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Point Cloud Dialects in Europe: Review of Point Cloud Datasets and their Quality Descriptors in Europe – towards greater Uniformity

Joint Research of Rijkswaterstaat,
3D Geoinformation Research Group (TU Delft),
het Waterschapshuis and EuroSDR

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POINT CLOUD DIALECTS IN EUROPE:
REVIEW OF POINT CLOUD DATASETS AND THEIR QUALITY DESCRIPTORS IN EUROPE - TOWARDS GREATER UNIFORMITY

Joint Research of
Rijkswaterstaat, 3D Geoinformation research group (TU Delft),
het Waterschapshuis and EuroSDR

With 18 figures and 51 tables

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This is an updated version of the document published in October 2025.

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Abstract

National mapping agencies are acquiring point cloud datasets across Europe. In 2023, in collaboration with the European Association of Aerial Surveying Industries, the Joint Research Centre attempted to provide an overview of the current state of these datasets in 2024. As data acquisition in Europe is ongoing, acquisitions and datasets vary in scope. To create a harmonised dataset within each nation, uniformity in data acquisition is crucial for the sharing of cross-border elevation information.

Rijkswaterstaat, TU Delft, Het Waterschapshuis, and EuroSDR invited EuroSDR members to complete the questionnaire in 2024 to identify the different 'dialects' in European point cloud acquisition programmes. The questionnaire results served as a starting point for the desk study, which aimed to identify all publicly available point cloud datasets in Europe.

The questionnaire and desk study results provide valuable insights into the current steps towards a pan-European point cloud dataset, revealing minor variations between datasets across three primary quality parameters: spatial distribution, absolute accuracy, and relative accuracy. The harmonisation of quality descriptors as defined in specifications should lead to fewer European 'dialects' concerning point cloud datasets, thereby paving the way for collaborative datasets at national and pan-European scales.

While the report provides an overview of the available datasets during the research period (the questionnaire in autumn 2024 and the writing process until 2025), it remains a **snapshot** in time, as new point clouds in Europe are continually acquired. Therefore, alongside the publication of the report, a web portal has been developed. The European Point Cloud (EuPC) portal regularly presents new point cloud datasets and, when available, point-cloud-based digital elevation models. The portal can be accessed via the following link: https://europeanpointclouds.tudelft.nl/

Acknowledgement

EuroSDR hosted the questionnaire, and the results were presented at the workshop "Data Acquisition, Processing and Distribution" within NMCA, in Amersfoort, hosted by Het Waterschapshuis.

The questionnaire owes its success to the participation of the EuroSDR and the responsible personnel from geodetic departments across Europe, who were willing to share their insights and expertise on point cloud acquisition in their respective countries, regions, and cities.

1 INTRODUCTION

In 2024, various government institutions in the Netherlands studied the possibility of harmonising point cloud datasets into one data facility. The study focused on a federated dataset facility, where each government institution in the Netherlands remains responsible for the data acquisition in its governance area (Balsterand, et al., 2021).

Currently, multiple point cloud datasets, differing in acquisition platform and purpose, are available in the Netherlands and in some cases even from the same area. The study concluded that several dialects are available in the Netherlands to meet the acquisition requirements, given the required quality of point clouds. The dialects in quality descriptions pose a significant challenge for the harmonisation process, as different dialects in point cloud definitions can lead to variations across datasets, making it difficult to integrate them into a single elevation data facility (van der Heide, van Natijne, Alkemade, & Hulskemper, 2024).

A similar study to that of van der Heide, van Natijne, Alkemade, & Hulskemper (2024) was conducted in 2023 by the Joint Research Centre, examining the current state of the art of LiDAR point cloud data in Europe. The aim was to highlight the variation in point cloud datasets that were then available. Here, the first attempt was made to identify all open point cloud datasets from European countries, along with their quality parameters when available.

A follow-up study was published in the Lidar magazine in 2023 and 2024 (Perello, 2023) (Perello, 2024), aiming at determining the possibility of a pan-European point cloud or elevation dataset based on a federated data approach. The study aimed to understand the various approaches to lidar mapping in Europe. The European Association of Aerial Surveying Industries (EEASI) study concluded that a pan-European dataset remained a complex goal due to the differing project systems and data standards. While acknowledging cross-border cooperation in the future acquisition campaigns for point cloud datasets, an increase in harmonisation approaches can be seen, which could pave the way for a pan-European dataset.

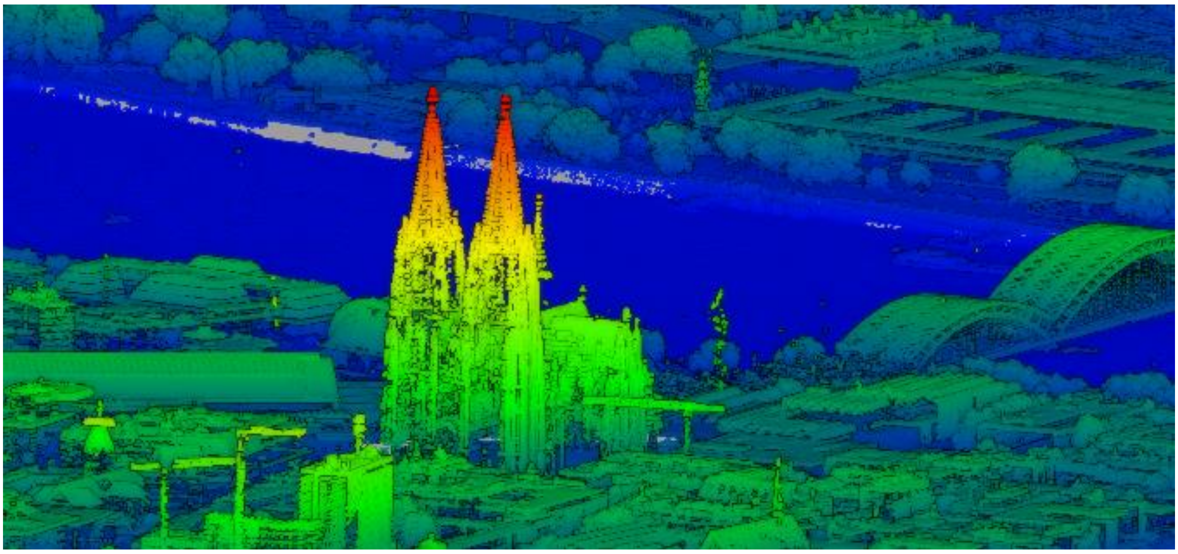

Figure 1: Example of the open accessible point cloud of North Rhine-Westphalia, Cologne Cathedral, Germany

Several other studies were conducted (Hobič, 2016); (Landscape Archaeology, 2025) to supply an overview of all the point clouds in Europe or the World, for instance, for landscape archaeology and climate change efforts. However, the mentioned studies are outdated and do not provide links to open point clouds or elevation datasets. In addition, none of the projects reported the temporal resolution of the datasets, due to the focus of these studies.

These studies provide an overview of point cloud datasets in Europe at various scales. However, as van der Heide, van Natijne, Alkemade, & Hulskemper (2024) concluded, the available point clouds and elevation models differ in their interpretations of the specifications, potentially due to the specific goal of the point cloud or elevation model. The various interpretations of the quality of point cloud datasets contradict the dedicated INSPIRE elevation directive, which dictates that each European country should strive to harmonise geodata to tackle the multiple shared challenges.

However, the harmonisation process of point cloud datasets in Europe remains relatively unknown. For instance, when a point cloud dataset is required to cover the entire country, the acquisition can involve multiple cycles and be conducted by different organisations/companies. Therefore, alignment must be undertaken to harmonise the point clouds into a single dataset. Various techniques can be applied to perform this process, which essentially utilise stable points (e.g., house ridge lines or precise benchmarks) to align the geometry of different point clouds. The semantics of the different cycles, often described in the quality requirements/descriptions of the point cloud dataset, should be the same. However, cross-border harmonisation of point cloud datasets for a pan-European dataset does not exist based on the current elevation datasets.

Therefore, to continue the work of the Joint Research Centre, Perello and van der Heide et al, this study is a collaboration between EuroSDR, Rijkswaterstaat, TU Delft and Het Waterschapshuis to update the point cloud overview in Europe and to provide an overview of the different dialects and point clouds that are available in Europe. The primary goal of the research is to determine the potential for harmonising available point cloud datasets.

Therefore, the following research question for this research was formulated:

What quality descriptions can be derived from European point cloud datasets to support the cross-border harmonisation?

This report highlights the quality parameters considered for point clouds and point cloud-based elevation models in Europe, where point clouds are generated using either Light Detection and Ranging (LiDAR) or photogrammetry.

1.1 Type of point cloud acquisition

The point clouds can be acquired using laser scanning (i.e., Light Detection and Ranging (LiDAR)) or acoustics. The active method relies on the principle of travel time, which is the time elapsed between the moment of transmission and the reception of a pulse. The travel time is divided by the pulse type's velocity in the transmission medium (e.g., air, water, or the vacuum of space). The emphasis of the position estimation lies on the accuracy of the time-measuring sensor, as an error in time measurement directly affects the ability to determine the distance between the transmission and reception of the pulse.

Point cloud datasets can be constructed from images using photogrammetry techniques and dense matching. The 3D geometry of a point is constructed from differences in the same object across overlapping (stereo) images. The straight lines drawn from the camera's centre through the object in both images intersect at a single point, representing the object's elevation. With the so-called tie points, each corresponding image can be linked to place the same object in the real environment. The matching principle is repeated for each corresponding pixel detected in the images. To extract surface elevation information from the overlapping images, two main approaches can be distinguished:

- Digital photogrammetry attempts to detect well-reliable corresponding objects in the images (e.g., road markings, ridge lines of buildings, or other objects showing a significant change in contrast), resulting in a reliable 3D geometry of these well-recognisable objects but lacking the ability to create a full dense point cloud.
- Dense matching searches for all the pixels in the images. This is achieved by searching row by row in the two overlapping images for all corresponding pixels. The matching search assumes that a pixel likely represents the same point in the real world. When a high likelihood is determined for the stored pixels in both images, traditional photogrammetry techniques are applied to derive the elevation.

The point cloud acquisition platforms can be divided into small- and large-scale area coverage. The *small*-scale category, focusing on small areas, includes static and on-foot data-acquisition platforms (e.g., tunnels). In contrast, the large-scale category (e.g. nationwide) encompasses mobile acquisition by platforms moving on water, land, air, and space. Passalacqua, Tarolli, and Foufoula-Georgiou (2015) provided an overview of the platforms used to acquire point cloud datasets. Table 1 presents an adapted version, which includes the category, acquisition methods, Area coverage, and the various platforms associated with each category.

Table 1: Point cloud acquisition platform overview inspired by (Passalacqua, Tarolli, & Foufoula-Georgiou, 2015)

Category	**Methods**	**Area coverage**	**Platform**
Static	LiDAR	Small	Fixed tripod/station
On foot	LiDAR	Small scale	Hand scanner and mobile phone
Mobile Land	LiDAR	Large scale	Car and train
Mobile water	Acoustic	Large scale	Ships
Mobile Airborne	LiDAR	Large scale	Drones, helicopters, and aeroplanes
	Dense Matching	Large scale	Drones, helicopters, and aeroplanes
Spaceborne	LiDAR	Large scale	satellite (ICEsat1 and 2)

1.2 Quality parameters of point cloud datasets

General quality parameters are necessary to define standards and establish uniform approaches for various point cloud datasets. Based on the research by van der Heide et al (2024), Kakoulaki, Martinez, & Florio (2021), Perello(2024), Tiberius et al. (2021) and Kjørsvik (2022), the quality-defining parameters of point cloud datasets are given in Table 2.

Table 2 presents two categories of quality-defining parameters: (1) the condition of the point cloud, and (2) the classification capabilities for which the point cloud dataset could be used.

Table 2: Quality parameters of point cloud datasets

Quality parameter	***Info***
Spatial distribution	The number of points per metric unit.
Absolute accuracy	The difference between the acquired and the actual environment
Relative accuracy:	The differences in an acquired dataset
Noise & Outliers:	The amount of noise can be present in the point cloud, regardless of the accuracy or spatial distribution parameters.
Coordinate system:	Which coordinate system and projection is used for the point cloud?
Feature registration definition & accuracy	How are the features described (i.e. what are the definitions of vegetation), and to what order is a feature labelled correctly in a point cloud dataset
Environment impact	What environmental effects are acceptable in a point cloud dataset, and how are they treated (interpolated, left out, etc)?
RGB colouring	How the colours of the complementary photos are modelled in the point cloud dataset, and what are the acceptable colour ranges
Calibration parameters	The errors in the measurement instrument were found during the calibration of the point cloud acquisition instruments.
External factors	Information regarding how the point cloud is acquired, e.g. survey lines, flight altitude and benchmark network

1.3 Data formats

The data format of a point cloud significantly impacts the types of information that can be stored in the dataset and how it can be utilised. Given that the data can be irregular and unstructured, point cloud datasets are often considered unordered (e.g. the order in which the points are stored does not affect the data itself).

An overview of the available types of point cloud dataset structures is given in Appendix A. The table provides an overview of the most used point cloud formats, along with recommendations on when to use each data format.

1.4 Label names

In the LAS format, the 'Classification' item allows the dataset to contain multiple classification labels, enabling the addition of user-defined labels. Hence, new labels can be added to the scheme for point clouds when new objects are deemed valid. The American Society for Photogrammetry and Remote Sensing (ASPRS), a scientific association serving professional members worldwide, introduced standard point classes for the LAS point cloud data format in 2019. Figure 2, based on the American Society for Photogrammetry & Remote Sensing (2019), illustrates the standardised values and their meanings. Each value is divided into four categories: (blue) Administrative/Meta, (red) Natural Terrain, (yellow) Man-made Structures and (red) noise. Note that the table does not give definitions. Consequently, the user is still responsible for defining objects in point cloud datasets.

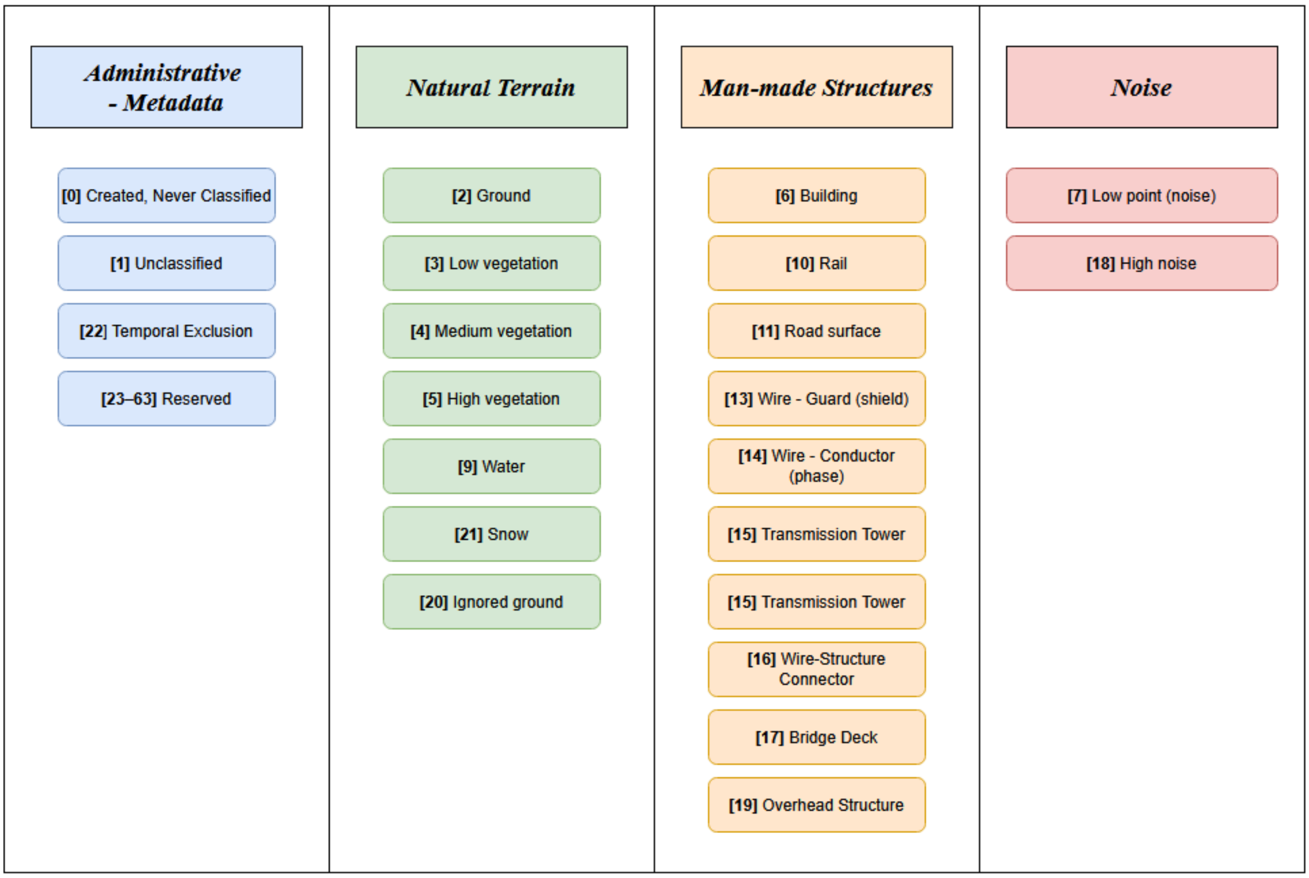

Figure 2: ASPRS labels divided into three classes: large scale, specific and other based on American Society for Photogrammetry & Remote Sensing (2019)

2 QUESTIONNAIRE SUMMER/AUTUMN 2024

2.1 Set-up and response

An online questionnaire was conducted from August to early October to inventory available point cloud datasets in Europe and their specifications. The preliminary results were presented at the workshop *"Data Acquisition, Processing, and Distribution" within NMCA, held in Amersfoort on January 29,* **2025**. During the workshop, participants were additionally invited to complete the questionnaire and to provide further information on the point cloud datasets available in each country. The results from the questionnaire and workshop were compared with those of a desk study to expand the inventory of point cloud datasets included in this study.

Furthermore, this study distinguishes between the types of datasets considered. A point cloud dataset must either be distributed as a standalone dataset or be used to generate Digital Elevation Models (DEMs). The latter may be a Digital Terrain Model (DTM) or a Digital Surface Model (DSM). However, the study did not differentiate between these two representations and instead generalised them under the term DEM.

The point cloud datasets considered in this study are based on either LiDAR or photogrammetric techniques. This resulted in over 50 European point cloud datasets of national and regional acquisition programs.

2.2 Responses to the questionnaire

The following figure (Figure 3) presents the countries that either responded to the questionnaire or were included in this analysis after contacting them. Some countries that did not respond to the questionnaire were contacted separately to obtain their quality descriptions. The different inputs are indicated as online inventory (brown), questionnaire (grey), and in case no information was found (white).

Note that *Austria* did respond to the questionnaire. However, no national initiative was to acquire point cloud data or digital elevation models. Therefore, the individual regions of Austria were considered.

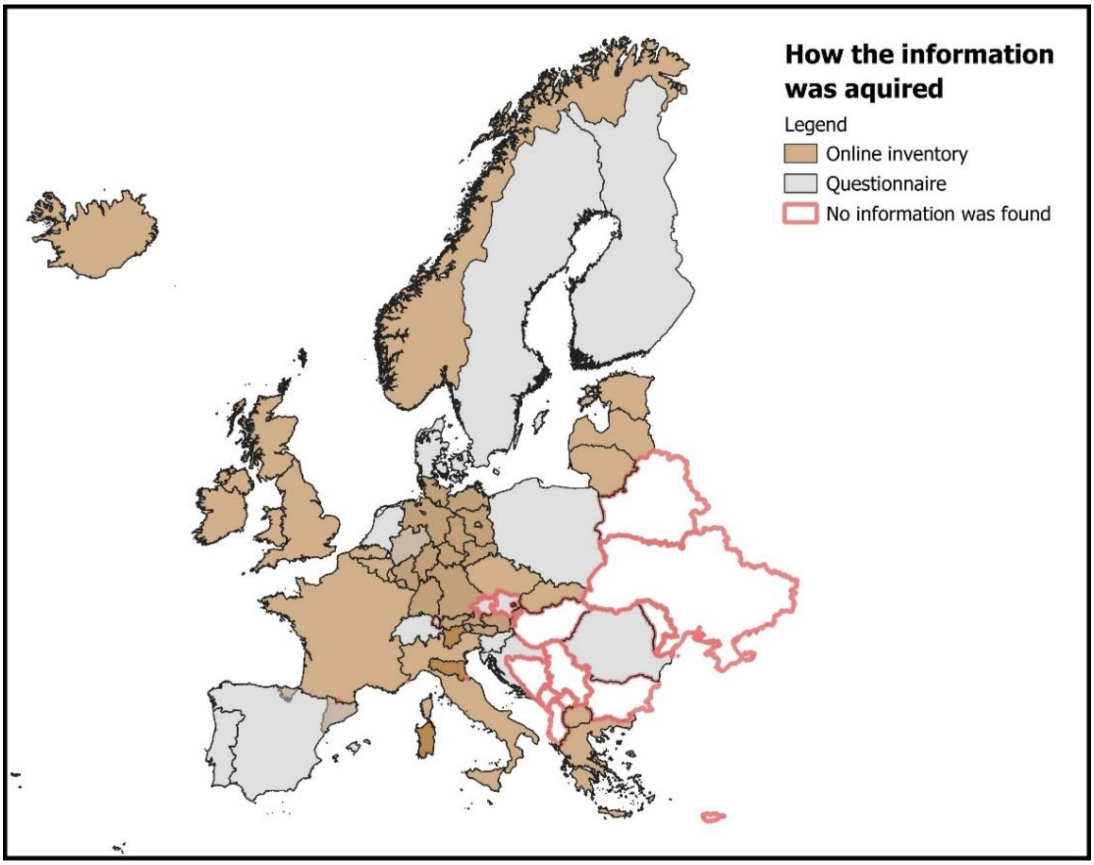

Figure 3: Overview of the 2024 EuroSDR Questionnaire responses

2.3 Questions of the questionnaire

Table 3 lists the questionnaire questions, including the page number in this report where the answers can be found.

Table 3: Question overview of the 2024 questionnaire

Question number	Question	Page
1	What kind of elevation data is available in your country, and in which format(s) is the point cloud dataset available?	17
2a	What is the point density of the considered dataset?	18
2b	For the point density, what unit do you prefer for this point cloud dataset?	18
3	Could you give an estimation of the absolute accuracy of the dataset? (cm)	19

4	Could you describe the definition of relative accuracy for point clouds used by your country or organisation?	20
5	When definitions for object classification in point clouds are available, which framework is used by your organisation or country?	21
6	How often is the dataset updated/acquired	22
7	Does the climate footprint influence the update/acquisition frequency of the datasets?	24
8	Is the point cloud and the specification(s) compliant with the federal INSPIRE directive?	25
9	Part of our research is identifying the parameters deemed crucial to describe the quality of point clouds. Hence, what are, in your opinion, the primary quality components of point clouds?	25
10	Are specification parameters missing in the previous question considered essential for point cloud datasets in your country?	26
11	Does your country integrate different point cloud datasets to create one national homogeneous dataset?	26

2.3.1 Question 1: What kind of elevation data is available in your country, and in which format(s) is the point cloud dataset available?

Figure 4 shows the availability of elevation data. Countries shown in green have publicly available point clouds, either accessible through an online platform or upon request. Countries in grey have a Digital Elevation Model (DEM) based on LiDAR acquisition. In some countries, regional governmental institutions are responsible for acquiring elevation information (e.g., point clouds), and these point cloud datasets are marked with points. In contrast, marked dashed patterns are associated with point cloud-based elevation models.

Iceland and Scotland only have partial information available (see Chapter 3); Germany and Portugal will have a national point cloud dataset from 2025 onwards. In contrast, Romania has a national dataset that is only available in a few counties.

All distributed point cloud datasets use the LAS/LAZ data structure. Minor exceptions were identified in the national datasets of Switzerland and Luxembourg, which supply their data using the "**.LAS.zip*" extension. Although Ireland does not have a national point cloud dataset available, the city centre of Dublin has made parts of its urban dataset publicly accessible. The point cloud data for Dublin is available in the BIN format (Zolanvari, et al., 2019).

Most responses indicated using the Creative Commons Attribution 4.0 International Public License or their licenses. Only three countries responded that the datasets are closed to the public, due to costs or military reasons.

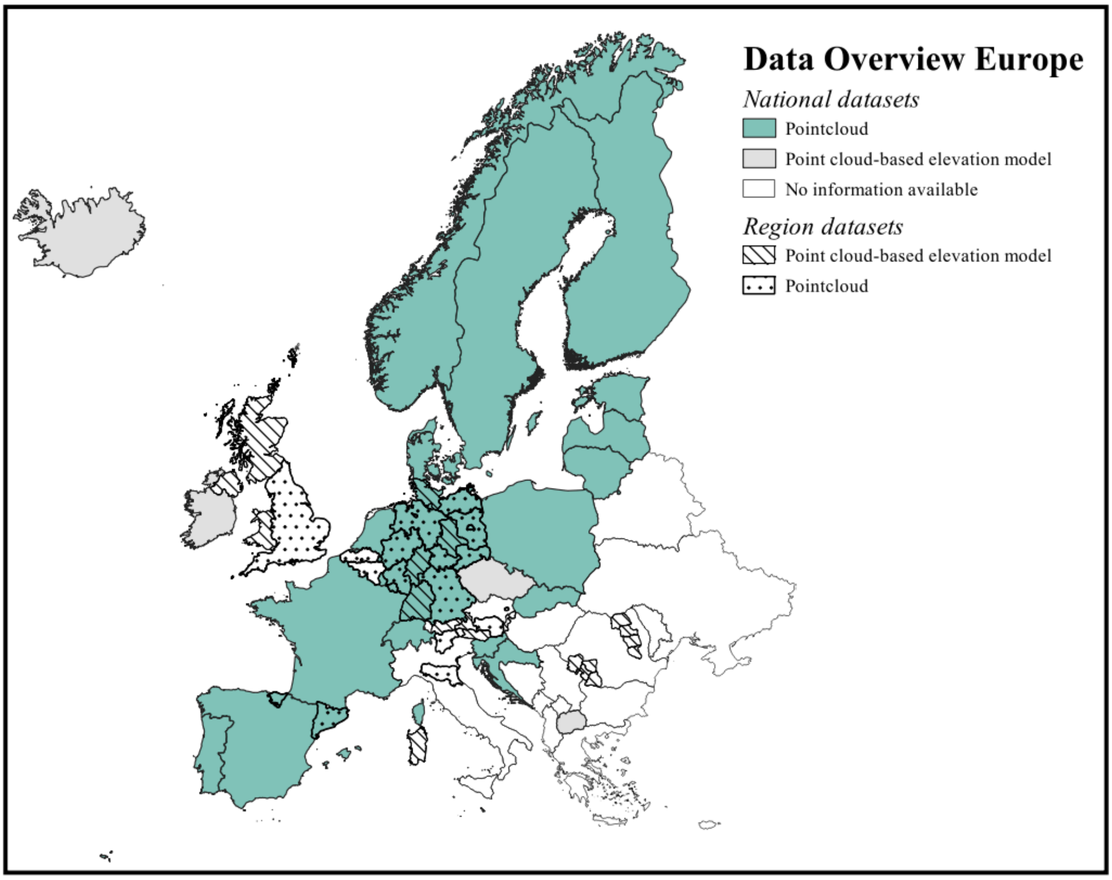

Figure 4: Data overview of point cloud (solid green), point cloud-based elevation model (solid grey), and no elevation information was available. While the regional (e.g. counties, countries in a union) gives the overview of point clouds (dots) and point cloud elevation models (dashed).

2.3.2 Question 2: (a) Point density and (b) the definition

100% of the participants indicated that the unit used for point density is defined as points per square metre (ppsm). Only the Norwegian general point cloud specification defines point spacing as the primary quality indicator, derived from point density expressed in points per square meter (ppsm).

The summarising statistics of the point densities indicated by the different acquisition campaigns are given in Table 4. The minimum, maximum and average are given in points per square meter for the' low' and' high' point density. The categories can be inferred from Poland's response, which indicates that the point density is generally lower in rural or densely vegetated areas than in urban environments (e.g., cities), influencing the average point density and the low/high range.

Table 4: Point density statistics in Europe

	Low point density [ppsm]	High point density [ppsm]
Min	0.5	2
Max	40	40
Average	6.56	14

Figure 5 shows the point cloud datasets with a density below the European average. Among all countries and regions that reported the availability of point cloud datasets, only 36% have a density equal to or above the average (shown in solid green). A total of 45% reported a density below the average (dotted), while the remaining 19% did not provide information on point density in the elevation model (shown in dashed brown).

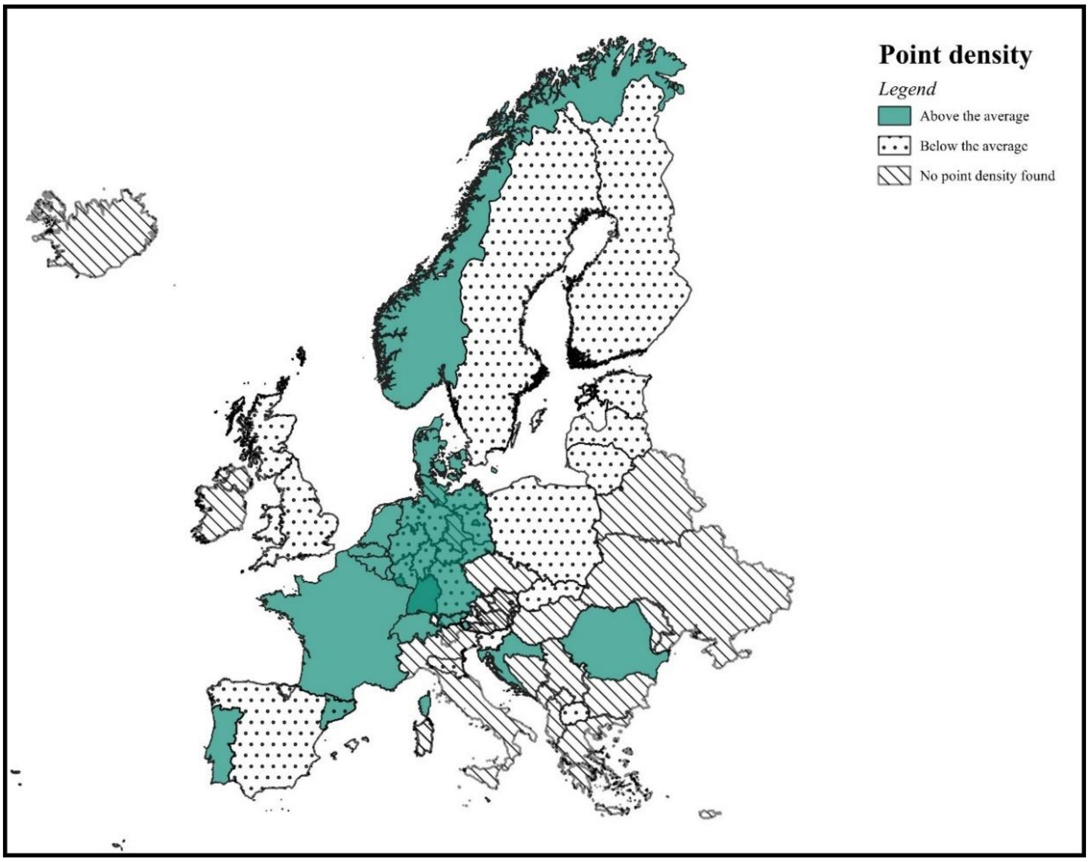

Figure 5: Average point cloud density overview in Europe, where the above average (solid green), below average (dotted) and where no point cloud density was found (dashed)

2.3.3 Question 3: Could you give an estimation of the absolute accuracy of the dataset?

The absolute accuracy of the point clouds and elevation models was determined to determine the average, minimum, and maximum absolute accuracy of point clouds in Europe. Accuracy is defined in planimetric (XY) and altimetric (Z) components. The percentage of point cloud datasets in Europe that meet or exceed the average accuracy value is also reported. The results are presented in Table 5.

Table 5: Absolute accuracy statistics in Europe

	Planimetric [m]	**Altimetric** [m]
Min	0.03	0.04
Max	1	0.659
Average	0.26	0.13
Per. Above [%]	32%	74%
Per. Below [%]	39%	10%
No info	29%	16%

Figure 6 provides an overview of the absolute accuracy available in Europe. The regions considered are shown, where green indicates that the absolute accuracy is below the European average, and grey means that the absolute accuracy is above average.

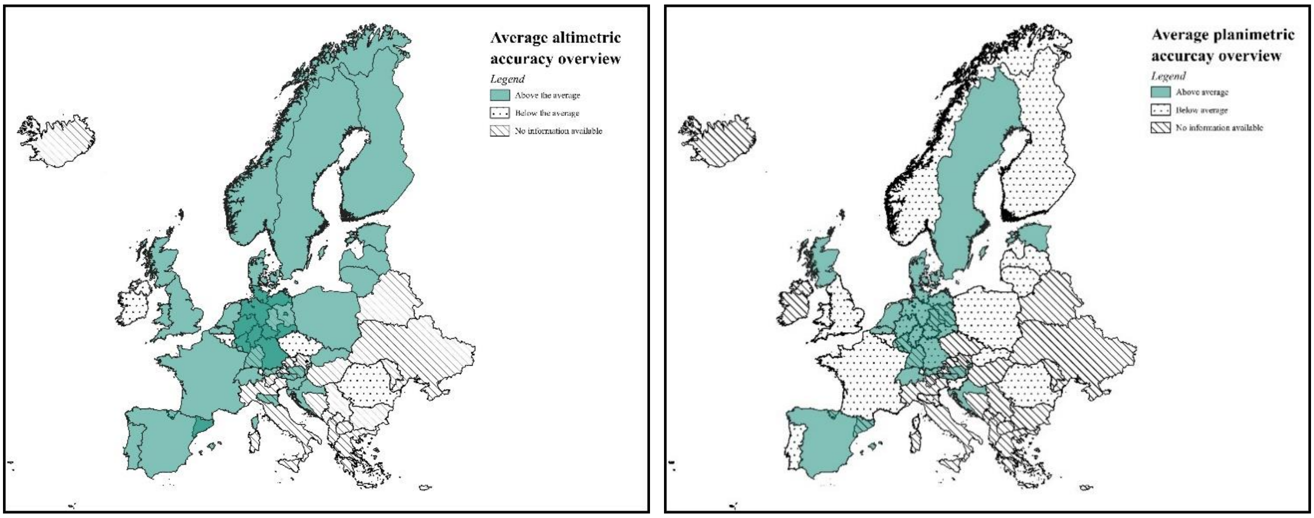

Figure 6: Overview of the absolute accuracy of point clouds in Europe, where the planimetric average is shown on the ***left*** *and the altimetric accuracy on the* ***right****. Green indicates values above the average, grey indicates values below the average, and white indicates areas without information.*

2.3.4 Question 4: Could you describe the definition of relative accuracy for point clouds used by your country or organisation?

Relative accuracy in point clouds is a key metric for defining the overall quality of the dataset (Kjørsvik, 2022). As the definition of relative accuracy varies across the description of point cloud quality documents, this question was included to identify different interpretations or “dialects” of this term. The responses to this question were, for example, as follows:

- *“The precision of the ALS system is around 1cm from point to point. After strip-adjusting and country-wide GCP correction, this results in an accuracy of 5cm in z and 15cm in xy.”*

- *“A metric used by the flight companies for flight strip adjustment in case of flight strip overlap”*
- *“The relative RMSE is determined between data that cover the same areas”*
- *“Sees relative accuracy as absolute accuracy”*
- *“Looking into internal swat accuracy/discrepancies”*

The responses indicate that relative accuracy is considered a measure of comparison between two-point cloud datasets representing the same area, assuming no significant spatial variations exist. In such cases, often a threshold of approximately 6 metres is used to indicate the absence of significant variations. To ensure that the spatial difference is low, the descriptions usually impose stricter requirements for relative accuracy than for absolute accuracy. Figure 7 shows how the relative accuracy can be regarded in point cloud datasets.

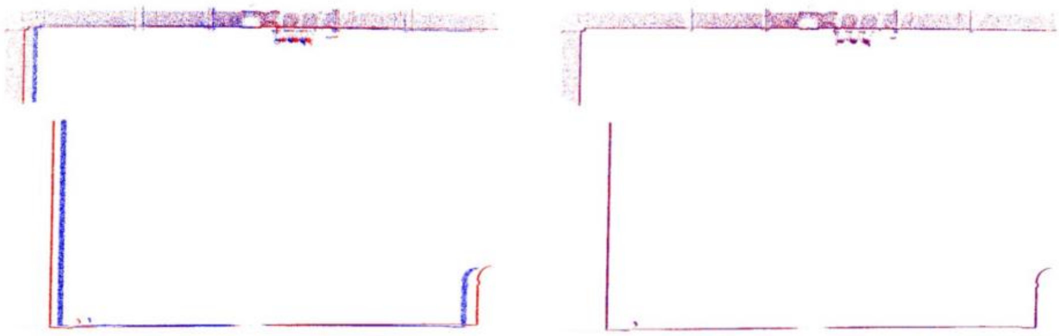

Figure 7: Illustration of the relative accuracy at the Drechttunnel, The Netherlands, where the left Schematic illustration shows having low relative accuracy between two surveys of the same object (blue and red), and the ***proper*** *schematic illustration shows having high relative accuracy between two surveys of the same object (blue and red)*

2.3.5 Question 5: How often is the dataset updated/acquired?

The acquisition cycle of a nation or region depends on the scope and geographic extent of the survey. A cycle of four to six years is commonly observed across Europe. Different parts of the area are acquired in separate blocks within such a cycle. A relevant aspect of this cycle structure is the temporal resolution of the data. For example, Poland reported that the acquisition cycle for urban areas is more frequent than for rural areas, thereby prioritising data collection in urban environments over vegetated areas.

The current temporal resolution of the point cloud datasets and Digital Elevation Models (DEMs) in Europe is presented in Figure 8. The overview indicates the most recent year of acquisition for each country or region, ranging from 2008 [red] to 2024 [blue], with the expected point clouds in 2025 [dashed black]. The black dots highlight the countries for which it is not specified when the point cloud acquisition took place. Please note that this does not necessarily represent full national coverage; in many cases, only parts of a country or region were surveyed due to cycle acquisition.

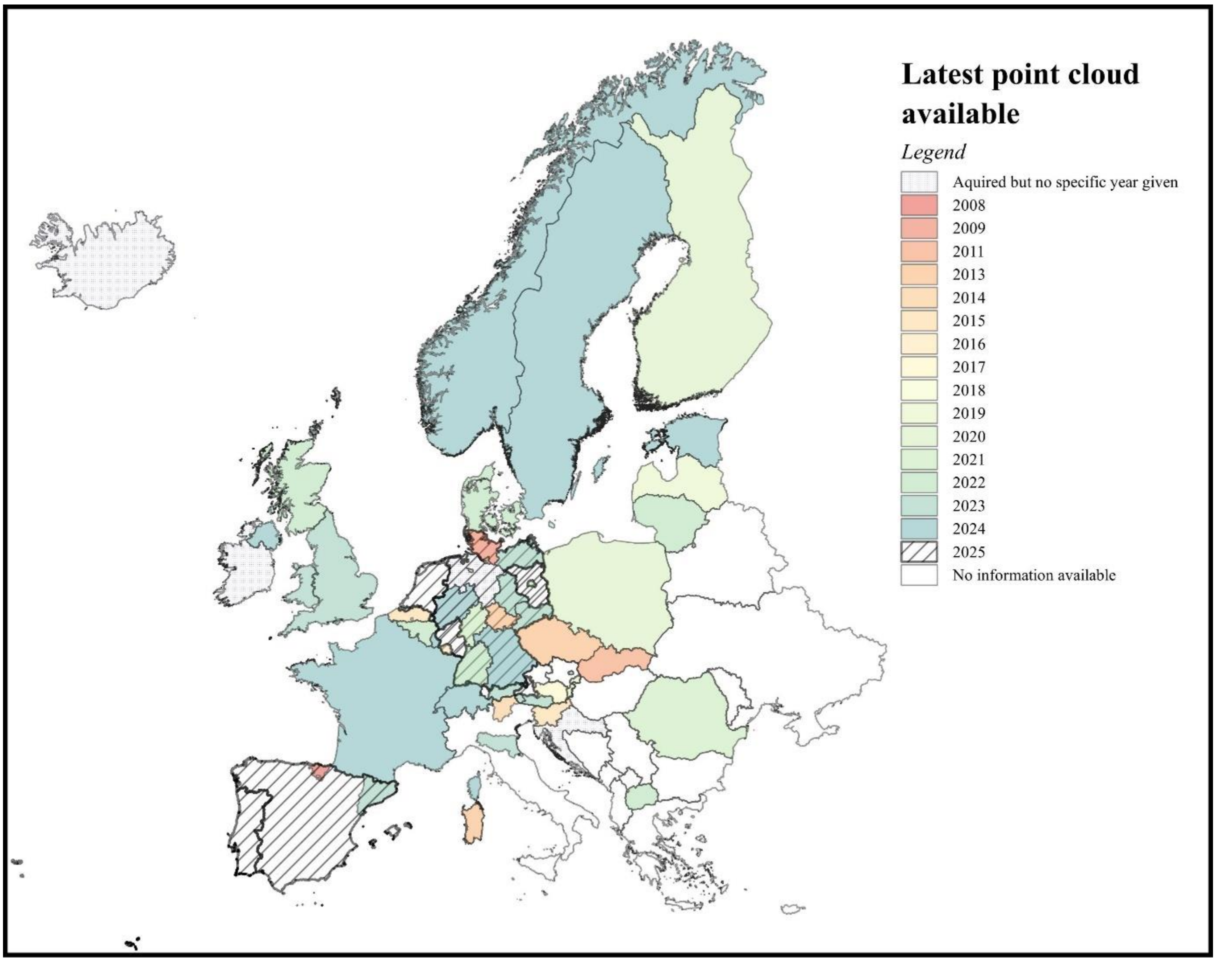

Figure 8: The Latest point cloud dataset available, ranging from (red) 2008 to (blue) 2024, (dashed) with the new point clouds that are expected in 2025, with the countries that have point cloud-based elevation data available (indicated by dots).

2.3.6 Question 6: When definitions for object classification in point clouds are available, which framework is used by your organisation or country?

Question 6 was included in the questionnaire to gather information on the object classifications and labels used in the various datasets. Among all the considered point clouds (both in the questionnaire and the online inventory), only 48% included information on the classification labels. The agencies responsible for acquiring the various point clouds apply classifications based either on the ASPRS standard or locally defined classification schemes.

Based on the responses to the questionnaire and the online inventory, Table 5 presents an overview of the identified classes in the categories of Figure 2 (i.e. Administrative/Meta, Natural Terrain, Man-made Structures and noise) including the percentage of point clouds of the 54 considered nation and regional datasets found in Europe, that contain classifications, as well as the corresponding codes used within the LAS format. The latter may include multiple codes, which are ranked from most to least used.

Table 6: Overview of all used ASPRS codes of the considered European point cloud datasets

Class name	***Number of point clouds***	***Most common class***
Administrative/meta	44%	Unclassified
Natural terrain	48%	Ground & low vegetation
Artificial structures	43%	Building
Noise	43%	Low point
User defined	4%	-

As Table 5 presents, 48% of the point cloud datasets include the natural terrain category, where the **Ground** class is the most used label in European point clouds. The definition of this label was uniform in all the investigated point cloud datasets. However, in the case of the Netherlands, the vegetation is classified as part of the Ground class. Therefore, there is no separate vegetation class.

The **vegetation** class is interpreted differently across various descriptions of point cloud quality. In some cases, vegetation is included within the ground classification, while in others, a fixed height threshold (in metres) is applied to distinguish vegetation from the ground. The categorisation of vegetation into low, medium, or high classes remains subject to interpretation and is, in some instances, inaccurately included in the ground class. For the LiDAR-acquired point clouds, the Swedish quality distribution (Lantmäteriet, 2024) gives two explanations that cause this misclassification:

1. Return pulses occurring at a short interval after a previous one may not be accurately recorded.
2. Vegetation materials can vary; in some cases, laser pulses cannot penetrate the vegetation to ground level.

The limitations and interpretations of the different vegetation types result in different interpretations regarding the height of the vegetation. Table 7 presents the height interpretations for each vegetation class, obtained from the online inventory.

Table 7: Definition of the ASPRS vegetation class

Name	***Height of the vegetation***
Low vegetation	Up to 0,15m; 0.3m; 0.4m or 0.5m
Medium vegetation	Up to 1.5m, 2m and 5m
High vegetation	Starting from 1.5m, 2m and 5m

In the category of artificial constructions, the **bridge** class seemed to lack uniformity across point cloud datasets, as different bridge components are classified under varying object types. Since the ASPRS standard defines a bridge as a specific class, its application varies depending on the point format of the LAS files. For example, the bridge deck is defined as Class 17, whereas Classes 10 and 13 refer to wires or guardrails, and Class 20 is used for bridge decks. The class variation suggests that the ASPRS classification scheme may be too detailed for a consistent application across European point cloud datasets.

Eight user-defined ASPRS labels were identified in the national and regional point cloud datasets, accounting for approximately 4% of the point clouds in Europe. These user-defined label definitions are further explained in Chapter 3 for each country. Since there are no guidelines on the user-defined class codes, other than the range of 65 to 255, the codes can overlap between different point clouds (i.e., the same code is used for different classes).

2.3.7 *Question 7: Does the climate footprint play a role in the update/acquisition frequency of the datasets?*

Point cloud datasets are frequently utilised to address challenges associated with climate change. However, their acquisition typically relies on platforms that are not carbon-neutral, such as aeroplanes, helicopters, and cars. To assess whether point cloud quality is influenced by efforts to reduce the climate footprint, Question 7 was included in the questionnaire. The answers provided by the respondents are presented in Figure 9, where *brown* indicates that the footprint was not considered, and white indicates that the footprint was considered. Grey indicates the countries where no point cloud data acquisition took place.

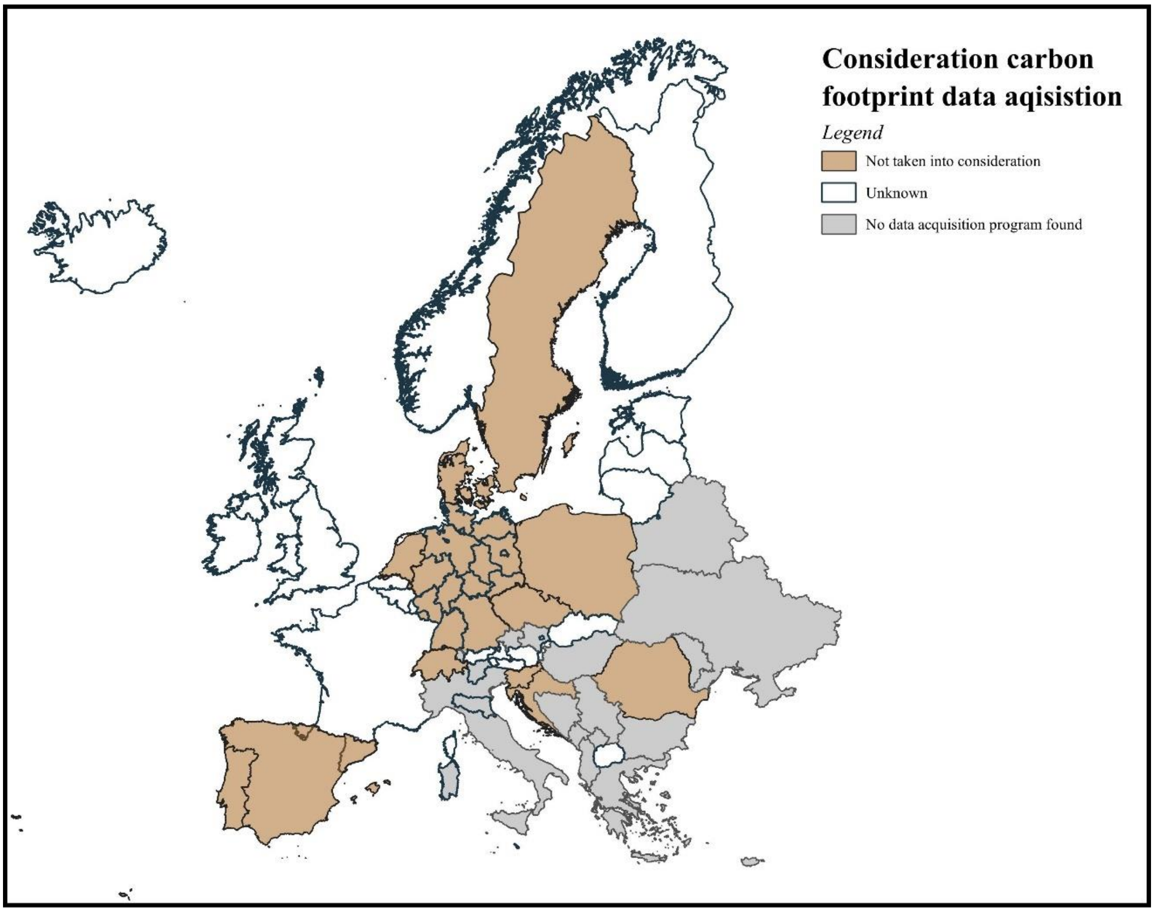

Figure 9: Climate footprint of point cloud dataset acquisition

Additionally, some respondents supplied further information in the questionnaire:

- With flooding becoming increasingly frequent, updating the point cloud datasets more frequently is essential. On the other hand, reducing the carbon footprint during updates also receives more attention, as evidenced by the use of aerial missions that combine sensors to capture both LiDAR and imagery in a single lift.

- It has not played a role so far, but it will likely be used for future data collection.
- Climate change is considered, at least a little. The role might increase shortly.
- No climate effect has been considered; however, the first acquisition has been made to support flood management.

No additional information was found in the online inventory based on carbon-neutral acquisition for the available point cloud datasets. Only that the data, for instance, in the case of Slovenia, is acquired to predict natural effects caused by climate change.

2.3.8 Question 8: Are the point cloud and the specification(s) compliant with the federal INSPIRE directive?

Most point clouds in Europe are reported to comply with the INSPIRE Directive. One respondent indicated that the data is still under development, while only one country reported that its data is not compliant with the directive. Although no specific INSPIRE Directive is dedicated to point clouds, a directive addresses elevation data relevant to point cloud datasets. More in-depth research is required to see what "being compliant with the INSPIRE directive" means for the respondents.

2.3.9 Question 9: The respondents were asked to rank a given list of quality parameters in the literature.

Table 8 summarises the respondents' answers:

Table 8: Quality component ranking based on the questionnaire results

Ranking	***Quality description name***
1	Point density
2	Absolute accuracy
3	Relative accuracy
4	Feature registration accuracy and definition
5	Coordinate system
6	Dataformat
7	Calibration parameters available
8	Environmental impact (e.g. leaves on trees, occlusion, etc.)
9	RGB colouring
10	Noise & Outliers

2.3.10 *Question 10: According to you, are there specification parameters missing in the previous question that are considered essential in your country for point cloud datasets?*

The respondents were asked if a quality component was missing to determine if the listed quality components for point clouds are sufficient. The following responses were given:

Quality components regarding <u>classification</u>

- The classification scheme and classification accuracy,
- Normalised intensity
- Metadata concerning the acquisition date and the number of classes

Quality components regarding the <u>Point Density</u>

- Point cloud spacing homogeneity and smoothness (on a flat surface). In the online inventory, the Norwegian "generic" point cloud quality description gives the following equation:

  $$point\ spacing = \sqrt{\frac{1}{point\ density}} \quad [1]$$

- The definition of point density is quite essential. In a point cloud dataset, 99% of the 1x1 m cells are expected to fulfil this point density requirement. That is entirely different from an average point density.
- As homogeneous data as possible, which is not easy to define. The gyro-stabilized mount during the data acquisition will improve the data
- Average point distance on the ground
- Point distribution

Responses other than the mentioned quality components:

- Date/time, especially for obtaining information about the state of vegetation.
- The actuality of the data (up to date)
- Maximum footprint
- Maximum scanning angle

2.3.11 *Question 11: Does your country integrate different point cloud datasets to create a single national homogeneous dataset?*

As this study focuses on determining the correlation between various point clouds acquired across Europe, based on availability and quality parameters, one of the questions addresses whether countries are already integrating point clouds to create a single, nationally harmonised dataset.

The responses indicate that available point cloud datasets in most European countries are not yet harmonised or integrated into a single dataset. However, many countries have plans to do so in the future. There is also growing interest in incorporating datasets not acquired by the leading national surveying authorities or produced at other levels of governance.

The respondents reported three harmonised national datasets distinguished by point density. In contrast, other respondents stated that harmonisation occurs when acquired using the same acquisition platform or under the same administrative level (e.g. national, provincial, or local). The national dataset in Switzerland stated that it currently maintains a fully harmonised national point cloud dataset. Based on online reviews of available descriptions in other countries, point cloud datasets appear harmonised in structure but not necessarily in intended use. For example, Norwegian point cloud quality descriptions guide different types of datasets, promoting a level of standardisation. The generic quality descriptions enable point clouds acquired under the *Høydedata.no* programme to be harmonised into a single, unified dataset.

The online inventory revealed that the respective national agencies in Germany and Austria had not published a national dataset until recently. At the same time, the respective regions (Bundesländer) acquired point cloud datasets so that national elevation data of both countries are available. Although the datasets are available for a harmonised national dataset, no attempt seems to have been made to create a harmonised point cloud dataset based on the available dataset of the provinces (Bundesländer).

3 ADDITIONAL INFORMATION ON THE EUROPEAN ACQUISITION PROGRAMS

To delve deeper into the main quality components and the potential point cloud dialects of each of the considered point cloud datasets, each country was researched that either responded to the questionnaire, reached out to the authors, or was identified during the desk study in 2024 to early 2025 (see Figure 3).

For each European country, the following is described when present: (1) the way point cloud datasets are available, (2) the accompanying quality parameters, (3) if an attempt is made to harmonise the dataset and (4) the classification labels that are present in the point cloud dataset.

Please note that the research was conducted using publicly available information between 2024 and 2025; during this period, variations in the data and new publications can have occurred without the authors' knowledge.

3.1 Austria

The results of the EuroSDR questionnaire, as stated by the Bundesamt für Eich- und Vermessungswesen (BEV), the responsible mapping agency in Austria, indicate that no national point cloud or point cloud elevation model is available. Therefore, data acquisition in Austria is more focused on the different regions in the country. Figure 4, which shows the different regions in Austria, is enlarged in Figure 10, where the availability of elevation data (point cloud or other elevation dataset) is provided for each region.

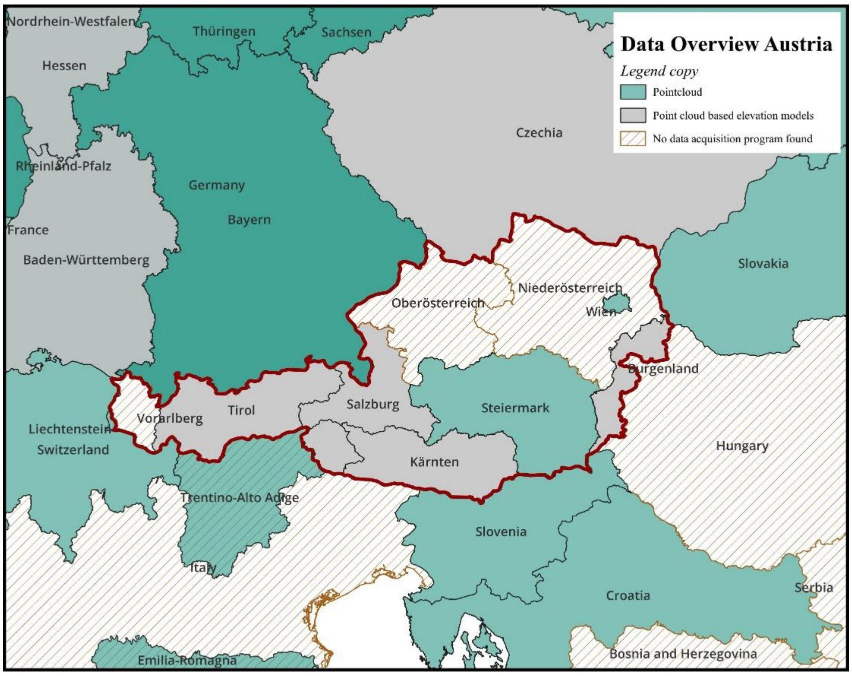

Figure 10: Overview of the Austria elevation data,
where green indicates the availability of the point cloud dataset,
grey is the point cloud-based digital elevation data,
dashed brow is when no information is available,
and red is the borders of Austria.

Table 9 presents the details for each region in Austria, including the type of elevation data, point density, planimetric and altimetric accuracy, temporal resolution, and data source. The point cloud datasets are acquired based on WGS 84 / UTM zone 33N (EPSG 32633).

Table 9: Quality parameters of the Austria point cloud datasets

Region	***Elevation data***	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
Burgenland	DEM	Unknown	0.15	0.075	2019
Kärnten	DEM	Unknown	0.2	0.075	2003-2006 2022-2023
Steinmark	LiDAR		0.40	0.15	2017
Salsburg	DEM	4-16	0.5	0.15	2007-2025
Wien [ALS]	LiDAR	15-20	0.15	0.1	2007
Wien [MLS]	LiDAR		0.01	0.01	2020
Tirol	DEM[1]	8	0.15	0.1	2018-2023

Based on the information pages, no classification definitions are available for the different open point cloud datasets or elevation models in Austria.

3.2 Belgium

Belgium has no (harmonised) national point cloud dataset available, but it is divided into two regions: Flanders, Wallonia, and Brussels. The following datasets are available as references for planimetric coordinates in Belgium Lambert 72 (EPSG: 31370) and altimetric coordinates in the Tweede Algemene Waterpassing (TAW) or the Deuxième Nivellement Général (DNG).

- For Flanders, this dataset is called the Digitaal Hoogtemodel Vlaanderen (DHV). The point cloud dataset is acquired by ALS and divided into different NGI kaartbladen, each containing 43 smaller areas. The Flanders point cloud dataset is a harmonised dataset from the same acquisition platform. (Agentschap voor Geografische Informatie Vlaanderen (AGIV), 2017)
- The point cloud data set of Wallonia was acquired by the Service public de Wallonie (SPW), by the ALS acquisition platform and is divided into six blocks. Wallonia's point cloud dataset is harmonised from the same acquisition platform. The point cloud dataset is available in LAS 1.2-1.4 and can be downloaded in LAZ (Dominique Buffet, 2014).
- The point cloud dataset of Brussels was acquired in April 2012 and October 2021. The data was acquired to create a city model, initially for a LoD2 and the second acquisition was to build a digital twin of the city (Perello, 2024), (Brussels-Capital Region, 2023).

Both point cloud datasets are also available in DTM and DSM (1m & 5m) and are freely accessible in the public domain. The quality descriptions for the Flanders, Wallonia, and Brussels point cloud datasets are provided in Table 10, which includes the version, point density (pssm), planimetric accuracy (m), altimetric accuracy (m), and the temporal resolution (time of acquisition(s)).

[1] The data is open for the DSM and DTM, but the LAS data is closed source and retrievable for a download fee.

Table 10: Quality parameters of the Belgium point cloud datasets.

	Version	**Point density [ppsm]**	**Planimetric accuracy [m]**	**Altimetric accuracy [m]**	**Temporal resolution**
Flanders	DHV-1	1	-	-	2001 - 2004
	DHV-2	8 - 16	0.10	0.05	2013 - 2015
Wallonia	-	1.29-1.78	1	0.4	2013 – 2014
	-	6.8	1	0.4	2021 - 2022
Brussels (city model)	-	30			April 2012
	-	67			October 2021

The DMV point cloud datasets include the following metadata information, in addition to location and classification: GPS time, intensity, return number, Number of returns, Point source IF, and RGB.

The classification labels for the Flanders and Wallonia point cloud datasets are given in Table 11. Please note that the DHV-I did not include any classification labels.

Table 11: ASPRS classification code overview of the Flanders point cloud dataset

Name	**APSRS Code**	**Flanders**	**Wallonia (2014)**	**Wallonia (2022)**
Reject/Unclassified	0	-	-	X
Above-ground (buildings, roofs, and others)	1	-	X	X
Undefined	1	X		
Ground	2	X	X	X
Tall vegetation (including linear vegetation)	4	-	X	X
Water	9	X	X	X
Bridge	10		X	X
Power lines	15	-	-	X

Additionally, the classification of the Wallonia point cloud dataset was further defined in three steps:

1. Full wave analysis for the classification of hard surfaces and vegetation
2. Morphological analysis to define the above-ground elements
3. Quality control and assisted classification to correct for false classifications in the dataset (e.g. points below the water level).

3.3 Croatia

Lidar data from the multi-sensor aerial survey of the Republic of Croatia were collected for disaster risk reduction assessment. The State Geodetic Administration (SGA) of Croatia acquired the data. The dataset is not available on an online platform but was, at the time of writing, only accessible from physical storage (hard disk). Based on the questionnaire responses, the initial acquisition covering the entire territory of Croatia has been completed, with plans to repeat it every 5 years. The quality parameters of the point cloud data are provided in Table 12.

Table 12: Overview of the quality parameters of the national point cloud of Croatia

	Point density [ppsm]	*Planimetric accuracy [m]*	*Altimetric accuracy [m]*	*Temporal resolution*
National point cloud	10	0.2	0.1	5 years

The classification scheme used to define the classes in the point cloud was defined internally by the SGA for reference purposes in tender documentation.

3.4 Czech Republic

The Czech Republic has no publicly accessible point cloud dataset, only an ALS-derived digital elevation model. The *Digitální model reliéfu České republiky* (DRM) is available in different generations, including the fourth (4G) and fifth (5G). Based on the DMR 5G quality report, the LiDAR acquisition was conducted at an elevation of 1200m and 1400m (Leitmannová, Gálová, & Michalík, 2017).

The elevation model has an altimetric error ranging from 0.18m to 0.3m, depending on the terrain type. The DMR 5G dataset was acquired between 2009 and 2013 and was published on June 30, 2016. The data has an update cycle, with the latest acquisition campaigns between 2020 and 2025.

There is no information about the classification of the digital elevation model.

3.5 Denmark

Denmark's national point cloud acquisition campaign is the ’Danmarks Hojdemodel (DHM)’. The dataset is available as open data; however, you must register to download the data through the Danish geoportal. The acquisition is conducted every five years, covering one-fifth of Denmark each year. The point cloud is acquired in five blocks and integrated into a single national dataset (Danish Agency for Data Supply and Efficiency, 2020).

The point cloud of the DHM (product name**:** *Punktsky***)** is available in accordance with LAS 1.4 specifications, utilising the LAZ data structure to distribute the data. The point cloud is referenced to zone 32 of ETRS89 (EPSG: 25832) and uses the DVR90 vertical reference system.

The following quality parameters are provided with the dataset, as listed in Table 13: point density (ppsm), altimetric and planimetric accuracy (in meters), and temporal resolution.

Table 13: ASPRS classification code overview of the Denmark national point cloud dataset

	Point density [ppsm]	**Altimetric accuracy [m]**	**Planimetric Accuracy [m]**	**Temporal resolution**
DHM	8	0.06	0.15	2018 - 2022

The DHM classifications are based on the ASPRS code scheme, presented in Table 14, along with the name and label codes in the point cloud.

Table 14: ASPRS classification code overview of the Denmark national point cloud dataset

Name	**ASPRS Code**
Noise	1, 7 or 18
Ground[2]	2
Water	9
Low Vegetation (up to 0.3m)	3
Medium Vegetation (0.3m to 2m)	4
High vegetation (>2m)	5
Building[3]	6
Bridges	17
Power lines	#
Construction cranes	#
Other surfaces	#

3.6 Estonia

The Estonian national point cloud dataset is collected in a 4-year cycle, except for the regions of Tallinn, Tartu and Pärnu areas, which are acquired in a 2-year cycle (Maa-ja Ruumiamet, 2020) & (Maa-ja Ruumiamet, 2025). There are four versions available as open data: ALS1 (2008-2011), ALS-II (2012-2015), ALS III (2017 -2020) and ALS IV (2021-2024).

The Tallinn, Tartu, and Pärnu regions are at a lower altitude (1200m) than the national dataset (2000m or 2600m). These datasets are integrated into a single national dataset and released on a regular update cycle. To meet the requirements of the forest department, a high-altitude point cloud was acquired. The national mapping agency published Table 15 about the quality parameters based on the flight altitude (Maa-ja Ruumiamet, 2020) (Maa-ja Ruumiamet, 2025).

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[2] Points on the road or roads are not classified as roads surface (class 11) or railway (class 10), but as ground points

[3] Points that deemed to fall within building interiors (ground and vegetation) are not included in the computation of the DTM/DSM, such as that these points are unclassified in the DHM/Puntsky.

Table 15: Overview of the point densities of the national point cloud of Estonia

Purpose	Altitude range [m]	Point Density ALS1	Point density ALS-II	Point density ALS-III	Point density ALS IV
Mapping of densely populated areas	1200-1500	2.3	2.3	18	18
Priority mapping for imaging	2000	-	-	3.5	3.5
Nationwide mapping	2400 - 2600	0.445	0.445	2.1	2.1
Forest mapping	3100 - 3800	0,14	0.14	0.8	0.8

The national point cloud of Estonia is a harmonised dataset in which datasets with different quality parameters and cycles are aligned.

The following classifications are applied in Estonia's national dataset, as shown in Table 16.

Table 16: ASPRS classification code overview of the Estonia national point cloud dataset

Name	ASPRS code
Unclassified	1
Terrain	2
First and middle reflections [4]	5
Buildings[5]	6
Noise (below terrain)	7
Water[6]	9
Terrain under bridges (overlap bit)	17
Noise (above terrain)	18

3.7 Finland

Finland's national point cloud dataset, *Laserkeilausaineisto*, is acquired by the National Land Survey of Finland (NLS). The dataset is available in two versions, based on point density (National Land Survey of Finland, 2019) & (National Land Survey of Finland, 2025) namely the *0.5p* and *5p*. The 5p point cloud dataset can be accessed, but it may incur additional download costs. The point cloud is provided

[4] Mostly trees/ bushes
[5] Points which fall inside the buildings layer of Estonian Topographic Database, starting from the year 2012 data
[6] Points which fall inside the water layer of Estonian Topographic Database, starting from the year 2012 data

in the LAS 2.0 format and uses the ETRS-TM35FIN coordinate system (EPSG:3067) with the N2000 height system (EPSG:3900).

The following quality parameters describe the two datasets, given in Table 17.

Table 17: Overview of the quality parameters of the national point clouds of Finland

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
0.5p	0.5	0.60	0.15	2008 – 2019
	0.5	0.45	0.10	2020 onwards
5p	5	0.45	0.10	2020 onwards

The quality specifications of both versions also specify the point density,

- In the 0.5p version, the mean distance between the points is approximately 1.4m
- In the 5p version, the mean distance between the points is approximately 0.4m.

The classifications in the 0.5p version of the 2008 to 2019 dataset are given in Table 18, with the ASPRS code for the temporal resolution.

Table 18: ASPRS classification code overview of the Finland national point cloud dataset

Name	***ASPRS Code (2008 – 2019)***	***ASPRS Code (2020 onwards)***
Unclassified	1	1
Ground	2	2
Low vegetation	3	3
Medium vegetation	-	4
High vegetation	-	5
Low error points	7	-
Overlap area	-	12
Standing water	9	-
Bridge points	10	-
Overlap area	13	-
Streaming water	14	-
Air points	-	15
Isolated	-	16
Fault points	-	17

The NLS uses its own definitions; however, these classes can differ from year to year. The following variations in classes are present between the two cycles of point clouds:

Vegetation

The class *vegetation* is defined in the 2008–2019 point cloud as 'low vegetation' for all the points that do not correspond to the final return echoes. While in the 2020 onwards point cloud, the vegetation is separated into three classes defined by the height above the ground level:

- Low: from the height of 0.0–0.5 metres above ground level
- Medium from the height of 0.5–2.0 metres above ground level
- High: from the height of 2.0–50.0 metres above ground level

Low error points

The class *low error points* are defined in the 2008 – 2019 point cloud datasets by either (1) intense glare, (2) bright objects of multiple laser pulse reflections or (3) points that are high in the air due to the multipath of high objects. The points that have not been classified as low-error points are present in classes 1, 13, or 3. In the data sets acquired 2020 onwards, low-error points are automatically classified as statistically too low compared to the surrounding points.

Standing and streaming water [2008 – 2019]

The values of the *standing water class* are automatically computed based on the water level in the topographic database and the average water level of the standing water points in the point cloud. The *streaming water class* values are points within the fluvial areas of the Topographic database that have been assigned to the 'Ground' class by the automatic surface classification.

Air points [2020 onwards]

The class *Air points* contains the points defined as clouds, flying objects or other airborne objects.

Isolated points [2020 onwards]

The class Isolated is defined in the 2020 onwards point cloud as single points in the air and below ground level, where 10 or fewer points are within a 5m radius of the original point. This class can also include points from power lines or tree trunks in an open forest.

Fault points [2020 onwards]

Points due to scanner faults, remaining after automatic classifications, are classified in this class.

3.8 France

In France, the *Institut national de l'information géographique et forestière* (IGN) is responsible for acquiring and distributing point cloud data. There are three LiDAR point cloud datasets available in France: (1) national DEM, (2) LiDAR Haute density (HD) and (3) the bathymetric dataset Litto3D. The National DEM is not available as a point cloud dataset; however, LiDAR and photogrammetric methods are used to generate it.

The Lidar-Haute Density (HD) program is expected to have a point cloud dataset by 2026, covering metropolitan France, its departments, and overseas regions (excluding French Guiana). The HD program covers multiple areas and uses various reference systems for the LiDAR data. The mainland on the European continent uses a geodetic system (XY) known as RGF93 (Lambert 93), while the altimetric system is IGN 1969. Based on (Institut Géographique National (IGN), 2024) (Institut Géographique National (IGN), 2018), the following quality parameters are used for the elevation models in France (Table 19).

Table 19: Overview of the quality parameters of the national point clouds of France

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
National DEM[7]	>1	0.6	0.2	<2018
LiDAR HD[8]	>10	0.5	0.1	2024 onwards
Litto3D	0.4	0.6	0.2	

The LiDAR HD point cloud dataset classification codes include the following ASPRS codes; three classes are added as user-defined classes in Table 20.

Table 20 ASPRS classification code overview of the France national point cloud dataset

Name	***ASPRS Code***
Unclassified	1
Ground	2
Low vegetation	3
Medium vegetation	4
High vegetation	5
Building	6
Water	9
Bridge deck	17
Perennial overlay	64
Virtual points	66
Miscellaneous – built-up areas	67

The following definitions were provided in the LidarHD for the classification codes listed in Table 20.

<u>*Vegetation*</u>

The France LiDAR HD defines vegetation as:

- Low: from the height of 0.0m to 0.5m above ground level, while the vegetation should be at least 0.2m from the ground.
- Medium from the height of 0.5m to 1.5m above ground level
- High: from a height that is higher than 1.5 metres above ground level

[7] photogrammetric method, these altimetric error cannot exceed between 0.5m and 0.7m, where the pixel size cannot exceed a 0.2m

[8] The LiDAR HD also includes a relative accuracy where the relative planimetric accuracy is set at 0.25m and the altimetric accuracy at 0.05m.

Perennial overlay

This user-defined class contains all the overburden features, excluding buildings, vegetation, and bridges. These features are classified as perennial, meaning the objects mark the landscape. Examples that are included in this class are: high points such as wind turbines, cable cars, telecommunications aerials,

- electricity distribution networks (cables and pylons), catenaries, etc.
- bridge elements above the deck (stays, pillars, etc.).

This class does not include:

- vehicles of any kind.
- people, animals
- transitory objects (construction cranes, wood piles, manure, beetroot, bales of hay or straw, etc.)
- items too small to be identified with confidence

Virtual points

The 'Virtual Points' class contains artificial points created under bridges to facilitate their removal from numerical models. Only 'optimised point clouds' contain points classified with this value.

Miscellaneous - built-up areas

The groups of points in this class exhibit building characteristics (such as flat and high surfaces), but do not pass the cross-confirmation test of the BD TOPO and the Artificial Intelligence processing module.

This is included in this class (non-exhaustive list):

- Certain types of vegetation (well-trimmed hedges, umbrella pines, clumps close to housing)
- Rocks and areas of broken slopes.
- Terraces
- building site huts, storage of materials and small-scale construction buildings.
- buildings not visible on aerial photos and not present in the building database (i.e. recently constructed)
- parts of low buildings (i.e. awnings).
- caravans and bungalows.
- buildings with atypical shapes.

3.9 Germany

In Germany, the availability of point cloud datasets is divided between the federal government and the *Bundesländer* (federal states), reflecting a distinction between national and regional scopes. Several datasets in Germany are available as open-access point cloud data. All elevation or point cloud datasets are acquired using the ETRS89 / UTM Zone 32 or 33 coordinate systems. For vertical reference, data acquired before 2017 use the DHHN92 height system, while data acquired from 2017 onwards use the DHHN2016 height system.

The availability of point cloud datasets across the *Bundesländer* is shown in Figure 11. Note that the federal dataset is not included in this figure; however, the entire country is acquired through acquisitions by federal institutions.

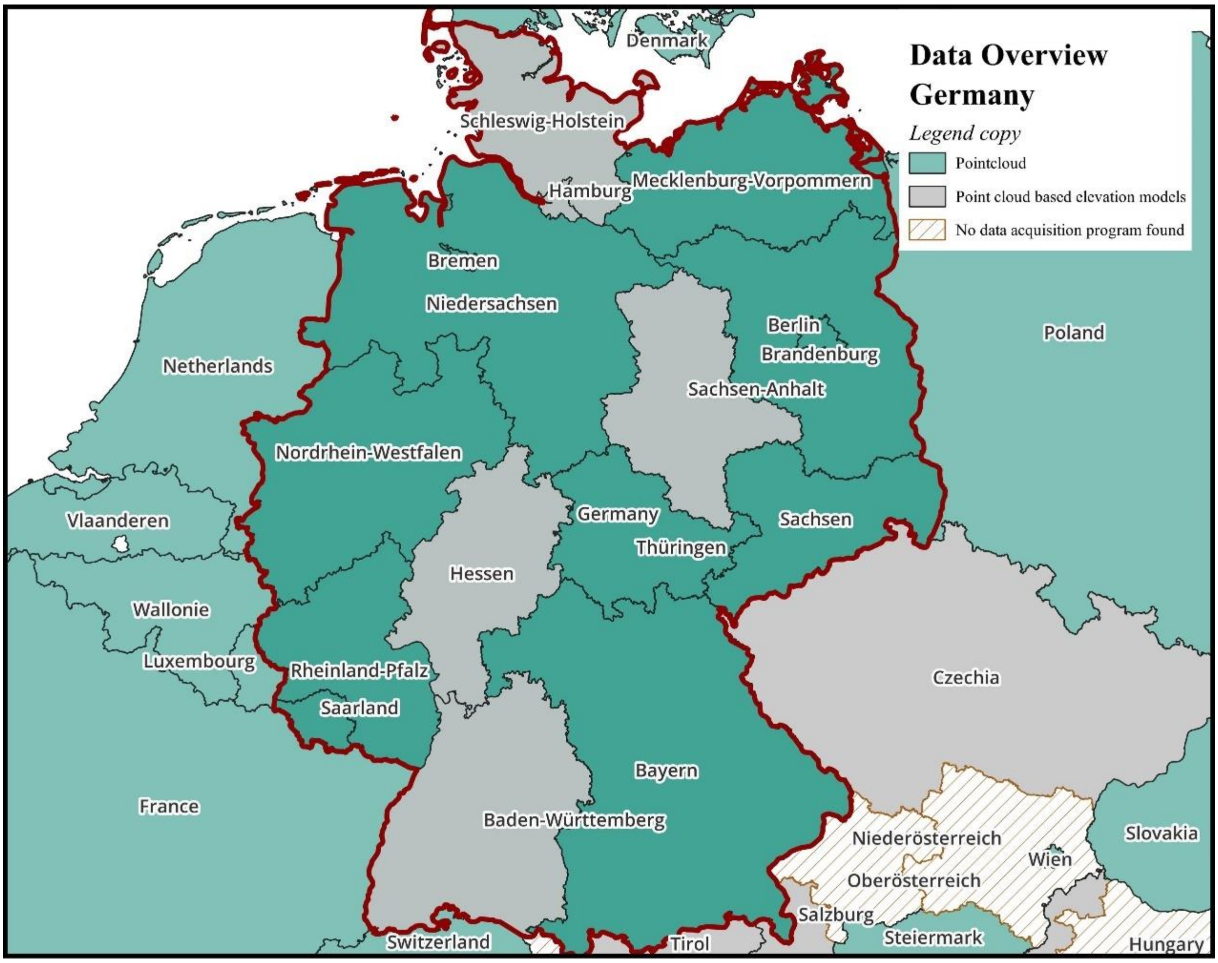

Figure 11: Overview of the German elevation data, where green indicates the availability of the point cloud dataset, grey is the point cloud-based digital elevation data, A dashed brow is when no information is available. Furthermore, red is the colour of the borders of Germany.

In Table 21, the quality parameters are provided for each Bündnerländ and federal dataset, including the data type, point density (ppsm), planimetric accuracy (m), altimetric accuracy (m), and temporal resolution.

Table 21: Overview of the quality parameters of the federal and Bündnerländern point clouds of Germany

Region	Data type	Point density [ppsm]	Planimetric accuracy [m]	Altimetric accuracy [m]	Temporal resolution
Federal (national)	Point cloud	40	0.2	0.1	2025
Baden Wuttenburg	DEM	8	-	-	2022
Bayern	Point cloud	1	0.5	0.15	To 2012
	Point cloud	4	0.5	0.15	2012 onwards (latest of 2025)
Berlin	Point cloud	9.98	0.05	0.05	2021
Brandenburg	Point cloud	1	-	-	2008-2012
		5	-	-	2016 onwards
Bremen	DEM	-	0.1	0.1	2018
Hamburg		1 – 2	-	0.7	2010
Hessen	DEM	4	0.3	0.15	2021 (6-year cycle)
Mecklenburg-Vorpommern	Point cloud	<2	0.3	0.15	2023
Niedersachsen	Point cloud	4	0.3	0.15	-
North Rein West has fallen[9]	Point cloud	4 to 10	0.3	0.15	2024 (5-year cycle)
Saarland	Point cloud	8		0.2	2016
Sachsen	Point cloud	4	0.3	0.15	2023 (6-year cycle)
Schleswig-Holstein	DEM	4	0.3	0.15	2009
RheinlandPfalz	DEM	4	0.3	0.15	2025 (4-year cycle)
Thüringen	Point cloud	4	0.3	0.15	2013 (5-year cycle)

The online inventory did not find a harmonised point cloud dataset where all the regional point cloud datasets made available by the Bündnerländern are aligned. The table shows that the quality specifications show strong similarities in accuracy. The planimetric accuracy is <0.3m, and the altimetric accuracy is <0.15 (apart from Hamburg).

Germany's federal national point cloud dataset is specified so that the point cloud remains entirely homogeneous across all acquisition blocks. While the point density is significantly higher than in the Bündnerländern, the accuracy is 0.1m (planimetric) and 0.05m (altimetric) lower.

In Germany, not all point cloud datasets of the Bündnerländern include classification. Hence, Table 22 presents the datasets and their classifications. Please note that the federal point cloud dataset will have

[9] The specification mentions that this value can increase in areas where vegetation is present (depending on the time of flight).

12 classification labels, but the authors do not know which labels are present in the data (Andreas & Patrick, 2025).

Table 22: ASPRS classification code overview of the Federal & Bunderlanden point cloud datasets

Name	***ASPRS Code***	***Bayern***	***Berlin***	***Hessen***	***Nieder-sachsen***	***North Rein West fallen***
Default	0	-	X	-	-	-
Unclassified	1	X	-	X	X	X
Ground	2	X	X	X	X	X
Low Vegetation	3	-	-	X	X	-
Medium Vegetation	4	-	-	X	X	-
High Vegetation	5	-	-	X	X	-
Buildings	6	X	-		X	-
Low Point (Noise)	7	-	-	X	-	-
Water	9	-	-	-	X	-
Wire - conductor	14	-	-	-	X	X
Bridges	17	-	-	-	-	-
High Noise	18	-	-	-	-	-
Ignored ground	20	-	-	-	-	X
High-voltage power lines	64	X (since 2025)	-	-	-	-
Towers / Masts / electric pylons	19 (69)	X (since 2025)	-	-	-	-

The required class definitions do not differ between contractors collecting point cloud datasets across different areas, ensuring the same classification throughout the country.

3.10 Greece

Greece does not offer an open-access point cloud dataset, as data acquisition is conducted primarily for military purposes (Kakoulaki, Martinez, & Florio, 2021). However, aside from the restricted national elevation data [JRC], one dataset is available through the OpenTopography database: the *2012 Santorini, Greece LiDAR dataset EU-12-12-137***.**

This dataset was acquired for the research conducted by P. Nomikou et al. (2014) on the Greek volcanic islands of Nea Kameni and Palea Kameni, Santorini, Greece. The point cloud was obtained using ALS, with a point density of 2.08 points per square meter. Unfortunately, no information is available regarding the altimetric and planimetric data. The dataset includes two classification labels: unclassified and no low point (noise).

3.11 Iceland

Iceland does not have a national point cloud dataset available. Figure 12 shows this country's elevation datasets acquired by LiDAR, photogrammetric and radar platforms. The elevation model, in this case a DTM, was built by the Institute of Nature Research from these datasets. The DTM covers approximately 38% of the country at a 10 x 10 m pixel resolution. An overview of the LiDAR-acquired digital elevation models in Iceland is given in Figure 12 (Landmælingar Íslands, 2025).

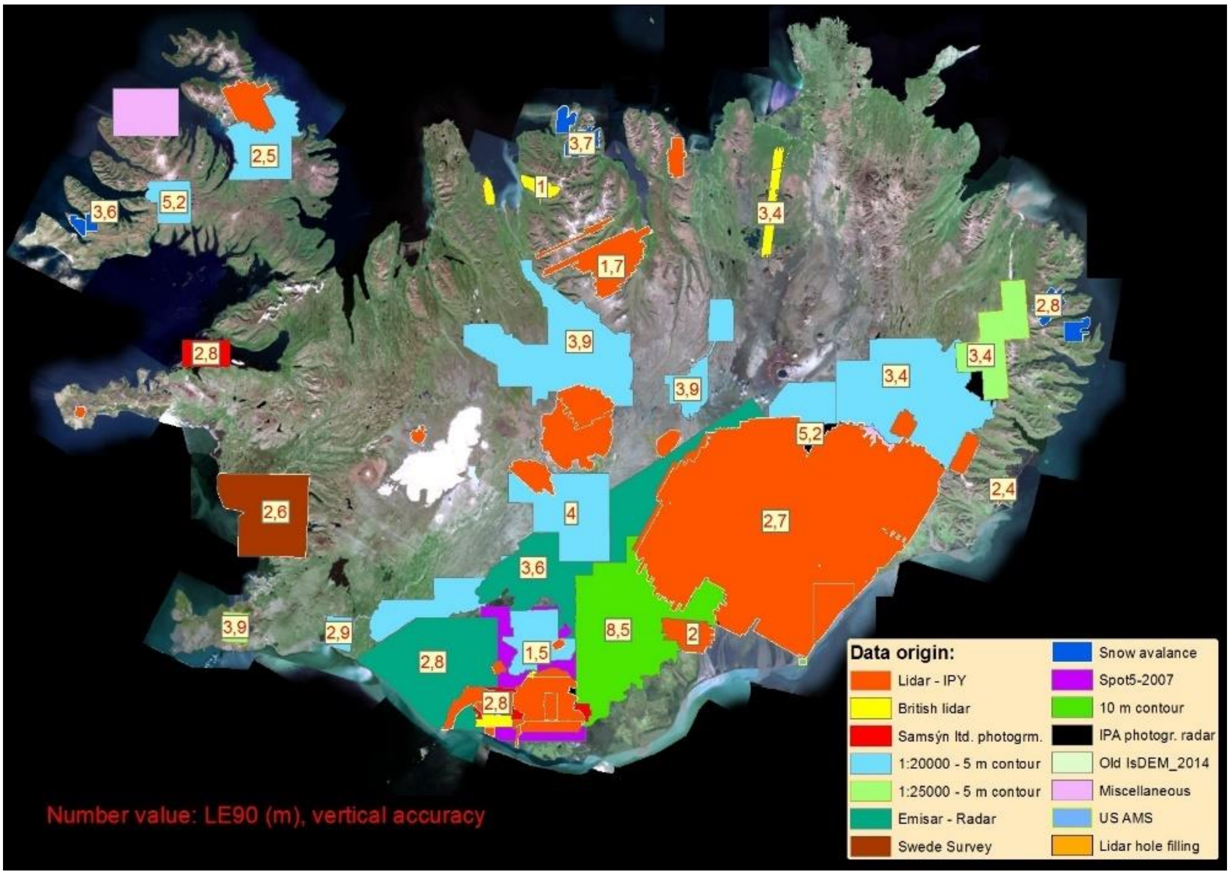

Figure 12: Overview of the elevation data sets acquired, among others, by a point cloud dataset. (Landmælingar Íslands, 2025)

3.12 Ireland

A LiDAR point cloud in Ireland is available only for specific regions. The data was collected between 2005 and 2014 and has an overall accuracy of 0.25m. The data is not freely accessible but can be purchased by a transfer view and will be delivered in TXT format in Irish Grid (IG) or Irish Transverse Mercator (ITM) projections. An overview provided by Tailte Éireann (2025) is presented in Figure 13, where the green polygons provide a visual representation of the available LiDAR point clouds.

Figure 13: Overview of available point cloud datasets in Ireland, where in green the regions with available LiDAR point cloud data are available (Tailte Éireann, 2025)

The Open Topographic LiDAR Data of Ireland (Geological Survey Ireland, 2024) indicates that LiDAR point clouds were used for elevation models during an acquisition campaign between 2015 and 2021. No further information is given regarding the quality parameters, harmonisation or classifications. According to the article by Zolanvari et al. (2019), the city centre of Dublin was acquired by the Urban Modelling Group at University College Dublin in 2007 and 2015. The data have a point density of 250-348 points per square metre (ppsm). No information was provided regarding the accuracy levels. There are 13 classes available in the Dublin point cloud, as shown in Figure 14. However, no labelling structure was provided to indicate how the codes in the point cloud correspond to these classes.

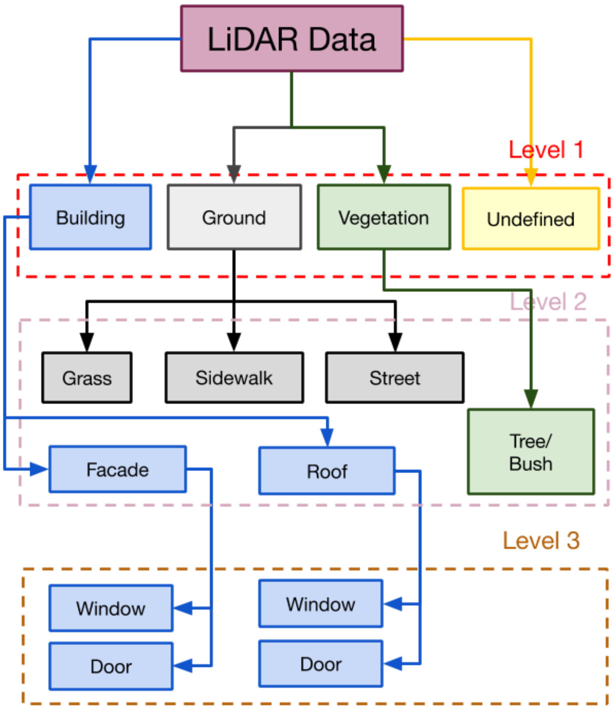

Figure 14 Classification levels and categories of the Dublin City Centre point cloud dataset (Zolanvari & Natanzi, 2020)

3.13 Italy

Italy lacks a national LiDAR dataset, as geo-data acquisition is typically conducted by the regions or for specific cases. The elevation model, TINITALY/01, available in Italy, is constructed from contour lines and spot heights derived from the Italian Regional topographic, satellite-based global positioning system points, ground-based and radar altimetry data (Tarquini, et al., 2007). The latest version of the digital elevation model was constructed in 2023.

Part of the TINITALY is the regional elevation data. The online inventory for the provinces indicated that Regione Emilia-Romagna (Regione Emilia-Romagna, 2025), Sicily, Sardinia, Tuscany, Trentino, South Tyrol and Lombardian have specific elevation models available. The quality descriptions are given in Table 23 for the two regional point cloud datasets in Italy. In Italy, the point clouds or elevation models are not combined into a single dataset.

Table 23: Overview of the quality parameters of the regional point clouds of Italy

Region	***Data type***	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
Regione Emilia-Romagna	Point cloud	8	0.3	0.08	2023 onwards
South Tyrol (Autonomous Province of Bolzano)	Point cloud	4	0.15	0.5 to 0.7	2007-2013

No information was found regarding the classification labels of the two-point cloud datasets available in Italy.

3.14 Latvia

Two open point cloud datasets are available in Latvia: (1) the national point cloud dataset acquired for the digital elevation model (Latvian Geospatial Information Agency (LGIA), 2025), and (2) the historical city model of Riga (GEO RiGA, 2025). The reference system of the point cloud datasets is linked to the LKS-92 TM and the Latvian standard height system LAS-2000.5. The national point cloud was acquired between 2013 and 2019, and the data were processed in acquisition blocks. Therefore, the different blocks were integrated into a single data set to make the data available to the public domain.

The quality parameters of both point cloud datasets are given in Table 24, where the point density [ppsm], altimetric and planimetric accuracy and the temporal resolution are shown.

Table 24: Overview of the quality parameters of the national point clouds of Latvia

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
National point cloud	4	0.36	0.12	2013-2019 (7 cycles)
Historical city centre	200 to 300	-	-	2022

The national point cloud dataset utilises ASPRS classification labels, as listed in Table 25. The labels are automatically annotated in the Latvian point cloud, while only the ground surface is manually detected.

Table 25: ASPRS classification code overview of the Latvia national point cloud dataset

Name	***ASPRS Code***
Ground	2
Low Vegetation	3
High Vegetation	5
Building points	6

3.15 Liechtenstein

The Liechtenstein dataset is available through Switzerland's national point cloud dataset. The dataset includes the same classifications, specifications and quality parameters (see Table 48) as the Switzerland dataset.

3.16 Lithuania

Lithuania's national point cloud dataset is available through a specific geoportal. The point cloud was acquired in 4 cycles using the ALS platform. The data is available in LAS format. The acquisition was conducted between 2019 and 2022. The resulting data were combined to create a single national point cloud dataset, which was then made publicly available. The point cloud dataset is available in Lithuania's LKS-94 local coordinate system.

According to Geoportal Lithuania (n.d.), the quality parameters of the point cloud dataset are presented in Table 26, including point density, planimetric accuracy, altimetric accuracy, and temporal resolution.

Table 26: Overview of the quality parameters of the national point clouds of Lithuania

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
Lidar_DR_LT	4 to 14	0.36	0.12	2019- 2022

The national point cloud dataset is, according to the metadata information of the dataset, smoothed and classified according to the LAS specification into eight classes:

Table 27: ASPRS classification code overview of the Lithuania national point cloud dataset

Name	***ASPRS Code***
Created, never classified; Unclassified	1
Ground	2
Low Vegetation	3
Medium Vegetation	4
High Vegetation	5
Building points	6
Noise points Low Point (noise)	7
Overlap Points	12

No further definitions are given for the LiDAR-DR-LT point cloud dataset classes.

3.17 Luxembourg

In Luxembourg, the national point cloud dataset is acquired by the *Le Géoportail National du Grand-Duché de Luxembourg*. An ALS acquisition platform acquired the Luxembourg national point cloud dataset from 2019 to 2024. Based on the (Administration du Cadastre et de la Topographie, 2019) the following quality parameters apply to this point cloud dataset are presented in Table 28.

Table 28: Overview of the quality parameters of the national point clouds of Luxembourg

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
National point cloud	15	0.3	0.6	2019-2024

The classification labels used in the Luxembourg point cloud data set are based on the ASPRS, which uses nine classes, as shown in Table 29.

Table 29: ASPRS classification code overview of the Luxembourg national point cloud dataset

Name	***ASPRS Code***
Unclassified points	0
Ground	2
Low vegetation	3
Medium vegetation	4
High vegetation	5
Buildings	6
Low Points (noise)	7
Water	9
Bridges, Footbridges, Viaducts	13
Powerlines	15

3.18 Malta

The airborne laser scanning platform acquired the point cloud for Malta, CloudISLE, in 2018. Table 30 shows the quality components of this dataset (Malta Planning Authority, 2018).

Table 30: Overview of the quality parameters of the national point clouds of Malta

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
CloudISLE	40	-	0.116	2018

Malta's point cloud is classified according to the ASPRS LAS data format. Table 31 shows the names and codes used for the Malta point cloud dataset.

Table 31: ASPRS classification code overview of the Malta national point cloud dataset

Name	***ASPRS Code***
Unclassified points	0
Ground	2
Low vegetation	3
High vegetation	5
Building	6
Low Points (noise)	7
Water	9

3.19 Netherlands

In the Netherlands, four large-scale point cloud datasets are available as open datasets:

- LiDAR Actueel Hoogtebestand (Actueel Hoogtebestand Nederland (AHN), 2025)
- 3D Basisvoorziening photogrammetric point clouds (van der Heide et al, 2024)
- Spoor in Beeld (van der Heide, et al, 2024)
- 3D Geodatafundament (high and waterways focused) (3DG) (van der Heide, et al, 2024)

Note that many municipalities in the Netherlands also acquire elevation information that is published on different platforms. Totaal3D and the urban data platform of Rotterdam are examples of available point cloud-derived elevation models. Consequently, multiple point clouds in the Netherlands have different quality parameters and classification definitions. The primary point cloud dataset in the Netherlands is the AHN, which has been acquired in six iterations for the whole country. The acquisition cycles are depicted in Figure 15, where each colour highlights a distinct acquisition cycle.

Figure 15: Acquisition cycles in the Netherlands' national point cloud dataset (AHN1 to AHN6).

The other 3-point cloud datasets have different cycles. The 3D Basisvoorziening is derived annually from national aerial imagery, while Spoor in Beeld and 3DG follow a project-based acquisition cycle. The quality parameters of all these datasets are given in Table 29. It shows the scope, point density, planimetric and altimetric accuracy and the temporal resolution.

Table 32: Overview of the quality parameters of the point clouds in the Netherlands

Name	**Scope**	**Point density [ppsm]**	**Planimetric accuracy [m]**	**Altimetric accuracy [m]**	**Temporal resolution**
AHN3	National	6	0.15	0.1	2014-2019
AHN4	National	>10	0.13	0.1	2020-2022
AHN5	National	>10	0.13	0.08	2022-2024
AHN - Coastal	National	0.5	0.5	0.1	Yearly
AHN6	National	>10	0.13	0.08	2025-2027
Spoor In Beeld	Railway infra	-	-	0.12	
Basisvoorziening	National			0.75	Yearly
3D Geodatafundament (3DG)	Highway and water infra.				Project based
(3DG) Topographic elevations	#		0.05 to 0.155	0.1 to 0.15	#
(3DG) Digital terrain models	#		0.75 to 0.25	0.025 to 0.065	#
(3DG) Tunnels	#	10,000		0.25	#
Municipality platforms	Municipalities	8 to 8000		0.02 to 0.1	Yearly cycles or project-based

The data point cloud datasets are available in LAS format and in the Cloud-optimised point cloud format. According to the online inventory, the AHN datasets include the mandatory classification codes in the point cloud datasets. These are presented in Table 33. In contrast to other point cloud datasets in Europe, vegetation is included in the ASPRS ground class.

Table 33: ASPRS classification code overview of the Netherlands national point cloud dataset

Name	**ASPRS Code**
Maaiveld (Ground & vegetation)	2
Buildings	6
Water	9
Power cable	14
Bridge	26

3.20 North Macedonia

The Kartverket of Norway acquired the LiDAR acquisition for the digital elevation models in North Macedonia. The acquisition project started in June 2018 and lasted until December 2022 (GIM International, 2021), (Agency for Real Estate Cadastre, 2018), (Norwegian Mapping Authority (Kartverket), 2021). The data is not publicly available. Instead, the data is only available to the project partners and the United Nations Development Programme's country office.

The only quality parameter available for the national digital elevation model of North Macedonia is the point density of the point cloud dataset. The point density is estimated between 2 and 5 [ppsm].

3.21 Norway

The Landmåler is responsible for acquiring Norwegian point cloud datasets. The quality descriptions are based on a matrix representing the standard requirements for each sensor type used (Kartverket, The Norwegian Mapping Authority, 2023). Descriptions are defined for ALS, bathymetric LiDAR, terrestrial LiDAR, MBES, and photogrammetry point clouds. The matrix is divided into four quality categories:

- High: for detailed mapping projects
- Medium: for specific projects
- Minimum: for the Nasjonal Detaljert Høydemodell (NDH)/ the national height dataset
- Custom: point clouds that will not be published on Norway's elevation data platform.

The point density for Norway is calculated based on the high category, where 80% of the 2m × 2m cells within a 10m × 10m area must meet the point spacing requirements, as shown in the table below. The density for this category must be computed using only the ground class of the point cloud. In contrast, the densities for the medium and low categories are calculated within 10 m × 10 m grid cells, requiring 95% of the cells to meet the specified criteria.

Table 34 presents the quality parameters per acquisition platform, level of detail, point spacing [m], planimetric accuracy [m] and the altimetric accuracy [m].

Table 34: Overview of the quality parameters of the generic descriptions for point clouds in Norway

Platform	***Level***	***Point spacing***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***
ALS	High	0.32	0.20	0.08
	Medium	0.45	0.40	0.14
	Low	0.70	0.50	0.14
TLS	High		0.20	0.08
	Medium		-	-
	Low		-	-
Image Matching	High		X	X
	Medium		0.08 – 0.12	0.12-0.18
	Low		0.20-0.50	0.30-0.75

The Norwegian point cloud datasets have mandatory classes based on the category and acquisition platform. The standard class labels are 1, 7 and 9, while the bathymetric lidar acquisition introduces new label classes, as shown in Table 35.

Table 35: ASPRS classification code overview of the Norway national point cloud dataset

Name	***ASPRS Code***
Seafloor	40
Water surface	41
Water surface Derived	42
Object submerged	43
Down object	44
No Bottom	45

3.22 Poland

In Poland, the Head Office of Geodesy and Cartography (GUGiK) acquired the point cloud dataset (2023). The data are acquired in the PL-EVRF2007-NH altimetric reference system (EPSG: 9719) for cities on a 2-year cycle and for other areas on a 4–5-year cycle. Besides the signal reflection, the point cloud dataset contains the red, green, and blue image values for a coloured representation. The quality description of the Poland point cloud dataset, divided into the rural and urban regions, is presented in Table 36.

Table 36: Overview of the quality parameters of the national point clouds of Poland

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
Rural	4	0.3	0.15	4-to-5-year cycle
Urban	24	0.3	0.15	2-year cycle

The classifications of the LiDAR point cloud are given in Table 37.

Table 37: ASPRS classification code overview of the Poland national point cloud dataset

Name	***ASPRS Code***
Created but never classified	0
Ground	2
low vegetation, i.e. 0–0.40 m;	3
Medium vegetation, i.e. 0.40–2.00 m;	4
High vegetation, over 2.00m	5
Buildings and engineering objects	6
Noise	7
Water	8
Overlap points	12

3.23 Portugal

In Portugal, there are two open point cloud datasets: (1) the Airborne LiDAR for the coastal areas of Portugal mainland - obtained in 2011, and (2) the Airborne LiDAR for the whole territory of Portugal mainland - currently being produced, to be finished in 2025 (Direção-Geral do Território (DGT), 2024)]. These two datasets differ in terms of quality parameters, including density, absolute accuracy, and relative accuracy. The mainland dataset will be available in the LAS format. The data are collected in PT-TM06/ETRS89 and Datum Altimétrico de Cascais.

Table 38, Direção-Geral do Território (DGT) (2024), presents the quality parameters for Portugal's mainland and coastal point cloud datasets.

Table 38: Overview of the quality parameters of the national point clouds of Portugal

Name	*Point density*	*Planimetric accuracy*	*Altimetric accuracy*	*Temporal resolution*
Coastland	1	-	0.20	2011
Mainland	10	0.3	0.1	2025

Additionally, the data is acquired in the same process as the aerial photo acquisition campaigns, where colour classification is fused with the point cloud data, including RGB and near-infrared.

The mainland point cloud of Portugal will include classification labels. These labels are listed in Table 39, along with their corresponding ASPRS codes.

Table 39: ASPRS classification code overview of the Portugal national point cloud dataset

Name	***ASPRS Code***
Other	1
Land	2
Low vegetation	3
Medium Vegetation	4
High Vegetation	5
Constructions	6
Noise	7
Bridges	20

Based on Table 39, the mapping agency further defines the vegetation class (Direção-Geral do Território (DGT), 2024).

<u>Vegetation</u>

The class *vegetation* is defined according to the following conditions:

- Low: from the height of 0.0–0.5 metres above ground level
- Medium height from 5 metres above ground level

3.24 Romania

The European Economic Area (EEA) and Norway Grants, in collaboration with the National Agency of Cadastre and Land Registration of Romania, funded the aerial point cloud datasets in Romania, specifically Laki2 and Laki3. The variation between the datasets is both in acquisition time and coverage. Both versions are available to academic users and public institutions. The data are acquired from the Krasovski 1940 ellipsoid, using the Stereographic 1970 projection (EPSG: 3844), and the elevation is referenced to the 1975 Black Sea normal height system (National Centre for Cartography, 2023).

However, based on the questionnaire, the available specifications, and the dedicated web portal, neither dataset has national coverage. They cover different regions of Romania, as given in Figure 16, where the transparent grey represents the region acquired in the Laki2 acquisition campaign, orange indicates the Laki3 acquisition area, and purple outlines the country of Romania. Such that the Laki2 dataset is available in Arad, Bihor, Hunedoara, and Alba, while Laki3 is available in Caraș-Severin, Gorj, Mehedinți, Dolj, Suceava, Neamț, Bacău, and Vrancea counties.

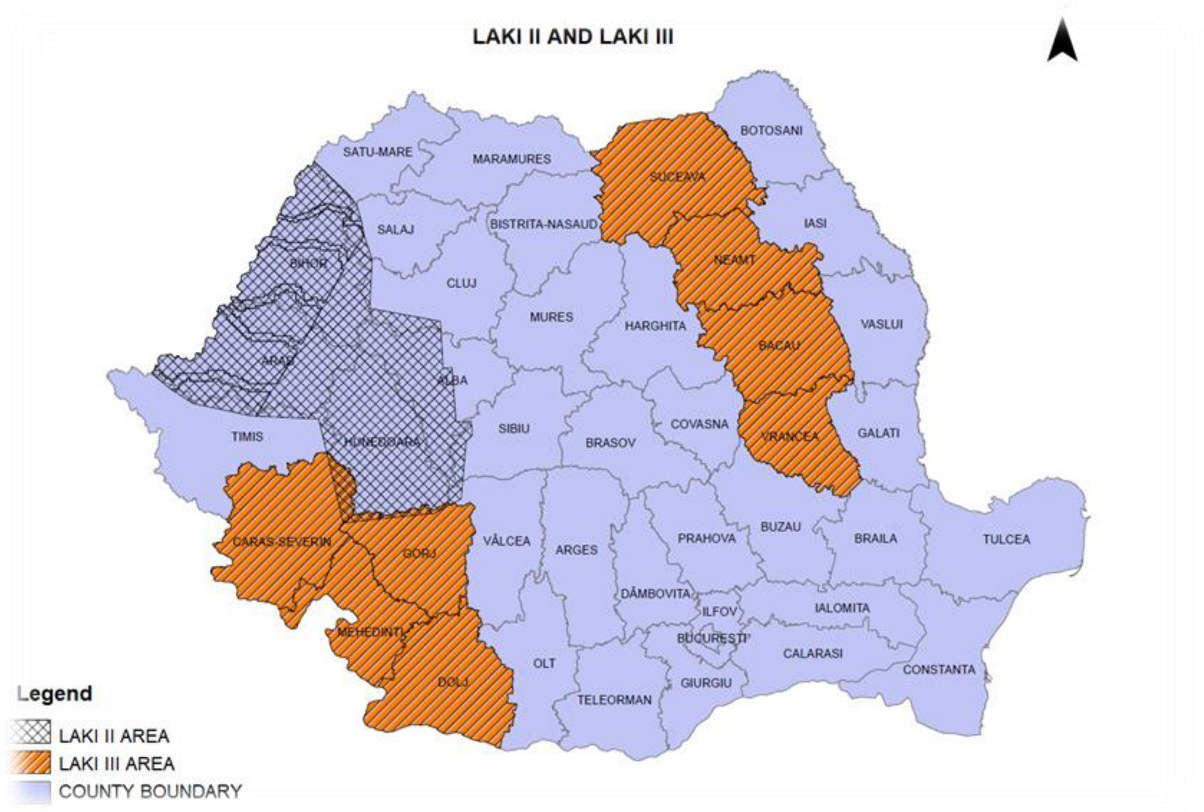

Figure 16: Overview of the Romania elevation data, grey indicates the Laki 2 acquisition area, orange the Laki3 acquisition area.

Based on the questionnaire results and the technical specifications provided by the National Centre for Cartography (CNC) (National Centre for Cartography, 2023); (Centrul Național de Cartografie, 2025), the following quality parameters were identified for the two different versions of the point cloud (Table 40). The point cloud datasets are delivered to the CNC in LAS 1.4 format, including point ID, X, Y, Z coordinates, GPS, time, return number, number of returns, intensity value, scan angle, flight strip number, and RGB value (RGB encoding based on the acquired images).

Table 40: Overview of the quality parameters of the national point clouds of Romania

Name	**Point Density [ppsm]**	**Planimetric accuracy [m]**	**Altimetric accuracy [m]**	**Temporal Resolution**
Laki 2	8 or 2 (depending on the area)	-	-	2017 - 2021
Laki3	5	≤0.4	≤0.3	2020 – onwards

Based on information from the *Centrul National de Cartografie of Romania,* the digital elevation model was constructed from the LiDAR point cloud. The RSME of DTM/DSM for Laki2 and Laki3 is 0.3 to 0.4 m and 0.4 m, respectively. The digital elevation model is available as open data.

The study by Perello (2024) highlighted that legal and military factors influence the point density of the Laki point cloud datasets. Stated in the Law article 182/2002, modified by Law 167/2015,

"*… aerial photogrammetric recordings obtained with airborne sensors of any type operating in the electromagnetic spectrum, with spatial resolution smaller than 15 cm, and aerial photogrammetric recordings obtained with active digital airborne sensors containing more than 9 points/m2, representing content elements relevant to national security, are considered state secrets."*

Therefore, a rigorous declassification process must be undertaken if the point density exceeds 9 points per square meter.

The ASPRS classes available in the point cloud dataset are presented in Table 41 for Laki2 and Laki3.

Table 41: ASPRS classification code overview of the Romanian national point cloud dataset

Name	**ASPRS code**	**Laki2**	**Laki3**
Unclassified	1	X	X
Bare earth	2	X	X
Medium vegetation	4		X
Building	6		X
Low point (noise)	7	X	X
Water	9		X
Bridge deck	17	X	X
High Noise	18		X

Definitions of Laki 3 apply to the classes Building [6] and Bridge Deck [17], which specify that they must have a minimum area of 50 square meters and 10 square meters, respectively.

3.25 Slovakia

In 2017, the Slovak Republic initiated a nationwide ALS mapping project in two cycles. The point cloud dataset is acquired in the ETRS89-TM34 reference system and the ETRS89-h height reference. The quality parameters of the point cloud dataset are given in Table 42 (Technical University in Zvolen, 2025)

Table 42: Overview of the quality parameters of the national point clouds of Slovakia

Name	***Point density required [ppsm]***	***Point density achieved [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
ALS cycle 1	5	15 to 52	0.3	0.15	2011
ALS cycle 2	15	34 to 45	0.2	0.10	2017

Based on Dekan (2024), the accuracy was validated by measuring the shift of the control points, while the points in the Ground class validated the altimetric accuracy. The following ASPRS classes are available in the point cloud dataset, presented in Table 43.

Table 43: ASPRS classification code overview of the Slovakia national point cloud dataset

Name	***ASPRS code***
Unclassified	1
Ground	2
Low vegetation	3
Medium vegetation	4
High vegetation	5
Building	6
Low point (noise)	7
Water	9
Bridge deck	17
High Noise	18
Power lines	14
Tower	15

3.26 Slovenia

The CLSS - Cyclic Laser Scanning Survey of Slovenia acquired the national point cloud dataset in 2015 to support flood management. The dataset was acquired in 36 blocks based on the ALS acquisition platform. The nationwide point cloud is distributed as LAZ and zLAZ files. The Surveying and Mapping agency commented that a new point cloud dataset was acquired in 2023.

Based on a presentation at the EuroSDR workshop (2020), the following quality descriptions were identified for Slovenia's national point cloud dataset (Table 44).

Table 44: Overview of the quality parameters of the national point clouds of Slovenia

Name	***Point density***	***Planimetric accuracy***	***Altimetric accuracy***	***Temporal resolution***
National point cloud dataset	2 to 10	0.3	0.15	2015 (3-to-6-year cycle)

The data includes classification labels, which follow the APSRS classification. No information was found on labels deviating from the APRS definitions or user-defined labels.

3.27 Spain

In Spain, the national data program is led by the National Geographic Institute, which utilises an ALS acquisition platform to create a nationwide points cloud dataset. Besides the point cloud dataset, a range of other geospatial height-related datasets are also acquired and available, including derived Digital Surface Models (DSM), Digital Terrain Models (DTM), and both national and local point clouds (de fomento, 2020). The data is acquired in the ETRS89 reference system except for the Canary Islands, which are in the REGCAN95.

For the point cloud dataset, the following quality parameters are defined in Table 45 and are based on the following sources (Instituto Geográfico Nacional (IGN), 2025), (Institut Cartogràfic i Geològic de Catalunya (ICGC), 2023) and (Gobierno Vasco, 2008). The data format for the PNOA LiDAR dataset changed from the LAS 1.2 format to the LAS 1.4 format between 2022 and 2025.

Table 45: Overview of the quality parameters of the point clouds of Spain

Name	***Point density***	***Planimetric accuracy***	***Altimetric accuracy***	***Temporal resolution***
PNOA LiDAR (national)	0.5	0.3	0.4	2008 - 2011
	0.5 to 2	0.3	0.2	2015 - 2021
	5	0.25	0.10	2022 - 2025
Catalonia	0.5	-	-	2008 - 2011
	0.5	-	-	2016 – 2017
	8	-	0.15	2021 - 2023
Basque (partly)	2	-	-	2007 – 2008

The point clouds are automatically classified and colour-coded, utilising RGB and the infrared images from the ortho photos captured at 0.25m or 0.5m pixel resolutions.

The classification scheme is not explicitly specified for the datasets, except for classes 0, 7, 11, and 24, which are used to define noise. However, the presentation by De Tejada (2025) suggested that classification for the third national acquisition programme will be based on AI, potentially allowing for more detailed classifications in the data.

3.28 Sweden

The Lantmäteriet acquires the National Laser Scanning Programme (SLS) point cloud dataset. The ALS acquisition platform acquires the data in the reference system SWEREF 99TM. The individual point clouds are harmonised into a single national point cloud dataset acquired in different cycles. There are two main versions available in Sweden: the "skog" (i.e. forest) point clouds covering agricultural and forest areas of Sweden, while the NH covers all other areas.

Based on the specifications of 2022 and 2024, the following quality descriptions are shown in Table 46 for Sweden's national point cloud.

Table 46: Overview of the quality parameters of the national point clouds of Sweden

Name	***Point density [ppsm]***	***Planimetric accuracy [m]***	***Altimetric accuracy [m]***	***Temporal resolution***
SLS – NH	0.5-1	0.2	0.05	2009-2019
SLS – Forrest	1 to 2	0.2	0.05	2009-2019
SLS – Forrest	1 to 2	0.2	0.05	2019 and onwards (3-to-6-year cycle)

The classification of the SLS point cloud dataset is divided into 3 three levels, which are published in phases (Lantmäteriet, 2022):

1) Automated land classification with minimal manual editing.
2) Classification of bridges and improved soil classification of dams.
3) Improved separation between land and water

These levels are translated into ASPRS classes, as listed in Table 47, with the corresponding name and ASPRS code available in the point cloud dataset.

Table 47: ASPRS classifications overview of the Sweden national point cloud dataset

Name	**ASPRS code**
Unclassified and temporary objects	1
Ground (point on the ground)	2
Low vegetation	3
Building	6
Low point (noise)	7
Water	9
Bridge deck	17
High noise	18

3.29 Switzerland

In Switzerland, the Swisstopo is responsible for acquiring the national point cloud dataset, known as swissSURFACE3D. Between 2000 and 2024, the elevation models were acquired by ALS. From 2024 onwards, point cloud acquisition will be conducted in Switzerland and Liechtenstein, and the resulting data will be freely distributed to the public. The LV95 spatial reference system and the LN02 height system acquire the point cloud datasets. The first version of the data is available in different blocks. The data volume for the whole country is 16TB (Federal Office of Topography swisstopo, 2024)

The quality parameters for these datasets, as described in (Federal Office of Topography swisstopo, 2024), are given in Table 48 (point density [ppsm], planimetric accuracy [m], altimetric accuracy [m], and temporal resolution).

Table 48: Overview of the quality parameters of the national point clouds of Switzerland

Name	**Point density [ppsm]**	**Planimetric accuracy [m]**	**Altimetric accuracy [m]**	**Temporal resolution**
swissSURFACE3D	>5	0.2	0.1	2000 - 2024
#	>10	0.2	0.1	2024 - 2029

The point density of Swisstopo's dataset ranges from 15 to 20 points per square meter (ppsm), with variation between urban and rural regions.

The data is stored in LAS 1.2 for the 2000-to-2024 point cloud datasets and LAS 1.4 for the 2024-to-2029 dataset. The first version of the dataset is currently available only in las.zip, while confirmation has been given that the second version of the national dataset will be made available in LAZ.

The classification for both point cloud datasets (2000-2024 and 2024-2029) is presented in Table 49.

Table 49: ASPRS classifications overview of the Switzerland national point cloud dataset

Name	**ASPRS code**	**ALS 2000-2024**	**ALS 2024-2029**
Unclassified and temporary objects	1	X	X
Ground	2	X	X
Low vegetation	3	X	X
Building	6	X	X
Water	9	X	X
Bridge deck	17	X	X
High voltage	-	-	X
Traffic lanes	-	-	X
Structural pylons/towers	-	-	X
Bridge piers	-	-	X
Viaduct stay cables	-	-	X

The new point cloud data acquired from 2024 onwards will include new classes. However, no definitions or ASPRS class codes were supplied.

3.30 United Kingdom

The United Kingdom's point clouds are acquired separately by each of its nations: Wales, Scotland, Northern Ireland, and England.

The environmental agency has conducted several LiDAR acquisition surveys in England since 1998. According to the Environment Agency (2016), the agency surveyed 75% of England's population (Environment Agency, 2015). From 2017 to 2023, Phase 1 of the country was recaptured. The data is available in LAS/LAZ. The different LiDAR tiles, referenced to the OSGB'36 British National Grid with elevations recorded in Ordnance Datum Newlyn (AODN), and overage is shown in Figure 17. Each year is highlighted in a different colour, and the r(b) value indicates the resolution of the acquired LiDAR data used to derive the digital elevation models, which are openly accessible.

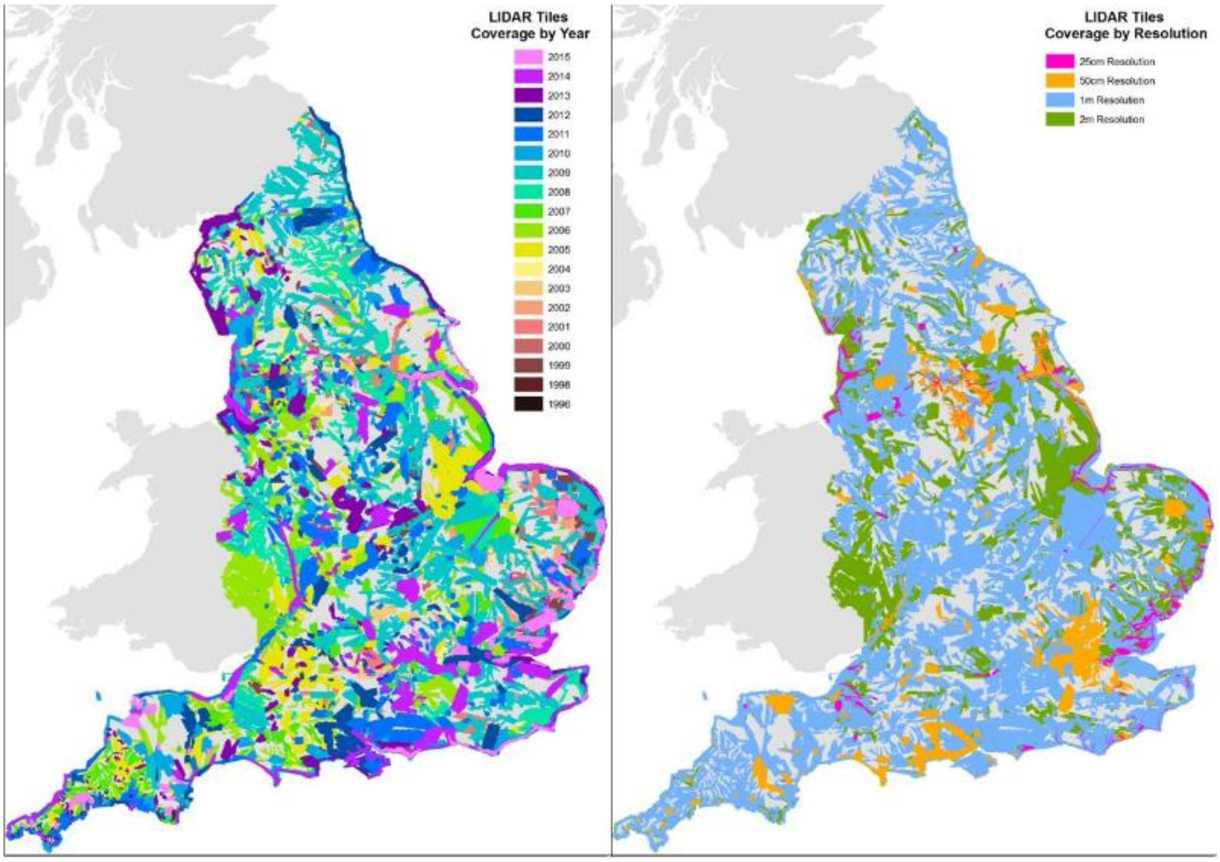

Figure 17 LiDAR Tiles availability, where (left) depicts the coverage by year and (right) by resolution in meters (Environment Agency, 2025).

In **Northern Ireland,** the Ordnance Survey acquired a point cloud dataset for the digital elevation models based on dense matching. The points are generated at a 1 in 4-pixel ratio, with a point spacing of around 0.4m (Historic Environment Division, Northern Ireland, 2020). The mapping agency highlighted that there is no full coverage due to several causes, including poor image quality and issues related to cloud distortions in pixel matching. For some smaller lakes and loughs, surfaces are estimated; however, this is not always possible, and gaps are left where an estimate would be misleading. The data has a total size of 4.7 GB (zipped). The data is not free, but it can be obtained at an additional cost.

In **Scotland,** the LiDAR dataset was acquired in 6 phases, representing parts of Scotland but not covering the whole country. The LiDAR acquisition occurred from 2011 to 2023, on behalf of Scottish Power Energy Network (SPEN) (Scottish Government, 2022). The data is distributed to the public in LAZ. In Figure 18, the areas where the point cloud dataset is available are dark grey.

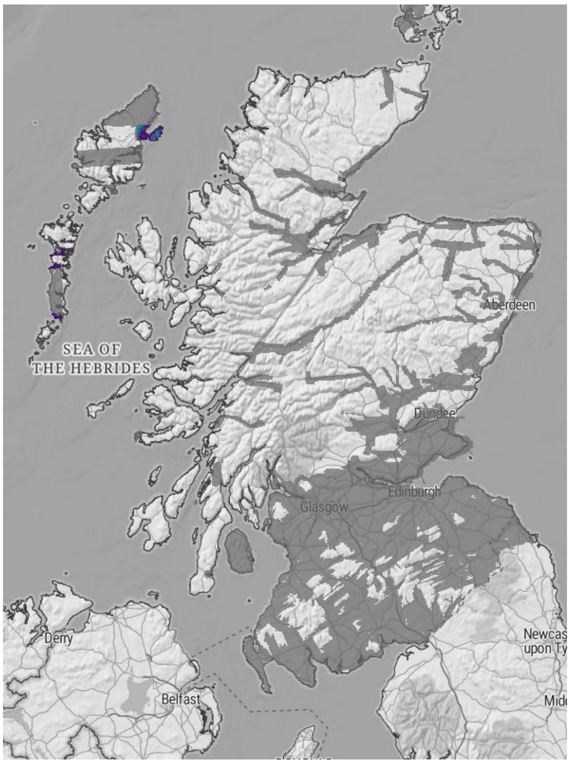

Figure 18 Regions where point cloud datasets are available in dark grey (Scottish Government, 2025).

LiDAR data is used in Wales to generate the DTM and DSM that the Welsh Government provides. The LiDAR data was acquired between 2020 and 2023 and will become open. For Wales, the point cloud had Vegetated vertical accuracy (VVA) quality parameter, which was set at less than 0.29m (Ffotograffiaeth Awyrol a Chartograffeg /Aerial Photography & Cartography)

Table 50: Overview of the quality parameters of the national point clouds of the UK

Name	***Type of data***	***Point density (ppsm)***	***Planimetric accuracy***	***Altimetric accuracy***	***Temporal resolution***
England [10]	Point cloud	1 to 16	0.4	0.15	2017 to 2023
Northen Ireland	DEM	-	-	0.659	-
Scotland	Point cloud	1 to 2	-	-	2011 to 2012
	Point cloud	1 to 2	-	-	2012 to 2014
	Point cloud	4	-	-	2015 to 2016
	Point cloud	4	-	-	2017 to 2019
	Point cloud	4	-	-	2020 to 2021
	Point cloud	4 to 25	-	0.10	2021 to 2022
Wales	DEM	1 to 2	1	0.10	2020- 2023

[10] The point cloud dataset of England does have relative accuracy requirements: relative planimetric accuracy is 0.1818m and the relative altimetric accuracy (random error) must be no more than 0.05m

The UK Environment Agency prescribed ASPRS labels for the point cloud datasets.

Table 51: ASPRS classification code overview of the UK point cloud datasets

Name	ASPRS Code	England	Northen Ireland
Default	1	X	-
Ground	2	X	X
Low surface object (0.05m => Ground =<0.15m)	3	X	X
Medium surface object (0.15m => Ground =<5m)	4	X	X
High surface object (5 => Ground =<100)	5	X	X
Buildings	6	X	X
Model keypoints[11]	8	X	-

In Northern Ireland, the point cloud classification for the elevation model is performed automatically. This automatic classification is conducted using the MATCH-T DSM GAST strategy, which is based on a small grid size and is suitable when a high level of detail must be preserved in the final terrain model. A certain degree of manual editing may still be necessary to refine the classification results. An exception is applied when an entire tile is incorrectly classified as predominantly built features; in such cases, all points are reclassified as ground points, as most points are likely to represent ground rather than buildings. The points are also colourised with colour values from the imagery.

[11] Thinned version of the ground model with reduced point density on flat surfaces and retained point density in areas of relief change

4 CONCLUSION

In Europe, point clouds are acquired and generated by different organisations and countries for different purposes. To align those point clouds and to make reuse and integration possible, uniformity and consistency of the specifications and quality parameters of the available point clouds are crucial.

Therefore, we conducted a questionnaire and an online desktop inventory to identify the available point cloud datasets in Europe and their corresponding quality descriptions.

The study identified over 50 cloud datasets at the national and regional levels of Europe. These identified point clouds or point cloud-derived digital elevation models are acquired (mainly) by Airborne Laser Scanning (ALS). In addition, project-based point clouds were also found (e.g., part of a highway in the case of reconstruction) and acquired by mobile laser scanning (MLS) or Terrestrial laser scanning (TLS) platforms.

The quality descriptions of the identified datasets revealed that the primary quality metrics for point clouds are (1) point density, (2) absolute accuracy, and (3) relative accuracy. Additionally, the classification can be regarded as the fourth quality parameter that defines the labels of point cloud datasets. For each quality parameter, the following observations can be made:

Point density (spatial distribution of the points)

In Europe, the primary factor influencing point cloud datasets is point cloud density, defined as the number of points per unit area. Often, it is assumed that a point cloud with a high number of points per unit is a “better” representation of the environment. However, the spatial distribution (e.g., the distance between points) also influences the ability to distinguish objects and therefore determines the quality of the point cloud. Depending on the surveyed area, we classified the available point densities into low and high. The average value for low is 6.6 points per square metre (ppsm), while the high point densities are on average 14 points per square metre (ppsm). Point density is closely linked to the scope of the acquisition campaign, often increasing in urban areas at the expense of longer acquisition cycles. The Romanian quality description illustrates that, in some instances, point density is influenced by government legislation. A higher point density results in a higher level of detail, which may necessitate down-sampling point cloud data for open data, as such densities can conflict with privacy-related requirements.

Although all point cloud datasets rely on the number of points per square meter to describe data quality, this approach is only suitable for airborne-acquired elevation models. For Mobile Laser Scanning (MLS) and Terrestrial Laser Scanning (TLS) datasets, point density can be a misleading quality parameter. The Norwegian approach, which describes point spacing rather than point density, addresses this ambiguity. Using the distance between points as a quality descriptor could support the development of a standard benchmark for the relative registration of point clouds. As the distance between points is evident, the distribution in a 3D environment highlights the ability to distinguish objects rather than indicating the average number of points in a two-dimensional area.

Absolute accuracy

The questionnaire respondents ranked absolute accuracy as the second factor in describing the quality of point clouds. Still, a variation can be seen for the point cloud datasets in Europe, as roughly three categories are present: (1) both the altimetric and planimetric values; (2) only the altimetric component or (3) the RMSE of the point cloud hence, for uniform quality descriptions to enhance the harmonisation of point cloud datasets, the planimetric and altimetric accuracy should at least be mentioned, rather than giving only one value.

Most point cloud quality descriptors use the first category, where the average was computed as 0.26m for planimetric and 0.13m for altimetric accuracy, respectively. The overview of Figure 6 implied that roughly 32% of the identified point clouds met this average planimetric accuracy and 74% the altimetric accuracy.

Relative accuracy

The definition of relative accuracy varies greatly between point cloud datasets. Only a small portion of datasets include this value, and the definition of relative accuracy varies between datasets. The questionnaire results gave no answer that describes the relative accuracy. The quality description is used locally to ensure proper alignment between point cloud datasets acquired in the same acquisition cycle.

Class definition in a point cloud dataset

Based on the responses to the questionnaire and the online inventory of point cloud quality descriptors, classification definitions are included for most datasets. Some quality descriptions go so far as to detail the classification process itself. However, the classification's accuracy, including potential misclassifications, is rarely mentioned. Harmonisation of definitions across regional or national borders is not addressed, except for the German federal point cloud dataset. Each region, nation or organisation defines the required classes independently.

The definitions of various classes can vary across point cloud datasets, though most use the first 10 base classes defined by the ASPRS classification. However, since this classification lacks definitions, the specific classes are used differently. Vegetation remains the most debated category across datasets. A range of vegetation classes, typically defined as low, medium, or high, is applied inconsistently. Therefore, to harmonise point clouds in Europe, a standard set of thresholds should be established to define these values.

The same applies to user-defined labels, as the ASPRS standard does not prescribe the names users may assign. However, as the need for classification in point clouds increases, the number of user-defined labels is expected to grow, potentially overlapping with those in other datasets. Consequently, classification parameters should be clearly defined prior to any harmonisation process.

Uniformity in quality descriptors of point clouds

None of the questionnaire respondents mentioned a harmonisation effort of their point clouds. However, the online inventory indicated that combining different acquisition blocks into a single dataset does occur. This process requires some level of harmonisation between point clouds that generally occurs locally or nationally, where datasets are acquired from the same platform and within the same country, region, or city by the same agency. No cross-border harmonisation is currently observed, leaving the responsibility for achieving uniformity to the collective efforts of Europe's national mapping agencies.

Thus, uniformity in the quality descriptors for spatial distribution, absolute accuracy, relative accuracy, and class definitions will enhance cross-border harmonisation. This is increasingly needed now that more MLS and TLS point clouds are openly distributed. The harmonisation of quality descriptors defined in specifications should lead to fewer European dialects for point cloud datasets, thereby paving the way for collaborative point cloud datasets at national and pan-European scales.

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Appendix A: Frequently used point cloud file format table

Format	Encoding / Structure	Standardisation / Ownership	Typical Distribution Use	Interoperability Remarks
ASCII (XYZ / ASC)	Plain text; each point stored as X, Y, Z (optionally attributes)	No formal standard body; de facto exchange format	Simple data exchange, small datasets	Universally readable but inefficient in size and performance
LAS	Binary file with header and fixed-length point records (XYZ + attributes)	Open specification, LASzip; community-maintained, de facto ASPRS ecosystem.	Primary distribution format for LiDAR	Open, stable, and widely supported across GIS and surveying software
LAZ	Lossless compressed LAS (LASzip)	Open specification (community-maintained)	Large-scale LiDAR distribution	De facto standard for efficient storage and download
COPC.LAZ (Cloud Optimised Point Cloud)	LAZ with standardised internal spatial hierarchy and indexing, enabling HTTP range requests	Open community specification	Cloud-native distribution and partial access	Optimised for streaming and cloud storage; increasingly adopted by mapping agencies
E57 (ASTM E2807)	Hybrid: binary bulk data with embedded XML metadata	ASTM International (vendor-neutral standard)	Cross-vendor scanner data exchange	Strong interoperability in terrestrial scanning; less GIS-centric
PLY (Polygon File Format)	ASCII or binary; vertex-based structure	Stanford University (research origin)	Research and photogrammetry distribution	Limited semantics; not LiDAR-specific
PCD (Point Cloud Data)	ASCII or binary; structured point cloud format	Open Source (Point Cloud Library – PCL)	Robotics and computer vision datasets	Common outside GIS; limited adoption in mapping workflows
3D Tiles	JSON tileset with spatially indexed binary tiles	OGC Community Standard (origin: Cesium)	Web-based streaming of large point clouds	Designed for scalable visualisation rather than raw data exchange
I3S / SLPK	Hierarchical spatial index with JSON + binary geometry	OGC Community Standard (origin: Esri)	Web distribution of massive point clouds	Strong web performance; partial platform dependency

Terrasolid BIN	Binary format with block-based point attributes	Terrasolid (TerraScan)	Professional LiDAR data delivery in surveying	Widely accepted in practice, though proprietary
PTS (Leica PTS)	ASCII point list with XYZ and optional attributes	Leica Geosystems	Neutral export and exchange	Simple and readable; large file sizes
PTX (Leica Cyclone)	ASCII structured scan grid with scanner pose	Leica Geosystems	Distribution of terrestrial scan data	Preserves scanner geometry; scanner-centric
Esri zLAS	LAS-based binary with proprietary indexing	Esri	Legacy GIS distribution	Deprecated; superseded by LAZ and COPC
OBJ (Wavefront)	ASCII geometry definition (vertices, optional faces)	Openly documented	Limited point-set distribution	Not designed for point clouds; minimal attributes