Support to LULUCF reporting in Luxembourg

Roll out of the LULUCF methodology for the Grand Duchy of Luxembourg

Final Report

Version 1.0

31 May 2021

«Using Space to provide Space for the Environment»

Title:

Support to LULUCF reporting in Luxembourg: Roll out of the LULUCF methodology for the Grand Duchy of Luxembourg

Authors:

Stefan Kleeschulte, Karolina Korzeniowska, Christopher Philipsen

Place and date:

Niederanven, 31.05.2021

Contact information:

Stefan Kleeschulte

space4environment sàrl

48, rue Gabriel Lippmann

L-6947 Niederanven

Tel: +352 26 71 41 35

Fax: +352 26 71 45 54

kleeschulte@space4environment.com

http://www.space4environment.com

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Term	Abbreviation
Administration de l'Environnement	*AEV*
Corine Land Cover	*CLC*
Copernicus Land Monitoring Service	*CLMS*
Earth Observation	*EO*
European Union	*EU*
Greenhouse Gas	*GHG*
Geographic Information System	*GIS*
High Resolution Layer	*HRL*
Intergovernmental Panel on Climate Change	*IPCC*
Joint Research Centre	*JRC*
Land Cover	*LC*
Land Information System Luxembourg	*LIS-L*
Land Use	*LU*
Land Cover map 2018	*LC 2018*
Land Parcel Identification System	*LPIS*
Land Use map 2012	*LU 2012*
Land Use map 2018	*LU 2018*
Land Use, Land Use Change and Forestry	*LULUCF*
Minimum Mapping Unit	*MMU*
National Forest Inventory	*NFI*
National Inventory Report	*NIR*
Occupation Biophysique du Sol	*OBS*
space4environment	*s4e*

1 INTRODUCTION

1.1 European Regulation and Luxembourg GHG emissions reported under CRF Sector 4 – LULUCF

In June 2018, the European Parliament and Council of the European Union (EU) adopted a legislative Regulation[1] for incorporating greenhouse gas (GHG) emissions and removals from Land Use, Land Use Change and Forestry (EU-LULUCF) under its 2030 Climate and Energy Framework. The *Administration de l'Environnement* (AEV) is in charge of preparing the national reporting for Luxembourg under the EU-LULUCF Regulation. In 2019, the AEV has prepared a LULUCF GHG inventory for the period between 1990 and 2017[2], which was based on spatially explicit data already existing for the country, namely the OBS (Occupation Biophysique du Sol) maps for the reference years of 1989, 1999, and 2007, as well as a land use map of 2012 (LULUCF12), specifically updated for the National Inventory Report (NIR). Ancillary land parcel identification system (LPIS) and national forest inventory (NFI) data existing for the country were also used in order to calibrate statistics on some specific agricultural and forest land use transitions.

Since then, new and more recent LU/LC data sets have been produced by space4environment (s4e) for the whole Luxembourg (LIS-L 2015[3] and LC 2018[4] and LU 2018[5]) from very high-spatial resolution Earth Observation (EO) imagery with improved thematic and geometric accuracies. It is necessary for future reports that spatial data sets already existing for the past are matching the technical characteristics of the new products in order to provide a consistent reporting under Approach 3: Geographically explicit land use data, which is presented in Figure 1-1 and introduced in the next section.

The EC guidelines[6] for reporting consistent land use and land use change information under the LULUCF Regulation present a matrix approach (see Figure 1-1) to improve the quality of emissions data. This matrix is composed of a combination of tiers and approaches, aiming at moving towards higher levels on each axis.

The Regulation introduced reporting requirements so that significant sources of emissions and removals are calculated using at least Tier 2 methodologies in accordance with the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines, with the encouragement to use Tier 3 methodologies. With the move to higher tier methodologies, the LULUCF regulation also calls for the use of geographically explicit land use conversion data (Approach 3), and that best use should be made of available European Union and Member States land use/land cover data.

The **Tier 1** approach uses default emission factors as provided by the IPCC Guidelines.

Tier 2 can use the same methodological approach as Tier 1 but applies emission factors and activity data which are defined by the country for the most important land uses/activities.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0842
[2] https://unfccc.int/sites/default/files/resource/lux-2019-nir-15apr19.zip
[3] http://space4environment.com/news/news-detail/news/update-of-land-cover-data-for-luxembourg/?tx_news_pi1%5bcontroller%5d=News&tx_news_pi1%5baction%5d=detail&cHash=dc1669b2a0cafa86c72bdb3a50604be3
[4] http://space4environment.com/news/news-detail/news/high-resolution-land-cover-map-2018-for-luxembourg/?tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail&cHash=24591d2188979eb9ad7e260268349d4d
[5] http://space4environment.com/news/news-detail/news/land-use-map-2018-for-luxembourg/?tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail&cHash=defacc5cb381ac44432d8f66cc61a6aa
[6] https://eur-lex.europa.eu/legal-content/LV/TXT/?uri=CELEX%3A52016SC0249

At **Tier 3**, higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national to fine grid scales.

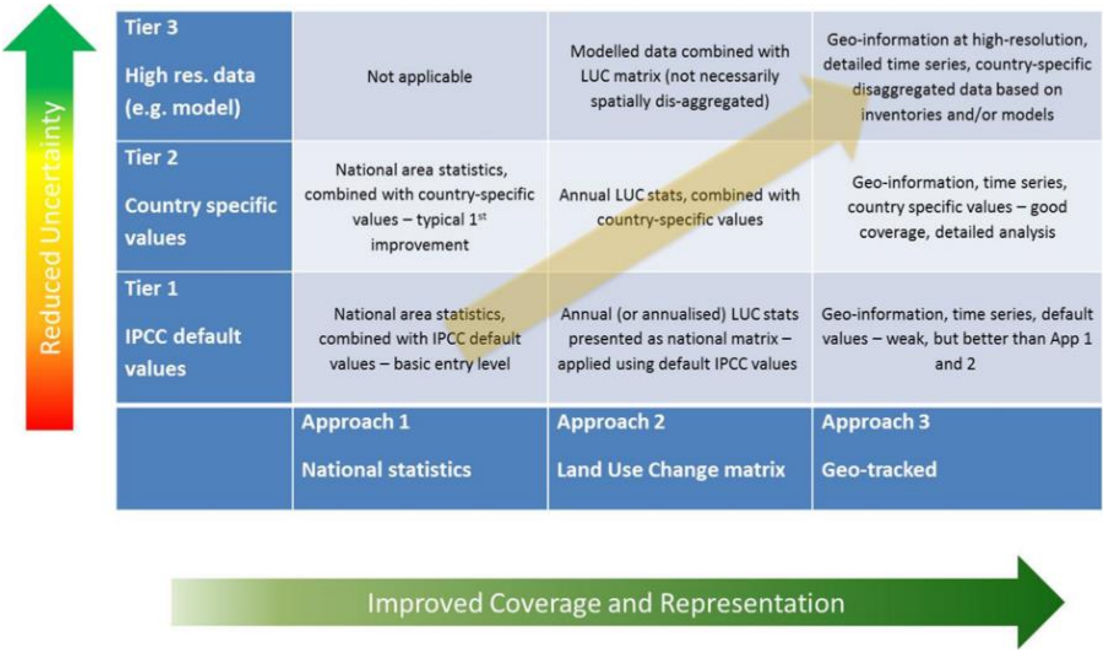


Figure 1-1 Improving accuracy and coverage in the LULUCF sector in accordance with IPCC guidance[7]

The IPCC guidelines define six top-level categories of land for representing the territory within a country:

- Forest land (FL)
- Cropland (CL)
- Grassland (GL)
- Wetlands (WL)
- Settlements (SL)
- Other land (OL)

Table 1-1 lists the possible transitions between these categories, as well as the most important transitions in terms of carbon stock changes (orange cells).

To describe and account for these land categories and the changes between them, three approaches have been defined.

Approach 1 identifies the total area for each individual land-use category but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level.

Approach 2 introduces tracking of land-use changes between categories.

Approach 3 extends Approach 2 by allowing land-use changes to be tracked on a spatial basis.

[7] https://eur-lex.europa.eu/legal-content/LV/TXT/?uri=CELEX%3A52016SC0249

The approaches are not mutually exclusive and may be combined to reflect calculation needs and national circumstances.

Table 1-1 Potential LULUCF land use transitions and main transitions in terms of carbon changes (orange cells).

From/To	SL	CL	GL	FL	WL	WT	OL
SL	SL - SL	SL - CL	SL - GL	SL - FL	SL - WL	SL - WT	SL - OL
CL	CL - SL	CL - CL	CL - GL	CL - FL	CL - WL	CL - WT	CL - OL
GL	GL - SL	GL - CL	GL - GL	GL - FL	GL - WL	GL - WT	GL - OL
FL	FL - SL	FL - CL	FL - GL	FL - FL	FL - WL	FL - WT	FL - OL
WL	WL - SL	WL - CL	WL - GL	WL - FL	WL - WL	WL - WT	WL - OL
WT	WT - SL	WT - CL	WT - GL	WT - FL	WT - WL	WT - WT	WT - OL
OL	OL - SL	OL - CL	OL - GL	OL - FL	OL - WL	OL - WT	OL - OL

1.2 Project objectives

During the first half of 2020 space4environment implemented a feasibility study to develop a methodology for supporting the national LULUCF reporting in Luxembourg. The method makes use of existing national data between 1989 and 2018 and is open for inclusion of upcoming data.

The objectives of the current project include the following steps:

- Rolled out of the developed methodology to the full territory of Luxembourg;
- Population of the grid database for six reference years according to LULUCF categories;
- Assessment of the uncertainty associated with the main land use transitions[8] (FL-FL, FL-L, L-FL, L-SL)
- Estimation of carbon stock changes Forest Land (FL), Grassland (GL) and Cropland (CL), including information on soil associations.

1.3 Document content

This document contains 9 main Chapters which firstly introduce the LULUCF regulation and in the following detail the Luxembourg approach towards land use change mapping and carbon accounting:

- Chapter 1 presents the content of this document, the European Union regulations related to the task and the main objectives of the project.
- Chapters 2 and 3 provide an overview of the national data sets and their translation into LULUCF categories.

[8] FL = Forest land, SL = Settlement, L = Land – any other land use category

- Chapter 4 summaries the main issues observed when working with the data and the attempts to make the data more consistent.
- Chapter 5 summarises the set-up of the point grid database, its population further improvement of the data consistency at grid level.
- Chapter 6 provides information about the uncertainties of the data before and after improvement as well as the uncertainty associated with the land use changes.
- Chapter 7 presents the methodology for the assessment of land use changes and the calculation of carbon accounting figures.
- Chapter 8 summaries the carbon accounting results.
- The final Chapter 9 provides some final conclusions of the work.

2 Technical description of available land use and land cover (LU/LC) spatial data sets for LULUCF reporting in Luxembourg

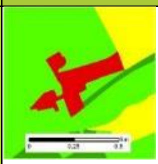
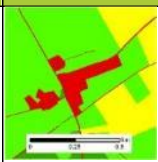
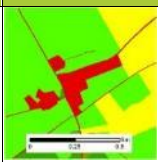
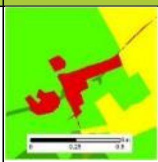
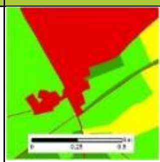
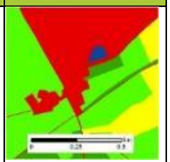
2.1 Overall information about main national data sets

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 for 2015;
- Land Cover map of 2018;
- Land Use map of 2018;
- Land Use map of 2007, 2015 and 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 2-1 summarizes general information on the Land Use data existing for the country.

Table 2-1 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, LIDAR, 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.	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.

	OBS 1989	OBS 1999	OBS 2007	LU 2012	LIS-L 2015	LU 2018
			User's accuracy: 81.76% Producer's accuracy: 85.82%			
Minimum mapping unit	1500m²	2500m² for surface features 1500m² or less 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.

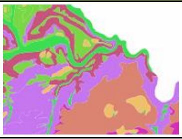
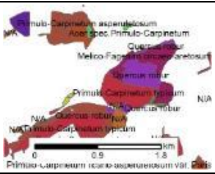
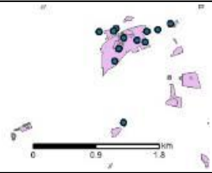
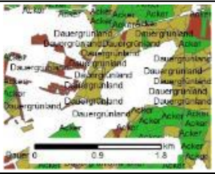
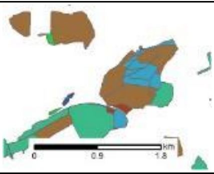
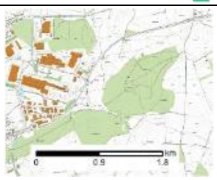
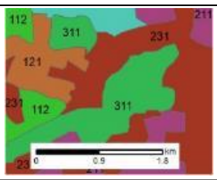
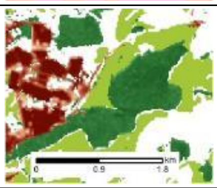
2.2 Other ancillary data

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 2-2 and listed below:

- National ancillary data:
  - Carte des associations de sols / map of soil associations (1 :100 000)
  - Cartographie phytosociologique des végétations forestières (Phyto);
  - Biotopkataster of the open landscapes;
  - LPIS inventories for the period 2009 – 2019 ("FLIK" data);
  - National Forest Inventory (NFI);
  - Topographic maps.
- International ancillary data:
  - Corine Land Cover (CLC);
  - Copernicus High Resolution Layers (HRL)[9]: Imperviousness, Forest and Grassland.
  - Urban Atlas.

[9] https://land.copernicus.eu/

Table 2-2 Technical specification of ancillary data.

Data	Visual representation of data	Type of data (raster/vector)	Geodetic reference	Time reference
Carte des associations de sols		Vector	LUREF	1969
Cartographie phytosociologique des végétations forestières (Phyto)		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, Forest and Grassland		raster (20×20m) raster (10 x 10m) from 2018	-	2012, 2015, 2018 in production

2.2.1 Copernicus Land Monitoring Service (CLMS)

Copernicus is the European system for monitoring the Earth. Data is collected by different sources, including Earth observation satellites and in-situ sensors. In Europe, the data provided by the Copernicus Land Monitoring Service (CLMS) is divided into three main components:

- Global;
- Pan-European;
- Local.

The pan-European component is coordinated by the European Environment Agency (EEA) and produces land cover / land use (LC/LU) information in the CORINE Land Cover data and High Resolution Layers.

The CORINE Land Cover is provided for 1990, 2000, 2006, 2012, and 2018. This vector-based dataset includes 44 land cover and land use classes. The time-series also includes a land-change layer, highlighting changes in land cover and land-use.

The High Resolution Layers (HRL) are raster-based datasets which provides information about different land cover characteristics and is complementary to land-cover mapping (e.g. CORINE) datasets. Five HRLs describe some of the main land cover characteristics: impervious (sealed) surfaces (e.g. roads and built-up areas), forest areas, grasslands, water & wetlands, and small woody features.

The local component is also coordinated by the EEA and aims to provide specific and more detailed information that is complementary to the information obtained through the Pan-European component. The local component focuses on different hotspots, i.e. areas that are prone to specific environmental challenges and problems. It is based on very high resolution imagery (2,5 x 2,5 m pixels) in combination with other available datasets (high and medium resolution images) over the pan-European area.

In the context of national LULUCF inventory, the following Copernicus data sets are important to review/comment in more detail:

- Pan-European:
  - CORINE Land Cover (CLC) 2000, 2006, 2012, 2018 (https://land.copernicus.eu/pan-european/corine-land-cover)
  - HRL Imperviousness (IMP) 2006, 2012, 2015, 2018 (https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness)
  - HRL Forest (FOR) 2012, 2015, 2018 (https://land.copernicus.eu/pan-european/high-resolution-layers/forests)
  - HRL Grassland (GRA) 2015, 2018 (https://land.copernicus.eu/pan-european/high-resolution-layers/grassland)
- Local:
  - Urban Atlas (UA) 2006, 2012, 2018 (https://land.copernicus.eu/local/urban-atlas)

In order to evaluate the usability of the CLMS datasets to complement the LU datasets in Luxembourg for LULUCF GHG inventory at the national scale, a set of 12 European products can be timewise compared with the national products, as illustrated in Table 2-3.

Table 2-3 Copernicus datasets compared to the national LU databases in Luxembourg.

National datasets	OBS 1999	OBS 2007	LU 2012	LIS-L 2015	LU 2018
CLMS Datasets	CLC00	CLC06	CLC12		CLC18
		UA06	UA12		
		IMP06	IMP12	IMP15	IMP18
			FOR12	FOR15	FOR18
				GRA15	GRA18

From Table 2-3 it can be seen that CLMS datasets are mostly matching in time (+/- 1year) with the national LU datasets. Therefore, from the point of view of enriching the national LU time series with more frequent LU instances, there is no advantage in adding the CLMS datasets for national LULUCF inventory purposes.

Regarding the geometric and thematic characteristics of the CLMS datasets, it can also be argued that the added value for improving the LULUCF inventory in Luxembourg is overall limited. For example, the minimum mapping unit (MMU) of CLC is 25ha, which means that forest parcels below that size will not be mapped. This leads to an underestimation of forest area for the country as compared to national datasets that have overall between 0.25ha and 0.05ha MMU from 1989 to 2018.

Concerning the HRLs, it can be argued that their resolution of 20x20m (respectively 10x10m for 2018) would be sufficient to cover the geometric detail required for LULUCF inventory in Luxembourg, i.e. 0.5ha. Still, from the thematic point of view, there are some specificities with the information provided by the datasets, which makes them not totally suitable for use in LULUCF inventory. For example, the HRL Forest does not take into account land management activities, such as clear cuts, and classifies those areas as non-forest land.

The HR Grassland includes all urban grassland patches, such as parks, golf courses, sports fields and others, which in the case of Luxembourg are classified as settlement. Also, the fact that they are produced based on automatic classification approaches based on earth observation images from a single year, makes it difficult to distinguish from other land uses covered by herbaceous vegetation, such as arable land. Indeed, the fact that FLIK (LPIS) data is available for Luxembourg, the results from national grassland classification are more accurate.

An assessment of the HRL Imperviousness layer performed by s4e for Luxembourg in the context of the activities for the EEA European Topic Centre on Urban, Land and Soil Systems (ETC/ULS) – not presented in this report, has shown that there is an omission of almost 50% of settlement areas for Luxembourg, as compared to the statistics provided by national datasets. The use of this Copernicus dataset would provide an underestimation of the artificial surfaces for the country and urbanization rates along time, which are a very important and dynamic national LU flow.

The improvement of the geometric resolution (from 20m to 10m) of the underlying earth observation data allows to map sealing degrees / imperviousness with a higher spatial detail and probably more realistic, but it has led to a sharp increase of the sealing degree when comparing the 2018 data to previous data. While the 2018 IMP data are probably closer to reality, the time series derived from them would be skewed towards the recent data.

Finally, the Urban Atlas is a dataset that provides pan-European comparable land cover and land use data for some Functional Urban Areas (FUA), which in the case of Luxembourg covers the whole country. Still, the dataset is dedicated to the mapping of urban classes, rather than other more generic and rural LU classes. In the context of LULUCF inventory for Luxembourg, there is no need for distinguishing between LU categories within settlement land, which overall makes the use of the dataset not so useful.

In conclusion, it can be stated that despite the good coverage with Copernicus data, the data situation based on national data is of equal quality regarding the frequency of availability and of better quality regarding long-term time series (Copernicus only provides data from 2006 onwards), spatial resolution and thematic detail.

3 LULUCF NOMENCLATURE AND PROPOSED RECLASSIFICATION OF EXISTING LU / LC DATA SET TABLES FOR THE LULUCF CATEGORY

3.1 LULUCF nomenclature

Based on *Good Practice Guidance for Land Use, Land-Use Change and Forestry*[10], the AEV has decided on 8 main LU categories (Cropland (CL) has been split into 2 strata – annual (or arable land AL) and permanent crops (PC), the category "wetland" has been divided into wetlands (WL) and water (WT)).

The adopted nomenclature is shown in Table 3-1 and includes the description of the main LU categories for LULUCF reporting in Luxembourg. Figure 3-1 shows an example of the main LULUCF classification for the year of 2018, as derived from the 2018 LU of Luxembourg.

An important remark to the LULUCF nomenclature is that the affiliation of a given land use class to specific LULUCF class can be defined by the country, leading to possible differences how the same land use class is considered in LULUCF across different countries. For example, in Luxembourg urban green areas, golf courses and green areas at airports are considered to be part of the settlement category.

Table 3-1 LULUCF nomenclature.

	LULUCF		
	Class code	Class name	Class description[10]
Final classes	100	Settlements (SL)	Settlements includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.
	210	Cropland annual (ACL)	Cropland annual can encompass various land cover classes, such as bare soil (fallow land), herbaceous (crops) and even woody (coppice < 30 years) vegetation. A differentiation by crop type is not foreseen.
	220	Cropland permanent (PCL)	Cropland permanent includes special crops such as: wine, fruits, orchards and other special crops.
	230	Grassland (GL)	Grassland This category includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and are not expected to exceed, without human intervention, the threshold used in the forest land category.
	300	Forest (FL)	Forest includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and also by ecosystem type. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.
	340	Other land (OL)	Other land 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.
	400	Wetland (WL)	Wetland includes land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, and grassland or settlements categories.
	500	Water (WT)	Water includes permanently water covered surfaces, including adjacent, functionally associated areas such as slopes, riparian vegetation and foot paths.

[10] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

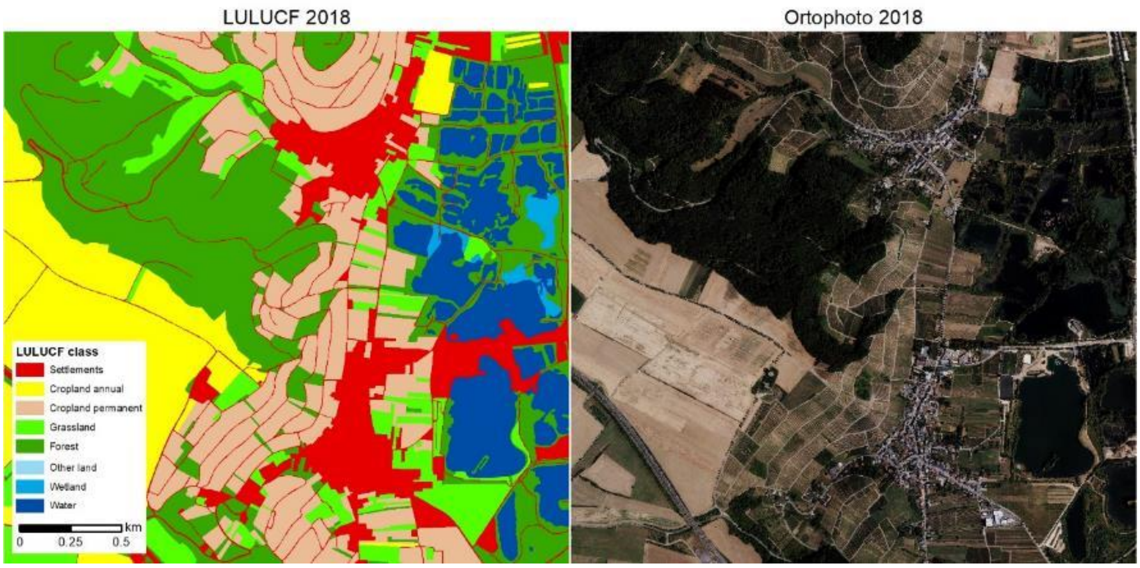


Figure 3-1 LULUCF nomenclature presented for LU 2018 data set and the corresponding ortophotomap. The map on the left is derived from the reclassification of the 2018 LU map for Luxembourg.

3.2 Nomenclature of existing LU data sets and their reclassification to LULUCF

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. The classes with "-" are class headings or not occurring in the physical GIS data set.

Table 3-2 (OBS 1989), Table 3-3 (OBS 1999), Table 3-4 (LU 2012), and Table 3-5 (LIS-L 2007, 2015, 2018) present the original LU classes of all data sets and their reclassification to the LULUCF nomenclature.

Following the experiences made during the feasibility study and during an initial sample-based review of specific land use changes, the original reclassification table has been adapted for some specific classes. These changes concern in their majority classes with natural vegetation:

- OBS 1989 class 1.2.3 (port) has been changed to "water" instead of "settlement";
- OBS 1989 class 1.3.2.3 (unused areas outside urban areas) was changed to "grassland" instead of "settlement" as the features mapped inside this class describe an unused area outside the urban area and are characterised by a significant vegetation cover;
- OBS 1989 classes 3.2.4.1.1 to 3.2.3.1.3 (thicket) have been changed to "grassland" instead of "forest land";
- OBS 1999 classes 3.2.4.1 to 3.2.4.5 (bushes) were changed to "grassland" instead of forest";
- LIS-L2018 class 450 (natural surfaces: bushes) was changed to "grassland" instead of forest".

These changes were necessary as otherwise the change towards forest (e.g. afforestation) would have been strongly overestimated. The features now included in the "grassland" category actually represent hedges, tree lines, roadside vegetation and other similar features which were previously not mapped (due to less good image support) and now would have represented a change towards “forest”.

3.2.1 OBS 1989 and OBS 1999

The classes with “-“ are class headings or not occurring in the physical GIS data set.

Table 3-2 OBS 1989 (OBS 1989) nomenclature and its reclassification to LULUCF.

OBS 1989		LULUCF89	
Class code	**Class name**	**Class code**	**Class name**
1.1	Städtisches Gebiet	"-"	
1.1.1	Zusammenhängendes Stadtgebiet	"-"	
1.1.1.1	dicht besiedeltes Gebiet	100	Settlements
1.1.1.1.1	mit hohen Gebaeuden	100	Settlements
1.1.1.1.2	mit niedrigen Gebaeuden	100	Settlements
1.1.2	Unzusammenhängendes Stadtgebiet	100	Settlements
1.1.2.1	semiurbaner Raum	100	Settlements
1.1.2.1.1	mit bedeutenden Vegetationsanteilen	100	Settlements
1.1.2.1.2	ohne bedeutende Vegetationsanteile	100	Settlements
1.1.2.2	Siedlungen entlang von Strassen	100	Settlements
1.1.2.3	unbebauter staedtischer Raum ohne bedeutende Vegetation	100	Settlements
1.1.2.3.1	Plaetze	100	Settlements
1.1.2.3.2	Parkplaetze	100	Settlements
1.1.2.3.3	Siedlungsbrache	100	Settlements
1.1.2.4	laendlicher Siedlungsraum	100	Settlements
1.2	Industrie- und Handelsflächen sowie Transportgelände	"-"	
1.2.1	Flächen genutzt von Industrie, Handel und Kultur	"-"	
1.2.1.1	Industrie- und Handelsflächen	"-"	
1.2.1.1.1	Schwerindustrie	100	Settlements
1.2.1.1.2	Industriegebiet (+ militaerische Nutzung)	100	Settlements
1.2.1.1.3	Zone zahlreicher Nutzungen	100	Settlements
1.2.1.1.4	Gartenbau- und Landwirtschaftsinfrastruktur	100	Settlements
1.2.1.2	Flächen für Freizeit- und Kulturnutzung	"-"	
1.2.1.2.1	Universitaetscampus und Schulhof	100	Settlements
1.2.1.2.2	Ausstellungen und Messen	100	Settlements
1.2.1.2.3	Krankenhaeuser	100	Settlements
1.2.1.2.4	Zentrum fuer Kultur und Sport	100	Settlements
1.2.1.3	Sonderflächen	"-"	
1.2.1.3.1	Stromversorgung	100	Settlements
1.2.1.3.2	Klaeranlage	100	Settlements
1.2.1.3.3	Gas- oder Kohlenwasserstofftanks	100	Settlements
1.2.2	Schienenwegenetz und zugehörige Flächen	"-"	
1.2.2.1	Strassennetz	"-"	
1.2.2.1.1	Autobahnen	100	Settlements

OBS 1989		LULUCF89	
Class code	Class name	Class code	Class name
1.2.2.1.2	Bundesstrasse	100	Settlements
1.2.2.1.3	Weg zur Entnahme	"-"	
1.2.2.1.4	Landstrasse	100	Settlements
1.2.2.1.5	Betriebsstrassen ?	"-"	
1.2.2.1.6	befahrbare Oberflaechen und Plaetze	100	Settlements
1.2.2.2	schienewegenetz	"-"	
1.2.2.2.1	wichtiger Bahnhof	100	Settlements
1.2.2.2.2	Zug	100	Settlements
1.2.2.2.3	Schienennetz	100	Settlements
1.2.3	Hafengebiete	500	Water
1.2.3.1	Industriehafen	100	Settlements
1.2.3.2	Yachthaften	100	Settlements
1.2.4	Flughafen	100	Settlements
1.2.4.1	Terminals, Hangar	100	Settlements
1.2.4.2	Landebahnen	100	Settlements
1.3	Minen, Schutthalden und Baustellen	"-"	
1.3.1	Abbauflächen	"-"	
1.3.1.1	Steinbruch	100	Settlements
1.3.1.2	Kiesgrube	100	Settlements
1.3.1.3	Tagebau	100	Settlements
1.3.2	Brachflächen	100	Settlements
1.3.2.1	Muelldeponie	100	Settlements
1.3.2.2	Halde und industrielle Brache	100	Settlements
1.3.2.3	Brachen ausserhalb besiedelter und industrieller Gebiete	230	Grassland
1.3.3	Baustellen	"-"	
1.3.3.1	aktuelle Baustellen	100	Settlements
1.3.3.2	Aufschuettungen	100	Settlements
1.4	Grünflachen, nicht landwirtschaftlich genutzt	"-"	
1.4.1	städtische Grünflächen	"-"	
1.4.1.1	Friedhof	100	Settlements
1.4.1.2	Gruenanlagen, Parks	100	Settlements
1.4.1.3	Strasse mit bedeutenden Gruenstreifen	100	Settlements
1.4.1.4	Parkplatz mit bedeutender Vegetation	100	Settlements
1.4.2	Sport- und Freizeitanlagen	"-"	
1.4.2.1	Sport- oder Spielplatz	100	Settlements
1.4.2.2	Erholungsgebiet	100	Settlements
1.4.2.3	besondere Einrichtung	100	Settlements
1.4.2.4	Kleingartenanlagen	100	Settlements
2.1	Ackerland	"-"	
2.1.1	Ackerland, nicht bewässert	"-"	
2.1.1.1	jaehrliche Kulturen	210	Cropland annual
2.1.1.2	Baumschule	220	Cropland permanent

OBS 1989		LULUCF89	
Class code	**Class name**	**Class code**	**Class name**
2.2	Dauerkulturen	220	Cropland permanent
2.2.1	Weinberge	220	Cropland permanent
2.2.1.1	Weinberge in Steillagen	220	Cropland permanent
2.2.1.2	Weinberge in Terrassen	220	Cropland permanent
2.2.1.3	Weinberge in ebenen Gebieten	220	Cropland permanent
2.2.2	Streuobst und kleine/niedrigwachsende Fruechte	220	Cropland permanent
2.2.2.1	Streuobst mit hohen Staemmen	220	Cropland permanent
2.2.2.2	Streuobst mit niedrigen Staemmen	220	Cropland permanent
2.3	Wiesen	"-"	
2.3.1	Dauerwiesen	"-"	
2.3.1.1	Halbnatürliche Wiesen	"-"	
2.3.1.1.1	Feuchtwiese kaum oder nicht geduengt	230	Grassland
2.3.1.1.2	Feuchtwiese kaum oder nicht geduengt mit Binsen	230	Grassland
2.3.1.1.3	Feuchtwiese mit einem krautigen Rosaceaengewaechs	230	Grassland
2.3.1.1.4	Ungedüngte Feuchtwiese mit bestimmtem Suessgrasgewaechs	230	Grassland
2.3.1.1.4.1	wenig Naehrstoffe	"-"	
2.3.1.1.4.2	mittelmaessig Naehrstoffe	"-"	
2.3.1.1.4.3	viel Naehrstoffe	"-"	
2.3.1.2	mesophile Weidewiese	"-"	
2.3.1.2.1	mesophile Mahdwiese	230	Grassland
2.3.1.2.2	untypische mesophile Mahdwiese	230	Grassland
2.3.1.2.3	Futterpflanzen in breiten Streifen und Klee	230	Grassland
2.3.1.2.4	Wiesen mit geringer Biodiversitaet	230	Grassland
2.3.1.2.5	aufgegebene mesophile Wiese mit Ruderalvegetation	230	Grassland
3.1	Wald	"-"	
3.1.1	Laubwald	"-"	
3.1.1.1	Saure Wälder	"-"	
3.1.1.1.1	artenarmer saurer Eichenwald	300	Forest
3.1.1.1.2	saurer Buchen und Eichen-Buchenwald	300	Forest
3.1.1.1.3	saurer Eichenwald	300	Forest
3.1.1.1.4	Buchen mit weissen Luzernen	300	Forest
3.1.1.1.5	Eichenwald mit Luzernen	300	Forest
3.1.1.1.6	Buchenwald mit hohen Graesern	300	Forest
3.1.1.1.7	besondere trockenheitsliebende Eichenart auf Schiefer und Sandstein	300	Forest
3.1.1.2	Wälder auf neutralen Bodenverhältnissen	"-"	
3.1.1.2.1	Buchenwald mit irgendeinem bestimmten Unterwuchs	300	Forest
3.1.1.2.2	besondere Eichenart auf feuchten Standorten	300	Forest

OBS 1989		LULUCF89	
Class code	Class name	Class code	Class name
3.1.1.2.3	besondere Eichenart mit irgendeinem Unterwuchs	300	Forest
3.1.1.3	Wälder auf basischen Bodenverhältnissen	"-"	
3.1.1.3.1	Buchenwald auf kalkhaltigem Substrat	300	Forest
3.1.1.3.2	trockenheitsliebende besondere Eichenart	300	Forest
3.1.1.4	Schuttwälder	"-"	
3.1.1.4.1	Ulmenwald in Aufschuettungen	300	Forest
3.1.1.5	Laubwald Anpflanzung	"-"	
3.1.1.5.1	Pappelwald in trockenen Gebieten	300	Forest
3.1.1.5.2	Pappelwald in feuchten Gebieten	300	Forest
3.1.1.5.3	Anpflanzungen Other Landr Laubbaeume	300	Forest
3.1.1.6	Schluchtwälder	"-"	
3.1.1.6.1	Schluchtwald auf kalkhaltigem Substrat	300	Forest
3.1.1.6.2	Schluchtwald auf silikatischem Substrat	300	Forest
3.1.1.7	Auewald auf mineralischem Boden	"-"	
3.1.1.7.1	Ulmen-Eschenwald in Flusssedimenten	300	Forest
3.1.1.7.2	Erlen-Eschenwaelder in Flusssedimenten	300	Forest
3.1.1.7.3	Erlenwaelder in nitratreichen Flusssedimenten	300	Forest
3.1.1.7.4	Erlen-Eschenwaelder in Quellgebieten und an Rinnsalen	300	Forest
3.1.1.8	Moorbruchwälder	"-"	
3.1.1.8.1	Erlenwaelder mit Seggen	300	Forest
3.1.1.8.2	sumpfiger Birkenwald	300	Forest
3.1.2	Nadelwald	"-"	
3.1.2.1	Fichte, Tannen	300	Forest
3.1.2.2	Kiefern, Lärchen	300	Forest
3.1.2.3	Other Land Nadelbaeume	300	Forest
3.1.3	Mischwald	"-"	
3.1.3.1	truppenweise Mischung (uebernommen aus 1999)	300	Forest
3.1.3.2	Mischung in Parzellen	300	Forest
3.2	Gehölze und Buschwerk	"-"	
3.2.1	Naturnahe Weideflächen	"-"	
3.2.1.1	Silikatrasen mit irgendeiner Viehfutterpflanze	230	Grassland
3.2.1.2	Silikatraseen mit irgendeiner aromatischen Krautpflanze	"-"	
3.2.1.3	Kalkrasen	230	Grassland
3.2.1.3.1	auf Mergel	230	Grassland
3.2.1.3.2	auf steinreichem Boden	230	Grassland
3.2.1.3.3	auf sandreichem Boden	230	Grassland
3.2.1.4	Pionierrasen in Steinbruechen	230	Grassland
3.2.1.5	Rasen auf giftigem (vielleicht schwermetallbelasteten) Gelaende	"-"	
3.2.2	Heide und Buschwerk	"-"	
3.2.2.1	trockene Heide mit irgendeinem speziellen Heidekrautgewaechs	230	Grassland

OBS 1989		LULUCF89	
Class code	**Class name**	**Class code**	**Class name**
3.2.2.2	Heidekrautgewaechse mit Strauch mit widerstaendigen, stacheligen Blaettern, der Beeren ausbildet	"-"	
3.2.2.3	degradierte Heide mit speziellem Heidekrautgewaechs	230	Grassland
3.2.2.3.1	mit Dominanz irgendeines Suessgrasgewaechses	"-"	
3.2.2.3.2	mit Dominanz einer flexible biegsamen Futterpflanze	"-"	
3.2.2.3.3	mit Dominanz eines bestimmten Farns	230	Grassland
3.2.2.4	trockene Heide mit Heidelbeere	"-"	
3.2.2.5	Torfheide mit Heidelbeere	"-"	
3.2.2.6	Heide mit Ginster	230	Grassland
3.2.3	Holzartiges Gebüsch	"-"	
3.2.4	Wald und Gehölz im Übergang	"-"	
3.2.4.1	Wälder auf trockenen Standorten	"-"	
3.2.4.1.1	dorniges Dickicht	230	Grassland
3.2.4.1.2	Dickicht auf kalkhaltigem Untergrund	230	Grassland
3.2.4.1.3	Buchsbaumdickicht	230	Grassland
3.2.4.1.4	Vegetation der Waldrodungsflaechen	300	Forest
3.2.4.1.5	verschiedene Pionierpflanzen nach Rodung	300	Forest
3.2.4.2	Wälder auf feuchten Standorten	"-"	
3.2.4.2.1	Weidenbaeume auf einem feuchten, torfigen oder sauren Boden	300	Forest
3.2.4.2.2	Weidenbaeume auf einem feuchten, mittelmaessig oder gut mit Naehrstoffen versorgten Boden	300	Forest
3.3	Offene Flächen mit wenig oder keiner Vegetation	"-"	
3.3.2	Offener Fels	"-"	
3.3.2.1	aufgegebener Steinbruch	340	Other Land
4.1	Feuchtflächen im Binnenland	"-"	
4.1.1	Sumpfgebiete	"-"	
4.1.1.1	Schilf	400	Wetland
4.1.1.1.1	mit Rohrglanzgras (aehnlich Schilfrohr)	400	Wetland
4.1.1.1.2	wasserliebendes Suessgras mit langen Blaettern	400	Wetland
4.1.1.1.3	wasserliebendes Kraut mit langem Stengel	400	Wetland
4.1.1.1.4	mit schmalblaettrigem Rohrkolben	400	Wetland
4.1.1.1.5	gemischt	400	Wetland
4.1.1.1.6	Schilf	400	Wetland
4.1.1.2	Feuchtgebietsvegetation	400	Wetland
4.1.1.3	saures Niedermoor	400	Wetland
4.1.1.4	basisches Niedermoor	"-"	
4.1.1.5	basisches Niedermoor (ruderal)	400	Wetland
5.1	Wasserflächen im Binnenland	"-"	
5.1.1	Wasserläufe und -strassen	"-"	
5.1.1.1	natuerliche Wasserlaeufe	500	Water
5.1.1.2	kuenstliche Wasserlaeufe	500	Water
5.1.2	Wasserflächen (Seen, Teiche etc.)	"-"	

OBS 1989		LULUCF89	
Class code	Class name	Class code	Class name
5.1.2.1	natuerliche Wasserflaeche	500	Water
5.1.2.1.1	mehr oder weniger salzhaltig	"-"	
5.1.2.1.2	wenig Naehrstoffe	500	Water
5.1.2.1.3	mittelmaessig Naehrstoffe	500	Water
5.1.2.1.4	viel Naehrstoffe	500	Water
5.1.2.2	kuenstliche Wasserflaeche	500	Water
5.1.2.2.1	mehr oder weniger salzhaltig	500	Water
5.1.2.2.2	wenig Naehrstoffe	500	Water
5.1.2.2.3	mittelmaessig Naehrstoffe	500	Water
5.1.2.2.4	viel Naehrstoffe	500	Water
5.1.2.3	Altarm	500	Water
5.1.2.4	Teich	"-"	
5.1.2.5	Becken, Reservoir	500	Water
5.1.2.5.1	wenig Naehrstoffe	"-"	
5.1.2.5.2	mittelmaessig Naehrstoffe	500	Water
5.1.2.5.3	viel Naehrstoffe	500	Water
5.1.2.5.4	ohne biologischen Wert	500	Water

Table 3-3 OBS 1999 (OBS 1999) nomenclature and its reclassification to LULUCF.

OBS 1999		LULUCF99	
Class code	Class name	Class code	Class name
1.1.1	Stark verdichtete, städtisch geprägte Gebiete (City)	100	Settlements
1.1.2.1.1	Sonstige Siedlung mit bedeutender Vegetation	100	Settlements
1.1.2.1.2	Sonstige Siedlung ohne bedeutende Vegetation	100	Settlements
1.1.2.2	Siedlungsbänder entlang von Straßen	100	Settlements
1.1.2.3.1	Öffentliche Plätze	100	Settlements
1.1.2.3.2	Siedlungsbrachen ohne/geringe Vegetation, Siedlungs-Ödland	100	Settlements
1.1.2.4	Einzelhäuser, Höfe etc. außerhalb geschlossener Bebauung	100	Settlements
1.2.1.1.1	Großindustrielle Anlagen, Schwerindustrie	100	Settlements
1.2.1.1.2	Gemischte Industrie und Gewerbegebiete, Militär, großformatige Dienstleistungsgebäude	100	Settlements
1.2.1.2	Öffentliche und soziokulturelle Einrichtungen und Bebauungen	100	Settlements
1.2.1.3.1	Sondergebiete, Flächen der Stromversorgung	100	Settlements
1.2.1.3.2	Sondergebiete, Flächen der Wasserversorgung	100	Settlements
1.2.1.3.3	Sondergebiete, Flächen der Gasversorgung	100	Settlements
1.2.1.4	Landwirtschaftliche und gartenbauliche Infrastruktur, (Stallanlagen, Gewächshäuser)	100	Settlements
1.2.2.1.1	bedeutende Straßen (>20m)	100	Settlements
1.2.2.1.2	Parkplatz	100	Settlements
1.2.2.2	Bahnanlage und deren Nebenbetriebe	100	Settlements
1.2.3	Hafengebiete	100	Settlements
1.2.4.1	Flughafen, Terminal und Hangargebäude,	100	Settlements
1.2.4.2	Flughafen, Landebahn und Fahrbahnen	100	Settlements
1.3.1	Abbaufläche, Tagebau	100	Settlements

OBS 1999		LULUCF99	
Class code	Class name	Class code	Class name
1.3.2.1	Aufschüttung und Deponien	230	Grassland
1.3.2.2	Halden	100	Settlements
1.3.2.3	Brachen industrieller Gebiete	100	Settlements
1.3.2.4	Baustellen	100	Settlements
1.4.1.1	Friedhöfe	100	Settlements
1.4.1.2	Grünanlagen, Parks	100	Settlements
1.4.2.1	Sport-, Spiel-, Camping-, Golfplätze	100	Settlements
1.4.2.2	Kleingartenanlagen	100	Settlements
2.1.1.1	Ackerflächen, einjährige Kulturen	210	Cropland annual
2.1.1.2	Baumschule, Gartenbau, Weihnachtsbaumkulturen	220	Cropland permanent
2.2.1.1	Weinbauflächen im Terrassenanbau	220	Cropland permanent
2.2.1.2	sonstige Weinbauflächen	220	Cropland permanent
2.2.2.1	Obstanbau, Streuobstwiesen, Hochstammkulturen	220	Cropland permanent
2.2.2.2	Obstanbau, Niederstammkulturen	220	Cropland permanent
2.3.1.1	Feuchtgrünland	230	Grassland
2.3.1.2	Mesophiles Grünland	230	Grassland
3.1.1.1	Laubwald mit dominierender Eiche	300	Forest
3.1.1.2	Laubwald mit dominierender Buche	300	Forest
3.1.1.3	Laubwald aus sonstigen Laubbaumarten	300	Forest
3.1.1.4	Laubwald, gemischt, Eiche, Buche	300	Forest
3.1.1.5	Eichen-Niederwald	300	Forest
3.1.1.6.1	Laubwald, Pappel-Monokulturen	300	Forest
3.1.1.6.2	Schluchtwald auf silikatischem Substrat	"-"	
3.1.2.1	Nadelwälder aus Fichten (Douglasie / Tanne)	300	Forest
3.1.2.2	Nadelwälder aus Kiefern u/o Lärchen	300	Forest
3.1.2.3	Nadelmischwälder aus 3.1.2.1 und 3.1.2.2 gemischt	300	Forest
3.1.3.1	Mischwald (Laub/Nadel), einzeln oder truppweise Mischung	300	Forest
3.1.3.2	Mischwald (Laub/Nadel), fließende Durchmischung	300	Forest
3.1.3.3	Forstliche Pflanzung (Aufforstungen, Naturverjüngung, Dickungen; Baumart nicht erkennbar)	300	Forest
3.1.3.4	Sonstige Forstflächen (Schlagflur, Windbruch)	300	Forest
3.2.1.1	Silicattrockenrasen, Sandtrockenrasen	230	Grassland
3.2.1.2	Kalkmagerrasen	230	Grassland
3.2.1.3	Fels- und Schotterrasen, Pionierfluren	230	Grassland
3.2.2	Heiden, Rohbodenstandorte	230	Grassland
3.2.3.1	Ruderalstandorte außerhalb besiedelter Bereiche, Brachen und Staudenfluren mittlerer bis trockener Standorte	230	Grassland
3.2.3.2	Ruderalstandorte außerhalb besiedelter Bereiche, Brachen und Staudenfluren feuchter Standorte	230	Grassland
3.2.4.1	Buschwerk, Vorwälder trockener Standorte	230	Grassland
3.2.4.2	Buschwerk, Vorwälder mittlerer Standorte	230	Grassland
3.2.4.3	Buschwerk, Vorwälder feuchter Standorte	230	Grassland
3.2.4.4	Blockschutt- und Geröllwälder / -vorwälder	230	Grassland
3.2.4.5	Gehölzpflanzungen (junge Strauch und Böschungspflanzungen)	230	Grassland
3.3.2	Offene Felsflächen	340	Other Land
3.3.2.1	Offene Blockschutt- und Schotterflächen	340	Other Land
4.1.1.1	Röhrichte, Landröhrichte	400	Wetland

OBS 1999		LULUCF99	
Class code	**Class name**	**Class code**	**Class name**
4.1.1.2	Großseggensümpfe, Großseggenrieder	400	Wetland
4.1.1.3	Übergangsmoore, Kleinseggenrieder	400	Wetland
5.1.1.1.1	Naturnahe Fließgewässerabschnitte	500	Water
5.1.1.1.2	Naturferne Fließgewässerabschnitte	500	Water
5.1.1.2	Fließgewässer künstlicher Entstehung (Kanal)	500	Water
5.1.2.1	Stillgewässer, anthropogen, naturnah	500	Water
5.1.2.2	Stillgewässer künstlicher Entstehung	500	Water
5.1.2.3	Altarme, Altwasser	500	Water
5.1.2.4	"Mardelle"	500	Water
5.1.2.5.1	Becken, Reservoir (Ufer u/o Grund aus künstlichem Material) von biol. Interesse	500	Water
5.1.2.5.2	Becken, Reservoir (Ufer u/o Grund aus künstlichem Material) ohne biol. Wert	500	Water

3.2.2 LULUCF 2012

Table 3-4 LU 2012 (LU12) nomenclature and its reclassification to LULUCF.

LU12		LULUCF12	
Class code	**Class name**	**Class code**	**Class name**
100	Settlements	100	Settlements
210	Cropland	210	Cropland annual
220	Permanent Crops	220	Cropland permanent
230	Grassland	230	Grassland
310	Deciduous Forest	300	Forest
320	Coniferous Forest	300	Forest
330	Mixed Forest	300	Forest
331	Forest without trees	300	Forest
340	Other land	340	Other land
400	Wetland	400	Wetland
500	Water	500	Water

3.2.3 LIS-L 2007, 2015 and LU 2018

Table 3-5 LIS-L 2007 / 2015 / 2018 nomenclature and its reclassification to LULUCF.

LIS-L07 / LIS-L15 / LIS-L18		LULUCF07/15/18	
Class code	**Class name**	**Class code**	**Class name**
111	Settlement (S) -- Settlement & Estate (1) -- Residential (1)	100	Settlements
112	Settlement (S) -- Settlement & Estate (1) -- Agriculture facilities (2)	100	Settlements
113	Settlement (S) -- Settlement & Estate (1) -- Industry & Commerce (3)	100	Settlements
114	Settlement (S) -- Settlement & Estate (1) -- Unused urban areas and brownfields (4)	100	Settlements

LIS-L07 / LIS-L15 / LIS-L18		LULUCF07/15/18	
Class code	Class name	Class code	Class name
115	Settlement (S) -- Settlement & Estate (1) -- Social, Military, Cultural and Other (5)	100	Settlements
131	Settlement (S) -- Public facilities (3) -- Cemetery (1)	100	Settlements
132	Settlement (S) -- Public facilities (3) -- Square (2)	100	Settlements
133	Settlement (S) -- Public facilities (3) -- Park (3)	100	Settlements
134	Settlement (S) -- Public facilities (3) -- other (4)	100	Settlements
141	Settlement (S) -- Sports and leisure (4) -- Golf course (1)	100	Settlements
142	Settlement (S) -- Sports and leisure (4) -- Camp ground (2)	100	Settlements
143	Settlement (S) -- Sports and leisure (4) -- Other sports facilities (3)	100	Settlements
144	Settlement (S) -- Sports and leisure (4) -- Other recreation facilities (4)	100	Settlements
151	Settlement (S) -- Technical infrastructure (5) -- Utility (production, disposal facilities) (1)	100	Settlements
152	Settlement (S) -- Technical infrastructure (5) -- Mining / extraction (2)	100	Settlements
160	Settlement (S) --- Construction (6)	100	Settlements
210	Agriculture (A) -- Arable land (1)	210	Cropland annual
220	Agriculture (A) -- Grassland (2)	230	Grassland
231	Agriculture (A) -- Special cultures (3) -- Wine (1)	220	Cropland permanent
232	Agriculture (A) -- Special cultures (3) -- Fruit trees (2)	220	Cropland permanent
233	Agriculture (A) -- Special cultures (3) -- Orchard (3)	220	Cropland permanent
234	Agriculture (A) -- Special cultures (3) -- Other (4)	220	Cropland permanent
311	Forest (F) -- Forest block (1) -- Coniferous (1)	300	Forest
312	Forest (F) -- Forest block (1) -- Mixed (2)	300	Forest
313	Forest (F) -- Forest block (1) -- Deciduous (3)	300	Forest
314	Forest (F) -- Forest block (1) -- Young forest(4)	300	Forest
321	Forest (F) -- Clearing (2) -- Burnt area (1)	300	Forest
322	Forest (F) -- Clearing (2) -- Storm damage (2)	300	Forest
323	Forest (F) -- Clearing (2) -- Clear cuts (3)	300	Forest
410	Natural surfaces (N) -- Gravel (1)	340	Other Land
420	Natural surfaces (N) -- Rocks (2)	340	Other Land
430	Natural surfaces (N) -- Grassland (3)	230	Grassland
440	Natural surfaces (N) -- Heathland (4)	230	Grassland
450	Natural surfaces (N) -- Bushes (5)	300	Forest
460	Natural surfaces (N) -- Wetland (6)	400	Wetland
511	Water (W) -- Running water (1) -- Natural (1)	500	Water
512	Water (W) -- Running water (1) -- Artificial (2)	500	Water
521	Water (W) -- Standing water (2) -- Natural (1)	500	Water
522	Water (W) -- Standing water (2) -- Artificial (2)	500	Water
611	Transport (T) -- Roads (1) -- Rural roads (1)	100	Settlements
612	Transport (T) -- Roads (1) -- Main roads (2)	100	Settlements
620	Transport (T) -- Railways (2)	100	Settlements

LIS-L07 / LIS-L15 / LIS-L18		LULUCF07/15/18	
Class code	**Class name**	**Class code**	**Class name**
631	Transport (T) -- Air traffic (3) -- commercial (1)	100	Settlements
632	Transport (T) -- Air traffic (3) -- sport & leisure (2)	100	Settlements
640	Transport (T) -- Water traffic (4)	100	Settlements
650	Transport (T) -- Parking (5)	100	Settlements

4 THEMATIC AND GEOMETRIC CONSISTENCY OF EXISTING LU DATASETS FOR LUXEMBOURG

The most important prerequisite for the calculation of reliable land use change statistics is the availability of a consistent land use time series database. When comparing two map products for different time periods, usually three types of differences can occur:

- real changes, i.e. an evolution of the situation in the landscape over time (e.g. the construction of a new road);
- technical changes, due to the application of different specifications like different scales, different minimum mapping units, different nomenclatures or slightly different delineation of the same object;
- thematic and geometric errors.

The "difficulties" associated with a consistent assessment of land use types and their changes is described in detail in the feasibility report. Here just a short summary of the main issues found:

- Use of different nomenclatures (OBS 1989, OBS 1999 and OBS 2007 = mix of land cover and land use, LULUCF2012 = LULUCF land use categories, LIS-L2015 & LU2018/LC2018 = separate mapping of land use and land cover features in different dedicated layers).
- OBS 1989 is based on field mapping and transfer of the boundaries to the topographic map of 1989 as geometric reference. Compared to the orthophotos of 2001, the topographic map shows many geometric differences. Therefore, objects whose geometry matches the topographic map of 1989 do not match the shape of the same object in the orthophoto of 2001.
- The settlement area between 1989 and 1999 shows a very steep increase. Reasons for this are the fact the OBS 1989 only mapped a small part of the existing road network which was present in OBS 1999 and the rather low quality in the delineation of settlement areas with significant omission and commission errors. This would lead to an underestimation of the Settlement area in 1989 and an overestimation of the potential change.
- In the data set for 2012, the road network was partially removed and replaced by adjacent classes. This introduced an important number of topological errors (gaps in the database, sliver polygons of the road network in some places).
- Different interpretation of natural surfaces, especially in OBS 1989 vs. other datasets.
- Different handling of complex landscape objects (e.g. golf courses, airport) based on their land cover, respectively, their land use.
- Interpretation and handling of clear cuts, i.e. mapped as grassland (i.e. LULUCF category GL), respectively as "clearing" (i.e. LULUCF category FL) in different products.
- The continuously improving quality / geometric resolution of the image quality as well as the availability of LIDAR data (for 2018) has led to a better recognition of features, in particular the inclusion of landscape elements (such as hedgerows, tree lines) in the most recent data set, while these elements, though already existing, were generalised as part of the surrounding land and not mapped as individual objects in the past.
- Grassland also shows a very heterogenous pattern over the period from 1989 to 2018, with some stabilisation after 2012. This is potentially due to the misclassification of

cropland and grassland in earlier years which was overcome by the use of FLIK data as ancillary information for the production of land use databases in more recent years.

- Finally, also forest land reveals a similar issue. Not only the area of the different leaf types shows big differences in the different spatial databases, but also the total area of forest (see Table 4-1) is quite different. This occurs not only within the mapping products presented in Section 2.1, i.e. OBS, LIS-L, Phyto-socio[11], LULUCF 2012, but also comparing the statistical figures provided by the National Forest Inventory (NFI) in 2000 and 2010.

Table 4-1: Forest area in Luxembourg based on several sources

	OBS89	OBS99	NFI 2000	LU2007	NFI 2010	LULUCF 2012	LU2015	Phyto 2014	LU2018
Total Forest (ha)	92136	91132	92350	92628	92150	95646	92498	95010	92435

Table 4-2 provides the different definitions of forest applied in the different products. While FAO and NFI are based on strict criteria, the mapping products seem to be predominately based on an area criterion and less on tree density.

Table 4-2: Forest definitions

FAO[12]	Forest: Land spanning more than 0.5 hectares (5,000m^2) with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. Other wooded land: Land not defined as “Forest”, spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds; or with a combined cover of shrubs, bushes and trees above 10 percent.
National Forest Inventory (NFI)[13]	The NFI includes the following typologies: Forest (fr. forêt): Land covered by more than 10% with trees and a minimum surface of 5000m^2 (0.5 ha). Minimum height at maturity level is 5m. Included are as well natural regenerations, any forest plantations, tree nurseries, forest roads, clear cuts, waste land with a surface between 1,000 and 5,000m^2. Grove (fr. bosquet): Land covered trees by more than 10% and a minimum surface between 500 and 5,000m^2. Minimum height at maturity level is 5m. Other wooded land:

[11] Cartographie phytosociologique des végétations forestières
[12] http://www.fao.org/3/ap862e/ap862e00.pdf
[13] https://environnement.public.lu/fr/publications/forets/IFL2_fr.html

	Areas without forest cover that are enclosed or bordered on one side by a forest environment and have an individual area greater than 5000m² (e.g. clear cut, wasteland, pond).
OBS	MMU for forest = 1,000m² Tree height 6m
LIS-L	MMU for forest = 500m² Actual tree height (LIDAR) = 3m
Copernicus HRL Forest	The HRL Forest is a land cover data set and does not considered the forestry use of a given area. The HRL includes several sub-products: Tree Cover Density (TCD) – a continuous level of tree cover density in a range from 0-100% Dominant leaf type (DLT) – broadleaved or coniferous majority Forest Type (FTY) – approximation of the FAO definition, composed of DLT with a MMU of 0.5 ha and 10% TCD. The 2018 10m FTY product has agricultural/urban trees removed. In the past this was done only for the aggregated 100m product.
Conclusion: Definition used for LULUCF in Luxembourg	1989-2012: forest definition according to OBS (1000m² & tree height 6m at maturity) 2012-today: 500m² and 3m (actual height)

The following improvements were done to increase the consistency of the different years and layers (see feasibility report for details):

1. Update the geometric and thematic accuracy of OBS 1989 based on OBS 1999 and ancillary information, e.g. including missing features (e.g. road network and water).
2. Re-introduction of the road network into the data from 2012.
3. Convert all databases to LULUCF categories.
4. Consider the LU2018 database as the main geometric and thematic reference for the full LU time series.
5. Update the LU classification of earlier data sets based on the better geometry and thematic content of LU2018.
6. Make use of dedicated change layers[14] between 2 reference years to incorporate changes and avoid major technical discrepancies between datasets, otherwise keep the content of LU2018.

[14] The national land use data sets for Luxembourg were generated mostly based on previous land use versions with the support of ancillary data. For example, OBS 2007 was based on the OBS 1999 dataset. In case of detecting a wrong delineation of the polygon border of 1999, such error was corrected in the new database of 2007, but not necessarily in 1999. This caused the data sets to have different geometries, making it difficult to compare and extract correct land use changes.

7. Create a grid database to overcome minor geometric inaccuracies.
8. Definition of a set of rules to correct for remaining inconsistencies (see section 5.4).
9. Development of an application to identify permanent land use changes according to the understanding of the LULUCF regulation (i.e. over a 20-year period) and the calculation of corresponding land use changes as basis for carbon accounting (see sections 7.1 and 7.1.1).

The creation of change layers is a simple method to ensure that only differences between two dates which represent real land use changes are ingested in the further analysis. In a change layer all technical changes and errors should already have been eliminated to the widest possible extent.

5 SETTING UP OF A GRID DATABASE

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.

5.1 Grid resolution

A first decision to be taken when implementing a point grid sample, is to choose the best grid resolution for the task, i.e. the distance between the sampling points.

Since the grid with a 50m spatial resolution already captures around 95% of the at national level (see feasibility report), 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.

5.2 Alignment of a gridded database

A second important issue for the development of a point database is the alignment of the grid. The *Administration du Cadastre et de la Topographie* (ACT) and the *Administration de l'environnement* (AEV) are currently using two different, not compatible grid systems. While the ACT uses a regularly spaced grid with 1 km spacing in LUREF projection, the AEV uses the EMEP grid which is based on grid cells of 0.1° spatial resolution defined in geographical coordinates (Latitude / Longitude). Being based on geographical coordinates, the EMEP grid does not allow for area calculations as the size of a grid cell changes with is position on the globe (Figure 5-1).

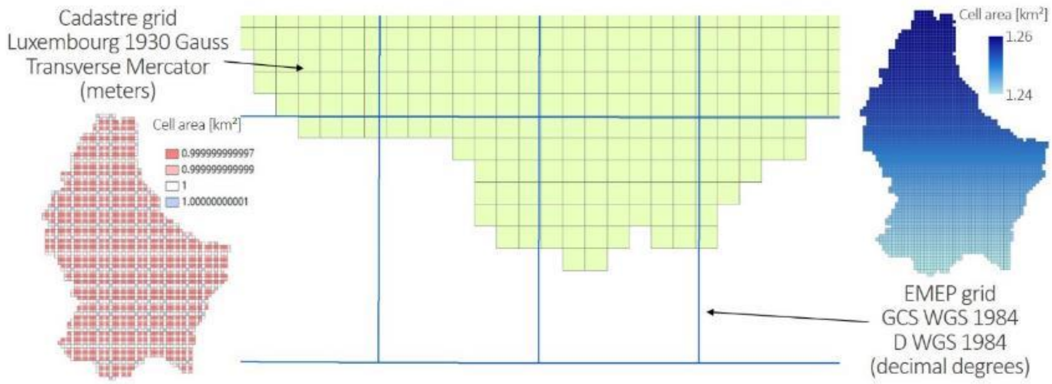


Figure 5-1 Visual comparison of EMEP grid with ACT grid and surface distortion when applying both grids.

Therefore, for the calculation of land use change statistics the metric grid of the ACT will be used. Upon request the final results can always be reprojected to the EMEP grid.

5.3 Populating the grid 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.

In total, the grid database for the full Luxembourg contains 1,034,395 points, corresponding to a surface of 258,598.75 ha. To match the correct total area of Luxembourg grid points falling too close to the border were not considered in the further analysis and removed from the final database.

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, as shown in the column on the left in Figure 5-2.

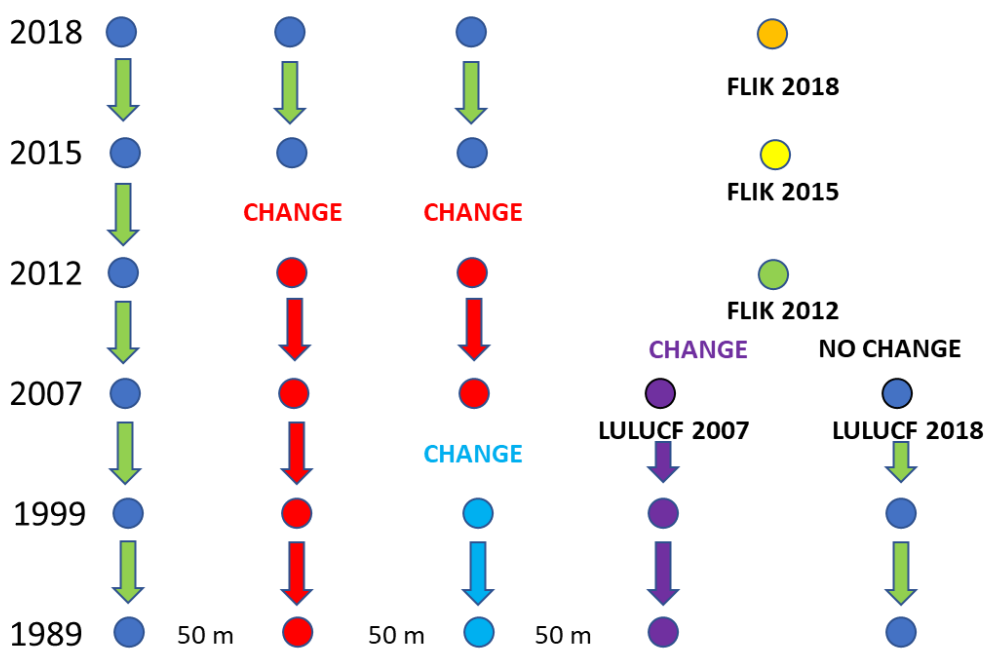


Figure 5-2: Principle of populating the grid database

In case a change was observed from the change database, the LULUCF category of the LULUCF layers for the subsequent years was assigned to the sample point in the grid database, as shown in the two middle columns in Figure 5-2.

Figure 5-2 also shows the exception to those rules for the agriculture related points (classified as 210, 220, 230, Table 3-1). For these cases, the national Land Parcel Information System (LPIS / FLIK) data provided by ASTA for the years of 2012, 2015 and 2018 always were considered as the "truth", i.e. in case of differences between FLIK and the remaining LULUCF maps for agricultural points, FLIK was considered to be correct. On the other hand, the LULUCF classification of non-agricultural classes was retained whenever there was a difference with the FLIK information. The reason was that by visual analysis it was verified that the LU classification is updated closer to the date where the change is occurring, as compared to the FLIK database. For example, some changes in land use, such as the creation of farmer houses, are usually not considered in FLIK in the same year when they are occurring, but usually one or two years later.

5.4 Thematic correction of LULUCF codes in the grid database

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 which should be corrected before defining any relevant LULUCF related changes, i.e. across the 20-year period.

These inconsistencies are mostly related to the fact that one point (not at the start or end) in an otherwise homogeneous series showed a different land use category, i.e. a point classified as settlement inside a series of grassland points. Such points are often “border points” and the inconsistency is triggered by minor geometric shifts between two objects, e.g. a road (mapped as settlement) and the adjacent meadow (mapped as grassland). In such a case the “settlement” point was corrected to “grassland”.

Three types of time-series pattern have been identified:

a) Inconsistences as described above: for these cases rule sets have been defined to correct the specific situation (see below).

b) Do nothing – no adaptation of the combination needed (e.g. no land use change or real changes).

c) Unsolved cases – times-series of land use categories that have numerous transitions leading to random patterns that cannot be corrected based on a standard rule set.

Table 5-1: Example of time-series patterns to keep, to correct or unsolved.

LULUCF89	LULUCF99	LULUCF07	LULUCF12	LULUCF15	LULUCF18	Pattern
230	230	100	100	100	100	Do nothing (real change)
100	100	100	300	100	100	Correction needed
300	300	210	300	300	300	Correction needed
210	230	230	220	220	300	Unsolved
500	210	230	100	100	300	Unsolved

Examples of proposed corrections for time series patterns included in category a) include the following cases (Table 5-2; for an exhaustive list of currently proposed corrections please check ANNEX I):

- If a point is mapped as wetland in at least three points in time and the remaining observations are grassland, then reclassify all time stamps to wetlands. In this case the grassland is more a “land cover” information, while wetland is a habitat information which has been established in 1989 during an in-situ visit.

- If 1989 shows water (500), but the rest of the time series is consistent with a different category, then reclassify 1989 to the rest of the time series. This assumes that accuracy of mapping the water class in 1989 was less precise than in later years.

Table 5-2: Example of proposed corrections for time series patterns included in category a.

LULUCF89	LULUCF99	LULUCF07	LULUCF12	LULUCF15	LULUCF18	Pattern
400	400	**230**	400	**230**	**230**	Original 1
400	400	400	400	400	400	Corrected 1
500	210	210	210	210	210	Original 2
210	210	210	210	210	210	Corrected 2

The resulting grid (version 5) from this step was considered the version to be used for the assessment of LULUCF relevant land use changes.

5.5 Soil carbon information

In order to properly estimate the carbon balance, two carbon pools are important:

- Above ground carbon: represented by the land use information;
- Below ground carbon: represented by soil carbon.

Information on soil carbon is an important variable to differentiate carbon storage in different regions of Luxembourg. Based on the underlying geology, soils have a different natural carbon storage capacity, therefore the total carbon balance for the same land use but on different soils is different and can be taken into account in the proposed geospatial approach.

5.6 Final grid database

The final grid database contains for each grid point the following information:

- The unique identifier (ID) of each point.
- The final LULUCF category (version 6) for each point and each reference year of the input data.
- Information on the soil association type to be used for each grid point to estimate the related soil carbon information.

A second “working version” or “raw database” is provided for expert usage and tracing of the individual processing steps. This working version contains the full “history” of the different steps:

- All grid points falling inside the territory of Luxembourg, also those lying close to the border.
- The original land use / cover information of the original source data sets (i.e. OBS, LIS-L) for the respective years.
- The initial translation of the original national land use classes into LULUCF categories, based on the translation tables provided in chapter 3.

- The successive improvement of individual points using ancillary information (i.e. FLIK) and the rule set described in section 5.4.
- The soil association information.
- The final LULUCF category for each point and each reference year of the input data.

The different processing steps are stored as “versions” in the database. The draft final version used for the uncertainty assessment is v5, the fully final database is version 6 (or v6).

The meta-information on the attribute structure and the meaning of each attribute in the final grid database and in the working version are providing in Annex II.

6 UNCERTAINTY ASSESSMENT

A thematic validation of several LU changes was carried out to determine the uncertainty associated with particular change types and the years where they have occurred. The selection of sampling points was based on the corrected grid (as explained in section 5.4) and analysis of uncertainty for the changes before (i.e. the initial translation of the original land use data to LULUCF categories) and after (i.e. the final LULUCF code) correction was performed. It is expected, for both cases, that datasets for more recent years would show lower uncertainty due to the improved quality of the underlying input data.

For the following change types an uncertainty assessment was carried out:

- 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).

6.1 Sampling strategy

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.

Table 6-1: Reference data used for the respective observation years

1989	Grayscale monochrome aerial photographs from 1987, not orthorectified, only roughly georeferenced Topographic map of 1989
1999	Orthophotos from 2001 Topographic map of 2000
2007	Orthophotos from 2007
2012	Orthophotos from 2013
2015	Orthophotos from 2016
2018	Orthophotos from 2018

6.2 Results of the uncertainty assessment

The uncertainty assessment was done for the LULUCF category assigned to each sample point BEFORE (columns in blue in Table 6-3) and AFTER (columns in green in Table 6-3) the improvement / processing in the Grid. The improvement / processing includes the steps as described in chapter 5.3 and 5.4, i.e. the inclusion of FLIK information or the update of the earlier class code by a more recent code in case that no change was indicated (i.e. point grid version 5).

The following information is provided in Table 6-3:

- The transition period (e.g. 1989 – 1999) and the change type (e.g. Forest Land remaining Forest Land: FL-FL).
- The total number of points in the complete grid database representing this particular transition.
- The actual number of points in the sample. In case where the total number of points representing a specific transition is less than 400, all grid points were included in the sample.
- The share of the sample size compared to the total number of points representing this particular transition (e.g. for the transition FL-L between 1989 and 1999 the sample size (400) represents 14.65% of the total number of points (2,728)).
- The number of correct sample points <u>before</u> the improvement (blue) based on a visual comparison of the sample point and the reference data (see Table 6-1).
- The number of correct sample points <u>after</u> the improvement.
- The respective percentage of correct points and the lower and upper boundary of the associated confidence interval.
- The change of the uncertainty due to the processing (BEFORE = 100%).

The following results can be concluded from Table 6-3:

- In each transition period, the total number of points that have undergone a land use change is rather small (compared to the unchanged forest surface), ranging from 5% between 1989 and 1999 and less than 1% between 2007 and 2012 as well as between 2015 and 2018.
- In most of the cases (16 out of 20) the processing has resulted in a decrease of the uncertainty after the processing. In three cases the processing led to an increase of the uncertainty (highlighted in yellow). In one case there was no difference.
- The “overall accuracy” increased from 70.8% to 75.4% due to the processing.
- Due to the better input data, the number of errors is generally lower for the more recent dates. Considering this trend, the overall uncertainty should reduce further in the coming years as input data will remain on a high-quality level.
- The “accuracy” of the unchanged points is higher than for the points having undergone a change.
- In four cases the percentage of correct points is less than 50% (after processing). In three of these cases the change from Land to Forest Land (“afforestation”) is concerned.
- For these erroneous forest related changes, it should be noted that the identified errors are not “completely wrong”, in many cases a real change (afforestation, deforestation) did happen, but in a different time stamp (earlier or later).
- The transitions to settlement are generally of lower uncertainty than those associated with forest land involved. It is also assumed that the uncertainty of transitions related to arable land is also lower as independently reported FLIK data are used as basis for the changes since 2012, but this has not been assessed in detail.

Table 6-2 shows the information from Table 6-3 converted to area figures. The total number of change points can be converted to an area (hectare) figure by dividing the number of points by 4 (each point represents 0.25 ha). This is shown in column 3 (“Area in ha”) in Table 6-2.

The other columns in the table show:

- “Lower limit” – the actual surface covered by the given class based on the lower limit of the confidence interval;
- “Upper limit” – the actual surface covered by the given class based on the upper limit of the confidence interval.

Due to the multiplication of the area mapped as a specific class (“Area in ha”) with the percentage values of the lower and upper limit of the confidence interval, the resulting real surface can be lower than the initial value.

This means that from the 92,357 ha identified as stable forest land between 1989 and 1999 in the database, the real surface area is between 88,337 ha and 91,297 ha based on the accuracy assessment and the lower and upper limit of 95% confidence interval associated with the accuracy of 97.3%. In case where the class accuracy is 100% (as for FL remaining in 1999-2007), the lower and upper limits are the same and correspond to the original area.

The same is valid for the other transitions: the real deforestation value between 1989 and 1999 is between 287 ha and 354 ha, based on the accuracy of the transition (“total correct”) and the associated confidence interval.

Table 6-2: Uncertainty assessment and related area values

Time period	Transition	Area in ha	Lower limit	Upper limit
1989 - 1999	FL Remaining	92,357	88,337.03	91,297.34
	Deforestation	682	287.18	353.90
	Afforestation	805	487.85	563.00
	Urbanisation	3,323	2,342.46	2,625.42
1999 – 2007	FL Remaining	92,702	92,702.00	92,702.00
	Deforestation	460	255.23	299.37
	Afforestation	617	252.15	312.40
	Urbanisation	2,321	1,891.43	2,053.85
2007 – 2012	FL Remaining	93,235	93,234.75	93,234.75
	Deforestation	84	56.45	64.55
	Afforestation	63	13.15	19.96
	Urbanisation	479	428.88	453.95
2012 – 2015	FL Remaining	93,098	89,958.98	92,513.59
	Deforestation	200	147.51	163.71
	Afforestation	110	46.49	57.23
	Urbanisation	1,011	545.19	642.74
2015 – 2018	FL Remaining	93,143	91,657.13	93,232.22
	Deforestation	65	49.80	55.89
	Afforestation	3	-	-
	Urbanisation	662	581.53	619.09

By analysing the sample points and the change matrices the following facts have been observed:

- Most of the errors are associated with the first year of the transition. This is often due to passing the LULUCF code from the more recent observation to earlier points in time (see Figure 5-2) in case where the change layer does not show a change where in fact it has happened (omission) or where it indicates a change that actually did not happen (commission).
- The inconsistent handling of areas with felled trees as clear cuts or grassland leading to false changes in the L-FL and FL-L transitions.
- The inconsistent mapping of landscape features which represent a transitional stage between grassland, bushes and forest in the input datasets. The same feature can be mapped once under an original class translated into a LULUCF forest or a grassland category.
- The remaining overall geometric uncertainty in the delineation of objects in different years leading to errors in case the sample point is located close to the border of such objects.

After performing the uncertainty analysis, all grid points which had been identified as erroneous were updated and changed to the correct LULUCF category identified during the uncertainty assessment. This was done to improve the resulting carbon accounting. The original uncertainty assessment was not changed.

The grid and the area figures resulting from this last step is referred to as LULUCF version 6.

In 2020, the EEA Eionet in-situ expert group analysed the replies of 26 countries to a questionnaire about the LULUCF reporting process in the countries. Luxembourg was one of the respondents. The countries reported the following challenges:

- Many of the countries are moving towards geospatial data-based approaches, but available data remain a challenge. Most frequently used data is forest information (maps and statistics), still followed by Corine Land Cover (for data prior to 2000 or due to an overall lack of spatial data in some countries).
- The time series (especially of spatial data) rarely go back to the 1990s.
- The time series often has significant time gaps, i.e. the number of years between two inventories is rather long (sometimes 10 years or more); i.e. leading to only a few “stepping stones” to be available for the creation of the reporting time series.
- Data consistency and the identification of “real changes” was mentioned by most countries. Consistency of national data sources is a critical issue as often more than one source has to be used to analyse the changes of specific LULUCF categories and often the definitions of those categories in the different sources do not match. This, by consequence, leads to and partly triggers the second issue: the identification of real changes and their differentiation from technical differences due to different scales or nomenclatures of the data sets.
- Even though data consistency and the quality of change mapping is important, only 3 out of 26 countries are doing an uncertainty assessment of their data and results.

In its 2019 report "EU LULUCF Regulation explained"[15] the Öko-Institut states that, based on estimates provides in the National Inventory Reports (NIR), the uncertainty of emission levels of CO_2 was estimated to be about 32%. Forest inventories were said to provide rather accurate estimates of CO_2 emissions and removals (20%), while cropland is more uncertain (48%) and grassland even amounts to 374%.

The report also states that spatially explicit land use conversion data ("approach 3") are assumed to provide more accurate numbers. Nonetheless, while forest data is available in lost countries (similar as stated in the in-situ report), spatial data for cropland or grassland is generally at lack.

[15] https://www.oeko.de/fileadmin/oekodoc/Analysis-of-LULUCF-Regulation.pdf

Table 6-3: Uncertainty assessment (based on grid version 5)

File	Total number of change points in the GRID	Sample size	Proportion (Sample/Total) in %	No. of correct samples BEFORE	No. of correct samples AFTER	Total correct	CI_lower	CI_higher	Total correct	CI_lower	CI_higher	Improvement (before = 100%)
QA 89 - 99 FL-FL	369,428	400	0.11	378	389	94.5%	92.3%	96.7%	97.3%	95.6%	98.9%	102.9%
QA 89 - 99 FL-L	2,728	400	14.65	167	188	41.8%	36.9%	46.6%	47.0%	42.1%	51.9%	112.6%
QA 89 - 99 L-FL	3,221	400	12.32	86	261	21.5%	17.5%	25.5%	65.3%	60.6%	69.9%	303.5%
QA 89 - 99 L-SL	13,292	400	3.00	297	299	74.3%	70.0%	78.5%	74.8%	70.5%	79.0%	100.7%
QA 99 - 07 FL-FL	370,808	400	0.11	378	400	94.5%	92.3%	96.7%	100.0%	100.0%	100.0%	105.8%
QA 99 - 07 FL-L	1,841	400	21.65	213	241	53.3%	48.4%	58.1%	60.3%	55.5%	65.0%	113.1%
QA 99 - 07 L-FL	2,468	400	16.09	256	183	64.0%	59.3%	68.7%	45.8%	40.9%	50.6%	71.5%
QA 99 - 07 L-SL	9,283	400	4.30	282	340	70.5%	66.0%	75.0%	85.0%	81.5%	88.5%	120.6%
QA 07 - 12 FL-FL	372,939	400	0.11	383	400	95.8%	93.8%	97.7%	100.0%	100.0%	100.0%	104.4%
QA 07 - 12 FL-L	337	337	100.00	164	242	48.7%	43.3%	54.0%	71.8%	67.0%	76.6%	147.6%
QA 07 - 12 L-FL	252	255	100.00	159	67	62.4%	56.4%	68.3%	26.3%	20.9%	31.7%	42.1%
QA 07 - 12 L-SL	1,914	400	20.88	330	369	82.5%	78.8%	86.2%	92.3%	89.6%	94.9%	111.8%
QA 12 - 15 FL-FL	372,393	400	0.11	378	392	94.5%	92.3%	96.7%	98.0%	96.6%	99.4%	103.7%
QA 12 - 15 FL-L	798	400	50.06	293	312	73.3%	68.9%	77.6%	78.0%	73.9%	82.1%	106.5%
QA 12 - 15 L-FL	439	400	91.12	223	189	55.8%	50.9%	60.6%	47.3%	42.4%	52.1%	84.8%
QA 12 - 15 L-SL	4,044	400	9.86	227	235	56.8%	51.9%	61.6%	58.8%	53.9%	63.6%	103.5%
QA 15 - 18 FL-FL	372,573	400	0.11	392	397	98.0%	96.6%	99.4%	99.3%	98.4%	100.1%	101.3%
QA15 - 18 FL-L	259	261	100.00	213	213	81.6%	76.9%	86.3%	81.6%	76.9%	86.3%	100.0%
QA 15 - 18 L-FL	13	13	100.00	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	#DIV/0!
QA 15 - 18 L-SL	2,646	400	15.11	328	363	82.0%	78.2%	85.8%	90.8%	87.9%	93.6%	110.7%
		Average				**70.8%**		**Average**	**75.4%**			

Note: change type from or to L („any land") like FL-L include all other classes except the class the change alters to or comes from in "any land", e.g. FL-L includes all classes except FL in L.

7 DEVELOPMENT OF AN APPROACH FOR IDENTIFICATION OF RELEVANT LULUCF CHANGES

7.1 Land use changes

After correcting potential technical changes and random errors in the grid, the following approach was developed to assess land use changes (using version 6):

- Each grid point with a different LULUCF category in two different observation years was considered.
- The LULUCF framework considers a 20-year timeframe for a transition (as those described in Table 1-1) from one LULUCF category to another to be completed. That means during this time the carbon storage capacity has changed from the initial class to the capacity of the new land use category.
- Points for which the 20-year time span has not been completed are marked as “in transition”.
- As the available input data do not provide land use information on an annual basis, the actual starting year of a transition is not known. It was agreed to use the middle of the time period between two available observations as starting point of the transition and to apply a linear interpolation over the 20-year period. For the assumed starting year of the transition, see Table 7-1.
- Assignment of a land use category for on an annual basis for each grid point. Every unchanged point keeps its category along the timeline (e.g. FL), those in transition are marked by the type of transition (e.g. FL-SL), (see Table 7-2)

Table 7-1: Assumed starting and end years of land use transitions

Period with observed transition (based on input data)	Assumed starting year	Assumed end of the transition period
1989 – 1999	1994	2013
1999 – 2007	2003	2022
2007 – 2012	2010	2029
2012 – 2015	2014	2033
2015 – 2018	2017	2036

Table 7-2: Schema of grid point coding

1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
FL	FL	FL	FL	FL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL
FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL-SL	FL-SL	FL-SL

Table 7-3 shows a subset of the area statistics for arable cropland and forest and their related transitions for the years 1989 to 2000. For the year 1989 Forest Land shows a surface of 93,019 ha. Based on the process explained in Table 7-1 above, the land use transitions start in the year 1994. In that year the total area of FL diminishes due to the land use changes and the area “leaving” that forest land. The sum of FL and all the transitions is equal to the total area before the transitions started.

These area figures and their changes over time are the basis of the carbon accounting described in the next section.

Table 7-3: Area statistics per land use category and transition per year (extract)

Transition	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ACL	55934.77	55934.77	55934.77	55934.77	55934.77	46309.22	46309.22	46309.22	46309.22	46309.22	46309.22	46309.22
ACL-FL	0	0	0	0	0	115.7506	115.7506	115.7506	115.7506	115.7506	115.7506	115.7506
ACL-GL	0	0	0	0	0	8458.291	8458.291	8458.291	8458.291	8458.291	8458.291	8458.291
ACL-OL	0	0	0	0	0	0	0	0	0	0	0	0
ACL-PCL	0	0	0	0	0	148.2507	148.2507	148.2507	148.2507	148.2507	148.2507	148.2507
ACL-SL	0	0	0	0	0	901.5044	901.5044	901.5044	901.5044	901.5044	901.5044	901.5044
ACL-WL	0	0	0	0	0	1.500007	1.500007	1.500007	1.500007	1.500007	1.500007	1.500007
ACL-WT	0	0	0	0	0	0.250001	0.250001	0.250001	0.250001	0.250001	0.250001	0.250001
FL	93019.2	93019.2	93019.2	93019.2	93019.2	92355.7	92355.7	92355.7	92355.7	92355.7	92355.7	92355.7
FL-ACL	0	0	0	0	0	65.25032	65.25032	65.25032	65.25032	65.25032	65.25032	65.25032
FL-GL	0	0	0	0	0	415.752	415.752	415.752	415.752	415.752	415.752	415.752
FL-OL	0	0	0	0	0	0.500002	0.500002	0.500002	0.500002	0.500002	0.500002	0.500002
FL-PCL	0	0	0	0	0	17.00008	17.00008	17.00008	17.00008	17.00008	17.00008	17.00008
FL-SL	0	0	0	0	0	164.0008	164.0008	164.0008	164.0008	164.0008	164.0008	164.0008
FL-WL	0	0	0	0	0	0	0	0	0	0	0	0
FL-WT	0	0	0	0	0	1.000005	1.000005	1.000005	1.000005	1.000005	1.000005	1.000005

7.1.1 Final land use change matrixes

Table 7-4 to Table 7-8 show the area change (based on grid version 6) between the different years of inventory presented as hectare area (ha). It compares the LULUCF class assigned to a point for the initial time step on the left (rows, named “from”) to the following time step on top (columns, named “to”).

The diagonal shows the unchanged land (e.g. FL remaining FL = 92,355.2 ha between 1989 and 1999). The rows show how much land has changed (“exited”) from a specific class to a new class (i.e. 901.5 ha of arable crop land (ACL) have changed into settlement (SL) area between 1989 and 1999). The values in the columns provide information on the “gains” per category. The “total” per row show the total area of the specific land use category of the starting year of the transition period, while the “total” of the column show the area of the class for the end year of the transition.

As shown by the tables the area which has changed has decreased between the first change period 1989/1999 and the last step 2015/2018. Even taking the longer time span in the first change period of 10 years into account compared to only 8, 5 or respectively 3 years in the later change periods the change rate is the highest for the first change period. This is partially due to jumps in the mapping resolution, technique and quality. The annual rate of change is given below each table.

Table 7-4: 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 7-5: 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 7-6: 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 7-7: 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 7-8: 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 7-9: Revised forest area (compare to Table 4-1) after corrections and improvements

	1989	1999	NFI 2000	2007	NFI 2010	2012	2015	Phyto 2014	2018
Total Forest area in original data (ha)	92,136	91,132	92,350	92,628	92,150	95,646	92,498	95,010	92,435
Total Forest in LULUCF grid v6 (ha)	93,018	93,178	N/A	93,345	N/A	93,320	93,199	N/A	93,146

Table 7-9 provides a comparison of the revised forest area based on the original input data and the final LULUCF grid (version 6). The area figures based on the map data are much more stable now, but still different from the figures of the National Forest Inventory. This difference can be explained by what is considered “forest” in both approaches (see definitions in Table 4-2).

Figure 7-1 shows the main land use changes (excluding changes with the agricultural categories) for the period from 1989 to 2018 per commune. The afforestation map nicely shows the communes in the south of Luxembourg where mainly former mining areas have been converted to forest land. Deforestation mainly happened around Luxembourg City and can be explained in combination with the urbanisation map which shows most activities in the know development poles of the country.

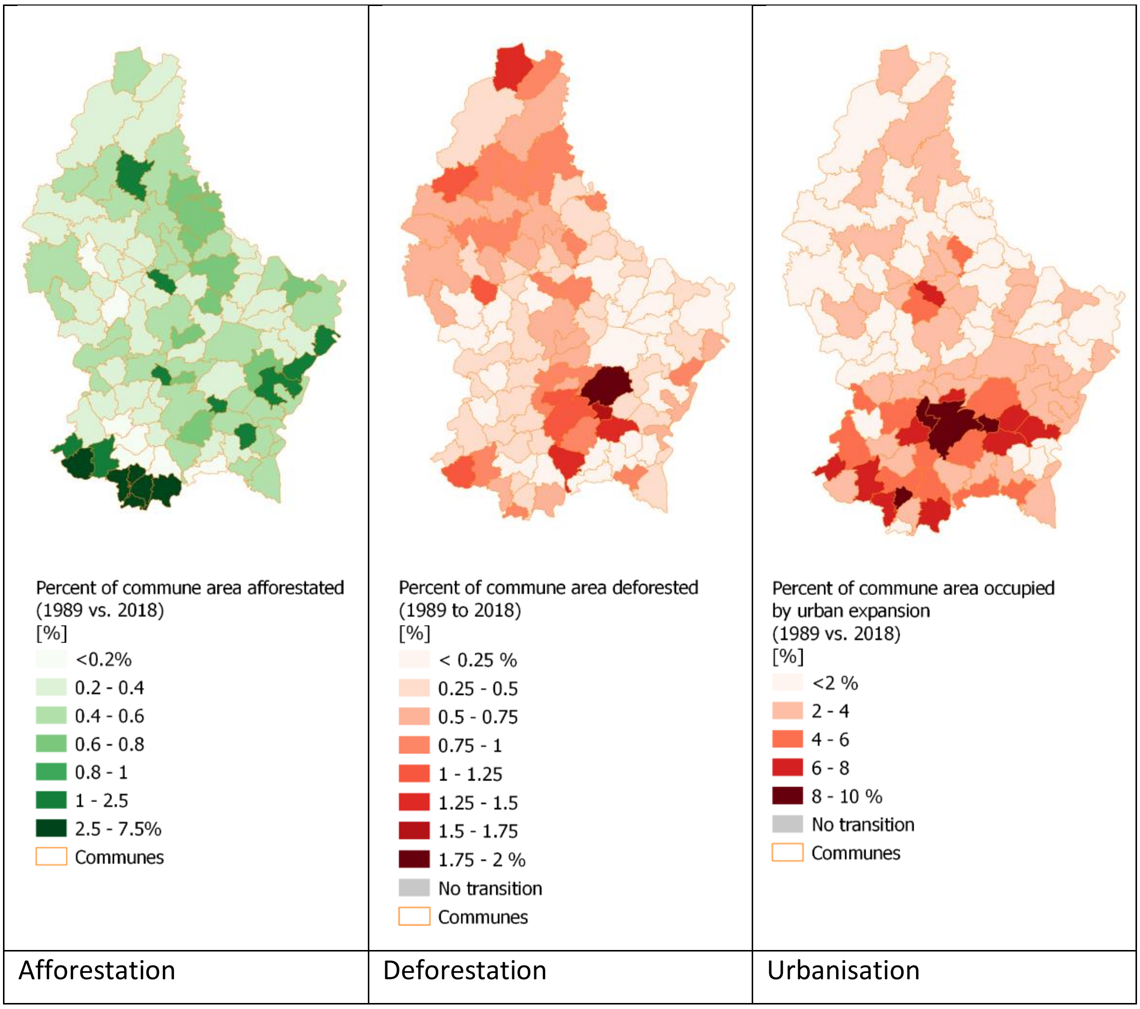


Figure 7-1: Main land use changes between 1989 and 2018 per commune

7.2 Carbon accounting

A final step to complete the information content of the grid points was the addition of soil carbon information to each grid point. Soil carbon values for the different region of Luxembourg have been estimated by the Administration des services techniques de l'agriculture (ASTA)[16]. The study provides predicted organic carbon stock value in croplands, grasslands and forest for different soil association in different regions.

For the further work, the average value for organic carbon (red boxes) in Table 7-10 were used for the different regions / soil associations in Luxembourg. The actually used values are summarised in

Table **7-11**.

[16] Stevens, A., van Wesemael, B., Marx, S. & Leydet, L. (2014): Mapping topsoil organic carbon stocks in the Grand-Duchy of Luxembourg

Table 7-10: Summary statistics of OC stock prediction (t C / ha) (source Stevens et al., 2014)

Soil associations	n	Min	q_1	$\bar{x}$	$\tilde{x}$	q_3	Max	IQR
Oesling	26753	48.5	83.3	91.5	90.6	98.8	159.0	15.6
Buntsandstein	4373	43.2	59.3	66.7	63.8	69.4	136.4	10.2
Dolomies du Muschelkalk	3746	49.3	72.0	85.5	84.0	96.7	136.9	24.7
Calcaires du Bajocien	310	53.8	64.1	75.2	77.7	83.3	117.9	19.2
Grès de Luxembourg	6038	34.0	45.7	50.7	50.2	54.7	80.7	9.1
Dépôts limoneux sur Grès	7581	36.5	50.0	58.6	57.2	62.7	143.5	12.8
Argiles du Lias inf. et moyen	10333	40.6	59.5	69.8	67.7	77.9	133.8	18.5
Argiles lourdes du Keuper	4629	40.7	56.3	67.7	65.4	74.9	153.3	18.6
Argiles lourdes des schistes bitumineux	1535	52.2	67.5	88.2	89.2	107.6	126.7	40.2
Autres	2313	39.2	60.0	80.7	72.2	103.3	177.1	43.3
all	67611	34.0	60.0	76.8	78.1	91.4	177.1	31.4

Table 5: Summary statistics of OC stock predictions (t C ha-1) in Cropland

Soil associations	n	Min	q_1	$\bar{x}$	$\tilde{x}$	q_3	Max	IQR
Oesling	18775	60.7	86.2	89.2	89.8	92.1	118.5	5.9
Buntsandstein	3626	56.5	75.7	82.8	79.4	89.1	148.3	13.4
Dolomies du Muschelkalk	5299	68.3	99.1	112.1	116.0	123.9	168.5	24.9
Calcaires du Bajocien	251	91.2	115.9	122.0	119.6	128.1	149.3	12.2
Grès de Luxembourg	3574	56.6	72.7	83.3	80.0	93.3	134.7	20.5
Dépôts limoneux sur Grès	8133	65.1	85.2	99.4	96.3	111.8	191.1	26.6
Argiles du Lias inf. et moyen	14451	72.2	115.3	121.6	122.9	129.1	198.1	13.8
Argiles lourdes du Keuper	13690	68.8	110.5	121.3	124.0	130.5	175.7	20.0
Argiles lourdes des schistes bitumineux	3445	102.6	141.0	145.7	147.2	153.9	178.2	12.9
Autres	6889	60.8	102.3	110.8	113.1	121.9	191.8	19.5
all	78133	56.5	89.8	107.4	107.3	124.0	198.1	34.2

Table 6: Summary statistics of OC stock predictions (t C ha-1) in Grassland

Soil associations	n	Min	q_1	$\bar{x}$	$\tilde{x}$	q_3	Max	IQR
Oesling	42055	82.5	122.0	132.2	130.4	141.9	185.3	20.0
Buntsandstein	4901	70.3	92.1	112.1	103.0	133.4	193.5	41.3
Dolomies du Muschelkalk	4673	77.1	108.2	117.0	120.1	127.4	145.1	19.2
Calcaires du Bajocien	3030	88.5	99.5	111.5	105.2	118.0	155.3	18.5
Grès de Luxembourg	21308	57.1	75.8	80.6	80.0	84.7	165.6	8.9
Dépôts limoneux sur Grès	11903	67.3	85.2	95.7	92.6	105.4	140.4	20.2
Argiles du Lias inf. et moyen	9351	72.7	87.2	95.2	91.4	100.5	152.4	13.3
Argiles lourdes du Keuper	8160	72.3	92.8	102.6	100.0	110.8	137.6	18.1
Argiles lourdes des schistes bitumineux	3263	77.6	97.9	104.8	102.2	109.6	139.9	11.7
Autres	6296	65.2	90.0	126.6	126.2	158.9	213.2	68.9
all	114940	57.1	88.3	110.7	108.2	129.6	213.2	41.3

Table 7: Summary statistics of OC stock predictions (t C ha-1) in Forest

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 as well as permanent crops for which the carbon value was provided by AEV, based on previous work.

Calculation of carbon storage values for the LULUCF category settlement:

- Share of unsealed surfaces within the urban area in Luxembourg based on LU 2018 and LC 2018: 53%
- Average carbon stock grassland: 107.4 t C/ha
- Formula: 107.4 C t/ha x 0.53 = 56.92 t C/ha

Table 7-11: Soil organic carbon values used for land use categories and soil associations (t C / ha), (based on Stevens et al., 2014, and own calculations)

Soil association	Settlement	Arable Cropland	Permanent crops	Grassland	Forest Land	Other land	Wet-lands	Water
Oesling	56.9	91.5	89.8	89.2	132.2	0	0	0
Buntsandstein	56.9	66.7	75.7	82.8	112.1	0	0	0
Dolomies du Muschelkalk	56.9	85.5	75.7	112.1	117	0	0	0
Calcaires du Bajocien	56.9	75.2	119.6	122	111.5	0	0	0
Grès de Luxembourg	56.9	50.7	80	83.3	80.6	0	0	0
Dépôts limoneux sur Grès	56.9	58.6	96.3	99.4	95.7	0	0	0
Argiles du lias inf. et moyen	56.9	69.8	122.9	121.6	95.2	0	0	0
Argiles lourdes du Keuper	56.9	67.7	75.7	121.3	102.6	0	0	0
Argiles lourdes des schistes bitumineux	56.9	88.2	147.2	145.7	104.8	0	0	0
Autres	56.9	80.7	75.7	110.8	126.6	0	0	0

With the help of the geospatial data set on soil associations in Luxembourg (scale 1:100,000) and its land use category, the median value of soil organic carbon was attached to each grid point.

Table 7-12 uses the example of LULUCF categories and its transitions as presented in Table 7-2, but amended with the carbon stock values per grid point. In the first example, in the starting year the grid point is part of the Forest Land which changes into Settlement:

- The carbon stock value for the soil association “Oesling” and Forest Land is 132.2 t C/ha.
- Each grid point represents a 0.25 ha, i.e., 132.2 / 4 = 33.05 t C
- A change from Forest Land to Settlement (FL-SL) has been mapped.
- The carbon value for SL ha is 43.236 t C/ha (or 10.809 C t per point).
- Over the 20-year period, the carbon value will decrease in a linear manner from 33.05 t C per point to 10.809 t C per point, i.e., in steps of (33.05 – 10.809) / 20 = 1.1121 t C per point per year.
- In 2013 the value of 10.809 t C will be reached for the respective grid point.

The total carbon stock and its changes can be summed up by simply adding up the values for the different LULUCF categories.

All carbon accounts are currently calculated / extrapolated until the year 2036 (i.e. the end of the 20-year period starting in 2017). The figures are linearly extrapolated over the period. However, as soon as new land use data / transitions will become available (probably early 2022 based on newly acquired orthophotos in 2021) the calculations will need to be updated based on latest land use changes and extended to 2039.

Table 7-12: Example for LULUCF carbon accounting

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
LULUCF Cat.	FL	FL	FL	FL	FL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL	FL-SL
t C / point	33.05	33.05	33.05	33.05	33.05	31.938	30.826	29.714	28.602	27.49	26.378	25.266	24.154	23.042	21.93	20.817	19.705
LULUCF Cat.	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL-SL	FL-SL	FL-SL
t C / point	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	33.05	31.938	30.826	29.714

8 RESULTS OF NATIONAL CARBON ACCOUNTING

The carbon accounting maps in Figure 8-1 show the summary of carbon emissions and/or removals for the land use categories arable cropland, grassland, forest land and settlement over the observation period from 1989 to 2018, aggregated per commune.

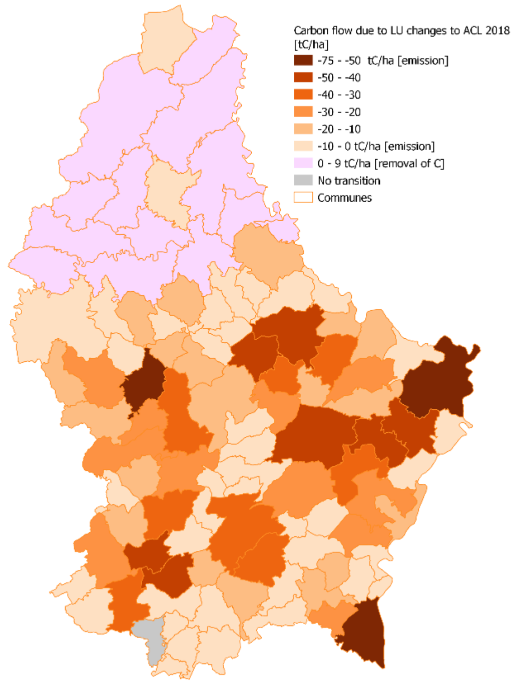
In most maps (except for settlement activities), a clear separation into two main regions of Luxembourg can be observed: the Oesling and the rest of the country.

In the Oesling the change to arable cropland is characterised by a removal of CO_2 while in other parts of the country this change is associated with emissions. One explanation for this is that in the Oesling the carbon storage capacity of the arable cropland soils is the second highest (after forest soils), i.e. a change to arable cropland has a positive effect on the carbon balance. While in most other regions of Luxembourg, arable cropland has a lower carbon storage capacity and thus is associated with emissions.

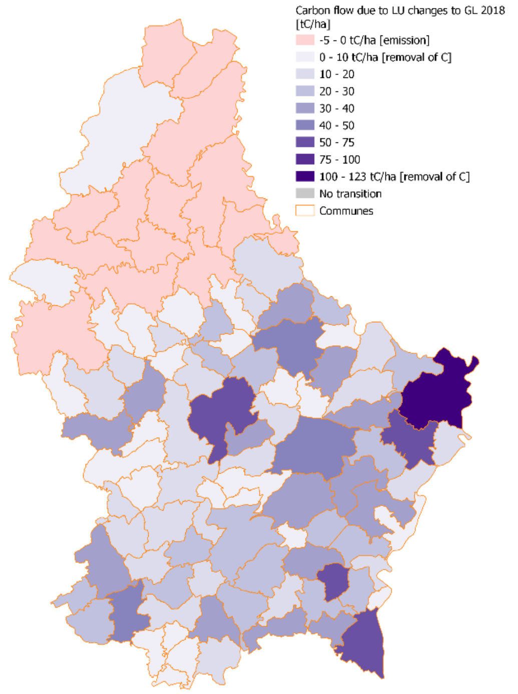
A similar split, but with opposite signs can be observed for conversions to grassland: while the Oesling is characterised by emissions, conversions to grassland in the rest of the country are associated with a positive carbon balance (removals).

The forest map shows mostly positive effects of the conversion to forest land, as in most regions forest land has the highest soil carbon storage capacity. This is especially visible in the Oesling which itself has the highest soil carbon values of the country. So a change to forest in the Oesling has the highest CO_2 removal potential. An emission of carbon is possible when the afforestation is taking place on former grassland areas on clay soils.

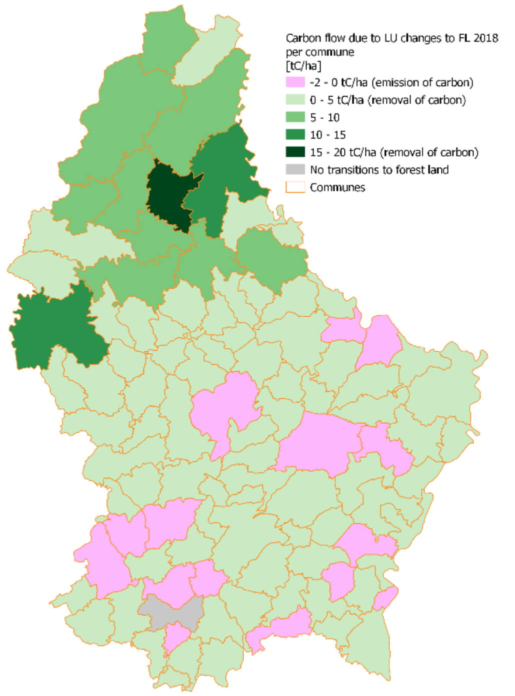
The settlement map is characterised by an overall negative carbon balance (emissions) in all regions of the country. A certain concentration is visible in around the capital and the major development poles in the south of the country.



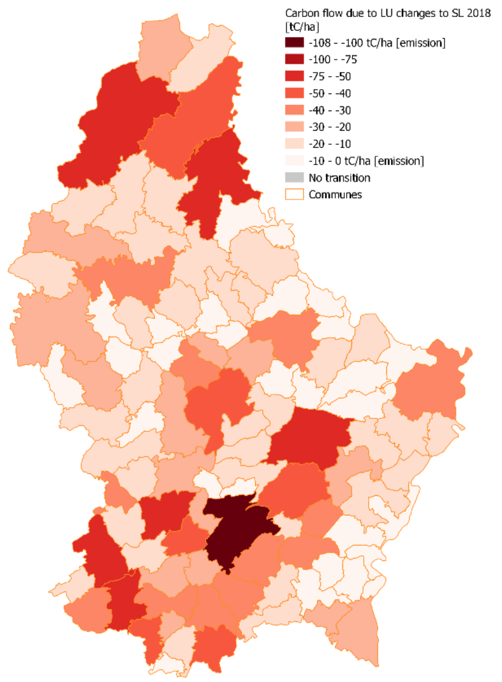
Emissions / removals due to land use changes to arable cropland



Emissions / removals due to land use changes to grassland



Emissions / removals due to land use changes to forest land



Emissions / removals due to land use changes to settlements

Figure 8-1: Carbon accounting maps

9 Conclusions

The present report describes the opportunities as well as limitations of using spatially explicit data in support of LULUCF reporting for Luxembourg.

Luxembourg can rely on a rather favourable data situation compared to other countries. A first land use / land cover database is already available for the year 1989, with subsequent updates in 1999, 2007, 2012, 1015 and 2018 ensuring a rather dense time series, especially when compared to statistical sampling data (like national forest inventories) which are often carried out only every 10 years. Further updates are likely as the government has decided on a plan for annual updates of the national orthophoto coverage and probably a 3-year update cycle of the derived national land cover and land use maps.

The limitations are, as in many other countries, related to the spatial and thematic consistency of the individual data sets and the identification of “real” changes.

To overcome these limitations the project converted the original nomenclatures to common LULUCF categories, transferred the original polygon data to a point grid with 50m spacing (i.e. each point representing 2,500m^2) and developed an approach to fill the grid database based on status and change information from the respective maps and the respective years.

The steps to improve the consistency of the information resulted in an overall reduction of the uncertainty and an overall accuracy of 75%. This accuracy is better for recent year and less good for early years due to limited quality in the spatial delineation of objects in those years and an inconsistent handling of the same features on the ground in different years.

When talking about uncertainty, it should not be forgotten that information on land use and its changes is only one component of the variables (e.g. emission factors) needed to estimate CO_2 emissions and removals.

Overall, it can be concluded that the approach works well with the data available and is open to the ingestion of additional ancillary information (like the LPIS / FLIK data used to improve the identification of agricultural lands) as well as a temporal extension – towards the past (data permitting) and towards the future with the update of the current national land use data sets.

The use of Copernicus data has been considered but declined as the existing national data provide a better spatial resolution, can be directly related to land use (Copernicus is mostly land cover) and provide a temporal coverage back to 1989 (Copernicus HRL data are only available since 2006).

ANNEX I

Rule set for the correction of grid points based on time series of LULUCF codes:

Pattern	Situation	Action
1	If LULUCF classes are the same in all time stamps	Do nothing
2	If some time stamp has no value (zero)	Do nothing
3	If arable land or grassland in all time stamps (210, 230), and if 1999 is different than others (1989=2012=2015=2018)	Reclassify 1999 to 2018
4	If arable land or grassland in all time stamps (210, 230), and if 2007 is different than others (1989=2012=2015=2018)	Reclassify 2007 to 2018
5	If only agriculture exist (210, 220, and 230)	Do nothing
6	If only LULUCF18 is different	Do nothing
7	From anything (agriculture 210/220/230 treated as one class) except 101 and 500 to 100 and year 2018 = 100	Do nothing
8	From 300 in 1989 to other class that stays consistent (except 340, 400, and 500 in 1999)	Do nothing
9	From 210, 220, 230, 340, 400 in 1989 to forest that stays consistent	Do nothing
10	1989 and 1999 are the same (210, 220, 230 treated as one class), and the rest is consistent 2007=2012=2015=2018	Do nothing
11	If 1989 = 210/220/230, 1999 = 100 and the rest is = 300	Do nothing
12	If one point in the time series is different (not 1989 or 2018)	Recode point to 2018
13	1989 is 340, 400, or 500 and the rest is consistent 1999=2007=2012=2015=2018	Recode 1989 to 1999
14	1989 is NOT 340, 400, or 500 and the rest is 340, 400, or 500 and is consistent 1999=2007=2012=2015=2018	Recode 1989 to 1999
15	If 1989 = 100 and rest of series consistent (210, 220, 230 treated as one class)	Do nothing
16	At least three time stamps are classified as 400	Recode all time stamps to 400
17	If 1999 and 2007 is different than other time stamps	Recode 1999 and 2007 to 2018
18	If 1999 and 2012 is different than other time stamps	Recode 1999 and 2012 to 2018
19	If 1999 and 2015 is different than other time stamps	Recode 1999 and 2015 to 2018
20	If 2007 and 2012 is different than other time stamps	Recode 2007 and 2012 to 2018
21	If 2007 and 2015 is different than other time stamps	Recode 2007 and 2015 to 2018

22	If 2012 and 2015 is different than other time stamps	Recode 2012 and 2015 to 2018
999	Pattern not assigned	Do nothing

ANNEX II

List of attributes of the final grid database (LULUCF_GRID.shp) – a subset of the working version below

Attribute name	Attribute explanation
id	a unique ID of the GRID point
PECODE	soil category taken from the original soil association map
RECLASS	reclassified soil category (PECODE)
LULUCF89_6	final LULUCF classification for 1989
LULUCF99_6	final LULUCF classification for 1999
LULUCF07_6	final LULUCF classification for 2007
LULUCF12_6	final LULUCF classification for 2012
LULUCF15_6	final LULUCF classification for 2015
LULUCF18_6	final LULUCF classification for 2018

List of attributes available in working version / raw database (LULUCF_GRID_all_attributes.shp)

Attribute name	Attribute explanation
id	a unique ID of the GRID point
LU89	the original LU class code of the input data in 1989 (OBS)
LU99	the original LU class code of the input data in 1999 (OBS)
LU07	the original LU class code of the input data in 2007 (OBS)
LU12	the original LU class code of the input data in 2012 (LULUCF based on RapidEye)
LU15	the original LU class code of the input data in 2015 (LIS-L)
LU18	the original LU class code of the input data in 2018 (LIS-L)

Attribute name	Attribute explanation
C8999_I_89	the original LU class code for 1989 of the input change layer 1989-1999
C8999_I_99	the original LU class code for 1999 of the input change layer 1989-1999
C9907_I_99	the original LU class code for 1999 of the input change layer 1999-2007
C9907_I_07	the original LU class code for 2007 of the input change layer 1999-2007
C0712_I_07	the original LU class code for 2007 of the input change layer 2007-2012
C0712_I_12	the original LU class code for 2012 of the input change layer 2007-2012
C1215_I_12	the original LU class code for 2012 of the input change layer 2012-2015
C1215_I_15	the original LU class code for 2015 of the input change layer 2012-2015
C1518_I_15	the original LU class code for 2015 of the input change layer 2015-2018
C1518_I_18	the original LU class code for 2018 of the input change layer 2015-2018
LULUCF89_I	the initial LULUCF class code assigned to the LU class of the input data in 1989
LULUCF99_I	the initial LULUCF class code assigned to the LU class of the input data in 1999
LULUCF07_I	the initial LULUCF class code assigned to the LU class of the input data in 2007
LULUCF12_I	the initial LULUCF class code assigned to the LU class of the input data in 2012
LULUCF15_I	the initial LULUCF class code assigned to the LU class of the input data in 2015
LULUCF18_I	the initial LULUCF class code assigned to the LU class of the input data in 2018
C8999_R_89	the LULUCF class code assigned to the LU class code for 1989 of the input change layer 1989-1999
C8999_R_99	the LULUCF class code assigned to the LU class code for 1999 of the input change layer 1989-1999
C9907_R_99	the LULUCF class code assigned to the LU class code for 1999 of the input change layer 1999-2007
C9907_R_07	the LULUCF class code assigned to the LU class code for 2007 of the input change layer 1999-2007
C0712_R_07	the LULUCF class code assigned to the LU class code for 2007 of the input change layer 2007-2012
C0712_R_12	the LULUCF class code assigned to the LU class code for 2012 of the input change layer 2007-2012
C1215_R_12	the LULUCF class code assigned to the LU class code for 2012 of the input change layer 2012-2015
C1215_R_15	the LULUCF class code assigned to the LU class code for 2015 of the input change layer 2012-2015
C1518_R_15	the LULUCF class code assigned to the LU class code for 2015 of the input change layer 2015-2018

Attribute name	Attribute explanation
C1518_R_18	the LULUCF class code assigned to the LU class code for 2018 of the input change layer 2015-2018
C89_99	indicator informing about the land use change of a grid point between 1989-1999; 0 - no change, 1- change
C99_07	indicator informing about the land use change of a grid point between 1999-2007; 0 - no change, 1- change
C07_12	indicator informing about the land use change of a grid point between 2007-2012; 0 - no change, 1- change
C12_15	indicator informing about the land use change of a grid point between 2012-2015; 0 - no change, 1- change
C15_18	indicator informing about the land use change of a grid point between 2015-2018; 0 - no change, 1- change
ForestR_89	0, 1 indicator informing that the point has been classified as forest road in LU 2018 and is located inside a forest
FLIK_12	the original class code of the FLIK data for 2012
FLIK_15	the original class code of the FLIK data for 2015
FLIK_18	the original class code of the FLIK data for 2018
LUX_AREA	indicator informing for which time period a GRID point is located within territory of the Grand Duchy of Luxembourg
PECODE	soil category taken from the original soil association map
RECLASS	reclassified soil category (PECODE)
BORDER	selection of points contributing the correct total area for Luxembourg
LULUCF89	the LULUCF class code assigned to a GRID point based on LULUCF99 where attribute C89_99 = 0; or based on attribute C8999_R_89 where attribute C89_99 = 1
LULUCF99	the LULUCF class code assigned to a GRID point based on LULUCF07 where attribute C99_07 = 0; or based on attribute C9907_R_99 where attribute C99_07 = 0
LULUCF07	the LULUCF class code assigned to a GRID point based on LULUCF12 where attribute C07_12 = 0; or based on attribute C0712_R_07 where attribute C07_12 = 1
LULUCF12	the LULUCF class code assigned to a GRID point based on LULUCF15 where attribute C12_15 = 0; or based on attribute C1215_R_12 where attribute C12_15 = 0
LULUCF15	the LULUCF class code assigned to a GRID point based on LULUCF18 where attribute C15_18 = 0; or based on attribute C1518_R_15 where attribute C15_18 = 1
LULUCF18	the LULUCF class code assigned to a GRID point based on LULUCF18_I (the values are the same as in LULUCF18_I)
FLIK_12_v2	the attribute FLIK_12 reclassified to LULUCF

Attribute name	Attribute explanation
FLIK_15_v2	the attribute FLIK_15 reclassified to LULUCF
FLIK_18_v2	the attribute FLIK_18 reclassified to LULUCF
LULUCF89_2	LULUCF89 attribute improved based on FLIK_12_v2, FLIK_15_v2, and FLIK_18_v2 attributes (correcting border effect occuring due to different geometry of input LU datasets)
LULUCF99_2	LULUCF99 attribute improved based on FLIK_12_v2, FLIK_15_v2, and FLIK_18_v2 attributes (correcting border effect occuring due to different geometry of input LU datasets)
LULUCF07_2	LULUCF07 attribute improved based on FLIK_12_v2, FLIK_15_v2, and FLIK_18_v2 attributes (correcting border effect occuring due to different geometry of input LU datasets)
LULUCF12_2	LULUCF12 attribute improved based on FLIK_12_v2, FLIK_15_v2, and FLIK_18_v2 attributes (correcting border effect occuring due to different geometry of input LU datasets)
LULUCF15_2	LULUCF15 attribute improved based on FLIK_12_v2, FLIK_15_v2, and FLIK_18_v2 attributes (correcting border effect occuring due to different geometry of input LU datasets)
LULUCF18_2	LULUCF18 attribute improved based on FLIK_12_v2, FLIK_15_v2, and FLIK_18_v2 attributes (correcting border effect occuring due to different geometry of input LU datasets)
LULUCF89_3	the LULUCF class code assigned to a GRID point based on LULUCF89_2
LULUCF99_3	the LULUCF class code assigned to a GRID point based on LULUCF99_2
LULUCF07_3	the LULUCF class code assigned to a GRID point based on LULUCF07_2
LULUCF12_3	LULUCF12_2 attribute improved based on FLIK_12_v2 attribute
LULUCF15_3	LULUCF15_2 attribute improved based on FLIK_15_v2 attribute
LULUCF18_3	LULUCF18_2 attribute improved based on FLIK_18_v2 attribute
LULUCF89_4	LULUCF89_3 attribute improved based on ForestR_89 attribute
LULUCF99_4	LULUCF99_3 attribute improved based on ForestR_89 attribute
LULUCF07_4	LULUCF07_3 attribute improved based on ForestR_89 attribute
LULUCF12_4	LULUCF12_3 attribute improved based on ForestR_89 attribute
LULUCF15_4	LULUCF15_3 attribute improved based on ForestR_89 attribute
LULUCF18_4	LULUCF18_3 attribute improved based on ForestR_89 attribute
Pattern	indicator informing on the Pattern number assigned to improve the LULUCFXX_4 classification between 1989-2018

Attribute name	Attribute explanation
LULUCF89_5	LULUCF89_4 attribute improved based on Pattern attribute
LULUCF99_5	LULUCF99_4 attribute improved based on Pattern attribute
LULUCF07_5	LULUCF07_4 attribute improved based on Pattern attribute
LULUCF12_5	LULUCF12_4 attribute improved based on Pattern attribute
LULUCF15_5	LULUCF15_4 attribute improved based on Pattern attribute
LULUCF18_5	LULUCF18_4 attribute improved based on Pattern attribute
QA_89_CODE	LULUCF code for 1989 assigned in QA
QA_99_CODE	LULUCF code for 1999 assigned in QA
QA_07_CODE	LULUCF code for 2007 assigned in QA
QA_12_CODE	LULUCF code for 2012 assigned in QA
QA_15_CODE	LULUCF code for 2015 assigned in QA
QA_18_CODE	LULUCF code for 2018 assigned in QA
LULUCF89_6	final LULUCF classification for 1989; LULUCF89_5 attribute improved based on QA_89_CODE attribute
LULUCF99_6	final LULUCF classification for 1999; LULUCF99_5 attribute improved based on QA_99_CODE attribute
LULUCF07_6	final LULUCF classification for 2007; LULUCF07_5 attribute improved based on QA_07_CODE attribute
LULUCF12_6	final LULUCF classification for 2012; LULUCF12_5 attribute improved based on QA_12_CODE attribute
LULUCF15_6	final LULUCF classification for 2015; LULUCF15_5 attribute improved based on QA_15_CODE attribute
LULUCF18_6	final LULUCF classification for 2018; LULUCF18_5 attribute improved based on QA_18_CODE attribute