LAMASUS
Land Management for Sustainability

D2.3 High Resolution LUM Geodatabase Requirements and Technical Specifications

Funded by the European Union

Date
28.04.2023

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Grant Agreement	101060423
Call identifier	HORIZON-CL6-2021-GOVERNANCE-01
Project full title	Land Use and Management Modelling for Sustainable Governance
Work package	WP2
Due date	28/02/2023 (updated May 31/05/2023)
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Abstract

This deliverable presents the requirements for, and the technical specifications of, the Land Use Management (LUM) geodatabase, to be developed in WP2 of the LAMASUS project. The requirements consider the classes to be used by different models in the project as well as policy needs to ensure that the LUM classes are policy relevant. The proposed classes are then presented along with a brief overview of the methodology. The deliverable concludes with the next steps in the development of the LUM geodatabase.

Keywords

Land cover and land use, land use management, spatially explicit data, high resolution data

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Dissemination level

PU	Public, will be published on CORDIS	✓
SEN	Sensitive, only for members of the Consortium (including the EC services)	

Nature of the deliverable *: R

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Abbreviations

CAP	Common Agricultural Policy
CLC	Corine Land Cover
EC	European Commission
EU	European Union
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization of the United Nations
LUCAS	Land Use/Cover Area Survey
LUM	Land use management
NFI	National Forest Inventory
NWFP	Non-woody forest products

Executive summary

The LAMASUS project will develop an integrated modelling framework to support the policy needs related to the EU Green Deal and its many integrated policies, targets, and actions. The proposed model toolbox will allow a variety of stakeholders to investigate the impacts of different policy options while gaining a better understanding of the drivers and impacts of land use change. Many different models will be integrated within the LAMASUS project to meet these policy needs, but a key input to these models will be information on how the land is used and managed. Much of the data needed are available, but they are located in disparate places that require collation and harmonization as well as the development of spatially explicit data on land use management (LUM) that is policy relevant. The objective of work package 2 in the LAMASUS project is to produce such a LUM geodatabase.

The requirements for the LUM geodatabase were gathered through a workshop held with different modeling teams in the project to collect feedback on their needs and their views on a set of proposed LUM classes. The general feedback, which is presented in this deliverable, was generally positive, with some suggestions made for modifications, but modeling teams will now need to consult internally to determine how the classes can be used within each model. Requirements were also based on the need to be policy relevant. The LAMASUS Science and Policy Advisory Board consists of members from different EU level agencies, and their views regarding the need for the LUM geodatabase are summarized along with the main EU policies that could benefit from better spatially explicit information on LUM. Thirdly, consultation with different funded projects that have a need for the LUM geodatabase or could provide relevant inputs was undertaken; a list of these projects and their synergies are provided in this deliverable. Finally, feedback on the LUM geodatabase and LUM classes was collected at the first LAMASUS Stakeholder Workshop, held 4 to 5 April 2023, which is summarized in the deliverable and has fed into the current proposed version of the LUM classes. Overall, the feedback from the stakeholders was positive regarding the proposed LUM geodatabase.

The LUM geodatabase is specified in two parts: (i) the annual time series based on CORINE data that will be produced from 1990 to 2020 that preserves the original 100m resolution, projection and grid, which can then be aggregated to higher resolutions (i.e., 1 km shares and NUTS administrative zones); and (ii) the LUM classes that will be used together with the CORINE time series and many other input data sets to create a set of rules that will allow the LUM classes to be assigned to the land use database. A set of LUM layers will be created initially for 2000, 2010 and 2020 at the CORINE resolution and aggregated to higher resolutions (i.e., 1 km shares and NUTS administrative zones). Depending on the data availability, an annual LUM time series between 2000 and 2020 will be derived if possible.

The current set of LUM classes is presented for forest, cropland, grassland and urban. The forest classes have been developed by considering existing classifications and the need to better represent forest structure and intensity while refining the multifunctional forest class into three further classes. The cropland classes reflect the need to differentiate between irrigated and rainfed as well as intensive and extensive cultivation. Organic farming is also reflected in the nomenclature. Grassland classes include extensive and intensive management, with and without livestock as well as agroforestry with livestock. Finally, the urban classes reflect different intensities of urbanization in terms of the density of buildings and the infrastructure. The LUM classes were developed taking the needs of the LAMASUS models, EU policies, other ongoing projects and feedback from the First LAMASUS Stakeholder Workshop into account.

The methodology for the generation of the LUM geodatabase is briefly presented in this document. In the next phase of the project, the details of the methodology will be fleshed out, and work on the development of the geodatabase will continue, with a beta version to be available by M18 of the project and a final version by M24.

1. Introduction

As part of the European Green Deal, the EU has the ambitious target to achieve climate neutrality by 2050. This will require large changes within the land use sector, implemented via instruments such as the reformed Common Agricultural Policy (CAP) in which 40% of the budget will support climate relevant activities. Other EU policies impact land use management, e.g., decreasing biodiversity loss (EU Biodiversity Strategy 2030), the provision of safe and nutritious food (Farm to Fork Strategy), the Organic Farming Action Plan targeting 25% of agricultural land by 2030, and the Zero Pollution Action Plan, which has implications for animal feeding practices, manure management, and the use of fertilizers and pesticides.

To formulate and implement effective policies to support the Green Deal, an integrated modelling framework is needed, so that the impacts of different policy options can be investigated while providing a better understanding of the drivers and impacts of land use change. Many different models will be integrated within the LAMASUS project to meet these policy needs, but a key input to these models will be information on how the land is used and managed. Data on European land use already exists, e.g., from the Copernicus Land Monitoring Service, in national and statistical databases, from new remotely sensed products, etc., but they are disparate and in need of integration and harmonization. Moreover, there is an increasing need for spatially explicit information so that problems or hotspots can be identified geographically to develop more effective, targeted policies. Likewise, the monitoring of policy impacts can be easier to do using spatially explicit outcomes. Information on land use management (LUM) is even scarcer and is not necessarily represented in a way that aids policy formulation and implementation. Hence, one of the main aims of the LAMASUS project is to improve the basic information on land use and LUM to support policy relevant modelling. Such a 'LUM geodatabase' would also support many other activities in research and innovation.

The purpose of this document is to present the technical specifications of the LUM geodatabase that will underpin many of the other activities in the LAMASUS project, in particular the ex-post econometric models for assessing the drivers of LUM and the ex-ante macro-level models for producing future policy options and for detailed modelling of environmental effects, e.g., on carbon and biodiversity. These technical specifications are driven by requirements from a broad range of stakeholders with the aim to satisfy as many of these as possible within the scope of the project. This document also provides an inventory of the input data sets that will be used to generate the LUM geodatabase including the latest products from remote sensing, statistical data, data sets available from individual EU countries and in situ data.

In the next section, the need for spatially explicit information on land use management (LUM) is highlighted, including definitions and the current availability of datasets. This is followed by a section that outlines the requirements of the LUM geodatabase, which takes model requirements, current EU policies, other projects and feedback from the first LAMASUS Stakeholder Workshop into account. Based on these requirements, the technical specifications for the LUM geodatabase are outlined including a brief overview of the methodology. Finally, a brief summary of the next steps in the process is provided.

2. Land Use Management

2.1. DEFINITIONS

The starting point for any discussion on land use management is land cover, which is defined as the biophysical cover of the Earth. This includes vegetation such as forests and shrubs, man-made features such as artificial surfaces, bare soil, water and snow/ice (Di Gregorio and Jansen, 2001). In contrast, land use refers to the economic and cultural uses of the land by humans, e.g., agricultural, industrial, recreational, etc. (US EPA, 2022). The monitoring of land cover is frequently undertaken by remote sensing since it is possible to train classifiers to differentiate between different land cover types, but land use is much more difficult to see from space. For example, a forest may be used for timber production or recreation yet from space these areas may simply appear as forest cover. However, products such as Corine Land Cover (CLC), produced by the European Environment Agency, do capture different types of land use.

Land use management refers to the way in which the land is used for production, conservation or aesthetic purposes, and it requires decision making that is based on both the purpose and the properties of the land (Verheye, 2009). In the past, land use management was mainly focused on agricultural production, but it now deals with other types of land use where humans have an impact on the landscape. In the sections that follow, a brief overview of different types of land management practices are presented, along with issues related to land management; much is taken from Verheye (2009) and supported with additional references where relevant.

2.1.1. Agricultural land use management

According to Eurostat (2022), in 2020, 157 million ha of land was used for agricultural production, which represents 38% of the total land area of the EU, divided into 9.1 million agricultural holdings. Around two-thirds of these farms were less than 5 ha in size. Although the number of farms in the EU has been declining steeply, the total amount of land used for production has remained stable. Family farms, which are defined as farms that have a labor force comprised of 50% or more of family members, were the dominant farm type in all EU member states. Farms can be grouped into four main types. The first is semi-subsistence where a high proportion of the food feeds the family, accounting for 3.3 million farms that produce around 1% of the EU's total agricultural output. The second is family run businesses that are small in size and account for an additional 2.5 million farms while a further 3 million are medium-sized. The last one is large agricultural enterprises, which are comprised of around 300K farms and produce 56.4% of the EU's agricultural output. Geographically, around 60% of the EU's agricultural output is generated by farms in Italy, France, Germany and Spain.

Agricultural management is driven by a number of decisions that farmers must make as outlined below:

- What crops will be grown and what type of cropping system will be employed (mono-cropping or crop rotation)

- How the land will be prepared, including different types of tillage practices including conventional tillage, reduced tillage, no tillage and mulching, and rotation-adapted tillage
- What the plant nutrient requirements are, which will determine what types of fertilizer to apply and in what amounts, including chemical fertilizers, organic fertilizers, etc.
- What crop establishment methods will be employed including planting density, crop arrangements, etc.
- What weed control measures will be used including chemical applications and mulching
- What pest and disease control methods will be used, including consideration of the principles of Integrated Pest Management (IPM)
- How will water be managed including rainfed systems and irrigation, as well as the types of irrigation from conventional to drip-fed
- What methods of harvest will be applied for crops and/or grassland
- What crop residue management practices will be applied
- What types of livestock will be raised and what feeding systems will be used.

Under the new CAP reform, there are incentives for the use of sustainable and climate-friendly practices (EC, 2022a), which will influence these aforementioned, complex agricultural land use management choices as well as other EU policies with targets such as increasing organic farming to 25% of agricultural land area by 2030, improving soil quality by reducing nutrient losses from fertilizers by 50%, a reduction of fertilizers by at least 20% and chemical pesticide use by 50% by 2030, and at least 10% of agricultural area to be under high-diversity landscape features (EC, 2021a, 2021b, 2022b).

2.1.2. Forest land use management

According to the State of EU Forests report (FOREST EUROPE, 2020), Europe has 227 million ha of forest, covering 35% of total land area. Around 75% of the forest area is available for wood supply. Forests in Europe are a major carbon sink, and they sequester about a tenth of the carbon dioxide emissions produced in other sectors in their biomass each year. Carbon stored in harvested wood products also contributes to a reduction in CO_2 emissions. Over the last 30 years, forest area has expanded but only a part of this growth has been harvested, so the volume of wood and the amount of carbon stored in biomass has grown by 50%. However, the report concluded that, on average, the state of European forests is deteriorating.

In 2021, the EU adopted a new forest strategy for 2030, which aims to improve the quantity and quality of EU forests, reversing negative trends and adapting EU forests to the new conditions, weather extremes and the high uncertainty brought about by climate change. The strategy includes a set of regulatory, financial, and voluntary measures for 2021-2030, with particular emphasis on the multi-functional role of forests. Some of the measures proposed include: sustainable forest management; adoption of environmentally friendly practices, in particular carbon storage and sequestration through financial incentives; planting 3 billion new trees by 2030; promoting alternative forest industries including ecotourism and non-woody forest products; encouraging the take-up of financial support under the CAP to help forests and forest-based industries mitigate against climate change; establishing a legally binding instrument for ecosystem restoration, and a new legislative proposal on EU forest observation, reporting and collection; and protecting the EU's remaining primary and old-growth forests.

Different types of forest use and management are briefly outlined below:

- **Commercial production forests:** are for producing timber in a profitable way through selective felling of high-quality trees in natural forests or production in artificially created plantations. Pulpwood is another main forest output. These forests can also be a source of non-woody forest products (NWFPs) such as cork, resins, medicinal plants, mushrooms, berries and pine kernels.
- **Industrial plantations:** established artificially by afforestation of land after clear-cutting of the previous vegetation.
- **Agroforestry:** combines agriculture, both crop and/or animal production, with forestry on the same piece of land, either simultaneously or sequentially. This is type of integrated land use that is well suited to marginal areas and low input systems. Alley cropping is one form of agroforestry where crops are grown in spaces between two hedgerows.
- **Forests for biodiversity and environmental protection:** can protect the soil against erosion and runoff, maintain biodiversity, increase the water storage capacity, have a recreational function, and can have an impact on the terrestrial carbon cycle.

In addition to the management of the forest itself, fire prevention is a key part of forest management since fires in forest areas can have very destructive and long-lasting effects. Forest fires occur mainly in the Mediterranean areas of Europe although climate change is increasing the severity of forest fires, which may be further exacerbated during extended periods of dry weather. The management of pests and diseases in forests is also important to limit their spread.

2.1.3. Urban land management

Urban and peri-urban areas include a wide variety of land uses such as residential, commercial, industrial, recreational, and urban agriculture (in the form of small-scale farming such as kitchen gardens and fruit tree orchards). More recently, there have been trends in decentralizing industry from urban areas, with industrial parks appearing on the outskirts of cities. Areas within the city can have multiple purposes, e.g., greenspaces may have both a recreational and conservation function. Urban issues that require management include pluvial flooding due to increased soil sealing and the overloaded capacity of sewage systems, the urban heat island effect and heat waves, air pollution and water quality. Roads and infrastructure also affect urban ecosystems by increasing erosion, runoff and pollution, causing habitat fragmentation and roadkill, and the development of a new biotope along road verges. Finally, there are other types of land use such as golf courses, mines and landfills, which are included in the urban class of CLC and require different management practices. Golf courses are large consumers of water while mines and landfills can be sources of GHG emissions. Reclamation of mine sites also has challenges related to the composition and eco-toxicity of the mine spoil.

2.1.4. Wetland management

Wetland management in the context of LAMASUS is related to the potential of peatland rewetting since these areas hold a large share of the world's carbon stocks. Peatlands cover an estimated 350,000 km^2, occurring in most EU countries, where around half have already been degraded by drainage for use in agriculture or forestry (Noebel, 2023). The degraded area is around 7% of the total EU-27 annual GHG emissions and 25% of the annual agricultural emissions (EC, 1995; Greifswald Mire Centre, 2020). To reach climate neutrality by 2050, most drained peatlands would need to be restored, where the mitigation potential would be 185 MtCO2eq/year (Andrés et al., 2022). The EU Nature Restoration Law includes specific targets that state restoration measures should be in place on 30% of drained peatland areas, of which at least 25% should be rewetted, and 50% and 70% by 2040 and 2050, respectively, with at least 50% rewetted (EC, 2022c). In addition to reducing GHG emissions, other benefits in peatland rewetting include habitat restoration for biodiversity, reducing the risk of floods and fires, and improving water quality.

2.2. LAND USE INTENSITY AND MANAGEMENT: CURRENT STATE

Land use intensification refers to increasing the outputs from currently used land (Erb et al., 2013). To understand the effects of intensification and to design policies that promote sustainable increases in production, we need to represent the land use intensity, which is the degree to which humans impact the land. In some previous studies, land use intensity has been characterized by a single production factor, e.g., the amount of fertilizer applied (Temme and Verburg, 2011) but land use intensity is much more complex. It has also been defined in different ways in past studies, e.g., how much area is farmed, capital expenditures on farm inputs such as fertilizer, irrigation, mechanization, crop yields, etc., and these methods of characterization may differ between countries and/or disciplines (Kuemmerle et al., 2013).

Based on conceptual work undertaken by Erb et al. (2013), defining land use intensity requires the integration of: (i) inputs to the land such as cropping frequency and the amount of fertilizer; and (ii) outputs from the land such as production and felling rates in order to examine (iii) changes due to land use intensification, e.g., on biodiversity, carbon stocks, the water and nutrient cycle, etc. (Erb et al., 2013). Putting this approach into practice, a number of research studies have appeared that have attempted to map land use systems and land use intensity. A brief overview is provided in the sections that follow.

2.2.1. Maps of land use systems and intensities

A number of different land use system classifications have been developed that capture elements of land use management or land use intensities. Table 1 presents some of the main products that have been developed along with their typologies. Anthropogenic biomes (Ellis and Ramankutty, 2008) represent an attempt to merge different kinds of land cover and agricultural land use with population density as one of the first products to capture human ecosystem interactions. The global land system typology of Letourneau et al. (2012) also contains explicit reference to populated areas but extends the cropland and pastoral systems to more detailed intensive and extensive classes. The rest of the classification systems outlined in Table 1 use the notion of low to high intensities for various LUM classes and incorporate more input data sets and dimensions as more data have become available, especially from remote sensing.

Table 1: Summary of products on land use systems, management classes and intensities from the literature

PRODUCT	DETAILS	CLASSES
Anthropogenic biomes (Ellis and Ramankutty, 2008)	Global, 9.3 km^2, around 2005	**Dense settlements:** 11 Urban Dense; 12 Dense settlements **Villages:** 21 Rice villages; 22 Irrigated villages; 23 Cropped and pastoral; 24 Pastoral villages; 25 Rainfed villages; 26 Rainfed mosaic villages **Croplands:** 31 Residential irrigated; 32 Residential rainfed mosaic; 33 Populated irrigated; 34 Populated rainfed cropland; 35 Remote croplands **Rangeland:** 41 Residential rangelands; 42 Populated rangelands; 43 Remote rangelands **Forested:** 51 Populated forests; 52 Remote forests **Wildlands:** 61 Wild forests; 62 Sparse trees; 63 Barren
Land systems (Letourneau et al., 2012)	Global, 9.3 km^2, 2000	**Bare soils:** Remote bare soils, Accessible bare soils, Populated areas covered by bare soils **Cropland systems:** Accessible rainfed croplands, Rainfed croplands with intensive livestock breeding, Remote rainfed croplands, Rice croplands with intensive bovines breeding, Partly irrigated croplands with intensive livestock breeding, Partly irrigated croplands with extensive livestock breeding, Irrigated croplands with intensive bovine breeding **Densely populated systems:** Urban areas, Villages or peri-urban areas, Villages and rice croplands, Villages and irrigated croplands **Forest:** Sparse trees, Populated areas with forests, Remote forests **Pastoral systems:** Extensive pastures, Intensive pastures with bovines and small ruminants, Intensive pastures with bovines **Mosaic systems:** Mosaic landscape, Populated areas mosaic landscape
Land system archetypes (Václavík et al., 2013)	Global, 2005, 9.3 km^2	LSA1: Forest systems in the tropics LSA2: Degraded forest/cropland systems in the tropics LSA3: Boreal systems of the western world LSA4: Boreal systems of the eastern world LSA5: High-density urban agglomerations LSA6: Irrigated cropping systems with rice yield gap LSA7: Extensive cropping systems LSA8: Pastoral systems LSA9: Irrigated cropping systems LSA10: Intensive cropping systems LSA11: Marginal lands in the developed world LSA12: Barren lands in the developing world
Land systems (van Asselen and Verburg, 2012)	Global, 2000, 9.3 km^2	Cropland extensive: few livestock; bovines, goats and sheep; pigs and poultry Cropland medium intensive: same as above Copland intensive: same as above Mosaic: Nine classes combining different types of intensities of cropland, grassland and livestock Dense forest; Forest, few livestock; Forest, pigs and poultry; Mosaic grassland and forest; Mosaic grassland and bare Natural grassland; Grassland, few livestock; Grassland, bovines, goats and sheep Bare; Bare, few livestock Peri-urban and villages; Urban

PRODUCT	DETAILS	CLASSES	
Typology of agricultural landscapes (van der Zanden et al., 2016)	Europe, 2003 to 2009, 1 km^2	**Expert-based typology** Small-; large-scale extensive arable land Small-; medium-; large-scale intensive arable land Small-; large-scale; very intensive arable land Enclosed; open extensive grassland Small-scale intensive grassland Enclosed; open large-scale intensive grassland Enclosed; open extensive mosaic land use Enclosed; open; very-intensive mosaic land use Small-; large-scale permanent crops	**Typology based on classification algorithm** Cluster 1: Medium-scale mosaic land use Cluster 2: Open grassland Cluster 3: Enclosed grassland Cluster 4: Small-scale mosaic land use Cluster 5: Enclosed mosaic land use Cluster 6: Enclosed arable land Cluster 7: Small-scale arable land Cluster 8: Intensive arable land Cluster 9: Very intensive arable land Cluster 10: Permanent crops Cluster 11: Extensive arable land Cluster 12: Large-scale arable land
Mediterranean land systems (Malek and Verburg, 2017)	Mediterranean countries in Europe and Northern Africa, 2 km^2, covers 2001 to 2014	Bare/desert, Wetlands Open rangeland, Extensive arid grazing, intensive open grazing, intensive arid grazing Cropland and rangeland, Open woodland, Open wooded rangeland Cropland and wooded rangeland, Permanent crops and rangeland, Closed wooded rangeland Extensive annual crops, extensive permanent crops, Extensive annual-permanent mosaic, Rainfed intensive annual crops, Rainfed intensive permanent crops, Rainfed intensive annual-permanent mosaics, Irrigated annual crops, Irrigated permanent crops, Irrigated annual-permanent mosaics Medium intensity forest, natural and semi-natural forest, high-intensity forest, planted forests Peri-urban, urban	
Cultural landscapes (Tieskens et al., 2017)	EU-27 and Switzerland, 1 km^2, 2006 but input layers of varying years used	Cultural landscape index (CLI) for agriculture and forestry calculated based on three dimensions: management intensity (based on economic farm size, nitrogen input, energy content output and harvest intensity of forests); landscape structure; value and meaning and then mapped the CLI and the dominant dimension for agriculture and forestry.	
Archetypical patterns and trajectories of land systems (Levers et al., 2018)	EU-27, 1 km^2 2006	High intensity cropland, Large-scale permanent cropland, Low-, Medium- and High-intensity arable cropland, Fallow farmland, Low- and High-intensity livestock farming, Low- and High-intensity grassland area, Low- and High-intensity forest, Low- and High-intensity agricultural mosaic, Urban built-up	
Land system representation (Dou et al., 2021)	EU, 1 km^2, 2017	Settlement systems (low, medium high intensity), Forest systems (low, medium, high intensity), Cropland systems (Arable, Permanent, with levels of intensity, Grassland systems (low, medium, high intensity), Shrubs, bare soils, water and wetlands; 7 mosaic classes. See Annex A for a more detailed table containing these classes and their input dimensions.	

The most recent product has been developed by Dou et al. (2021), who have generated a land use intensity map for Europe. This product was designed for use with the CLUMondo land use model but also with a view to improving biodiversity impact assessments. The set of classes and the drivers used to develop the classification is provided in Annex A. As it represents the most up-to-date European product on land use management, the input datasets and methodology were considered when developing the proposed LUM typology presented in section 4.

2.2.2. Maps of forest management

Although the products presented in section 2.2.1 do provide classes of forest intensity as part of a nomenclature that considers all land use types, there have also been products generated that focus specifically on forest management. For example, the product by Schulze et al. (2019) integrated existing data to map forest management globally at a 1km resolution through downscaling of national data from FAO's Forest Resources Assessment and additional subnational forest data from seven countries with the largest amount of forest area. Two levels of forest management were distinguished: Level 1 includes primary, naturally regrown and planted forests while Level 2 distinguishes between production, multiple use and other types of use (e.g., recreation and protection) for the year 2000. Twenty-one predictors were used to determine the probabilities of the occurrence of naturally regrown, plantation and production forests including the forest loss gain layers of Hansen et al. (2013), net primary productivity, various inputs related to soils, as well as socio-economic variables such as population density and national governance, among others.

A global map of planted forest and tree crops was developed by Harris et al. (2019) where the purpose was to differentiate planted forests (for wood production or ecosystem protection) and tree crops (perennial tree crops such as rubber, oil palm, etc.) from natural and seminatural forests on a global scale so that natural forest areas could be more readily isolated for better tracking of national and global progress toward major international commitments that relate to forests, climate, and biodiversity. The map represents a combination of data from different sources including FAO as well as requests made to individual countries to provide the data. The final product is intended to be representative of the year 2015 although data may vary temporally for individual countries.

A recent forest management map for Europe was developed by Nabuurs et al. (2019) at a 1 km resolution. The classes are arranged in increasing intensity of forest management as follows: strict nature management (i.e., strictly protected areas); close to nature management aimed at conservation and restoration of biodiversity; low intensity management for conservation, carbon sequestration and low intensity wood and timber production; multifunctional management where the forest may have more than one objective in the same location; intensive management; and very intensive management, where the latter two are aimed at wood and timber production but the latter is for short rotation, clear cutting over semi-large areas and fast growing tree species like Poplar, Eucalyptus and Sitka Spruce. Different drivers of forest management were combined using a Bayesian Belief Network, informed by experts who helped to determine the thresholds for the drivers, which include: the World Database of Protected Areas including the IUCN protection categories, the size of the felling areas, the soil types, the climate zone, the ruggedness of the terrain, the elevation, an accessibility indicator as the average time cost to different sized cities, the tree species and the contribution to the national Gross Domestic Product.

In contrast, Lesiv et al. (2022) used a different approach to develop a global map of forest management for the year 2015 at a 100 m resolution. The Geo-Wiki crowdsourcing tool was used to collect a large sample of detailed information on forest management based on visual interpretation of very high-resolution satellite imagery informed by a time series analysis tool, where the data were collected separately for tropical, boreal, and temperate forests around the world. The training data were then used as inputs to a random forest algorithm that classified Proba-V satellite imagery to produce a wall-to-wall forest management layer. The classes included: Naturally regenerating forest without any signs of management, including primary forests; Naturally regenerating forest with signs of management, e.g., logging, clear cuts etc.; Planted forests; Plantation forests (rotation time up to 15 years); Oil palm plantations; and Agroforestry.

2.3. THE NEED FOR BETTER DATA ON LAND USE MANAGEMENT

Recent reviews by Erb et al. (2017) and Kuemmerle et al. (2013) both highlight the need for better data on land use management. The review by Erb et al. (2017) identified 10 land use management activities that have a large impact on the Earth's surface. They then searched for data sets that characterize these activities at a global scale. Both irrigation and cropland harvest were characterized as having good data availability while there are severe gaps in data on forest wood harvesting, tree species selection, grazing and nitrogen fertilizer even though the understanding of the processes related to these activities is relatively advanced. Finally, they found severe gaps in both the data and in process understanding for crop species selection, artificial wetland drainage for agricultural purposes, tillage, fire management and crop residue management. In the context of LAMASUS and the focus area of Europe, some of these data sets will become available through requests made to the FADN, to Eurostat and to National Forest Inventories while information on other types of activities will be more difficult to obtain, e.g., on tillage.

Kuemmerle et al. (2013) outlined two main approaches to mapping land use intensity, i.e., ones that are based solely on remote sensing and others that combine remote sensing with statistical inventory data to produce gridded estimates. They also identified priority areas where improvements in data availability are needed, including suggestions for where these improvements might come from. In cropland systems, improvements in organic farming extent were highlighted, which is one area that will be addressed by the LUM geodatabase while some of the others will be addressed through access to FADN, Eurostat and NFI data.

Although the European land use intensity data set of Dou et al. (2021) provides low, medium and high land use intensities of major land cover types, further improvements are needed. For example, there are 7 mosaic classes, which some models can use while others require shares per grid cell instead. The product is only for one year so the panel dimension is missing, and hence temporal dynamics cannot be modelled. The typology in its current form is missing an irrigation layer for cropland, and intensive versus extensive farming is not represented. Finally, the classification is missing policy relevant land-use classes such as organic farming, peatlands, forests close to nature, and short rotation plantations. The development of the LUM geodatabase within LAMASUS will be designed to address these different requirements as much as possible, given the data availability.

3. Requirements for the LUM Geodatabase

The requirements for the LUM Geodatabase are based on (i) the needs of the models that will be used in the LAMASUS project (biophysical, ex-ante, ex-post) to better capture information on land use management; (ii) the need to be policy relevant; (iii) the needs of other projects; and (iv) feedback from the first LAMASUS Stakeholder Workshop. This helps to maximize the utility of the LUM geodatabase beyond the LAMASUS project. The requirements derived from these four areas are outlined in the sections that follow.

3.1. THE DATA NEEDS OF THE MODELS IN LAMASUS

The LAMASUS modelling toolbox will bring together many models that will need data on land use management. The requirements of the ex-post (econometric) models that will be developed by INRAE require a time series of panel data. Based on discussions with them, they need only major land use classes.

In addition, there are ex-ante models, some of which receive inputs from biophysical models, which are listed in Table 2, including their current state and the LU and LUM information they currently use. In some cases, these models do not require data from the LUM geodatabase or would benefit from better information on the input dimensions that will be used to develop the LUM classes.

Table 2: Biophysical models used in LAMASUS with with land use (LU) and land use management (LUM) used

MODEL DESCRIPTION	LU/LUM INFORMATION
G4M: combines estimates of forest productivity under different forest management regimes to calculate forest development; can be used to calculate incomes related to different options for land use **Spatial resolution:** 8km for Europe **Temporal resolution:** 1990 at 10-year increments (interpolating to annual for model time steps)	• GLC-2000 and CLC 2000 for land cover for forest classes and GLOBIOM for non-forest land use • Forest biomass from Gallaun et al., Kindermann et al. 2008, Forest Europe 2015 and FAO FRA for forest biomass • Kindermann et al. 2008 and FAO FRA for litter, deadwood and soil carbon • National forest inventories for forest age (country level) Verkerk et al. map of wood production for initializing forest wood production • UNFCCC CRF for land use change on country level • Fulvio et al. 2016 for wood and residues harvesting and transportation costs
EPIC: assesses crop productivity in response to management interventions such as cropping practices, fertilization, irrigation practices and sustainable agricultural practices, as well as climate change and soil degradation **Spatial resolution:** 1km soil and terrain; NUTS2 land management	Does not require LUM geodatabase for LAMASUS but would find LUM intensities (building on those produced by Dou et al. (2021)) useful for other modelling purposes. EPIC already uses the Dou et al. (2021) classes.

MODEL DESCRIPTION	LU/LUM INFORMATION
Temporal resolution: uses dynamic weather data; static land cover (2000); static land management (2000 – 1995 to 2005 average)	
ORCHIDEE: land surface model simulating energy/water balance, biogeochemical processes, anthropogenic processes including forest, cropland, and grassland management **Spatial resolution:** At European scale, 0.1 to 0.5 degrees; can also be run at plot scale **Temporal resolution:** 30 minutes to 1 year time steps to simulate different time-dependent processes	Does not require LUM geodatabase for LAMASUS but requires the LUM classes and definitions from the LUM geodatabase for consistency.
LPJmL: Dynamic Global Vegetation Model (DGVM) to simulate the global terrestrial carbon cycle and the response of carbon and vegetation patterns under climate change **Spatial resolution:** Any resolution but has been run at 5 to 30 arc minutes **Temporal resolution:** Different processes run at different time steps, e.g., daily but can be run over multiple years	• Natural vegetation (11 PFTs: Tropical broadleaved evergreen tree, Tropical broadleaved raingreen tree, Temperate needle-leaved evergreen tree, Temperate broadleaved evergreen tree, Temperate broadleaved summergreen tree, Boreal needle-leaved evergreen tree, Boreal broadleaved summergreen tree, Boreal needle-leaved summergreen tree, Tropical herbaceous, Temperate herbaceous, Polar herbaceous) • Agricultural crops (12 crop types: Temperate cereals, Rice, Maize, Tropical cereals, Pulses, Temperate roots, Tropical roots, Sunflower, Soybean, Groundnut, Rapeseed, Sugar cane) • Managed grasslands • Bioenergy plantations (3 types: Tropical tree, temperate tree and C4 grass) • Irrigated (sprinkler, surface, drip)/rainfed for all managed classes

The ex-ante models used in LAMASUS are listed in Table 3. The LAMASUS modelling toolbox will bring together many models that will need data on LUM. A workshop was held with all ex-ante modeling teams to (i) take stock of their models and the land cover/land use/LUM information that they currently use; (ii) examine the Dou et al. (2021) land use intensity product to see whether models could already work with these data in the short-term as well as gain feedback on the shortcomings of this product; and (iii) to propose a set of LUM classes, which were developed jointly with the GLOBIOM, G4M and EPIC teams as well as the ForestNavigator project, for discussion and feedback. Column 3 of the table addresses whether the models could use the Dou et al. (2021) classes in the short-term as well as what additional classes would be useful/other relevant comments. Column 4 provides feedback on the proposed LUM classes during the workshop.

Table 3: A description of the ex-ante models used in LAMASUS, its land use and land use management classes, potential to incorporate Dou et al., and stakeholder feedback on proposed classes.

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
GLOBIOM: partial-equilibrium model used to analyze the competition for land use between agriculture, forestry, and bioenergy sectors **Spatial resolution to be used in LAMASUS:** 1km grid (uses shares) harmonized to Eurostat NUTS2 statistics **Temporal resolution to be used in LAMASUS:** 5 or 10 years (2000, 2010, 2020) but annual time series of land use and land management is desirable for proper calibration of model parameters governing temporal dynamics	• Cropland • Grassland • Short rotation plantations • Managed forests • Unmanaged forests, other natural vegetation land + other agricultural land, wetlands, and not relevant (bare areas, water bodies, snow and ice, and artificial surfaces) derived from CLC 2000	Shares at 1km resolution would be better than mosaic classes but there are other issues: • Missing panel dimension (only cross section, does not say anything about temporal dynamics) • Missing irrigation layer for cropland, intensive vs extensive farming not represented • Missing policy relevant land-use classes organic, peatlands, forests close to nature, short rotations)	The GLOBIOM and EPIC model teams have developed proposed LUM classes for cropland and grassland. This has included improvements such as: • Cropland (divided in intensities: subsistence, low-input rainfed, high-input rainfed, high-input irrigated, crop types) • Grassland - intensive/extensive, mowed versus grazed • Organic farming (consider different intensities?) • Peatlands and their current management, e.g., forestry, grazing, • Short rotation plantations • Managed forests - different managements, climate smart forestry at least • Greenhouses could be part of a vegetable farming class (maybe separated from other crop types, and probably permanent, TBD)
MAGNET: global general equilibrium model for analyzing the substitution between forestry, natural forests and agriculture – coupled with IMAGE **Spatial resolution to be used in LAMASUS:** currently national but in LAMASUS will go to	• Fertilizer input (country level) • Forest plantations (country level) • Irrigation (country level) • Grassland management (country, modelled based on feed data and livestock systems) - would benefit from	The model does not use mosaic classes, but the use of some type of LUM classes will be developed as part of the project, which is	It may not be possible to go beyond 2 or 3 subdivisions in the forest management classes.

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
NUTS2 level and 5 arc-min (following IMAGE res.) - IMAGE acts as the downscaler **Temporal resolution to be used in LAMASUS:** starts from 2014, then 2019, 2030, 2050, end of century	more detailed grassland LUM classes from the geodatabse • Agricultural land use classes (i.e., crop-specific)	currently under discussion with the IMAGE team. Organic farming and different management systems per LU class would be useful for the model.	
IMAGE: integrated assessment model to assess interactions between the human and environmental system. Represents land use, energy and climate systems. Coupled to MAGNET model for agro-economic dynamics **Spatial resolution to be used in LAMASUS:** 26 regions (2 regions in EU) and 5 arc-minute grid - for LAMASUS, may go to country resolution in EU **Temporal resolution to be used in LAMASUS:** 5 years/annual - typically scenario period from 1970 to 2100 - in LAMASUS more recent data could be good enough, but at least 2010, 2015 and (is possible) 2020	• Food crops (16 crop types and irrigated/rainfed) • Irrigated for surface, sprinkler and drip irrigation • Grassland • Bioenergy (5 types) • Forestry systems (clear-cut, selective cut, plantations) • Natural land cover (14 classes)	The model does not use mosaic classes, but this is a planned development. It would be possible to start with Dou et al. (2019) but simplifying it as global coverage is needed.	It should be possible to link the LUM classes to nutrients, pesticides, carbon and water dynamics.
CAPRI: global partial equilibrium model for the agricultural sector, with an EU focus **Spatial resolution to be used in LAMASUS:** NUTS2 (CAPRI-NUTS2), 1km (CAPRI-	• All arable crops excluding rice and fallow • Paddy rice, Fruit and citrus, Olive Groves, Vineyard, Nursery and permanent crops	The model does not use mosaic classes and has only 6 land use classes so the Dou et al. (2021) system cannot be used by the model. In	No comments on forestry and artificial (aggregated in CAPRI). The cropland classification should be complete or at least understandable so that irrigated/rainfed is not overlaid on top of intensive / extensive and organic / conventional. Organic

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
1x1km), NUTS2 (CAPRI-Agclim50v – global and will use HILDA+) **Temporal resolution to be used in LAMASUS:** annual from 1984 but at least from 1995; for modelling, any set of simulation years after the CAPRI based year (2012 or 2017)	• Fallow land • Temporary grassland • Broad leaved wood, Coniferous wood, Mixed wood, Plantations (wood) and eucalyptus • Shrub land - no tree cover, Shrub land - tree cover • Grassland - no tree cover, Grassland - tree cover • Other sparsely vegetated or bare • Inland waters, Marine waters **CAPRI-1x1km gridded** • FSS at NUTS3 overlaid with 10x10km grid • European forest map • LUCAS data • SPAM 2010 data • FAO irrigation map • Peseta data for irrigated vs rainfed yields	principle the idea is to use regional data and do the downscaling within the project. Useful would be to have a class on organic farming.	grassland is not identified but would be needed for the modeling. Heathland might be a part of a "rough grazings" class or silvio-pastural systems. Annual time series would be useful to help in CAPRI database consolidation. What about wetlands?
CLUMondo: spatially explicit, dynamic land system change model **Spatial resolution to be used in LAMASUS:** 1km but can use mosaic classes **Temporal resolution to be used in LAMASUS**: for model set up, one recent year; time series would be good for	The Dou et al. legend was made for the CLUMondo Europe application in its current state	Modifications will be made for LAMASUS to fit policy goals and to arrive at some level of simplification. Changes towards Dou et al. might include (decisions in March 2023):	Less classes are needed given the increasing complexity of the model. In principle there are no limitations to the modelling per se (although demands for extensive farming vs conservation farming might be tricky). Classes must be decided soon as we will set up the model in the coming months and cannot adapt it later, given the large workload to change these classes. Some class

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
calibration; yearly time steps using path-dependence		• no intensity classes for permanent crops • some mosaic classes merged • slightly different set of forest management classes (tbd) • add organic farming • add wetlands • urban/residential classes will be re-defined a little bit	distinctions may not be possible given the data available, e.g., livestock distribution data are tricky and grazing densities are very difficult. We have produced new data on grazing in semi-natural areas (CLC named semi-natural areas) with the EEA, which will become available once the paper goes through review.
LUISA-BEES: allocates demand and supply of resources (biotic and abiotic, including primary energy sources), socio-economic activities (e.g., housing, industry, services, tourism, etc.) and infrastructure (e.g., for transport, energy, etc.) based on growth scenarios producing 50+ land functions indicators across multiple sectors; used for impact assessment of CAP; gets inputs from CAPRI **Spatial resolution to be used in LAMASUS:** 1km grid, could be aggregated to any NUTSX level and FUA's **Temporal resolution to be used in LAMASUS:** Starts with baseline year and	• Corine land cover 2018, modified for forest area to match SOEF statistics, using forest map from Copernicus • Urban, Industry, Urban green • Arable, Permanent crops • Pastures • Mature forest (calculated from natural succession) • Transitional woodland & burnt areas • Abandoned arable (calculated when demand < actual) • Abandoned permanent crops (same as above) • Abandoned pastures (same as above) • New energy crops • Semi-natural vegetation	The model does not use mosaic classes and it would not be able to use the Dou et al. (2021) classes although it is a topic of interest. Ancillary data would be need as well as historical data for the calibration. Grassland intensity would allow the model to assess the impact of alternative policies aimed at changing agriculture use and grassland. Mapping land	Forests available for wood supply - only useful for one year (start of simulation) and no way of simulating future treatments (data are available but not yet public).

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
predicts change every 5 years from 2020 up to 2050	• Young forest (calculated as abandoned land becomes forest) • Infrastructure (ports, airports, roads) • Other nature • Salines, bogs and marches • Water courses, lagoons and estuaries	management and intensity could have potential applications for improving biodiversity, assessing and mapping ecosystem services, mitigating climate change through carbon sequestration, and reversing land degradation.	
FARMDYN: a dynamic mixed integer bio-economic farm scale model to simulate changes in farm management and investment under changes in boundary conditions such as prices or policy instruments, for a wide range of different farming systems **Spatial resolution to be used in LAMASUS:** Single farm (case studies focusing on Norway and German federal state of North Rhine-Westphalia) **Temporal resolution to be used in LAMASUS:** 2 weeks to 1 year	• Arable: crop type, soil type (exogenous), tillage type (plough, minimal tillage, no tillage, organic), fertilizer input, machinery use • Permanent grassland: fertilizer, mowing/grazing events • Intensities are reflected in the management for different activities • FarmDyn requires farm level data (e.g., FADN or synthetic farm population generated in WP2). LUM geodata base is not required for the FarmDyn work in Lamasus, we will rely on existing farm typologies or FADN data. However, information from the geodata base may be used for farm characteristics which is not part of the farm level data (e.g., mowing events).	The model does not use mosaic classes. Intensity classes 3.1 to 3.3 and 4 from Dou et al. (2021) could be reflected in FarmDyn. The Dou et al. (2021) classes could easily be provided by the model as an output. FarmDyn will be extended to capture the new CAP.	FarmDyn does not cover forest, irrigated cropland, or semi-natural elements. Intensities of grassland and arable land should be reflected in FarmDyn. FarmDyn will not be able to calibrate on observed intensities (except fixing the intensities and excluding them as decision variables). However, the model results can be presented reflecting these intensity classes.

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
AGRISPACE: a recursive-dynamic regionalized Partial Equilibrium model of agriculture and key food sectors for Norway presenting the full farm population **Spatial resolution to be used in LAMASUS:** NUTS3 for Norway **Temporal resolution to be used in LAMASUS:** annual	• Arable, Permanent cropland (6 cereals, rape seed, potatoes, pulses, tomatoes, other vegetables, apples, other fruits) • Grassland • Livestock (Dairy cows, suckler cows, other cattle, sheep, goat, sows, slaughtered pigs, laying hens, poultry • Agrispace does not require the LUM geodata base. The spatial resolution extends to single farms that are geolocated to the municipality level.	The model cannot use the mosaic classes of Dou et al. (2021) but the model might be able to use this system if the supply functions were modified. Modelling could maybe begin with this data set. Modeling the impacts on biodiversity and nutrient cycling are of interest.	No comments on forest or cropland classes. These classes could be used with modifications of the supply function (making fertilizer explicit).
PREDICTS: database of abundance and occurrence data for over 50,000 species and over 30,000 sites in nearly 100 countries for use in modelling; development of the Biodiversity Intactness Index **Spatial resolution:** N/A as the database contains locations, which can then be applied to IAMs at different resolutions **Temporal resolution:** Data come from many studies across multiple times	• Primary vegetation (Minimal use, Light use, Intense use) • Mature secondary vegetation (Minimal use, Light/intense use) • Intermediate secondary vegetation (Minimal use, Light/intense use) • Young secondary vegetation (Minimal use, Light/intense use) • Plantation forest (Minimal use, Light use, Intense use) • Cropland (Light use, Intense use) • Pasture (Light use, Intense use) • Urban (Light use, Intense use)	There are similarities between the Dou et al. (2021) classes and the current classes used in PREDICTS although the age of the vegetation is not reflected, and the plantation classes are more detailed.	Forest: Response functions cannot be obtained for the protection and recreation forest classes. Will there be a secondary vegetation class? How is the age-structure covered in the forest classes (maturity, young secondary?). These are usually core to the forest class modelling. Cropland: It will not be possible to differentiate between conservation/organic farming unless the former is mapped as low-intensity farming. Getting response functions of irrigated vs rainfed farming will be quite challenging and will need to map these against low/medium intensity farming. Permanent cropland is challenging but may be doable but unsure if there are enough data points of this type.

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
			Grassland and shrubland: Should be manageable to cover by the PREDICTS LUM classes/ data. Silvopastural agroforestry might be tricky owing to a lack of data. Shrubland is currently mapped as secondary vegetation. Urban: We can do minimal, light and intense urban but cannot cover road/rail mortality in terms of biodiversity as this is not what the PREDICTS framework was created for. A different legend would be needed here. The biodiversity impact side is limited by available input data and what can be mapped against any of the classes. Most are represented in PREDICTS and for some, additional evidence can be collected. However, not classes may be covered detail, constrained by the available data.
GLOBIO: model that relates animal species abundance or survival based on distance to infrastructure and other pressures (land use, nitrogen deposition, fragmentation, and climate change). Developed 'mean species abundance = the mean abundance (or species richness) of the original species relative to their abundance in pristine ecosystems; fed by IMAGE model inputs **Spatial resolution:** 0.5 degrees	From GLC-2000 + IMAGE: • Primary vegetation • Lightly used natural forest: 50% of Mosaic of cropland forest class, Secondary forests, Forest plantation: used FAO national forest data to proportionally allocate to all grid cells with forest classes • Agroforestry	Not included in the workshop because linked to IMAGE	Not included in the workshop but linked to IMAGE

MODEL DESCRIPTION	LUM CLASSES AT PRESENT	DOU ET AL. (2021) OTHER AND COMMENTS	FEEDBACK ON PROPOSED LUM CLASSES
Temporal resolution: 2000, 2050	• Livestock grazing: estimated by IMAGE and distributed proportionally to all classes containing low vegetation • Man-made pastures: herbaceous cover class if found in originally forested areas according to potential vegetation map (from IMAGE) • Low-input agriculture, Intensive agriculture: based on estimates from Dixon et al. (2001) or 100% intensive + 50% of Mosaic of cropland forest class • Built-up areas		

Source: LAMASUS (Work Package 2 and Workshop 1)

3.2. EU POLICIES AND REPORTING

One of the requirements of the LUM geodatabase is that it must have relevance for EU policy, i.e., it must provide inputs to models that can be used to assess the impact of a policy in the area of agriculture and forestry on properties of the land system such as biodiversity, the carbon and water cycle, etc. or aid in monitoring the progress towards meeting a policy objective. When combined with other data sets, it should also contribute to analyses that highlight locations where policy interventions may be needed to ensure sustainable production and land use. Based on a desk review of EU policies, the next section highlights the set of policies, targets and actions that can be supported by the LUM geodatabase. This is followed by a summary of policy-related needs from members of the Scientific and Policy Advisory Board from the LAMASUS kickoff meeting.

3.2.1. EU Policies based on a Desk Review

Table 4 lists the relevant EU policies, the aspects of the policy that are relevant to LUM and the ways in which the LUM geodatabase can support the monitoring and impact of the policy. One clear area of policy support is in promoting sustainable agricultural and forest land use management in terms of natural resource use (soil, water, etc.), restoration, and halting degradation and land take (through urban encroachment). A second key policy area is in climate change adaptation/mitigation and the reduction of emissions in terms of a specific target for removal in the LULUCF sector, targets for the rewetting of peatlands and relevant CAP objectives to support farmers in practices that reduce the impacts of climate change. Monitoring of the new CAP, the uptake of eco-schemes and sustainable forest management will also benefit from the LUM geodatabase and the LAMASUS modelling results. Finally, the LUM geodatabase can support the new requirement for spatially explicit emission reporting of LULUCF by providing a high-resolution land use time series.

Table 4: EU policies relevant to land use management (LUM) and how they can be supported by the LUM geodatabase.

EU POLICIES	TARGETS OR ACTIONS	HOW LUM GEODATABASE CAN SUPPORT THE POLICY
EU Nature Restoration Targets	Restoration measures should be in place on 30% of drained peatland areas of which at least 25% should be rewetted by 2030, and 50% and 70% by 2040 and 2050, respectively, with at least 50% rewetted	The database can be coupled with improved products on wetlands, peatlands and organic soil information to identify areas for peatland rewetting.
EU Forest Strategy	Promoting of alternative forest industries, such as ecotourism, as well as non-wood products, such as cork, honey and medicinal plants	The database will improve the multifunctional forest management class by dividing it into conservation, recreation and forests for non-wood products, so it can be used for monitoring the changes in these alternative forest industries.

EU POLICIES	TARGETS OR ACTIONS	HOW LUM GEODATABASE CAN SUPPORT THE POLICY
EU Soil Strategy for 2030	Combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world (Sustainable Development Goal 15.3)	The database can be combined with other data layers to identify degraded areas for potential restoration.
7th EU Environment Action Programme, Decision No 1386/2013/EU EU Soil Strategy for 2030	Reduce land take by 2030 and reach no net land take by 2050	The database can be used to monitor changes in urban areas, including levels of intensity of urbanization and how changes in the urban landscape can affect the ability to reach a no net land take by 2050.
Resolution of 14 March 2023 on LULUCF COM(2021) 554 EU Soil Strategy for 2030 FIT55	Achieve an EU net greenhouse gas removal of 310 million tonnes CO2 equivalent per year for the land use, land use change and forestry (LULUCF) sector	The database can be used in ex-ante models to generate scenarios for reaching this target.
Resolution of 14 March 2023 on LULUCF COM(2021) 554	For monitoring and reporting in the LULUCF sector, Member States shall use geographically explicit land-use conversion data in accordance with the 2006 IPCC Guidelines for national GHG inventories.	The geodatabase could support the reporting process for LULUCF through providing spatially explicit land use information annually from 2000 to 2020 (to be updated with further annual layers in the latter half of the project).
CAP Policy Objectives	Contribute to climate change mitigation and adaptation, including by reducing GHG emissions and enhancing carbon sequestration, as well as promoting sustainable energy	The geodatabase can be used in ex-ante models to develop scenarios for emission reduction for the LULUCF sector as well as carbon sequestration.
CAP Policy Objectives	Foster sustainable development and efficient management of natural resources such as water, soil and air, including reducing chemical dependency	The geodatabase can provide information for monitoring current/past land use and for modelling to support different scenarios related to CAP ecoschemes, changes in agricultural management, etc.
CAP Policy Objectives EU Forest Strategy	Support sustainable forestry	The geodatabase can support different scenarios of sustainable forest use
EU Biodiversity Strategy for 2030	Contributions are in several places; see Table 5	See Table 5

Table 5 lists the relevant targets found in the EU Biodiversity Strategy for 2030, along with other EU policies that also have these targets, and the ways in which the LUM geodatabase can support the monitoring and impact of these targets. This includes eight targets found in this strategy for 2030 that are related to the protection and restoration of land, more sustainable use of agricultural land (i.e., through reductions in chemical pesticides, chemical fertilizers, increases in organic farming and promotion of more high-diversity landscapes), and the planting of trees. The LUM geodatabase can support modelling scenarios related to these different targets.

Table 5: Relevant 2030 EU Biodiversity Strategy targets that can be supported by the LUM geodatabase.

EU BIODIVERSITY STRATEGY FOR 2030 TARGETS	OTHER EU POLICIES WITH THIS TARGET	HOW LUM GEODATBASE CAN SUPPORT THE POLICY
Subtarget: 1.1 - Legally protect a minimum of 30% of the EU's land area		Currently at 26%, the database could support analyses on additional areas for protection.
Target 2 - Strictly protect at least a third of the EU's protected areas, including all remaining EU primary and old-growth forests.		The database can provide spatial information on primary and old-growth forests and where to increase strict protection.
Target 4 - By 2030, significant areas of degraded and carbon-rich ecosystems are restored and at least 30% reach favorable conservation status or show a positive trend.		The database can be used to monitor restoration in combination with other datasets.
Target 6 - The risk and use of chemical pesticides is reduced by 50%, and the use of more hazardous pesticides is reduced by 50%.	Zero Pollution Action Plan, Farm to Fork Strategy, EU Soil Strategy	The database can highlight potential areas with intensive cropland management.
Target 7 - At least 10% of agricultural area is under high-diversity landscape features.	CAP Reform and CAP Policy Strategic Plans	The database can be used to monitor high-diversity landscape features in combination with other datasets.
Target 8 - At least 25% of agricultural land is under organic farming management, and the uptake of agro-ecological practices is significantly increased.	Organic Farming Action Plan as part of Farm to Fork Strategy	Organic LUM classes (or organic as an additional layer) can be used to monitor the target and can be used in ex-ante modelling.
Target 9 - Three billion additional trees are planted in the EU.	EU Forest Strategy for 2030	The database can highlight potential areas for afforestation.
Target 13 - The losses of nutrients from fertilizers are reduced by 50%, resulting in the reduction of the use of fertilizers by at least 20%	EU Soil Strategy for 2030	The database has cropland management classes that will include information on fertilizers so these reductions can be modelled and monitored by considering changes in LUM intensity classes.

The LUM geodatabase could also provide useful inputs to (i) the Destination Earth (DestinE) flagship initiative of the EC (2022d), which aims to develop a highly accurate digital twin of the Earth to support achieving the objectives of the EU Green Deal through modelling the interactions between natural phenomena and human activities, and (ii) the new proposal for ecosystem accounting regulations across the EU (EC, 2022e).

3.2.2. *EU Policies based on Inputs from the Science and Policy Advisory Board*

Members from the Science and Policy Advisory Board of LAMASUS made recommendations during the LAMASUS kickoff meeting regarding what key issues need to be tackled during the project, with implications for the LUM geodatabase. A summary of these key issues is provided below.

DG-CLIMA

Based on FIT55, DG-CLIMA needs to reduce net GHG emissions by at least 55% by 2030 compared to 1990 levels to reach climate neutrality by 2050. Removals of 310 GT are needed by 2030 to get on this pathway for 2050, and the link to agriculture in achieving this is crucial. However, the direction in which LULUCF is going needs to change if climate neutrality is to be achieved. This is not simply a question of tuning policies but combining incentives and achieving balance across the entire economy. The future will be dominated by the bioeconomy, and large changes to the agricultural and energy markets are required to develop a new baseline. Finally, it is not yet clear what can be expected from the EU on carbon farming initiatives.

DG-AGRI

They expect the project to support ex-ante assessment of future policy choices, considering all the sustainability dimensions and potential trade-offs and as an input to future sustainable European agricultural food policy (also beyond the EU). Other areas where the LUM geodatabase/LAMASUS project could be useful are: (i) for mapping peatlands and peatland management; (ii) to assess the carbon removal potential of land; (iii) to produce soil organic carbon maps; (iv) to support/improve member state GHG inventories and emission reporting; (v) to calculate standard average baselines for groups of farmers and regions for GHG removals; (vi) to assess carbon leakage and trade-offs; (vii) to make links to the EU Soil Observatory and LUCAS; (viii) for carbon farming; (ix) to provide spatially explicit information on land use management; (x) to provide support to the Nature Restoration Law (to answer such questions as: Where can land be restored? Where can connectivity be established? Which landscapes have certain features, e.g., hedgerows?) and the Habitat Directive, e.g., information on tree cover, tree species, extent of permanent grassland and intensities of management could contribute to reporting on the state, pressures and trends of ecosystems; (xi) for land abandonment; (xii) for changes in urbanization; (xiii) for improving how biodiversity is addressed in the models, using proxies such as soil disturbance, fragmentation, landscape features such as hedgerows, tree species, etc. The advice was to take what data already exist and make it more targeted, e.g., use data from JRC, extract the most relevant data from LUCAS/other data sets and make it policy relevant.

One suggestion made was to overlay all the information/data layers and then go back and look at the problem areas and the policies to see if these policies are responsible for the problems. For the 2024 CAP, the LUM geodatabase will be a key input to see where the problem areas are. Soil data and sharing of the data are key and the LUCAS survey data should be leveraged. They suggest taking a soil map and the season that is most representative along with maps of water (quantity and quality), GHG emissions, and income/profitability and overlay them to get a sense of the challenges. Questions such as: What are the LUM strategies that explain why some areas fare better than others and how thesecan then be addressed?

JRC (ISPRA)

As part of the EU Cohesion Policy – investment of 400 billion Euros (2021-2027) to reduce economic, social and territorial disparities – there will be an investment in the EU Green Deal, which is an investment in climate mitigation/adaptation. Now as an official partner of the LAMASUS project, the LUISA territorial model of the JRC will be used to assess the impacts of changes in demography on land use in urban and rural regions, e.g., depopulation in many areas, and the impacts of the EU Green Deal on land use, in particular, the demand for land for renewables; the hydrogen economy and carbon sequestration; nature conservation and restoration; and carbon uptake in land, forests, and increases in soil organic carbon.

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The land sector is expected to a make a huge contribution to the net zero target but this requires policy interventions and dramatic changes in the land use to achieve this. Hence the work of the LAMASUS project is very important. Three main comments were made: 1) where is the basic data coming from, e.g., costs related to rewetting of organic soils, costs of planting hedgerows, costs of implementation in different regions, etc.; 2) how will bioenergy be considered as all scenarios suggest that more bioenergy crops are needed to reach net zero; what is the demand for bioenergy and how will this be integrated; 3) how will social and behavioural responses of land owners be taken into account in the models? Moreover, one of the strengths of the project is the emphasis on the spatial dimension but this has implications for the stakeholders with whom the project will communicate, i.e., the EC but also national member states and stakeholders at the sub-regional level, in order to make use of the spatial dimension of the results. Finally, in relation to the land use targets in the 'Fit for 55' package, afforestation and agroforestry are one of the most effective ways to sequester carbon and should be considered in the modelling.

European Environment Agency (EEA)

The LUM geodatabase will integrate many datasets produced by the EEA and the Copernicus land monitoring service. The EEA expressed a strong interest in having their existing datasets used in the project. One of their main interests is in how changes in land use management can impact ecosystem services and biodiversity as well as the biocapacity potential, which is based on productivity, land use and human population. They are also interested in the impact of diets on the land (although this is not specifically covered in LAMASUS) as well as changes in agricultural systems with many landscape elements versus those with fewer elements.

Overall, the proposed LUM geodatabase has considerable relevance from a policy perspective, both for historical analyses and future impacts of policy. A key point is that existing data sets will be used (as stressed by most of the board members), and that a number of key areas can be considered in the model scenarios, underpinned by data that can support these scenarios.

3.3. POSITIONING WITH RESPECT TO OTHER PROJECTS

There are several projects that can contribute data to the LUM geodatabase (as inputs, for validation, or to create derived products from the database). In other situations, projects may want to use the LUM geodatabase for their modelling work or the proposed LUM classes within their projects for consistency; these projects are summarized in Table 6. In the call text for the proposal, it was made clear that links must be made to the LandSupport project (entitled 'Development of Integrated Web-Based Land Decision Support System Aiming Towards the Implementation of Policies for Agriculture and Environment'), which was funded under the

EU's Horizon 2020 program and ran from 2018 to 2022. In addition, the requirements from a series of ongoing projects have also been considered (and will continue to be considered during the LAMASUS project lifetime), either through discussions with people involved in these projects and/or through monitoring of their websites. The INSIGNIA project (https://www.insignia-bee.eu), which is focused on a method to detect pesticides, microplastics, heavy metals and air pollutants using citizen science and honey-bee colonies might provide some measurements of pesticides but only at point-locations across the EU. Hence it is not listed in Table 6.

Table 6: Synergies with other projects.

PROJECT	DETAILS AND SYNERGIES WITH LAMASUS
LandSupport (completed)	This project created a catalog with 18 spatially explicit layers at the EU level and 64 layers for selected countries and areas in Austria, Italy and Hungary, some of which could be used as inputs to the LUM geodatabase. https://www.landsupport.eu/
ForestNavigator	This project requires an improved forest management map for EU countries that is more detailed than Nabuurs et al. (2019) so would benefit from the LUM geodatabase. Ongoing collaborations with ForestNavigator and PathFinder (see below) have informed the development of the LUM forest classes. https://www.forestnavigator.eu/
PathFinder	In collaboration with LAMASUS and ForestNavigator, the project will produce a forest management map for EU countries at a 1km resolution for 2020 based on a methodology developed jointly by all three projects. This forest management map will feed into the work of LAMASUS and the LUM geodatabase. https://www.nibio.no/en/projects/pathfinder
ForestPaths	This project will produce several relevant products: annual, wall-to-wall European forest disturbance maps for 1984-2022; consistent and fine-scale maps of forest composition (e.g., dominant tree species, number of species) and structure (e.g., height, diameter, density, biomass); and maps of potential high conservation value forests that have high biomass carbon stocks as well as biological and structural diversity. This project will be monitored for input data that could be used in the forest LUM classes. https://forestpaths.eu/
BrightSpace	BrightSpace will provide an analytical toolbox to experiment, analyze, and coordinate the effects of innovative technologies, governance structures, as well as short- and long-term policies related to agriculture. Using many of the same models as LAMASUS, the LUM geodatabase will also be used in this project by some models. https://brightspace-project.eu/

PROJECT	DETAILS AND SYNERGIES WITH LAMASUS
DETECT	Funded by the German Research Foundation, this project will create 1km crop type maps, separated by irrigated/non-irrigated, from 1900 to 2020 that are consistent with official administrative data on crop cover areas, quantifying uncertainty. This information could be used in combination with the LUM geodatabase in the future.
ALFAWetlands	In addition to various case studies of different types of wetland management, the project will improve the European map of wetlands, which would be a useful input to the LUM geodatabase. https://alfawetlands.eu/
Wet Horizons	The project will compile and harmonize different wetland data sets for Europe to improve the knowledge base on the type, extent, location, condition, and type of current management practices on peatlands, floodplains, and coastal wetlands in Europe to produce an improved European wetland map. Such a map could be used as in input to the LUM geodatabase but will be produced too late for the first version. https://www.wethorizons.eu/
NaturaConnect	This project will develop a decision support tool for different scenarios of protected area configurations. They require LUM classes (and the continuous inputs to derive the classes). https://naturaconnect.eu/

3.4. FEEDBACK FROM THE FIRST STAKEHOLDER WORKSHOP

The first LAMASUS Stakeholder Workshop was held on 4-5 April 2023, which will be summarized in a summary stakeholder workshop report (D1.2) available in August 2025. During the first part of the workshop, Olaf Heidelbach a member of the Policy Advisory Board presented the DG-AGRI expectations of the LAMASUS project. These include supporting the ex-ante assessment of future policy choices, highlighting tradeoffs to sustainability, inputting to future CAP policies and as decision support to land managers for long-term land planning. Other expectations include mapping peatlands and defining best management practices (which are actually the subjects of other EU-funded projects), assessing the carbon removal of the land, and linking to the EU soil observatory, LUCAS and previous integrated modelling exercises. One of the main messages was to focus on having an early influence on the future CAP, i.e., already in 2024; identifying a limited number of policy relevant deliverables; and sharing data with other projects. In summary, the LUM geodatabase will be an important input to support the modelling related to current and future CAP policy.

In the second part of the workshop, four round tables were organized so that inputs could be sought from the stakeholder board. One round tables covered the LUM geodatabase and the proposed LUM classes. Four sessions of approximately 30 minutes each were held with between 3 to 5 stakeholders per session. The stakeholder board consists of landowners and their representatives, decision makers working in administration, and representatives from environmental NGOs and the research community, a full list will be provided on www.LAMASUS.eu in May 2023.

In each round table, the LUM geodatabase was briefly presented to the stakeholders as two parts (CORINE time series and LUM geodatabase – see Annex B) followed by a graphic containing the proposed LUM classes shown as a function of management intensity. The stakeholders were then asked to answer three questions followed by a discussion of any issues raised while answering these questions:

1. Is the CORINE time series useful for your job? If so, list potential applications.
2. Is the LUM geodatabase useful for your job? If so, list potential applications.
3. Do the LUM classes make logical sense? Anything missing? Suggestions/comments?

Regarding questions 1 and 2, the overall response from the group was that both the proposed CORINE time series and the LUM geodatabase are useful and that they would be used by some people in the group or by their colleagues. Examples of potential applications provided by the stakeholders included analysis of land use change in mountainous regions; the environmental impacts of land use change (air, water, biodiversity); forecasting; spatial regression; evaluation of ecosystem services; and for making links with CAP implementation (especially with certain types of interventions, e.g., coupled support schemes, eco-schemes, etc.).

Question 3, the proposed LUM classes, elicited many more comments and discussion. Table 7 contains a summary of the key points raised across all 4 round tables and how these comments are being considered by the project. There were a series of comments regarding definitions, i.e., what does management intensity mean. This will be defined by a series of input layers and thresholds in the next stage of the project, which should help to clarify this point. A series of comments were then made about the forest, cropland, grassland/shrubland and urban classes. One frequently raised comment was that definitions vary across EU countries, which clashes with the aim of the LUM geodatabase to produce a European product that is comparable across countries. We will consider this point during the methodological development of the intensity classes. Other comments were about potential changes to classes, i.e., they are not detailed enough, they do not include crops, and there is overlap between classes (particularly in the agroforestry, grassland, shrubland areas). There is a tradeoff between trying to characterize land management systems in as much detail as possible while satisfying the needs of the models that will be used in LAMASUS. Once the classes are more clearly defined, some of these concerns may be addressed or more detailed justifications will be provided for these class choices.

The point was raised that some low management input/low input farming practices could still be harmful (e.g., overgrazing or under grazing can have negative impacts in mountain pastoralism), which has been noted. It was also suggested to examine the regulation on plant protection products and what pesticides can be used in extensive farming.

Table 7: Summary of the key points raised during the round tables on the LUM classes.

AREA OF COMMENT	COMMENTS FROM STAKEHOLDERS	RESPONSE
Comments about definitions	• How is management intensity defined? For example, nature reserves can also be highly managed. • It would be good to explain the terminology used. • What is intensive? What are medium intensity classes? • It makes sense but it's very different to identify the intensity, but we need to expect [predict] the yield. • Intensive defined differently between different countries, e.g., in the Netherlands, 2.3 cows = intensive while 4 cows on average as intensive in other places	The management intensity will be defined in the next step of the methodology based on different input data sets available and expert knowledge regarding thresholds. European vs. country-specific intensity will be considered.
Forest management classes	• Forest management differs by country! • What is intensity in a forest management context? Does this include Rotation period? Protection categories are not always in line with intensity (differences between countries). • Categories need revision, especially multi-functional forests; need to include climate smart forestry; would never have a forest managed only for recreation, e.g., NWFP and recreation together or protection and recreation together, etc. • The biomass class in forestry could be important (it would be a question of productivity and/or age) • Very intense forestry could be coppice or plantation forestry for production • How is long-term standing wood product stored and used for building materials accounted for, emissions count after 20 years but not wood destroyed by bark beetle	Forest management intensity has been defined in more detail using a number of different input layers, which includes rotation periods and biomass among others. The point is well taken regarding multi-functional forests, but the idea is to identify dominant management types within multi-functional forests. There is a separate class for short rotation coppice (part of the permanent cropland class). Wood storage is not currently considered in the forest management classes but clearly has implications for emissions reporting.
Cropland management classes	• Arable cropland classes are very broad • Should have farming rainfed, farming some irrigation, farming complete irrigation • Another suggestion: Intensive irrigated farming, Traditional mainly rainfed farming with irrigation, Traditional farming without irrigationProfit margin of crops could be used to determine high intensity • Agroforestry should be in arable/permanent rather than grassland • Why only 3 classes for arable cropland (and forest) and why no crops?	These classes are largely based on model requirements rather than a complete characterization of agricultural systems. Crop type information will become available in another project and merged with the LUM geodatabase. The agroforestry class is a difficult one, which needs further consideration in the next phase of the methodology.

AREA OF COMMENT	COMMENTS FROM STAKEHOLDERS	RESPONSE
	• Agro-voltaic: a big potential class coming in the future; captures water, can have grassland with arable or grassland with livestock	
Grassland (and shrub) management classes	• What is intensive/extensive grassland? • Agropastoral Spain – is this intensive or extensive? • What about irrigation in grasslands? • Organic grassland is drained peatland so need to define this better; perhaps it makes sense to identify on which soil it is (peaty soil, sandy soil) to see how it changes in the future; peatland is small areas but very important (carbon dense) • Shrubs are not a permanent land type → transitional; commonage areas [unenclosed] • Shrubs: mostly transitional, occur on mountains, no field boundaries • Some classes overlap (e.g., shrubs and rough grazings) • Grasslands and shrubs are often interacting, e.g., alpine pastures • Big overlap between shrubs and extensively managed semi-natural grassland	The management intensity will be defined in the next step of the methodology based on different input data sets available and expert knowledge regarding thresholds, which will address the answers to some of these definitional questions. If high resolution information on irrigation is available, we could consider adding this as a sub-class to grassland. We agree that there is an overlap between grassland and shrubs but when we define the classes in more detail, we will try to address some of these issues.
Urban classes	• Green area percentage to be included; differentiate between residential/commercial/industry and take density and livability into account	Green area is partly taken into account through the soil sealing product of Copernicus, but a separate input layer could be added. The WUDAPT product can help to differentiate between residential and commercial as well as density of buildings. Livability is a difficult concept to include and may not be relevant to environmental impacts.
Missing classes	• What about abandoned land? If parcels disappear in LPIS, could indicate abandoned • Greenhouses are missing	Abandoned land is currently part of other natural land at present from a modelling perspective but we may consider identifying these areas in the geodatabase if possible (e.g., in Spain and Portugal). Greenhouses are difficult to identify so are not included at present.

4. The Technical Specifications of the LUM Geodatabase

The proposed LUM geodatabase has two parts: (i) the land cover and land use layers and (ii) the land use management layers. These two parts will be generated as separate products that together will comprise the 'LUM Geodatabase'. The specifications for each of these two parts is provided in the two sections that follow. The input data sets to the 'LUM Geodatabase' are then described along with a brief overview of the methodology that will be used to create this geospatial data database.

4.1. SPECIFICATIONS OF THE LAND USE GEODATABASE

The land use geodatabase will be an annual time series based on CLC from 1990 to 2020. The resolution will be the original 100m in which CLC is available, using the same grid and projection (ETRS89 / ETRS-LAEA). The CLC data are currently available for 1990, 2000, 2006, 2012 and 2018 including change layers. The EEA has also produced CLC data for these years that are already harmonized to European statistics, referred to as the CLC accounting layers (EEA, 2019). Using both sets of layers along with many other input data sets (see section 4.3), an annual time series will be derived. The data will be aggregated to a 1x1 km raster (with shares) and NUTS 2 regions following the NUTS 2016 classification (with some corrections to match the official statistics) and change between years will be calculated.

4.2. SPECIFICATIONS OF THE LAND USE MANAGEMENT CLASSES

There will be three levels in the LUM hierarchical nomenclature, where LUM classes will be specified for the following level 1 classes:

- Forest
- Cropland
- Grassland
- Built-up or urban areas

Each level 1 class is then further sub-divided into level 2 and level 3 classes, which become more detailed within this hierarchy. In addition, a set of input layers (or also referred to here as dimensions) have been identified, which will be used to define the classes in the next stage of the project.

The remaining classes (shrubland, water, wetland, bare soils and snow/ice) will stay as they are in the CLC land cover product although shrubland areas that are grazed (so called 'rough grazing') will be included within the grassland management class.

The LUM classes will be applied to the CLC data for 2000, 2010 and 2020 as a starting point, using layers from the annual time series as inputs and keeping the 100m resolution but then aggregating to 1km and NUTS2 regions. If the input data are available, a more frequent coverage will be produced, i.e., every five years or annually.

4.2.1. Forest LUM classes

The proposed LUM forest classes are outlined in Table 8. The starting point for these classes was the forest management layer produced by Nabuurs et al. (2019) and the global map of forest management produced by Lesiv et al. (2022). In the forest management layer of Nabuurs et al. (2019), the multifunctional forest class represents 45% of European forests and has now been broken down further into three level 3 classes. These multifunctional level 3 forest classes reflect the dominant activity, with the recognition that more than one type of activity can take place (as highlighted by feedback from the first stakeholder workshop).

Table 8: Level 1 Forest broken down into level 2 and 3 LUM classes along with the input layers/dimensions that will be used to define the classes

LEVEL2	LEVEL3	INPUT LAYERS/DIMENSIONS
Primary forests	Primary forests	• Old CLC, change layers, new 2018 CLC • GLC-2015 map from JRC • Forest loss (Hansen et al., 2013) • Primary forest (Sabatini et al., 2021) • Forest management layer (Lesiv et al., 2022) • Intact forest layer (Potapov et al., 2008) • WDPA and Natura 2000 layers • Disturbance maps (Senf and Seidl, 2020) • LAI maps from remote sensing • Dominant species from EFI map • Species occurrence map (Mauri et al., 2022) • National maps of species • Dominant age (Pucher et al., 2022) • 20 years of NFI data on age shares (8km) • European DEM, slope, roughness • European river network/water bodies • Soil map (to isolate Histosols) • Accessibility map (2018 update from JRC) • Canopy heterogeneity layer (from Herold) • Data from iNaturalist, Flickr, Geo-Wiki
Other not harvested	Other strictly protected forests	
Close to nature forests	Close to nature forest management	
Multifunctional forests	Protection forests	
	NWFPs (cork extractions, mushrooms, pine kernels)	
	Recreation	
Production forests	Intensive	
	Very intensive (plantation forestry)	

Source: LAMASUS WP 2

4.2.2. Cropland LUM classes

The proposed LUM cropland classes are outlined in Table 9. These classes are driven by the need to improve information on irrigation, intensive versus extensive agriculture and add information about organic farming. Although there was originally a separate class for organic farming, it was decided that information about organic farming should be added as a separate layer qualifying some of the level 3 classes. This could be considered as a level 4 in the hierarchy but is highly dependent on the information available. Another suggestion from the first stakeholder workshop was to have a third class for intensive farming to reflect partial irrigation. However, the data may not allow for this differentiation so has been left as two classes for now. Finally, there was a level 3 class on conservation farming under the level 2 arable class to reflect lower inputs and certain types of reduced tillage practices. As time series information on tillage is difficult to obtain, this class was removed. However, depending on the input data availability, this class may be reintroduced later.

Table 9: Level 1 Cropland broken down into level 2 and 3 LUM classes along with the input layers/dimensions that will be used to define the classes

<table>
<tr><th>LEVEL2</th><th>LEVEL3</th><th>INPUT LAYERS/DIMENSIONS</th></tr>
<tr><td rowspan="3">Arable*</td><td>Intensive farming, irrigated</td><td rowspan="7">• Old CLC, change layers, new 2018 CLC
• Fertilizer (low, high, low chemical, organic)
• Irrigation (irrigated/rainfed)
• Tillage (conventional, reduced, no tillage + mulching, rotation-adapted tillage)
• Crop rotation (mono-cropping, crop rotation)
• Plot size
• Productivity
• Crop residue management practices
• European DEM (altitude, slope)
• Hansen forest loss layer (Hansen et al., 2013)
• Tree species
• Age of trees</td></tr>
<tr><td>Intensive farming, rainfed</td></tr>
<tr><td>Extensive farming</td></tr>
<tr><td rowspan="4">Permanent</td><td>Intensive farming, irrigated</td></tr>
<tr><td>Intensive farming, rainfed</td></tr>
<tr><td>Extensive farming</td></tr>
<tr><td>Short rotation coppice</td></tr>
</table>

*Eventually by major crop category; Source: LAMASUS WP 2

4.2.3. Grassland LUM classes

The proposed LUM grassland classes are outlined in Table 10. These classes are driven by the need to differentiate between intensive and extensive grasslands and pastures as well as agroforestry with livestock. This is the area where there was a considerable amount of feedback from the first stakeholder workshop, in particular, overlap between shrubs and grassland in some of these classes and whether agroforestry should be in arable/permanent cropland instead. Defining these classes in more detail based on the input layers may help to provide more clarity on these overlaps. Information on organic farming can also be added to these classes, depending on the availability/quality of the information.

Table 10: Level 1 Grassland broken down into level 2 and 3 LUM classes along with the input layers/dimensions that will be used to define the classes

<table>
<tr><th>LEVEL2</th><th>LEVEL3</th><th>INPUT LAYERS/DIMENSIONS</th></tr>
<tr><td>Unmanaged</td><td>Unmanaged semi-natural and natural grassland (not supporting any livestock)</td><td rowspan="3">• Old CLC, change layers, new 2018 CLC
• Harvest intensity level (how much biomass is harvested)
• Input intensity (fertilizer and/or chemicals) from FADN
• Livestock data from FADN
• Harvest method (grazing or mowing)</td></tr>
<tr><td rowspan="2">Managed</td><td>Extensively managed semi-natural grassland systems</td></tr>
<tr><td>Extensively managed pasture</td></tr>
</table>

	Intensively managed pasture	• Share of semi-natural elements (pasture vs. semi-natural/mosaics) • European DEM (altitude, slope) • Heathland maps • Copernicus high resolution layers on grassland and shrubland
	Silvopastural agroforestry	
	Rough grazing	

Source: LAMASUS WP 2

4.2.4. Built-up/urban LUM classes

The proposed LUM classes for built-up/urban areas are outlined in Table 11. Greenspaces in Europe was added as an input dimension based on feedback from the first stakeholder workshop.

Table 11: Level 1 Built-up/urban broken down into level 2 and 3 LUM classes along with the input layers/dimensions that will be used to define the classes

LEVEL2	LEVEL3	INPUT DIMENSIONS
Buildings and industry	Minimal use	• Old CLC, change layers, new 2018 CLC • Urban Atlas (Copernicus) • Street tree layer (Copernicus) • Soil sealing (Copernicus) • Population density (JRC) • Building footprints and building heights • WUDAPT layer for Europe (Demuzere et al., 2019) • Greenspaces in Europe
	Light use	
	Intense use	
Infrastructure	Road and rail networks	
Other uses	Other uses such as mining, golf courses, etc.	

Source: LAMASUS WP 2

4.3. INPUT DATA SETS

The LUM geodatabase will be developed using existing data sets from a range of different sources as detailed in the sections that follow. The current list of data sets compiled is provided in Annex C; this list will be continually updated during the lifetime of the project to reflect the emergence of new products.

4.3.1. Remote sensing

One of the main sources of information are products derived from remote sensing. The starting point for the geodatabase is the set of Corine land cover products (CLC) that have been developed by the European Environment Agency within the framework of the Copernicus Land Monitoring Service as well as several high-resolution layers such as tree cover, grassland, the Urban Atlas, soil sealing, etc. Many other land cover products have been produced, some of which are global and have been clipped to a European extent. Some of these products cover all major land cover types while others are focused on a theme, e.g., forest/loss gain layers (Hansen et al., 2013). A current list can be found in Annex C.

4.3.2. National level data

In addition to remote sensing products that are global or European in scale, there are national level data sets available. The ones currently identified are listed in Annex C, but more datasets will be collected.

4.3.3. Statistical, survey and in situ data

Statistical data on land cover, land use and agricultural/forest data are openly available at coarse resolution aggregations, i.e., national or NUTS1/NUTS2 levels. However, to obtain more detailed information, e.g., at NUTS3, LAU (local administrative unit), or farm level/plot data, requests must be made. In the case of farm level data, a request has been made for many variables relevant to agricultural land use management data from FADN (Farm Accountancy Data Network), but it will take time for the application to be approved and for the data to be obtained. Data are available from the agricultural census/Farm Structural Survey (FSS). Other requests are currently being pursued with DG-AGRI and Eurostat. Similarly, plot level data from the National Forest Inventories of individual countries are currently being requested within the Forest Navigator/Pathfinder projects to support the development of the forest management classes.

The harmonized LUCAS in-situ land cover and use database for field surveys from 2006 to 2018 is available from d'Andrimont et al. (2020), who have downloaded the data from Eurostat and created a single database. For cropland and forest LUCAS survey locations, detailed information is available. The sample is systematic across EU member states and is on the order of 300K locations per survey.

Other in situ data include the training and validation data collected by IIASA and Wageningen University for the development of the Copernicus global land cover product for 2015 (and updates – C-GLOPS), training and validation data that will become available from the EU-funded RapidAI4EO project in which IIASA is a partner, and a validation data set for the land cover map of Europe 2017, which consists of land cover classes for 52,024 10m locations.

4.3.4. Crop type information from the Land Parcel Information System

Some EU countries have opened up their detailed data sets of crop types with field level data (in vector format) with the crops grown in each field, which is provided as part of the CAP reporting system. The list of these countries with the years for which data are available are provided in Annex C.

4.4. METHODOLOGY

Figure 1 provides an outline of the methodology to produce the LUM geodatabase, divided into two main parts. The first part will involve producing the annual time series of land cover/land use from 1990 to 2020. This will be based on a combination of all CLC layers and change layers combined with input layers from remote sensing, statistical data (for calculating transition matrices and for matching totals), etc. to generate the annual time series across the period 1990 to 2020 using linear programming. The outputs will be probabilities of CLC class types, which can then be redistributed to match official statistics. At the same time, a validation sample of change has been produced by sampling CLC (where change has occurred) and pairs of remotely sensed products produced at different time periods (e.g., Hansen's forest layers, Potapov's cropland layers) where change over time has occurred; this sample will be validated using Geo-Wiki and will provide an additional uncertainty layer to accompany the CLC time series.

The second part of the methodology will involve taking the LUM classes defined in section 4.2 (along with any additional refinements), the spatially explicit layers of the input dimensions that define these classes along with thresholds corresponding to different classes and the rules for the generation of the classes to produce a LUM layer initially for 2020. Based on information availability, a LUM management time series will be developed, which will be constrained by the available data on the input dimensions. Initially, the LUM layers will be produced at 10-year intervals (2000, 2010, 2020), with the aim to produce more data layers at more frequent intervals (i.e., every 5 years or annually), depending on the data availability.

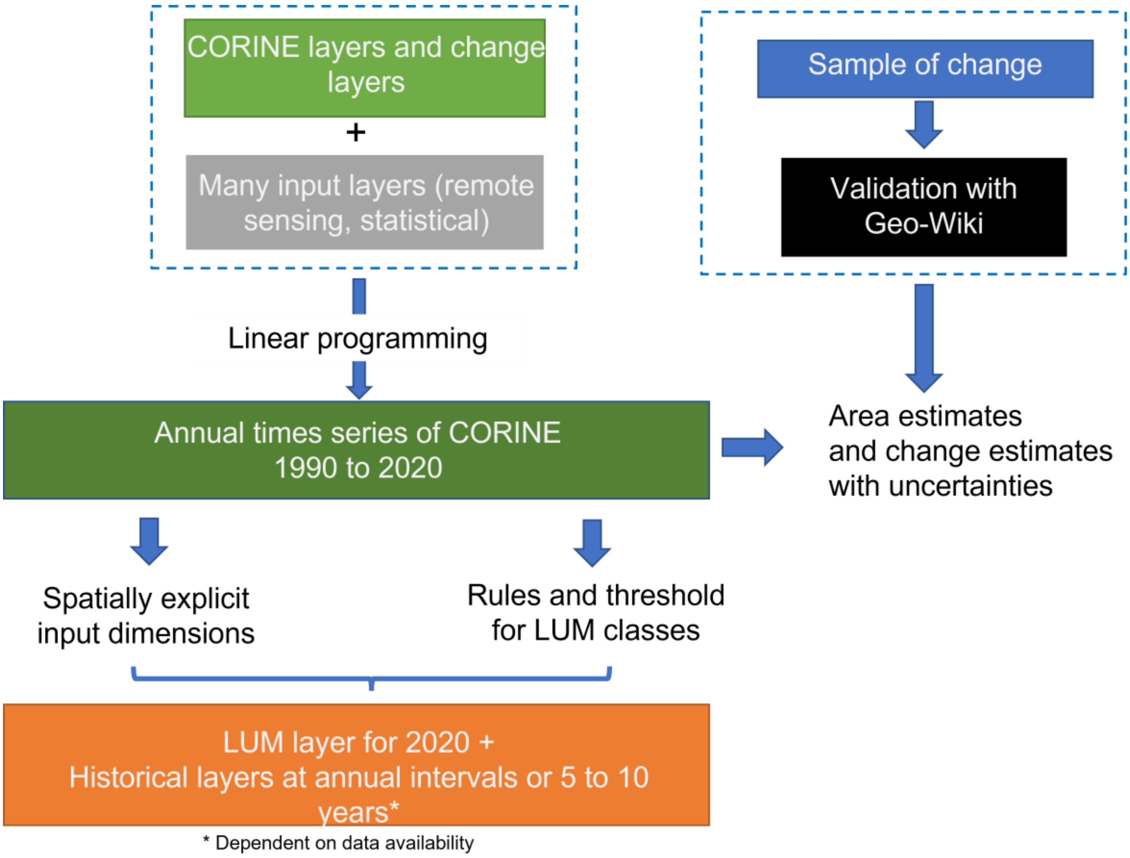

Figure 1: High level schematic of the methodology that will be used to generate the LUM geodatabase. Source: LAMASUS WP2.

Tools will also need to be developed that aggregate the data to high gridded resolutions (e.g., 1 km) and statistical zones, e.g., 2016 NUTS2 along with methods that generate consistency with reported statistics.

5. Conclusions

This deliverable has outlined the proposed LUM geodatabase, which is comprised of two components. The first component involves the generation of an annual CORINE time series from 1990 to 2020. Along with many other spatially explicit input dimensions, the CORINE time series will then be used to develop a LUM layer for 2020 historically going back in time. The current set of proposed LUM classes has been presented in this deliverable, which have been based on consultations with the modelers in LAMASUS, other related projects and feedback from the first LAMASUS Stakeholder Workshop. As a result, these LUM classes will address the modelling needs in LAMASUS as well as being policy relevant.

The next step will be to map out the methodology in detail to produce the annual time series of land cover/land use and the set of rules that will be used to generate the LUM classes. The latter will be heavily reliant on the data that can be obtained, in particular, from sources such as FADN, National Forest Inventories and Eurostat. The methodology will then be implemented, and the LUM geodatabase will be generated by month 18 in beta version and month 24 as a final product for the LAMASUS project (D2.1).

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7. Annexes

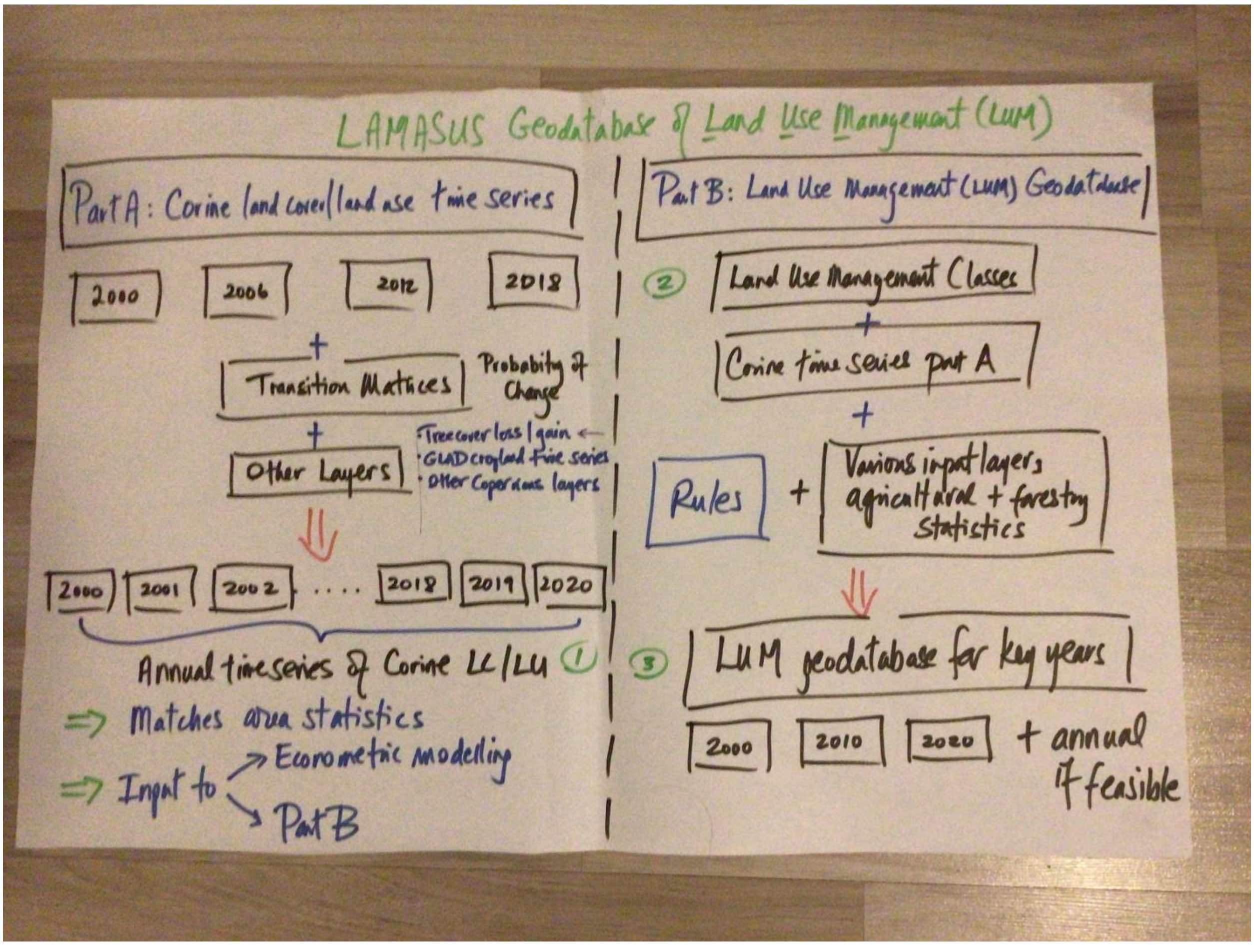
7.1. ANNEX A THE CLASSIFICATION OF DOU ET AL. (2021)

LAND SYSTEM	LEVEL2	DESCRIPTION	INPUTS/METHDOLOGY
1.0 Settlement systems	1.1 Low-intensity settlement	Low-medium density, far away from urban cores (villages)	Used HRL of imperviousness to distinguish between the three classes and then adjacency to the urban core to distinguish between low to medium density
	1.2 Medium-intensity settlement	Medium density or adjacent to urban core (peri-urban)	
	1.3 High-intensity settlement	High imperviousness (urban core)	
2.0 Forest systems	2.1 Low-intensity forestry	High probability as primary forest and low/medium wood production	Used wood production of Europe map and probability of finding primary forest (Sabatini) and a global data set of primary/naturally regrown and planted for non-EU countries
	2.2 Medium-intensity forestry	Low probability as primary forest and medium wood production	
	2.3 High-intensity forestry	Low probability as primary forest and high wood production	
3.0 Cropland systems	3.1 Low-intensity arable land	Low organic fertilizer input, medium field size	Used nitrogen application rate (JRC) and two field size data sets
	3.2 Medium-intensity arable land	Medium inorganic fertilizer input, medium field size	
	3.3 High-intensity arable land	High inorganic fertilizer input, large field size	
	3.4 Low-intensity permanent crops	Vineyards, olive groves, fruit gardens, with understory vegetation; also mix of annual and permanent crops	Used LUCAS to differentiate between these two types
	3.5 High-intensity permanent crops	Vineyards, olive groves, fruit gardens, without understory	
4.0 Grassland systems	4.1 Low-intensity grassland	Low density of livestock, low inorganic fertilizer input, and low mowing frequency	
	4.2 Medium-intensity grassland	Medium density of livestock, medium use of inorganic fertilizer input, and medium mowing frequency	
	4.3 High-intensity grassland	High density of livestock, high inorganic fertilizer input, and/or high mowing frequency	
5.0 Shrub		Areas dominated by shrub land cover	
6.0 Rocks and bare soil		Areas dominated by rocks and bare soil	
8.0 Snow, water, wetland systems	8.1 Glaciers	Areas dominated by glaciers	Used global glacier databases for 2012
	8.2 Water body	Areas dominated by water	Used Copernicus HRL at 20m and aggregated to 1 km
	8.3 Wetland	Areas dominated by wetlands	Used Copernicus HRL at 20m and aggregated to 1 km

Source: Modified from Dou et al. (2021). Class 7 is a set of 7 mosaic classes, which are not shown in this table

7.2 ANNEX B PRESENTATION OF LUM GEODATABASE AT THE FIRST STAKEHOLDER WORKSHOP

A brief description of the LUM geodatabase was presented to the stakeholders at the start of each round table using the sheet shown below.



7.3 ANNEX C LIST OF DATASETS FOR THE DEVELOPMENT OF THE LUM GEODATABASE

In this Annex we list separately European, Global, and National datasets from remote sensing in respectively tables 12, 13 and 14.

Table 12: European datasets from remote sensing

THEME	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
Land Cover/landuse	Corine Land Cover (CLC)	Raster	100m	1990, 2000, 2006, 2012, 2018
	CLC Change Layers	Raster	100m	1990-2000, 2000-2006, 2006-2012, 2012-2018
	CLC in Eastern Partnership Countries	Raster	100m	
	Imperviousness Density (High Resolultion Layers - HRL)	Raster	10 m (2018); 20 m (2006-2015); 100 m aggregations	2006, 2009, 2012, 2015, 2018
	Impervious Density Change (HRL)	Raster	Same resolution of parent products	2006-2009; 2006-2012; 2009-2012; 2012-2015; 2015-2018
	Imperviousness Built-up (HRL)	Raster	10 m, 100 m aggregation	2018 (2017-2019)
	HILDA V2.0	Raster	1 km	1900 to 2010
	High-resolution annual continental European land use / land cover data since 2000	Raster	30 m	2000 to 2020
	Land Cover Map of Europe	Raster	10 m	2017
	Pan-European land cover map	Raster	30m	2015
Protected areas	Natura 2000 sites	Vector	N/A	Latest version includes 2021
	European Digital Elevation Model (EU-DEM) v1.1	Raster	25 m	2011

THEME	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
DEM (Slope, Aspect)	European Digital Terrain Models (EU DTM)	Raster	30 m	-
Forest	Tree Cover Density (HRL)	Raster	20 m (2012, 2015), 10 m and 100 m aggregation (2018); 20 m change products	2012 (covers 2011-2013), 2015 (covers 2014-2016), 2018 (covers 2018), 2012-2015 (covers 2011-2016), 2015-2018 (covers 2014-2018)
	Dominant Leaf Type (HRL)	Raster	same as above	same as above
	Forest Type (HRL)	Raster	same as above but no change	2012, 2015, 2018
	Small Woody Features (SWF) and Additional Woody Features (AWF) INCLUDES HEDGEROWS	Raster, Vector	5 m, 100 m aggregation	2015, 2018 (will be released soon)
	European forest management map (Nabuurs)	Raster	1 km	Covers various years
	European primary forest database (v2.0)	Raster, Vector	Patches	-
	Potential and realized distribution of forest tree species (16 species)	Raster	30 m	2000 to 2020, not individual years
	Street Tree Layer (Urban Areas)	Vector	MMU 500msq ad 10m Mmwidth	2012, 2018
Cropland	Abandoned farmland	Raster	300 m	2001-2012
	European wide crop type map	Raster	30m	2018
	LAI produced by BOKU	Raster	10m	2020 to present
Grassland	Grassland (HRL)	Raster	20 m (2015), 10 m (2018), 100 m aggregation	2015, 2018, 2015-2018

THEME	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
Population	Geostat EU population grids	Raster	1 km	2006, 2011
Soils	European soils	Raster	30 m	2000 to 2020
	European Soil Database	Vector		2001 and 2013 (derived products)
	European topsoil properties	TBD	TBD	2015
Water	Water & Wetness (HRL)	Raster	20 m, 100 m aggregation	2015 (covering occurrence between 2012 and 2018)
	Intensity of and area affected by water deficit	Vector	NUTS3	2000 to 2016

Table 13: Global datasets from remote sensing and/or integrating data from multiple sources

THEME	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
Land cover/land use	Global Annual Burned Area Product (GABAM)	Raster	30 m	1990-2020
	Copernicus Global Land Cover	Raster	100 m	2015 to 2019
	ESA CCI Global Land Cover Maps, v.2.0.7	Raster	300 m	1992 to 2015
	MODIS Land Cover (MCD12Q1)	Raster	500 m	2001 to 2018
	GLC-2000	Raster	1 km	2000
	FAO's GLC-SHARE	Raster	1 km	2014 but aggregates multiple years
	GlobeLand30	Raster	30 m	2000, 2010, 2020
	FROM-GLC	Raster	30 m	2010, 2015, 2017
	Global land cover dynamics	Raster	5 km	1982 to 2015
	Hyde (History database of the Global Environment) land use data, v.3.2.000	Raster	10 km	10k BCE - 1 CE: 1000 yr, 1 - 1700 CE: 100 yr, 1700 - 2000 CE: 10 yr, Annual 2000 to 2015
	Harmonized Global Land Use for Years 1500 – 2100, V1	Raster	50 km	1500 to 2100
	Global land use change from HILDA+	Raster	1 km	1960 to 2019
	Annual maps of global land cover	Raster	30 m	2001 to 2020
	Annual maps of global land cover	Raster	10 m	2017 to 2020
Cropland	Global hybrid IIASA-IFPRI cropland mask	Raster	1 km	2005, 2010
	Global Unified cropland layer	Raster	250 m	2016 (but uses multiple years)

THEME	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
	1 km global cropland data set (Peng Gong)	Raster	1 km	10000 BCEt to 2100CE
	WorldCereal	Raster	10 m	2021
	Global cropland layer	Raster	30 m	2015
	Global GCE Cropland Dominance	Raster	1 km	2012
	Global GCE 1km Cropland Mask	Raster	1 km	2015
	Global cropland extent (Potapov)	Raster	30 m	2000 to 2019
Forest	Global hybrid forest layers	Raster	1 km	2000
	Global tree cover and loss/gain	Raster	30 m	2000, 2010 + loss/gain annual to 2021
	Tree cover height	Raster	30 m	2000, 2019 (52 N to 52 S), 2020
	Forest landscape integrity index	Raster	300 m	2019 but will be annual
	Intact forest landscapes	Raster	TBC	2000, 2011 (from GLAD website), 2013, 2016, 2020 and reduction in extents 2000-2013, 2013-2016, 2016-2020
	Tree plantations (Spatial Databases of Planted Trees)	Vector		Varies but centered around 2015
	Forest management (IIASA)	Raster	100 m	2015
	Global forest management map (Schulze)	Raster	1 km	2000
	Tree canopy cover	Raster	TBD	2000, 2010
	JAXA PALSAR forest/non-forest mask	Raster	25m	2007 to 2021
Artificial/Urban	Global Human Settlement Layer (GHSL)	Raster	250 m, 1 km	1975, 1990, 2000, 2014, 2016, 2018

THEME	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
	Global Urban Footprint (GUF)	Raster	12m to 84 m	2011
	Global World Settlement Footprint (WSF)	Raster	10 m	2015
	Global atlas of building heights	Raster	500 m	2015
Wetlands	WAD2M global dataset of Wetland Area	Raster	25km, 1km	2000 to 2018, monthly time step
Protected areas	World database on protected areas	Vector	N/A	Updated regularly
Population	WorldPop	Raster	100 m	TBC
	LandScan population	Raster	1 km	Annual but cost money, more details TBC
	Gridded Population of the World	Raster	1 km	2000, 2005, 2010, 2015, 2020
Water	Global Water Surface	Raster	30 m	1984 to 2021
	ESA CCI static open water bodies layer	Raster	150 m	2000 to 2012
Soils	Global soils	Raster	1 km	1982 to 2018
	ISRIC 250m soil grid	Raster, Vector	250m	Covers multiple years
	Harmonized World Soil Database	Raster	30 arc second	Covers multiple years
Livestock	Gridded Livestock of the World	Raster	10km	2010

Table 14: National level data sets

COUNTRY	DATASET	TYPE	SPATIAL RESOLUTION	TEMPORAL RESOLUTION
Austria	MAES/EUNIS habitat map	Raster	10m	2021
	Permafrost distribution	Raster	TBD	2009 to 2011
	Land cover fraction map of Austria	Raster	10m	2018
	Land cover Sentinel 2 for Austria	Raster	10m	2016
	Older land cover map of Austria	Raster	-	-
	Forest map of Austria	Vector	-	2013 to 2018
	Water bodies of Austria	-	-	-
	Land cover classification map of Germany's agricultural area based on Sentinel-2A	Raster	10m	2021
Germany	Land cover classification map of Germany's agricultural area based on Sentinel-2A	Raster	20m	2016
	Land cover fraction map of Germany	Raster	10m	2018
	National-scale crop- and land-cover map of Germany	Raster	-	2016
Portugal	Land use maps	Vector	-	1995, 2007, 2010, 2015, 2018
	Land cover maps	Raster	10m	2018, 2020, 2021
France	Land cover maps	Raster	10m	2018, 2019, 2020, 2021
	Land cover maps	Raster	30m	2009, 2010, 2011 and 2014
	Forest maps	Vector	2.25ha MMU	V1: Up to 2006, V2: 2007 to 2018
	Land cover/land use for parts of France	Vector	-	Various years
UK	UKCEH Land Cover Maps	Various formats	5 m to 25 m	1990, 2000, 2007, 2015, 2017, 2018, 2019, 2020, 2021 and change from 1990-2015

7.1.1. *Crop type data from the Land Parcel Information System (LPIS)*

Crop type data (as fields digitized with crop information) from the Land Parcel Information System (LPIS) are available for a number of regions/countries. These include two states in Germany (North Rhine Westphalia and Lower Saxony) for 2019 to 2022, Austria from 2016 to 2021, France from 2010 to 2021, for a number of other countries via the EuroCrops website for 2021 (Belgium, Estonia, Latvia, Lithuania, Netherlands, Portugal, Slovenia, Sweden), for two regions in Spain (Catalunya for 2019 and Andalucia for 2018) as well as crop surfaces and a crop yield survey for Spain (2019, 2021). For Ukraine, a point data set of observed crop types for 2018 and 2022 is available.

Statistical data on agriculture

There are three main sources of agricultural data:

1. LUCAS survey data, which provides a point sample across Europe
2. Data from FADN, where an application has been made on behalf of the project for a large number of relevant agricultural variables, but these can only be weighted for aggregation to NUTS2 regions.
3. Eurostat, which has publicly available information on many relevant agricultural variables at NUTS2 (and for some variables NUTS3) as well as data at LAU (local authority units) but must be applied for. We will apply for access to these data shortly.

Statistical data on forests

Some detailed information will become available from the National Forest Inventories of different countries through the ForestNavigator, Pathfinder and ForestPaths projects. Some derived products are already openly available in Pucher et al. (2022), e.g., on dominant age of the trees, while other derived products will be created as part of the ForestNavigator project by Wageningen University and in the ForestPaths project. These will be used in the development of the forest management classes.