Environmental Modelling and Software 176 (2024) 105972

Contents lists available at ScienceDirect

Environmental Modelling and Software

journal homepage: www.elsevier.com/locate/envsoft

An open web-based GIS service for biomass data in Finland

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ARTICLE INFO

Handling Editor: Daniel P Ames

Keywords:
Spatially explicit web-based application
Forest biomass
Agricultural biomass
Biodegradable waste
Thematic mapping
Database

ABSTRACT

Reliable, up-to-date biomass data are needed for climate change mitigation and resource efficiency. Therefore, a calculation and reporting tool with thematic maps and data was developed. A free web-tool, Biomass Atlas, collects the spatial distribution of biomasses in Finland. Over 300 data layers present land use, cultivation, residual biomasses from forest, crop production, animal husbandry, municipalities, and industry at 1 km^2 spatial resolution. The service enables calculations of biomass amount in a defined geographical area of interest and examining the opportunities and restrictions to utilise biomasses. The service was evaluated with six test-users in laboratory tests and 20 voluntary pilot test-users. Biomass Atlas shows the regional potential of biomaterials, fertilizer products, and renewable energy, as well as potential targets for utilized, recyclable biomass. Other possible uses include monitoring plant cover on fields and assessing land use diversity. Application enables users with no experience in GIS or biomass assessments to analyse biomass resources, produce maps and data summaries for decision making.

1. Software and data availability

The name of the application: Biomass Atlas.

Developer: The idea for the application has been developed in cooperation between Natural Resources Institute Finland (Luke), Finnish Environment Institute SYKE, University of Vaasa, University of Eastern Finland and Tapio. The data is provided by Luke and SYKE and the software development has been conducted in Luke.

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Year first available 2017.

Hardware required: Desktop computer with internet access.

Software required: Web browser (Chrome, Firefox and IE were tested).

Programming environment: Apache Tomcat, Geoserver, Java, JSP technology, Oskari map framework, Javascript, Open layers.

Availability: Openly accessible web-based application, available at https://biomassa-atlas.luke.fi/?lang=en.

Program code available at https://github.com/lukefi/biomass-atlas.

Data available via WMS https://biomassa-atlas.luke.fi/geoserver/wms and WFS at https:/biomassa-atlas.luke.fi/geoserver/wfs and by download for registered users.

Cost: Free.

Program language: Biomass Atlas system was developed using Java programming language for server end code and JPS technology for user end code. Oskari map framework was built in Java and Javascript. Apache Tomcat is used as web server and Geoserver for map drawing services.

Additional information: https://projects.luke.fi/biomassa-atlas/en/ https://www.luke.fi/fi/luonnonvaratieto/tiedetta-ja-tietoa/biomassaatlas

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https://doi.org/10.1016/j.envsoft.2024.105972
Received 1 September 2023; Received in revised form 5 December 2023; Accepted 9 February 2024
Available online 7 March 2024

2. Introduction

The Bioeconomy Strategy of European Union aims to reduce dependency on non-renewable, unsustainable resources. The strategy relies on a strong bio-based sector to replace non-renewable resources to achieve the targets set in the Paris Agreement (European Commission, 2018).

Furthermore, the Finnish bioeconomy strategy (2014) states that the knowledge base for bioeconomy, particularly biomass resource data, must be used more effectively and biomass data should be collected more systematically. The updated strategy (The Finnish Bioeconomy Strategy) considers the circular and bio-based economy essential in addressing global challenges, particularly the climate change, and emphasizes that securing the availability of raw materials is even more essential than before. The strategy aims to gather information on the availability and potential of various biomasses on regional and local levels. Understanding of biomass potentials is crucial for planning nutrient recycling, extracting value-added products, producing renewable energy, and managing the emissions to air and water. Additionally, climate change mitigation pathways introduced by Intergovernmental Panel on Climate Change (2023) include transitioning from fossil fuels to renewables. Many mitigation options have synergies with other aspects of sustainable developments, but afforestation or production of biomass crops can also have adverse trade-offs (IPCC et al., 2023). The utilization of biomass sidestreams can enhance resource efficiency and prevent negative impacts associated with the increased production of renewable energy.

Sustainable utilisation of biomass resources requires understanding of harvesting potentials which, as a matter of fact, are biomass specific. Any facility considering the use of biomasses should first ensure an adequate and sustainable supply of feedstocks. Moreover, information on such harvesting potentials is necessary to guide public policy decisions that might create incentives to promote the use of biomass.

Biomasses from forestry play an important part in the Finnish energy production. Forest-based fuels were the largest individual energy source with a share of 28,5 % of all energy production in 2022 (Official Statistics of Finland Osf, 2023). Fibre sludge from the pulp and paper industry is increasingly being used as a soil improver in fields as it leads to improved crop yields. Fibre sludge increases organic matter in the soil, improves its structure, water balance and reduces nutrient leaching. It is also expected to work as a carbon sink in the soil.

Biomasses from field and agricultural, municipal, and industrial sidestreams are also used for energy production, but their proportion in total energy production is still small, approximately 1 % of all consumed energy. It is noteworthy, though, that production and use of biobased fuels have multiplied in the past five years (Official Statistics of Finland Osf, 2023). While their specific energy uses may become important, such as in transition of transportation to renewable fuels, the potential to recycle valuable nutrients and organic matter is also increasingly recognised and targeted. For instance, animal manure is an integral resource for recycling nutrients in the food production system. As animal production, and thus the spatial distribution of manure, is concentrated into certain regions in Finland (Ylivainio et al., 2014), part of the manure nutrients should be redistributed to regions where arable farming is dominant. This can be achieved via manure processing, which simultaneously enables nutrient recycling, renewable energy production, reuse of the residual organic matter, and mitigation of manure-related emissions (e.g., (Marttinen et al., 2018)). The solutions may further include extraction of other valuable chemicals. Similar targets are also set for other nutrient-rich sidestreams from municipalities and industry.

Attempts to harmonize and distribute data on biomass potentials have been made in several projects at the European level (Verbruggen et al., 2010; Panoutsou et al., 2017). Some biomass assessments have been demand-driven, whereas most of them are resource-focused (http://www.biomassfutures.eu/webtools/webtools_intro.pdf).

Verbruggen et al. (2010) refer to IPCC mitigation potentials (2001), where physical potential is the highest theoretical upper-bound, still possibly shifting over time. Technological potential may almost approach the theoretical potential as research and development achieve new knowledge and technologies. Socioeconomic potential limits available amount by social norms, habits, attitudes, and values. Economic potential falls below in amount and its barriers include, for example, trade barriers, inadequate information, and undefined property rights. Market potential refers to the achieved amount of biomass when actual use of environmentally sound technologies and practices are present (Verbruggen et al., 2010). Panoutsou et al. (2017, pp. 18–19) describe the potentials in a parallel way but classify socioeconomic potential together with economic potential. Vis et al. (2010 p.18-19) distinguish two more potential types as a fraction of economic potential: implementation potential, which is somehow parallel to market potential of used by Verbruggen et al. (2010), and sustainable implementation potential, which integrates environmental, economic and social sustainability criteria in biomass resource assessments and is thus a fraction of implementation potential. Anyhow, the same limitations are included in the classification used by Verbruggen et al. (2010) at the upper level. Thus, conceptualizing actual calculated potential is not straightforward. Also, Böttcher et al. (2011) mention that there are some studies applying environmental constraints at higher levels and others at lower level, which makes comparisons across studies difficult.

To sum it up, there has been great variability among the assessments on biomass potentials due to several reasons: the assessments may cover different biomass types, concern different types of potentials (e.g., theoretical, technical or economic), focus on different time frames or geographical regions, and apply different methods and data sources (Rettenmaier et al., 2010). Furthermore, unestablished terminology, alternative units, and varying assumptions on scenarios and constraints hamper comparison of estimates.

The latest project produced an atlas providing access to potentials of 50 lignocellulosic biomass types at NUTS3 level (http://www.s2biom.eu). While supporting political decision-making, for operational level the spatial resolution is too coarse. As an example, nutrient recycling needs cooperation between animal and crop production farms, logistics need to be considered, and finally, nutrient flows in watersheds do not respect administrative units.

Regional, spatially explicit biomass availability assessments have been conducted both in forestry (Anttila et al., 2018; Zambelli et al., 2012) and food production (Höhn et al., 2014; Kahiluoto et al., 2011). First, a web-based atlas application was implemented for wind energy (Tammelin et al., 2011). Recently, a few web-based map services have been introduced to demonstrate and analyse regional biomass and bioenergy potential. The Global Atlas for Renewable Energy, compiled by the International Renewable Energy Agency (IRENA), displays renewable energy related datasets from international data providers such as the Food and Agriculture organisation of United Nations, UN Environmental Programme, European Space Agency and Open Street Map (IRENA 2020). The Bioraise tool places biomass resources and stakeholders, such as industries producing sidestreams, on the map and estimates biomass costs for energy use in Southern Europe. It provides spatial selection tools in different coordinate systems and an opportunity to view the data through the Web Map Service standard and download analysis results (Esteban and BIORAISE, 2022). The Natural Resource Atlas of Minnesota includes multidisciplinary spatial data sets, tools, and functionalities for assessing natural resources and identifying areas to business and enhanced protection (NRRI 2022). Tauro et al. (2021) recently introduced a web based spatial tool for estimating potential bioenergy planning at Mexico. The tool provides map and data layers on agriculture and forestry, selection tools for regions of interest, and analysis tools such as filters and summaries. The results can be exported as KML files.

The Biomass Atlas web portal (https://www.luke.fi/biomassa-atlas/en/) provides a single online point of access to detailed, up-to-date resource information of biomasses from agriculture, forestry, municipalities, and industry in Finland. The Biomass atlas is intended for public use and offers a wide range of information of the overall potential and location of biomasses. The user interface of the application includes features for searching biomasses, selecting regions, adjusting map layers, accessing profile information, as well as providing user instructions.

The novelty of Biomass Atlas compared to other biomass or bioenergy tools is, that it is planned to support not only renewable energy planning but also to enable other types of environmental analyses such as nutrient recycling, carbon binding, diversity calculations or regional planning or crop-specific analyses. It gathers data from various sources for different types of biomasses and represents it in spatially explicit maps and analysis tools. Biomass types are given in fine classification which enables also analysis for other applications than energy. For example, the land-use data can be used to diverse environmental analyses, such as land-use diversity indices, estimations of plant coverage on wintertime or suitable areas for manure application (See section 4.4 for more use cases of Biomass Atlas).

Before the introduction of Biomass Atlas, data on the amounts of different biomasses and their spatial distribution were either scattered across different databases by various data producers, covered only in some parts of the country, were non-existent or had limited access.

The purpose of Biomass Atlas is to simplify access to biomass data, maps, and analysis for strategic planning of the utilisation of biomasses for advisory personnel, businesspeople and researchers. It provides an online user interface which is easy to use, compared to traditional GIS used for biomass analyses. Therefore, the objectives of our work were:

- to form six new datasets and their metadata,
- organise datasets according to their potential type,
- and put them available through a new web map application,
- offer a toolset to analyse the regional availability of biomasses and
- evaluate the usability of the map application

In this article we will provide an overview of the Biomass atlas tool, its data, and technical environment. The six different data themes are introduced, and the data production methods and uncertainties are discussed. Readers are guided through the user interface and its main functionalities. Additionally, the most important results on usability testing of user interface are provided. The objective of the usability test was to ensure that the user interface is intuitive for the end user. Lastly, possible use cases and the initial use experiences are discussed (4.4) as well as the further needs for development (5.5).

3. Materials and methods

The Biomass atlas project was started by the preliminary study where stakeholder expectations were enquired in workshops, interviews, and a web survey. The aim was to find out which biomasses are of special interest, what kind of requirements the users set for data quality, which are the preferred format and accuracy of the data and what kind of functionality is needed (Lehtonen et al., 2014).

Development of Biomass Atlas was based on the results of the survey for stakeholders as well as a preliminary study about available databases and existing similar or applicable services. During the development process we needed to solve questions of combining data both in conceptual and technical means. Also, usability for different types of use cases was considered.

3.1. Biomass data harmonization

Before implementing the map and data service, the available data sources were explored. Data suitable for the map service were described in according to INSPIRE metadata requirements (Directive, 2007/2/EC). E.g., the information content, availability and spatial coverage were described. Then the calculation procedures for biomass dataset formation were defined and implemented to form a uniform grid database showing the amount of each biomass type. Included data themes and sources are described at Fig. 1.

The work combines biomass data originating from various scientific disciplines which have their own traditions and concepts. Established concept in one discipline might cause confusion in another, because of different meanings.

In our consideration biomass potentials of Biomass Atlas in most cases can be considered by the concepts described by Verbruggen et al. (2010) and Panoutsou et al. (2017) as market potential. Also, our assessments are resource focused.

Data which is taken as such from the registers such as biodegradable waste from companies can most probably be considered as market potential, whereas the concept of modelled potentials may vary. Forest chip potentials are based either on previous years use of forest (realized cutting removals), or model of maximum economically sustainable removal. The former corresponds the market potential and the latter to economic potential. Our potential concept can be divided roughly to the total potential and available amount, where the first concept describes how much biomass is formed and the second describes the amount which can be or is harvested.

In the biomass selection menu, one way for organising biomasses were their potential type (Table 1). The practical division of biomasses for different potential types is as follows: 1) Land use is the coarsest level of potential and gives more responsibility to the user to predict and calculate results further. 2) Production tab collects the total biomass growing in forest as well as crops harvested from the fields. 3) Sidestreams are biomasses which are formed when biomass is produced for some purpose, and something is left over from the original need.

3.2. Biomass themes

At the time of writing the Biomass atlas consists of approximately 300 maps and data layers in eight themes: 1) forest resources and forest land cover, 2) harvesting potential of forest chips, 3) land use in agriculture, 4) field crops and sidestream potentials, 5) estimates of animal manures, 6) estimate of biowaste from communities, 7) biodegradable waste from municipalities and 8) biodegradable waste from waste treatment plants. The schematic view of data themes and source data for each dataset is presented in Fig. 1. A detailed list of all the layers within themes can be found in appendix 1.

For each theme, the procedure for data formation is described in the following chapters.

After processing the original data to biomass datasets, each data layer was analysed and rules for data visualization (e.g., scaling and colouring) as thematic maps were defined.

3.2.1. Forest resources and forest land cover

Finnish forests have been assessed in sampling-based national forest inventories (NFIs) since the 1920s (Korhonen, 2016). In systematic cluster sampling inventory teams collect data on sample plots in forests and the unbiased results are subsequently calculated and presented at regional level. Nowadays, in addition to the regional results wall-to-wall thematic maps of various forest attributes are produced by so-called multi-source national forest inventory (MS-NFI) (Mäkisara et al., 2016). In the MS-NFI, satellite images, digital map data and other georeferenced data are utilized to create raster maps of selected, central attributes at a spatial resolution of 16 m × 16 m. Currently, maps concerning years 2006, 2009, 2011, 2013 and 2015 have been published. The maps are available for viewing at https://kartta.paikkatietoikkuna.fi/?lang=fi and for download at http://kartta.luke.fi/index-en.html.

Part of the MS-NFI data was brought to Biomass Atlas. The imported maps consisted of data describing land cover (Land class, Land class based on FAO FRA, Site main class and Site fertility class) and the growing stock (biomasses of trees broken down by tree parts and

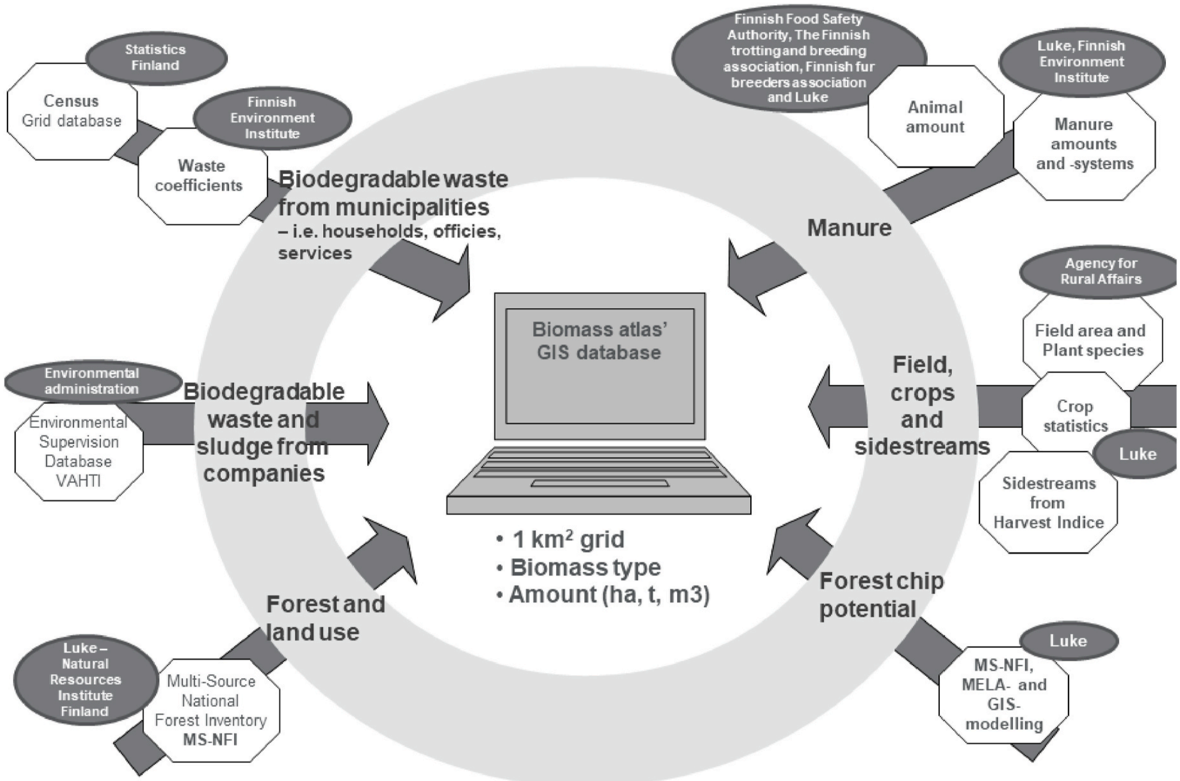

Fig. 1. Biomass data sources (in white octagons) used to form a uniform 1 km^2 grid biomass database. Original data is gathered from several different data providers (grey ellipses).

species). For detailed description of the attributes see Mäkisara et al. (2016).

3.2.2. Harvesting potential of forest chips

Technical harvesting potential of forest chips can be defined as the maximum potential procurement volume of chips available from the Finnish forests based on the prevailing guidelines for harvesting of energy wood (Koistinen et al., 2016). Technical potential was estimated for three assortments: Small-diameter trees from early thinnings, logging residues from final fellings, and stumps from final fellings (Anttila et al., 2018).

3.2.3. Land use in agriculture

Field use in agriculture changes annually. By the end of April each year, the farmers report their cultivation plans for the growing season to the Finnish Food Authority (former Agency for Rural Affairs), which is the national agency for governing EU agricultural subsidies. The shape and area of fields as well as the most important crop species cultivated are known and registered in the Integrated administration and control system (IACS) and in particular in its database for identification of agricultural parcels called the Land Parcel Identification System (LPIS). The LPIS information was too detailed (appr. 200 land use classes) for supposed average user of the Biomass Atlas. The plant species were therefore grouped in 40 classes to make the data easier to use. The grouping was based on the existing classification of crop statistics when it was appropriate. Otherwise, the expert knowledge of the land use and suitability for biomass production and harvest was used. This was especially necessary for land use types for which no yield statistics are available e.g., green fallows, buffer zones, pastures and so called “Nature Management Fields” which are mainly grassland areas cultivated to provide ecosystem services. Using more detailed classification than categories used in statistics is expected to be useful considering other use cases, e.g., estimating harvest areas or the areas with plant cover at wintertime.

The parcels were intersected by 1 km grid by a GIS tool and crop species within each grid were summarized.

3.2.4. Crops, sidestreams and grasslands

In Biomass Atlas the agricultural crop biomasses are reported as “Main yield” and “Sidestream biomass “. “Main yield” refers to the main product: grain, seed, tuber, root or harvested grass or hay biomass. The main yield can be used for food and forage or for bioenergy. “Sidestream biomasses” are straw, stem or top biomasses of seed, grain, tuber, bulb, or root crops. The biomasses from green fallows, buffer zones and from “nature management fields” are also calculated as sidestreams in the Biomass Atlas, as their biomasses are currently not used for food or feed in Finland. In “Sidestreams” the number of crop categories is smaller than in the “Main yield”, as similar types of sidestreams are pooled together, e.g., straw is shown as a pooled level of all cereal species. However, in the “Main yield” the number of species is high. Nearly all species of which yield statistics are available are presented individually, because it is expected that the “Main yield” data and acreage data can be used also for various purposes while their sidestreams are most likely used for bioenergy resource calculations. Such purposes could be for example estimation of potential acreages for silage harvesting or areas for plant protection; availability of a specific raw material e.g., malting barley for breweries from the neighbourhood; or calculation of spatial or diversity indices such as Shannon.

Field areas were calculated from LPIS into 1 km grid as such. The method for crop biomass calculation was to combine LPIS and regional and annual crop statistics (Official Statistics of Finland 2018a). The field parcels from LPIS with the crop species information are joined to the corresponding levels of crop production (yield per hectare) of each Centre for Economic Development, Transport and the Environment (ELY-centre), where the parcel is located. Thus, the estimated crop biomasses in the grids are the product of area and the biomass yield per

Table 1
Biomasses organised by potential type. The unit is provided at first hierarchy level where it is common for all the lower levels. In parenthesis there is the amount of map layers and biomass attributes.

Potential	Land cover, ha	Land class (3)		
		Land class based on FAO's FRA (4)		
		Site main class (4)		
		Site fertility (8)		
		Field land use	Utilized agricultural area	Field crops (31)
				Outdoor vegetables and roots (9)
				Berry bushes, fruit trees and strawberry (6)
	Total production	Forest biomasses, t (21)		
		Field biomasses, main crops, t/a (23)		
		Berries and garden plants, t/a (13)		
	Sidestream potential	Forest chip, m3/a	Small diameter trees (2)	
			Logging residues (3)	
			Stumps (2)	
		Communities biowaste, t/a	Biodegradable waste from communities (2)	
		Companies biowaste, t/a	Animal and vegetable waste (25)	
			Sludge (24)	
			Paper and cardboard waste (3)	
			Wood waste (7)	
			Mixed waste (2)	
		Treated biodegradable waste, t/a	Animal and vegetable waste (2)	
			Sludge (5)	
			Paper and cardboard waste (2)	
			Wood waste (4)	
			Mixed waste (1)	
		Ashes, t/a (5)		
		Field, t/a	Crop sidestreams (9)	
		Manure	Manure ex-housing	Slurry (5)
				Dung (9)
				Urine (4)
			Manure ex-storage	Slurry (5)
				Dung (9)
				Urine (4)

area.

The information for crop statistics is collected yearly from the sample of over 6000 farms in an online service and as a telephone interview (Luke 2020). The farmers inform the amount of their harvest by species and the acreage harvested. Reply percentage in this inquiry is very high, above 95 percent. Yield statistics for different ELY-regions are generated from the interview material and the ELY-region yield is used in calculation of "Main yield" and for "Sidestreams" when the sidestreams are calculated directly as a share of the main yield.

The amount of sidestream biomass for a crop species can be estimated by harvest index (HI) which is known for most crops (Hakala et al., 2009). HI refers to the proportion that main yield consist of the whole crop biomass above ground. The HI of cereals is normally about 0.4–0.5. A good rule of thumb is that cereals produce as much straw as grain yield. Exact estimation of straw biomass is difficult, as the HI depends not only on crop species, but also on crop variety and growing conditions. In Biomass Atlas the theoretical maxima for the amounts of field crop sidestreams were calculated according to the average HIs of each crop of interest (published estimates, see Hakala et al., 2009) thus sidestream represents other parts of the plant except the main yield.

After harvest, about one third of the straw or stems is left in the field as stubble, and only 60–70% of the theoretical straw or stem yield can be harvested, the amount depending on the cutting height (Hakala et al., 2016). This means that about 1700 (barley and rapeseed) to 2800 kg (rye) of dry sidestream biomass could be collected/ha/year in Finland. To preserve good soil quality, it is recommended that straw is harvested only every second year from the same field. Thus, depending on the crop, 900–1400 kg of dry straw or stem biomasses could be collected/ha/year (Pahkala and Lötjönen 2015). Tops of some root crops could be harvested for biogas production. For many root crops, the HI is known (Hakala et al., 2009). E.g., for sugar beet, 40% of total biomass is top biomass, the dry matter content of which is as low as 20% ((Juurikassarka, 2005, 1: 12). Sugar beet tops could be used for biogas fermentation, but they are also used as forage.

Permanent grassland types like green fallow, nature management fields, and buffer zones cover together around 10 percent of the agricultural land area in Finland. These forms of land use are based on promoting biodiversity or other ecosystem services. No yield statistics are available for such parcels. Still, they produce biomass, usually grass or hay, which could be harvested and used for raw material for biorefineries. In the Biomass Atlas we have used dry hay yield per hectare in the specific ELY-centre to estimate the biomass production as sidestream potential for these categories. Furthermore, the hay yield was corrected by a coefficient of 0.5 for natural pastures and 0.7 for green fallows, nature management fields, buffer zones and green manuring crops. The correction was done due the lower yield expectation for areas not fertilized.

The permanent grassland biomass production, mainly presented as sidestream potential, is therefore a rough estimate, which however represent a rather large area of the total cultivated area (see Table 2). The challenges related in estimating the yield and sidestream potential in grassland production are discussed in Niemeläinen (2011) and Hakala et al. (2012). The biomass yield between different field parcels of green fallow, buffer zones and nature management fields was observed to vary from 1300 to 10 300 kg DM/ha in study of Niemeläinen et al. (2014).

Even though we have information of the crop cultivated on a field parcel in a certain year, we are not able to acquire reliable information of the cultivation and harvesting technology (e.g., height of cutting), growing season weather, harvesting conditions or sown variety of the crop, all of which affect the technical sidestream potential. Therefore,

Table 2
Main yield and sidestream estimations for some grassland production types.

Grassland type	Yield data source	Unit	Area (ha) in Finland 2021
Silage	Yield statistics	tons[a]	620 570
Hay	Yield statistics	tons**	112 500
Cultivated pasture	Estimated based on silage ha yield	tons[a]	51 630
Green fallow and nature management fields	0.7 of hay ha yield calculated to 100% DM	tons dm	147 290
Buffer zone	0.7 of hay ha yield calculated to 100% DM	tons dm	43 950
Green manure	0.7 of hay ha yield calculated to 100% DM	tons dm	11 980
Natural pastures	0.5 of hay ha yield calculated to 100% DM	tons dm	21 080

[a] DM of silage is 33% **DM of dry hay is 85%.

we report the crop species and its yield in the Biomass Atlas and leave the deduction of potentially available sidestream biomasses to the user to estimate according to information locally available and the theoretical basis given above and in the cited literature.

Area used for gardening is also calculated from LPIS to Biomass Atlas and garden crops follow the same method as field crops except that garden crop yields come from horticultural statistics (OSF 2018b).

3.2.5. Wastes

The quantity and geographical data for wastes is based on data reported annually to the Finnish emission control and monitoring database YLVA and on waste statistics compiled by Statistics Finland. The YLVA database is maintained by environmental supervising authorities. It contains data reported by those enterprises having an environmental permit for their operation and therefore they are obliged to report waste data annually to YLVA.

The data on biodegradable waste is divided into three categories: 1) biowaste and other biodegradable waste generated by municipalities (including biodegradable municipal wastes from enterprises), 2) biodegradable wastes generated by enterprises, and 3) biodegradable wastes gone through treatment processes at waste treatment plants.

Municipal biowaste includes kitchen and canteen waste as well as biodegradable garden waste. Other biodegradable municipal waste includes separately collected paper and cardboard waste, wood waste, textile waste and vegetable oils from canteens. It also includes an estimation on the proportion of biodegradable wastes in non-separated mixed municipal waste. The estimation is based on research conducted at treatment facilities. The amount of biowaste and other biodegradable waste generated by municipalities is based on national waste statistics. The value is calculated from national amounts of biodegradable municipal wastes generated and it is expressed as kilos generated per inhabitant per year. The calculated amount per a certain area therefore depends on its population. The amounts reflect the potential of this type of wastes within the area rather than locations where they were generated.

Companies and enterprises that require an environmental permit for their operation report annually their waste data to supervising environmental authorities. Reported data is checked by the authorities and registered in the YLVA database. Waste types concern such wastes as sludge, paper and cardboard, wood waste and waste of animal and vegetation origin. It also includes some mixed municipal waste that is generated by enterprises for example in their canteens or offices. The amounts of wastes that are generated by enterprises reflect the actual amount of this type of wastes within the area where they were generated.

Biodegradable waste that is generated by municipalities is transported elsewhere of its origin to be treated, recovered, or disposed of centrally at various waste treatment plants. Municipal facilities such as households, office buildings, canteens, small businesses, schools, etc. are not obliged to report their waste data to environmental authorities. Those amounts need to be calculated based on amounts received at waste treatment facilities. Biomass Atlas therefore includes data on biodegradable wastes received and treated at waste treatment facilities. Those facilities are obliged to report annually waste data to environmental authorities. Biodegradable wastes treated by them concern mainly such wastes as sludge, paper and cardboard, wood waste, and waste of animal and vegetation origin. The waste amounts gone through the treatment processes reflect the potential of this type of wastes for market within the area.

In addition to data concerning biodegradable wastes also data on ashes were compiled for Biomass Atlas on the basis of YLVA database. Data on ashes concern ashes from power stations and other combustion plants: bottom ash, slag and boiler dust, coal fly ash, fly ash from peat and untreated wood, and non-hazardous bottom ash, slag, boiler dust and fly ash from co-incineration. Wood and peat ashes can be used for forest fertilization.

3.2.6. Manure

Manure of animal farms and horse stables is based on information on manure quantity and the location of animals. Manure quantity is defined by the Finnish Normative Manure System (Luostarinen et al., 2017a, Luostarinen et al., 2017b) which quantifies the Finnish manure production in different manure types per animal category.

Manure is calculated as a mass balance starting from animal feeding and excretion (*ex-animal)*, advancing to manure after removal from the housing units (*ex-housing*) and ending in manure after storage period (*ex-storage*). The manure data available in Biomass Atlas are both manure ex housing and manure ex storage. This is because the ex-housing values should be e.g., used when planning manure processing directly after removal from housing and the ex-storage values should be used e.g., when planning manure fertilizer use without processing.

The manure types available in Biomass Atlas are slurry, solid manure, and urine. Calculation of solid manure is done in more detail with a distinction between deep litter, farmyard manure and dung. These solid manure types are then summed up for Biomass Atlas. The average shares of different manure types per animal category in Finland are reported in Luostarinen et al. (2017b).

Also, the animal categories are calculated in a more precise way than presented in Biomass Atlas. The nine animal categories included derive from a more precise categorisation in the Finnish Normative Manure System (Appendix 2).

The spatial distribution of manure is derived from the official animal register collected by Finnish Food Authority for cattle, pigs, poultry, sheep, and goats. This register with farm-specific information on animal numbers and farm location are delivered by National Land Survey Finland. Animal numbers and location of fur animals are from Finnish Fur Breeders Association. The statistics hold information on the number of female and male foxes and minks used for breeding. The number of growers is calculated by multiplying the number of females by annual average brood sizes. The number of horses and ponies is from Suomen Hippos ry, Finnish trotting and breeding association. The location of horses in this registry is for horse owners and the location of the animals and hence manure may differ. Better statistics is planned, but not yet available (Hippos, 2023).

The manures are thus calculated as a multiplication by manure quantity and animal numbers per animal category and their spatial distribution connected with the addresses of the farms or horse owners. The manure quantity is then evenly distributed to the area of the municipality in which it is produced without presentation of the exact locations. This is due to the laws for general data protection and the statistics (Act on Data Protection 1050, 2018 and (Act on Statistics)).

3.3. Software development

3.3.1. Grids

The spatial harmonization of the different biomass types was achieved by generalizing the data from different data sources to a grid that is 1 km × 1 km in spatial dimensions. We also tested a smaller grid size (i.e., 250 m × 250 m) and larger one (10 km × 10 km). Consequently, it was concluded that the used 1 km × 1 km grid size is a good compromise between too detailed and too general representation. Additionally, it coincides with the Grid Database of Finland produced by Statistics Finland. This enables further modelling by using the socio-economic variables of that database in order to produce predictions for waste generation, for example. Finally, the unified data representation by this kind of grid structure also simplifies the database construction enabling faster computation times as well as uniform handling of the data.

As the data for every biomass type was calculated from varying sources, the procedure for grid calculation was unique for each data type and is described in detail in Appendix C.

Besides of 1 km × 1 km grid, all the data layers are also provided in other spatial units such as watershed catchments, municipality, postal zip-code areas, counties, and ELY-centres (Development, transportation, and environmental centres).

3.3.2. User interface and program code

Biomass Atlas is providing tools and functionalities to show biomasses on the map, make calculations based on biomasses of interest as well as adjusting the maps and user interface for users need through user interface. Biomass Atlas includes user registration for enabling further functionalities and personalization. System has also the functions to retrieve background maps from various Finnish data providers. System contains the functions to import different types of biomasses into the system and system logging for utilizing the biomass calculation tools. (Fig. 2). System technical architecture is described from infrastructure viewpoint in Appendix C.

Biomass Atlas system is using Apache Tomcat software for web application and Geoserver for map drawing services. Biomass Atlas system is developed using Java programming language for server end code while user end code is developed using JSP technology. Beside them, Oskari map framework, which is built in Java and Javascript has

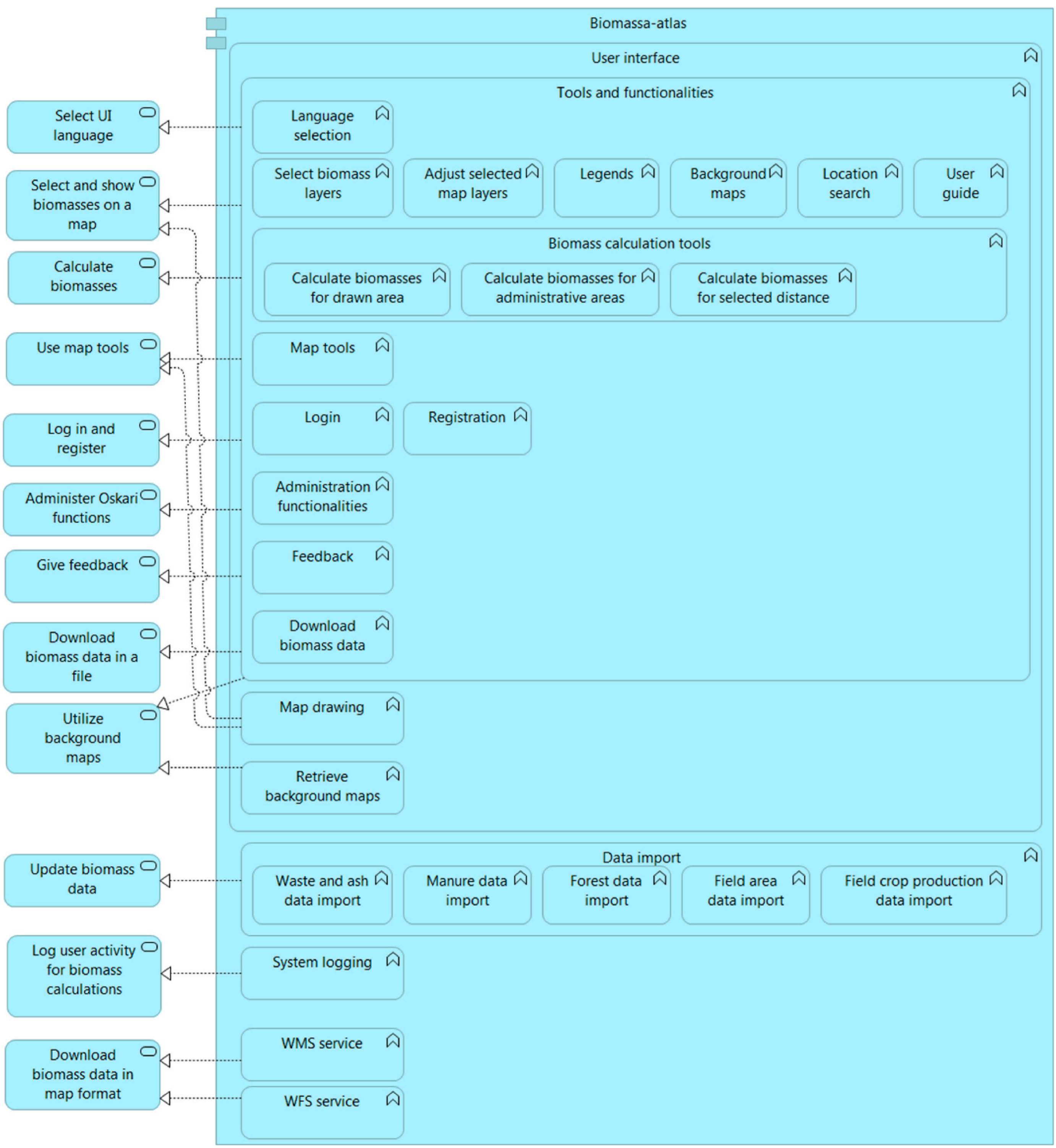

Fig. 2. System functions.

been used. It has several features related to map visualization, which made our work easier. Lack of proper documentation made it hard to use this framework, but slack communication helped a lot.

Oskari is a framework for building web mapping applications utilizing distributed spatial data infrastructures like INSPIRE. Oskari uses standard Open-Source components such as OpenLayers, GeoTools and GeoServer. All the developed code is released under open-source licenses (MIT/EUPL). More information of Oskari framework can be found at http://www.oskari.org/

The guideline for creating database structure was to keep it simple and compact. The basic structure for biomass data is only a couple of tables (Fig. 3). However, implementing the biomass data import processes additional tables were required in database. Biomass Atlas database uses PostgreSQL database system with PostGIS extension. There are two schemas; one for biomass data, which stores all data related to biomasses and another which stores data related to Oskari framework.

3.4. Usability testing

Systems with good usability have increased acceptance and better reputation, in addition to higher productivity and lower error occurrence. Maintenance costs and demands also decrease simultaneously (Lallemand 2011, p299). Considering the usability objectives and resources, the aim is to choose the most suitable usability evaluation methods. For example, the speed of the method or the number of usability issues can be set as a criterion (Sampola, 2008).

The user interface of Biomass Atlas has numerous components and selection parameters. Visualising and classifying this amount of information into a form-based web application is a challenge, especially when the intention is to serve end-users. To ensure that the user interface is intuitive enough for the end user, usability testing was conducted in the laboratory with six test users, and an open testing period with 20 voluntary test users was conducted. Nielsen and Landauer (1993) recommend that there should be at least five test users to optimize the cost-benefit ratio. Additionally, five test users provide sufficient reliability in usability evaluations (Molich and Nielsen, 1990).

3.4.1. Laboratory tests and interviews

Biomass Atlas was tested in eye tracking equipped research laboratory, in University of Vaasa. An eye-tracker is a device for measuring eye position and eye movement. Tracking and recording a person's eye sighting on the screen provides information on where on the program window the test person is looking for a solution.

The tasks performed by the test users were planned by the same team who developed the Biomass Atlas. The aim in designing the tasks was to optimize the test coverage while keeping the length of the whole test relatively short.

Test users performed pre-defined tasks using Biomass Atlas at their own pace. The test tasks consisted of searching the biomass sources, selecting the target areas, interpreting the results, and saving the data. The users could ask help from the supervisor of the test in case they were facing too difficult problems. Some of the six selected test users were experts in renewable energy and circular economy while others did not have previous experience in subject matter. None of the test users had used the Biomass Atlas application before.

An eye-tracker and eye-tracking experiment creator software (SMI REDn Scientic + SMI experiment Centre, SensoMotoric Instruments GmbH, Germany) were used in tests. The laboratory system recorded every test session in video format, eye-tracking information included (Fig. 4).

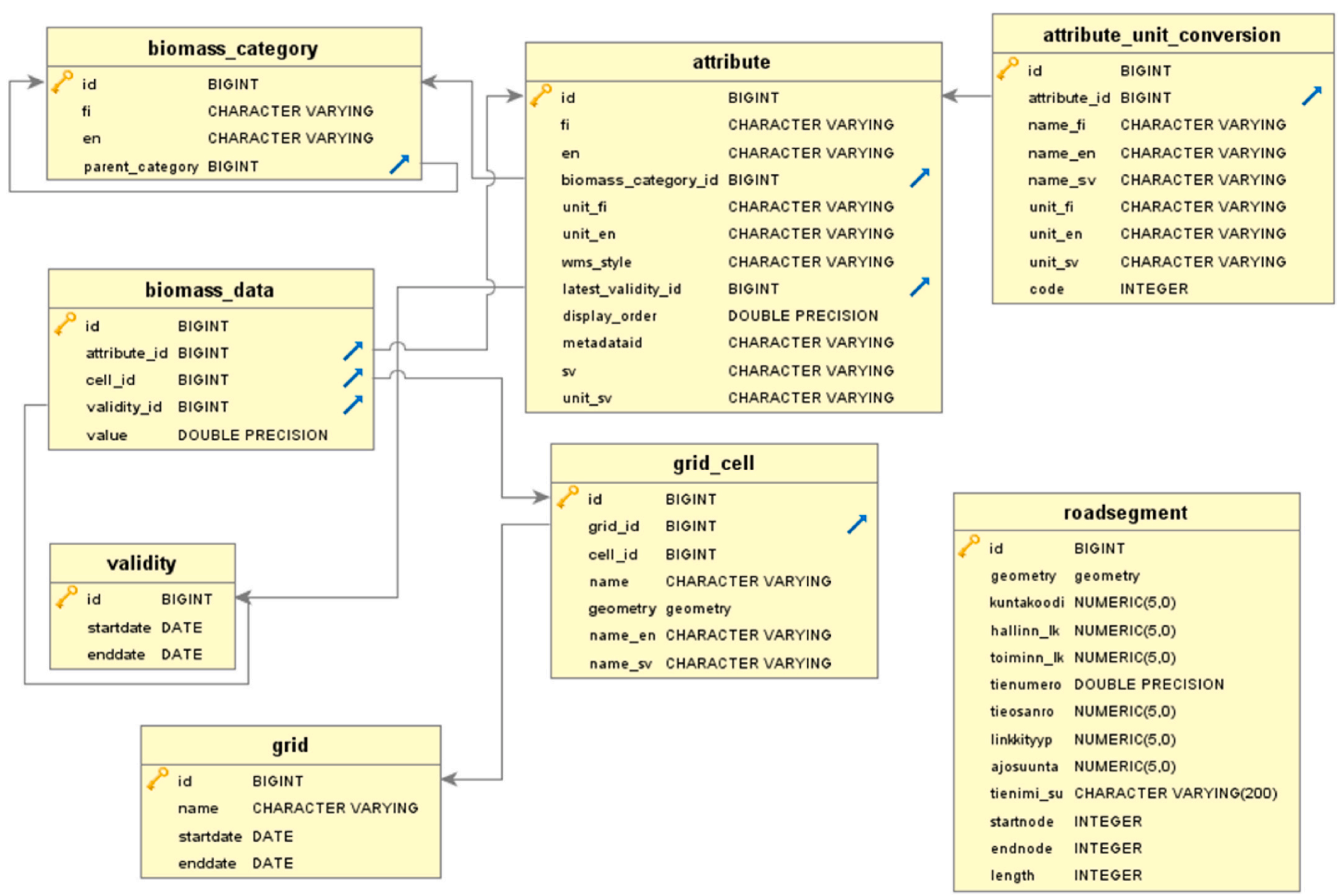

Fig. 3. Basic database structure.

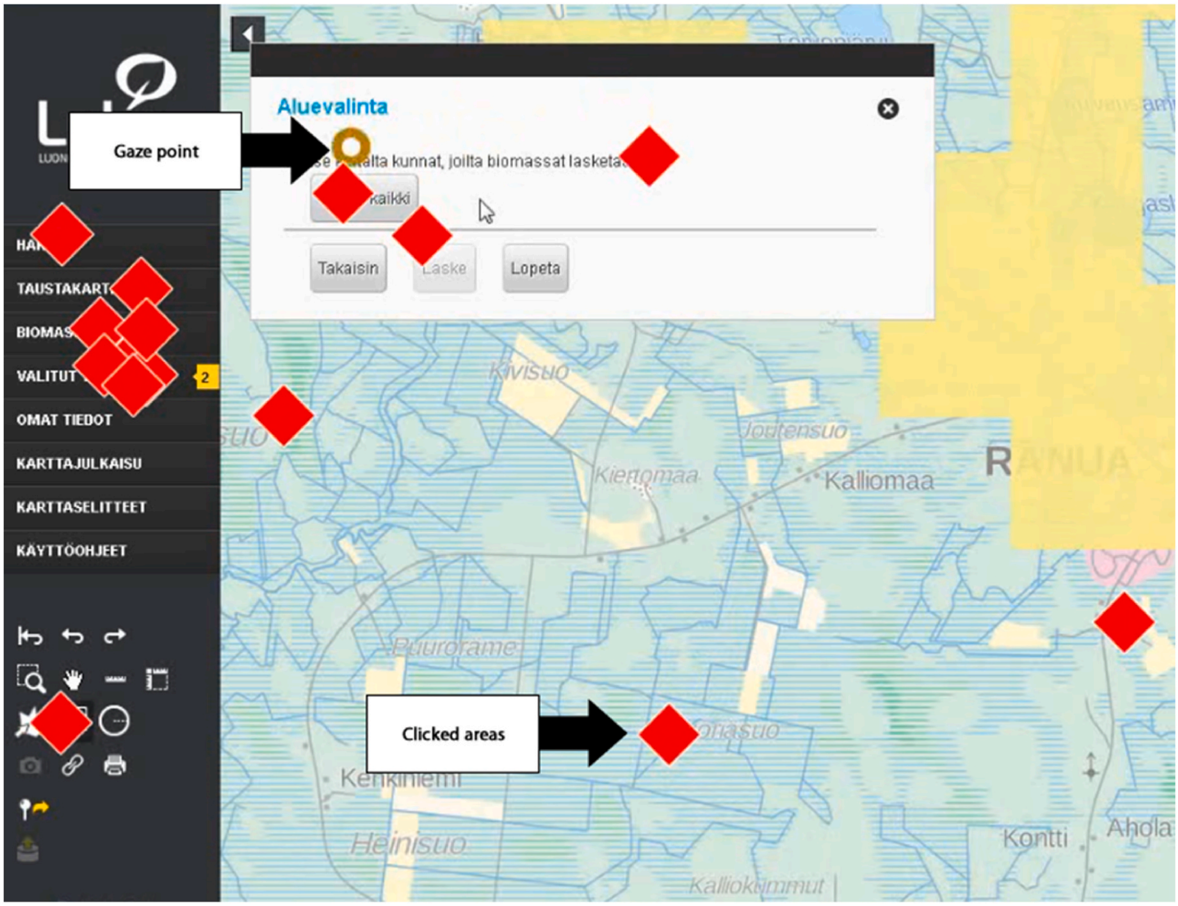

Fig. 4. Screenshot of captured video. The image shows all mouse clicks that were clicked, as well as the current gaze point on the screen.

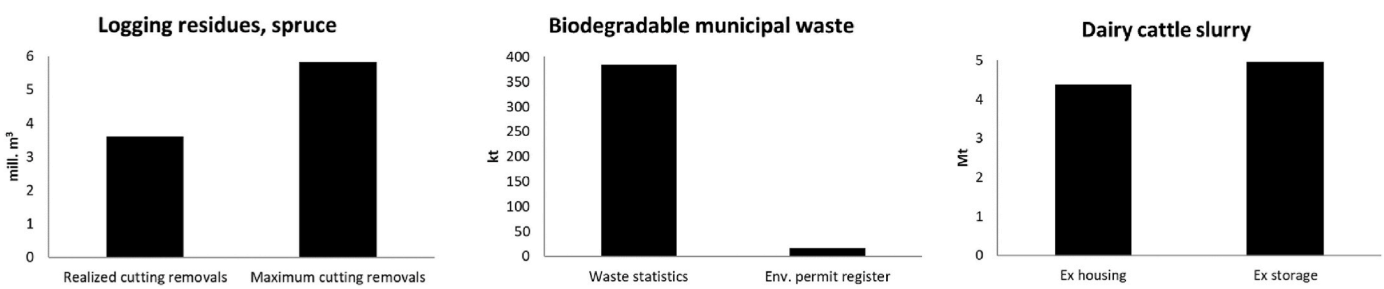

Fig. 5. The effect of different scenario assumptions (left), data sources (middle), and storage time (right) on the potentials.

Test users were interviewed after the usability test to hear their experiences, possible suggestions for improvements, and any challenging situations that arose during the test.

All the interviews and recorded test sessions were registered and categorized according to the seriousness of the problem according on Nielsen (1992) defined heuristics, categories being significant, moderate, minor, cosmetic or no problem in usability.

3.4.2. Open pilot testing period

Between usability test and launching Biomass Atlas to wide publicity, we also conducted a voluntary test use period and collected feedback from group of interested users. We asked and got feedback from 20 test users, five of them working at private sector, 13 at public sector and 2 in other type of organisation.

4. Results

4.1. Biomass potentials

An integral part of Biomass Atlas work was to gather all the biomass data into the same database, make it accessible through one user interface and form high resolution spatial data. With the help of application, it is possible to easy and quickly form a comprehensive picture of a particular biomass potential nationally and regionally. Still, there remains responsibility for user in understanding assumptions and choices made for calculations.

There is no systematic way to compare biomasses or harmonize the calculation methods for different biomass types as harvest methods, properties and use opportunities of different biomasses vary much. Calculation methods for forest biomass as well as for manure and field biomasses has been developed in the independent projects.

We collected and summarized biomasses within some main themes as an example of variety remaining in reporting. One can see from Table 3 that units vary between themes. Also harvest time makes differences for availability (see Table 3). Fig. 5 shows variation in selected biomass themes: Varying scenarios affect on potentials. Data sources vary in coverage. Biomass amount and quality are also dependent on storage time.

All the data layers in Biomass Atlas and their biomass amount summarized for the whole country as well as units can be found in appendix 2. We conclude that comparisons can be made within a theme, but a careful consideration is needed when comparing data between themes.

The spatial distribution and biomass hotspots can be visualised on thematic map for each biomass type. Three examples of these results can be seen in Fig. 6. Utilized agricultural land is most densely concentrated to the coastal zone in Finland and gets rare when going to Northern Finland (Fig. 6A). Spatial distribution of small diameter trees follows the realized fellings (Fig. 6B) and biodegradable waste is concentrated in densely populated, urban areas (Fig. 6C).

4.2. Tour to the Biomass Atlas

Biomass Atlas is a calculation and reporting tool as well as a collection of thematic maps on natural resources, freely available and useable in web browsers (functioning were tested by Mozilla Firefox and Chrome). Biomass Atlas enables production of thematic maps of biomass amount or intensity of certain land use types. User can visualize any of the 300 data layers, for example make a regional map of logging residue potential or a thematic map of intensity of oat or carrot cultivation (Fig. 1). It is also possible to select many data layers and summarize values of each selected layer in a selected region (Fig. 2). The result table can be exported, and it is possible to continue data analysis in other applications.

Table 3
Summaries of main biomass types [1].

Biomass type	Biomass	Amount	Unit	Year	Harvest time/ availability
Yield	Silage, fresh and dry hay	8 399 745	t/a	2017	summer
	Cereals	3 351 693	t/a	2017	summer
Total existing biomass	Spruce	548 019 424	t		not relevant
	Broadleaved trees	452 598 911	t		not relevant
	Pine	832 297 055	t		not relevant
Sidestream	Manure	14 669 779	t/a	2017	year round
	Sidestreams from field total	3 037 827	t DM/a	2017	summer
	Field sidestreams, cereal straw	2377213	t DM/a	2017	summer
	Field sidestreams, other straw	160 921	t DM/a	2017	summer
	Field sidestreams, grass	499 693	t DM/a	2017	summer
	Forest sidestreams	19 922 185	m^3/a		year round
Waste	Biowaste from waste treatment plants	16 968	t/a	2016	year round
	Biowaste from municipalities	384 455	t/a	2016	year round
	Other biodegradable waste from municipalities	1 440 342	t/a	2016	year round
	Plant and animal waste from industry	375 993	t/a	2016	year round
	Sludges from wastewater treatment	1 829 185	t/a	2016	year round
	Paper waste	83 446	t/a	2016	year round
	Wood waste	1 807 330	t/a	2016	year round

4.2.1. Overview of the service

Biomass Atlas web service consists of two parts: the website (www.biomassa-atlas.fi) and the web-based map application (www.biomassa-atlas.luke.fi). The website supports the map service with descriptions of different biomass types, their properties, current and alternative uses, and the process on how the data is produced. Use cases of Biomass Atlas are given as examples.

The web application consists of a map window and a toolbar (Fig. 7). The map window is equipped with general map tools, such as coordinates indicating the location of the cursor, zoom in and out, panning and going to previous extent. The toolbar holds the Biomass Atlas functionalities: In the biomass menu a user can select biomasses of interest to be drawn on the map and calculated for analyses. Selected layers tab is a tool for organising the drawing order and visibility of selected layers. Map legends show the scale and colour symbology of the selected layers. Background maps consist of a selection of web map services (WMS) of different themes from various data providers. Background maps do not involve in biomass calculations, they provide supplementary, visual information on the conditions and possible use constraints of biomasses. (Fig. 7).

Location search is a tool for searching locations by place or road name. It uses OpenStreetMap name database. My data is for registered users and allows a user to view her user profile and saved features and map views. User guide provides a detailed explanation on all functionalities of Biomass Atlas. Basic map tools allow moving between map views, zooming in or out the map, panning the map and measuring the distance and area. It is possible to mark a point on the map and create links to map view and biomass selections. A registered user can save the map view and biomass selections for later use and add her own material as a map layer.

Links for registration, logging in, giving feedback, description of how the personal data is managed, and a navigation link to Biomass Atlas website are also located in the toolbar.

In following chapters there is a more detailed description of the key functions of Biomass Atlas.

4.2.2. Biomass selection

In the biomass menu all the biomasses included in Biomass Atlas can be browsed and selected. The biomasses are organised in three different ways to three tabs. The first tab, “Potential” organises data based on the idea of different levels and concepts of potential. The second tab “Origin” categorises biomass types based on their origin, which is: forest, agriculture, communities, companies, or waste treatment. The third tab “Search” allows a search of biomass by name. It returns all biomass types containing the string typed in the search box. All tabs work in parallel. Thereby if a biomass is selected in one tab, the same biomass will be selected in other tabs also.

4.2.3. Tools and functionalities

Region selection tools are special tools tailored for biomass search and selection regionally. They enable calculation and summaries of the biomass potentials, which can be done in three different ways: Free outlining lets user draw the region freely by clicking the vertices of polygon; Predefined region lets user select from predefined areas such as municipalities, other administrative regions and drainage basins. The centre of circle lets users define a central point of interest and calculate

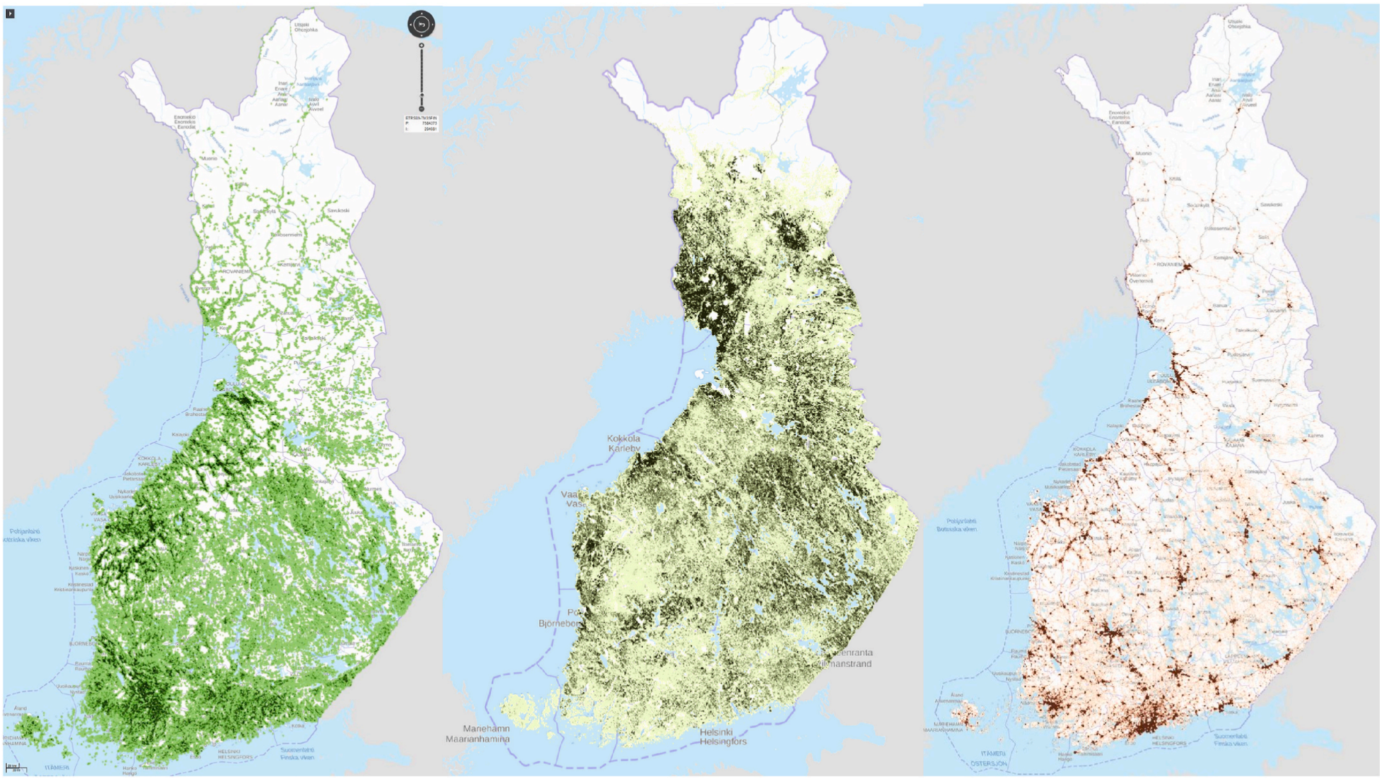

Fig. 6. Examples of thematic maps produced by Biomass Atlas. A) Utilized agricultural area B) Small diameter trees, diameter below 10 cm C) Biodegradable municipal waste.

the biomass amount around it within a chosen radius by beeline or along the road network (Fig. 8).

After a search by a region selection tool data is summarized to the result table from which it can be exported to csv- or xls-file where further calculation can take place (Fig. 2).

Metadata describing the biomass data is stored and maintained in separate national geodata portal http://www.paikkatietohakemisto.fi/geonetwork/srv/eng/and it is linked to the service by info icons and can be read in the window opening to the map service.

4.3. Usability test results

4.3.1. Usability experiments in laboratory

Every test user was able to complete all tasks. A total of nineteen usability issues were found in the tests. Most of the issues were non-critical. However, two major issues requiring immediate actions were found. The first critical issue was the difficulty to find the region selection tools. The issue was solved by highlighting the tool icons and re-ordering tools to the more logical order according analysis flow. The second critical issue was that the tool to define the centre of circle did not work at all for two test persons. The problem was fixed by software developers. Among the moderate usability issues the most reported was the inelegant layout of biomass selection menu. It was reported to be too wide, blocked the visibility of map and was difficult to structure visually. Due the feedback we paid special attention for the better design of the biomass menu. Biomass themes were structured further, titles and fonts were selected to be more distinguishable, search function by biomass name was added.

Another moderate usability issues mentioned was the user manual. Test persons hoped it to be available and visible all the time. Also, some content was still missing during the test sessions. These issues were solved before publishing the map service.

Minor usability issues were reported, such as naming the buttons for data exports more descriptively, pointer to be more clearly visible, the search functionalities be grouped to be found in one location. In some cases, the selected technical environment, Oskari, caused some pre-defined design. Re-design of it would have been complex. Most of the issues were solved though easily.

4.3.2. Interviews

All test subjects reported that the application worked in a logical and expected manner. Usage logic was familiar from other similar type of map-based web services. Suggestions for improvement included highlighting the icons for region selection tools, adding guidance on these tools, and clarifying units of some biomass fractions both within tools and used guide. More possibilities were also sought for searching regions and biomasses, such as text box searches. However, the interviews emphasized that the application was in general easy to use.

4.3.3. Eye-tracking

The eye-tracking system gave results of test users' eye sighting on the screen, especially the information considering the tools of the Biomass Atlas. As the test persons performed their first task, it was discovered by video observation that almost every test person went to the given task by trying to select the desired area first. However, this is not possible in the application. The logic of the application works by selecting first the desired biomass. As the test proceeded to the next task, all test users had learned the application logic, and this problem was no longer detected. Eye tracking clearly showed where the test users were looking for the tool they wanted. As the interviews already suggested, for some test users finding the desired tool selectors was at times challenging.

The tools were searched through several menus until finally the correct selector was found. This was particularly the case for the area selectors.

4.3.4. Analysing the results

The interviews and eye-tracking strongly supported each other. Many of the problems found during the interviews were repeated in the

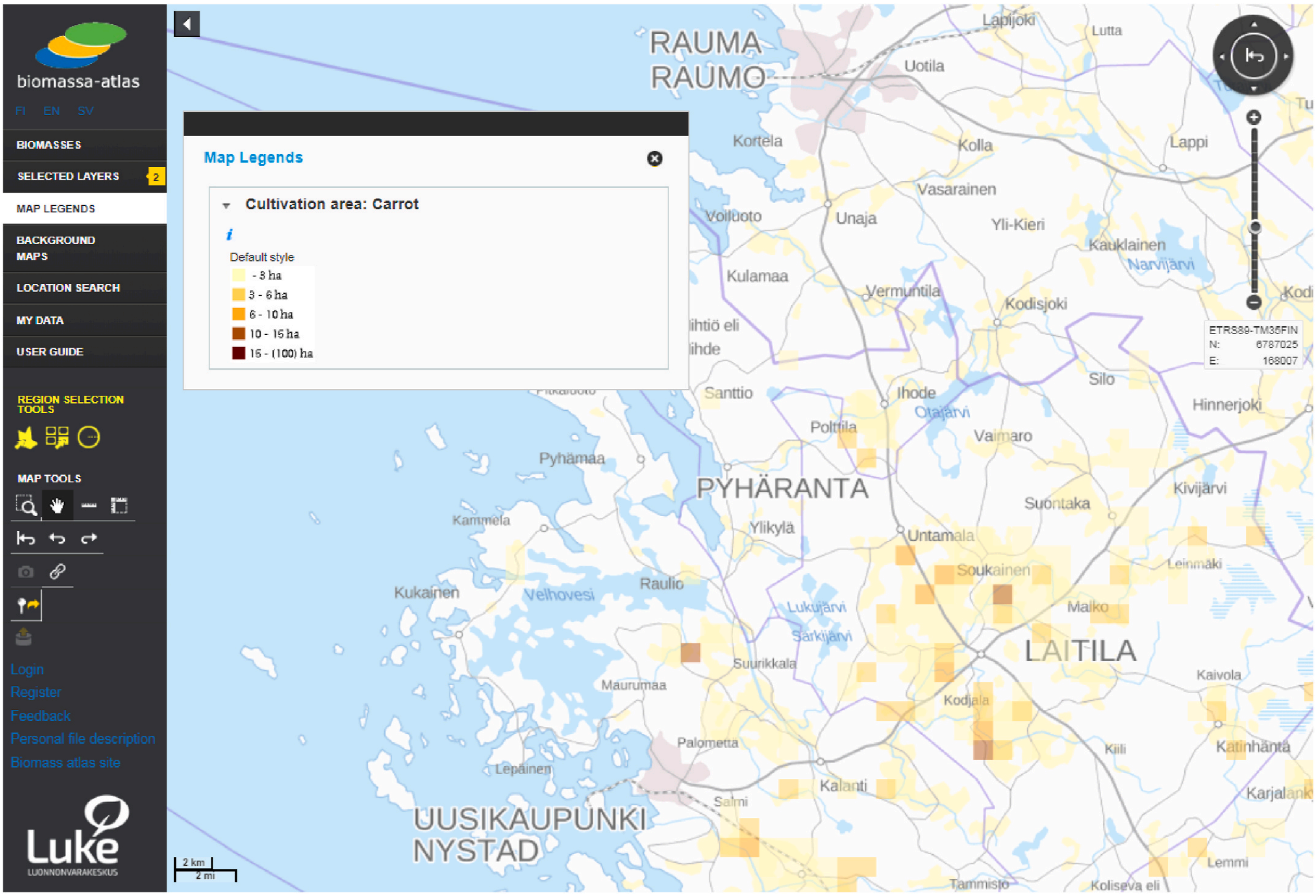

Fig. 7. Overview of Biomass Atlas and example of a thematic map, cultivation area of carrot in South-Western Finland.

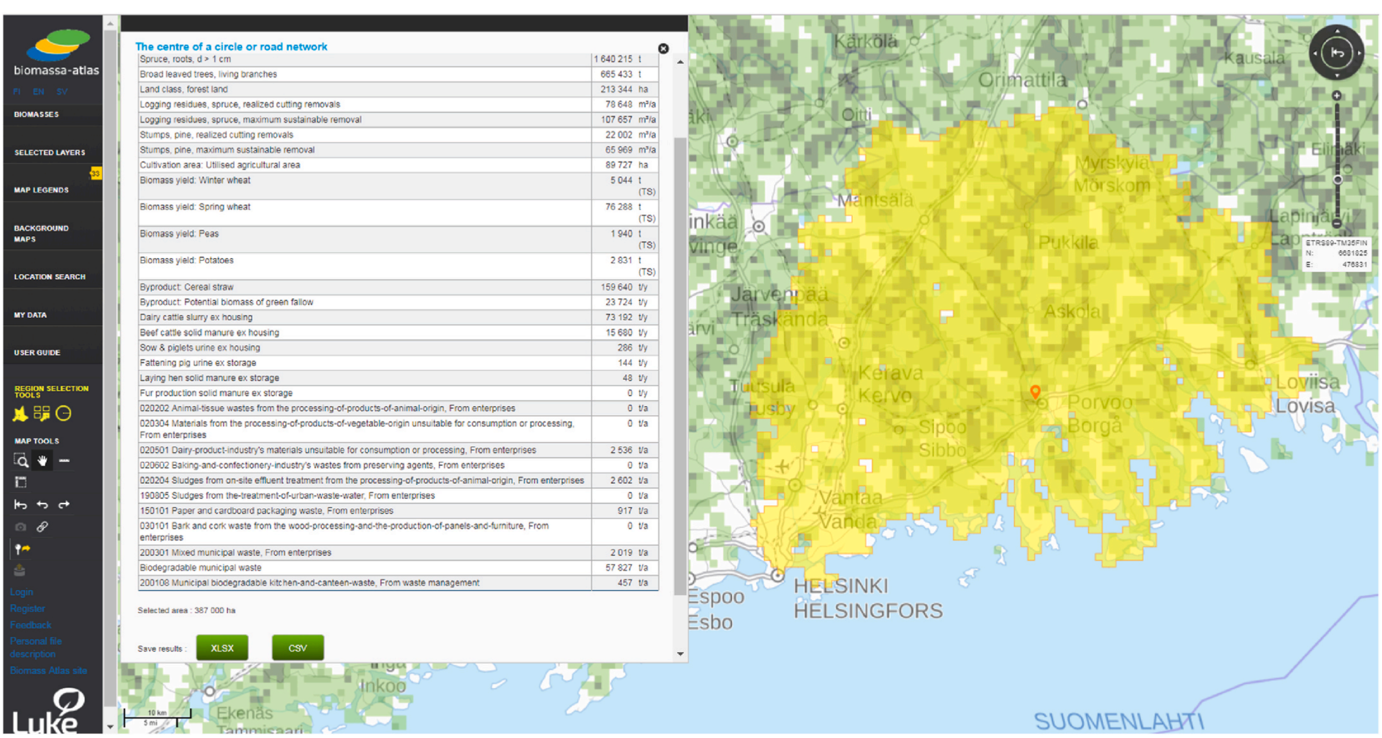

Fig. 8. Summary and analysis result of selected biomasses made by region selection tool. The red pointer is set as a central point in Southern Finland and in this case, an area accessible by 50 km along a road network is covered and biomasses summarized within it.

recorded videos, and the analysis of the videos deepened the understanding of the problems encountered. The logic of the users' actions was much easier to understand when eye tracking information was available. Combined, these two methods gave a very comprehensive picture of the usability of the application. The usability of the application was already at a good level at this stage.

All usability issues detected were sorted by severity. The severity classification based on Jakob Nielsen's heuristics (1990), which also determined the order of correction, was used to classify the problems encountered. Application tools, especially area selectors, were dynamically highlighted, guidance was added to suggested places, search functions were diversified, and menu item order was reorganized.

4.4. Open pilot testing period

The test users used from 3 to 45 min to search and find information of their interest. 80 % of them found the biomasses they were interested in and 90 % used region selection tools successfully.

Test users gave also open feedback. Altogether 41 suggestions or questions were listed. We classified them as follows: 0 = feature exists already, no need for actions, 1 = will be realized before publishing, 2 = will be realized soon after publishing, 3 = we will consider it later in following projects, 4 = feature is not possible to realise. The results were then used to enhance functionalities before and soon after the publishing.

More precise spatial information and newest possible information were wanted. Properties like nutrient content and biogas potential of biomasses were wished and data how the biomass is used currently. In some cases, the user themselves were aware, that the issue is too difficult to solve due the legislation or lack of data.

Six of the wished functionalities already existed, which most notably showed us that intuitiveness of user interface is still possibly to enhance. Also, some training for Biomass Atlas use would be useful. First though, we added frequently asked questions and their answers to the supporting webpage and provided more guidance straight to user interface.

Altogether 14 given feedbacks ended to class 1 and thus resulted in immediate changes in user interface design. In order to help users finding the desired information, we renamed some biomass classes in biomass menu and provided more precise metadata. List of municipalities was requested to make selection easier. Accordingly, we added municipality labels to region selection tool. Some of the metadata links were not working and were repaired. Biomasses were ordered differently in biomass menu and the biomass reports; thus, they were reordered. Nine of operations resulting on the given feedback were decided to be postponed after the publication of Biomass atlas. These operations were usually more laborious or of technical complexity. Moreover, six wishes made by test users were so wide, that they would be subject to another project to be solved. They included: the data on biomass use currently, integration to other calculation tools (two of them mentioned), classification of biomasses based on their nutrient content or biogas potential, and governmental change to be come.

Additionally, six of the given feedback were so general that it did not guide us to make any enhancements.

The test users were also asked, how they usually find answers to questions that they now solved with Biomass Atlas. Two most typical answers were either to collect the data from various open registers at internet or order a study from a consultant. Some of the responders said that they calculate the needed information from the same input data that is used for Biomass Atlas.

5. Discussion

The published version of Biomass Atlas is a first version of developing application. We created a generic service for many types of users and needed to make decisions without knowing all different user needs exactly. In the following chapters, we discuss about the questions still waiting to be solved.

5.1. Possibilities and challenges of maintenance and functionalities

To maintain Biomass Atlas as a continuously available service with up-to-date data, the service must be maintained, and the data updated regularly. The up-to-dateness of the source data varies, with waste and agricultural biomasses available for annual update and forest data every fifth year.

Biomass Atlas data production relies on various sources of data produced by other data providers. If there are changes in the structure or classification of the original data, there will be consequences to Biomass Atlas data classification as well. Therefore, complete automation of data production is not possible. For example., changes in the Common Agricultural Policy (CAP) necessitate updates in at least two ways: firstly, changes in CAP classifications require updates to the processes of data calculations. Secondly, changes to environmental subsidies might result in proportionally significant changes in agricultural sidestream biomasses.

Another consequence arising from the fact that data production is dependent on processes outside the Biomass Atlas is that all biomass potentials cannot be compared to each other. The source data and calculation rules are coherent within a group of potentials, such as field biomasses, forest chip potential, manure amount, or biowaste from municipalities. However, between these groups, the user must be aware that calculation rules are heterogeneous, and units as well as potential concepts might differ.

In Biomass Atlas there are approximately 300 map layers. We have created visually appealing thematic map for each individual data layer, but each one only works visually on its own. It would provide more opportunities for users if it was possible to visualize multiple layers of information in parallel. Additionally, the scale of the data differs from layer to layer. Visualising layers with a consistent scale would make thematic maps comparable to each other.

The map selection tools developed in Biomass Atlas are generic tools, and they could be used in other applications as well. Therefore, comprehensive documentation and sharing in GitHub or another suitable platform would enable wider use of the tools.

The EU's General Data Protection Regulation (GDPR, 2016/679) and the Finnish Act on Data Protection (1050, 2018) restrict the accuracy with which the data can be presented on the map. It cannot be linked to any personal data. We have resolved this issue by representing the manure data only at the municipality level. However, in some cases, more spatial accuracy is needed. Also, in a few municipalities, there are only one or two farms. Representing manure values at a spatial unit other than the municipality would be better choice. An algorithm to combine three or five closest units and obtain a location for them would solve the problem without limiting to existing administrative borders.

In a wider perspective the new solutions are under discussion either for making new legislation or finding new interpretations. There is certainly a conflict between private and common benefits. Data Protection Regulation protects the private rights, but there is a risk that too much of GIS data will be considered as personal data, while for general planning and regulatory purposes, it is necessary to have sufficient database and knowledge. Therefore, we continue to follow the discussion of interpretations of EU General Data Protection Regulation.

We expect to face challenges with changing input data. As we are partly dependent on third parties, whose data is designed originally for purposes other than compiling biomass statistics, we cannot influence much the form or accuracy of the data we get. Therefore, we need to be prepared to adjust our processes according to changes that possibly occur in our input data.

5.2. Uncertainties of data

5.2.1. Forest sidestreams

The accuracy of data on forest resources and forest land cover at pixel-level is low (http://www.paikkatietohakemisto.fi/geonetwork/srv/fin/catalog.search;jsessionid=5xucstm4ryvlfxq6q2bwg49z#/metadata/c2ca1093-c111-4062-9c32-0bb9e3de159d), but rises with increasing area. For example, the differences between species-level stem volumes calculated from field plot measurements and MS-NFI estimates vary between −0.3% and −2.9% for the whole country (Mäkisara et al., 2019). The errors in the estimates are due to, e.g., measurement errors, sampling errors and modelling errors.

The estimates of harvesting potential of forest chips are based on so-called MELA-model applied generally in forestry-related scenario modelling in Finland (Siitonen et al., 1996; Hirvelä et al., 2017). With the aid of linear optimization, a solution maximizing a desired target function for a future time period is obtained. The results are presented at regional level where they are considered to be accurate enough (http://mela2.metla.fi/mela/index-en.html). For Biomass Atlas the regional results were further allocated to the 1 km^2 grid by utilizing MS-NFI maps. The accuracy of grid cell level potentials is unknown.

5.2.2. Forest biomass and land use

Data of forest biomass and land use is derived from original dataset of Multi-Source National Forest Inventory of Finland and the advantages and limitations of the original dataset are discussed in Mäkisara et al., 2019. The original dataset is generalised in Biomass atlas to a coarser grid size.

5.2.3. Field area, crops and sidestreams

Sidestreams of food production are obvious potential sources of biomasses for fibre, nutrients, and bioenergy, as food is produced in every country in the world. The most obvious and easiest to collect is straw from cereals. In principle, cereals produce as much straw as grain yield, but the relationship varies according to species, variety (genetically determined harvest index) and soil and weather conditions (Hakala et al., 2009). In some years, straw cannot be collected because of weather conditions that make field work impossible or harmful for soil structure. In addition, not all sidestreams should be gathered, as it is crucial to leave biomass in the soil to conserve soil carbon (Hakala et al., 2016). However, the biggest problem in the usage of crop sidestream such as straw for energy is its low price, which makes its collection and transport economically unsustainable.

Different grassland cultivation types, including buffer zones and nature management fields, constitute over 40 percent of the utilized agricultural land area in Finland. The yield statistics of grassland production are not straight forward to convert to hectare yield of main production branches: silage and hay – the area is sown for grass, and it is harvested for silage or hay depending on weather conditions and needs. Estimation of dry matter is inadequate at farms. Yield statistics are not collected for pasture, green fallows, green manure and for nature management fields and buffer zones. For the last-mentioned categories, regional hay yield statistics were utilized to provide a rough estimate for sidestream potential. However, in the case of resource base studies for e.g., biogas plant planning, more specific sidestream calculations are needed as the variation in the biomass production on the different grassland categories can be very high (Niemeläinen et al., 2014).

5.2.4. Manure

The amount of manure produced is estimated using a model called Finnish Normative Manure System (Luostarinen et al., 2017a, Luostarinen et al., 2017b). Its strengths and limitations have been discussed in Luostarinen et al. (2018). Overall, the system is assumed to give a good estimation on the quantity of manure available in Finland for uses such as Biomass Atlas.

Manure amounts and their geographical distribution are obviously tied to the number of animals and location of animal farms. This information is known in detail in Finland due to the surveillance of farming activities. The precise data of animals and animal farms is available for research (Act on the Openness of Government Activities 621, 1999 and Act on Data Protection 1050, 2018) but the interpretation of its uses in such contexts as Biomass atlas is not entirely solved. To pinpoint exact farms on freely available maps has been a topic of discussion during the system development and for safety, it was decided that the exact locations of individual farms was not given, but the estimated amount of different manures was evenly distributed across municipalities.

The availability and degree of detail of the horse registry has been under development in Finland. At the time of writing, the registry includes data on the horse and the location where it is kept (Hippos, 2023). Another reason for not pinpointing the exact farms was also the fact that there is no statistics available on which manure type each farm produces and national data must be assumed for all farms. The manure type is dependent on the housing technology which might be extractable from environmental permits. The problem is that in Finland there is no collected database for the environmental permits of farms and further, some permits are given by a national authority (the largest farms), some by municipalities (middle-sized farms) and some farms do not need a permit at all (the smallest farms). Thus, the data on the shares of manure types are based on a large farm survey conducted in 2013 (animal farms) and 2014 (horse stables) (Grönroos et al., 2017, Appendix 2). All animal farms are assumed to produce all manure types relevant to an animal category in these shares. This is naturally not correct farm-specifically and there may be regions where the national data works well and others where it provides error to the real situation. At the moment, though, this is the best possible way to estimate the shares of slurry, solid manure and urine produced. As this data is also not stable, the farm survey on manure management should further be repeated after a few years. Unfortunately, so far this has not been possible.

5.2.5. Biodegradable waste from municipalities and enterprises

First, it is important to keep in mind when analysing data that most of the data in YLVA-database is based on information reported by enterprises having an environmental permit for their operation and therefore being obliged to report annually waste data to authorities based on the reporting regulations set in the permit. Data is therefore collected mainly for environmental supervising and monitoring purposes, and YLVA database on that account does not bend easily to statistical analysis.

Concerning biodegradable waste data, it is noteworthy to point out that currently some information in Biomass Atlas is lacking concerning such operations that do not require an environmental permit or the permit does not require reporting. This concerns mainly facilities having an environmental permit admitted by municipalities (e.g., animal shelter for a given size or food and feed manufacturing facilities). Later on, this type of information will be included in YLVA-database.

In general, waste data in the YLVA database contains information on various phases of waste streams from transporting, storing, and handling of wastes to recovery or final disposal of wastes. It is impossible to trace the original waste amounts after all the phases (processing, transporting, storing etc.). Waste amount characteristics change on the way, and for example, waste can be mixed with other waste fractions or separated into several fractions. Efforts have been made to reduce the duplication of this kind of waste stream (e.g., waste treatment and transport) in the data compiling.

In data mining process some observations were made for waste data quality accuracy in YLVA database. In registering information or data in YLVA database, several specific codes are used for waste classification, origin of waste, disposal, and recovery operations etc. Regarding the data mining process, it is crucial that correct codes are used throughout the registering process. Also providing information in requested dimensions (tonnes per year instead of m^3/year) is important. It was also noticed that sometimes waste was considered as a raw material for the production or fuel rather than reported as waste; in these situations, waste data might be lacking from Biomass Atlas.

In data mining process the data compiled was checked and processed both manually and by programming. However, due to YLVA's large data supply and many different usages and practices, it is almost impossible to produce flawless statistical data based on the data source used.

Considering the usage or utility of data compiled for Biomass Atlas, one must keep in mind, that data presented concern situation in the past, not present. The amounts reflect the potential of different types of biodegradable wastes or ashes within the area for a certain year. In analysing data, it is worthwhile to study data for several years for a certain area.

5.3. Reproducibility of Biomass Atlas for other countries and possible challenges

In Biomass Atlas we have used Finnish data as a case for biomass calculations. The availability and documentation of data in Finland is commendable; however it may not be analogous in other EU countries and not to speak of other countries. In principle, the common agricultural policy of the EU (CAP) mandates the maintenance of registries for land parcels and cultivation among them, and the same practice is applied overacross all EU countries. Therefore, data for agricultural biomass calculations should theoretically be accessible for any EU country. However, variations in prevailing conditions for biomass production must be acknowledged. For instance, the arrangement of land ownership may influence on potentials and their true availability, and the coverage of CAP is not uniform across the EU. Regarding other biomasses, our previous experiences from multilateral projects indicate that high resolution spatial data does not exist, or it is not readilyaccessible.

Our background maps are based on open data provided by National Land Survey Finland. The Open Street Map project appears to be the only openly available seamless background map applicable for all countries. It can also be employed for road network analyses, though it's worth noting that the quality may vary depending on the level of activity in the mapping project within the particular region.

5.4. Use cases for Biomass Atlas

Both the main yield and sidestreams of crops could be used for other purposes such as bioenergy, in addition to their main purpose (food, feed, or bedding). However, the quality, price, and weight by volume of sidestreams are usually lower than those of the main crop. Therefore, the cost of collecting and transporting of these biomasses can undermine the desired economic and environmental benefits of their use. In addition, straw collection also removes carbon and nutrients (especially potassium) from the field. The removal of carbon, a possible feedstock for soil carbon, may reduce the soil fertility, and replacing the nutrients removed may be more expensive than the compensation for the biomass by the energy plant (Hakala et al., 2016). The main obstacle to the usa of straw or other sidestreams for energy in Finland is the autumn climatic conditions. Even if grain or seed could be harvested at moisture content below 20%, the moisture content of straw and stem can be 30–60% at harvest. For economically viable storage, straw, should have less than 25% moisture before baling. Surplus grass biomass could be collected for bioenergy, but it must be conserved as silage or dried and baled for preservation, which again may undermine the economic benefit of the activity (Lötjönen and Niemeläinen, 2012). Certain field energy crops such as reed canary grass can be harvested dry in the spring. Moist biomasses can be used for fermentation processes for bioenergy, particularly when combained with manure, while dry straw or stem biomasses can be burned with turf in CHP plants. After fermentation the nutrients contained in the biomasses are left in the reject liquid, which can be used as organic fertilization product. Ashes from the CHP plant could be used to fertilize fields and forests.

Tampio et al., (2017) provide an example of how to use Biomass Atlas data. Treatment of biomass for biogas produces digestate that approximately equals in amount the biomass used as raw material. Digestate contains nutrients such as nitrogen and phosphorus and it can be used to fertilize fields near to biogas plant. An analysis of nutrient supply in the biomasses such as sludge, biowaste and manure was followed by calculation of nutrient need, based on crop cultivation areas. The calculation steps formed the assessment of regional nutrient utilisation.

Knowledge of the proportion of cultivated field covered by green vegetation during the winter season is important for estimating the risk of soil erosion and nutrient leaching along waterways. The Biomass Atlas provides a convenient tool for calculating the percentage of crops that provide green cover in winter in river catchment areas using the acreage data.

The Atlas provides a quick method for advisory personnel and agricultural businesspeople to obtain information on the cultivation of any area of interest. This provides opportunities for entrepreneurs in forage harvester industry to obtain information about the size of potential market area, specifically the area of silage production or for similar services for cereal producers like plant protection spraying or cereal harvesting. It also serves as a resource base for further processing of the harvested main yield.

5.5. Further needs for development

The development of Biomass Atlas will be guided by user expectations gathered during the pilot testing period and after the service launch.

Some case studies have been run to test statistical data visualization from PX Web APIs on Oskari (Dost, 2017). As part of the Biomass Atlas source data comes from PX Web API of Luke, there could be possibilities to develop Biomass Atlas thematic mapping properties and support thematic maps with more data sources and different visualizations.

To effectively plan for biobased materials, nutrients and energy, it is necessary to have more information about the routes that biomass takes from processing plant to another. The circular economy aims to increase resource efficiency and promote the cascading use of biomaterials. The Biomass atlas currently provides information on the location where biomass is formed or managed, but there is currently insufficient traceability data of biomasses to include in the Biomass Atlas.

6. Conclusions

Biomass Atlas introduces new data and improves data availability for regional planning. Register data, statistics and research parameters have been successfully converted to geographical data, map layers and visualised on maps in a free-to-use map service on the web. The novelty of the Biomass atlas tool is that it collects a wide range of resources with spatial accuracy not found in other biomass web applications. However, concerning the research questions, we noticed that the comparability of data between different data types and data sources is limited. This the various data sources and data production processes independent and antecedent of data collection for Biomass Atlas. Additionally, the concept of potential varies between biomass types.

With tens or hundreds of data layers, it is important in terms of usability that layers are organised in intuitive way. We organised the data by biomass sources as well as potential type. Additionally, we added a search tool which finds biomass layers by name. All three different options work parallel. The biomass map is an effective way to visually find the concentrated areas of a certain biomass, such as where different crop species cultivation is located. Thematic mapping works for every layer separately in Biomass Atlas. If thematic maps could be produced also from layer combinations, that would greatly help to form an idea of hotspots with a mixture of biomass types.

Good availability of biomass data enables a faster transition to bio-based production. There is a significant difference in GIS data availability in different fields of bioeconomy. For the agricultural and waste sectors the Biomass Atlas produces data which did not exist before. Additionally, access to forest data has been improved. The strict interpretation of personal data legislation may restrict the form and content of the open data. Biomass Atlas improves data availability, especially for regional planning.

Our experiences from users of Biomass Atlas show so far that the availability of data in one portal support the development of new cross-sectional concepts. Resource mappings for new biogas plants and other biorefineries have been made with the help of Biomass Atlas. The application helps in forming an idea of available resources and alternatives for them, and provides the first sight for biomass achievability.

Finally, Biomass Atlas is likely to have wider relevance for bio-based circular economy due its extensive data content and analysis tools, which together enable versatile analysis. The Atlas provides information on biomass and sidestream amounts at their location of formation, as well as the diversity of land use. This information has many applications, including studies on human health, plant pathology, nutrient recycling, and environmental planning.

CRediT authorship contribution statement

Eeva Lehtonen: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Perttu Anttila:** Data curation, Investigation, Methodology, Supervision, Writing – original draft. **Kaija Hakala:** Investigation, Methodology, Validation, Writing – original draft. **Sari Luostarinen:** Data curation, Investigation, Methodology, Validation, Writing – original draft. **Suvi Lehtoranta:** Resources, Validation, Writing – original draft. **Kirsi Merilehto:** Data curation, Formal analysis, Resources, Validation, Writing – original draft. **Harri Lehtinen:** Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft. **Virpi Mäntylä:** Software, Validation, Writing – original draft. **Anil Maharjan:** Software, Writing – original draft. **Oiva Niemeläinen:** Methodology, Validation, Writing – original draft. **Mikko Kolehmainen:** Conceptualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The Biomass Atlas project from 2014 to 2018 was funded by Ministry of Forestry and Agriculture. Ministerial Adviser Birgitta Vainio-Mattila and Counsellor Liisa Saarenmaa from the Ministry of Agriculture and Forestry provided valuable advice and encouragement throughout the project. The user survey was expertly organised by PhD Tanja Myllyviita. Senior Coordinator Teija Haavisto and group manager Tuuli Myllymaa selected the biowaste categories to be included to the Biomass Atlas. Technology research program director Markku Järvenpää helped to start the project and secure funding. We also like to express our gratitude to Riikka Nousiainen and Timo Muhonen from Luke, Samu Valpola from GTK and Risto Juntunen from Tapio for their valuable contributions and ideas towards the development of the Biomass Atlas.

Appendix 1. The biomass layers, amounts and units in Biomass Atlas

Main type	Biomass type	sum	unit_en
Field (area)	Cultivation area: Beetroots (red and yellow)	404	ha
Field (area)	Cultivation area: Berry bushes, fruit trees and strawberry	7405	ha
Field (area)	Cultivation area: Broadbeans	22 014	ha
Field (area)	Cultivation area: Buffer zones and buffer strips	56 773	ha
Field (area)	Cultivation area: Caraway	23 968	ha
Field (area)	Cultivation area: Caraway and other minor crops	20 714	ha
Field (area)	Cultivation area: Carrot	1435	ha
Field (area)	Cultivation area: Cultivated pasture	57 255	ha
Field (area)	Cultivation area: Currants and gooseberries	1814	ha
Field (area)	Cultivation area: Cut flowers and greenery	27	ha
Field (area)	Cultivation area: Fiber and energy plants	5645	ha
Field (area)	Cultivation area: Fruits	729	ha
Field (area)	Cultivation area: Garden pea	4102	ha
Field (area)	Cultivation area: Grass seed production	12 172	ha
Field (area)	Cultivation area: Green manure sward	22 118	ha
Field (area)	Cultivation area: Green set aside and natural treatment field	161 381	ha
Field (area)	Cultivation area: Hay	98 757	ha
Field (area)	Cultivation area: Head cabbages	618	ha
Field (area)	Cultivation area: Leguminous plants	25 612	ha
Field (area)	Cultivation area: Lettuce	303	ha
Field (area)	Cultivation area: Malting barley	75 005	ha
Field (area)	Cultivation area: Minor crops	3807	ha
Field (area)	Cultivation area: Mixed cereals	24 787	ha
Field (area)	Cultivation area: Mixed crops	18 441	ha
Field (area)	Cultivation area: Natural pasture	21 333	ha
Field (area)	Cultivation area: Nursery production	262	ha
Field (area)	Cultivation area: Oats	336 501	ha
Field (area)	Cultivation area: Oil crops	58 422	ha
Field (area)	Cultivation area: Oilseed rape	36 649	ha
Field (area)	Cultivation area: Onion	969	ha
Field (area)	Cultivation area: Other barley	359 771	ha
Field (area)	Cultivation area: Other cabbages	552	ha

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Main type	Biomass type	sum	unit_en
Field (area)	Cultivation area: Other oil crops	1869	ha
Field (area)	Cultivation area: Other root crops	1784	ha
Field (area)	Cultivation area: Outdoor cucumber	141	ha
Field (area)	Cultivation area: Outdoor vegetables and root vegetables	12 273	ha
Field (area)	Cultivation area: Peas	11 219	ha
Field (area)	Cultivation area: Potatoes	21 477	ha
Field (area)	Cultivation area: Raspberry	429	ha
Field (area)	Cultivation area: Rye	30 846	ha
Field (area)	Cultivation area: Set aside, uncultivated and other special areas	36 994	ha
Field (area)	Cultivation area: Silage swards	538 005	ha
Field (area)	Cultivation area: Silage swards, fresh	12 535	ha
Field (area)	Cultivation area: Spring cereals	1 038 469	ha
Field (area)	Cultivation area: Spring rye	911	ha
Field (area)	Cultivation area: Spring wheat	181 892	ha
Field (area)	Cultivation area: Strawberry	3657	ha
Field (area)	Cultivation area: Sugar beet	11 698	ha
Field (area)	Cultivation area: Triticale	693	ha
Field (area)	Cultivation area: Turnip rape	28 342	ha
Field (area)	Cultivation area: Utilized agricultural area	2 328 889	ha
Field (area)	Cultivation area: Whole crop cereals	18 240	ha
Field (area)	Cultivation area: Winter cereals	71 632	ha
Field (area)	Cultivation area: Winter wheat	35 815	ha
Field (biomass)	Biomass yield: Beetroots (red and yellow)	10 325	t/y
Field (biomass)	Biomass yield: Broad bean	40 832	t/y
Field (biomass)	Biomass yield: Caraway	11 969	t /y
Field (biomass)	Biomass yield: Carrot	59 877	t/y
Field (biomass)	Biomass yield: Cereals harvested green	123 087	t/y
Field (biomass)	Biomass yield: Currants and gooseberries	1466	t/y
Field (biomass)	Biomass yield: Fruits	6574	t/y
Field (biomass)	Biomass yield: Garden pea	7156	t/y
Field (biomass)	Biomass yield: Grassland cultivation	3226	t/y
Field (biomass)	Biomass yield: Hay	354 366	t/y
Field (biomass)	Biomass yield: Head cabbage	18 473	t/y
Field (biomass)	Biomass yield: Herbage seed	4319	t/y
Field (biomass)	Biomass yield: Lettuce	2940	t/y
Field (biomass)	Biomass yield: Linseed flax	2554	t/y
Field (biomass)	Biomass yield: Malting barley	297 155	t/y
Field (biomass)	Biomass yield: Mixed cereal crops	67 295	t/y
Field (biomass)	Biomass yield: Oats	1 123 408	t/y
Field (biomass)	Biomass yield: Oilseed rape	53 473	t/y
Field (biomass)	Biomass yield: Onion	22 397	t/y
Field (biomass)	Biomass yield: Other barley	1 447 295	t/y
Field (biomass)	Biomass yield: Other cabbages	2954	t/y
Field (biomass)	Biomass yield: Other root crops	15 502	t/y
Field (biomass)	Biomass yield: Outdoor cucumber	8259	t/y
Field (biomass)	Biomass yield: Pasture sward	260 942	t/y
Field (biomass)	Biomass yield: Peas	28 104	t/y
Field (biomass)	Biomass yield: Potatoes	564 441	t/y
Field (biomass)	Biomass yield: Raspberry	1265	t/y
Field (biomass)	Biomass yield: Reed canary grass	16 166	t/y
Field (biomass)	Biomass yield: Rye	83 462	t/y
Field (biomass)	Biomass yield: Silage swards	7 957 984	t/y
Field (biomass)	Biomass yield: Silage swards, fresh	87 449	t/y
Field (biomass)	Biomass yield: Spring rye	4405	t/y
Field (biomass)	Biomass yield: Spring turnip rape	39 014	t/y
Field (biomass)	Biomass yield: Spring wheat	751 821	t/y
Field (biomass)	Biomass yield: Strawberry	11 293	t/y
Field (biomass)	Biomass yield: Sugarbeet	426 350	t/y
Field (biomass)	Biomass yield: Winter wheat	93 511	t/y
Field (side stream)	Byproduct: Biomass of bufferzone vegetation	110 064	t(TS)/y
Field (side stream)	Byproduct: Cereal straw	3 195 475	t(TS)/y
Field (side stream)	Byproduct: Grass seed production	25 970	t(TS)/y
Field (side stream)	Byproduct: Hay production	35 437	t(TS)/y
Field (side stream)	Byproduct: Potato tops	138 545	t(TS)/y
Field (side stream)	Byproduct: Potential additional harvest of green manuring sward	65 306	t(TS)/y
Field (side stream)	Byproduct: Potential biomass of green fallow	394 314	t(TS)/y
Field (side stream)	Byproduct: Silage fresh	8745	t(TS)/y

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Main type	Biomass type	sum	unit_en
Field (side stream)	Byproduct: Silage sward	795 798	t(TS)/y
Field (side stream)	Byproduct: Stems from peas and broadbean	23 889	t(TS)/y
Field (side stream)	Byproduct: Stems of oils crops	156 304	t(TS)/y
Field (side stream)	Byproduct: Straw of herbage seed crops	46 339	t(TS)/y
Field (side stream)	Byproduct: Sugarbeet tops	46 123	t(TS)/y
Forest	Broad leaved trees, dead branches	2 682 802	t
Forest	Broad leaved trees, foliage	14 352 608	t
Forest	Broad leaved trees, living branches	46 211 697	t
Forest	Broad leaved trees, roots, d > 1 cm	75 491 623	t
Forest	Broad leaved trees, stem residual	47 069 418	t
Forest	Broad leaved trees, stump	23 277 656	t
Forest	Broad leaved trees, unbarked stemwood	246 246 208	t
Forest	Energy wood from integrated harvesting in early thinnings, 2004–2008	6 649 446	m^3/a
Forest	Land class based on FAO FRA, forest	23 169 716	ha
Forest	Land class based on FAO FRA, other land	3 042 045	ha
Forest	Land class based on FAO FRA, other land with tree cover	0	ha
Forest	Land class based on FAO FRA, other wooded land	376 693	ha
Forest	Land class, forest land	21 407 086	ha
Forest	Land class, poorly productive forest land	2 069 278	ha
Forest	Land class, wasteland	3 118 354	ha
Forest	Logging residues, deciduous, maximum sustainable removal	1 587 319	m^3/a
Forest	Logging residues, deciduous, realized cutting removals	767 395	m^3/a
Forest	Logging residues, pine, maximum sustainable removal	4 153 072	m^3/a
Forest	Logging residues, pine, realized cutting removals	2 249 350	m^3/a
Forest	Logging residues, spruce, maximum sustainable removal	5 838 058	m^3/a
Forest	Logging residues, spruce, realized cutting removals	3 607 775	m^3/a
Forest	Pine, dead branches	21 086 061	t
Forest	Pine, foliage	33 293 725	t
Forest	Pine, living branches	90 539 595	t
Forest	Pine, roots, d > 1 cm	121 162 688	t
Forest	Pine, stem residual	24 320 175	t
Forest	Pine, stump	40 949 399	t
Forest	Pine, unbarked stemwood	479 143 729	t
Forest	Site fertility, barren forests or Sphagnum fuscum dominated mires	308 734	ha
Forest	Site fertility, herb rich heath forests or mesothropic mires and fens	2 613 571	ha
Forest	Site fertility, herb rich sites or euthrophic mires and fens	205 310	ha
Forest	Site fertility, mesic forests or meso-oligothropic mires	12 139 534	ha
Forest	Site fertility, rocky and sandy soils and alluvial lands	328 890	ha
Forest	Site fertility, sub-xeric forests or oligothropic mires	7 259 466	ha
Forest	Site fertility, summit and fjeld land with single coniferous trees	129 731	ha
Forest	Site fertility, xeric forests or oligo-ombothropic mires	2 261 406	ha
Forest	Site main class, mineral soil	19 122 723	ha
Forest	Site main class, pine mire	4 942 202	ha
Forest	Site main class, spruce mire	866 446	ha
Forest	Site main class, treeless peatland	1 663 361	ha
Forest	Small-diameter trees, diameter below 10 cm	3 844 384	m^3/a
Forest	Small-diameter trees, diameter below 14 cm	4 823 548	m^3/a
Forest	Spruce, dead branches	12 881 696	t
Forest	Spruce, foliage	51 692 225	t
Forest	Spruce, living branches	74 776 319	t
Forest	Spruce, roots, d > 1 cm	103 298 323	t
Forest	Spruce, stem residual	19 277 426	t
Forest	Spruce, stump	26 494 457	t
Forest	Spruce, unbarked stemwood	279 239 642	t
Forest	Stemwood from early thinnings, 2004–2008	6 233 905	m^3/a
Forest	Stumps, pine, maximum sustainable removal	5 076 928	m^3/a
Forest	Stumps, pine, realized cutting removals	2 725 941	m^3/a
Forest	Stumps, spruce, maximum sustainable removal	6 913 525	m^3/a
Forest	Stumps, spruce, realized cutting removals	4 337 910	m^3/a
Forest	Whole trees from early thinnings, 2004–2008	8 316 048	m^3/a
Manure ex storage	Beef cattle deep litter ex storage	465 521	t/y
Manure ex storage	Beef cattle dung ex storage	225 795	t/y
Manure ex storage	Beef cattle farmyard manure ex storage	1 348 164	t/y
Manure ex storage	Beef cattle slurry ex storage	1 573 462	t/y
Manure ex storage	Beef cattle solid manure ex storage	2 039 480	t/y
Manure ex storage	Beef cattle urine ex storage	217 529	t/y

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Main type	Biomass type	sum	unit_en
Manure ex storage	Broiler, turkey and other poultry deep litter ex storage	163 163	t/y
Manure ex storage	Broiler, turkey and other poultry dung ex storage	0	t/y
Manure ex storage	Broiler, turkey and other poultry farmyard manure ex storage	1172	t/y
Manure ex storage	Broiler, turkey and other poultry slurry ex storage	0	t/y
Manure ex storage	Broiler, turkey and other poultry solid manure ex storage	164 336	t/y
Manure ex storage	Dairy cattle deep litter ex storage	195 846	t/y
Manure ex storage	Dairy cattle dung ex storage	1 087 499	t/y
Manure ex storage	Dairy cattle farmyard manure ex storage	988 520	t/y
Manure ex storage	Dairy cattle slurry ex storage	4 967 846	t/y
Manure ex storage	Dairy cattle solid manure ex storage	2 271 865	t/y
Manure ex storage	Dairy cattle urine ex storage	753 107	t/y
Manure ex storage	Fattening pig deep litter ex storage	4008	t/y
Manure ex storage	Fattening pig dung ex storage	6861	t/y
Manure ex storage	Fattening pig farmyard manure ex storage	2058	t/y
Manure ex storage	Fattening pig slurry ex storage	1 840 444	t/y
Manure ex storage	Fattening pig solid manure ex storage	12 927	t/y
Manure ex storage	Fattening pig urine ex storage	16 070	t/y
Manure ex storage	Fur production solid manure ex storage	146 673	t/y
Manure ex storage	Horse and ponies solid manure ex storage	679 259	t/y
Manure ex storage	Laying hen deep litter ex storage	29 146	t/y
Manure ex storage	Laying hen dung ex storage	0	t/y
Manure ex storage	Laying hen farmyard manure ex storage	88 995	t/y
Manure ex storage	Laying hen slurry ex storage	17 835	t/y
Manure ex storage	Laying hen solid manure ex storage	118 141	t/y
Manure ex storage	Sheep and goat dung ex storage	0	t/y
Manure ex storage	Sheep and goat farmyard manure ex storage	68 155	t/y
Manure ex storage	Sheep and goat solid manure ex storage	128 371	t/y
Manure ex storage	Sow & piglets deep litter ex storage	508	t/y
Manure ex storage	Sow & piglets dung ex storage	16 051	t/y
Manure ex storage	Sow & piglets farmyard manure ex storage	7541	t/y
Manure ex storage	Sow & piglets slurry ex storage	469 251	t/y
Manure ex storage	Sow & piglets solid manure ex storage	24 100	t/y
Manure ex storage	Sow & piglets urine ex storage	42 875	t/y
Manure ex housing	Beef cattle deep litter ex housing	442 020	t/y
Manure ex housing	Beef cattle dung ex housing	190 075	t/y
Manure ex housing	Beef cattle farmyard manure ex housing	1 172 350	t/y
Manure ex housing	Beef cattle slurry ex housing	1 398 962	t/y
Manure ex housing	Beef cattle solid manure ex housing	1 804 445	t/y
Manure ex housing	Beef cattle urine ex housing	187 679	t/y
Manure ex housing	Broiler, turkey and other poultry dung ex housing	0	t/y
Manure ex housing	Broiler, turkey and other poultry farmyard manure ex housing	1069	t/y
Manure ex housing	Broiler, turkey and other poultry slurry ex housing	0	t/y
Manure ex housing	Broiler, turkey and other poultry solid manure ex housing	158 220	t/y
Manure ex housing	Broiler, turkey and other poultry deep litter ex housing	157 151	t/y
Manure ex housing	Dairy cattle deep litter ex housing	189 823	t/y
Manure ex housing	Dairy cattle dung ex housing	902 608	t/y
Manure ex housing	Dairy cattle farmyard manure ex housing	866 050	t/y
Manure ex housing	Dairy cattle slurry ex housing	4 376 884	t/y
Manure ex housing	Dairy cattle solid manure ex housing	1 958 480	t/y
Manure ex housing	Dairy cattle urine ex housing	649 761	t/y
Manure ex housing	Fattening pig deep litter ex housing	5441	t/y
Manure ex housing	Fattening pig farmyard manure ex housing	2691	t/y
Manure ex housing	Fattening pig slurry ex housing	1 691 645	t/y
Manure ex housing	Fattening pig solid manure ex housing	17 132	t/y

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Main type	Biomass type	sum	unit_en
Manure ex housing	Fattening pig urine ex housing	13 787	t/y
Manure ex housing	Fattering pig dung ex housing	9000	t/y
Manure ex housing	Fur production solid manure ex housing	215 868	t/y
Manure ex housing	Horse and ponies solid manure ex housing	649 830	t/y
Manure ex housing	Laying hen dung ex housing	0	t/y
Manure ex housing	Laying hen farmyard manure ex housing	80 957	t/y
Manure ex housing	Laying hen slurry ex housing	16 571	t/y
Manure ex housing	Laying hen solid manure ex housing	108 191	t/y
Manure ex housing	Laying hen deep litter ex housing	27 234	t/y
Manure ex housing	Sheep and goat dung ex housing	0	t/y
Manure ex housing	Sheep and goat farmyard manure ex housing	61 508	t/y
Manure ex housing	Sheep and goat solid manure ex housing	121 439	t/y
Manure ex housing	Sow & piglets deep litter ex housing	667	t/y
Manure ex housing	Sow & piglets dung ex housing	21 289	t/y
Manure ex housing	Sow & piglets farmyard manure ex housing	9897	t/y
Manure ex housing	Sow & piglets slurry ex housing	430 381	t/y
Manure ex housing	Sow & piglets solid manure ex housing	31 852	t/y
Manure ex housing	Sow & piglets urine ex housing	36 785	t/y
Waste	020 101 Washing and cleaning sludges from the primary production, From enterprises	1665	t/a
Waste	020 102 Animal-tissue wastes from the primary production, From enterprises	22 609	t/a
Waste	020 103 Plant-tissue waste from the primary production, From enterprises	20 630	t/a
Waste	020 107 Wastes from forestry exploitation, From enterprises	64 466	t/a
Waste	020 199 Primary production’s other waste, From enterprises	2519	t/a
Waste	020 201 Washing and cleaning sludges from the processing-of-products-of-animal-origin, From enterprises	621	t/a
Waste	020 202 Animal-tissue wastes from the processing-of-products-of-animal-origin, From enterprises	97 355	t/a
Waste	020 203 Materials from the processing-of-products-of-animal-origin unsuitable for consumption or processing, From enterprises	18 991	t/a
Waste	020 204 Sludges from on-site effluent treatment from the processing-of-products-of-animal-origin, From enterprises	185 646	t/a
Waste	020 299 Other waste from the processing-of-products-of-animal-origin, From enterprises	5691	t/a
Waste	020 301 Processing sludges from the products-of-vegetable-origin, From enterprises	62 995	t/a
Waste	020 303 Solvent-extraction wastes from the processing-of-products-of-vegetable-origin, From enterprises	6	t/a
Waste	020 304 Materials from the processing-of-products-of-vegetable-origin unsuitable for consumption or processing, From enterprises	13 122	t/a
Waste	020 305 Sludges from on-site effluent treatment from the processing-of-products-of-vegetable-origin, From enterprises	7414	t/a
Waste	020 399 Other waste from the processing-of-products-of-vegetable-origin, From enterprises	352	t/a
Waste	020 403 Sludges from on-site effluent treatment from the sugar-processing, From enterprises	846	t/a
Waste	020 499 Other waste from the sugar-processing, From enterprises	2742	t/a
Waste	020 501 Dairy-product-industry’s materials unsuitable for consumption or processing, From enterprises	13 333	t/a
Waste	020 502 Dairy-product-industry’s sludges from on-site effluent treatment, From enterprises	27	t/a
Waste	020 599 Other waste from the dairy-product-industry, From enterprises	445	t/a
Waste	020 701 Beverage industry’s raw-materials-processing-sludges, From enterprises	194	t/a
Waste	020 702 Beverage industry’s wastes from spirits distillation, From enterprises	142	t/a
Waste	020 704 Beverage-industry’s materials unsuitable for consumption or processing, From enterprises	29 794	t/a
Waste	030 101 Bark and cork waste from the wood-processing-and-the-production-of-panels-and-furniture, From enterprises	286 842	t/a
Waste	030 101 Bark and cork waste from the wood-processing-and-the-production-of-panels-and-furniture, From waste management	286 842	t/a
Waste	030 105 Non-hazarous wood waste from the wood-processing-and-the-production-of-panels-and-furniture, From enterprises	705 470	t/a
Waste	030 301 Bark and wood waste from te pulp-paper-and-cardboard-production-and-processing, From enterprises	753 408	t/a
Waste	030 305 De-inking sludges from the paper-recycling, From enterprises	56 278	t/a
Waste	030 311 Sludges from on-site effluent treatment from the pulp-paper-and-cardboard-production-and-processing, From enterprises	613 567	t/a
Waste	030 311 Sludges from on-site effluent treatment from the pulp-paper-and-cardboard-production-and-processing, From waste management	613 567	t/a
Waste	100 101 Bottom ash, slag and boiler dust	155 616	t/a
Waste	100 102 Coal fly ash	325 275	t/a
Waste	100 103 Fly ash from peat and untreated wood	384 265	t/a
Waste	100 115 Bottom ash, slag and boiler dust from co-incineration	28 734	t/a
Waste	100 117 Fly ash from co-incineration	134 417	t/a
Waste	150 101 Paper and cardboard packaging waste, From enterprises	12 446	t/a
Waste	150 103 Wooden packaging waste, From enterprises	22 978	t/a
Waste	150 103 Wooden packaging waste, From waste management	22 978	t/a
Waste	170 201 Wood waste from the construction-and-demolition, From enterprises	8220	t/a

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Main type	Biomass type	sum	unit_en
Waste	190 603 Liquor from the anaerobic-treatment-of-municipal-waste, From enterprises	113	t/a
Waste	190 604 Digestate from the anaerobic-treatment-of-municipal-waste, From enterprises	12 506	t/a
Waste	190 604 Digestate from the anaerobic-treatment-of-municipal-waste, From waste management	12 506	t/a
Waste	190 606 Digestate from the anaerobic-treatment-of-animal-and-vegetable-waste, From enterprises	177 453	t/a
Waste	190 606 Digestate from the anaerobic-treatment-of-animal-and-vegetable-waste, From waste management	177 453	t/a
Waste	190805A Non-stabilized-sludges from the-treatment-of-urban-waste-water, From enterprises	483 866	t/a
Waste	190805B Aerobically-stabilized-sludges from the-treatment-of-urban-waste-water, From enterprises	488	t/a
Waste	190805C Decomposed-sludges from the-treatment-of-urban-waste-water, From enterprises	153 716	t/a
Waste	190805D Lime-stabilized-sludges from the-treatment-of-urban-waste-water, From enterprises	7728	t/a
Waste	190805E Thermally-treated-sludges from the-treatment-of-urban-waste-water, From enterprises	1097	t/a
Waste	190805F Sludges-treated-with-pathogen-reducing-methods from the-treatment-of-urban-waste-water, From enterprises	2000	t/a
Waste	190805G Composted-sludges from the-treatment-of-urban-waste-water, From enterprises	19 008	t/a
Waste	190805G Composted-sludges from the-treatment-of-urban-waste-water, From waste management	19 008	t/a
Waste	190 805 Sludges from the-treatment-of-urban-waste-water, From enterprises	39 374	t/a
Waste	190 805 Sludges from the-treatment-of-urban-waste-water, From waste management	39 374	t/a
Waste	190 812 Non-hazardous sludges from the biological-treatment-of-industrial-waste-water, From enterprises	32 963	t/a
Waste	190 902 Sludges from the water-clarification, From enterprises	1137	t/a
Waste	191 201 Paper-and-cardboard-waste from the mechanical-treatment-of-waste, From enterprises	91	t/a
Waste	191 201 Paper-and-cardboard-waste from the mechanical-treatment-of-waste, From waste management	91	t/a
Waste	191 207 Non-hazardous wood waste from the mechanical-treatment-of-waste, From enterprises	17 064	t/a
Waste	191 207 Non-hazardous wood waste from the mechanical-treatment-of-waste, From waste management	17 064	t/a
Waste	200 101 Municipal separately-collected paper-and-cardboard-waste, From enterprises	70 912	t/a
Waste	200 101 Municipal separately-collected paper-and-cardboard-waste, From waste management	70 912	t/a
Waste	200 108 Municipal biodegradable kitchen-and-canteen-waste, From enterprises	16 602	t/a
Waste	200 108 Municipal biodegradable kitchen-and-canteen-waste, From waste management	16 602	t/a
Waste	200 125 Municipal separately-collected edible-oil-and-fat-waste, From enterprises	866	t/a
Waste	200 138 Municipal separately-collected non-hazardous-wood waste, From enterprises	13 347	t/a
Waste	200 138 Municipal separately-collected non-hazardous-wood waste, From waste management	13 347	t/a
Waste	200 201 Municipal biodegradable waste from garden and park, From enterprises	805	t/a
Waste	200 201 Municipal biodegradable waste from garden and park, From waste management	805	t/a
Waste	200 301 Mixed municipal waste, From enterprises	80 513	t/a
Waste	200 301 Mixed municipal waste, From waste management	80 513	t/a
Waste	200 302 Municipal waste from markets, From enterprises	42	t/a
Waste	200 304 Municipal septic-tank-sludge, From enterprises	33 949	t/a
Waste	200 306 Municipal waste from the sewage-cleaning, From enterprises	4708	t/a
Waste	200 399 Municipal wastes not otherwise specified, From enterprises	4081	t/a
Waste	Animal and vegetable wastes	46 418	t/a
Waste	Biodegradable municipal waste	384 452	t/a
Waste	Mixed biodegradable municipal waste	17 539	t/a
Waste	Other biodegradable municipal waste	1 440 341	t/a
Waste	Paper and cardboard wastes	6	t/a
Waste	Sludges	98 867	t/a
Waste	Wood wastes	19 007	t/a

Appendix 2. Animal categories for manure in the Biomass Atlas and the more precise categorisation behind the summed values presented

ORIGINAL ANIMAL CATEGORY	ANIMAL CATEGORY IN BIOMASS ATLAS
Dairy cows	Dairy cattle
Heifers >1 year	Dairy cattle
Calves <1 year	Dairy cattle
Bulls >1 year	Beef cattle
Suckler cow	Beef cattle
Heifers >1 year	Beef cattle
Calves <1 year	Beef cattle
Fattening pigs	Fattening pigs
Sows and piglets	Sows and piglets
Boars	Sows and piglets
Weaned pigs	Sows and piglets
Laying hen	Laying hen
Cockerels	Laying hen
Chicken	Laying hen
Broilers	Other poultry
Turkeys	Other poultry
Other poultry	Other poultry
Sheep	Sheep and goats
Goats	Sheep and goats
Horses	Horses and ponies
Ponies	Horses and ponies
Fox, female	Fur animals
Fox, male	Fur animals
Fox, grower	Fur animals

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ORIGINAL ANIMAL CATEGORY	ANIMAL CATEGORY IN BIOMASS ATLAS
Mink, female	Fur animals
Mink, male	Fur animals
Mink, grower	Fur animals

Appendix C. Technical architecture of Biomass Atlas

C.1. Biomass Atlas grid

As the data for every biomass type was calculated from varying sources, the procedure for grid calculation was unique for each data type:

The forest resources and forest land use grids were formed based on original data consisting of raster layers at resolution of 16 m. The raster values were summarized to the 1 km grid. As the target grid is not evenly divisible by 16 m (16 m fits 62,5 times to 1 km), the raster cells were distributed first into 2 km × 2 km grids. Then 16 m rasters within them were divided into 1 km grids so that raster cells laying on the grid border were joined to the one grid at other side so that each grid inherited raster cell values from its one edge.

The field parcels are originally modelled into polygons, which vary in their size and shape accordingly fields' original properties. Field polygons were clipped by 1 km grid. Thus, each grid contains the field area that actually lies within it.

The biowaste from municipalities was modelled to grid with average values waste generated annually per person. The number of citizens is ready offered in grid format by Statistics Finland.

The biodegradable waste from companies is available as a table or database format, with pairs of coordinates. The coordinates were transformed to location points in GIS program. Then the points were summed to 1 km grid. Similar procedure was performed for data on ashes from power stations and other combustion plants.

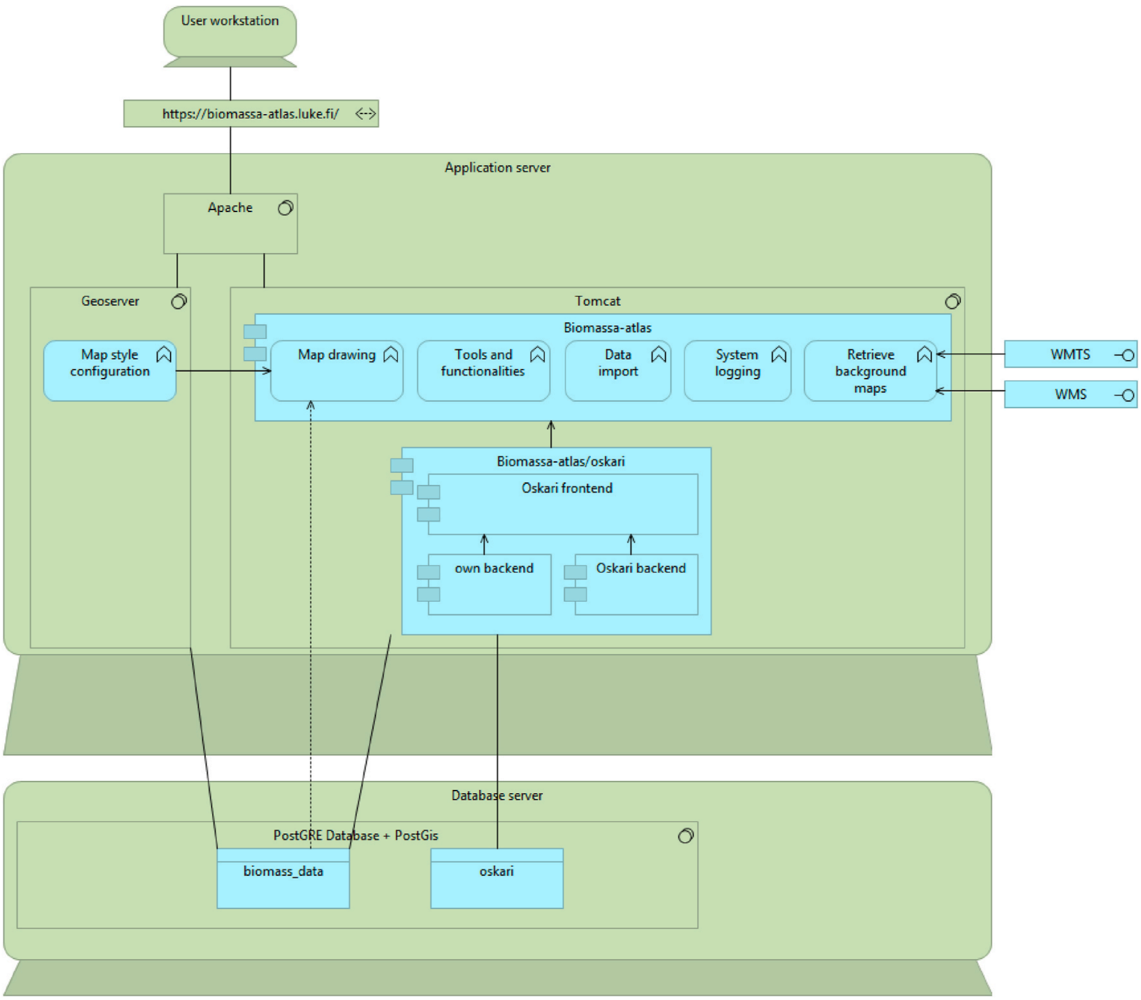
Animal amount and locations are known at farm level, but it is not allowed to put them to the publicly open map as they are because of regulation for personal data protection. The coordinates of farms were formed to location points in GIS program. The points were summed to the municipalities and manure calculations were conducted by animal amounts and manure calculation system of Finnish normative manure (Luostarinen et al., 2017a & b).

The forest chip potentials were first calculated for fifteen NUTS 3 based regions and later distributed on a raster grid at 1 km × 1 km resolution as follows: First, only grid cells on Forests Available for Wood Supply (FAWS) were considered when distributing the potentials. For this purpose, FAWS layer was obtained by subtracting restricted areas (e.g., nature protection areas) from the MS-NFI forest land. In addition, for small-diameter trees, FAWS was further constrained to pixels representing young forests suitable to small-diameter tree harvesting. Finally, the region-level potentials were distributed to the grid cells by weighting with MS-NFI biomasses (e.g., the biomass of living spruce branches was used as a weigh for spruce logging residues) (Anttila et al., 2018).

The grid format brings together different spatial data types. However there remain differences in data content. *The concept of potential* varies from one biomass main type to another. We have calculated technical as well as maximum potential. Users need to be aware of different calculation methods between different biomass types. For example, straw is reported as maximum potential, therefore user needs to apply restrictions to get available amount of straw, which is approximately 20–30 % of the theoretical maximum potential. Whereas restrictions caused by harvest methods and sustainability have been included already to calculation procedure of branches of tree thus leading to the technical potential. The different approaches in calculation methods depend on varying traditions in biomass utilisation. Forest chips has been utilized for a long time, and field sidestreams are still considered as a potential raw material for processes still under development. Therefore, the calculation methods for their existence are also still under development. Big fluctuations in climatic conditions during and between growing seasons cause insecurity for results.

Also, the allocation method for original data to grid varies. For instance, the harvesting potential of small-diameter trees was first estimated at provincial level and further allocated to those grid cells, which were considered young forest according to MS-NFI, by weighting with stem volume from MS-NFI. Whereas manure data was divided equally into the grids within a municipality.

C.2. Infrastructure viewpoint



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