waste producers) to develop a national network for the collection and recovery of substantial quantities of green waste, including viticulture, forestry and agriculture as well as orchards.

158 So far, emission estimates for composting are not taking CH4 recovery into account.

Table 7-15 lists the amount of compostable waste collected from households and commercial activities in Luxembourg.

The following CED2 waste categories are considered as activity data under 5B1 – Composting:

CED	Description
200108	Separately collected fractions - biodegradable kitchen and canteen waste (except 15 01)
200201	Garden and park waste, biodegradable waste
200302	Other municipal waste – waste from markets
190805	Sludges from treatment of urban waste water (only Soil-Concept)
020107	wastes from forestry (only Soil-Concept)
020204	sludges from on-site effluent treatment (only Soil-Concept)
020304	materials unsuitable for consumption or processing (only Soil-Concept)

Table 7-15 – Composting Activities – activity data

Composting Activities: 1993-2022

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
	tonnes wet														
Total	**5'805**	**6'746**	**8'398**	**7'354**	**16'083**	**26'685**	**27'729**	**37'169**	**34'088**	**38'424**	**53'310**	**51'692**	**54'817**	**57'242**	**58'196**
kg/habitant	*15*	*17*	*21*	*18*	*38*	*63*	*65*	*85*	*78*	*87*	*119*	*114*	*119*	*122*	*122*
Minett-Kompost	2'904	3'630	4'534	3'767	11'773	17'345	20'520	24'146	23'234	25'421	24'462	27'514	28'746	28'743	30'173
SICA Mamer	2'499	2'562	3'326	3'587	4'310	3'171	3'758	4'903	4'747	4'730	4'650	4'899	5'278	5'061	5'185
SIDEC Fridhaff						6'169	3'451	8'120	5'416	5'920	6'116	6'564	6'510	6'238	6'092
SIDEC Angelsberg									691	2'353	2'174	2'534	2'651	2'670	2'702
Hespérange											611	742	786	743	786
Ville de Luxembourg											15'297	9'439	8'083	11'108	9'733
SIGRE Muertendall													2'763	2'679	3'525
Pétange	402	554	538												
	tonnes dry														
Soil-Concept								9'370	10'574	13'607	15'484	14'460	16'225	19'922	18'223

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	tonnes wet														
Total	**59'628**	**63'866**	**62'202**	**38'399**	**41'521**	**38'490**	**41'150**	**38'800**	**46'091**	**43'512**	**44'690**	**46'377**	**49'374**	**56'136**	**48'284**
kg/habitant	*123*	*129*	*124*	*75*	*79*	*72*	*75*	*69*	*80*	*74*	*74*	*76*	*79*	*88*	*75*
Minett-Kompost	30'614	32'237	30'868	20'578	19'823	19'072	20'750	18'557	20'490	19'084	19'165	20'182	22'067	21'520	23'246
SICA Mamer	5'117	5'288	5'315						2'202	4'808	4'980	5'378	5'165	5'600	4'557
SIDEC Fridhaff	5'678	5'989	5'392	5'343	6'391	6'170	6'657	6'284	7'914	4'851	4'536	5'779	6'627	6'767	5'752
SIDEC Angelsberg	1'917	2'219	1'784	1'815	2'491	2'343	2'549	2'146	1'802	1'253	1'620	1'876	1'559	1'635	1'878
Hespérange	830	743	682	836	862			1'443	1'000	1'027	852	805	804	793	13
Ville de Luxembourg	11'921	12'187	13'767												
SIGRE Muertendall	3'551	5'203	4'394	9'826	11'953	10'904	11'194	10'369	12'683	12'489	13'537	12'358	13'152	19'822	12'837
Pétange															
	tonnes dry														
Soil-Concept	21'600	15'650	16'171	15'979	16'198	15'309	15'812	16'998	19'963	15'524	17'079	15'829	14'388	14'020	7'496

Notes: Grey cells indicate that the installation / project has not been running in the given year.

A few points are important to understand the fluctuations of organic waste streams in this table:

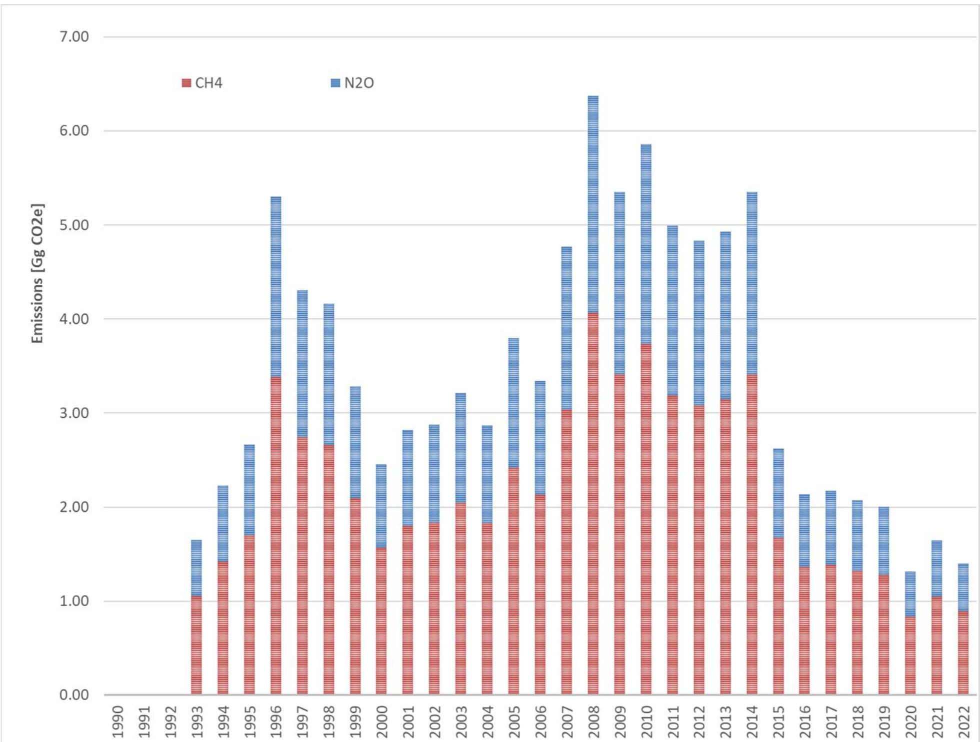
- Between 01/01/2011 and the 01/08/2018 the composting facility from SICA Mamer was not in operation as those waste streams were diverted to the biogas production facility in Kehlen. In 01/08/2016 the composting activity was however being restarted as composting allows also more woody organic waste to be processed.
- Between 2015 and 2016 a significant increase in composting activity can be observed. This can be attributed to the fact that a wide range of collection facilities (mainly at farms) were created for professionals and communes to dispose of green wastes (mainly hedge cuttings).

Pre-Treatment of Solid Waste Prior Landfilling

At the managed landfill site Fridhaff (managed by SIDEC), waste fractions are distributed within tunnels with forced aeration. The decomposition process takes 6 weeks, with rotations of the material every two weeks. Temperatures are rising to 60 - 70°C during the decomposition of waste.

In contrast, the pre-treatment in Muertendall (managed by SIGRE) is composed of the following steps: crushing, formation of rooting heaps with forced aeration, rotting process, and integration of waste residues into the landfill body. The decomposition lasts for up to 6 months in a 36-ton compactor. Since 2015 this process is not in operations anymore and hence the emissions have decreased (Figure 7-6).

Figure 7-6 – Emissions from Biological Treatment of Solid Waste in *5B1*



During a short period in 2020, due to the sanitary crisis, all MSW from SIDEC was temporarily sent for incineration to SIDOR and not to biological treatment. This explains the drop in emissions for 2020.

Table 7-16 lists the total emissions from *5B1 – Biogenic Waste Composted at Centralized Composting Plants*.

Table 7-16– Emissions from *5B1 – Biogenic Waste Composted at Centralized Composting Plants*

5B1 - Biogenic waste composted at centralised composting plants Emissions (Gg)				
Year	CO_2	CH_4	N_2O	Total in CO_2e
1990	NO	NO	NO	NO
1991	NO	NO	NO	NO
1992	NO	NO	NO	NO
1993	NO	0.06	0.00	2.67
1994	NO	0.08	0.00	3.41
1995	NO	0.09	0.01	4.14
1996	NO	0.15	0.01	6.60
1997	NO	0.16	0.01	7.13
1998	NO	0.20	0.01	8.85
1999	NO	0.19	0.01	8.15
2000	NO	0.24	0.01	10.44
2001	NO	0.24	0.01	10.39
2002	NO	0.27	0.02	11.72
2003	NO	0.34	0.02	14.92
2004	NO	0.32	0.02	14.17
2005	NO	0.36	0.02	15.90
2006	NO	0.38	0.02	16.48
2007	NO	0.40	0.02	17.74
2008	NO	0.46	0.03	20.20
2009	NO	0.43	0.03	18.95
2010	NO	0.44	0.03	19.24
2011	NO	0.32	0.02	14.21
2012	NO	0.33	0.02	14.63
2013	NO	0.32	0.02	14.02
2014	NO	0.34	0.02	14.98
2015	NO	0.27	0.02	12.01
2016	NO	0.30	0.02	13.34
2017	NO	0.28	0.02	12.18
2018	NO	0.29	0.02	12.55
2019	NO	0.29	0.02	12.59
2020	NO	0.28	0.02	12.24
2021	NO	0.31	0.02	13.77
2022	NO	0.25	0.02	11.19
Trend 1993-2022	NA	318.61%	318.61%	318.61%
Trend 2021-2022	NA	-18.77%	-18.77%	-18.77%

7.3.2.1.4 Parameters

Emission factors for compost production and biological pre-treatment of solid waste prior landfilling (Table 7-17) are actually default emission factors for CH_4 and N_2O emissions taken from Table 4.1 in IPCC 2006 Guidelines.

Table 7-17 – Default EFs for CH_4 and N_2O emissions from *5B - Biological Treatment of Waste*

Type of Biological Treatment	CH_4 EF *g CH_4/kg waste treated*	N_2O EF *g N_2O/kg waste treated*	Comment
	on a wet basis		Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%. EFs for dry waste are estimated from those for wet waste assuming moisture content of 60% in wet waste.
Composting (excluding Soil-Concept project)	4 (0.03 – 8)	0.24 (0.06 - 0.6)	
	on a dry basis		
Soil-Concept project	10 (0.08-20)	0.6 (0.2-1.6)	

7.3.3 Biogenic Waste Treated in Biogas Plants (5B2)

7.3.3.1 Methodological Issues

7.3.3.1.1 Data Origin

Luxembourg has only recently put together a preliminary list of anaerobic digestion plants based on the corresponding operating permits from the Environment Agency. While there has only been one agricultural facility in service before the year 2000, a total of 22 plants are known to be in service to date. Furthermore biogas production in sewage treatment plants have already been in operation for longer.

- Three of the 22 agricultural installations feed their cleaned and processed biogas into the local gas distribution system.
- The emissions due to the combustion of biogas (blended or not) are all considered under CRF Sector *1 - Energy*. The national energy balance provides the necessary activity data (energy production), and also the split in which CRF category the biogas is combusted:

- 1A1a – Public Electricity and Heat Production,
- 1A2g – Other,
- 1A4a – Commercial / Institutional,
- 1A4b – Residential, and
- 1A4c – Agriculture / Forestry / Fishing.

7.3.3.1.2 Methodology

The IPCC methodology has been followed to estimate CH_4 emissions from biogas plants due to unintentional leakages, which are assumed to be between 0 and 10% of the amount of CH_4 generated (Volume 5, Chapter 4, Paragraph 4.1, IPCC 2006).

Related to the preliminary analysis, Luxembourg proposes an own estimation starting from the activity data, i.e. produced biogas in m^3 available for the category *1 - Energy* to derive a level of CH_4 emissions for the subcategory *5B2 - Biogenic Waste Treated in Biogas Plants*.

In addition, the average fugitive emission rate has been adapted to 3.1% of the CH_4 gas production rate according to Flesch *et al.* (Flesch et al., October 2011). Comparably, the value of 3% of the CH_4 gas production rate emitted through leakages has been confirmed by the review of Dumont *et al.* (Dumont et al., 2011).

N_2O emissions for *5B2 - Biogenic Waste Treated in Biogas Plants* were split according to the origin of nitrogen inputs in: a) N originating from animal manure to be reported in category *3Bb - Manure management* (see section 5.3.3.2.2 and section 5.3.3.2.3), and b) N originating from energy crops and non-agricultural waste to be reported in category *5B2 - Biogenic Waste Treated in Biogas Plants.*

Direct N_2O emissions from annual nitrogen input via co-digestate originating from energy crops and non-agricultural waste was estimated according to equation 10.25 of the IPCC 2019 Refinements (Gavrilo, et al., 2019) for category *3Bb - Manure management* using the default EF values as provided in Table 10.21 of the 2019 Refinement of the 2006 IPCC Guidelines (Gavrilo, et al., 2019), i.e. 0.0006 (see section 5.3.3.2.2 (EF); section 5.3.3.1 and Table 5-37 (AD)).

Indirect N_2O-N emissions due to volatilisation of N from co-digestate, expressed as kg N_2O-N per year, were estimated by multiplying the NH_3 emissions from the digester and the storage of the co-digestate - and notified under NRF 5.B.2 (see Table 5-37 and IIR 2024) – by the default IPCC N_2O-N emission factor for indirect emissions from deposition in a wet climate (Hergoulac'h, et al., 2019), i.e. 0.014 (see section 5.3.3.2.3).

7.3.3.1.3 Activity Data

As mentioned, Luxembourg has only recently put together a preliminary list of anaerobic digestion plants based on the corresponding operating permits. Unfortunately however, the majority of annual reports are missing for the anaerobic digestion plants for the time-series before the year 2007. From a first analysis, one can state the following:

- Biogas production from agricultural facilities and sewage treatment plants has been reported in the national energy balance starting from the year 1992.
- – Three installations feed their cleaned biogas into the natural gas network. The regulation of 15 December 2011 (GDR, 12/2011) for conditions ("*Code de distribution"*) on how the biogas producers inject the cleaned biogas into the network is applicable. According to Article 12 (2) of this Grand-Ducal Regulation, the biogas producer must document to the Luxembourg Institute of Regulation[159] that CH_4 emissions from the process of treating raw biogas to biogas for injection are less than 0.5% of methane contained in the raw biogas for an amine treatment installation, and less than 1% of the methane contained in the crude biogas for a biogas pressurized treatment plant, respectively. Hence only emissions due to leakages are considered and not due to biogas processing before injection.
- – The other biogas facilities encounter the emissions due to the combustion of biogas (blended or not) considered under the CRF Sector *1 - Energy*. The national energy balance provides the necessary activity data.

The majority of the biogas plants in Luxembourg are modern. According to the report of J. Clemens (Clemens, 2014), the number of leakages however does not correlate with the number of years in service or the date of the completion of the facility.

Preliminary analysis of the annual reports (available only from 2007 on) shows that the activity data is composed of roughly 20% municipal waste, 60% agricultural waste, and 20% energy plants. Relating to these specific activity data, the methane content in the

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biogas production can vary between 55% to 62% (mean: 58.5%, n = 100) (Agriculture, Ecosystems & Environment, 2007) in dependence of the different feedstocks. Table 7-18 shows the CH_4 leakage emissions obtained by applying the method adapted to the feedstock distribution as described under Section 7.3.3.1.2.

Table 7-18 – CH4 and N2O emissions from 5B2 – Biogenic Waste Treated in Biogas Plants

5B2 - Biogenic Waste Treated in Biogas Plants

Year	Methane Production (m^3)	CH_4 leakage (Gg)	N_2O (Gg)	Total in CO_2e (Gg)
1990	*0*	*NO*	*NO*	*NO*
1991	*0*	*NO*	*NO*	*NO*
1992	*468'320*	*0.01*	*NO*	*0.29*
1993	*468'320*	*0.01*	*NO*	*0.29*
1994	*468'320*	*0.01*	*NO*	*0.29*
1995	*523'416*	*0.01*	*NO*	*0.32*
1996	*523'416*	*0.01*	*NO*	*0.32*
1997	*413'223*	*0.01*	*NO*	*0.26*
1998	*316'804*	*0.01*	*0.00000*	0.20
1999	*192'837*	*0.00*	*0.00001*	0.12
2000	*2'016'273*	*0.04*	*0.00001*	1.25
2001	*3'635'792*	*0.08*	*0.00002*	2.26
2002	*4'033'583*	*0.09*	*0.00004*	2.51
2003	*6'720'582*	*0.15*	*0.00006*	4.18
2004	*9'038'462*	*0.20*	*0.00014*	5.64
2005	*12'093'349*	*0.27*	*0.00022*	7.56
2006	*14'481'352*	*0.32*	*0.00034*	9.07
2007	*16'256'572*	*0.36*	*0.00040*	10.18
2008	*19'471'328*	*0.43*	*0.00045*	12.19
2009	*23'578'974*	*0.52*	*0.00062*	14.78
2010	*24'679'222*	*0.55*	*0.00059*	15.46
2011	*25'040'254*	*0.55*	*0.00092*	15.77
2012	*29'699'658*	*0.66*	*0.00091*	18.65
2013	*29'283'206*	*0.65*	*0.00090*	18.39
2014	*31'440'724*	*0.70*	*0.00106*	19.77
2015	*32'883'369*	*0.73*	*0.00097*	20.64
2016	*37'695'577*	*0.83*	*0.00103*	23.64
2017	*38'357'367*	*0.85*	*0.00120*	24.10
2018	*39'064'006*	*0.86*	*0.00138*	24.59
2019	*35'167'773*	*0.78*	*0.00108*	22.09
2020	*33'625'647*	*0.74*	*0.00102*	21.12
2021	*33'308'077*	*0.74*	*0.00093*	20.90
2022	*36'942'513*	*0.82*	*0.00083*	23.12
Trend 1992-2022	*7788.3%*	*7788.3%*	*NA*	*7864.0%*
Trend 2021-2022	*10.91%*	*10.91%*	*-11.18%*	*10.65%*

7.3.3.1.4 Parameters

The following parameters have been used for the estimation of CH_4 leakages based on the IPCC method adapted to national circumstances:

Table 7-19 – Parameters for estimation of CH_4 Leakages

Parameter	Value	Source
Molar mass of CH_4	16 g / mol	
Molar volume of CH_4	0.0224 m^3 / mol	
CH_4 leakage rate	3.1%	Biomass and Bioenergy Volume 35, Issue 9, October 2011, Pages 3927–3935

7.3.4 Uncertainties and Time-Series Consistency

7.3.4.1 Biogenic Waste Composted at Centralised Composting Plants (*5B1*)

The uncertainties for the composted waste quantities are considered very small (< 5 %), since the relevant activity data were obtained *via* high-quality annual reporting. The uncertainties for the solid waste quantities undergoing biological treatment are considered the same as in *5A*. A general uncertainty of 5% can be assumed since the activity data consists mainly of composted waste (Table 7-20).

The uncertainties from the literature vary between -100 % and +100 % for the CH_4 and N_20 emission factor (see IPCC Guidelines). As the duration of pre-treatment has an effect on the generation of emissions from waste, the emissions deriving from SIGRE are assumed to be different to the ones deriving from SIDEC.

7.3.4.2 Biogenic Waste Treated in Biogas Plants (*5B2*)

The activity data uncertainties for the *5B2* subsector are assumed to be equal to those for biogas in the Energy combustion sector (7%, data is obtained from the national energy balance). The uncertainty of the CH_4 emission factor corresponds to the uncertainty of the leakage factor, which can be derived from (Flesch et al., October 2011) (see Table 7-20).

Table 7-20 – Uncertainties with regard to Activity Data and Emission Factors for category *5B*

Uncertainties	Activity data	Emission factor CH_4	Emission factor N_2O
5B1 - Biogenic waste composted at centralised composting plants	± 5 %	± 100 %	± 100 %
5B2 - Biogenic waste treated in biogas plants	± 7%	± 68%	± 85% (combined uncertainty for N_2O emissions)

7.3.5 Category-Specific QA/QC and Verification

Category-specific QA/QC and verification include:

- Internal verifications and plausibility checks when compiling aggregated activity data on waste from the waste disposal sites;
- QA/QC procedures described under the different Waste Directives in the context of reporting on waste data. Indeed, the same aggregated data used for the inventory is also used for reporting to Eurostat;
- Use of the tools embedded in CRF Reporter.

7.3.6 Category-Specific Recalculations Including Changes Made in Response to the Review Process

Table 7-21 presents the main revisions and recalculations relevant to category 5B – Biological Treatment of Solid Waste since the last submission to the UNFCCC. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 7-21: Recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 → 2024v1	Type of revision
5B1a	Revision of AD for the year 2021	AD
5B2b	Revision of the AD for the years 2018 and 2021	AD
5B2	NEW: Direct and indirect N_2O emissions from digestate originating from energy crops and non-agricultural waste was reported in Sector CRF 5B2	AD and N_2O emissions

The activity data for two facilities has been updated due to an error correction in their reports. This impacts the amount of waste treated for the year 2021 in sector 5.B.1.a – Municipal Solid Waste. This correction has led to a recalculation of the emissions for the cited year.

Table 7-22 shows the recalculations with respect to the previous submission in sector 5.B.1.a.

Table 7-22: Recalculation with respect to previous submission in category 5.B.1.a

5.B.1.a Municipal Solid Waste							
Year	Annual waste amount treated		CH_4 Emissions		N_2O Emissions		Difference
	2023v1 (kt)	2024v1 (kt)	2023v1 (kt)	2024v1 (kt)	2023v1 (kt)	2024v1 (kt)	
2021	28.163	27.626	0.282	0.276	0.017	0.017	-1.91%

An update to the energy balance based on the update of the IEA-compliant energy balance compiled by the national statistics authority STATEC has been taken into account. This leads to a correction of the activity data and subsequently the emissions in sector 5.B.2.b – Anaerobic Digestion at Biogas Facilities. A recalculation of the emissions for the years 2018 and 2021 has been done.

Table 7-23 shows the recalculations with respect to the previous submission in sector 5.B.2.b.

Table 7-23: Recalculations with respect to previous submission in category 5.B.2.b

5.B.2.b Anaerobic Digestion at Biogas Facilities			
Year	CH_4 Emissions		
	2023v1 (kt)	2024v1 (kt)	Difference
2018	0.895	0.865	-3.40%
2019	0.779	0.779	0.00%
2020	0.745	0.745	0.00%
2021	0.706	0.738	4.47%

7.3.7 Category-Specific Planned Improvements

7.3.7.1 Biogenic Waste Composted at Centralised Composting Plants (*5B1*)

No planned improvements are foreseen for this subsector.

7.3.7.2 Biogenic Waste Treated in Biogas Plants (*5B2*)

No planned improvements are foreseen for this subsector.

7.4 Incineration and Open Burning of Waste (5C)

This category is presented under IPCC subcategory 1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production (Section 3.2.6) because in the sole incinerator of the country (SIDOR site), energy from waste burning is recovered and injected into the electric public network.

7.5 Waste Water Treatment and Discharge (5D)

7.5.1 Source Category Description

Category *5D* covers emissions from waste water treatment (WWT) and discharge, whether the waste water has been generated by households (reported under category 5D1 - Domestic wastewater) or by industrial enterprises (reported under category 5D2 - Industrial wastewater). Hence, it is assumed that commercial WWT is included in domestic municipal waste water treatment carried out in waste water treatment plants (*WWTPs*). Emissions from combustion activities in WWTPs (for example for heating certain processes) are not reported under category 5D but are included in category 1A-Fuel Combustion.

To summarize:

- category *5D1* covers methane and nitrous oxide emissions from waste water treatment in domestic (including septic tanks) and commercial sources. No CO_2 emissions deriving from non-biological or inorganic WWH residuals have been identified so far;

10) category *5D2* covers nitrous oxide emissions from waste water treatment in industry. Methane emissions in category *5D2* are not occurring in Luxembourg as the processes in these installations are entirely aerobic;
11) Emissions related to the sludge residues of domestic and commercial WWH are not accounted for in this sector. Indeed, sewage sludge spreading is accounted for in the agriculture sector (*3D - Agricultural Soils*), while other parts are incinerated with energy recovery and the emissions are therefore reported in the energy sector under (*1A2g - Other - Manufacturing Industries and Construction*). The remainder of sludge is composted and emissions are therefore reported under the category other (*5B - Biological Treatment of Solid Waste*).

In 2022, source category *5D* was responsible for 7.21% of the total GHG emissions from the waste sector – excluding waste incineration – and it represented 0.05% of the total GHG emissions in CO_2e (excluding LULUCF):

12) CH_4 from WWT represented 2.52% of waste treatment methane related emissions – excluding waste incineration – and 0.30% of the total methane emissions estimated for Luxembourg;
13) N_2O from WWT represented 59.50% of waste treatment nitrous oxide related emissions – excluding waste incineration – and almost 1.94% of the total nitrous oxide emissions estimated for Luxembourg.

From 1990 to 2022, GHG emissions from 5D decreased by 53.22%, from 2005 to 2022, they decreased by 45.35% and from 2021 to 2022 by 6.93% (see Figure 7-7). For N_2O emissions, the detailed emission trend per WWT system is given in Figure 7-8.

None of the source categories under WWT is a key category.

Figure 7-7 – Emission trend of wastewater treatment emissions (5D)

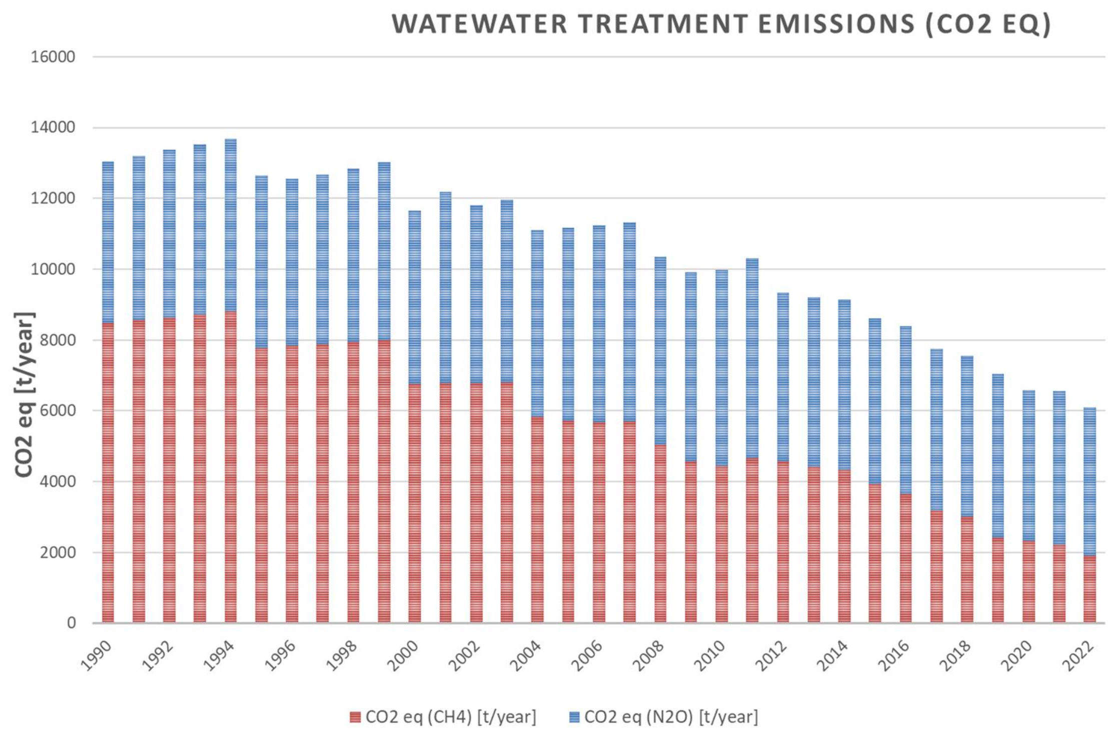
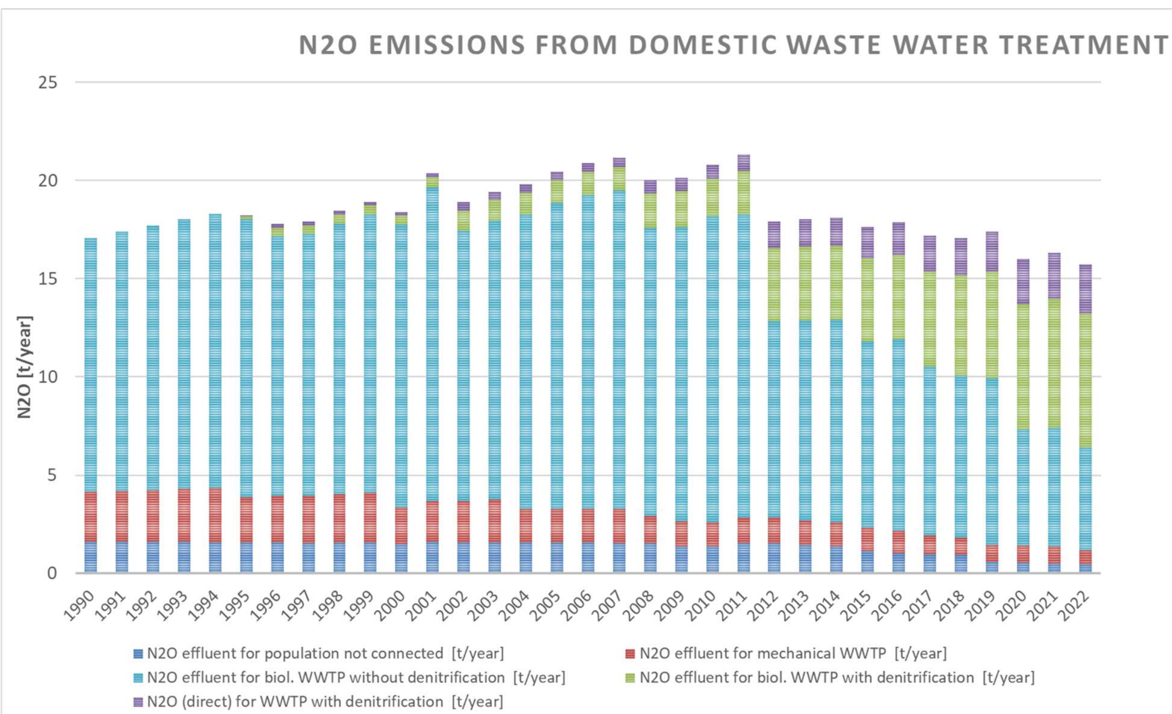


Figure 7-8 - N_2O emission trends for categories 5D1 and 5D2 WWH



Source: Water Management Agency.

7.5.2 Domestic wastewater (5D1)

7.5.2.1 Methodological Issues

In Luxembourg, domestic wastewater is treated in four different ways based on the location of the villages and municipalities. In the calculation method these four systems are considered seperatedly:

- Septic tanks used in remote places where a connection to a waste water treatment plant (WWTP) is not possible.
- Mechanical WWTPs, which in Luxembourg are to be considered as very basic installations with no sludge digesters and which are managed from a technical point of view in the same way as septic tanks. They consist of simple volumes with a baffle and no pre- or subsequent treatment (such as screen a grit compartment, or aerobic step). In addition, the management consists of simple regular emptying. Hence, it should also be noted, that the processes in these installations are very similar to septic tanks (which is particularly important for the calculation of methane emissions). Also, all sludge, removed from these mechanical WWTPs (as well as from septic tanks), is transferred to biological WWTPs where it is further treated either aerobically, or anaerobically in a digester. This is not to be compared to modern mechanical waste water treatment plants which might be operated in other European countries.
- Biological WWTPs without denitrification.
- Biological WWTPs with denitrification.

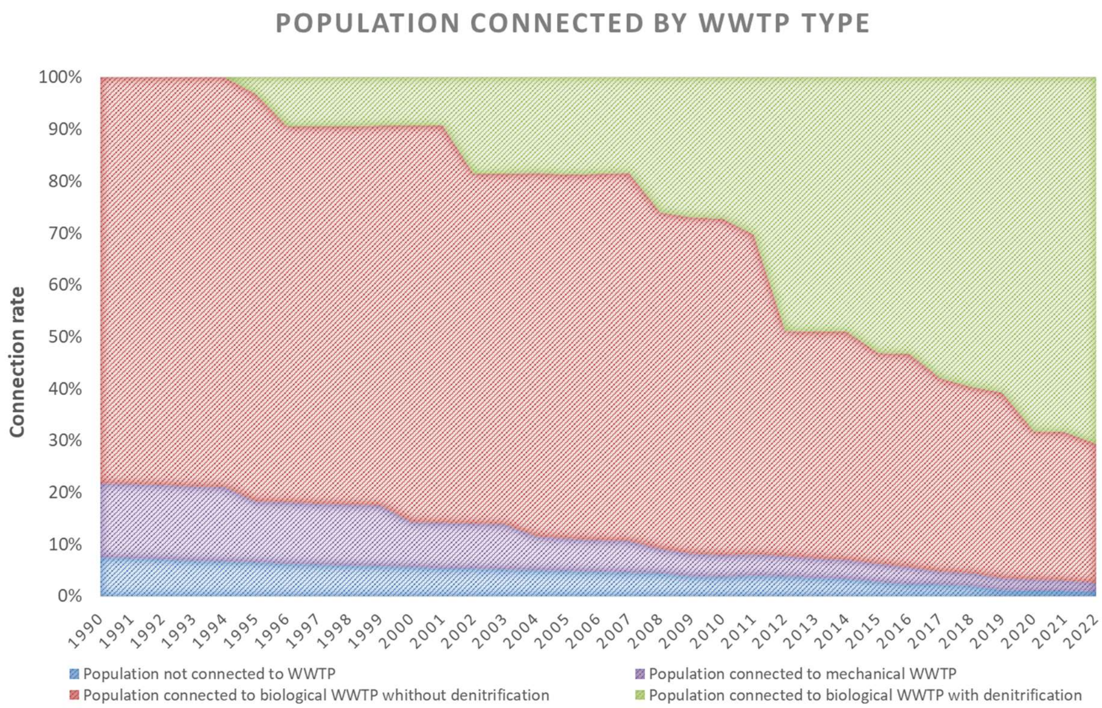
Emissions are calculated based on the population connected to these different systems. The population number connected to the different sytems was derived from the population census for 1991, 2001 and 2011 which contains the detailed population of each locality in Luxembourg (years in between were interpolated, respectively extrapolated for 1990). From 2012 onwards, detailed yearly population data per locality is provided by the national statistics institute STATEC. Each locality was attributed to a specific WWT system (septic tanks, mechanical WWTP and advanced biological WWTP with denitrification) as registerd with the Water Management Administration (AGE) (seeTable 7-24). The remaining population and half of the commuters (see next paragraph) was attributed to advanced biological WWTP without denitrification.

Table 7-24 - Population connected per WWT system

5.D.1 Domestic Wastewater					
	Share of population connected by WWT type				Total Population producing WW
Year	not connected	mec. wwtp	bio. wwtp - denitr.	bio. wwtp + denit.	
1990	7.84%	14.96%	77.20%	0.00%	396'950
1991	7.66%	15.05%	77.29%	0.00%	404'210
1992	7.48%	15.13%	77.39%	0.00%	411'570
1993	7.30%	15.21%	77.49%	0.00%	418'930
1994	7.13%	15.28%	77.59%	0.00%	426'490
1995	6.96%	12.57%	77.09%	3.38%	434'150
1996	6.78%	12.60%	70.45%	10.16%	442'300
1997	6.62%	12.65%	70.54%	10.18%	450'250
1998	6.47%	12.71%	70.62%	10.21%	458'850
1999	6.32%	12.75%	70.70%	10.23%	467'650
2000	6.16%	9.71%	73.86%	10.27%	478'750
2001	6.01%	9.72%	73.99%	10.27%	489'050
2002	5.88%	9.71%	63.59%	20.83%	496'450
2003	5.75%	9.73%	63.66%	20.85%	502'700
2004	5.60%	7.46%	66.16%	20.77%	512'200
2005	5.46%	7.19%	66.11%	21.24%	521'800
2006	5.30%	7.05%	66.53%	21.11%	533'600
2007	5.16%	7.05%	66.77%	21.02%	545'800
2008	5.02%	5.61%	59.26%	30.12%	558'500
2009	4.38%	5.08%	59.65%	30.90%	567'650
2010	4.23%	4.80%	59.55%	31.42%	578'050
2011	4.50%	4.76%	55.83%	34.91%	590'700
2012	4.33%	4.56%	34.93%	56.18%	604'450
2013	4.06%	4.35%	35.22%	56.37%	618'200
2014	3.90%	4.14%	35.59%	56.37%	632'350
2015	3.13%	3.98%	31.76%	61.13%	648'508
2016	2.69%	3.78%	32.13%	61.41%	664'849
2017	2.58%	2.93%	27.46%	67.02%	682'417
2018	2.35%	2.76%	25.75%	69.15%	698'055
2019	1.41%	2.60%	25.41%	70.59%	714'344
2020	1.29%	2.48%	16.84%	79.38%	728'558
2021	1.16%	2.39%	16.83%	79.62%	739'180
2022	1.02%	2.01%	14.53%	82.45%	754'273
Trend 1990-2022	-87.04%	-86.58%	-81%	NA	90.02%
2005-2022	-81.40%	-72.07%	-78%	288%	44.55%
2021-2022	-12.56%	-15.91%	-14%	4%	2.04%

Figure 7-9 provides an overview of the population of Luxembourg connected to the different types of WWT where "not connected to WWTP" (septic tanks) and "mechanical WWTP" are particularly important for the calculation of 5D1 methane emissions and centralised advanced "biological WTTPs" (with or without denitrification) are important for the calculation of 5D1 N_2O emissions. Hence, in 2012, the number of the population connected to WWTPs with denitrification increased considerably due to the fact that 3 new WTTPs with denitrification went online. Over the years, more and more localities are connected to centralised advanced biological WWTPs with denitrification.In 2020, the population connected to advanced biological WTTPs with denitrification increased again by 15% with the operational start of 5 new WWTPs.

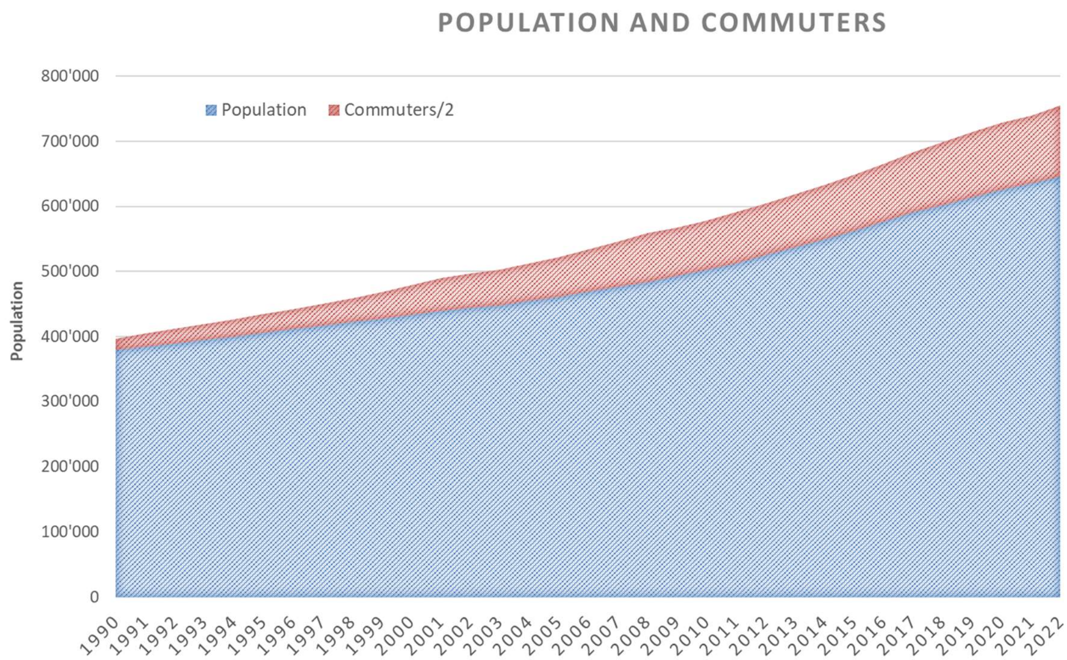
Figure 7-9 – Population connected to sewage system type



Source: Water Management Agency.

However, as Luxembourg's workforce is increased daily by about two hundred thousand commuters (from France, Belgium and Gemany), their impact on wastewater discharge had to be taken into account. Hence, as these daily commuters only spend their working hours in the country, their number was divided by half and added to Luxembourg's population. Figure 7-10 illustrates the population and cross-border commuters' growth between 1990 and 2022. Hence, this consideration is particularly important for the nitrous oxide emission calculation, where daily commuters had to be taken into account, in addition to the residents of the country, when calculating the nitrogen load of the effluent. Population and commuters are provided by the STATEC.

Figure 7-10 – Resident population and cross-border commuters as used for WWT emission calculations



7.5.2.2 Methane Emissions

7.5.2.2.1 Emission trends

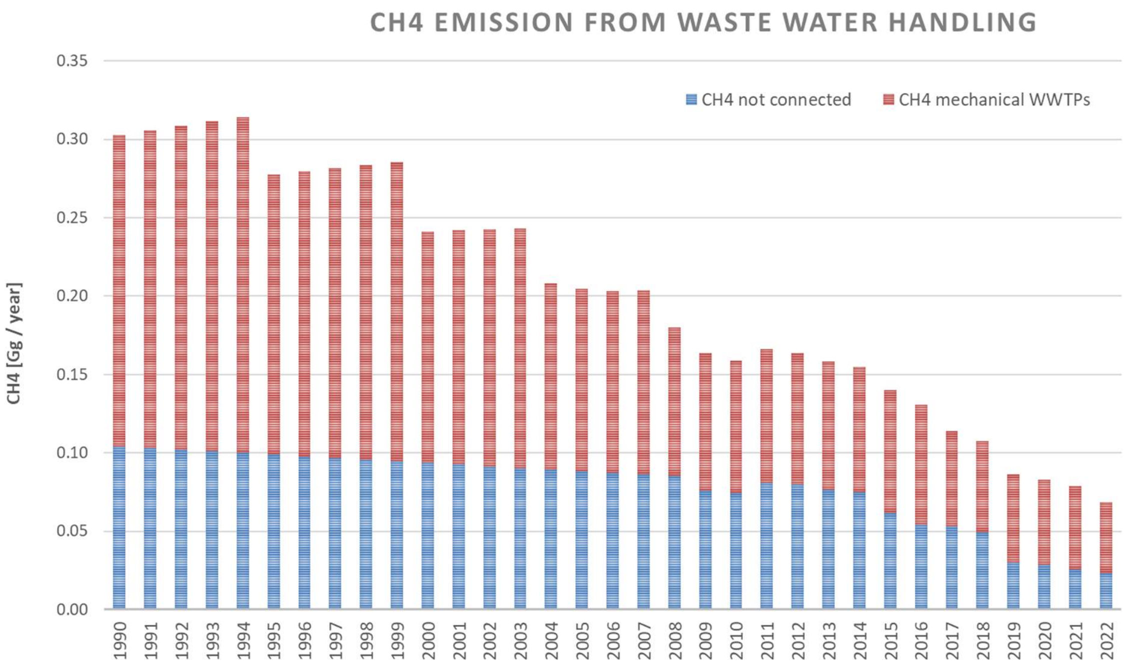
Methane emissions for category *5D1* are presented in Table 7-25 and Figure 7-11. Since 1990, emissions have been reduced by over 73%. This systematic reduction is due to the continuous efforts to reduce the use of septic tanks in remote localities and to connect these to centralised biological WWTPs. The same counts for mechanical WTTPs, which are old basic istallations in Luxembourg which can be compared, from their process and management, to septic tanks rather than to modern mechanical or biological WWTPs (please also refer to section 7.5.2.1 for more detals).

Table 7-25 – CH_4 emission trends for category *5D1 – Domestic & Commercial WWT*

CH_4 emissions (tonnes) 5.D.1 Domestic Wastewater			
Year	Mechanical	Septic Tanks	Total
1990	198.82	104.20	303.03
1991	202.70	103.14	305.84
1992	206.57	102.08	308.65
1993	210.45	101.01	311.46
1994	214.32	99.95	314.27
1995	178.72	98.89	277.61
1996	181.79	97.82	279.61
1997	184.86	96.76	281.62
1998	187.92	95.70	283.62
1999	190.99	94.63	285.63
2000	147.57	93.57	241.14
2001	149.58	92.51	242.09
2002	151.09	91.45	242.53
2003	152.85	90.38	243.23
2004	118.94	89.32	208.26
2005	116.20	88.26	204.46
2006	115.94	87.19	203.13
2007	117.58	86.13	203.71
2008	95.02	85.07	180.09
2009	87.79	75.68	163.46
2010	84.51	74.47	158.98
2011	85.47	80.88	166.34
2012	83.91	79.64	163.54
2013	81.90	76.32	158.23
2014	79.76	75.13	154.88
2015	78.57	61.70	140.27
2016	76.25	54.26	130.51
2017	60.75	53.34	114.09
2018	58.14	49.50	107.64
2019	55.86	30.26	86.12
2020	54.38	28.39	82.76
2021	53.11	25.84	78.95
2022	45.41	22.98	68.39
Trend 1990-2022	-77.16%	-77.95%	-77.43%
2005-2022	-60.92%	-73.97%	-66.55%
2021-2022	-14.49%	-11.09%	-13.38%

Source: Water Management Agency.

Figure 7-11 – CH_4 emission trends for category *5D1 – Domestic wastewater*



Source: Water Management Agency.

7.5.2.2.2 Methodological issues:

Municipal waste water treatment in Luxembourg uses mainly aerobic processes (see Table 7-26) such as activated sludge or bio-filtration. As a result, no or negligible methane emissions are produced, since such emissions only occur under anaerobic conditions. In the well managed advanced biological WTTPs, sludge stabilisation is carried out in order to prevent uncontrolled putrefaction. In facilities with a treatment capacity smaller than 30.000 population-equivalents (p. e.) the stabilisation is usually carried out aerobically, with oxygen and energy consumption, while for facilities with a treatment capacity larger than 30.000 p. e., the stabilisation is normally carried out anaerobically with production and recovery of methane gas at the digester. The gas produced is usually used for energy recovery in combined heat/power generating systems or may be flared.

Table 7-26 shows theoretical load that can be treated in municipal WWTPs since 1990. It also indicates the percentage of that load that is treated using aerobic procedures, *i.e.* in WWTPs applying a biological treatment to waste water.

Table 7-26 – Municipal WWTP capacities and aerobic procedures

Year	Load treated in municipal WWTP 1000 population-equivalents	Aerobic procedures %
1990	591.6	84.0%
1991	594.0	85.0%
1992	596.5	86.0%
1993	600.0	87.0%
1994	605.8	88.0%
1995	631.6	89.0%
1996	782.4	91.0%
1997	788.4	92.0%
1998	793.9	92.0%
1999	799.4	93.0%
2000	806.9	94.0%
2001	811.8	94.0%
2002	816.7	94.0%
2003	818.7	94.0%
2004	820.7	95.0%
2005	820.0	95.0%
2006	1'012.0	95.0%
2007	1'016.0	97.0%
2008	1'017.3	98.0%
2009	1'066.3	98.0%
2010	1'064.7	96.0%
2011	1'014.4	96.0%
2012	1'018.2	96.2%
2013	1'034.9	96.3%
2014	1'036.2	96.7%
2015	1'015.7	96.6%
2016	980.3	96.9%
2017	990.6	97.0%
2018	1'043.4	97.8%
2019	1'092.7	98.2%
2020	1'093.2	98.3%
2021	1'104.6	98.3%
2022	1'121.0	98.7%
Trend 1990-2022	89.5%	17.5%
2005-2022	36.7%	3.9%
2021-2022	1.5%	0.4%

Source: Water Management Agency

Treatment of human sewage from inhabitants connected to small mechanical WWTPs or septic tanks represents an exception. The percentage of organic loads discharged to these treatment units has been reduced consequently since 1990 (see also Table 7-24). Hence methane emissions are only estimated for WWT in septic tanks and mechanical WWTPs as uncontrolled anaerobic processes are likely to occur in these systems and as there is no methane revovery occurring in these systems.

The methodology used for estimating methane emissions from septic tanks and mechanical WWTPs is based on the IPCC Tier 1 method in which the relevant population connected to septic tanks and to mechanical WWTPs is considered to calculate the organic load in the wastewater. It should be noted that, in Luxembourg, mechanical WTTPs are to be considered as very basic installations with no sludge digesters and which are managed from a technical point of view in the same way as septic tanks (please refer to section 7.5.2.1 for further details).

Calculation of the organic load (BOD):

*BODsep [kg/year] = inhabitants connected to septic tanks * 60 g BOD (person/day) * 365 (days) / 1000*

*BODmec [kg/year] = inhab. connected to mechanical WWTP * 60 g BOD (person/day) * 365 (days) / 1000*

The organic load for septic tanks and mechanical WWTP's is calculated as described in the equations above, by multiplying the population connected the different systems with the default organic load *per* person (60 g BOD/day/person, 2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.4, p. 6.14).

Calculation of the methane conversion factor (MCF):

According to national expert judgment and based on the study of (Steinlechner, et al., 1994) the MCF has been adapted to the national situation in Austria, which is also applicable for Luxembourg. The MCF defines the portion of methane producing capacity (B0) that degrades anaerobically and may vary between 0.0 (completely aerobic) to 1.0 (completely anaerobic) according to the IPCC 2006 Guidelines. When the sludge treatment process is anaerobic, the temperature has a great influence. During the winter time, the temperature decreases to 10°C in the sludge part of the WWTP so that the biological activity is much reduced and the MCF = 0.1. During the rest of the year, the temperature in the sludge part is closer to 20°C, which is still low for an optimal biological activity and therefore the MCF factor is 0.35 according to Steinlechner *et al.* As the mechanical wastewater treatment plants are based on the same technical process as the septic tanks, the MCF factor used for both categories is the same and is calculated as follows:

*MCF = 2/3 * 0.35 + 1/3 * 0.1 = 0.27*

Calculation of the methane emissions:

CH_4 *sep [t/year] = BODsep * B0 * MCF / 1000*

CH_4 *mec [t/year] = BODmec * B0 * MCF / 1000*

Where:

sep = septic tanks

mec = mechanical WWTPs

B0 = 0.6 kg CH4/ kg BOD	2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.2, p.6.12
60 g BOD/person per day	2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.4, p.6.14 and European Directive 91/271/CEE on the treatment of urbane waste water, Article 2.6
MCF = 0.27	country-specific methane conversion factor: 0.35 * 2/3 + 0.1 * 1/3 = 0.27 (see above)

The number of inhabitants connected to a septic tank (sep) is determined annually by the Water Management Administration through a plant-spcific inventory. The number of inhabitants from agglomerations connected to a septic tank or to a mechanical WWTP is based on population statistics per locality as provided by STATEC and specific connection information from the Water Management Administration (see also section 7.5.2.1).

Total methane emission from waste water handling:

CH_4 *tot =* CH_4 *sep +* CH_4 *mec [t/year])]*

Total emissions are finally calculated by adding up the emissions from septic tanks and mechanical WWTPs.

7.5.2.3 Nitrous Oxide

N_2O emissions for 5D1 are estimated for the four WWT systems as presented in section 7.5.2.1.

7.5.2.3.1 Emission trends

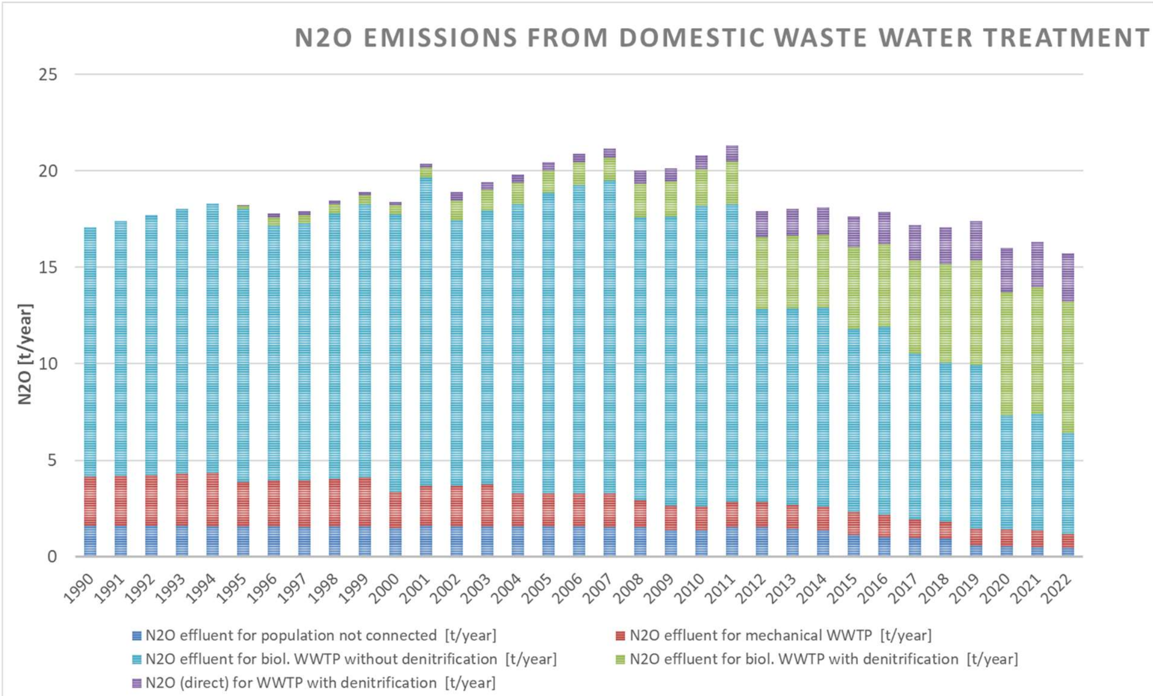
Overall, N_2O emissions have decreased 12% from 1990 to 2022 although the population and workforce have largely increased during the same period (see Table 7-27 and Figure 7-12). This increase in population and the following potential increase in emissions has been counterbalanced by the consequent move from septic tanks and basic mechanical WWTPs to advanced biological WWTPs without denitrification and, in more recent years, the consequent implementation of advanced biological WWTPs with denitrifaction since 1995. Hence, for example, in 2012, the number of the population connected to WWTPs with denitrification increased considerably due to the fact that 3 new WTTPs with denitrification went online. This consequent implementation is also best illustrated in Figure 7-12). In 2020, 5 new advanced biological WWTPs with denitrification came into operation (15% of the population was switched from older WWTPs without denitrification to modern andavanced biological WTTPs with denitrification, explaining the decrease in N_2O emissions in 2020 by a further 10%.

Table 7-27 – N_2O emission trends for category *5D1 – Domestic & Commercial WWH*

N_2O emissions (tonnes)						
5.D.1 Domestic Wastewater						
Year	effluent not con.	effluent mec. wwtp	effluent wwtp - denit.	effluent wwtp + denit.	direct wwtp-de	Total
1990	1.62	2.51	12.96	NO	NO	17.09
1991	1.61	2.57	13.21	NO	NO	17.39
1992	1.60	2.63	13.47	NO	NO	17.71
1993	1.59	2.70	13.74	NO	NO	18.03
1994	1.58	2.75	13.98	NO	NO	18.31
1995	1.57	2.31	14.16	0.14	0.06	18.24
1996	1.57	2.37	13.22	0.44	0.18	17.77
1997	1.54	2.39	13.33	0.44	0.18	17.90
1998	1.55	2.48	13.77	0.46	0.19	18.45
1999	1.56	2.55	14.15	0.47	0.00	18.72
2000	1.48	1.89	14.38	0.46	0.20	18.40
2001	1.60	2.10	15.95	0.51	0.20	20.35
2002	1.57	2.10	13.76	1.04	0.41	18.88
2003	1.58	2.17	14.18	1.07	0.42	19.42
2004	1.57	1.69	15.03	1.09	0.43	19.80
2005	1.58	1.69	15.57	1.15	0.44	20.44
2006	1.57	1.70	15.99	1.17	0.45	20.88
2007	1.55	1.71	16.25	1.18	0.46	21.15
2008	1.53	1.39	14.68	1.72	0.67	20.00
2009	1.36	1.28	15.01	1.79	0.70	20.14
2010	1.36	1.26	15.57	1.90	0.73	20.81
2011	1.53	1.31	15.41	2.22	0.82	21.30
2012	1.53	1.31	10.01	3.72	1.36	17.92
2013	1.44	1.26	10.17	3.76	1.39	18.02
2014	1.39	1.20	10.31	3.77	1.43	18.10
2015	1.15	1.19	9.48	4.21	1.59	17.61
2016	1.00	1.15	9.76	4.31	1.63	17.85
2017	0.99	0.92	8.60	4.84	1.83	17.19
2018	0.92	0.88	8.25	5.11	1.93	17.10
2019	0.58	0.87	8.48	5.44	2.02	17.38
2020	0.56	0.87	5.88	6.40	2.31	16.01
2021	0.51	0.86	6.03	6.58	2.35	16.33
2022	0.45	0.72	5.23	6.84	2.49	15.73
Trend 1990-2022	-72.24%	-71.24%	-59.69%	NA	NA	-7.98%
2005-2022	-71.58%	-57.34%	-66.43%	492.91%	461.05%	-23.05%
2021-2022	-12.16%	-15.52%	-13.29%	4.03%	5.67%	-3.66%

Source: Water Management Agency.

Figure 7-12 – N_2O emission trends for category *5D1 – Domestic & Commercial WWH*



Source: Water Management Agency.

7.5.2.3.2 Methodological issues

Nitrous oxide emissions from municipal waste water have been evaluated by applying the Tier 1 method described in the 2006 IPCC Guidelines (Volume 5, Chapter 6.3). Althought, this methodology is currently at discussion (e.g. the method assumes no N_2O-emissions from treatment of the older generation WWTP; the EF for advanced WWTP is very low) Luxembourg has several reasons to apply the 2006 GL:

- This is in agreement with the guidance on choice of method in the 2006 GL. Chapter 6.3.1.1 reads "it is *good practice* to estimate N_2O from domestic wastewater effluent using the method given here." In Luxembourg, the subsector is a non-key category source, so application of a Tier-1 methodology is justified;
- almost all EU Member States follow the methodology in the 2006 IPCC GLs, which makes Luxembourg's estimate more comparable to the estimate in other member states;
- IPCC is currently working on a 2019 Refinement. In the most recent draft the above mentionned concerns on the 2006-GL seem to be addressed. Rather than developing an own country-specific methodology Luxembourg prefers to wait for the new refinement to be made mandatory and then align its methodology with the new guidelines.

Hence, N_2O emissions from municipal waste water handling were calculated per discharge pathway (septic tanks, basic mechanical WWTPs, biological WWTP without denitrification, advanced biological WWTPs with denitrification) by taking into account the average per capita protein intake.

The average per capita protein intake was derived from FAOSTAT, which publishes values for the years 2000-2021. In this period, the protein consumption in Luxembourg increased from an average of 99.2 g/day/person to an average of 118.1 g/day/person. As no data was available for the other years, these were extrapolated based on a moving average of the preceeding (for 2022 onwards), respectively subsequent (for 1990-1999) 3 years.

<u>Determination of the N-effluent (2006 IPCC GLs, equation 6.8):</u>

*N-effluent(i) = P(i) * Protein * F NPR * F ind-com * F non-con * (1 – N-removal (i))*

Where:

(i) = WWT system: not connected (septic tanks), mechanical WWTPs, biological WWTPs without denitrification and biological WWTPs with denitrification.

Protein = protein intake per person (kg/year) (http://www.fao.org)

F ind-com = 1.25 (default fraction of industrial and commercial co-discharged protein, 2006 IPCC GLs, page 6.26)

F NPR = 0.16 kg N/kg protein (default fraction of N in protein, 2006 IPCC GLs, page 6.25)

F non-con = 1.1. (default factor to adjust for non-consumed protein, 2006 IPCC GLs, page 6.27)

N-removal(i) = percentage of N removed in the sludge (0% for septic tanks, 35% for mechanical WWTPs, 35% for biological WWTPs without denitrification, 85% for biological WWTPs with denitrification).

For all the four WWT pathways, the N-effluent was calculated in accordance with equation 6.8 of the 2006 GLs (Vol. 6. Chap. 5, Eq. 6.8, p. 6.25) and using the IPCC default values for F(NPR) (= 0.16 kg N/kg protein), F(non-con) (=1.1, since garbage disposal installations on sinks are not allowed in Luxembourg) and F(ind) (=1.25) (2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.11). Concerning N removed (in the sludge) either default or country-specific values were applied depending on the WWT system:

- For septic tanks, no correction is made for N removed with sludge, because no data are available on sludge removal or N-removal from septic tanks. In line with the 2006 Guidelines, a default value of N_{sludge} of 0 was applied;
- For mechanical WWTPs and older biological WWTPs without denitrification, it is assumed that 35% of $N_{effluent}$ is removed as N_{sludge}, so *indirect* emissions as a result of discharge of effluent of older WWTP are reduced by 35%. This 35% is based on measurements of N in the influent and effluent at several WWTPs. Calculations of sludge production at these WWTPs reveal that the majority of this 35% will be removed by sludge and this does not result in *direct* N_2O-emissions at the WWTPs. Minor part of the 35% might be removed by spontaneous nitrification/denitrification and this might result in *direct* emissions of N_2O. However, nitrate concentrations in the effluent of these WWTPs are generally low, and this is an indication that spontaneous nitrification is low as well. A sensitivity analysis reveals that the impact on *direct* N_2O-emissions of a more conservative assumption on spontaneous nitrification/denitrification (e.g. 10% out of 35% reduction in N is due to spontaneous nitrification/denitrification) results in additional N_2O-emissions below the threshold of significance for Luxembourg. Therefore, direct N_2O-emissions from these WWTPs can be neglected.
- For advanced biological WWTPs with denitrification, the guidance as provided in Box 6.1 in the IPCC guidelines, was applied and *indirect* aswell as *direct* emissions were calculated using the default IPCC EFs. Hence, for the calculation of the indirect emissions, a reduction of 85% of the N-effluent in the sludge is assumed. This 85% N removal is based on measurements of N in the influent and effluent at several WWTPs with denitrifcation. Indeed, denitrification is a treatment requirement in Luxembourg for Urban Waste Water Treatment Plants based on the European Directive 91/271/CEE concerning urban waste water treatment. WWTPs with an organic design capacity larger than 10 000 population-equivalents (p. e.) have to meet the minimum reduction rate of 75% of total nitrogen. The objective of denitrification is to reduce the risk of eutrophication of surface waters.

<u>Determination of *indirect* N_2O from waste water (2006 IPCC Guidelines, equation 6.7):</u>

Indirect N2O emissions for each pathway was calculated using equation 6.7 of the 2006 IPCC Guidelines (Vol. 6, Chap. 5, Eq. 6.7, p. 6.24-6.25) as detailed below:

$$N_2O(i)\ [t/year] = N\text{-}effluent(i) * EF\text{-}effluent / 1000 * 44/28$$

Where:

(i) = WWT system: not connected (septic tanks), mechanical WWTPs, biological WWTPs without denitrification and biological WWTPs with denitrification.

N-effluent (i) = Nitrogen content of the effluent per WWT system

EF effluent = 0.005 kg N_2O-N/kg N (default 2006 IPCC GLs, page 6.25)

44/28 = 1.57: conversion of N_2O-N to N_2O (44/28, N_2O/N))

Determination of *direct* N_2O from advanced biological WWTPs with denitrification:

As stated above, for advanced biological WWTPs with denitrification, direct N_2O emissions were calculated in accordance with the 2006 GLs, equation 6.9 (Vol. 6, Chap. 5, Box 6.1, Eq 6.9, p.6.26):

$$N_2O(wwtp\text{-}de) = P(wwtp\text{-}de) * F(ind\text{-}com) * EF\ plant / 1.000.000 \qquad [t/year]$$

Where:

wwtp-de = WWTPs with denitrification

P(wwtp-de) = inhabitants connected to wwtp-de

F(ind-com) = 1.25 (default fraction of industrial and commercial co-discharged protein, 2006 IPCC GLs, page 6.26)

EF plant = 3.2 g N_2O / person / year (default emission factor, 2006 IPCC GLs, Table 6.11)

Determination of N_2O total emission from waste water handling:

Finally, total N_2O emissions for category 5D1 were calculated by summing up the indirect N_2O emissions from the four WWT systems and the direct N_2O emissions from biological WWTPs with denitrification:

$$N_2O_{tot}\ [t/year] = N_2O_{indirect}\ (notcon) + N_2O_{indirect}\ (mec) + N_2O_{indirect}\ (biol) + N_2O_{indirect}\ (wwtp\text{-}de) + N2O_{direct}\ (wwtp\text{-}de)$$

Where:

notcon = not connected (i.e. septic tanks)

mec = mechanical WWTPs

biol = biological WWTPs without denitrification

wwtp-de = biological WWTPs with denitrification

7.5.3 Industrial wastewater (5D2)

In category 5D2, emissions from two industrial plants are reported (one chemical and one operating in food and beverages).

7.5.3.1 Methane Emissions

Industrial waste water treatment is carried out under aerobic conditions (activated sludge process). As only two plants fall under 5D2, one can hardly compare this specific situation to other EU Member States, which have very often a much larger number of plants in a multitude of operating modes. Indeed, Luxembourg's industrial plants are operated in aerobic mode with active injection of air/oxygen in order to exclude any anaerobic process which could occur in situ, in the same manner as the well managed advanced municipal biological WWTPs (with or without denitrification as reported in 5D1). In addition, the wastewater treated in these industrial plants is very specific to the industrial processes handeled in these planst and is not to be compared to municipal WWTPs in the sense that it contains much less sludge. The sludge formed at the end of the biological process is either pumped off, thickened, dehydrated and exported for incineration (one plant), either pumped off and transported to a biogas facility for anaerobic digestion (one plant). These sludge treatment processes are fully compatible with the IPCC guidelines and justify the use of the "NO" notation key in the CRF tables.

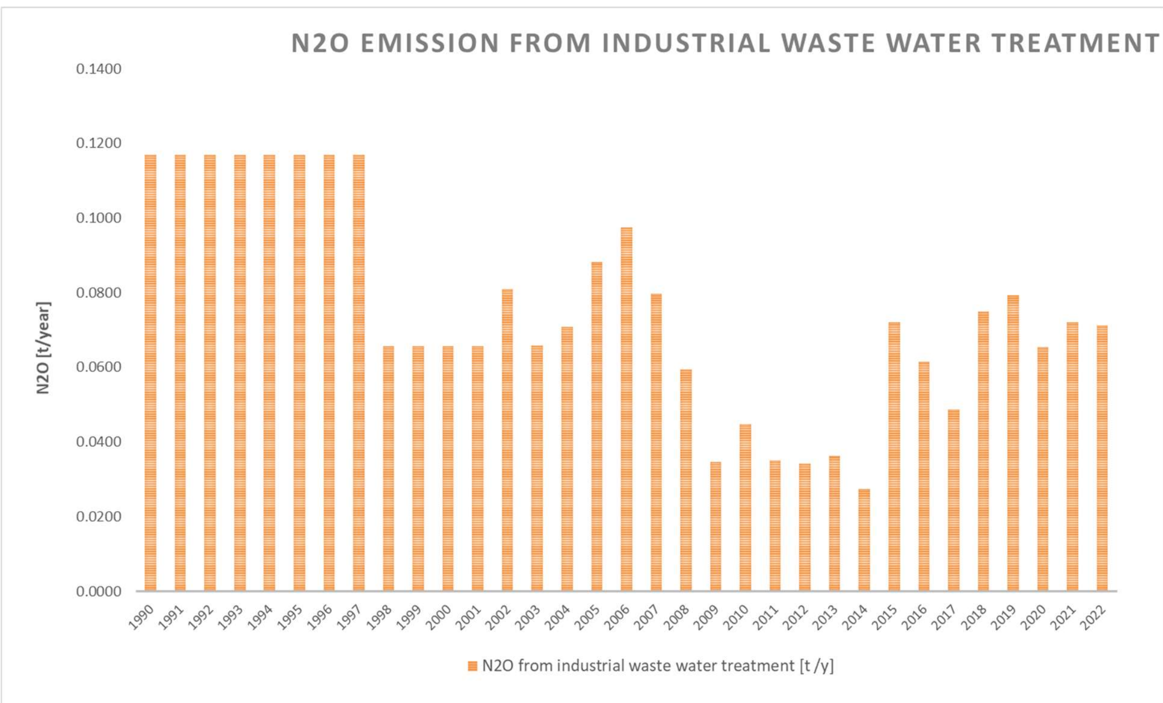
7.5.3.2 Nitrous Oxide Emissions

7.5.3.2.1 Emission trends

Nitrous Oxide emissions from industrial wastewater treatment have decreased by 39% over the period 1990-2022 (see Table 7-28 – N2O emission from 5D2 - *Industrial Wastewater*

and Figure 7-13). From 1990 to 2014, emission originate only from one industrial WWTP. The second was put in operation in 2015. In 1998, the original WWTP was replaced by one with denitrification, and hence the N concentration in the effluent was reduced. Since 2002, N reduction is based on analytical measurements of the N concentration in the flow in and flow out of the WWTP, which is also the case for the second industrial WWTP since its operational start. Hence, annual variations in N_2O emissions from industrial WWTPs are mainly due to the intensity of industrial activities and adaptations to the use of water in the processes.

Figure 7-13 – N_2O emission trends for category *5D2 – Industrial Wastewater*



Source: Water Management Agency.

Table 7-28 – N_2O emission from *5D2 - Industrial Wastewater*

N_2O emissions (tonnes) 5.D.2 Industrial Wastewater		
Year	N_2O ind	Total
1990	0.12	0.12
1991	0.12	0.12
1992	0.12	0.12
1993	0.12	0.12
1994	0.12	0.12
1995	0.12	0.12
1996	0.12	0.12
1997	0.12	0.12
1998	0.07	0.07
1999	0.07	0.07
2000	0.07	0.07
2001	0.07	0.07
2002	0.08	0.08
2003	0.07	0.07
2004	0.07	0.07
2005	0.09	0.09
2006	0.10	0.10
2007	0.08	0.08
2008	0.06	0.06
2009	0.03	0.03
2010	0.04	0.04
2011	0.04	0.04
2012	0.03	0.03
2013	0.04	0.04
2014	0.03	0.03
2015	0.07	0.07
2016	0.06	0.06
2017	0.05	0.05
2018	0.08	0.08
2019	0.08	0.08
2020	0.07	0.07
2021	0.07	0.07
2022	0.07	0.07
Trend 1990-2022	-39.06%	-39.06%
2005-2022	-19.23%	-19.23%
2021-2022	-1.18%	-1.18%

7.5.3.2.2 Methodological issues

N_2O emissions from industrial waste water handling are issued from two industrial plants, the first one produces plastics and, from 2015, a second one that produces milk based products. Both release N to aquatic environments. These industrial WWTPs are equipped with a biological treatment with denitrification.

Determination of N concentration:

N_2O emissions are based on the measured ata of the wastewater flow in, the N concentraition of the flow in and the N concentration of the flow out for each WWTP. This data is available since 2002. For the years where no data is available an extrapolation was operated:

Year 1990 – 1997	Year 1998 - 2002	Year 2002 – 2014	Since 2015
Flow in, N concentration extrapolated by expert judgment of the water management administration based on the operational permit.	Flow in and N concentration extrapolated by expert judgment of the water management administration. In 1998, the WWTP has been upgraded allowing also denitrification.	Flow in, N concentration of flow in and flow out based on monitoring analyses.	Flow in, N concentration of flow in and flow out based on monitoring analyses (for both industrial plants).

Determination of N effluent:

The N effluent from industrial WWTPs is calculated as follows:

*Neffluent(i) = Inflow(i) [m3/h] * Ncc(i) [mg/l] * (1- FRACdenit(i) [%])) * 24 [h/d] * 365 [d/y] / 1000 [kg/year]*

Where:

Inflow(i) = Average hourly flow in as measured for WWTP(i)

Ncc(i) = N concentration in flow in as measured for WWTP(i)

FRACdenit(i) = measured denitrification rate in % (% of waste water which is denitrified), the denitrification rate is calculated for each industrial WWTP using the average of the analytical results during the current year.

Determination of N_2O emissions:

N_2O from industrial WWTPs are then calculated as follows:

*N_2O ind = SUM(Neffluent(i)) * EFind * 44/28 / 1000 [t/year]*

Where:

Neffluent(i) = amount of N in the effluent per industrial WWTP (i)

EFind = 0.01 (according to (Orthofer, Knoflacher, & Züger, 1995) 1% of the denitrified N is emitted as N_2O)

44/28 = conversion of N_2O-N to N_2O (44/28, N_2O/N)

7.5.4 Uncertainties and Time-Series Consistency

14) Waste water quantity: 10 % not connected to waste water treatment plants
15) Emission factor for N_2O: 50% (IPCC 2006 - Guidelines)
16) Emission factor for CH_4: 50%

    (Treatment of uncertainties for national estimates of GHG Emission, Charles D., 1998, referenced by Wilfried Winiwarter)

For further information on uncertainties, please refer to Section 0.

7.5.5 Category-Specific QA/QC and Verification

Category-specific QA/QC procedures have been completed for the following parameters:

1) Activity data:

17) Population and commuters from the STATEC (national data inventory of Luxemburg);

18) Number and size of WWTP from national inventory from the Water Management Administration;

19) Measured data for the denitrification efficiency;

2) Parameters and emission factor:

20) References are indicated, waste expert (QA);

3) Emissions:

21) References are indicated, waste expert (QA).

7.5.6 Category-specific recalculations including changes have been made in response to the review process

No outstanding UNFCCC review and EU-ESD review recommendations triggered recalculations for categories 5.D.1 and 5.D.2.

Table 7-29 - Changes in GHG inventory since submission 2023v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
5D1	• For the years 2017-2021, N_2O emissions from domestic wastewater were recalculated due to updated protein intake data published on the FAOSTAT website for 2017 to 2021, which are higher than previously reported. • Following an UNFCCC review recommendation (W13 in ARR 2020) and EU review recommendation (LU-5D-2023-0001) parameter F(ind-com) was changed from the default value 1.25 to the lowest value (1.0) of the 20026 IPCC Guidelines (Chapter 6, Table 6.11, p.6.27) for septic tanks (not connected population) with the argumentation: UNFCCC ERT noted that "it may not be relevant to apply the "fraction of industrial and commercial co-discharged protein" to this population [not connected to WWTPs (i.e. using septic tanks)], noting that the use of that factor may lead to an overestimation of emissions. This change affected the entire time series. In total, these recalculations led to a decrease of N_2O emissions by 0.10 kt CO_2eq in average for 1990-2016 and an increase of emissions in average of 0.0.11 kt N_2O (0.01 – 0.26 kt CO_2eq) for the years 20017-2021Table 7-29 summarises the main revisions and recalculations done relevant to category *5D*.	updated AD

Table 7-30 - Recalculations in category *5.D – Wastewater treatment*

Year	Recalculations 5.D.1 CH_4 [kt CO_2eq]	5.D.1 N_2O [kt CO_2eq]	5.D.2 CH_4 [kt CO_2eq]	5.D.2 N_2O [kt CO_2eq]
1990	NO	-0.11	NO	NO
1991	NO	-0.11	NO	NO
1992	NO	-0.11	NO	NO
1993	NO	-0.11	NO	NO
1994	NO	-0.10	NO	NO
1995	NO	-0.10	NO	NO
1996	NO	-0.10	NO	NO
1997	NO	-0.10	NO	NO
1998	NO	-0.10	NO	NO
1999	NO	-0.10	NO	NO
2000	NO	-0.10	NO	NO
2001	NO	-0.11	NO	NO
2002	NO	-0.10	NO	NO
2003	NO	-0.10	NO	NO
2004	NO	-0.10	NO	NO
2005	NO	-0.10	NO	NO
2006	NO	-0.10	NO	NO
2007	NO	-0.10	NO	NO
2008	NO	-0.10	NO	NO
2009	NO	-0.09	NO	NO
2010	NO	-0.09	NO	NO
2011	NO	-0.10	NO	NO
2012	NO	-0.10	NO	NO
2013	NO	-0.10	NO	NO
2014	NO	-0.09	NO	NO
2015	NO	-0.08	NO	NO
2016	NO	-0.07	NO	NO
2017	NO	0.01	NO	NO
2018	NO	0.07	NO	NO
2019	NO	0.14	NO	NO
2020	NO	0.21	NO	NO
2021	NO	0.26	NO	NO

7.5.7 Category-Specific Planned Improvements

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 7-31 will be explored.

Table 7-31 – Planned improvements for category 5D – WWH

GHG source & sink category	Planned improvement
5D1	Align the current 2006 IPCC based methodology to the one proposed in the 2019 IPCC Refinement. Major changes are to be expected as for direct N_2O emissions all WWTP types seem to be considered.

8 Other

CRF Sector 6 is not applicable to Luxembourg's inventory.

9 Indirect CO_2 and nitrous oxide emissions

No indirect CO_2 and nitrous oxide emissions have been reported.

10 Recalculations and Improvements

10.1 Explanations and justifications for recalculations

Table 10-1 summarises the main revisions and recalculations done since the last submission. More details can be found in the sector chapters. The detailed effects of the revisions and recalculations on the individual sectors can also be found in the sectors' chapters while more general and sector-overarching effects are shown in this chapter. The effects of the revisions and recalculations on the total GHG emissions are shown in and Table 10-9.

Table 10-1: Revisions and recalculations done since submission 2023v1

GHG source & sink category	Revisions 2023v1 ➔ 2024v1	Type of revision
1A1a	Revision of the natural gas and biogas activity data due to changes in the national energy balance for 2021 (+733 TJ for natural gas compared to the previous submission and +62 TJ for biogas compared to the previous submission). As a result, greenhouse gas emissions in the 1A1a sector increased by 41.6 Gg CO_2 eq. for 2021 in this submission.	AD
1A1a	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-6} Gg CO_2 for any given year).	CO_2 EF
1A2c	Error correction in the calculation of greenhouse gas emissions from gas oil from a specific operator for the years 1998-2011. The recalculations are quantified in Table 3-60.	Error correction
1A2c	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-6} Gg CO_2 for any given year).	CO_2 EF
1A2e	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-6} Gg CO_2 for any given year).	CO_2 EF
1A2f	Revision of the country-specific CO_2 emissions factor for LPG for 2016-2021. The effects on the GHG emissions are marginal (less than 10^{-3} Gg CO_2 for any given year)	CO_2 EF
1A2f	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-4} Gg CO_2 for any given year).	CO_2 EF
1A2gviii	Revision of the residual fuel oil, liquid petroleum gas, and biogas activity data due to changes in the national energy balance for 2021 (+7728 GJ for RFO, +47 GJ, and +2993 GJ for biogas compared to the previous submission). As a result, greenhouse gas emissions in the 1A2gviii sector increased by 0.6 Gg CO_2 eq. for 2021 in this submission.	AD
1A2gviii	Revision of the country-specific CO_2 emissions factor for LPG for 2016-2021. The effects on the GHG emissions are marginal (less than 10^{-2} Gg CO_2 for any given year)	CO_2 EF
1A2gviii	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-5} Gg CO_2 for any given year).	CO_2 EF
1A2gvii	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-61).	AD
1A2gvii	For several years, the country-specific CO2 EFs for diesel oil (2017-2020) and motor gasoline (2017-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10 2 for further details.	CO_2 EF
1A2a/c/d/e/f/gviii	In the latest national energy balance, changes were made to the allocation method of natural gas to the different sectors for the year 2021. While significant differences are observed for each sub-category, the total amount of natural gas consumed by the energy sector in 2021 decreases only by 155GJ (corresponding to -0.060 Gg CO2eq). The affected sectors and the respective recalculations are shown in Table 3-62.	AD

1A3b/c/d	For several years, the country-specific CO2 EFs for diesel oil (2017-2020), motor gasoline (2017-2021) and LPG (2016-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	updated CO2 EF
1A3b/c/d	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-81).	Updated AD
1A3d	Updated AD (liquid fuels, biomass, and other fossil fuels) for leisure boats for 2021 (interpolation between 2020 and 2022) (Table 3-82).	AD
1A4	Revision of the liquid petroleum gas and biogas activity data due to changes in the national energy balance for 2021 (-47 GJ for LPG and +39 TJ for biogas compared to the previous submission). The effects on the greenhouse gas emissions are marginal (< 10^{-3} Gg CO_2 eq.).	AD
1A4	Revision of the country-specific CO_2 emission factor for gasoil for 2017-2020. The effects on the GHG emissions are marginal (less than 10^{-2} Gg CO_2 for any given year).	CO_2 EF
1A4	Revision of the country-specific CO_2 emission factor for LPG for 2016-2021. The effects on the GHG emissions are marginal (less than 0.1 Gg CO_2 for any given year).	CO_2 EF
1A4cii	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-97).	AD
1A4bii/1A4cii	For several years, the country-specific CO2 EFs for diesel oil (2017-2020) and motor gasoline (2017-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	CO_2 EF
1A4	In the latest national energy balance, changes were made to the allocation method of natural gas to the different sectors for the year 2021. While significant differences are observed for each sub-category, the total amount of natural gas consumed by the energy sector in 2021 decreases only by 155GJ (corresponding to -0.060 Gg CO2eq). The affected sectors and the respective recalculations are shown in Table 3-62.	AD
1A5b	Due to an error correction, the total activity data for diesel oil for the entire timeseries was revised, which impacts several mobile combustion sub-categories (1A2gvii, 1A3b, 1A3c, 1A3d, 1A4cii, 1A5b, and 1D1d). As the fuel consumptions in mobile combustion are allocated to different vehicle categories by the NEMO and GEORG models, the change in total diesel activity data also impacts the allocations of gasoline, biomass and other fossil fuels (the total activity data of these three fuel types remains unchanged) (Table 3-106).	AD
1A5b	For several years, the country-specific CO2 EFs for diesel oil (2017-2020) and motor gasoline (2017-2021) have changed due to changes of the emission factors of the importing countries. Please refer to Table 10-2 for further details.	CO_2 EF
1B2biii5 – Transmission of natural gas	An error correction was made which slightly changes the CO_2 emissions for the entire timeseries (Table 3-112).	CO_2 emissions
2A3	CO_2 emissions have been revised for the year 2020 and have increased by 47.4% (34.287 Gg -> 50.539Gg).	CO_2 emissions
2D1	Emissions have been revised for the year 2021 and have decreased by -36.66% (6.129 Gg CO2eq -> 3.882 Gg CO2eq).	CO_2 emissions
2D3 – urea-based catalysts	Due to an error correction of diesel oil AD for the entire timeseries, the emissions from urea-based catalysts from 2005 to 2021 have changed.	CO_2 emissions
2F1	Activity data has been update as such the emissions for 2020 and 2021 have been revised	AD

2F2	Activity data has been update as such the emissions for 2020 and 2021 have been revised	AD
3.A / 3.B	Error correction of the number of laying hens in 2021; Used in 3.A & 3.B and impacting 3.D	Revised AD
3.B	Revision of origin of solid manure to be used as feedstock in biogas facilities from 2005 onwards from laying hens and cattle rather than just cattle. Used in 3.B and impacting 3.D	Revised AD
3.B	Revision of the calculation methodology whereby the imported manure to be used as feedstock was split according to its origin and added to the corresponding livestock categories. Used in 3.B and impacting 3.D	Revised calculation methodology and error correction
3D	Having additional data w.r.t. export of digestate originating from energy crops and non-agricultural waste. AD was revised	Revised AD
3.A	Sheep and goats were split into low and high productivity systems; and hence revised mature weights	Revised AD
3.A.	Revising the EFs for enteric fermentation for all livestock categories other than cattle using a Tier 1 approach whereby applying the 2019 Refinement of the 2006 IPCC GLs ; Enteric fermentation for rabits and ostrichs were for the first time considered in the current submission	EF
3.A	Revising Y_m for the different cattle categories whereby applying the 2019 Refinement of the 2006 IPCC GLs; For all cattle categories other than lactaiting dairy cows, a first attempt of the diet was made, and DE% estimated rather than assuming values from an IPCC table..	EF
3.B.a	Revision and adaptation of the methodology for methane emissions from manure management: i) for all ivestock categories other than cattle, using a Tier 1 approach according to the 2019 Refinement; and ii) for cattle, using a Tier 2 approach according to the 2019 Refinement.	EF
3.B.b	Revision: Direct and indirect N_2O emissions from N input via co-digestate originating from energy crops and non-agricultural waste was reported in Sector CRF 5B2	Methodology
3.D.1	The provisional activity data for sewage sludge for the year 2021 was replaced by published data	AD
3.D.1	Revision of the 2021 data on the application of slurry, digestate and solid manure. Provisional data were replaced.	AD / N emissions
3.D.2	Revision of N volatilised from managed soils because of new EF for NH3-emissions from synthetic fertilizer by using updated EF of the 2023 EMEP/EEA guidelines, and hence revised N volatilised from managed soils;	AD
3.D.2	Error correction: The consideration of NO-N emissions from crop residues in N volatilised from managed soils	AD
3G	Revision of the quantities used, as for the years 2018-2022 having data of the quantities sold of two additional sellers rather than estimates of the market share of the two main sellers and extrapolating. Revision of the quantities, as having collected information of the composition of the different lime fertilizers on the market in the years 1990-2021	Revised AD
4	Please refer to section 6.11 for detailed descriptions of the recalculations in the LULUCF sector.	
5B1a	Revision of AD for the year 2021	AD
5B2b	Revision of the AD for the years 2018 and 2021	AD
5B2	Direct and indirect N_2O emissions from digestate originating from energy crops and non-agricultural waste are reported as a new source in Sector CRF 5B2	AD and N_2O emissions
5D1	• For the years 2017-2021, N_2O emissions from domestic wastewater were recalculated due to updated protein intake data published on the FAOSTAT website for 2017 to 2021, which are higher than previously reported.	updated AD

	• Following an UNFCCC review recommendation (W13 in ARR 2020) and EU review recommendation (LU-5D-2023-0001) parameter F(ind-com) was changed from the default value 1.25 to the lowest value (1.0) of the 20026 IPCC Guidelines (Chapter 6, Table 6.11, p.6.27) for septic tanks (not connected population) with the argumentation: UNFCCC ERT noted that "it may not be relevant to apply the "fraction of industrial and commercial co-discharged protein" to this population [not connected to WWTPs (i.e. using septic tanks)], noting that the use of that factor may lead to an overestimation of emissions. This change affected the entire time series. In total, these recalculations led to a decrease of N_2O emissions by 0.10 kt CO_2eq in average for 1990-2016 and an increase of emissions in average of 0.0.11 kt N_2O (0.01 – 0.26 kt CO_2eq) for the years 20017-2021Table 7-29 summarises the main revisions and recalculations done relevant to category *5D*.	
General – uncertainty assessment	The uncertainty assessment for the base year was reported for the first time in the present submission (G.6 in UNFCCC ARR 2022, G.13 in UNFCCC ARR 2020).	transparency

Table 10-2 – Recalculation of the country-specific CO_2 emission factors of gas/diesel oil, motor gasoline, and LPG between submissions 2023v1 and 2024v1 for the entire time series.

	country-specific CO_2 emission factors (kg CO_2/TJ)								
	diesel oil / heating gasoil			gasoline			LPG		
	2024v.1	2023v.1	difference	2024v.1	2023v.1	difference	2024v.1	2023v.1	difference
2016							65163.9	65222.0	-58.1
2017	74155.7	74155.7	0.1	73191.0	73191.2	-0.1	65229.6	65281.1	-51.5
2018	74129.5	74129.8	-0.2	73104.0	73104.4	-0.4	65210.0	65264.9	-54.8
2019	74077.2	74077.7	-0.5	73186.1	73181.0	5.1	65487.3	65528.8	-41.5
2020	74145.4	74145.9	-0.5	73008.5	73096.4	-87.9	65458.5	65493.2	-34.7
2021				72931.4	72975.8	-44.4	64955.3	65009.8	-54.6

Source: Environment Agency.

10.2 Implications for emission levels

Table 10-3, Table 10-4, Table 10-5, Table 10-6, and Table 10-7 present the recalculations of CO_2, CH_4, N_2O, F-gases and total GHG emissions for the years 1990, 2000, 2010 and 2019-2021.

Table 10-3 – CO_2 emissions: recalculations done since submission 2023v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2019	2020	2021
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**-4.41**	**1.56**	**-0.09**	**0.29**	**-0.79**	**0.28**
A. Fuel Combustion (Sectoral Approach)	-4.41	1.56	-0.09	0.29	-0.79	0.28
1. Energy Industries	-	-	-	0.00	0.00	41.50
2. Manufacturing Industries and Construction	-	0.02	0.01	0.00	0.00	-14.97
3. Transport	-4.41	1.54	-0.10	0.32	-0.77	-0.28
4. Other Sectors	-	-	0.00	-0.02	-0.02	-25.97
5. Other	-	-	0.00	0.00	0.00	0.00
B. Fugitive Emissions from Fuels	0.00	0.00	0.00	0.00	0.00	0.00
1. Solid Fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy pro	0.00	0.00	0.00	0.00	0.00	0.00
C. CO2 transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial Processes	**2.11**	**-2.54**	**-2.46**	**-5.61**	**11.14**	**-7.01**
A. Mineral industry	-	-	-	-	16.25	-
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	-	-	-	-	-	-
D. Non-energy products from fuels and solvent use	2.11	-2.54	-2.46	-5.61	-5.12	-7.01
E. Electronic industry						
F. Product uses as ODS substitutes						
G. Other product manufacture and use	NO	NO	NO	NO	NO	NO
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**-0.03**	**-0.20**	**-0.38**	**-2.54**	**-3.11**	**-2.40**
A. Enteric fermentation						
B. Manure management						
C. Rice cultivation						
D. Agricultural soils						
E. Prescribed burning of savannas						
F. Field burning of agricultural residues						
G. Liming	-0.03	-0.20	-0.38	-2.54	-3.11	-2.40
H. Urea application	NO	NO	-	-	-	-
I. Other carbon-containing fertilizers	-	-	-	-	-	-
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**-0.01**	**-0.01**	**0.00**	**0.00**	**0.00**	**0.00**
A. Forest land	0.00	-	-	0.00	0.00	0.00
B. Cropland	-0.01	-0.01	0.00	0.00	0.00	0.00
C. Grassland	-	-	-	0.00	0.00	0.00
D. Wetlands	-	-	-	-	-	-
E. Settlements	-	-	-	0.00	0.00	0.00
F. Other land	-	-	-	0.00	0.00	0.00
G. Harvested wood products	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	**NO,IE**	**NO,IE**	**NO,IE**	**NO,IE**	**NO,IE**	**NO,IE**
A. Solid waste disposal	NO	NO	NO	NO	NO	NO
B. Biological treatment of solid waste						
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge						
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Memo items:						
International bunkers	-	-	0.00	0.00	0.00	0.00
Aviation	-	-	-	-	-	-
Navigation	-	-	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO_2 emissions from biomass	-	-	0.00	0.00	0.00	0.05
CO_2 captured	NO	NO	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	NE	NE	NE	NE	NE	NE
Indirect N_2O						
Total CO_2 equivalent emissions without LULUCF	-2.33	-1.19	-2.93	-7.86	7.24	-9.14
Total CO_2 equivalent emissions with LULUCF	-2.34	-1.20	-2.93	-7.86	7.24	-9.13
Total CO_2 equivalent emissions, including indirect CO_2,	NA	NA	NA	NA	NA	NA
Total CO_2 equivalent emissions, including indirect CO_2, with	NA	NA	NA	NA	NA	NA

Table 10-4 – CH_4 emissions: recalculations done since submission 2023v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990 (Gg)	2000 (Gg)	2010 (Gg)	2019 (Gg)	2020 (Gg)	2021 (Gg)
1. Energy	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
A. Fuel combustion (sectoral approach)	0.00	0.00	0.00	0.00	0.00	0.00
1. Energy industries	-	-	-	-	-	0.00
2. Manufacturing industries and construction	-	0.00	0.00	0.00	-	0.00
3. Transport	0.00	0.00	0.00	0.00	0.00	0.00
4. Other sectors	-	-	0.00	0.00	0.00	0.00
5. Other	-	-	0.00	0.00	0.00	-
B. Fugitive emissions from fuels	-	-	-	-	-	-
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy pro	-	-	-	-	-	-
C. CO2 transport and storage						
2. Industrial processes	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
A. Mineral industry						
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	NO	NO	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	NO	NO	NO	NO	NO	NO
E. Electronic industry						
F. Product uses as ODS substitutes						
G. Other product manufacture and use						
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**0.17**	**0.09**	**0.01**	**-0.12**	**-0.09**	**-0.05**
A. Enteric fermentation	-0.25	-0.34	-0.33	-0.69	-0.72	-0.72
B. Manure management	0.43	0.43	0.34	0.58	0.64	0.66
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	NO	NO	NO	NO	NO	NO
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming						
H. Urea application						
I. Other carbon-containing fertilizers						
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**NO,NE**	**NO,NE**	**NO,NE**	**NO,NE**	**NO,NE**	**NO,NE**
A. Forest land	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
B. Cropland	NO	NO	NO	NO	NO	NO
C. Grassland	NO	NO	NO	NO	NO	NO
D. Wetlands	NO	NO	NO	NO	NO	NO
E. Settlements	NO	NO	NO	NO	NO	NO
F. Other land	NO	NO	NO	NO	NO	NO
G. Harvested wood products						
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	-	-	-	-	-	**0.03**
A. Solid waste disposal	-	-	-	-	-	-
B. Biological treatment of solid waste	NO,IE	-	-	-	-	0.03
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge	-	-	-	-	-	-
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Total CH_4 emissions without CH_4 from LULUCF	**0.17**	**0.09**	**0.01**	**-0.12**	**-0.09**	**-0.03**
Total CH_4 emissions with CH_4 from LULUCF	**0.17**	**0.09**	**0.01**	**-0.12**	**-0.09**	**-0.03**
Memo items:						
International bunkers	-	-	-	-	-	0.00
Aviation	-	-	-	-	-	-
Navigation	-	-	-	-	-	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO2 emissions from biomass						
CO2 captured						
Long-term storage of C in waste disposal sites						
Indirect N2O						

Table 10-5 – N_2O emissions: recalculations done since submission 2023v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2019	2020	2021
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	0.00	0.00	0.00	0.00	0.00	0.00
A. Fuel combustion (sectoral approach)	0.00	0.00	0.00	0.00	0.00	0.00
1. Energy industries	-	-	-	-	-	0.00
2. Manufacturing industries and construction	-	0.00	0.00	-	-	0.00
3. Transport	0.00	0.00	0.00	0.00	0.00	0.00
4. Other sectors	-	-	0.00	0.00	-	0.00
5. Other	-	-	-	-	-	0.00
B. Fugitive emissions from fuels	NO	NO	NO	NO	NO	NO
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy pro	NO	NO	NO	NO	NO	NO
C. CO2 transport and storage						
2. Industrial processes	**-**	**-**	**-**	**0.00**	**0.00**	**0.00**
A. Mineral industry						
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	NO	NO	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	NO	NO	NO	NO	NO	NO
E. Electronic industry						
F. Product uses as ODS substitutes						
G. Other product manufacture and use	-	-	-	0.00	0.00	0.00
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
A. Enteric fermentation						
B. Manure management	-	0.00	0.00	0.00	0.00	0.00
C. Rice cultivation						
D. Agricultural soils	0.01	0.01	0.00	0.00	0.00	0.00
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming						
H. Urea application						
I. Other carbon-containing fertilizers						
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**-**	**-**	**-**	**0.00**	**0.00**	**0.00**
A. Forest land	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
B. Cropland	-	-	-	-	-	-
C. Grassland	-	-	-	-	-	-
D. Wetlands	-	-	-	-	-	-
E. Settlements	-	-	-	-	-	-
F. Other land	-	-	-	0.00	0.00	0.00
G. Harvested wood products						
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
A. Solid waste disposal						
B. Biological treatment of solid waste	NO,NE	0.00	0.00	0.00	0.00	0.00
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge	0.00	0.00	0.00	0.00	0.00	0.00
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Total direct N_2O emissions without N_2O from LULUCF	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Total direct N_2O emissions with N_2O from LULUCF	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Memo items:						
International bunkers	**-**	**-**	**-**	**0.00**	**-**	**0.00**
Aviation	-	-	-	-	-	-
Navigation	-	-	-	0.00	-	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO2 emissions from biomass						
CO2 captured						
Long-term storage of C in waste disposal sites						
Indirect N2O	NE,NO	NE,NO	NE,NO	NO,NE	NO,NE	NO,NE

Table 10-6 – F-gas emissions: recalculations done since submission 2023v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2019	2020	2021
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
Emissions of HFCs - (kt CO2 equivalent)	-	-	-	0.00	0.36	0.39
Emissions of PFCs - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO
Unspecified mix of HFCs and PFCs - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO
Emissions of SF6 - (kt CO2 equivalent)	-	-	-	-	-	-
Emissions of NF3 - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO

Table 10-7 – Total GHG emissions: recalculations done since submission 2023v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2019	2020	2021
CO_2 equivalents	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**-4.31**	**1.67**	**0.34**	**1.03**	**-0.12**	**0.66**
A. Fuel combustion (sectoral approach)	-4.30	1.67	0.34	1.03	-0.12	0.66
1. Energy industries	-	-	-	0.00	0.00	41.55
2. Manufacturing industries and construction	-	0.02	0.01	0.00	0.00	-14.98
3. Transport	-4.30	1.65	0.33	1.05	-0.10	0.16
4. Other sectors	-	-	0.00	-0.02	-0.02	-26.06
5. Other	-	-	0.00	0.00	0.00	0.00
B. Fugitive emissions from fuels	0.00	0.00	0.00	0.00	0.00	0.00
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy pro	0.00	0.00	0.00	0.00	0.00	0.00
C. CO2 transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial processes	**2.11**	**-2.54**	**-2.46**	**-5.64**	**11.47**	**-6.65**
A. Mineral industry	-	-	-	-	16.25	-
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	-	-	-	-	-	-
D. Non-energy products from fuels and solvent use	2.11	-2.54	-2.46	-5.61	-5.12	-7.01
E. Electronic industry	NO	NO	NO	NO	NO	NO
F. Product uses as ODS substitutes	-	-	-	0.00	0.36	0.39
G. Other product manufacture and use	-	-	-	-0.02	-0.02	-0.03
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**6.61**	**4.08**	**1.07**	**-4.74**	**-4.63**	**-2.61**
A. Enteric fermentation	-7.11	-9.57	-9.23	-19.44	-20.29	-20.08
B. Manure management	11.96	12.17	9.52	16.15	17.76	18.57
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	1.79	1.68	1.16	1.09	1.01	1.30
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming	-0.03	-0.20	-0.38	-2.54	-3.11	-2.40
H. Urea application	NO	NO	-	-	-	-
I. Other carbon-containing fertilizers	-	-	-	-	-	-
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**-0.01**	**-0.01**	**0.00**	**0.00**	**0.00**	**0.00**
A. Forest land	0.00	-	-	0.00	0.00	0.00
B. Cropland	-0.01	-0.01	0.00	0.00	0.00	0.00
C. Grassland	-	-	-	0.00	0.00	0.00
D. Wetlands	-	-	-	-	-	-
E. Settlements	-	-	-	0.00	0.00	0.00
F. Other land	-	-	-	0.00	0.00	0.00
G. Harvested wood products	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	**-0.11**	**-0.09**	**0.06**	**0.43**	**0.48**	**1.16**
A. Solid waste disposal	-	-	-	-	-	-
B. Biological treatment of solid waste	NO,NE,IE	0.00	0.16	0.29	0.27	0.89
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge	-0.11	-0.10	-0.09	0.14	0.21	0.26
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Memo items:						
International bunkers	-	-	0.00	0.00	0.00	0.00
Aviation	-	-	-	-	-	-
Navigation	-	-	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO_2 emissions from biomass	-	-	0.00	0.00	0.00	0.05
CO_2 captured						
Long-term storage of C in waste disposal sites						
Indirect N_2O						
Total CO_2 equivalent emissions without land use, land-use	**4.30**	**3.12**	**-0.98**	**-8.92**	**7.20**	**-7.45**
Total CO_2 equivalent emissions with land use, land-use change	**4.29**	**3.11**	**-0.99**	**-8.92**	**7.20**	**-7.44**
Total CO_2 equivalent emissions, including indirect CO_2,	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Total CO_2 equivalent emissions, including indirect CO_2, with	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

Table 10-8 presents the absolute and relative recalculation differences of national total GHG emissions (excl. LULUCF) for 1990-2021 (in Gg CO_2 eq. and in %). Table 10-9 shows the absolute recalculations by gas and by sector.

Table 10-8 - Recalculation differences of national total GHG emissions (without LULUCF).

Total GHG emissions excl. LULUCF				
	Submission 2023v1	Submission 2024v1	Recalculation difference	Recalculation difference
Year	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.	%
1990	12722.41	12726.71	4.30	0.03%
1991	13353.28	13349.37	-3.90	-0.03%
1992	13118.29	13114.48	-3.81	-0.03%
1993	13281.35	13278.36	-2.99	-0.02%
1994	12447.63	12433.46	-14.17	-0.11%
1995	10078.52	10062.47	-16.05	-0.16%
1996	10141.47	10123.90	-17.57	-0.17%
1997	9494.70	9483.23	-11.47	-0.12%
1998	8590.88	8588.89	-1.99	-0.02%
1999	9051.27	9056.36	5.10	0.06%
2000	9635.00	9638.12	3.12	0.03%
2001	10137.26	10142.89	5.63	0.06%
2002	10915.32	10919.05	3.73	0.03%
2003	11366.76	11375.19	8.44	0.07%
2004	12740.93	12745.74	4.81	0.04%
2005	12993.83	13000.50	6.66	0.05%
2006	12824.48	12829.81	5.33	0.04%
2007	12236.27	12242.32	6.05	0.05%
2008	12126.21	12131.48	5.27	0.04%
2009	11584.16	11584.83	0.67	0.01%
2010	12159.05	12158.06	-0.98	-0.01%
2011	12040.48	12037.83	-2.65	-0.02%
2012	11804.17	11803.37	-0.80	-0.01%
2013	11281.31	11281.15	-0.16	0.00%
2014	10785.44	10782.16	-3.27	-0.03%
2015	10313.87	10313.09	-0.78	-0.01%
2016	10077.82	10079.64	1.81	0.02%
2017	10259.74	10260.52	0.78	0.01%
2018	10563.28	10562.69	-0.59	-0.01%
2019	10739.99	10731.07	-8.92	-0.08%
2020	9029.90	9037.10	7.20	0.08%
2021	9390.73	9383.28	-7.45	-0.08%

Table 10-9 - Recalculation differences of national emissions by gas (without LULUCF) and by sector.

Recalculation difference (2023v1 vs. 2024v1)					Recalculation difference (2023v1 vs. 2024v1)					
Total GHG emissions excl. LULUCF (Gg CO_2 eq.)					Gg CO_2 eq. (sum of all GHGs)					
Year	CO_2	CH_4	N_2O	F-gases	Year	1 - Energy	2 - IPPU	3 - Agriculture	4 - LULUCF	5 - Waste
1990	-2.33	4.88	1.75	0.00	**1990**	-4.31	2.11	6.61	-0.01	-0.11
1991	-11.09	5.37	1.82	0.00	**1991**	-12.66	1.70	7.16	-0.01	-0.11
1992	-10.20	4.42	1.97	0.00	**1992**	-11.34	1.30	6.34	-0.01	-0.11
1993	-10.86	6.08	1.80	0.00	**1993**	-11.63	0.97	7.78	-0.01	-0.11
1994	-17.67	1.80	1.70	0.00	**1994**	-16.24	-1.19	3.37	-0.01	-0.10
1995	-20.36	2.64	1.67	0.00	**1995**	-16.93	-3.22	4.20	-0.01	-0.10
1996	-21.27	2.02	1.68	0.00	**1996**	-17.60	-3.48	3.61	-0.01	-0.10
1997	-17.13	4.00	1.66	0.00	**1997**	-12.98	-3.90	5.51	-0.01	-0.10
1998	-8.54	4.91	1.64	0.00	**1998**	-5.70	-2.51	6.33	-0.01	-0.10
1999	-0.23	3.62	1.70	0.00	**1999**	2.97	-2.95	5.18	-0.01	-0.10
2000	-1.19	2.62	1.69	0.00	**2000**	1.67	-2.54	4.08	-0.01	-0.09
2001	0.15	4.05	1.43	0.00	**2001**	2.75	-2.25	5.22	-0.01	-0.10
2002	-1.92	4.16	1.49	0.00	**2002**	2.37	-3.87	5.32	-0.01	-0.09
2003	-1.48	8.71	1.21	0.00	**2003**	1.57	-2.65	9.60	-0.01	-0.09
2004	-2.33	5.59	1.55	0.00	**2004**	1.66	-3.64	6.85	-0.01	-0.07
2005	-2.81	8.16	1.31	0.00	**2005**	1.68	-3.96	8.99	-0.01	-0.05
2006	-2.25	6.21	1.36	0.00	**2006**	1.32	-3.09	7.12	-0.01	-0.01
2007	-1.92	6.64	1.33	0.00	**2007**	1.49	-2.89	7.44	-0.01	0.00
2008	-3.14	7.00	1.41	0.00	**2008**	1.48	-4.06	7.83	0.00	0.02
2009	-5.19	4.35	1.51	0.00	**2009**	-1.66	-2.76	5.02	0.00	0.07
2010	-2.93	0.34	1.61	0.00	**2010**	0.34	-2.46	1.07	0.00	0.06
2011	-5.29	0.81	1.83	0.00	**2011**	-0.02	-4.20	1.42	0.00	0.14
2012	-5.51	2.84	1.86	0.00	**2012**	0.53	-4.84	3.37	0.00	0.14
2013	-5.06	3.01	1.90	0.00	**2013**	1.21	-4.93	3.42	0.00	0.14
2014	-7.42	2.25	1.89	0.00	**2014**	-0.77	-4.96	2.26	0.00	0.19
2015	-5.73	2.99	1.95	0.00	**2015**	1.07	-4.76	2.72	0.00	0.18
2016	-3.81	3.54	2.08	0.00	**2016**	1.37	-2.92	3.16	0.00	0.21
2017	-5.16	3.78	2.15	0.00	**2017**	1.49	-3.71	2.68	0.00	0.33
2018	-6.61	3.89	2.13	0.00	**2018**	1.20	-4.35	2.98	0.00	-0.42
2019	-7.86	-3.24	2.18	0.00	**2019**	1.03	-5.64	-4.74	0.00	0.43
2020	7.24	-2.50	2.10	0.36	**2020**	-0.12	11.47	-4.63	0.00	0.48
2021	-9.14	-0.81	2.11	0.39	**2021**	0.66	-6.65	-2.61	0.00	1.16

Figure 10-1 - Recalculation differences of national emissions by gas (without LULUCF, 2023v1 vs. 2024v1)

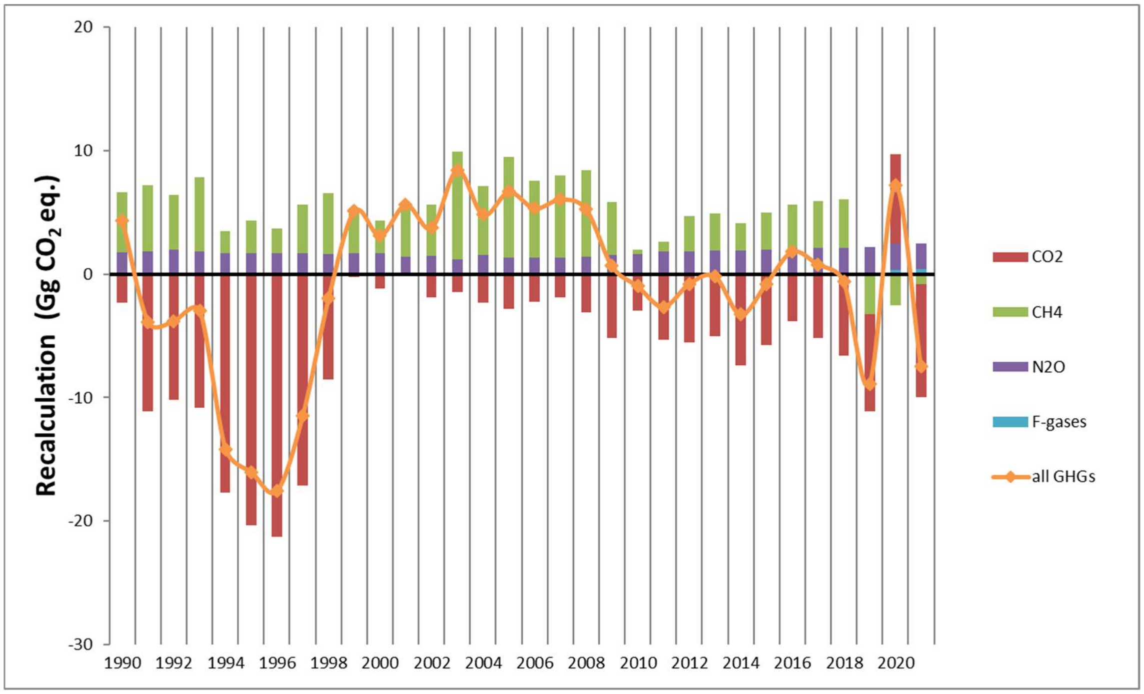
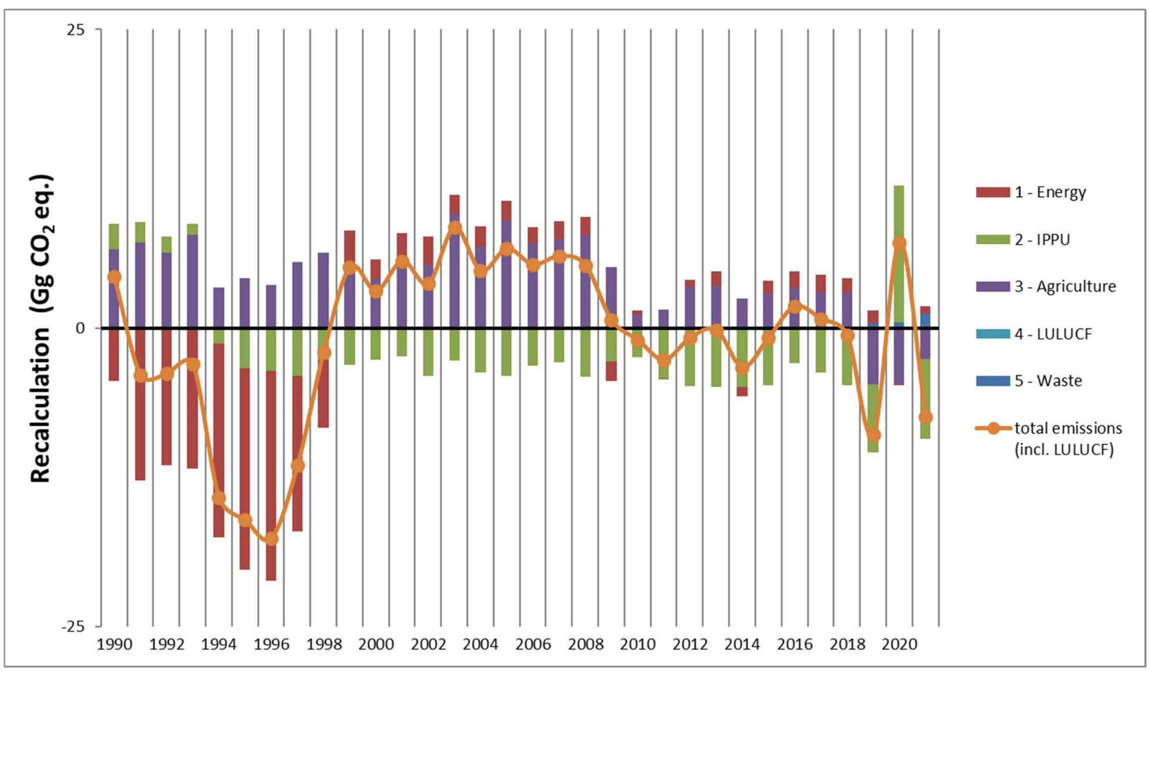


Figure 10-2 - Recalculation differences of national emissions by sector (2023v1 vs. 2024v1)



10.3 Implications for emission trends, including time series consistency

The impact of the recalculations presented in the previous sections is presented in Table 10-10. The GHG emission trend from 1990-2021 of the national total (including LULUCF) has changed from -3331.68 Gg CO_2 eq. in submission 2023v1 to -3343.43 Gg CO_2 eq. in submission 2024v1.

Table 10-10: GHG emission trends (in CO2eq) 1990-2021 in submissions 2023v1 and 2024v1.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Submission 2024 v1			Submission 2023 v1		
	1990	2021	trend 1990-2021	1990	2021	trend 1990-2021
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**10291.98**	**8039.85**	**-2252.13**	**10296.28**	**8039.18**	**-2257.10**
A. Fuel combustion (sectoral approach)	10270.03	8005.94	-2264.09	10274.34	8005.28	-2269.05
1. Energy industries	34.82	263.55	228.73	34.82	222.00	187.18
2. Manufacturing industries and construction	6244.49	1178.92	-5065.57	6244.49	1193.90	-5050.59
3. Transport	2626.66	4919.20	2292.53	2630.97	4919.04	2288.07
4. Other sectors	1360.91	1644.16	283.25	1360.91	1670.22	309.31
5. Other	3.14	0.11	-3.03	3.14	0.11	-3.03
B. Fugitive emissions from fuels	21.95	33.90	11.95	21.95	33.90	11.95
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	21.95	33.90	11.95	21.95	33.90	11.95
C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial processes	**1609.76**	**559.29**	**-1050.48**	**1607.66**	**565.94**	**-1041.72**
A. Mineral industry	592.93	382.02	-210.91	592.93	382.02	-210.91
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	984.91	91.53	-893.38	984.91	91.53	-893.38
D. Non-energy products from fuels and solvent use	22.65	26.91	4.26	20.54	33.92	13.38
E. Electronic industry	NO	NO	NO	NO	NO	NO
F. Product uses as ODS substitutes	0.00	40.50	40.50	0.00	40.11	40.11
G. Other product manufacture and use	9.28	18.32	9.05	9.28	18.35	9.08
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**708.68**	**694.73**	**-13.94**	**702.07**	**697.35**	**-4.72**
A. Enteric fermentation	428.62	422.74	-5.88	435.74	442.81	7.08
B. Manure management	126.18	135.57	9.39	114.22	117.00	2.78
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	147.83	125.22	-22.61	146.04	123.92	-22.12
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming	0.23	7.45	7.22	0.26	9.85	9.59
H. Urea application	NO	0.07	NE	NO	0.07	NE
I. Other carbon-containing fertilizers	5.82	3.70	NO	5.82	3.70	NO
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**8.98**	**-605.34**	**-614.33**	**8.99**	**-605.35**	**-614.34**
A. Forest land	-42.65	-646.09	-603.45	-42.65	-646.09	-603.45
B. Cropland	48.35	29.88	-18.46	48.36	29.88	-18.48
C. Grassland	-34.66	-28.23	6.43	-34.66	-28.23	6.43
D. Wetlands	0.15	2.23	2.08	0.15	2.23	2.08
E. Settlements	31.50	42.86	11.36	31.50	42.86	11.36
F. Other land	0.05	0.17	0.12	0.05	0.17	0.12
G. Harvested wood products	2.11	-9.11	-11.21	2.11	-9.11	NO
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	**116.29**	**89.42**	**-26.88**	**116.40**	**88.26**	**-28.14**
A. Solid waste disposal	103.25	48.19	-55.06	103.25	48.19	-55.06
B. Biological treatment of solid waste	NO,NE,IE	34.67	NA	NO,NE,IE	33.78	NA
C. Incineration and open burning of waste	IE,NO	NO,IE	NO,IE	IE,NO	NO,IE	NO,IE
D. Waste water treatment and discharge	13.05	6.56	-6.49	13.15	6.29	-6.86
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Memo items:						
International bunkers	**398.03**	**1881.04**	**1483.01**	**398.03**	**1881.04**	**1483.01**
Aviation	397.95	1881.02	1483.08	397.95	1881.02	1483.08
Navigation	0.08	0.01	-0.07	0.08	0.01	-0.07
Multilateral operations	NO	NO	NO	NO	NO	NO
CO_2 emissions from biomass	162.60	1496.35	1333.75	162.60	1496.30	1333.70
CO_2 captured	NO	NO	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	NE	NE	NE	NE	NE	NE
Indirect N_2O	NE,NO	NO,NE	NO,NE	NE,NO	NO,NE	NO,NE
Indirect CO_2 (3)	NE,NO	NO,NE	NO,NE	NE,NO	NO,NE	NO,NE
Total CO_2 equivalent emissions without land use, land-use change and	**12726.71**	**9383.28**	**-3343.43**	**12722.41**	**9390.73**	**-3331.68**
Total CO_2 equivalent emissions with land use, land-use change and forestry	**12735.69**	**8777.94**	**-3957.75**	**12731.40**	**8785.38**	**-3946.02**
Total CO_2 equivalent emissions, including indirect CO_2, without land use,	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Total CO_2 equivalent emissions, including indirect CO_2, with land use, land-	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

10.4 Recommendations, including in response to the review process, and planned improvements to the inventory

Table 10-11 summarises the planned improvements.

Table 10-11– Planned improvements

GHG source & sink category	Planned improvements	Tentative timeframe
1A4a – Commercial/Institutional, 1A4b – Residential	collecting information helping to refine the fuel consumption split between the commercial/institutional sectors, on the one hand, and the residential sector, on the other hand.	2025
1B2a5 - Distribution of refined oil products	Assess whether these emissions occur and, if appropriate, estimate and report fugitive emissions from the infrastructure supporting the transport, distribution, storage and sale of refined fuel oils.	2025
2.D.2 Paraffin wax use	Obtaining country specific data for the years 1990 to 1998, alternatively improvements to the estimations of the activity data and emissions concerning those years will be performed.	2025
2.D.3.1 Solvent use	A detailed revaluation of the solvent model is planned for the next submission to IPCC sub-category 2.D.3.1.	2025
2.F.2 – Foam blowing	continue the quest for country-specific data	2025
2.F.4 – Aerosols	continue the quest for country-specific data	2025
3.A	Continue the quest for additional data on feet diet for dairy cows	2025
3.D	Export of animal manure and digestate: countine the quest for data on quantities exported of locally produced animal manure and digestate to France and Germany.	2025
3.I	Looking for additional information/data source allowing to eventually confirm, respectively to revise, if not applicable, the assumption that 100% of CAN would be presented as $CaCO_3$	2025
4.A	Luxembourg plans to revise its OBS maps by 2023-2024	2024
4.A	Luxembourg plans to carry out a new NFI by 2025	2025
5D1	Align the current 2006 IPCC based methodology to the one proposed in the 2019 IPCC Refinement. Major changes are to be expected as for direct N2O emissions all WWTP types seem to be considered.	

11 Other information

n/a

12 References

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13 ANNEXES TO THE NATIONAL INVENTORY REPORT

Annex 1: Key categories

The method used to identify key source categories follows the Tier 1 method (quantitative approach) as described in the IPCC 2006 Guidelines, Volume 1, Chapter 4. The analysis includes all greenhouse gases reported by Luxembourg under the UNFCCC (CO_2, CH_4, N_2O, HFC, and SF_6). All IPCC categories are included. Key categories were identified for the inventory excluding LULUCF and for the full inventory including LULUCF categories. Further details can be found in section 1.4 of Luxembourg's NIR.

Annex 2: Detailed discussion of methodology and data for estimating CO_2 emissions from fossil fuel combustion

Please refer to sections 3.2.5 to 3.2.11 for methodology descriptions.

Annex 3: Other detailed methodological descriptions for individual source or sink categories, including for KP-LULUCF activities

13.1 Annex 3 A : Average livestock population – additional information

Table A3- 1: Annual average small ruminants and rabbits livestock population

3 - Agriculture

Activity data - annual average small rumiants and rabbits population (heads/animal places per year (* 1000))

Year	High productivity system - Mature sheep	High productivity system - Lamb	Low productivity system - Mature sheep	Low productivity system - Lamb	High productivity system - Dairy does	High productivity system - Kits (dairy goats)	Low productivity system - Other goats	Low productivity system - Kits (other)	Rabbits - Breeding animals	Other rabbits
1990	3.7	2.3	2.0	1.3	NO	NO	0.46	0.26	2.31	11.2
1991	3.9	2.5	2.0	1.3	NO	NO	0.50	0.28	1.83	11.7
1992	3.8	2.4	2.0	1.3	NO	NO	0.41	0.24	1.65	10.4
1993	3.3	2.1	2.0	1.3	NO	NO	0.48	0.27	1.48	7.1
1994	4.1	2.6	2.1	1.3	NO	NO	0.40	0.21	1.34	6.4
1995	4.1	2.7	2.1	1.4	NO	NO	0.32	0.18	1.39	5.8
1996	3.8	2.4	2.1	1.4	NO	NO	0.26	0.14	1.13	4.8
1997	4.0	2.6	2.1	1.4	NO	NO	0.32	0.18	1.27	6.0
1998	4.5	2.7	2.2	1.3	NO	NO	0.26	0.14	1.07	5.7
1999	4.3	2.8	2.2	1.4	NO	NO	0.22	0.12	0.97	5.2
2000	4.3	2.8	2.2	1.4	NO	NO	0.27	0.15	1.44	5.2
2001	4.8	3.0	2.2	1.4	NO	NO	0.28	0.16	1.00	5.5
2002	4.7	2.9	2.2	1.4	0.34	0.36	0.30	0.14	1.13	5.9
2003	5.6	3.6	2.2	1.4	0.68	0.53	0.42	0.17	0.97	5.5
2004	5.6	3.5	2.2	1.4	0.98	0.66	0.45	0.20	0.86	5.7
2005	5.2	3.4	2.3	1.5	1.11	0.62	0.45	0.17	0.92	5.6
2006	5.8	3.6	2.3	1.5	0.99	0.49	0.45	0.17	0.88	6.0
2007	5.2	3.0	2.3	1.3	1.03	0.53	0.69	0.15	0.77	4.0
2008	5.0	3.2	2.3	1.4	1.45	0.96	0.67	0.17	0.68	3.4
2009	5.1	3.3	2.4	1.5	1.78	1.06	0.48	0.18	0.76	3.4
2010	5.1	3.2	2.3	1.5	2.46	1.61	0.67	0.24	0.67	2.8
2011	5.2	3.3	2.4	1.5	2.75	1.49	0.55	0.19	0.65	2.1
2012	4.9	3.2	2.3	1.5	3.10	1.69	0.73	0.20	0.71	2.9
2013	5.2	3.2	2.4	1.5	2.75	1.30	0.60	0.18	0.73	2.7
2014	5.2	3.4	2.3	1.5	2.47	1.18	0.67	0.20	0.74	2.3
2015	5.6	3.6	2.3	1.5	2.76	1.50	0.78	0.24	0.76	2.0
2016	5.2	3.3	2.3	1.5	2.87	1.44	0.65	0.21	0.61	2.2
2017	5.1	3.2	2.3	1.4	2.89	1.38	0.72	0.19	0.54	1.9
2018	5.1	3.2	2.3	1.4	2.93	1.42	0.79	0.23	0.57	2.2
2019	5.1	3.2	2.3	1.4	2.64	1.28	0.93	0.30	0.60	1.8
2020	5.7	3.5	2.3	1.4	2.80	1.44	0.93	0.28	0.51	1.6
2021	5.9	3.8	2.3	1.5	2.98	1.55	0.93	0.29	0.47	1.8
2022	6.2	3.9	2.3	1.4	2.96	1.42	1.13	0.29	0.40	1.7
Trend 1990 -2022	67%	69%	14%	14%	NA	NA	146%	11%	-83%	-85%
Trend 2021 -2022	5%	4%	0%	-1%	-1%	-8%	21%	-1%	-14%	-3%

13.2 Annex 3 B : Lactating dairy cow diets

The amount of CH_4-emissions produced during the enteric fermentation depends on the amount of feed consumed and on the characteristics and composition of the feed diet (Tamminga, Bannink, Dijkstra, & Zom, 2007). The feed diet of lactating dairy cows in Luxemburg consist mainly of roughaghe complemented with concentrates. The feed consumption of cows was based on the animal's need for feed and the national availability of feed.

Concentrates

Concentrated feed includes compound feed, single components as well as moisture-rich concentrated feed. The amount of concentrated feed in the diet of lactating dairy cows was based on kg concentrated feed per lactating dairy cow per year derived from the Luxemburgish "landwirtschaftliche Testbestriebsnetz" (LTBN)[160]. For the years 1990-1996, 2000, 2001 and 2006-2010 the data were derived from annual publications on the economic situation of the Luxemburgish agriculture farms with kg concentrated feed per dairy cow per year being one of the key figures reported (SER 1991-1997; Kreis, 2001, 2002; Mangen, 2008; Jacqué et al. 2009, 2010, 2011; Brücher et al. 2012, Jacqué et al. 2013, 2014). There were no data for the years 1997-1999, why interpolating using the data from 1996 and 2000. The same was done for the missing period from 2002 to 2005 with interpolation using the data from 2001 and 2006. For the year 2011 and onwards detailed information on the bought quantities of concentrated feed - total and per category - were available and were extracted directly from the LTBN database and expressed as kg /dairy cow per year (Sandra Brücher, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles, 2011-2019 data: personal communication 28-06-2021; 2020 data: personal communication 25-10-2021; 2021 data: personal communication 23-11-2022; 2022 provisional data: personal communication 28-09-2023). However, in Luxembourg, not all concentrated feed fed to animals was bought, some was self-produced on the farm such as fodder cereals, pulses, potatoes and in more recent years also in small amount grain mais. Such data was available since 2014, and extracted from the LTBN database (Monja Majerus, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles, 2011-2019 data: personal communication 11-06-2021; 2020 data: personal communication 19-10-2021; 2021 data: personal communication 17-11-2022; 2022 data: personal communication 22-08-2023). Having no data on the quantities of self-produced concentrated feed for the period 2011-2013, a trend estimation was done for those years based on the data from 2014-2018. From 2011 onwards detailed data allowed a distinction between a) dairy cow compound feed; b) starch rich concentrated feed, in the majority fodder cereals, some maize feed meal and small amounts of fodder potatoes; c) protein rich concentrated feed, consisting of protein rich compound feed and single components such as soya bean and rape seed expeller; d) beet pulp, including small amounts of fodder beets; and e) brewer grains. Having no detailed data for the earlier years, and presuming that the observed trend from the years 2011-2019 would apply to the earlier period, the

160 Luxemburg has the obligation to collect data from agriculture farms for the Farm Accountancy Data Network (FADN). For details on the FADN see http://ec.europa.eu/agriculture/rica/, for the Luxemburgish "landwirtschaftliche Testbetriebsnetz (LTBN)" see https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html. The LTBN is situated in the division «Division de la gestion, de la comptabilité et de l'entraide agricoles», at the SER. This division gets from about 840 farms farm accountancy data (https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung.html). Out of these farms, a representative sample of 450 farms are selected to form the sample size shared with FADN (https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html).

distinction was made using a trend estimations based on the relative distributions of the years 2011-2019. Given that quantities were either based on bought quantities, or on produced and harvested quantities, a correction was necessary to correct for losses during storage.

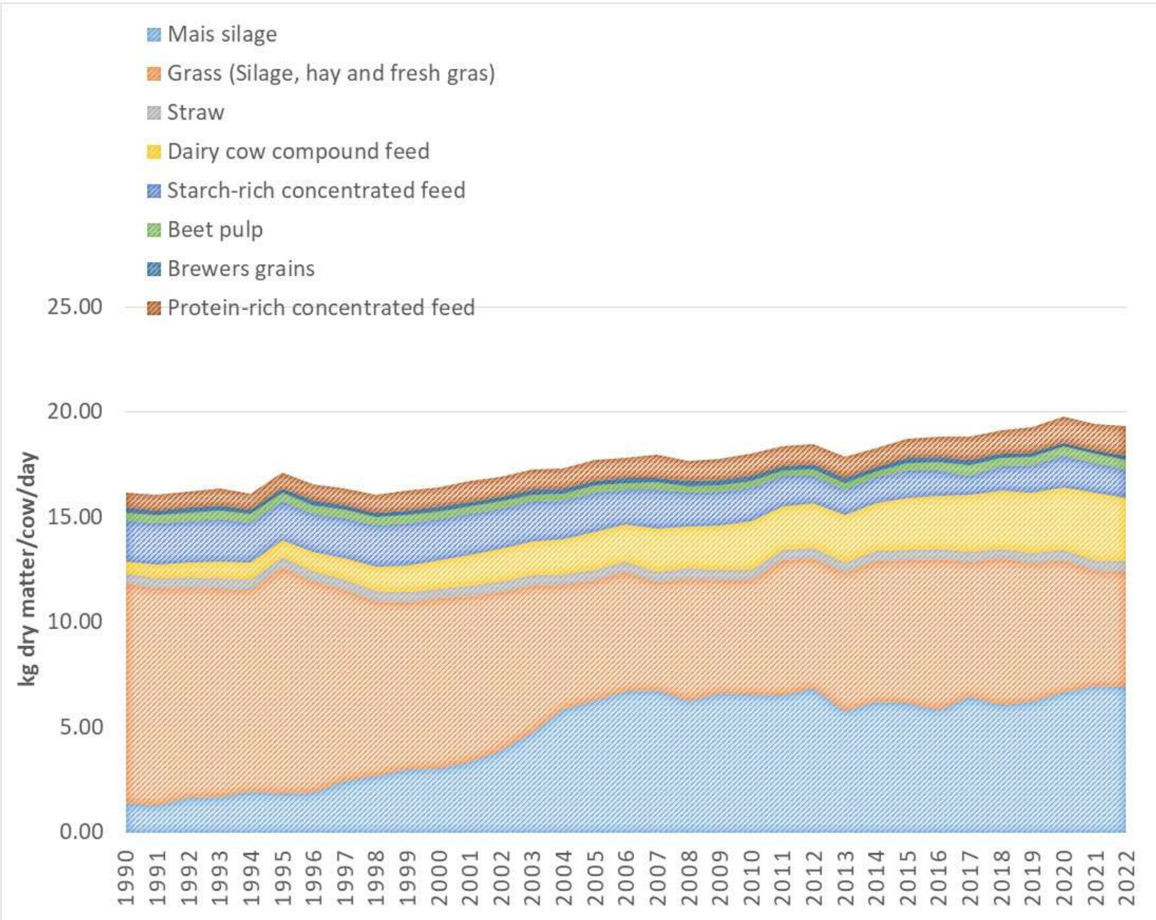
The dry matter content, feed ingredients, energy content and the digestibile energy were based on published table values (CVB, 2021). The quantities and the composition of contrated feed (i.e. dairy cow coumpound feed; starch rich contentrated feed; protein-rich concentrated feed; beet pulp and brewer grains), all expressed in kg dry matter/dairy cow/day is summarized in Figure A3- 1 for the period 1990-2022. The digestible energy, expressed as a percentage of gross energy (DE%), is shown for the different concentrated feed in Table A3-1.

Roughages

The roughage is cultivated by Luxemburgish farmers and consists mainly of grass silage, hay, pasture gras and maize silage with the whole plant being ensiled. Maize silage harvest is estimated based on the area cultivated by luxemburgish farmers (independent if cultivated in Luxembourg or in neighbouring countries (see Annex 3C) multiplied by the crop harvest (see Table 5-49), whereby correcting for feed losses during harvest (harvest estimates were derived from test fields) and during storage. In the absence of on-farms stock mutation a four-year average was used for the harvest, allowing to smooth annual harvest impacts. Further were the quantities of maize silage used as feedstock in biogas facility subtracted from the total to obtain the quantity of maize silage used as animal feed. This quantity was then allocated to beef production, cow fattening, dairy youngstock and the remaining maize quantity were allocated to dairy cows. The maize silage fed per dairy cow in kg dry matter/day for the period 1990-2022 is summarized in Figure A3- 1. The same approach was taken for estimating the quantity of gras produced and fed to animals, and for estimating the quantity of fodderbeet produced and fed to animals. Fodderbeets were however only seldom grown, and were for simplification reasons assumed to be fed only to dairy cows. The quantity was so low, why considered together with beet pulp in the category "beet pulp", Figure A3- 1. Gras produced and fed to animals consist of pasture grass, hay and grass silage, and was assumed to be fed to meet the feed requirements. Based on statistics on grazing (see section 5.1.1.1) and divers grazing projects it was assumed that in 1990 pasture grass would account for 10% of the dry matter intake/ day of a dairy cow with a linear decrease up to 2020 where pasture grass would account only for 5% of the dry matter intake/day/dairy cow. In the same time had also the quantity of hay decreased in a dairy cow diet from 2 kg/day/dairy cow to 1 kg/day/dairy cow. For health reasons does the diet contain 0.5 kg straw/cow/day. Consumption of grass silage (i.e. the largest part of grass) was calculated on the basis of the remaining feed requirements of cows after all other feed consumed had been fed. Silage grass, hay and pasture grass is summarized as "gras" in Figure A3- 1 for the years 1990-2022.

The dry matter content, energy content and the digestibile energy for mais silage, grass silage, hay and pasture grass were based on national statistics from ASTA – Laboratoire de Contrôle et d'Essais, and for straw and fodder beets on published table values (CVB, 2021). However, national statistics were not necessary for all required content available for the whole time period, why using either the median, or where possible a trend estimate. For preserved feed, it was assumed that, up to and including the grazing period, feed composition was that harvested in the previous year, and for the remaining three last months of a year, it was assumed that the composition of the feed would correspond to the one harvested in that year. The digestible energy, expressed as a percentage of gross energy (DE%) for the different roughages is shown in Table A3-1.

Figure A3- 1 : The different component of an average feed diet (expressed in kg dry matter/dairy cow/day) of a lactating dairy cow in Luxembourg for the period 1990-2022



Digestible energy in the feed diet of lactating dairy cows

For dairy cow a Tier 2 approach was used when calculating country- and year-specific emission factors. The general EF for enteric fermentation related methane emissions in kg CH_4 per head per year was estimated following the IPCC guidelines (IPCC, 2019 Refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Chapter 10 Emissions from Livestock and Manure Management., 2019a), see section 5.2.3.2. The digestible energy expressed as a percentage of gross energy (DE%) is one of the relevant input in those calculations.

The DE% of the feed diet of lactating dairy cows ($DE\%_{Dairy\ cow\ feed\ ratio}$) for the different years was calculated using the following formula:

$$DE\%_{dairy\ cow\ feed\ diet} = \frac{\left(\sum_f (Quantity_f * DE\%_f)\right)}{\left(\sum_f (Quantity_f)\right)}$$

- whereby *f* stands for the different feed components listed in Table A3-1.
- $Quantity_f$ stands for the quantity of feed component *f* expressed as dry matter and shown in Figure A3- 1.
- $DE\%_f$: digestible energy expressed as a percentage of gross energy for feed component $_f$, shown in Table A3-1.

The so-obtained $DE\%_{Dairy\ cow\ feed\ diet}$ for the year 1990-2022 is shown in the last column in Table A3-1 for the period 1990-2022.

Table A3- 2 : Digestible energy expressed as a percentage of gross energy (DE%) in the feed diet of lactating dairy cows for the period 1990-2022, for both, the whole feed diet and the different feed component

3 - Agriculture

Activity data - Digestible energy expressed as a percentage of gross energy (DE %) of the different feed components and of the whole feed diet of dairy cows

Year	Maize silage	Gras-silage	Hay	Straw	Fresh grass	Dairy cow compound feed	Starch-rich concentrated feed	Beet pulp	Brewers grains	Protein-rich concentrated feed	Dairy cow feed diet
1990	67	69	55	23	69	77	73	57	80	91	68
1991	64	71	54	23	69	77	73	57	80	91	69
1992	67	66	52	23	69	77	73	57	80	91	67
1993	59	65	55	23	69	77	73	57	80	91	66
1994	71	68	57	23	69	77	73	57	80	91	68
1995	68	68	57	23	69	77	73	57	80	91	68
1996	66	71	57	23	69	77	73	57	80	90	69
1997	68	68	57	23	69	77	72	57	80	90	68
1998	64	70	57	23	69	77	72	56	80	90	68
1999	68	68	57	23	69	77	72	56	80	90	69
2000	71	66	57	23	69	77	72	56	80	90	68
2001	69	69	57	23	69	77	72	55	80	90	69
2002	72	67	57	23	69	77	72	55	80	90	69
2003	66	69	57	23	69	77	72	55	80	90	68
2004	73	71	57	23	69	77	72	55	80	90	71
2005	69	71	57	23	69	77	72	55	80	90	70
2006	71	69	57	23	69	77	72	55	80	90	70
2007	69	70	57	23	69	77	72	55	80	90	69
2008	69	71	57	23	69	77	72	55	80	90	70
2009	72	70	57	23	69	77	71	54	80	90	71
2010	74	72	57	23	69	77	71	54	80	90	72
2011	74	74	57	23	69	77	72	55	80	86	72
2012	74	68	57	23	68	77	72	55	80	88	71
2013	74	69	57	23	66	77	71	55	80	89	71
2014	74	73	57	23	69	77	71	56	80	89	72
2015	76	72	57	23	73	77	71	55	80	89	73
2016	75	70	57	23	62	77	71	56	80	88	71
2017	74	73	58	23	73	77	69	57	80	84	72
2018	72	73	58	23	63	77	71	56	80	86	71
2019	74	74	58	23	72	77	70	55	80	85	72
2020	70	74	57	23	62	77	70	56	80	86	71
2021	69	72	56	23	73	77	70	55	80	86	70
2022	68	75	59	23	74	77	70	56	80	86	71

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13.4 *Annex 3 C : Utilized agricultural area in Luxemburg*

A large part of the utilized agriculture area (UAA) cultivated by Luxemburgish farmers is situated outside the country, see Table A 3-2, whereas the UAA cultivated by foreign farmers and situated in Luxemburg is rather marginal. The utilized agriculture area as reported by STATEC and EUROSTAT refers to the UAA utilized by luxemburgish farmers whereby no distinction is made w.r.t. to the country of origin of the UAA. The UAA cultivated in Luxemburg was therefore derived from the databases of the Ministry of Agriculture[161,162] set in place to pay divers EU and national subsidies. This was done for the first time for submission 2023, whereas in previous submission the UAA cultivated by Luxemburgish farmers had been used (more details in Annex 3:B in the NIR 2023).

Data were available from 2005 onwards for the UAA cultivated by farmers in Luxemburg, see Table A3- 3. For the years 1990-2004 no reliable data were in place why using the Farm Structure Survey (FSS) data as collected by STATEC[163]. FSS data were however corrected for the fact that 3.67% of the land (i.e. the portion in 2006) would have been situated in neighbouring countries. Note that Luxemburg farmers used to have always land in neighbouring countries, why assuming that the last available reliable observation (i.e. 2006) would hold also for previous years. A significant increase of the UAA in neighbouring countries and cultivated by Luxemburgish farmers started only thereafter, with new Common agricultural policy in place.

However, not all UAA is also utilized by farmers. The remaining UAA is mostly extensive grassland with either ochard trees, with or without animals, or grassland on which small ruminants and horses are kept by other persons than professional farmers. Reliable data on the UAA cultivated by non-farmers were available since 2014 (Anne Peschon, personal communication, 2022). For the period 1990-2013 a trend estimate was used.

161 https://agriculture.public.lu/de/agrarpolitik-landliche-entwicklung/gemeinsame-agrarpolitik/direkte-einkommensbeihilfen.html

162 https://agriculture.public.lu/de/betriebsfuhrung/gis.html

163 https://lustat.statec.lu/vis?fs[0]=Th%C3%A8mes%2C1%7CEntreprises%23D%23%7CAgriculture%20et%20foresterie%23D2%23&pg=0&fc=Th%C3%A8mes&df[ds]=release&df[id]=DF_D2100&df[ag]=LU1&pd=1990%2C2021&dq=.A

Table A3- 3 : UUA in LU versus UUA by lux. Farmers

3 - Agriculture					
Activity data - Utilised agricultural area (UAA) in Luxemburg (ha)					
Year	UAA (ha) cultivated by luxemburgish farmers *Source: STATEC*	UAA (ha) in BE, DE &FR cultivated by luxemburgish farmers *Source: MA / SER*	UAA (ha) in LU cultivated by farmers *Source: MA-SER*	UAA (ha) in LU not declared *Source: MA-ASTA*	UAA (ha) in LU - total
1990	126 177		*121 774*	*3 896*	*125 671*
1991	125 362		*120 975*	*3 952*	*124 927*
1992	125 643		*121 238*	*4 008*	*125 246*
1993	127 128		*122 658*	*4 064*	*126 722*
1994	126 684		*122 225*	*4 120*	*126 344*
1995	126 792		*122 321*	*4 176*	*126 497*
1996	126 306		*121 844*	*4 232*	*126 075*
1997	126 561		*122 093*	*4 287*	*126 381*
1998	127 075		*122 582*	*4 343*	*126 926*
1999	127 345		*122 842*	*4 399*	*127 241*
2000	127 591		*123 071*	*4 455*	*127 526*
2001	127 892		*123 359*	*4 511*	*127 870*
2002	128 068		*123 525*	*4 567*	*128 092*
2003	128 110		*123 567*	*4 623*	*128 189*
2004	128 030		*123 486*	*4 678*	*128 164*
2005	129 101	5 492	124 885	*4 734*	*129 619*
2006	128 850	4 616	125 625	*4 790*	*130 415*
2007	130 876	4 823	125 096	*4 846*	*129 942*
2008	130 413	5 281	125 061	*4 902*	*129 963*
2009	130 754	5 873	123 541	*4 958*	*128 499*
2010	131 095	6 116	124 366	*5 014*	*129 379*
2011	131 320	6 614	124 019	*5 069*	*129 088*
2012	131 479	6 839	124 163	*5 125*	*129 288*
2013	131 031	6 995	123 805	*5 181*	*128 986*
2014	131 065	6 951	123 610	5 215	128 826
2015	131 373	7 722	122 878	5 225	128 103
2016	130 640	7 401	122 505	5 414	127 919
2017	131 154	7 808	122 378	5 442	127 821
2018	131 548	8 235	121 746	5 475	127 221
2019	131 582	8 928	120 956	5 534	126 490
2020	132 127	9 329	121 119	5 573	126 692
2021	132 811	9 618	121 111	5 581	126 692
2022	132 520	10 280	120 821	5 573	126 394

Note: Estimates are in italic

Annex 4: CO_2 reference approach and comparison with sectoral approach, and relevant information on the national energy balance

Please refer to section 3.2.1 for a comparison of the reference approach and the sectoral approach.

The following tables summarize the data of the national energy balance (2000-2022). The data was submitted to AEV by Statec in December 2023.

Solid fuels (all) (tons)	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
Total imports	187249	130641	113335	83873	74477	71077	71977
Total exports	2	2	1	12	69	26	18
Stock changes			2506	-134	8091	-1780	1065
Gross inland deliveries	187248	130639	110828	83994	66317	72831	70894
Final consumption	187248	130639	110828	83994	66317	72831	70894
Total Industry	184438	129312	109760	82972	65832	72210	69971
other extractive industries	0	0					
food, beverages and tobacco	0	0					
textiles and leather	0	0					
wood and wood products	0	0					
pulp, paper and printing	0	0					
chemical and petro-chemical	0	0					
non-metallic mineral products	128192	89783	73550	65335	55974	60604	63416
iron and steel	45778	33006	26676	11871	4811	4000	3424
machinery	0	0					
transportation equipment	0	0					
other industries	0	0					
construction	10467	6523	9535	5766	5046	7606	3131
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential	2810	1328	1068	1023	485	621	923
Agriculture							
Non specified (others)							

Natural gas (m^3)	2000	2005	2010	2015	2020	2021	2022
Total imports	757984857	1336605223	1364362316	874777108	703453966	756749758	588968737
Total exports							
Stock changes							
Gross inland deliveries	757984857	1336605223	1364362316	874777108	703453966	756749758	588968737
Final consumption	682619208	716627094	769927158	679641776	633348048	681831315	531756774
Total Industry	338053394	373871820	352929621	312974499	259223157	282872397	198898001
other extractive industries	51175	742055	405678	571700	84734	768746	462151
food, beverages and tobacco	8538974	6042655	4345036	6892043	4468434	5541129	4673688
textiles and leather	30709656	28092391	21283224	30800367	29301061	1703071	1023845
wood and wood products	292540	502126	214565	675858	883122	38138	22927
pulp, paper and printing	5471186	8365197	2390990	2579909	192447	6585406	3958988
chemical and petro-chemical	10400534	15567451	10477927	17613083	7957470	3016589	1813501
non-metallic mineral products	95851071	90463858	87738236	79606788	55920735	44744090	6312195
iron and steel	163666827	202470750	205986749	156010594	148107777	150707090	129208647
machinery	3330984	1590720	975226	3191240	300381	14754910	9739434
transportation equipment	113808	338426	268440	401014	123400	10935	6574
other industries	16669159	16643239	14945081	9364025	9155951	49866601	37500300
construction	2844436	2910652	2564132	4777792	2586678	4953342	4066126
Total energy sector				0	0		
Total transportation sector	2862172	1145907	2836975	1845240	1659287	3156908	2242451
Commercial and public services	164827432	109884658	152657606	115021008	82669834	125822388	92479033
Residential	176848039	231695729	261466366	249800387	289794768	269979621	238132524
Agriculture	28171	28979	36589	643	1002	0	4765
Non specified (others)							

Biogas (m^3)	2000	2005	2010	2015	2020	2021	2022
Total imports							
Total exports							
Stock changes							
Gross inland deliveries	2016273	12093349	24860513	32958691	33653389	33334527	36963009
Final consumption	1158777	6950200	10908529	12923428	10531945	6734350	11020801
Total Industry				2574955	2314003	1999254	1624633
other extractive industries				4704	756	5433	3775
food, beverages and tobacco			0	56703	39888	39163	38176
textiles and leather				253406	261561	12037	8363
wood and wood products				5561	7883	270	187
pulp, paper and printing				21226	1718	46544	32338
chemical and petro-chemical				144909	71034	21320	14813
non-metallic mineral products				654954	499187	316237	51559
iron and steel				1283556	1322111	1065151	1055399
machinery				26255	2681	104283	79553
transportation equipment				3299	1102	77	54
other industries				77041	81732	352442	306309
construction				39309	23090	35009	33213
Total energy sector				0	0	0	0
Total transportation sector				15181	14812	22312	18317
Commercial and public services	777886	1152283	1417588	2878859	2362508	2036902	3212613
Residential				2055198	2586906	1908132	1815820
Agriculture	380891	5797917	9490942	5399234	3253715	767750	4349418
Non specified (others)							

Motor gasoline (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	595007	494066	346851	275034	257510	305779	315799
Total exports	3000	1000	0	0	0	0	0
Stock changes	10203	-8073	-4467	-9506	3086	-2652	2453
Gross inland deliveries	581804	501139	351318	284540	254425	308430	313347
Final consumption	581804	501139	351318	284540	254425	308430	313347
Total Industry	733	2602	2082	1914	1465	1221	1244
other extractive industries	25	41	35	65	58	35	51
food, beverages and tobacco	60	99	73	62	60	39	41
textiles and leather	3	7	6	4	54	34	1
wood and wood products	18	31	21	20	20	15	15
pulp, paper and printing	15	32	14	5	2	2	2
chemical and petro-chemical	46	128	66	14	19	16	6
non-metallic mineral products	28	9	5	122	80	75	66
iron and steel	109	166	148	72	49	38	40
machinery	21	44	37	27	24	19	15
transportation equipment	4	12	17	1	1	1	1
other industries	16	45	5	76	30	25	25
construction	386	1986	1518	1316	969	839	887
Total energy sector	180	562	137	73	61	49	60
Total transportation sector	455863	384807	266371	199798	157056	203273	202197
Commercial and public services	5004	11937	14157	13840	10167	8790	7837
Residential	120025	101231	68571	68915	85675	95097	102009
Agriculture							
Non specified (others)							

Biogasoline (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	0	0	1103	10796	22074	27722	31572
Total exports	0	0	0	0	0	0	0
Stock changes	0	0	-14	-373	264	-240	245
Gross inland deliveries	0	0	1117	11169	21809	27963	31326
Final consumption	0	0	1117	11169	21809	27963	31326
Total Industry	0	0	7	75	126	111	124
other extractive industries	0	0	0	3	5	3	5
food, beverages and tobacco	0	0	0	2	5	4	4
textiles and leather	0	0	0	0	5	3	0
wood and wood products	0	0	0	1	2	1	1
pulp, paper and printing	0	0	0	0	0	0	0
chemical and petro-chemical	0	0	0	1	2	1	1
non-metallic mineral products	0	0	0	5	7	7	7
iron and steel	0	0	0	3	4	3	4
machinery	0	0	0	1	2	2	1
transportation equipment	0	0	0	0	0	0	0
other industries	0	0	0	3	3	2	3
construction	0	0	5	52	83	76	89
Total energy sector	0	0	0	3	5	4	6
Total transportation sector	0	0	847	7843	13463	18429	20214
Commercial and public services	0	0	45	543	872	797	783
Residential	0	0	218	2705	7344	8622	10198
Agriculture	0	0	0	0	0	0	0
Non specified (others)	0	0					

Diesel (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	997105	1839706	1748205	1562486	1256571	1305028	1083161
Total exports	2000	2000	0	593	1232	0	0
Stock changes	5409	23781	-6786	-1933	929	774	-6145
Gross inland deliveries	989696	1813925	1754991	1563826	1254410	1304255	1089306
Final consumption	989698	1813925	1754991	1563826	1254410	1304255	1089306
Total Industry	22183	78704	62640	57896	44322	36941	37623
other extractive industries	753	1226	1047	1959	1752	1072	1544
food, beverages and tobacco	1819	2994	2193	1872	1812	1169	1253
textiles and leather	104	199	172	130	1649	1026	33
wood and wood products	545	923	624	602	593	459	446
pulp, paper and printing	441	963	435	149	62	49	56
chemical and petro-chemical	1392	3859	1988	438	567	472	179
non-metallic mineral products	856	262	161	3695	2410	2271	1997
iron and steel	3287	5024	4445	2185	1474	1155	1216
machinery	649	1320	1123	811	738	561	444
transportation equipment	123	375	498	37	36	38	24
other industries	490	1376	145	2288	913	754	765
construction	11673	60089	45674	39806	29301	25386	26819
Total energy sector	979	3089	4143	2195	1845	1486	1825
Total transportation sector	865100	1559012	1471167	1298517	1051445	1086049	883311
Commercial and public services	27279	65578	76769	75450	55426	47919	42724
Residential	59907	90923	119714	111661	80568	110587	103560
Agriculture	14250	16620	20557	18107	20803	21274	20261
Non specified (others)							

Gasoil (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	336101	294331	238262	244240	266359	257107	223873
Total exports	6000	6000	1978	48	314	0	0
Stock changes	29706	-11189	-10748	-5309	-5361	-2173	-3116
Gross inland deliveries	300395	299520	247032	249501	271406	259280	226989
Final consumption	298973	298947	246575	249055	271145	259167	226811
Total Industry	21818	17710	10029	7949	27806	25652	20116
other extractive industries	763	164	89	444	684	631	495
food, beverages and tobacco	2283	1412	729	1212	6790	6264	4912
textiles and leather	502	837	508	80	82	76	59
wood and wood products	336	285	133	20	242	223	175
pulp, paper and printing	470	348	93	33	66	61	48
chemical and petro-chemical	5148	4099	1768	2084	1522	1404	1101
non-metallic mineral products	840	506	196	1122	4964	4580	3591
iron and steel	8478	2439	1782	434	1046	965	757
machinery	1866	1695	1437	527	3582	3304	2591
transportation equipment	95	378	312	7	269	248	195
other industries	160	105	29	186	656	605	474
construction	836	5360	2684	1629	5665	5226	4099
Total energy sector	371	445	321	73	59	68	82
Total transportation sector	3584	3047	2371	3078	3806	3511	2753
Commercial and public services	56623	53940	46086	65732	106850	98573	77299
Residential	216577	223804	187768	172223	132625	131363	126561
Agriculture	0	0	0	0	0	0	0
Non specified (others)							

Biodiesel (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	0	570	45519	83539	143242	133903	120965
Total exports	0	0	0	32	140	0	0
Stock changes	0	0	-175	-103	106	79	-686
Gross inland deliveries	0	570	45694	83610	142996	133823	121651
Final consumption	0	570	45694	83610	142996	133823	121651
Total Industry	0	0	1626	3093	5052	3789	4201
other extractive industries	0	0	27	105	200	110	172
food, beverages and tobacco	0	0	57	100	207	120	140
textiles and leather	0	0	4	7	188	105	4
wood and wood products	0	0	16	32	68	47	50
pulp, paper and printing	0	0	11	8	7	5	6
chemical and petro-chemical	0	0	52	23	65	48	20
non-metallic mineral products	0	0	4	197	275	233	223
iron and steel	0	0	115	117	168	118	136
machinery	0	0	29	43	84	58	50
transportation equipment	0	0	13	2	4	4	3
other industries	0	0	4	122	104	77	85
construction	0	0	1186	2127	3340	2604	2995
Total energy sector	0	0	107	117	210	152	204
Total transportation sector	0	570	38363	69412	119863	111440	98649
Commercial and public services	0	0	2017	4055	6317	4916	4771
Residential	0	0	3091	5966	9183	11344	11564
Agriculture	0	0	531	967	2371	2182	2262
Non specified (others)	0	0					

Residual fuel oil (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	6469	2217	2276	998	1137	1199	956
Total exports				0	14	65	0
Stock changes	0	-1					
Gross inland deliveries	6469	2218	2276	998	1123	1134	956
Final consumption	6469	2218	2276	998	1123	1134	956
Total Industry	6469	2218	2276	998	1123	1134	956
other extractive industries							
food, beverages and tobacco	6469	2218	2276	0	0	0	0
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries				998	1123	1134	956
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

LPG (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	30202	16609	12800	11876	7322	10369	7878
Total exports	6025	4555	1304	2243	62	70	47
Stock changes			16	-40			
Gross inland deliveries	24177	12054	11480	9673	7260	10299	7831
Final consumption	24177	12054	11480	9673	7260	10299	7831
Total Industry	56	440	36	44	79	51	41
other extractive industries				0	0	0	0
food, beverages and tobacco				1	1	1	1
textiles and leather				4	9	7	4
wood and wood products				0	0	0	0
pulp, paper and printing				0	0	0	0
chemical and petro-chemical		3		2	2	1	2
non-metallic mineral products	54	11	0	11	17	8	6
iron and steel			36	22	45	33	25
machinery	0	412		0	0	0	0
transportation equipment				0	0	0	0
other industries				1	3	1	1
construction	2	14		1	1	0	1
Total energy sector				0	0	0	0
Total transportation sector	1998	1245	1352	1287	174	258	257
Commercial and public services	19882	8124	8029	7876	6479	9777	7305
Residential	2241	2245	2063	466	529	212	228
Agriculture				0	0	0	0
Non specified (others)							

Lubricants (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	7047	6194	13364	9480	6861	7278	8500
Total exports			3970	1731	607	693	723
Stock changes	-55	41	-31	13	0	0	-3
Gross inland deliveries	7102	6153	9425	7736	6254	6585	7780
Final consumption							
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							
Total non-energy use	7102	6153	9425	7736	6254	6585	7780

Bitumen (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	33315	11784	20758	22908	12727	13592	9147
Total exports	2719	1275	114	2039	614	0	235
Stock changes	0	0					
Gross inland deliveries	30596	10509	20644	20869	12113	13592	8912
Final consumption							
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							
Total non-energy use	30596	10509	20644	20869	12113	13592	8912

Other kerosene (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	1170	1685	642	840	523	608	642
Total exports			0	0	0	0	0
Stock changes	-13	11	-26	12	13	0	-8
Gross inland deliveries	1183	1674	668	828	510	608	650
Final consumption	1183	1674	668	828	510	608	650
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential	1183	1674	668	828	510	608	650
Agriculture							
Non specified (others)							

Aviation gasoline (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	266	145	352	220	186	236	216
Total exports			0	0	0	0	0
Stock changes	2	0	0	0	0	0	20
Gross inland deliveries	264	145	352	220	186	236	196
Final consumption	264	145	352	220	186	236	196
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector	264	145	352	220	186	236	196
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

Jet kerosene (tons)	2000	2005	2010	2015	2020	2021	2022
Total imports	317804	419704	422170	443598	530523	606014	628731
Total exports			0	0	0	0	0
Stock changes	6169	-899	3422	-921	-441	278	-26
Gross inland deliveries	311635	420603	418748	444519	530964	605736	628757
Final consumption	311635	420603	418748	444519	530964	605736	628757
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector	311635	420603	418748	444519	530964	605736	628757
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

Biomass (all wood) (GJ)	2000	2005	2010	2015	2020	2021	2022
Total imports	3626	30110	95615	1273222	575303	775788	754926
Total exports	5393	62162	135574	899344	801439	889395	1141052
Stock changes							
Gross inland deliveries	640646	1587606	1706714	2548326	6673610	7306702	7024456
Final consumption	635882	1541040	1611302	1756677	784775	995740	993922
Total Industry		880933	863371	807701	142051	321609	84102
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products		880933	863371	807701	142051	321609	84102
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services	3626	3154	5811	9974	2056	5806	4855
Residential	632256	656953	742120	939001	640668	668325	904966
Agriculture							
Non specified (others)							

Biomass (fuel wood) (GJ)	2000	2005	2010	2015	2020	2021	2022
Total imports	3626	9245	67694	54240	60417	65319	66587
Total exports	5393	48612	69625	118418	961	488	510
Stock changes							
Gross inland deliveries	635882	649812	737410	644968	255646	108364	366820
Final consumption	635882	649812	737410	644968	255646	108364	366820
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services	3626	3154	5811	9974	2056	5806	4855
Residential	632256	646658	731599	634993	253590	102558	361965
Agriculture							
Non specified (others)							

Biomass (pellets) (GJ)	2000	2005	2010	2015	2020	2021	2022
Total imports		20865	27921	118371	182401	234376	293839
Total exports		13549	65949	213092	463077	519839	303878
Stock changes							
Gross inland deliveries		10296	15196	293303	881602	1086247	1244103
Final consumption		10296	10521	267069	370964	561363	512458
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential		10296	10521	267069	370964	561363	512458
Agriculture							
Non specified (others)							

Biomass (wood chips) (GJ)	2000	2005	2010	2015	2020	2021	2022
Total imports				1100611	332485	476092	394500
Total exports				567834	337401	369068	836665
Stock changes							
Gross inland deliveries	4764	927498	954107	1610056	5536362	6112091	5413534
Final consumption		880933	863371	844640	158165	326014	114645
Total Industry		880933	863371	807701	142051	321609	84102
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products		880933	863371	807701	142051	321609	84102
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential				36939	16115	4405	30543
Agriculture							
Non specified (others)							

Annex 5: Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded for the annual inventory submission

Please refer to section 1.7, and in particular Table 1-14, for information about the completeness assessment of Luxembourg's greenhouse gas inventories.

Annex 6: Tables 6.1 and 6.2 of the IPCC good practice guidance

Please refer to section 0 for a detailed description of the uncertainty analysis of Luxembourg's greenhouse gas inventory.

Table 1-12 contains the information required by Table 6.1 of the IPCC good practice guidance.

Annex 7: Information on changes in the national registry

The following changes to the national registry of Luxembourg have occurred in 2023. Note that the 2023 SIAR confirms that previous recommendations have been implemented and included in the annual report.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	None
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	No changes.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	There have been five new EUCR releases in production (versions 13.10, 13.10.2, 13.10.3, 13.10.4 and 13.11.2) after version 13.8.2 (the production version at the time of the last Chapter 14 submission). No changes were applied to the database, whose model is provided in Annex A. No change was required to the application backup plan or to the disaster recovery plan. No change to the capacity of the national registry occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	The changes that have been introduced with versions 13.10, 13.10.2, 13.10.3, 13.10.4 and 13.11.2 compared with version 13.8.2 of the national registry are presented in Annex B. It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B). No other change in the registry's conformance to the technical standards occurred for the reported period.
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	No changes regarding security were introduced.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	No change to the list of publicly available information occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change to the registry internet address during the reported period.
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	No change during the reported period.