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Non-commercial Light Detection and Ranging (LiDAR) data in Europe

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Abstract

The EU has recently launched a building renovation wave as part of the Green Deal. However, a detailed georeferenced pan-European building database is absent. The use of very high-resolution (VHR) satellite imagery combined with LiDAR (Airborne Laser Scanner Light Detection And Ranging) data could provide a homogeneous and accurate solution. To provide a basis for further work, this report summarises the results of an investigation into the availability of LIDAR data in the EU Member States.

This report aims to share and inform member states, the public sector, researchers, and other practitioners on the status of the available non-commercial **Li**ght **D**etection **a**nd **R**anging (LiDAR) data in Europe, (EU27+ Norway, Switzerland, UK, Serbia). Of the 32 countries explored, 18 countries are fully covered by using LiDAR data, nine countries are partially covered, while no information or no data is available for the remaining five countries. The resolution and products release conditions (freely available) derived from LiDAR datasets varied among countries.

Disclaimer

This document aims to provide a starting point for an overview of the availability of non-commercial LiDAR data in Europe. This document should be regarded as written considering the best efforts from the authors, who acknowledge that there could be missing or inaccurate information, for which none the authors or their working institution are responsible. All the links included were last accessed at the time of writing. Readers are invited to inform the authors about any inaccuracies or updated information that they may be aware of, which will be gladly considered in future editions of the document.

1 Introduction

The EU has recently launched a building renovation wave as part of the Green Deal that aims to radically reduce the energy used by more than 200 million buildings, transforming our building stock over the coming decade and engaging citizens in common climate action. Currently, aggregated statistics on buildings exist at the Member States level, collected by the European Building Stock Observatory (BSO) within the DG ENER. However, a detailed georeferenced pan-European building database is absent. Information about individual building attributes such as building footprint or rooftop shape are scarce and not publicly available due to the complexity of building shapes. Recent studies indicate that the use of very high-resolution (VHR) satellite imagery combined with LiDAR (Airborne Laser Scanner Light Detection And Ranging) data could provide a homogeneous and accurate solution. To provide a basis for further work, this report summarises the results of an investigation into the availability of LIDAR data in the EU Member States.

Light Detection and Ranging or LiDAR was introduced in the 1930s to measure air density profiles in the upper atmosphere, by determining the scattering intensity from searchlight beams (McManamon, 2019; U. Wandinger, 2005). After the development of the first optical laser, instruments employing this new technology were developed to measure distance by timing round trip travels of a laser pulse between the laser transmitter, the measured surface and the laser receiver (Lohani & Ghosh, 2017; Ritchie, 1996). One of the first studies using airborne laser for micro-relief studies was introduced in 1968. In the 70s, all basic LiDAR techniques had been suggested and demonstrated with the first textbook on LiDAR edited by E.D. Hinkley (1976).

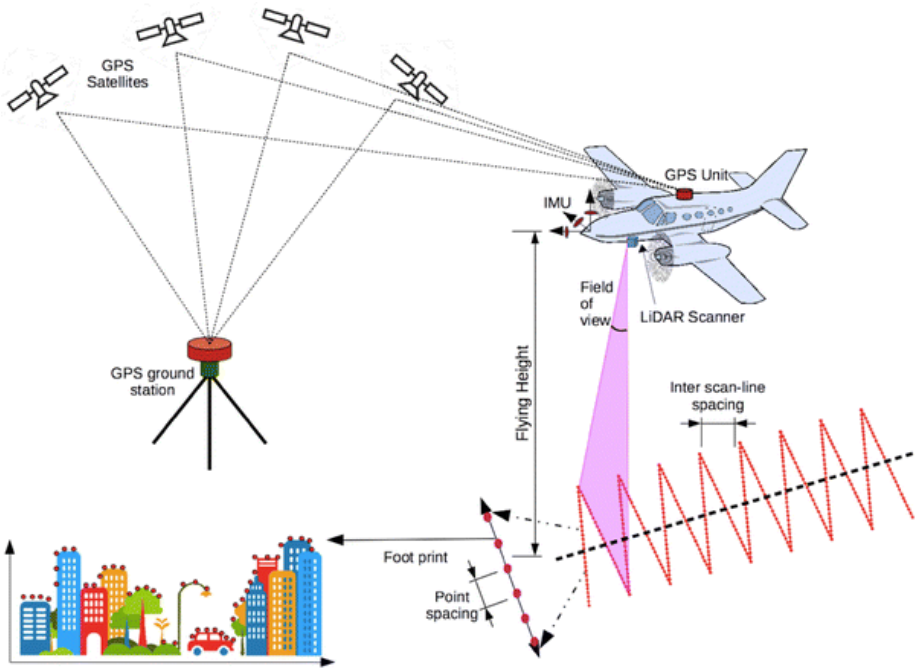
LiDAR can be employed as an optical remote-sensing technique to densely sample the surface of the Earth, producing highly accurate x, y, z measurements ([1]) depending upon the collection of the data. LiDAR systems allow scientists and mapping professionals to examine both natural and human-made environments with accuracy, precision, and flexibility.

Such need for accurate and rapid inspections of land surface terrain covers a wide range of scopes, e.g.:

- estimation of land surface roughness
- water movement
- air movement
- erosion
- deposition
- vegetation cover and distribution.

([1]) https://cteco.uconn.edu/data/lidar/faq.htm.

Figure 1. Airborne LiDAR data.



Source: Lohani and Ghosh, 2017.

How is LiDAR Data collected? ([2], [3])

There are two types of LiDAR data, airborne (topographic and bathymetric) and terrestrial (mobile and static). We are only focusing on the former in this report.

An airborne system combines laser ranges with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data, to generate a dense, detail-rich group of elevation points, called a "point cloud".

Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth's surface from which a laser pulse was reflected. The point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours.

LiDAR products

A digital elevation surface is usually characterised as one of five general types

— point cloud

— digital surface model or first reflective surface

— digital terrain model or bare-earth surface

— bathymetric surface

— mixed surface.

Point Cloud

A point cloud elevation file is a raw data file containing three-dimensional (3-D) point samples, i.e., single points with multiple elevations. An example of a point cloud file would be a LIDAR multi-return dataset where there may be multiple z-values for each x/y coordinate.

([2]) oceanservice.noaa.gov/facts/LiDAR.html.
([3]) celebrating200years.noaa.gov/visions/remote_sensing/imu.html.

Digital Elevation model (DEM)

A Digital Elevation Model (DEM) is a digital representation of the elevation of the Earth's surface typically above mean sea level. There are two types of DEMs, Digital surface models and Digital Terrain models, briefly described below ([4]).

Digital Surface Model (DSM) or First Reflective Surface

A Digital Surface Model is created by the interpolation of individual mass points containing the elevation characteristics of natural or human-made elements such as trees, buildings etc. (Priestnall, Jaafar and Duncan, 2000; Jensen, 2006). A DSM is also mentioned as the first reflective surface or LiDAR first return and represents the highest reflective surface of ground features captured by the laser sensor.

Digital Terrain Model (DTM)

A Digital Terrain Model (DTM) approximates a part or the whole of the continuous terrain surface by a set of discrete points with unique height values over 2D points (Hirt, 2014). The DTM does not include features like buildings or trees.

Figure 2. Examples of a DTM (left panel) and a DSM (right panel) ([5]).

Source: Hirt, 2014.

LAS data format

All the information about LiDAR data is stored in LAS (Laser) file format. The LAS format has evolved from its earlier version 1.0 to the current 1.4 version and has provision for storing waveform data as well (Lohani and Ghosh, 2017). Compression of the LAS format is called LAZ.

The LAS file contains several fields for each point that can be useful for analysis and display:

— x, y coordinates, most often in the UTM projection and an equivalent z,

— the point Classification ([6]) and the intensity of the returned pulse,

— an RGB value, captured from a camera flown with the laser scanner,

— the return number, and the total number of returns from the pulse,

— the scan angle, which indicates how far from nadir the scanner was pointed; this is typically up to about 20-25 degrees – positive and negative depending on which side of nadir. Away from nadir, smooth water surfaces will act like mirrors and there will be no returned energy.

— overlap points, where two flight lines covered the same area.

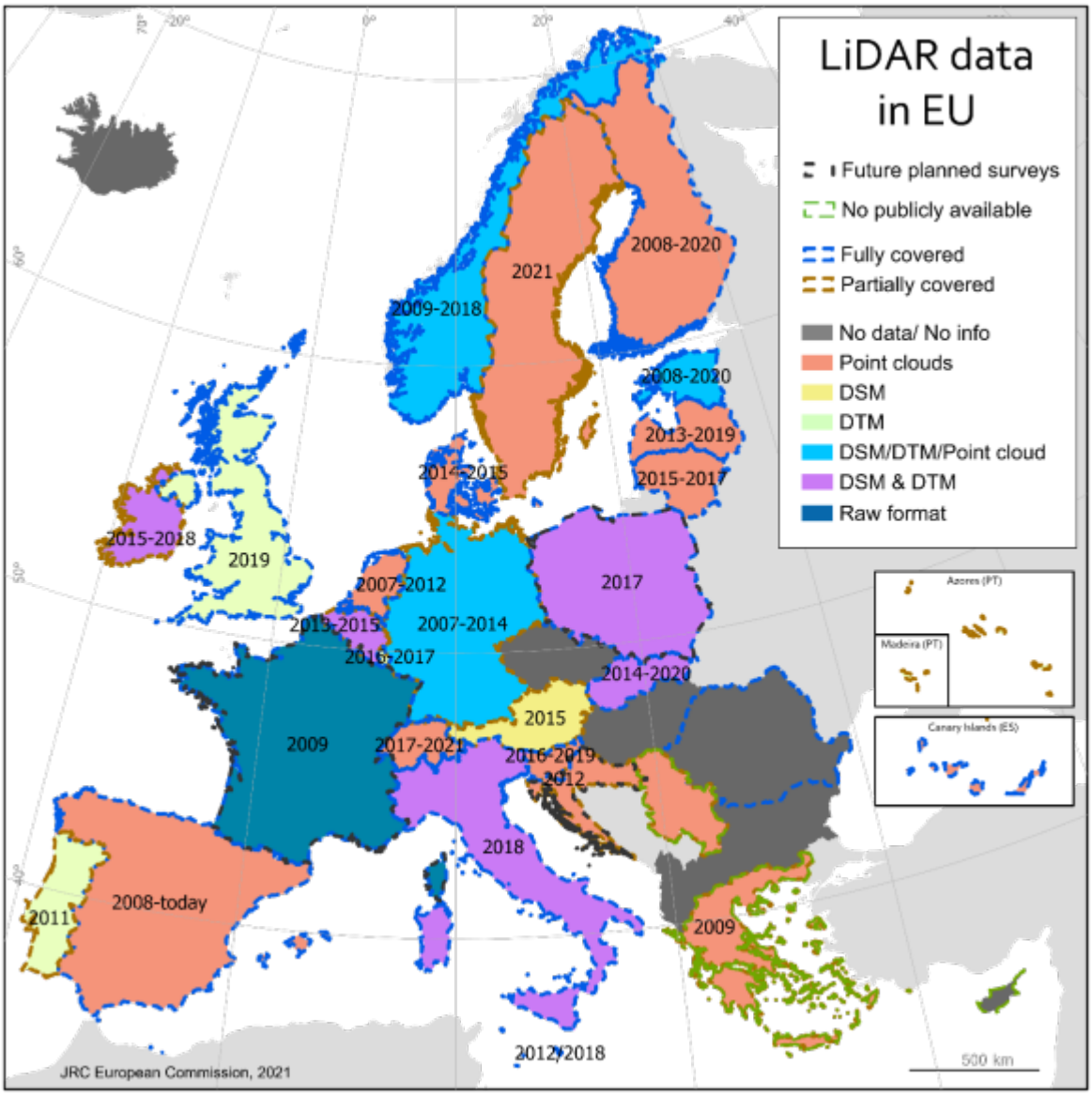
([4]) www.mdpi.com/2072-4292/12/14/2308/htm.
([5]) Both products were derived from data obtained from airborne laser scanning, resolution 1 m.
([6]) www.usna.edu/Users/oceano/pguth/md_help/html/las_format_classification_codes.htm.

2 Availability of non-commercial LiDAR data in EU

The availability of non-commercial data in Europe varies across countries and regions. In Figure 3, a synoptic map of the coverage, products and field survey data is presented. In general, most countries provide one product or all of them, so either the point clouds are available, or a DSM or DTM derived from point clouds or all the above. Available information for future surveys was found for Croatia and France. Greece and Cyprus do not make their LiDAR datasets available due to security restrictions.

Note that there are cases where different regions in the same country provide different data formats (e.g. the State of North Rhine-Westphalia and Thüringen provide DSM/DTM/Point Cloud, whereas the town of Abenberg in Bayern provides it in ASCII format). In this case, the characteristics corresponding to the largest area are depicted on the map.

Figure 3. Synoptic map of the available non-commercial LiDAR in EU with survey dates, products and coverage.



3 Countries with free LiDAR data available

Products derived from LiDAR data might be varying in resolution and format. Although a homogeneous product does not exist across Europe, nevertheless, an individual effort to produce from LiDAR data (of which, however, no information is given) a homogeneous DTM for a majority of EU countries (see below a complete list) can be found in the Austrian Open Data Portal. For more details, please follow the link: data.opendataportal.at/dataset/dtm-europe.

Countries with LiDAR-Terrain Models

- data.opendataportal.at/dataset/dtm-austria(Austria)
- data.opendataportal.at/dataset/dtm-belgium (Belgium)
- data.opendataportal.at/dataset/dtm-denmar (Denmark)
- data.opendataportal.at/dataset/dtm-estonia(Estonia)
- data.opendataportal.at/dataset/dtm-finland (Finland)
- data.opendataportal.at/dataset/dtm-france(France, Monaco)
- data.opendataportal.at/dataset/dtm-germany (Germany)
- data.opendataportal.at/dataset/dtm-iceland(Iceland)
- data.opendataportal.at/dataset/dtm-italy(Italy, San Marino, Vatican City, Malta)
- data.opendataportal.at/dataset/dtm-latvia(Latvia)
- data.opendataportal.at/dataset/dtm-luxembourg (Luxembourg)
- data.opendataportal.at/dataset/dtm-nethertands (Netherlands)
- data.opendataportal.at/dataset/dtm-norway (Norway)
- data.opendataportal.at/dataset/dtm-poland(Poland)
- data.opendataportal.at/dataset/dtm-slovakia(Slovakia)
- data.opendataportal.at/dataset/dtm-slovenia(Slovenia)
- data.opendataportal.at/dataset/dtm-spain(Spain, Andorra, Gibraltar)
- data.opendataportal.at/dataset/dtm-sweden (Sweden)
- data.opendataportal.at/dataset/dtm-switzerland (Switzerland, Liechtenstein)
- data.opendataportal.at/dataset/dtm-united_kingdom (United Kingdom)

Also, another effort as part of the Virtual Terrain Project to collect all the info of the available LiDAR data in EU can be found at vterrain.org/Locations/eu/.

The above-mentioned website gives wider information and is not only focused on open-source LiDAR datasets. The latest updates seem to date back to 2015.

Another useful link with information about countries with national LiDAR datasets (globally) is via Wikipedia, available at en.wikipedia.org/wiki/National_LiDAR_dataset.

The INSPIRE geoportal is another source available to users to find LiDAR data, but few countries have made their datasets available via this portal (tip: search for "LiDAR"), available at inspire-geoportal.ec.europa.eu.

Another portal available to users to find and download LiDAR data is data.europa.eu.

3.1 Austria

Austria has partial LiDAR non-commercial coverage, according to the authors' research. Only Vienna (Wien) has several geo-datasets available to download for free (bounding box, WGS84: POLYGON [16.577511 48.322571, 16.18218 48.117668]. Specifically, a DSM is available at 50 cm spatial resolution and DGM at 1 m spatial resolution. Follow the following link to access Vienna's geodata web-viewer wien.gv.at/ma41datenviewer/public.

From the following link, users can get more information about the data and how to download it: data.gv.at/katalog/dataset/47b36dc6-4555-49bf-900e-8cd67b19dece.

3.2 Belgium

Belgium is not fully covered with non-commercial LiDAR data, as far as the authors are aware. The region of Flanders (Flemish Region of Belgium) has collected LiDAR data in two time periods: 2001-2004 and 2013-2015. From these campaigns, DSM and a DTM raster products in Belgissche Lambert 1972 projection (EPSG 31370) were made available. The DSM resolution is at 1 m, 5 m, and the DTM has a resolution of 100m, 25/5/1 m. The area covered includes a buffer of 5 km and the Brussels-Capital Region. The datasets are available from the website of the Flemish government through the Agency of Geographic Information, online at download.vlaanderen.be/Producten/Detail?id=966&title=Standaardproducten_Digitaal_Hoogtemodel_Vlaanderen_II.

Geo-portal accessible at remotesensing.vlaanderen.be/apps/openLiDAR.

Figure 4. Areas in Flanders region covered with LiDAR surveys.

Source: remotesensing.vlaanderen.be/apps/openLiDAR.

3.3 Croatia

Croatia does not have non-commercial LiDAR data at the national level at the time of writing.

There is a point cloud dataset available for the city of Zagreb, with a density of 1 pts/m2 for an area of 641 km^2 obtained in 2012, which is not directly available for download but can be requested to the City Office for strategic planning and development of the city of Zagreb by email (strategija@zagreb.hr). The official website is available at geoportal.zagreb.hr.

We have been informed that the national administration is planning an overall LiDAR survey for the whole country, including Zagreb.

3.4 Denmark

Denmark provides to the public a point cloud dataset in LAZ format with an average point density of approximately 4.5 pts/m^2 and vertical and horizontal RMSE (i.e. root-mean-square error) approx. 5 cm and 15 cm respectively.

The data is available at download.kortforsyningen.dk/content/dhmpunktsky (Only in Danish; registration is needed). The dataset was collected during the period 2014-2015.

3.5 Estonia

Estonia has the whole country scanned with LiDAR data from 2008 to 2011, 2012-2015 with point cloud density equal to 0.5 pts/m^2. Another campaign was launched in 2017–2020, which covered the whole territory in two-year cycles with higher resolution than the previous years, 18 pts/m^2 than 2.1 pts/m^2. An Index map (ESRI Shape file format) about springtime flights is provided via the following link: https://geoportaal.maaamet.ee/docs/Avaandmed/epk2_eng.zip. The whole country is covered in a two-year

circle scanning for the years 2008-2020 (shapefile field: ALS_YEARS, listing year numbers of all springtime flights from years 2008-2020).

The size of the LAZ files is approx. 5 TB, (total of 325 000 files) and is available for download at geoportaal.maaamet.ee/est/Ruumiandmed/Korgusandmed/Aerolaserskaneerimise-korguspunktid/ALS-III-ring-2016-20172020-p625.html.

The detailed information was provided by personal contact with the MAA-AMET (the Estonian Land Board). Registration is needed and the page is also available in English. Moreover, a DTM (with resolutions from 1 m to 100 m), nDSMs, CHMs are also downloadable via the same download page.

Figure 5. Maps of the already made scanning survey for Estonia with the corresponding dates.

Source: https://geoportaal.maaamet.ee/.

3.6 Finland

The most up to date national-wide dataset was obtained in 2020 and can be accessed from Finland's National Land Survey, available online at maanmittauslaitos.fi/kartat-ja-paikkatieto/asiantuntevalle-kayttajalle/tuotekuvaukset/laserkeilausaineisto-05-p.

The original dataset had a density of 5 pts/m^2 and has been sampled at 0.5 pts/m^2. The mean height error of the laser scanning material shall not exceed 15 centimetres and the mean error of the planar accuracy shall not exceed 60 cm for unambiguous objects. A DEM at 2 m spatial resolution was derived from the laser data as well.

More details can be found online at (in Finnish):

maanmittauslaitos.fi/sites/maanmittauslaitos.fi/files/attachments/2021/02/tuoteajantasaisuus 2021.pdf.

Coverage is as shown in Figure 6 and can be accessed from the following link

https://hkp.maanmittauslaitos.fi/hkp/published/fi/4343c1b4-7d8f-4473-896a-70f930f36be1.

Figure 6. Coverage of LiDAR data in Finland.

Source: https://hkp.maanmittauslaitos.fi/hkp/published/fi/4343c1b4-7d8f-4473-896a-70f930f36be1.

Another national-wide point cloud dataset was obtained in 2008-2019 with point density 0.5 pts/m^2, which is available via the following website

https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=e.

3.7 France

France has covered the whole country with LiDAR data during the period 2003-2009. The data is available in raw format via the website ids.equipex-geosud.fr/web/guest/france. It must be noted that the download links are not working at the time of writing.

There is a new program for obtaining LiDAR data national-wide at a high density of 10 pts/m^2 over the course of 5 years. More information is available (in French) at cnig.gouv.fr/?p=24332.

In addition, several local authorities grant access to recent high-resolution LiDAR scans from their online geo-portals (e.g. Rennes, Brest, Strasbourg, Le Havre, Lyon, Nantes, Annecy, Dijon, Paris, Toulouse, Marseille), based on information shared by an IGN (National Institute of Geography and Forest) official.

Strasbourg, 2016 data available at data.strasbourg.eu/explore/dataset/odata3d_LiDAR/information.

Metropolis of Lyon, 2015 data available a tdata.gouv.fr/en/datasets/nuage-de-points-LiDAR-2015-de-la-metropole-de-lyon.

Bordeaux, 2012data available at data.gouv.fr/en/datasets/modele-numerique-de-terrain-bordeaux-metropole-20121.

Paris, 2015data available at grindgis.com/tag/france-free-LiDAR-data.

Vosges, 2015 data available at geo.data.gouv.fr/fr/datasets/b9ab0f5f5ffed34be70062e99e707f20fb762d67.

Moreover, LiDAR data in the territory of the Community of Agglomeration of the Basin of Aurillac can be found at data.europa.eu/data/datasets/0a3efb5c-11d7-4efc-a505-630a030f42a9?locale=en.

LiDAR technology has also been deployed in France for flood-prone and coastal areas and on large forest areas in 2009-2011 (Alps, Pyrenees, Cevennes, Corsica). A DEM over these areas has a resolution between 0.2 and 0.5 m, and the final product called RG ALTI has a resolution of 1 or 5 m.

More information is available in Annex A (resolution, accuracy and data quality control in specific areas) of the RGE ALTI document available at geoservices.ign.fr/sites/default/files/2021-07/DC_RGEALTI_2-0.pdf.

The IGN provided the authors with the following link to download the data: https://geoservices.ign.fr/telechargement#rge-alti-1-m.

3.8 Germany

To the authors' knowledge, Germany is not fully covered by LiDAR data. Only a few states agreed to make LiDAR data publicly available at the time of writing.

A DTM product covering Germany at 20 and 50 m spatial resolution is available at data.opendataportal.at/dataset/dtm-germany.

The first state to make LiDAR data open was the State of North Rhine-Westphalia. LiDAR data is freely available through the Ministerium für Wirtschaft (Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen) or in English Ministry of Economy, Innovation, Digitization and Energy of the State of North Rhine-Westphalia, at open.nrw/open-data.

Some LiDAR data in the area of Bochumer is available from GeologischerDienst Nordrhein-Westfalen-Landesbetriebatthe link open.nrw/dataset/b6f18e0b-0b52-454b-814a-0ae182aa126c.

Furthermore, in the South of Germany (close to Thüringen), point clouds are available in a resolution of 4.5 m-1.5 pts/m^2– obtained during 1996-2006, and 0.5 m obtained in 2010. This data is available at data.europa.eu/data/datasets/c8363eb8-7f2a-49b5-bb59-a1571f40a21f_1?locale=en. The dataset's extent is given by the following coordinates of a bounding box [9.87, 51.64], [12.65, 51.64], [12.65, 50.2], [9.87, 50.2], [9.87, 51.64]. The responsible authority is the Thüringer Landesamt für Bodenmanagement und Geoinformation (Thuringian State Office for Soil Management and Geoinformation), which has its official website online at https://www.geoportal-th.de/de-de/GDI-Th/Kompetenzzentrum-GDI-Th.

Some data is also provided for the city of Abenberg in Bavaria. It shall be noted that the download link does not work at the time of writing, but the software development company rapidlasso GmbH (https://rapidlasso.com) converted the original ASCII files into LAZ format available at rapidlasso.com/2020/02/17/surprise-release-of-airborne-LiDAR-in-germanys-closed-data-state-bavaria.

Moreover, some open-source LiDAR data is available in Thuringia. A DSM, DTM, and point clouds for Thuringia are available at geodaten.sachsen.de/digitale-hoehenmodelle-3994.html.

Berlin has LiDAR open data available for download at geobasis-bb.de/lgb/de/geodaten/3d-produkte/gelaendemodell. The Berlin point cloud, the so-called grid or mesh size, is 1 m for the DGM1, 2 m for the DGM2 and 5 m for the DGM5, etc. The website also provides historical maps for Berlin, DOM and DEMs (in 2 m and 5 m ground resolution).

Additional information about the potential benefits of opening LiDAR data and other detailed information about LiDAR data in Germany and other European countries are available at rapidlasso.com.

The International Society for Photogrammetry and Remote Sensing (ISPRS) organised a semantic labelling contest from airborne image datasets. For this aim, they have made available DSM datasets for some areas within Potsdam, with a ground sampling distance of 9 cm and 5 cm, respectively. The data can be requested by filling the online form available at www2.isprs.org/commissions/comm2/wg4/benchmark/data-request-form.

3.9 Greece

Greece does not provide public LiDAR data. The authors contacted the Geospatial Information Department in the Hellenic Cadastre and received information about the existence of DSM layers for the two metropolitan areas in Greece (Athens and Thessalonica) and the urban part of the prefecture capitals (major cities in the country). Those datasets were acquired in 2007-2009 as part of the development of the cadastre process.

Despite this information, a LiDAR point cloud dataset of the Kameni islands of high-resolution swath bathymetry of the seabed and a DEM of the Santorini Island group is available by visiting the following websitefigshare.com/articles/dataset/2012_Santorini_LiDAR_data/1138718/2.

Onshore LiDAR data was acquired over the central volcanic islands of Nea Kameni and Palea Kameni on 16 May 2012 by the UK's Airborne Research and Survey Facility's (ARSF). The final dataset comprised more

than 40-million-point measurements and provided an average point density of ~5 points per m^2. (Nomikou et al., 2014).

3.10 Iceland

The Icelandic Met Office and the Institute of Earth Science have worked on detailed mapping on Icelandic glaciers using LIDAR technologies. More information about the surveys and data follow is available via the linkcrs.hi.is/?page_id=389.

Figure 7. Areas in Iceland scanned with airborne LiDAR.

Source: NERC Airborne Research & Survey Facility.

3.11 Ireland

The Geological Survey of Ireland has published LiDAR data mainly in DSM and DTM format, available for free download at data.gov.ie/dataset/open-topographic-LiDAR-data.

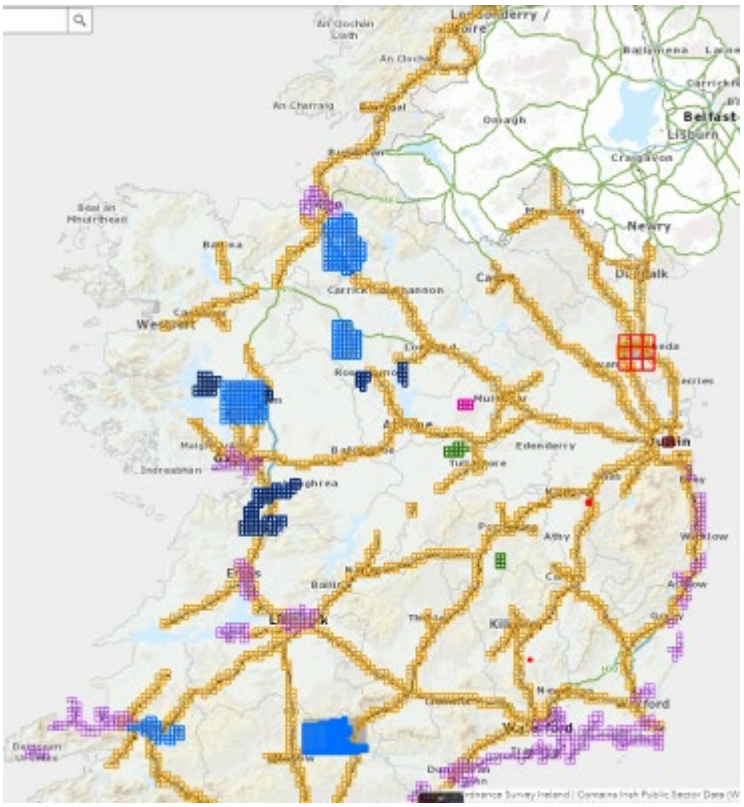
The dataset adheres to the INSPIRE Directive. The coverage does not include the whole country, but the specific areas listed below.

- Areas with a spatial resolution of 1 meter:
    - Geological Survey Ireland Cork
    - Kerry
    - Galway
    - Roscommon
    - Sligo
    - Gaeltacht Clara Bog
    - Abbeyleix Bog
    - Boyne Valley
- Areas with higher resolution, less than 1 meter:
    - Dun Ailline: 25cm resolution
    - Discovery Programme Newtown Jerpoint: 10cm resolution
    - Skellig: 10 cm resolution
    - Tara: 10 cm resolution

A WMS service is available via the link:

secure.dccae.gov.ie/arcgis/services/Groundwater/LIDAR_Mosaic/ImageServer/WMSServer?request=GetCapabilities&service=WMS.

Figure 8. Print screen of the Irish LiDAR scanning surveys and coverage.



Source: Open Topographic Data Viewer (2021).

Moreover, a significant dense and high-resolution LiDAR dataset is available for the city of Dublin collected in March 2015 for a small area of 2 km^2 through the New York University. The dataset is available via the Center for Urban Science and Progress website using the link geo.nyu.edu/catalog/nyu_2451_38684.

3.12 Italy

Italy has DSM and DTM created from LiDAR data available via the INSPIRE platform, available online at inspire-geoportal.ec.europa.eu/results.html?country=it&view=details&theme=el.

The resolution of both products is at 1 m, and the latest dataset was published in 2013. Moreover, buildings as LOD1 ([7]) for main cities in Lombardia Region are available for download from cartografia.servizirl.it/viewer32-3D/ and pcn.minambiente.it/mattm/visualizzazione-metadati/?keyword=LiDAR&rid=localsciamlab.com/opendatahub/dataset.

Some isolated areas in Italy with LiDAR data can be found at data.europa.eu portal, e.g., Ravina 2007, comune d'Ota, Paneveggio 2007, Dolomites in Bolzano Province created in 2017.

A geospatial S-DSS tool ([8]) developed within the Life+ project SOILCONSWEBfor supporting integrated forest knowledge at landscape is based on LiDAR data (5 pts/m^2) collected in a 20,000 ha inland patchy area which was representative of soil land use in the Apennines mountains of southern Italy. (Campania Region) (Marano et al., 2019); through a web-viewer it is possible to draw an area of interest (AOI) and obtain a map with the main features (e.g., forest types, soils, forest road network and, as a function of several LiDAR metrics

([7]) Within the concept of the OGC standard CityGML 2.0, the level of detail (LOD)is intended to differentiate multi-scale representations of semantic 3D city models. The coarse prismatic LOD1 model is usually obtained by extruding anLOD0 (i.e., a representation of footprints and optionally roof edge polygons marking the transition from 2D to 3D GIS) model (Biljeckiet al. 2016).

([8]) http://www.soilconsweb.ariespace.com/.

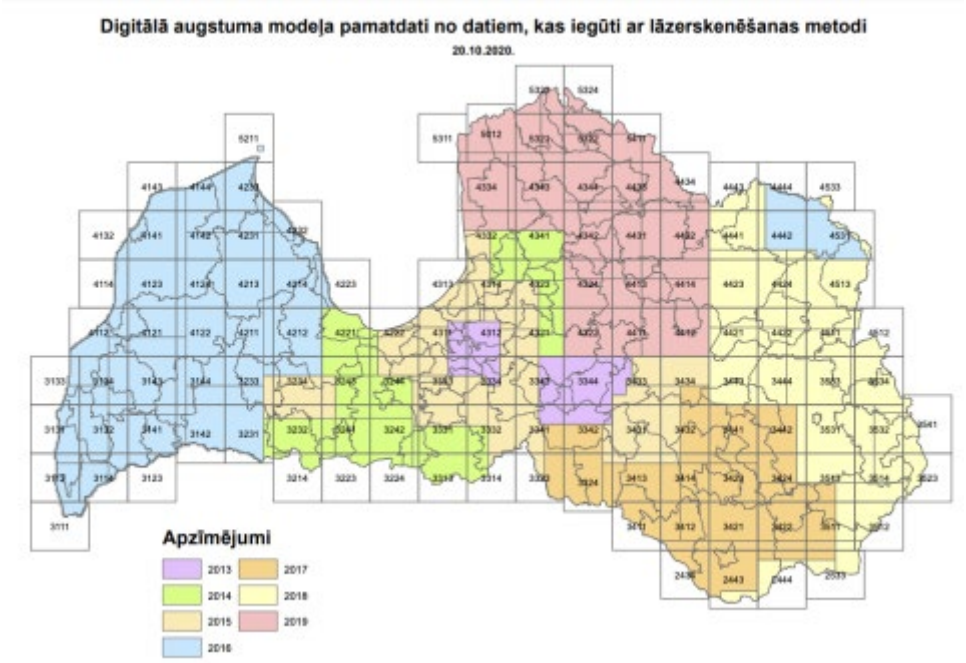
(Teobaldelli et al. 2017), the profile curvatures, solar radiation index, slope, exposure, mean stand height (Hm), growing stock volume (V) and total above-ground biomass (AGB) (Marano et al., 2019).

The Ministry of the Environment and Protection of the Territory and the Sea (MATTM) carried out surveys relating to the territory of the Lombardy Region during the years 2008-2009, 2010-2011 and 2013-2015. The technical documentation is available at pcn.minambiente.it/mattm/en/online-the-new-procedure-for-the-request-of-LiDAR-data-and_or-interferometric-ps.

3.13 Latvia

The Latvian government has a publicly available LiDAR point cloud with the total density of points obtained not less than 4 pts/m^2 and the mean density of points characterising the surface not less than 1,5 pts/m^2. The data is available in LAS data format, coordinate system LKS-92 TM and the Latvian normal height system LAS-2000.5. A DSM with a resolution of 1 m was prepared from aerial laser scanning data (available in raster data format – GeoTiff). It was collected from 2013 to 2019 and is available at https://www.lgia.gov.lv/lv/Digit%C4%81lais%20virsmas%20modelis.

Figure 9. LiDAR grid coverage in Latvia.



Source: https://www.lgia.gov.lv/sites/lgia/files/document/LV_LAS_shema_1.pdf.

Moreover, visualised images of the DTM are available from aerial laser scanning data with a resolution of 25 cm and 1 m spatial resolution (available raster data format - TIFF and ECW).

3.14 Lithuania

The Nacionalinė žemės tarnyba prieŽemės ūkio ministerijos (English: National National Land Service, Ministry of Agriculture) provides point cloud data with a mean density of 45 pts/m^2 for the county centres of Lithuania, available at geoportal.lt/map/index.jsp?lang=en – registration and the use of e-signature are needed. The most updated dataset is from 2017 and can be downloaded as ASCII Simple Point Cloud or ESRI Binary Grid.

More information about the available datasets is available at geoportal.lt/geoportal/web/inspire-en/data-availability.

3.15 Luxemburg

Luxemburg's LiDAR full-coverage data obtained in 2019 is available for download in the geo-portal atLiDAR.geoportail.lu, where also more information is available. On average the points were measured with a density of 15 points per square meter and a horizontal precision of +/- 3 cm and vertical of +/- 6 cm.

Moreover, a DTM is publicly available at 5 m resolution derived from LiDAR datasets obtained in 2012-2017 in a TIF or binary terrain or ESRI Ascii Grid format, in LUREF EPSG2169 projection. More info is available at data.public.lu/en/datasets/bd-l-mnt5.

More information can be found at data.public.lu/en/datasets/lidar-2019-releve-3d-du-territoire-luxembourgeois/.

3.16 Malta

Malta has covered the whole country with LiDAR point cloud data, 40 pts/m^2, obtained in 2012 and 2018, part of the DiNamic ERDF156 (2012 data capture) and the SIntegraM ERDF.02.030 (2018 data capture) projects.

A web-viewer is available for 3-D visualisation of the data from the University of Malta. The whole country is divided into grid cells of 1 km^2 area, which can provide the 3-D visualisation of the LiDAR data (buildings, trees, terrain) by clicking on the cell. The 3D-tool is available in French, English, German, and Japanese, and provides several properties for the users to browse. The tool is available at um.edu.mt/projects/cloudisle/DATA1/cloudisle.html.

A manual including how to visualise the data is available at um.edu.mt/projects/cloudisle/Navigating_Cloudisle_2021.pdf.

Figure 10. Print screen from Malta's 3D LiDAR point web-viewer.

Source: um.edu.mt/projects/cloudisle/DATA1/cloudisle.html.

3.17 Netherlands

The Netherlands is one of the countries fully covered with high-resolution LiDAR data taken between 2007 and 2012. The point cloud was converted to a 50 cm grid resulting in a DEM. The DEM is available from Google Earth Engine, from the Minister of Infrastructure and Water – also through Web Mapping Service (WMS) or direct download using the link developers.google.com/earth-engine/datasets/catalog/AHN_AHN2_05M_RUW#description.

The AHN (Actueel Hoogtemodel Nederland) DEM is a 0.5 m DEM covering the Netherlands. It was generated from LiDAR data taken in the spring between 2007 and 2012. This version contains both ground level samples and items above ground level (such as buildings, bridges, trees etc). The point cloud was converted to a 0.5 m grid using a squared inverse distance weighting method.

3.18 Norway

Norway has free available LiDAR data accessible from the Norwegian Hydrographic Service for marine geospatial data, available on the Hoydedata website at hoydedata.no/LaserInnsyn – website in Norwegian and

registration needed. Through the Norwegian portal, the DSM, DTM, and point cloud datasets obtained between 2009-2018 are available for download in LAS or LAZ format. Specific areas are also covered during 2019 and 2020. Several DTMs were created with point clouds varying from a density of 0.5 to 5 pts/pixel across the country, except in the Gjerdrum area – where the density raises to 50 points. These datasets are more useful for research related to sea-level rise and storm surges, as a DSM is not available from the website.

On the website, the export tab allows users to customise an export or download pre-generated zip-files of the 1/10/50 m DTM or DSM in UTM-zone 32, 33 and 25 where applicable. Only zone 33 covers the whole country. Moreover, LAZ and LAS datasets can be downloaded. An API option is also available.

The Norwegian Hydrographic Service offers WCS and WMS services, available on hoydedata.no through Geonorge. The WCS for DTM in 25833 is also available at kartkatalog.geonorge.no/metadata/nasjonal-hoeydemodell-digital-terrengmodell-25833-wcs/0f0a0f38-00c4-4213-a9e5-2d861dc4abb0 and the similar DSM is available at kartkatalog.geonorge.no/metadata/nasjonal-hoeydemodell-digital-overflatemodell-25833-wcs/e36ea427-13a1-4d7c-be82-977068dfc3e3.

Data can also be downloaded as WMS or WFS layers at:kartkatalog.geonorge.no/metadata/hoeydedata-metadata-wms/639f6c7a-68c6-4dce-ae94-5adabb276e2c and https://kartkatalog.geonorge.no/metadata/hoeydedata-metadata-wfs/dcdf9142-90ba-407e-a74cb849635c2fc5.

3.19 Poland

All elevation data (DTM, DSM, point clouds) by the Polish Geodetic and Cartographic Resource is available free of charge.

Poland offers for download:

- Digital Terrain Model (DTM): Arc/Info ASCII GRID, 1 m or 5 m cell size
- Digital Surface Model (DSM): Arc/Info ASCII GRID- 0.5 m or 1 m cell size
- LIDAR point cloud data: LAS format, point density: 4 to 12 pts/m^2.

A particularly significant fact is that elevation data for the Polish area is available in two vertical coordinate systems: PL-KRON86il 2019 and PL-EVRF2007-NH. Height differences between the systems are from 12 to 20 cm.

According to Geodetic and cartographic law (Journal of Laws of 2020, item 2052), the elevation data in Polish Geodetic and Cartographic Resource are available free of charge, without any restrictions. Entities that use the elevation data of the Polish Geodetic and Cartographic Resource are only required to indicate the source of origin in the published material.

Additionally, below are the two possibilities to download the data:

- Via downloaded services WCS using the link geoportal.gov.pl/uslugi/usluga-sieciowa-wcs.

  Via WMS services related to DTM: https://www.geoportal.gov.pl/uslugi/usluga-przegladania-wms?%0BinheritRedirect=true.

3.20 Portugal

Information for the LiDAR coverage for Portugal are available at dgterritorio.gov.pt/cartografia/cartografia-topografica/modelos-digitais-do-terreno.

A DTM and a DSM are available in a matrix format from the Portuguese Environmental Agency. The Portuguese coastal areas are covered with LiDAR surveys in 2011 with DSM and DTM products at 1 and 2 m resolution. A WMS is available via: http://ows.dgterritorio.pt/wss/service/MDT2M2011-Lidar-wms/guest?service=wms&request=getcapabilities&version=1.3.0.

3.21 Romania

Romania is planning to scan the Romanian territory with LiDAR data through the project “Geographical information for the environment, climate change and EU integration - LAKI III”. Through this project, ANCPI, an

institution subordinated to the Ministry of Development, Public Works and Administration (MDLPA), will acquire land scanning services using LiDAR technology and will generate DTM and DSM with full coverage of approximately 50,000 km^2. The LAKI III project aims to obtain these by scanning two areas:

- zone A - Caras-Severin, Gorj, Mehedinți counties, Dolj
- zone B - Suceava, Neamț, Bacău, Vrancea counties

The data will be publicly available through the ANCPI geoportal in April 2024 online at ancpi.ro/bucuresti-19-martie-cinci-milioane-de-euro-pentru-scanarea-teritoriului-cu-tehnologie-LiDAR (website last accessed on 16 May 2021).

3.22 Serbia

The Republic Geodetic Authority (RGA) has LiDAR data for certain areas in the Republic of Serbia, but these are not open data and cannot be downloaded from national geo-portal GeoSrbija online at https://geosrbija.rs/en.

However, RGA provides the possibility of issuance of requested data under defined conditions and after the payment of a charge according to the official Law on Republic Administrative Taxes.

A DTM of grid 1 m in a specific region in Servia, which is produced by Republic Geodetic Authority, is obtained through LiDAR scanning surveys implemented in 2017-2020. The LiDAR data had been mainly collected for hydrographic purposes. The Serbian DTM is available for download at metakatalog.geosrbija.rs/geonetwork/srv/eng/catalog.search#/metadata/1f1e9654-f62c-484b-b9d8-27b4e9fcf34a.

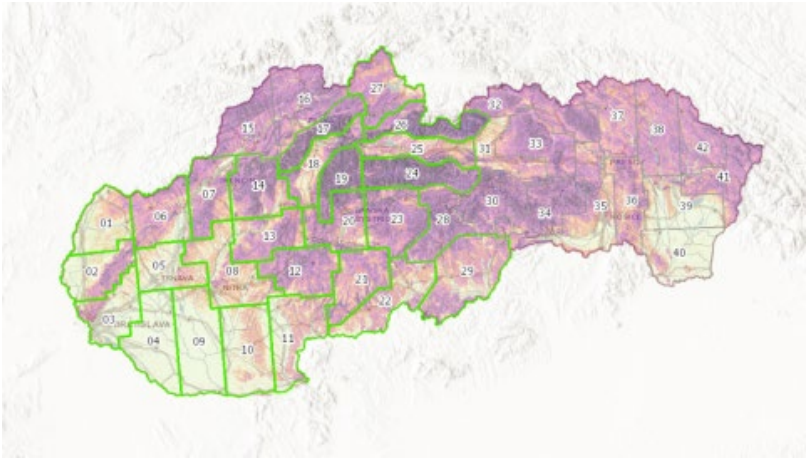
A geoportal is also available at a3.geosrbija.rs.

3.23 Slovakia

The Geodesy Cartography and Cadastre Authority of the Slovak Republic, via their geo-portal, provides a DSM at 1 m spatial resolution, a DTM at 5m resolution, and a point cloud dataset. The maximum polygon size defined by the user to download data from an area is 2 km^2. The whole territory is divided into 42 localities, see Figure 11. Each area is scanned separately, from west to east. The scanning density is at least 5 pts/m^2. Data is available in horizontal and vertical systems: S-JTSK(JTSK03)+HBpv; ETRS89-TM34+hETRS89. The already scanned areas at the time of writing are highlighted in green in Figure 11. The data is available at zbgis.skgeodesy.sk/mkzbgis/en/teren.

Isolated surveys in some Slovak areas can be found on the data.europa.eu portal. The project started in 2016 and has a six-year time duration.

Figure 11. Slovakia's LiDAR survey coverage with the gridded areas.



Source: Geodesy Cartography and Cadastre Authority of the Slovak Republic.

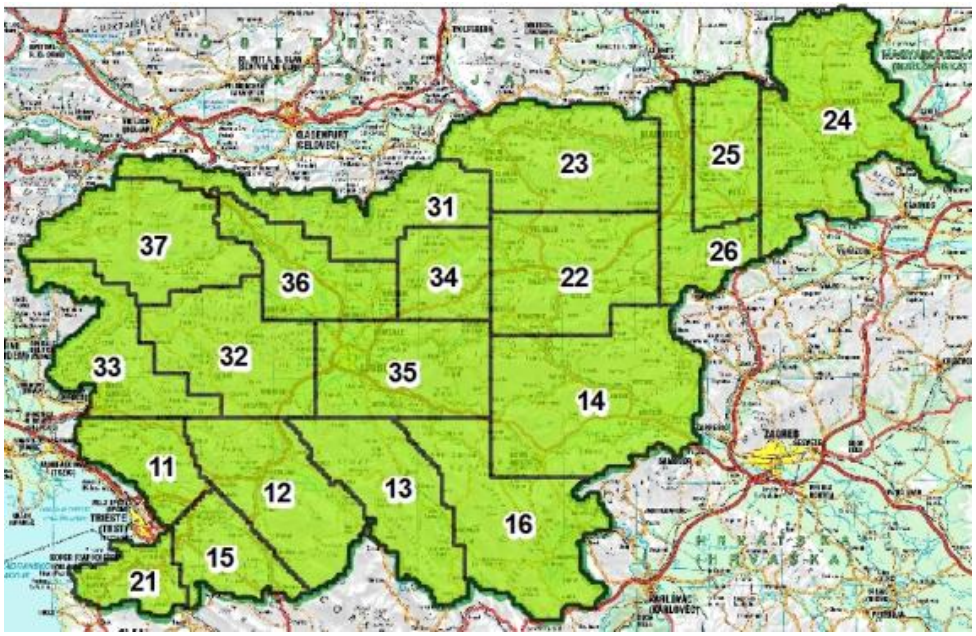
3.24 Slovenia

Slovenia provides a LiDAR point cloud for any area in the country and a DSM at 1 m spatial resolution obtained in 2006-2019 via the Minister of Environment, RS Water Directorate portal. The map is available in D96TM or D48GK projections. The LiDAR fishnet is at a resolution of 1 km^{2}and is available at gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_LiDAR@Arso.

A web-viewer is available as well at:

gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_LiDAR%40Arso&culture=en-US&initialExtent=499500.5%2C109841.5%2C264.58333.

Figure 12. Available LiDAR data coverage in Slovenia.



Source: geoportal.sk/en/zbgis/als.html.

3.25 Spain

The Spanish territory is covered by LiDAR data for the period 2008-2015 (1st coverage) and from 2015 up to date (2nd coverage). The download format is LAZ in ETRS89 for the Iberian Peninsula, Balearic Islands, Ceuta and Melilla, and REGCAN95 for the Canary Islands (both systems are compatible with WGS84). UTM projection in the corresponding zone. The download unit is generally a 2x2 km area, with some exceptions where the unit is set at 1x1 km areas. The point density is 0.5-2 points/m^2. The altimetric precision obtained is up to 20 cm RMSE Z. The files have been automatically classified and coloured with infrared and RGB, obtained simultaneously with the LiDAR data collection. In addition, a DSM at resolution 25cm and a DTM at 2/5/25/200 m grid spacing are available, covering the entire Spanish territory. More information about the data and instructions about how to download it are available at centrodedescargas.cnig.es/CentroDescargas/locale?request_locale=en.

For some specific areas in Spain, LiDAR datasets are provided separately via the data.europa.eu portal:

- Béznar reservoir, Granada 2008: data.europa.eu/data/datasets/12e122da-ecdd-476b-971c-03b0be96be26?locale=en
- CuencasGuadalete-Barbate, 2008: data.europa.eu/data/datasets/d1aefa3f-d92a-42c0-9a35-688e0883aa87_1?locale=en
- Canary Islands, 2010/2011: data.europa.eu/data/datasets/spagrafcan_152LiDAR2010_20160101?locale=en.

3.26 Sweden

The LiDAR point data available for Sweden covers approximately 75% of the country with a point density of 0.5-2 pts/m^2. Data capture began in 2018. The quality control of the collection is reported and assigned as completed. The LIDAR data ready to download are classified as class 1. The website with all the information is available in English as well. The product is divided into squares of 2.5x2.5 km in SWEREF99. More info can be found: www.lantmateriet.se/en/maps-and-geographic-information/geodataprodukter/produktlista/laser-data-nh/#qry=lidar%20data and www.lantmateriet.se/globalassets/kartor-och-geografisk-information/hojddata/lidar_data_nh_v2.6.pdf.

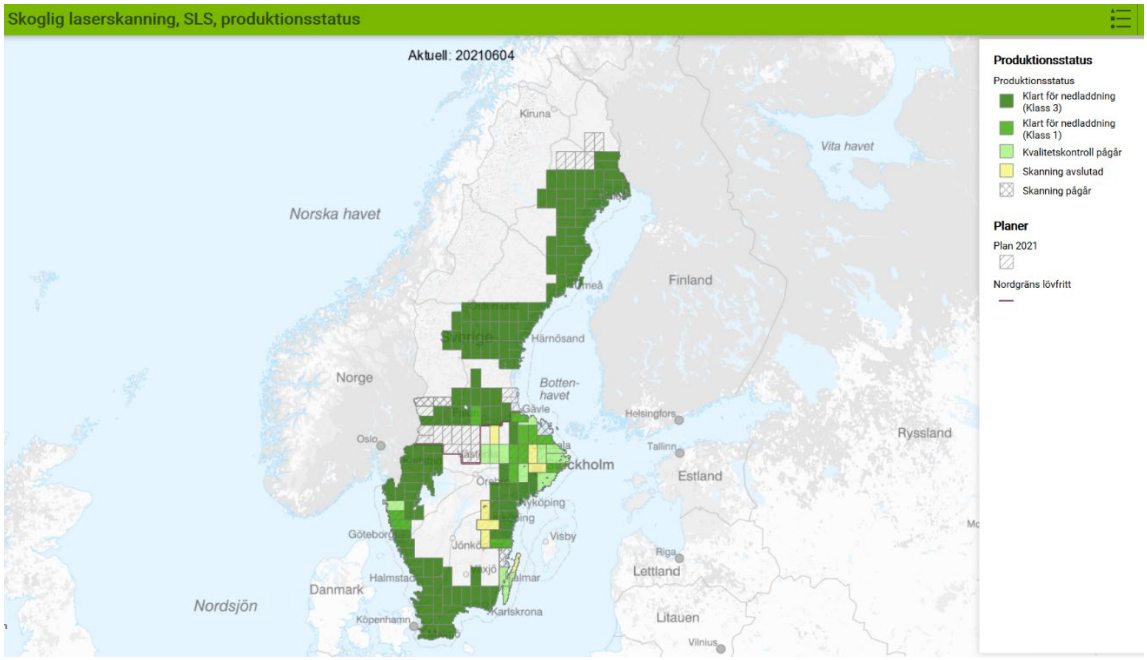
Data is available for download before registration at the link lantmateriet.se/en/maps-and-geographic-information/geodataprodukter/produktlista/laserdata-nedladdning-skog/#steg=2.

A download via FTP is available.

A web-viewer with the available data is available at webgisportal.lantmateriet.se/portal/apps/webappviewer/index.html?id=36d1e8bd49694da289e2ec7f774f531c.

A scanning plan from 2021 is available at lantmateriet.se/contentassets/c2462a5ddc3f45679def0de9822119c6/arsplan_extern_2021.pdf.

Figure 13. Print screen of the LiDAR scanning survey coverage in Sweden.



Source: www.lantmateriet.se.

3.27 Switzerland

The Swiss Federal Office of topography provides a point cloud (minimum 5 pts/m^2, mean around 15-20 pts/m^2) covering the whole country. The current availability of the LiDAR data is given via the portal and download via swisstopo.admin.ch/en/geodata.html.

WMS, WMTS and API services are available.

Figure 14. Plenary for LiDAR acquisition in Switzerland.

Source: swisstopo.admin.ch.

3.28 United Kingdom

The British Environment Agency National LiDAR programme provides elevation data at 1 m spatial resolution for the whole country that will conclude by the end of 2021. The survey started in November 2016 and the surveys are undertaken during the winter months (Nov.-Apr.) each year. Data is available for download at environment.data.gov.uk/DefraDataDownload/?Mode=survey and data.europa.eu/data/datasets/national-LiDAR-programme?locale=ro.

Instructions on how to download this data are published online at environment.data.gov.uk/portalstg/home/item.html?id=258c1b4744d8488abf57deae1bc87374.

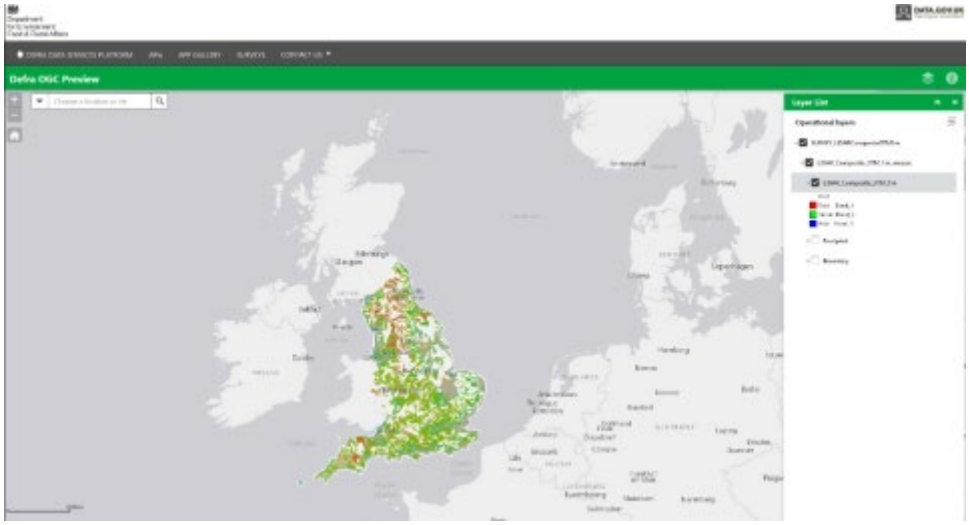
For a large amount of data, the user should directly contact the service for an offline download. The point cloud is available for surveys going back to 2006. Historic data are available for some areas where they have carried out repeat surveys, such as in the coastal zone for monitoring change. All LIDAR data has a vertical accuracy of +/-15cm RMSE. Data is available in 5km download zip files for each year of the survey. Within each downloaded zip file are LAZ files aligned to the Ordinance Survey grid. The size of each tile is dependent upon the spatial resolution of the data ([9]). Geographic Extent: Latitude from 50 to 55.8 and Longitude from -5.7 to 1.8.

Coordinate Reference System: http://www.opengis.net/def/crs/EPSG/0/27700.

DSM and DTM in 2020 are available in GeoTiff format, whereas point clouds are available for download in LAZ format. Data is presented in metres, referenced to Ordinance Survey Newlyn, using the OSTN'15 transformations. All LIDAR data has a vertical accuracy of +/-15 cm RMSE. WCS and APIs services are available.

([9]) https://environment.data.gov.uk/dataset/094d4ec8-4c21-4aa6-817f-b7e45843c5e0.

Figure 15. Print screen of the LiDAR coverage in the UK.



Source: environment.data.gov.uk.

Whales provide a DSM and a DTM of the whole country plus Liechtenstein in various resolutions: 0.25/0.5/1/2 meters.

The products are available for download at lle.gov.wales/GridProducts#data=LiDARCompositeDataset.

Table 1. Summary table with the countries and the downloadable links of non-commercial LiDAR data.

Country	**Link to LiDAR data**	**Product**	**Resolution**	**Coverage**	**Year**
Austria	data.gv.at/katalog/dataset/47b36dc6-4555-49bf-900e-8cd67b19dece	DSM	0.5 m	Partial	2007
Belgium	download.vlaanderen.be/Producten/Detail?id=966&title=Standaardproducten_Digitaal_Hoogtemodel_Vlaanderen_II	DSM, DTM	1/5/25/100 m	Partial	2001-2004 2013-2015
Croatia	geoportal.zagreb.hr	Point cloud	1 pts/m^2	Partial (Fully, future survey planned)	2012
Denmark	download.kortforsyningen.dk/content/dhmpunktsky	Point cloud	4.5 pts/m^2	Fully	2014-2015
Estonia	geoportaal.maaamet.ee/eng/Maps-and-Data/Elevation-data/Download-Elevation-Data-p664.html	Point cloud	0.5/18 pts/m^2	Fully	2012-2015 2017-2020
Finland	maanmittauslaitos.fi/kartat-ja-paikkatieto	Point	0.5 pts/m^2	Fully	2020

Country	Link to LiDAR data	Product	Resolution	Coverage	Year
	/asiantuntevalle-kayttajalle/tuotekuvaukset/laserkeilausaineisto-05-p tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en.	cloud/DEM			2008-2019
France	ids.equipex-geosud.fr/web/guest/france	Wave format	-	Fully (future survey planned)	2003-2009
Germany	geoportal-th.de/de-de/Downloadbereiche/Download-Offene-Geodaten-Th%C3%BCringen	DSM/DTM/ Point cloud	Varies	Partial	2006/2010
Greece	Link not available for security reasons	DSM/DTM	-	Partial	2007-2009
Ireland	data.gov.ie/dataset/open-topographic-LiDAR-data	DSM/DTM	Varies	Partial	2015-2018
Italy	inspire-geoportal.ec.europa.eu/results.html?country=it&view=details&theme=el	DSM/DTM	1 m	Fully	2013
Latvia	lgia.gov.lv/lv/Digit%C4%81lais%20virsmas%20modelis	DSM/Point cloud	0.5 pts/m^2, 1m	Fully	2013-2019
Lithuania	geoportal.lt/map/index.jsp?lang=en#	Point cloud	45 pts/m^2	Partial	2017
Luxemburg		Point cloud/ DTM	15 pts/m^2 /5m	Fully	
Malta	um.edu.mt/projects/cloudisle	Point cloud	40 pts/m^2	Fully	2021-2018
Netherlands	developers.google.com/earth-engine/datasets/catalog	DEM/ Point cloud	50 cm / -	Fully	2007-2012
Norway	hoydedata.no	DSM/DTM/ Point cloud	0.5 to 5 pts/pixel, 1/10/50m	Fully	2009-2018
Poland	gugik.gov.pl/projekty/isok	DSM/DTM/ Point cloud	4 to 12 pts/m^2, 0.5/1/5m	Fully	2007-2017
Portugal	dgterritorio.gov.pt/cartografia/cartografia-topografica/modelos-	DSM/DTM	1/ 2m	Partial	2011

Country	Link to LiDAR data	Product	Resolution	Coverage	Year
	digitais-do-terreno				
Slovakia	geodatastore.sk/katalog/digitalny-model-povrchu	DSM/DTM	1/5 m	Fully	2016-2022
Slovenia	gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_LiDAR@Arso	DSM/Point cloud	1m	Fully	2006-2019
Spain	centrodedescargas.cnig.es/CentroDescargas/locale?request_locale=en#	DSM/DTM/ Point cloud	0.25/2/5/25/ 200m, 0.5-2 pts/m^2	Fully	2008-2015 2015- up to date
Sweden	lantmateriet.se/sv/Kartor-och-geografisk-information/geodataprodukter/produktlista/laserdata-nedladdning-skog/#steg=4	Point cloud	1-2 pts/m^2	Fully (75%)	2019-2021
Switzerland	swisstopo.admin.ch/en/knowledge-facts/geoinformation/LiDAR-data.html	Point cloud	minimum 5 pts/m^2, mean around 15-20 pts/m^2	Fully	2017-2021
United Kingdom	environment.data.gov.uk/dataset/	DSM/DTM/ Point cloud	0.25/0.5/1/2 m, -pts/m^2	Fully (88%)	2016-2021

Source; JRC, 2021.

4 Countries with non-free LiDAR data available

Table 2. Summary table with countries with non-free LiDAR data available.

Country	**Availability**	**Accessibility**
Bulgaria		Not freely available
Cyprus		Not publicly available, restricted for national security reasons.
Czech Republic		Not freely available, https://geoportal.cuzk.cz
Greece		Not publicly available, restricted for national security reasons.
Hungary		Commercial products in some small areas (Envirosense Hungary Ltd, Eurosense). Budapest (RODIS,kapu.budapestkozut.hu)
Romania	No LiDAR availability (planned)	
Serbia		Not freely available

Source; JRC, 2021.

5 Conclusions

This report aims at giving a comprehensive overview of the availability of LiDAR data in the whole of Europe based on public domain data. It provides concise information about the presence of non-commercial LiDAR data for each country along with other information such as: whether the spatial coverage is total or partial, the type and format of the LiDAR data available, their point density and resolution depending on the format, the year or range of years of the surveys, and the links for download. Future work could include regional coverage maps for the different countries.

The authors hope the report can be helpful to other researchers and interested parties and acknowledge that there could be missing information: the readers are invited to report any additional content to be considered for inclusion in future versions of the current document.

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List of abbreviations and definitions

CHM	Canopy Height Models
DEM	Digital Elevation Model
DGM	Digital Geological Model
DTM	Digital Terrain Model
DSM	Digital Surface Model
LiDAR	Light Detection and Ranging
LAS	LASer file format for the interchange and archiving LiDAR point cloud data
LAZ	variation of LAS with optimised compression
WMS	Web Map Service
WMTS	Web Map Tiling Service

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