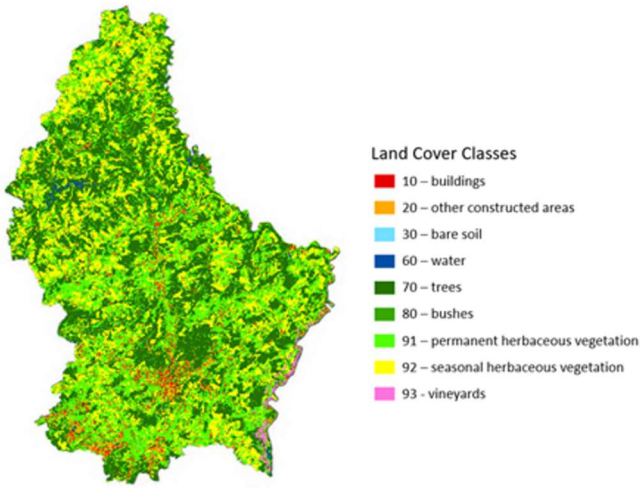
High-resolution Land Cover Map 2024

Land Cover Classification 2018-2021-2024 Luxembourg - using high resolution imagery



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space 4 environment

«Using Space to provide Space for the Environment»

DOCUMENT RELEASE SHEET

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LIST OF ACRONYMS

LC	Land Cover
LCC	Land Cover Change
LU	Land Use
LiDAR	Light Detection and Ranging
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared

1 INTRODUCTION

Land Cover (LC) and Land Cover Change (LCC) classification is based on the systematic analysis of aerial and satellite imagery to map and monitor spatial and temporal variations in land surface characteristics. This process provides a comprehensive overview of both current and historical land cover conditions and enables the identification of key trends, including deforestation, urban expansion, and ecosystem restoration. By translating remotely sensed imagery into standardized land cover classes, the classification supports the derivation of area statistics and indicators that are essential for informed decision-making and sustainable land and resource management.

The ability to consistently map LC and LCC represents a critical tool for environmental monitoring and the development of effective mitigation strategies. It allows for the clear identification of where changes occur, their extent and magnitude, and their potential environmental implications, thereby facilitating targeted and evidence-based interventions.

This report describes the technical approach applied for the LC and LCC classification for 2024 and presents the resulting land cover products in comparison with the previous land cover mappings 2018 & 2021.

The land cover map was produced using a robust semi-automatic classification methodology based on object-oriented image analysis. This approach ensures a high level of precision and consistency across the entire study area. The workflow commenced with the acquisition and pre-processing of input data, including aerial and satellite imagery, to ensure suitability for subsequent analysis. The semi-automatic classification stage applied advanced object-proving spatial coherence and overall map accuracy. To ensure full traceability and reproducibility, comprehensive metadata will be generated as part of the final deliverables, documenting each step of the production process. This structured and transparent methodology results in a reliable, high-resolution land cover dataset that supports data-driven environmental monitoring and sustainable resource management.

With the LC2024 the previous layers LC2018 and LC2021 were re-examined and any thematic or geometric error corrected to ensure the quality and continuity of the time series.

2 INPUT DATASETS

In this Section all the data sources that went into the production of LC2024 and LCC2021-2024 are briefly described. A summary of the datasets can be found in Table 1.

The main data source for LC2024 and LCC2021-2024 are the official orthophotos openly available via the Luxembourg Open Data Portal. The orthophotos are used as visual aid for the mapper but also to derive additional supporting layers such as the NDVI layer and land cover change layer.

The latest orthophoto was produced in 2025 and refers to the summer season. The previous orthophoto dataset refers to 2023. In other words, no official orthophoto is available for the reference year 2024, which is the target year of the Land Cover product. To overcome this limitation, the digital surface models (DSM) and digital terrain models (DTM) available for 2019 and 2024 were used. DSMs and DTMs are derived from LiDAR data and are freely available in the Luxembourg Open Data Portal. Section 2.1 explains in more detail how the digital models were further processed and used.

A NDVI time series for April-October 2024, derived from lower-resolution (10m) Sentinel-2 imagery, was also used to support the classification of the vegetation classes in LC2024.

Special consideration to the buildings class (10) was taken. We isolated and revised the Buildings dataset from LC2021, by manually adding, deleting or updating the objects based on the orthophotos. This approach allowed building footprints to be delineated more accurately. For example, if a building is partially obscured by shadows or trees, the full footprint of the building can still be captured in this manual step.

Finally, the 2023 Dauergrünland dataset (agricultural and viticulture parcels) is used as reference for the LC classes Permanent herbaceous vegetation and Seasonal herbaceous vegetation.

Table 1: Technical characteristics of input data used for classification.

INPUT DATASETS			
Name	**Type**	**Spatial resolution**	**Source**
Land Cover classification 2018 and 2021	Vector	-	Ministère de l'Environnement, du Climat et de la Biodiversité & Ministère du Logement et de l'Aménagement du territoire
Digitized Buildings 2024	Vector	-	space4environment
Dauergrünlandkartierung	Vector	-	https://geocatalogue.geoportail.lu/geonetwork/srv/api/records/f6f493c2-f57b-419d-8953-ab8018576ac7?language=ger
Orthophoto 2018	Raster	0.2m	https://data.public.lu/fr/datasets/orthophot

INPUT DATASETS			
Name	**Type**	**Spatial resolution**	**Source**
(red, green, blue and NIR band)			o-officielle-du-grand-duche-de-luxembourg-edition-2018/
Orthophoto 2021 (red, green, blue and NIR band)	Raster	0.1m	https://data.public.lu/en/datasets/orthophoto-officielle-du-grand-duche-de-luxembourg-edition-2021/
Orthophoto 2023 (red, green, blue and NIR band)	Raster	0.1m	https://data.public.lu/fr/datasets/orthophoto-officielle-du-grand-duche-de-luxembourg-edition-2023/
Orthophoto 2025-winter (red, green, blue and NIR band)	Raster	0.1m	https://data.public.lu/fr/datasets/orthophoto-officielle-du-grand-duche-de-luxembourg-edition-hiver-2025/
Digital Terrain Model 2019	Raster	0.5m	https://data.public.lu/fr/datasets/lidar-2019-modele-numerique-de-terrain-mnt/
Digital Terrain Model 2024	Raster	0.5m	https://data.public.lu/fr/datasets/lidar-2024-releve-3d-du-territoire-luxembourgeois/
NDVI Sentinel image time series (April – October 2024)	Raster	10m	EO- Browser https://apps.sentinel-hub.com/eo-browser/

2.1 PROCESSING OF DIGITAL TERRAIN AND SURFACE MODELS

The digital terrain model (DTM) and a digital surface model (DSM) are both derived from the same LiDAR acquisition phase. DTM represents the height of the bare-earth terrain (excluding objects on the ground), while DSM represent the highest visible surface, including the ground and any object, natural or man-made, on the ground. The normalised DSM (nDSM) is calculated as the difference between DTM and DSM, hence extracting buildings, vegetation, and other objects from the bare-earth terrain (Figure 1). With the nDSM, the height of features standing above the ground is clear and comparable across different acquisition times.

The nDSM was calculated for 2019 and 2024 and then the difference between the two outputs. The resulting layer, nDSMdiff, gives a first impression of land cover changes between 2019 and 2024, highlighting the construction of new buildings and forest clear cuts. nDSMdiff is a raster dataset. Negative values represent a decrease in object height (e.g., clear cut), while positive values represent an increase in object height (e.g., the construction of new buildings or new forest growth.

To extract meaningful land cover change information, nDSMdiff was first classified into six categories based on object height differences:

- <-10m
- -10m to –5m
- -5m to – 0.5m
- 0.5m to 5mm
- 5m to 10m
- 10m

Continuous patches of pixels were vectorized and a regularization step was added to remove spurious pixels and smaller patches.

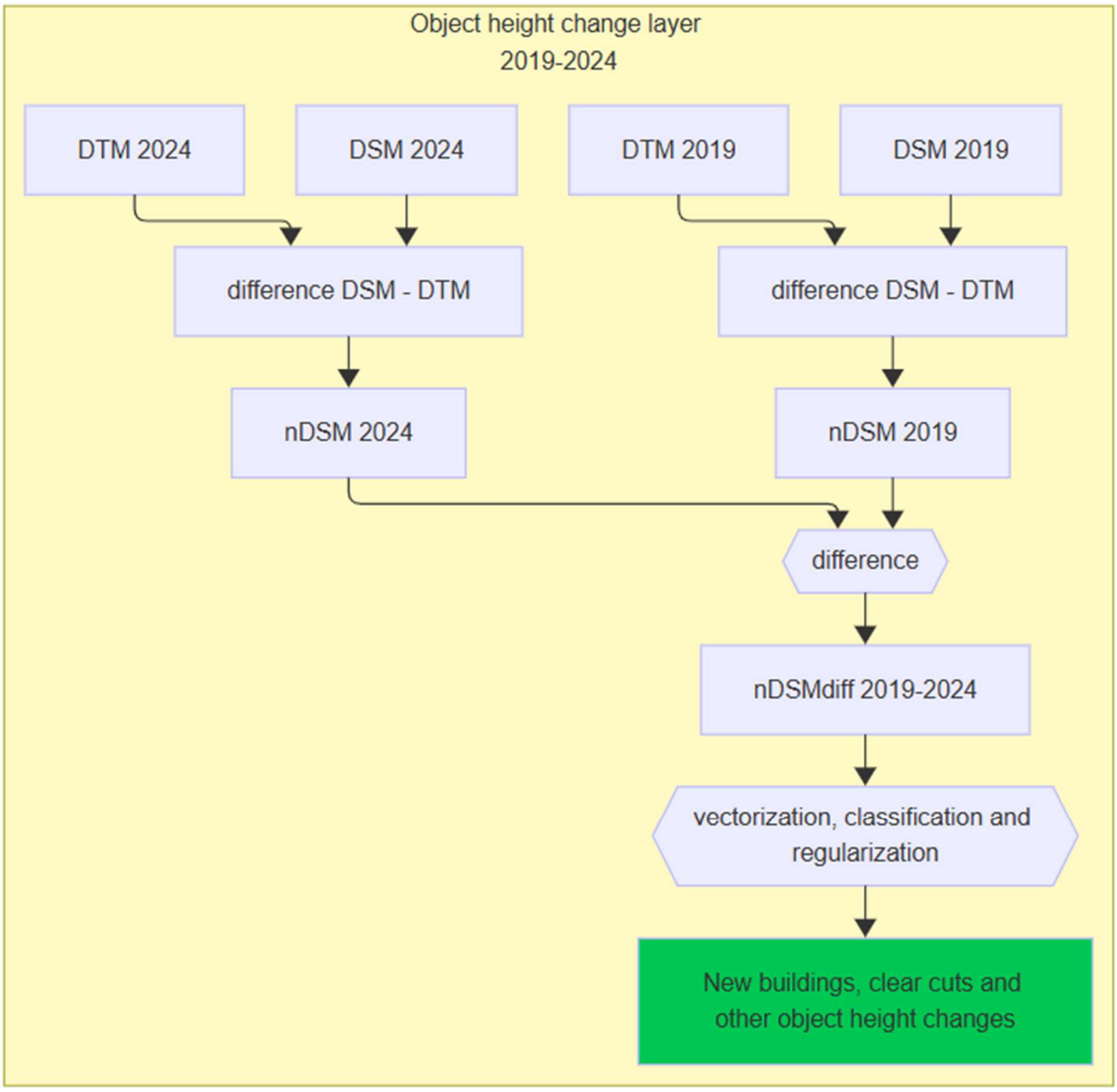

Figure 1: Processing steps to create the object height change layer 2019-2024 using DSM and DTM.

3 METHODOLOGY

To be consistent with the classification used in 2021, the same terminology and number of classes were used:

- (10) Buildings
- (20) Other constructed areas
- (30) Bare soil
- (60) Water
- (70) Trees
- (80) Bushes
- (91) Permanent herbaceous vegetation
- (92) Seasonal herbaceous vegetation
- (93) Vineyards

For a detailed description of the land cover classes, please see ANNEX .

The classification process was implemented through a multi-step Python workflow tailored for large-scale data processing. The flowchart in Figure 2 shows the main steps of the classification approach:

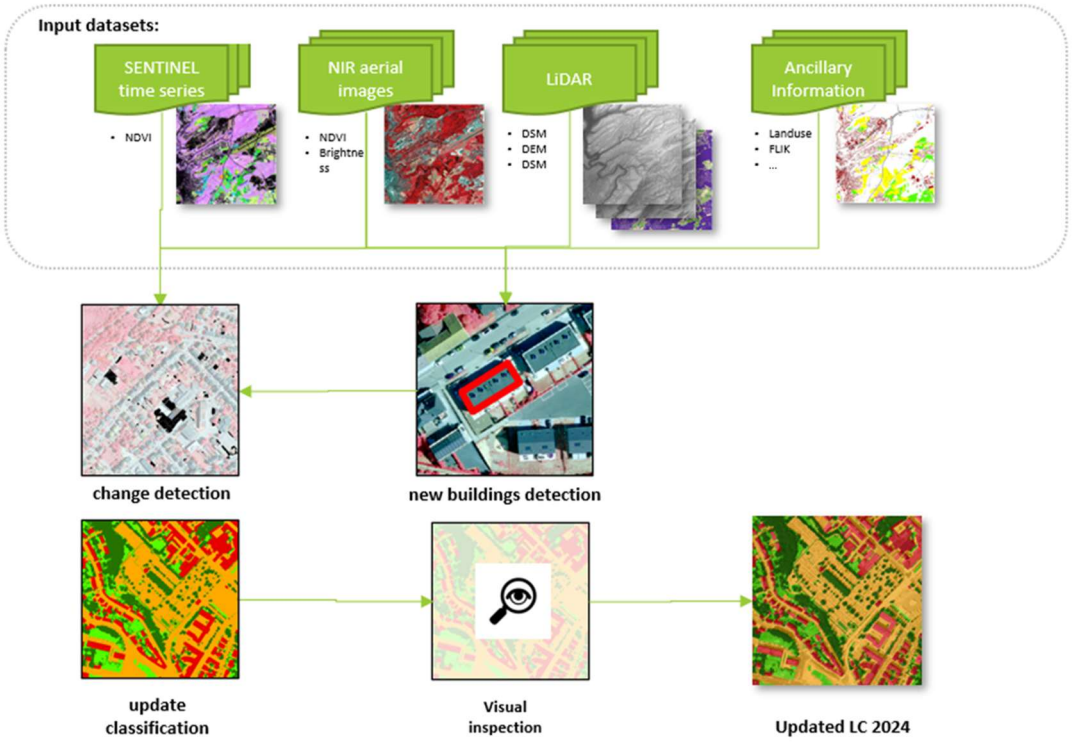

Figure 2: Detailed workflow of the LC 2024 classification

The various steps of the mapping process can be summarised as follows:

- ***Data Pre-processing***
    - Merging and tiling: Orthophotos and LiDAR data were merged and tiled into working units. Due to landscape specificities and the volume of processing data, the classification was performed in these working units. This step included the definition of the dimensions of the working units, merging orthophotos, and clipping other ancillary data for each unit.
- ***Data Processing***
    - **Automatic Building Detection**

      New or removed buildings were identified and their footprints were updated in the land cover (LC) vector dataset.
    - **Change Detection Analysis (2021–2023)**

      A pixel-level change detection was performed using aerial imagery from 2021 and 2023 to classify the following transitions:
        - Removed vegetation: Loss of vegetation cover between 2021 and 2023.
        - New vegetation: Establishment of new vegetation during the same period.
        - New water bodies: Emergence of ponds, lakes, or flooded areas.
        - Removed water: Disappearance of water bodies due to drainage, evaporation, or human activity.
    - **nDSM-Based Change Detection (2019–2024)**

      A nDSM-based change dataset was generated to identify and map key transitions:
        - New trees: Establishment of tree cover between 2019 and 2024.
        - Removed trees: Loss of tree cover during the same period.
        - New buildings: Construction of new structures detected in 2024.
        - Removed buildings: Demolition or removal of buildings between 2019 and 2024.
    - **Temporal Consistency & Segmentation**

      The land cover segments for the period 2018–2021 were adjusted to the aerial photographs from 2023. A simplified 2023 land cover classification (vegetation, water, non-vegetation) was generated, segmented into homogeneous polygons, and integrated into the existing dataset for seamless continuity.

- **Decision-Tree Analysis**

  Change classification results were analysed using a decision-tree approach. Segments with reduced tree height were labelled as LC2024_pot_91 (“potentially removed tree”).

- **Visual Interpretation & Validation**

  All potential changes underwent visual inspection. Validated changes were incorporated into the LC 2018-2021-2024 time series.

- **Final LC 2018-2021-2024 Map**

  The final map was clipped by commune borders and archived alongside the LC2018 and LC2021 products.

4 RESULTING DATASETS

Finally, spatial datasets for Luxembourg in LUREF projection (EPSG: 2169) were compiled into a file geodatabase (GDB) **LC2018_2021_2024_part1.gdb** (Figure 3):

- **LC2018_2021_2024:** Combined dataset with land cover data for 2018, 2021 and 2024, as well as changes between the years.
- **LC2024**: Land cover status for the year 2024.
- **LC2021**: Land cover status for the year 2021.
- **LC2018**: Land cover status for the year 2018.
- **LC2018-2021**: Changes in land cover between 2018 and 2021.
- **LC2021-2024**: Changes in land cover between 2021 and 2024.
- **LC2021-2024**: Changes in land cover between 2018 and 2024.

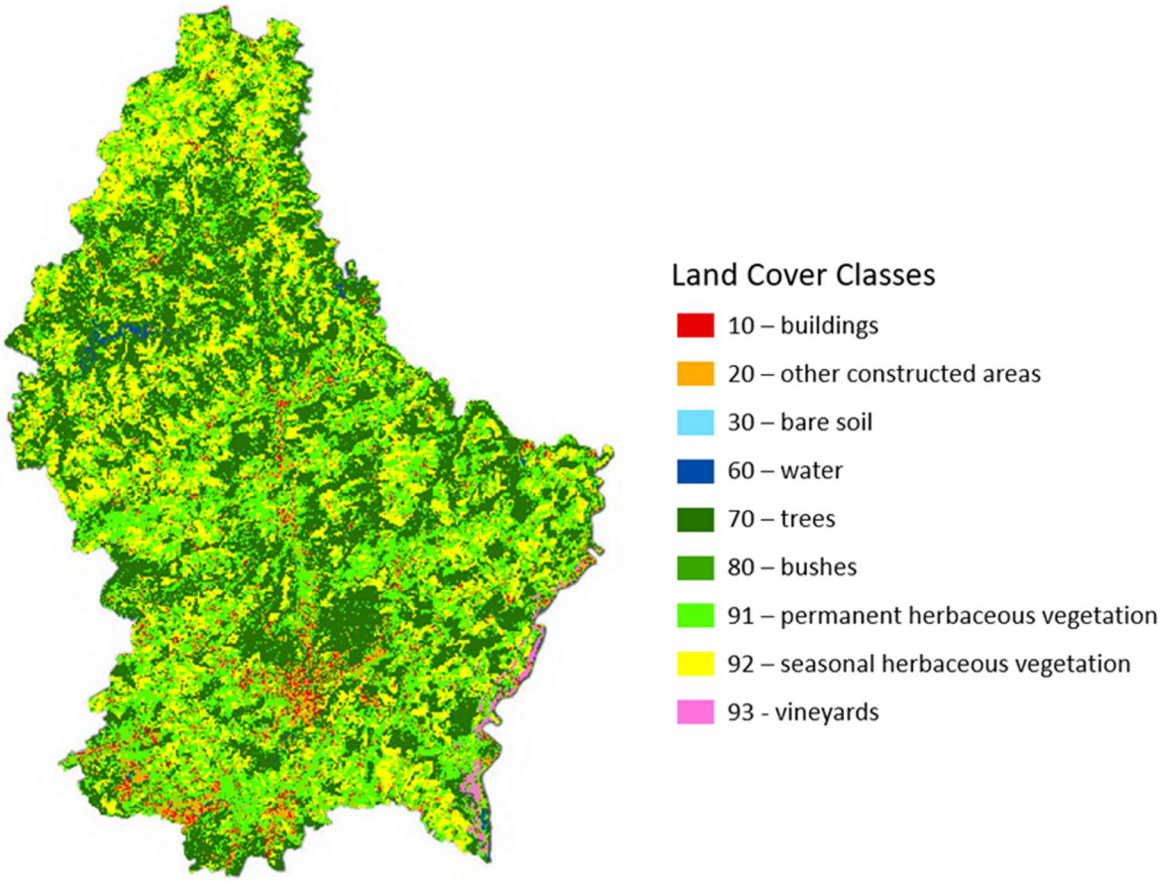

Figure 3: Land cover classification of Luxembourg (2024).

5 STATISTICS

Once the data was ready, statistics were compiled from the three revised periods, which are reproduced and shown in this chapter.

As shown in Table 2, most of the country is covered by forests (LC class code: 70), accounting for 93 526 hectares (36.1%) of the analysed area. The smallest proportion corresponds to 'bare soil', covering 81 hectares and representing 0.03% of the country.

Table 2: Area (in % and ha) covered by all the Land Cover classes and the changes between 2018 - 2021 - 2024.

LC class code	LC class name	2018 [ha]	Area [%] 2018	2021 [ha]	Area [%] 2021	2024 [ha]	Area [%] 2024
10	Buildings	4577	1.8	4787	1.9	4917	1.90
20	Other constructed areas	13122	5.1	13562	5.2	13787	5.32
30	Bare soil	132	0.1	85	0.0	81	0.03
60	Water	1189	0.5	1193	0.5	1194	0.46
70	Trees	97502	37.6	96057	37.0	93526	36.10
80	Bushes	7455	2.9	7456	2.9	8694	3.40
91	Permanent herbaceous vegetation	78976	30.5	79915	30.8	80842	31.20
92	Seasonal herbaceous vegetation	55131	21.3	55031	21.2	55050	21.25
93	Vineyards	1219	0.5	1215	0.5	1212	0.47
Grand Total		259303		259303		259303	

To assess land cover changes between 2021 and 2024, a change matrix was calculated (Table 3).
The X-axis indicates the LC 2021 values, while the Y-axis denotes the LC 2024 values. The diagonal cells of the matrix indicate the area that remained constant in both years. The remaining cells illustrate the transition of land cover from one category to another.

Table 3: Land Cover change matrix area[ha] between 2021 and 2024.

		LC2004									
Area[ha]		10	20	30	60	70	80	91	92	93	**Total Changes**
LC 2021	10	4751	16	0	0	0	0	1	0	0	17
	20	108	13287	0	1	0	1	170	8	0	289
	30	0	1	78	0	0	0	5	1	0	7
	60	0	2	0	1191	0	0	1	0	0	3
	70	5	56	0	0	94176	0	1817	1	0	1879
	80	3	28	0	0	239	6583	605	0	0	875
	91	45	336	3	2	38	1194	78092	165	0	1783
	92	4	56	0	0	0	0	97	54917	0	159
	93	0	1	0	0	0	0	2	0	1211	3
Total Changes		166	497	3	3	277	1197	2699	174	0	254287

A marked change is evident when comparing the figures from 2018, 2021 and 2024. The area occupied by buildings exhibited an increase from 4 577 hectares in 2018 to 4 769 hectares in 2021, and subsequently to 4 917 hectares in 2024 (Figure 4).

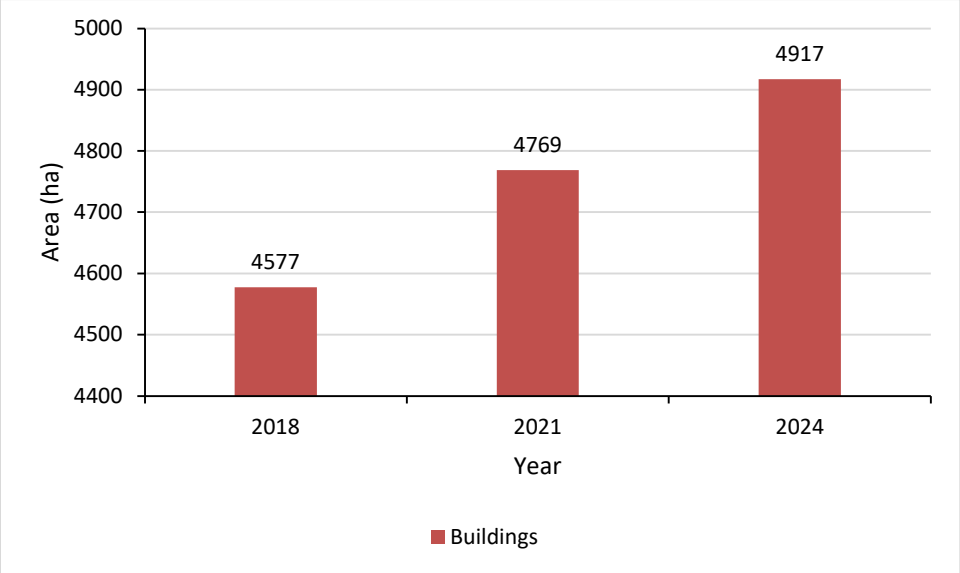

Figure 4: Changes in the "Buildings" area (ha) from 2018 to 2024.

This increase can also be seen in the land cover class "other constructed areas". Figure 5 shows the increase in these areas from 2018 to 2024.

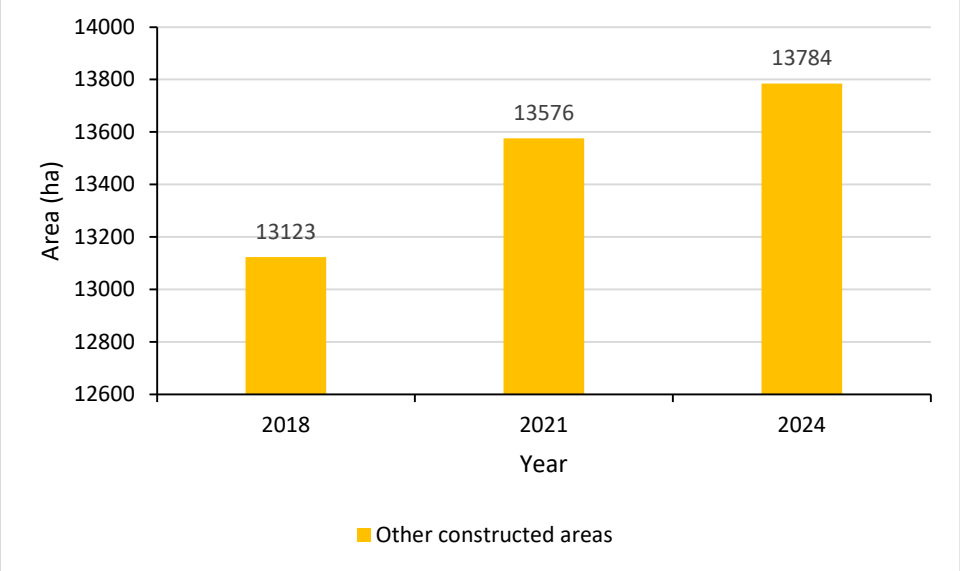

Figure 5: Changes in the "Other constructed areas" area (ha) from 2018 to 2024.

Conversely, the tree area has decreased by 3976 ha, from 2018 to 2024 which is due to large clear-cuts (Figure 6). Most of the tree areas were thereby transferred to class "Permanent herbaceous vegetation (91). The area of land taken from class 91 to class 10 was 45 hectares lower than expected, and this was also considered a lower estimate.

The artificialisation process has the potential to impact biodiversity and ecosystem services. As illustrated in Figure 6, the total area of trees across the years 2018, 2021, and 2024 has been consistently decreasing.

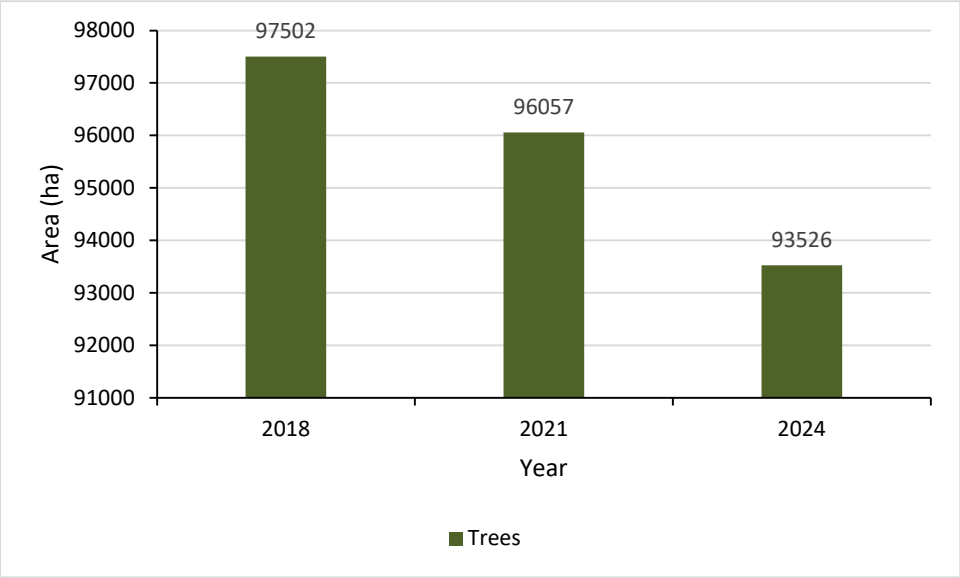

Figure 6: Changes in the "Trees" area (ha) from 2018 to 2024

One important aspect to highlight in this analysis report is the land take, that is the conversion from vegetation classes to artificial classes. In this context, the most significant change occurred from "Permanent herbaceous vegetation" to "Other constructed areas", with an area of 336 hectares. The second largest area of land change was recorded between "Seasonal herbaceous vegetation" to "Other constructed areas"

6 QUALITY CONTROL

The production of a land cover map is a complex process that integrates remote sensing data, classification algorithms, and expert knowledge. However, the reliability and utility of such a map depend critically on its accuracy and consistency. Quality Control (QC) is an essential step in ensuring that the final product meets the required standards for precision, completeness, and thematic integrity. For this land cover map of Luxembourg, a rigorous QC process was implemented to validate the classification results. The QC procedure involved selecting 519 reference points based on their distribution of area across the study area (Table 4).

Table 4: Land cover classification statistics for 2024 and distribution of validation points by class.

LC class code	LC class name	2024 [ha]	Area [%]	validation pts [count]
10	**Buildings**	4917	1,90	36
20	**Other constructed areas**	13787	5,32	64
30	**Bare soil**	81	0,03	23
60	**Water**	1194	0,46	26
70	**Trees**	93526	36,07	165
80	**Bushes**	8694	3,35	34
91	**Permanent herbaceous vegetation**	80842	31,18	171
92	**Seasonal herbaceous vegetation**	55050	21,23	72
93	**Vineyards**	1212	0,47	28
		259 303		**619**

These points were independently verified against high-resolution imagery (2023, 2025, LiDAR 2024) to assess the accuracy of the classified land cover.

The primary objectives of this QC process are:

- To quantify the overall accuracy of the land cover classification,
- To identify potential sources of misclassification or confusion between classes, and
- To ensure that the final map is robust and suitable for applications in environmental monitoring, urban planning, and policy-making.

This chapter outlines the methodology used for the QC, presents the results of the accuracy assessment, and discusses the implications for the map's reliability and potential improvements for future iterations.

Each of the 619 points were checked individually using aerial photographs from 2023 and 2025, as well as the LIDAR-DSM dataset from 2024. The classification's plausibility was verified during this process. If a point did not correspond to the mapped class, the observer's preferred class code was entered. This enabled a confusion matrix to be created for all classes (Table 5)

Table 5: Confusion matrix for status 2024 classification

Validation ground truth / LC2024 classification	10	20	30	60	70	80	91	92	93	Grand Total	Users accuracy
10	33	1					1			35	*94,29*
20		49					1			50	*98,00*
30	1		23				4			28	*82,14*
60				25			1			26	*96,15*
70	1	5		1	162		8			177	*91,53*
80	1	3				29	3			36	*80,56*
91		5			3	3	145			156	*92,95*
92		1				2	8	72		83	*86,75*
93									28	28	*100,00*
Grand Total	36	64	23	26	165	34	171	72	28	619	91,44
Producer´s accuracy	*91,67*	*76,56*	*100,00*	*96,15*	*98,18*	*85,29*	*84,80*	*100,00*	*100,00*		

The land cover validation results for the LC2024 classification show a robust overall accuracy of 91.44%. Classes such as Vineyards, Water, and Other Constructed Areas achieved nearly perfect accuracy, with Vineyards reaching 100% in both user's and producer's accuracy, reflecting highly reliable classification for these categories. However, some challenges remain, particularly with Bushes and Bare Soil, which exhibited lower accuracy rates—80.56% and 82.14%, respectively—suggesting occasional confusion with other classes like Trees or Permanent Herbaceous Vegetation.

The confusion matrix highlights that most misclassifications occur between visually or spectrally similar classes, such as Trees and Bushes, or Other Constructed Areas and Buildings. While the model performs exceptionally well for distinct and homogeneous classes, there is room for improvement in distinguishing more ambiguous or fragmented land cover types. This analysis provides a solid foundation for further refinement, especially in addressing the misclassification patterns observed in the less accurate categories.

More figures and statistics can be found at the following link:

https://public.tableau.com/views/LandcoverinLuxemboug2018-2021-2024/Story1?:language=en-US&publish=yes&:sid=&:redirect=auth&:display_count=n&:origin=viz_share_link

7 DISCUSSION

During the classification update, several mapping constraints were encountered, as briefly explained below:

- Mismatch between LiDAR 2024 and Aerial image 2023

The main challenge in producing the LC2024 map was the need to represent land cover conditions for 2024, despite the unavailability of aerial imagery from that year. Although 2024 LiDAR data was available, it introduced certain complications in the mapping process. Changes in height, such as modifications in buildings and tree heights, could be accurately detected using the 2024 LiDAR data. However, changes that were not related to height, including new roads and construction sites, had to be mapped using 2023 aerial imagery due to the absence of 2024 coverage.
As a result, the final product now includes new buildings detected in the 2024 LiDAR data, which naturally do not appear in the 2023 imagery. Conversely, infrastructure developments like roads built in 2024 are missing from the map, as their identification relied solely on the outdated 2023 aerial photographs.

- Consideration of the existing Land Cover classification 2018 & 2021

The existing land cover segments, originally derived from 2018 and later updated in 2021, do not align perfectly with the pixel-level information from 2023, even after integrating the 2023 segments. This mismatch complicates a fully automated classification, making it impractical to achieve accurate results without substantial development efforts. While it was attempted to address this using current software and hardware resources, the outcomes fell short of the required quality. Consequently, a semi-automatic approach was once again adopted to ensure the reliability of the final classification.

ANNEX

Detailed description of HRLC'24 land cover classes

Land cover class code	Land cover class name
10	Buildings
20	Other constructed areas
30	Bare soil
60	Water
70	Trees
80	Bushes
91	Permanent herbaceous vegetation
92	Seasonal herbaceous vegetation
93	Vineyards

ABIOTIC (NON-VEGETATED)

The primary separation of land cover elements is based on the vegetation cover. Abiotic includes all landscape elements that are primarily not covered by vegetation. It is further differentiated whether the surface is built-up (i.e. covered by artificial material) or non-built-up and water.

Built-up surfaces

10 Buildings

Permanent construction with a roof, providing storage, shelter or residence to people, animals or things. A building is characterised by its extension into the third dimension (contrary to "other constructed area which is "flat"). A minimum height is not defined.

Parking lots with more than one floor, but without a roof are included in this class. Wind turbines are also included in this class.

Buildings under construction – where the roof has not been finished – shall be classified as "other constructed areas". The MMU of a building is 20m².

20 Other constructed areas

This class comprises artificial surfaces that are partially or fully covered by impervious materials and are typically maintained over long periods of time. Common surface materials include asphalt or tarmac, concrete, gravel, and stone.

It includes infrastructure such as roads, sidewalks, pavements, parking lots, and other purpose-built surfaces, including tennis courts, running tracks, swimming pools and slurry tanks.

This class also includes artificial objects with three-dimensional extent that have no permanent roof or only a temporary covering, such as permanent tents and greenhouses, provided that they are permanently installed and have impervious surfaces underneath.

In addition, surfaces associated with construction sites, commercial or industrial activities such as storage areas, access roads, and mining areas—as well as permanent agricultural roads, are included.

Bare areas

30 Bare soil

This class represents open soil areas that are permanently not covered by vegetation, regardless of whether their origin is natural or artificial, and where vegetation cover does not exceed 10%. If an area of bare soil is seasonally covered by vegetation exceeding 10%, it should instead be classified as "herbaceous vegetation."

The class includes both naturally occurring bare soil and managed or artificial surfaces that are not covered by vegetation or impervious materials, such as sand areas on golf courses, playground sand, beach volleyball courts, and equestrian facilities.

Areas associated with construction activities are not included in this class. Bare soil within construction sites, or areas temporarily cleared due to construction (e.g., temporary parking or access areas), should be classified as *other constructed areas*, as the absence of vegetation in these areas is temporary rather than permanent.

Water

60 Surface water

This class represents open surface water, including both running and standing water bodies, and excludes flooded areas or other forms of temporary water. Artificial water-filled features, such as wastewater treatment plants, are also included in this class.

BIOTIC (VEGETATED)

Biotic or vegetated surfaces represent the second main aspect of land cover classes. These surfaces are covered with biomass at the moment of the image acquisition. The amount of biomass can be detected with the help of vegetation indices (e.g. NDVI).

Woody vegetation

Perennial plants with stem(s) and branches from which buds and shoots develop. Distinctions between trees and bushes are made based on the height information obtained from LiDAR data.

70 Trees

A tree is defined as a woody perennial plant with a single, well-defined stem carrying a more-or-less-defined crown, with a height generally greater than 5m at maturity. Exceptions are young growth areas.

The class “trees” encompasses single trees, groups of trees and continuous forest stands. They normally are characterised by a height difference from their neighbouring surfaces (i.e. shadow).
Orchards, plantations and Christmas tree farms are also included under this class.
It is important to note that the current FAO definition of a tree is > 5m.

80 Bushes

Bushes are woody perennial plants with persistent woody stems and without any defined main stem in the range of 0.5 – 5m height.
Young trees with a height less than 5m are also mapped under this class.

Herbaceous vegetation

Plants without persistent stem or shoots above ground and lacking definite firm structure.

90 Herbaceous vegetation (green cover)

Any surface covered with low vegetation (grassy or herbaceous) with an above-ground coverage of more than 10%.

91 Permanent herbaceous vegetation

All surfaces with permanent herbaceous vegetation (including intensive and extensive grasslands) fall into this class. This class also contains all vegetation-covered, but non-woody surfaces, including natural grasslands, pastures, parks, lawns in residential garden, soccer fields or green areas associated to traffic.

92 Seasonal herbaceous vegetation

Agricultural areas covered by seasonal herbaceous vegetation cover (e.g., cereals, maize) or temporarily bare soils resulting from agricultural practices are classified into this class.

93 Vineyards

Areas of land covered by cultivated grapevines (Vitis vinifera), arranged in regular rows.