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Literature study and concept paper regarding peri-urban areas and grassland indicators

Final report

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Content

1. Introduction

The document intends to draft indicator specifications for peri-urban areas and grasslands, making use of the latest available Copernicus data, namely, the Urban Atlas (UA) and the High Resolution Layers Imperviousness and Grassland (HRL Imperviousness and HRL Grassland). It addresses in particular the urban peripheries and also the status and prospects for European grasslands, thus, enhancing the knowledge base.

The Copernicus land monitoring service (CLMS) offers more and more data derived from EO and other sources, at high and very high spatial resolutions. Copernicus data constitutes a huge source of new and comparable data not existing before at European level, offering to be further explored and used.

In addition, the Programming Document 2018-2020 calls for the development of indicators for land system assessments using Copernicus land monitoring services and other Earth Observation products.

It is therefore of interest to exploit possible uses of Copernicus data for the development of indicators. Indicators based on the Copernicus local component Urban Atlas (UA) and the pan-European component (HRL grasslands) are requested to support the monitoring of policies and the status of environment in general.

The aim of this working document is to provide baseline literature summary with respect to policy context related to peri-urban areas and grassland, monitoring approaches (with focus on the Copernicus Urban Atlas, HRL imperviousness and grassland datasets) and their potential and limitation for existing or future peri-urban and grassland indicators. It is a draft outline of current status and a reference point for further peri-urban and grassland related indicator potential exploration and development within the task as well as ideas towards integration into on-going EEA work. The report comprises parts about policy context - importance of peri-urban and grassland related information, recent peri-urban and grassland mapping and monitoring attempts (with focus on current Urban Atlas, Copernicus HRL imperviousness and grassland service specification) and existing and potential grassland indicators and their related development.

2. General overview and Policy context

2.1 Peri-urban Areas

2.1.1 Policy context

As stated by Fertner et al. (2010) [1] the EU has no explicit competence in spatial development. However, the European ministers responsible for spatial planning have developed a set of territorial policy goals and priority topics during the last decades, documented in the ESDP (European Spatial Development Perspective), the CEMAT (Council of Europe Conference of Ministers responsible for Spatial/Regional Planning) guidelines, and recently in the Territorial and Urban Agendas of the EU.

Furthermore, several EU policies also have an indirect influence on spatial development. E.g. the regulation on rural development policy is explicitly promoting rural-urban links. Besides these spatial relevant sector policies, the EU enforces legislation which is translated into spatial explicit instruments on sub-regional level. E.g. the Habitat and Birds Directive caused the development of Natura 2000 areas. The implementation of Trans-European Networks through funding programmes is another policy having an impact on land-use change and rural-urban relations.

Reference to peri-urban aspects can be explicitly found in current environment and sustainability policies. The following, non-exhaustive, list of policy documents clearly makes reference to the importance of **peri-urban areas**:

- In the preamble of the 7th EAP[1] it is mentioned that "*The Union is densely populated, and over 70 % of its citizens live in urban and peri-urban areas and face specific environmental and climate-related challenges*". Also, priority objective 8 (To enhance the sustainability of the Union's cities) states that "*The Union is densely populated and by 2020, 80 % of its population is likely to live in urban and peri-urban areas. Quality of life will be directly influenced by the state of the urban environment. The environmental impacts of cities also spread well beyond their physical limits, as they rely heavily on peri-urban and rural regions to meet demand for food, energy, space and resources, and to manage waste".* This document also proposes to have policies in place to achieve no net land take by 2050.

- The report from the Commission to the Council on the Urban Agenda for the EU (COM(2017) 657 final)[2] published on the 20th of November makes reference to the 12 priority themes identified in the Pact of Amsterdam which are addressed in the Urban Agenda taking into account a number of cross-cutting issues which reflect some of the important policies of the EU, especially the territorial dimension: "*the need to have a good cooperation between cities and rural areas*". The Urban Agenda promotes the involvement of urban authorities in achieving three key pillars: i) Better Regulation: ii) Better Funding: iii) Better Knowledge (knowledge base and exchange). Regarding the better knowledge pillar the objective is to improve the knowledge base, exchange best practices and knowledge and enhance evidence-based urban policy making.

[1] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1386&from=EN
[2] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0657&from=EN

- The Sustainable Use of Land and Nature-Based Solutions (SUL-NBS) Partnership Action Plan (Draft, July 2018 and Final October 2018) also expressed the fact that "*the governance of urban areas and urban land use planning, do not fall directly within the competences of European Union*." Therefore, the Partnership has operated in absence of a specific and defined European policy making "umbrella". The Partnership discussions highlighted a number of challenges among which the "*limited availability of quality data on spatial development and urban governance, particularly around the impacts of urban sprawl*" and "*issues of sustainable land use in European cities have not been comprehensively addressed in policies at European and, in many cases, national and local levels*". This Partnership calls the attention to the fact that "*There is the recognised need for communicating the challenges of the use of land in urban and peri- urban areas*". As suburbanisation in Europe is increasing, and built-up areas often stretch beyond administrative boundaries to peri-urban areas, there is a need for the better coordination of spatial planning practices within Functional Urban Areas (FUAs).
- The list of proposed actions by the SUL-NBS Partnership (extracted from the Action plan; some of them being closely linked to the work of the EEA on urban sprawl and land take indicators) is the following:

Name of the action	Main Contribution	Action leader
1. INCLUDING LAND TAKE AND SOIL PROPERTIES IN IMPACT ASSESSMENT PROCEDURES	**BETTER REGULATION**	**Bologna and UNIBO**
2. FUNDING AND FINANCING GUIDE FOR BROWNFIELD REDEVELOPMENT	**BETTER FUNDING & KNOWLEDGE**	**Luxembourg**
3. IDENTIFYING AND MANAGING UNDER-USED LAND	**BETTER KNOWLEDGE**	**INCASÒL Government of Catalonia**
4. INDICATORS OF LAND TAKE	**BETTER KNOWLEDGE**	**Bologna and UNIBO**
5. PROMOTING FUA COOPERATION AS A TOOL TO MITIGATE URBAN SPRAWL	**BETTER KNOWLEDGE**	**Poland**
6. BETTER REGULATION TO BOOST NBS AT EU AND LOCAL LEVEL	**BETTER REGULATION**	**Bologna and UNIBO**
7. BETTER FINANCING ON NATURE-BASED SOLUTIONS (7.1 & 7.2)	**BETTER REGULATION & FUNDING**	**Zagreb**
8. AWARENESS RAISING ON NATURE-BASED SOLUTIONS AND URBAN SPRAWL	**BETTER KNOWLEDGE**	**Bologna**
9. DEVELOPING COMMON TARGETS AND INDICATORS	**BETTER KNOWLEDGE**	**Stavanger**

- In the stakeholder meeting that took place at the EEA in the beginning of December, for framing the ESIC[3] 2020 report as input for SoER2020, it was mentioned that cities depend on their hinterland and therefore their interdependencies need to be carefully assessed.
- The briefing from the European Parliamentary Research Service published in January 2016 (Bridging the rural-urban divide[4]) in its Preamble states that "*In today's Europe, the traditional rural-urban dichotomy seems no longer relevant from a territorial development point of view. The boundaries of both rural and urban regions are becoming increasingly blurred, and traditional geographic definitions no longer fully reflect the reality of areas connected by a range of complex socioeconomic linkages. At the European level, statistical methods have been refined to better reflect this complexity and provide a clearer view of the European Union's territory according to a new rural-urban typology. Both types of regions have different assets and resources which can be used in a complementary manner. At the rural/urban interface, however, conflicts can arise in connection to land use, whenever cities spread over what used to be agricultural land… Studies on the nature and extent of urban/rural linkages have identified the key concept of 'functional regions', which are defined by their socio-economic integration rather than by administrative boundaries. (…) The policy framework for 2014-2020 puts even greater emphasis on rural-urban interactions (…)"*. The document also lists EU strategic documents on rural-urban linkages, namely the European Spatial Development Perspective (ESDP), adopted at the informal Council of Ministers responsible for Spatial Planning in Potsdam (May 1999), which underlined for the first time the need for urban-rural partnerships, stressing the importance of balanced spatial development. The Territorial Agenda 2020 (2011), building on the ESDP, acknowledges the diverse links that urban and rural territories throughout Europe can have with each other, ranging from peri-urban to peripheral rural regions.
- In January 2017, the coordinators of the European Parliament's Committee on the Environment, Public Health and Food Safety requested authorisation to draw up an own-initiative implementation report on the 'Implementation of the 7th Environment Action Programme (Decision 1386/2013/EU)[5]. As a result, The European Parliamentary Research Service produced a supportive study that looked at the progress made on the implementation of the 7th EAP on the basis of a stakeholder consultation. Regarding objective 8 the respondents identified a number of understudied areas where evidence was missing namely the fact that "*the interrelations between cities and their hinterland (rural areas) need more attention, especially as regards the identification of (supply and disposal) interdependencies, food and commuter flows*", among others. It was also stated in relation to objective 8 that "*lack of targets makes it hard to measure progress*".

As a result, it can be stated that the European Commission has increased its focus on urban sustainability and the role cities can play in achieving Europe's objectives for a low-carbon, resource-efficient and ecosystems resilient society (EEA, undated).

[3] Environmental Sustainability in Cities
[4] http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573898/EPRS_BRI(2016)573898_EN.pdf
[5] http://www.europarl.europa.eu/RegData/etudes/STUD/2017/610998/EPRS_STU(2017)610998_EN.pdf

2.1.2 Overview – review

The concept of peri-urban areas (PUA), i.e. the interface between urban and rural areas, to be applied in this study is based on a literature study. Based on the state of the art peri-urban research the role of Copernicus (UA) and/or in combination with other spatial data can be defined. In the literature review regarding relevant indicators on basis of UA (and/or other spatial data) a subdivision is being made into 1) indicators relevant for defining PUA and 2) indicators relevant for monitoring policy relevant processes taking place in PUA. In both cases the indicators should use multi-temporal information to monitor changes over time. They should support the analysis of urbanisation trends and the impacts on the hinterland, so that ways can be identified to monitor this process and mitigate its negative impacts.

Several important studies were considered during the literature search on how to define PUA and on how to monitor urban developments on basis of indicators:

- PLUREL (Peri-Urban Land Use RELations) project [2]
- SPIMA (Spatial dynamics and strategic Planning In Metropolitan Areas) project [3]
- Urban Agenda for the EU [4]
- The State of European Cities 2016 [5]
- EEA 2020 report on Environmental Sustainability in Cities [6]
- Cities in Europe. The new OECD-EC definition [7]
- A harmonised definition of cities and rural areas: the new degree of urbanisation [8]
- Similarities and diversity of European cities. A typology tool to support urban sustainability [9]
- Development of indicators by EEA [10, 11, 12, 13]
- Additional literature [14, 15].

The project PLUREL (Peri-Urban Land Use RELations) was most useful as it defined the concept of PUA as the interface between urban areas and rural hinterland. The following figure makes clear what is meant with urban, peri-urban and rural areas or rural hinterland.

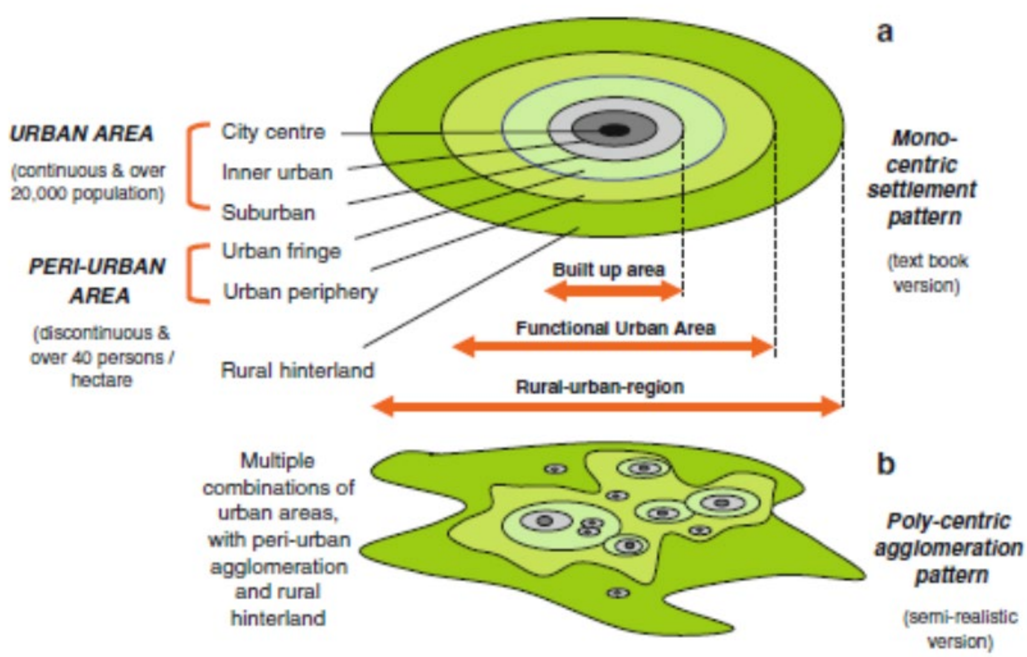

Figure 1 ***PLUREL concept of peri-urban areas and rural-urban regions [2].***

Within the PLUREL project [2], a 'rural-urban region' (RUR) has been defined as the main unit of analysis, with a range of area types shown below as nesting circles (Figure 1).

- *Urban core* – which includes the Central Business District and other civic functions;
- *Inner urban area* – generally higher density built development (built-up areas);
- *Suburban area* – generally lower density contiguous built-up areas that are attached to inner urban areas and where houses are typically not more than 200 metres apart;
- *Urban fringe* – a zone along the edges of the built-up area, which consists of a scattered pattern of lower density settlement areas, urban concentrations at transport hubs and large green open spaces;
- *Urban periphery* – a zone surrounding the main built-up areas with a lower population density, but belonging to the Functional Urban Area as described below. This can include smaller settlements, industrial areas and other urban land uses;
- *Rural hinterland* – rural areas surrounding the peri-urban area, but within the rural-urban region.

The **peri-urban area** includes both the urban fringe and urban periphery. This is defined for the PLUREL project as: *'discontinuous built development containing settlements of each less than 20,000 population, with an average density of at least 40 persons per hectare (averaged over 1km cells)*'.

A number of different concepts related to urban system units with different boundary definitions are in use. Some of these are vague and some are quite specific. The PLUREL project focuses on two classifications:

- Functional Urban Area (FUA): "an urban core and the area around it that is economically integrated with the centre, e.g. the local labour market. Belonging to a commuter catchment area, FUAs represent common local labour and housing markets."
- Rural-urban region (RUR): "spatial clusters of three interrelated regional subsystems – the urban core, the peri-urban surroundings and the rural hinterland. Areas of recreational use, food supply and nature conservation located in predominantly rural areas are also part of the rural-urban region."

For more relevant background information we refer to the working paper produced in this task [16].

An inventarisation within the EIONET NRC's Land Use and Spatial Planning (LUSP) revealed that Italy (ISPRA) used the dispersion index to differentiate within urban areas between natural areas with artificial land cover below 10%, low density urbanized areas and high density urbanized areas (>50%). The Portuguese NRC mentioned that the delimitation and conceptualisation of peri-urban areas is difficult due to their heterogeneity. A list of possible indicators related to urban and peri-urban areas which are currently being exploited at the level of Portugal can be found in Annex 1.

2.2 Grasslands

Sustainable development is the guiding principle of current European environmental policy focusing on green growth of the economy, nature protection and safeguarding of the health and quality of life of people living in the EU. In this context, grassland represents an important and also a complex phenomenon with an enormous diversity and richness across the Europe, providing important both economic and ecological assets playing an important role in landscape and conservation policies.

According to *General Union Environment Action Programme to 2020 (7th EAP)'Living well, within the limits of our planet (COM(2012) 710 final)'* [6] agriculture and forestry together represent 78 % of land cover in the Union and play a major role in maintaining natural resources, especially good quality water and soil as well as biodiversity and diverse cultural landscapes. In addition to the 7th EAP, the *"EU Roadmap to a Resource Efficient Europe" (COM(2011) 571 final)* is a second key component of the EU policy framework relevant to grassland with vision of the sustainable management of resources (specifically mentioning land and soil) and the protection and restoration of biodiversity and ecosystem services. Natural capital, or the global natural assets upon which society depends, is considered as one component of the green economy and encompasses biodiversity, land and soils and is crucial to the delivery of ecosystem services.

Grasslands, non-woody vegetation formations or semi-natural areas are integral part of agricultural landscape and represent one of the most valuable bio-environmental regions with a multi-functional use, not only by its biodiversity, but also for agriculture and recreation, amongst others. Among other land-use types, permanent grassland is generally considered to be the most important from a landscape and nature conservation perspective. Extensively managed permanent grassland provides habitats for many specialized plant and animal species. Grazing has created the landscape and habitat diversity of pastoral farming systems, which remain particularly important for the conservation of biodiversity in many regions [17]. As Akeroyd and Bădărău [18] characterise, Intensive grassland management practices throughout Europe, including increased use of fertilizers and excessive grazing, have damaged and destroyed grassland biodiversity. Thus, intensive agriculture has a high ecological cost, whereas, by comparison, traditionally managed grasslands perform multiple functions in addition to the protection of biodiversity. In addition a list of consequences of responsible management are listed as reduction of soil erosion, storage and purification of rainwater for a gradual supply to local rivers, trapping of carbon that might otherwise contribute to climate change, supports gene-bank of plants of agricultural, medicinal and horticultural value etc. At the same time some of the negative impacts of intensive use of grasslands are mentioned as overgrazing by sheep, scrub invasion, weed and alien species spread and other. Finally is stated, that management of dry grassland for biodiversity conservation does not conflict with farm economic activity and, indeed, will enhance pasture and hay-meadows managed for quality food production.

2.2.1 Biodiversity and habitat perspective

Thus, grasslands are also integral part of agricultural landscape and grassland habitats biodiversity conservation strategies as a part of the **Habitats Directive** (represented in the Annex I of the Habitats Directive on biodiversity through the conservation of natural habitats) and play (together with Forest and Wetlands areas) a crucial role in the **EU Biodiversity Strategy 2020** implementation in general, contributing to the concepts of ecosystem services, green infrastructure or the **High Nature Value farmland (HNV)**. The High Nature Value farming concept was established in the early 1990s and describes those types of farming activity and farmland that, because of their characteristics, can be expected to support high levels of biodiversity or species and habitats of conservation concern (Baldock et al., 1993; Beaufoy et al., 1994; Bignal and McCracken, 2000) in [19]. In many areas of Europe, semi-natural land cover survives only as smaller patches in a more intensively farmed landscape. These patches may still be of sufficient local value for biodiversity conservation to be considered as HNV farmland [19]. Introduction of HNV farmland concept was closely linked to the aim of integrating environmental concerns into Community policies. In

[6] DECISION No 1386/2013/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet' source: http://eur-lex.europa.eu/eli/dec/2013/1386/oj

addition the issue of HNV intended to support the discussion on indicators for the integration of environmental concerns into the Common Agricultural Policy (CAP).

2.2.2 The CAP perspective

As mentioned, grasslands are closely related to **the Common Agricultural Policy (CAP)** of the European Union and object of direct payments and covers a significant part of utilized agricultural area (UUA, up to approx. 40%) [20]. As a cause of technological developments, and commercial pressures to maximise returns and minimise costs, have given rise to a marked intensification of agriculture and grassland, particularly in the last 30 years. Also the CAP has evolved a lot since the beginning and CAP reforms were meant to contribute to overall grassland stabilisation (change of form of the support for farmers, greater emphasis on rural development and biodiversity), two major trends presents progressive liberalization and higher concern for the environment. The decrease of the permanent grassland area (e.g. agronomic pressures to plough up grassland) has several negative environmental consequences including biodiversity loss, Green House Gas (GHG) emissions (with related to LULUCF activities) and soil degradation (**the Soil Thematic Strategy**) [20, 21]. On the contrary conversion of unused arable land in higher altitudes into grassland was in progress e.g. in Central Europe [22].

So called **"greening"** initiative within the 2013 CAP reform brings further innovation and makes the direct payments system more environment-friendly introducing a set of greening measures intended to enable the CAP to be delivering its environmental and climatic objectives. Besides crop diversification and Ecological Focus Area (EFA) the **Maintenance of permanent grassland** proves its significance (limit the decline of permanent grassland, protect grassland from ploughing)[23].

2.2.3 Other environmental perspectives

Straightforward, non-contractual practices that benefit the environment and the climate may include among others permanent maintenance of grasslands or conserving soil carbon & grassland habitats associated with permanent grassland. Further national governments must designate environmentally sensitive permanent grasslands in Natura2000 areas. They may also designate environmentally sensitive permanent grasslands outside such areas. Environmentally valuable grasslands cannot be ploughed or converted and the ratio of permanent grassland to the total agricultural area must be maintained. If not, EU countries are obliged to take action. For instance, farmers who have previously converted permanent grassland to other uses must reverse the conversion, and bans on further conversions are issued[7].

Nowadays, grassland areas are under huge pressure due to multiple socio-economic factors, mentioning increased human population, related urbanization, intensification of agriculture and industry, bio-fuels and related changes in farming practices as well as marginalization of rural areas. Beside, climate change has an important effect on the diversity, extent and distribution of grasslands. Grassland species depend, apart from other environmental conditions, mainly on temperature and precipitation. Changes in temperature and precipitation affect the characteristics of grassland associations, for instance the disappearing or emerging of grasslands, changes in species composition and changes in the production of biomass.

[7] Greening - EC website/Agriculture and Rural Development (https://ec.europa.eu/agriculture/direct-support/greening_en)

Furtherly, the role of **LULUCF activities** in the mitigation of climate change has long been recognized. Mitigation can be achieved through activities in the LULUCF sector that increase the removals of greenhouse gases (GHGs) from the atmosphere or decrease emissions by sources leading to an accumulation of carbon stocks. The rate of build-up of CO2 in the atmosphere can be reduced by taking advantage of the fact that atmospheric CO2 can accumulate as carbon in vegetation and soils in terrestrial ecosystems. Under the United Nations Framework Convention on Climate Change any process, activity or mechanism which removes a greenhouse gas from the atmosphere is referred to as a "sink". Human activities impact terrestrial sinks, through **land use, land-use change and forestry (LULUCF)** activities, consequently, the exchange of CO2 (carbon cycle) between the terrestrial biosphere system and the atmosphere is altered. [31]

Under EU legislation adopted in May 2018, EU Member States have to ensure that greenhouse gas emissions from land use, land use change or forestry are offset by at least an equivalent removal of CO_2 from the atmosphere in the period 2021 to 2030. It is also in line with the Paris Agreement, which points to the critical role of the land use sector in reaching our long-term climate mitigation objectives. Moreover, the scope is extended from only forests today to all land uses (and including wetlands by 2026).

The new rules provide Member States with a framework to incentivise more climate-friendly land use, without imposing new restrictions or red tape on individual actors. This will help farmers to develop climate-smart agriculture. The LULUCF Regulation additionally broadens the **scope of accounting to cover all managed land** within the EU, using more recent benchmarks for performance – and thereby improving accuracy of the accounts. [3232]

In a broader context the grassland may also relate to network of healthy ecosystems. Through the EU's general environmental legislation, working to ensure that European citizen's enjoy cities with clean air and water, avoiding exposure to excessive noise and cities that deal properly with waste, and that protect their nature and biodiversity, and promote better green infrastructure. This **Green infrastructure** is a strategically planned network of natural and semi-natural areas, including grasslands and should be an integral part of spatial planning *(COM(2013) 249 final).*

3. Relevant data sources

3.1 Peri-urban areas

3.1.1 European Settlement map

The European Settlement Map 2016 (also referred as 'EUGHSL2016') represents the percentage of built-up area coverage per spatial unit. The GHSL method uses machine learning techniques in order to understand systematic relations between morphological and textural (pantex) features, extracted from the multispectral and panchromatic (if available) bands, describing the human settlement. It has been produced with GHSL technology by the European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Global Security and Crisis Management Unit. This work has been partly financed by the Directorate General of Regional and Urban Policy, European Commission.

Given that the thematic content of this product is somewhat similar to the imperviousness HRL (HRL IMD), please find a short summary table below, listing the main features and differences between the two datasets. However, this map is not as 'advanced' as HRL IMD (Table 1).

Table 1 ***HRL IMD versus European Settlement Map 2012 (releases in 2016/2017)[8].***

	Imperviousness HRL	**European Settlement Map (ESM), JRC**
Available reference years	2006, 2009, 2012, (2015 under preparation)	2012
Sensor used in production	Copernicus HR imagery at 20m pixel size (mainly IRS and SPOT 5 with Sentinel 2 from 2015 reference year)	SPOT 5 and SPOT 6 data of 2.5m pixel size
Spatial resolution	20m and 100m (10m from 2018 reference year)	2.5m, 10m and 100m
Mapping approach	Supervised classification with extensive manual post-processing. Based on RS imagery only	Automated classification using GHSL method based on machine learning. Uses external vector building footprint datasets (OSM) through data fusion
Mapped features	Percentage sealed (impervious) surface including road infrastructure and all other sealed surfaces	Percentage built up (Settlement only) for 2016 release. Thematic classes for 2017 release.
Status of operationally	Operational product. Currently updated in 3-year cycles	Scientific product (not operational). Update frequency unknown
Data policy	Free and open	Free and open
Change information	2006-2009, 2009-2012 exist. 2012-2015 and 2006-2012 (for CLC comparison) under production	Not available

3.1.2 Population grid

The GEOSTAT grid is a population dataset maintained by Eurostat which reports residential population for each 1 km^2 cell. The grid is based on censuses carried out in most countries in 2011, and largely produced by aggregating point-based population records[9]. Next to the GEOSTAT 2011 grid dataset there is also a GEOSTAT 2006 grid dataset. Data can be downloaded from the Eurostat website[10]

[8] https://land.copernicus.eu/pan-european/GHSL/european-settlement-map/view

[9] Further information available at https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_grids

[10] https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat

3.1.3 HRL Imperviousness

Built-up areas are characterized by the substitution of the original (semi-) natural land cover or water surface with an artificial, often impervious cover. These artificial surfaces are usually maintained over long periods of time. The imperviousness HRL (HRL IMD) captures the spatial distribution of artificially sealed areas, including the level of sealing of the soil per pixel (20*20m). The level of sealed soil (imperviousness degree 1-100%) is produced using an automatic algorithm based on calibrated NDVI.

A series of high resolution imperviousness datasets (new for 2015 and re-processed for all previous years 2006, 2009 and 2012) is available. These time series of imperviousness data contain two products: a status layer for any reference year (e.g. degree of Imperviousness 2015 – IMD2015), as well as imperviousness change layer between reference years (e.g. evolution from 2012 to 2015 – IMC 2012-2015), and a categorical classification of the changes (e.g. IMCC 2012-2015) [24].

Data for 2006 and 2009 were produced in the frame of GMES precursor activities and Geoland2, respectively, and are distributed by EEA in the framework of the Copernicus land monitoring service. The European Settlement Map is a spatial raster dataset that is mapping human settlements in Europe based on SPOT5 and SPOT6 satellite imagery. It is published with two associated data layers.

3.1.4 Urban Atlas

Urban Atlas currently covers 2 reference years (2006 and 2012) and will be extended to 2018 (Framework contract in place; execution only dependent on the future 2018 Very High resolution coverage being procured by ESA for Copernicus land purposes). The Urban Atlas provides Pan-European comparable land use and land cover data for 693 Functional Urban Areas (FUA)[11]. FUA's cover not only the urban centres but also the rural areas around them based on commuting patterns, thus providing the optimal dataset for analysing rural-urban interlinkages [25, 7].

Population estimates by Urban Atlas polygon are tabular data of the residential population at the vector polygon level that can be joined to the Urban Atlas 2012 datasets in a GIS environment. The estimation was done by downscaling, or disaggregating, census population reported at country-specific geometries ('source geometry') to the Urban Atlas land use/land cover polygons ('target geometry'). The downscaling method combined land use/land cover information from Urban Atlas, building densities from the European Settlement Map and census data [25].

Urban Atlas Building Height 2012 is a 10m high resolution raster layer containing height information is generated for core urban areas of selected cities (capitals in EU28 + EFTA) as part of the Urban atlas. Height information is based on IRS-P5 stereo images and derived datasets like the digital surface model, the digital terrain model and the normalized DSM[11].

3.2 Grassland monitoring

Precise, harmonised, pan-European and timely accurate spatial information on grassland distribution is essential to support all above mentioned initiatives and policy strategies and supply them with relevant, accurate and up-to-date relevant data. Better understanding of **amount of grassland areas, their location**

[11] https://land.copernicus.eu/local/urban-atlas

and spatial distribution, their characteristics and qualities and (in future) also evolution of grassland ecosystem is therefore of critical importance and provides background information for the implementation of above mentioned strategies. Grasslands have a multi-functional use, not only by its biodiversity, but also for agriculture and recreation, amongst others. Altogether, 8% of Europe's surface (27 million hectare) is covered by grasslands and even 24% of the Earth's vegetation is covered by grasslands. The economic and scenic values of grasslands are therefore of significant importance.

Copernicus pan-European Land Monitoring Service (coordinated by the European Environment Agency (EEA)) has the ultimate goal to provide high-quality information on the state of environment for policy development, implementation and control demanded by a broad range of European environmental legislation, framed by the 7th Environment Action Programme (EAP).

3.2.1 CORINE and 2nd generation CORINE Land Cover - CLC+

Despite field-based grassland inventories in some countries, consistent harmonized data on European level based on EO data exists only as part of **CORINE Land Cover (LC)**, so in detail not optimal for related indicators for most of the above-mentioned applications. In particular, the main limitation represents coarse minimal mapping unit of 25 ha, and presence of Land Use defined classes as airports or agro-forestry areas, which includes grassland, but in combination with other types of Land Cover with negative or unwanted influence on possible indicator value. Beyond the LC class, no further qualitative information is available. On the other hand CORINE LC represents a well-established service providing consistent information on LC/LU and related changes including grassland classes since 1990.

There were some well-received test activities with the aim to test and set up a detailed specification of possible Pan-European grassland layer done for selected areas within the **geoland2 project** (2013), but until then no European-wide harmonised and consistent data were available to continue, despite of many attempts to collect e.g. data for that purpose. The added value of geoland2 HRL Grassland exercise was the fact, that it provided among grassland identification additional data layers dealing with basic physical or process-oriented properties of the surface (e.g. crown cover density or vegetation dynamics). This targeted additional qualities of identified areas with derived indicator-like features estimating e.g. cover density, intensity of use, mixture with other vegetation elements as trees/shrubs. However it required the use of multi-seasonal data to cover the different phenological dynamics of different vegetation types during the year. Corresponding layers may also serve as possible source of HNV farmland layer enhancement excluding e.g. intensively managed grasslands as described in [26].

Although CLC has become well established and has been successfully used, mainly at the pan-European level, there are a number of deficiencies and limitations that restrict its wider exploitation. This is partly due to the fact that the MMU of CLC (25 ha) is too coarse to capture the fine details of the landscape at local and regional scales, but also to the fact that in some cases more detailed, precise and timely information from national mapping programs are available. Moreover, landscape dynamics that are highly relevant to locally decided but globally effective policy, such as small-scale forest rotation, changes in agricultural practices and urban in-filling, may be missed due to low spatial resolution and / or thematic depth of CLC class definitions.

Given the above issues and the known reporting obligation (especially related to LULUCF commitments), a revised concept for European Land Monitoring is required which both provides improved spatial and thematic performance and builds on the existing heritage. The EEA in conjunction with DG GROW now aims to harmonise and integrate some of the Copernicus Land Monitoring System activities by investigating the concept and technical specifications for a higher performance pan-European mapping product under the banner of "**2nd generation CLC**".

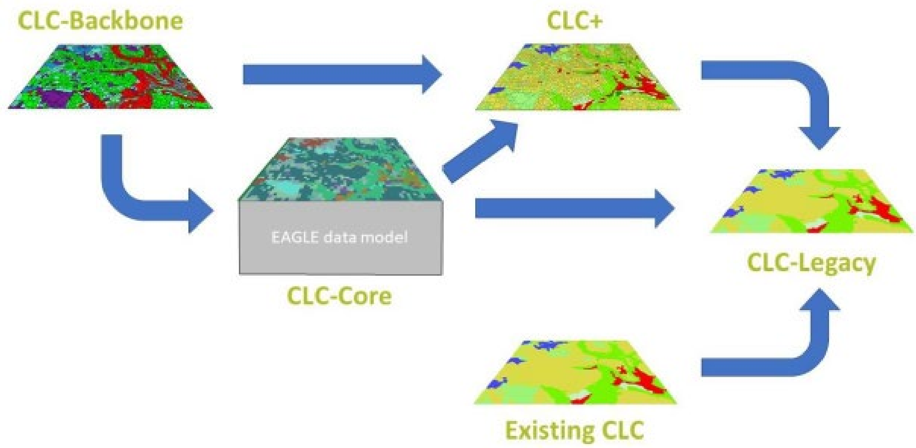

Figure 2 Conceptual design of 2nd generation CLC

The four new elements / products of the conceptual strategy can be summarized as follows to aid understanding of the conceptual design:

1. **CLC-Backbone** is a spatially detailed, large scale inventory in vector format providing a geometric spatial structure attributed with raster data for landscape features with limited, but robust, EO-based land cover thematic detail on which to build other products.

2. **CLC-Core** is a consistent multi-use grid database repository for environmental land monitoring information populated with a broad range of land cover (including but not limited to CLC-Backbone), land use and ancillary data form the CLMS and other sources, forming the information engine to deliver and support tailored thematic information requirements.

3. **CLC+** is the “nominal” end point or final product in the establishment of CLC 2nd generation. It is a derived raster / grid product from the CLC-Core and will be a LULC monitoring product with improved spatial and thematic performance, relative to the current CLC, for reporting and assessment.

4. The final element of the conceptual design, although not strictly a new product, is the ability to continue producing the existing CLC, which may be referred to as **CLC-Legacy** in the future, which already has a well-established and agreed specification.

The conceptual development is still work in progress, although quite advanced already. For some elements there is even a detailed specification finalized (e.g. CLC-Backbone). Below recent specification for raster and vector land cover products are outlined. [33]

Raster dataset (MMU 10x10m)	
Land Cover classes	
1	Sealed (built-up of flat sealed surfaces)
2	Needle-leaved Woodland
3	Broad-leaved Woodland
4	Broad-leaved evergreen Woodland
5	Shrubland
6	Permanent herbaceous land (i.e. grasslands)
7	Periodically herbaceous land (i.e. arable land)
8	Lichens and mosses land
9	Partly vegetated land
10	Non-vegetated land
11	Water
12	Snow and Ice

Figure 3 CLC+ CLC-Backbone land cover classes specs for raster dataset

Vector dataset (MMU 0.5ha)		
	Land Cover classes	
1	Built-up land	1.1 Very high sealing degree (>80%)
		1.2 High sealing degree (50-80%)
2	Needle-leaved Woodland	2.1 Pure Needle-leaved (>75%)
		2.2 Dominantly Needle-leaved (50-75%)
3	Broad-leaved Woodland	3.1 Pure Broad-leaved Woodland (>75%)
		3.1.1 Pure deciduous (>75%)
		3.1.2 Pure evergreen (>75%)
		3.2 Pure Broad-leaved Woodland (>75%)
4	Shrubland	Shrubland
5	Permanent herbaceous land (i.e. grasslands)	5.1 Without trees (=<10%)
		5.2 With few trees (10-30%)
		5.3 With many trees (30-50%)
6	Periodically herbaceous land (i.e. arable land)	Periodically herbaceous land (i.e. arable land)
7	Lichens and mosses land	Lichens and mosses land
8	Partly vegetated land	8.2 Intermediate vegetation cover (30-50%)
		8.1 Low vegetation cover (10-30%)
10	Non-vegetated land	
10	Water	
11	Snow and Ice	

Figure 4 CLC+ CLC-Backbone land cover classes specs for vector dataset

3.2.2 COPERNICUS HRL Grassland

A new **Copernicus product HRL Grassland** is now newly available (from spring 2018) and fully replaces the previous Permanent grassland HRL (2012) based on the updated specification and requirements reflecting the changing focus from agricultural point of view, related to CAP and subsidies linked to production, to rather environmental and biodiversity aspects. In addition, the envisaged repeat cycle (every three or five years) of this Pan-European layer will lead to the derivation of changes between the assessment dates or periods and will enable long term monitoring. Therefore HRL Grassland represents unique opportunity to monitor grassland distribution in Europe and the results will support further development of grassland management policies. Since 2012, five high resolution layers on imperviousness, forest, grassland, wetlands and water are produced for the EEA39 coverage as the part of the Copernicus pan-European component activities, complementing regular CORINE Land Cover (CLC) information updates. Although the HR Layers are designed to primarily support European policy level, they offer much more detailed information than CLC and thus additionally also various national and regional applications can be supported. Furthermore the HR Layers allow users or value added providers to produce downstream products based on user driven specific HRL interpretation or combination with other data sources.

Such HR Grassland layer may serve European-level users (such as EEA and EC DG's) and various national applications with harmonised and validated information on status of valuable grassland areas to fulfil several reporting obligations in the context of sustainable agriculture and Biodiversity 2020 targets (e.g. High Nature Value farmland (HNV), green infrastructure and connectivity of NATURA2000 sites or MAES assessment)) or support further development of grassland management policies. It provides sufficient accuracy (>85%), detailed distribution pattern (raster resolution 20m/100m) and thematic content (all relevant grassland surfaces; specification in [27]) and geographical coverage of all EU39 with outlook for regular update within standard HRL mapping range (3 years) enabling mapping of changes as extension or loss of grassland. Additionally possible derived indicators (as many others defined by EEA related to environment) may be designed to answer key policy questions and to support all phases of environmental policy making, from designing policy frameworks to setting targets, and from policy monitoring and evaluation to communicating to policy-makers and the public[12].

3.2.3 Other grassland related datasets

Some other datasets may also be considered, however they suffer by serious limitations as reduced (non-seamless) coverage as **NATURA2000** or inappropriate thematic content (**1st HRL Grassland** (natural grassland)) not reflecting the requirements. The purely statistical data – namely - **EUROSTAT** database can't be considered as spatially relevant dataset, since it provides information on statistical units only (NUTS3). Similarly other non-EO based data sources with insufficient spatial coverage for our purposes as point based **LUCAS survey**. Nevertheless these sources may still serve as useful data e.g. for validation purposes. Finally, for grassland definition and monitoring also thematically diverse, indirect sources can be utilized. This approach is based on the assumption of the relation of local species to the grassland habitat. As an example the **bird species populations** or the **prime butterfly areas** are considered within the HNV definition [28].

The Land Parcel Identification System (LPIS) related to CAP serves for registration of agricultural land for effective land management purposes. Among arable land and permanent crops LPIS comprises permanent

[12] About EEA indicators source: https://www.eea.europa.eu/data-and-maps/indicators#c0=10&c5=&b_start=0

grasslands too, but covers agriculturally used areas only, not including e.g. grassland within urbanized areas as parks or entirely natural grasslands. Besides, the exact definition of LPIS is missing within the Regulations and thus the LPIS generation approach may vary in different EU countries originating from land blocks or alternatively from cadastral parcels lacking common methodology. Finally the access conditions to the LPIS differ throughout the countries and access constraints are often due to privacy concerns of the data.

Meanwhile the 2013 reform aims to re-target CAP support in favour of farming types addressing environmental targets to stop/reduce biodiversity decline. To improve the agricultural productivity in a sustainable manner the **SEN4CAP** initiative aims at providing to the European and national stakeholders of the CAP validated algorithms, products, workflows and best practices for agriculture monitoring relevant for the management of the CAP based on Sentinel data[13]. Some of the outputs as crop maps may be beneficial in future also for grassland monitoring.

An overview of basic characteristic of most relevant data sources is listed in Table 2.

Table 2 Overview of selected grassland monitoring approaches

	Name	Ref. Year	Mapping Period	Theme	Format	Resolution	MMU	Additional quality	Extent
	Relevant sources								
1	**2nd HRL PanEU Grassland**	2015	3 years	Grassland and non woody vegetation	raster	20/100 m	1ha/20m	GRAVPI, PLOUGH indicators	PanEU
2	**HNV**	2012	(4)	Agriculture / Grassland / Semi-natural	raster	100m	-		PanEU
3	**CLC**	2018	6 years	Landcover / LandUse	vector/ polygon	-	25ha/ 5ha change	Time series from 1990	PanEU
	Limited sources								
4	**Natura2000**	2017		Landcover /LandUse	vector/ polygon	-	0,5ha/10m		PanEU (lim)
5	**geoland2 Grassland HRL**	2006	-	Grassland	raster	60m		Shrub and tree indicator, Grassland density, Cutting,	transect (DE, CZ, AT)

[13] SEN4CAP website - http://esa-sen4cap.org

								ploughing indicator	
6	**1st HRL PanEU Grassland**	2012	-	Natural grassland	raster			replaced by 2ndHRL	PanEU
	Inadequate								
7	**LUCAS**	2018	3 years	Landcover / LandUse	vector/ point	Grid (2x2sqkm)	-	Insitu photography	PanEU
8	**EUROSTAT**	2017	1 year	LandCover / LandUse / Grassland	stat. Data	-	-	-	PanEU

4. Indicators

4.1 Peri-urban areas

4.1.1 Definition of Peri-Urban Areas (PUAs)

The PLUREL project [2] used the combination of land use data and population densities to define the following entities within the rural-urban regions (RURs):

Urban high density areas: CLC class 11 (continuous settlement area), if inside the general urban sub-region. No population density values were applied as threshold for delineation, because high density urban cores are not necessarily inhabited, but also contains business, manufacturing and commercial areas with service and retail workplaces.

Urban low density areas: CLC class 1 (artificial surfaces), excluding CLC 13 (mining) and with population numbers in the respective centres above 20,000 inhabitants.

Peri-urban high density areas**:** defined by a population density greater than 75 inhabitants per km^2 or by CLC class 11 (settlement area) and population numbers above 10,000 inhabitants within the low density regions.

Peri-urban low density areas**:** population density greater than 40 inhabitants per km^2 when located within 300m of urban areas. The density threshold avoids the need for complex rules including or excluding certain land cover classes. The 300m distance criteria assumes a spatial connection between urban core regions and avoids the exclusion of areas separated from urban areas by rivers or small open space corridors.

Rural high density areas: defined by a population density greater than 10 inhabitants per km^2.

Rural low density areas: are defined by a population density greater than 0 inhabitants per km^2. This classification includes all remaining areas which host any population at all, even very little.

These sub-region entities could be grouped in a way that PUAs are seen as the combination of peri-urban high density and low density areas.

4.1.2 Relevant indicators

The peri-urban – the space around urban areas which merges into the rural landscape – is growing rapidly across Europe. There is about 48,000 km^2 of built development in peri-urban areas, almost equal to that in urban areas. But while most urban areas are now slow growing (at 0.5-0.6% per year), built development in peri-urban areas is growing at four times this rate [2].

For monitoring developments in PUAs and between PUAs, UAs and hinterland or characterising the Functional Urban Areas for which UA data is existing the following indicators are relevant:

- Land take [13]

The indicator provides information on the change from agricultural, forestry and semi-natural/natural land, wetlands or water to urban land cover. Currently it is defined on basis of land cover flows based on CLC data [29].

Land take = LCF2 (21+22) + LCF3 (31+32+33+34+35+36+37+38) + LCF13 - part of LCF38. The land cover flows LCF2 and LCF3 (except LCF38)[14] are often seen as the LCFs indicating the development of urban sprawl between different reference years. See Annex 2 for more elaborate definitions of relevant LCFs.

- Land recycling [11]

The indicator provides information on the redevelopment of previously developed land (brownfield) for economic purpose, ecological upgrading of land for the purpose of soft use (e.g. green areas in the urban centres) and renaturalisation of land (bringing it back to nature) by removing existing structures and/or de-sealing surfaces. In the EEA report 31/2016 [11] the following land recycling indicators based on LCF are defined and discussed (see Table 3). Part of the indicators are also developed from UA data.

Table 3 Land recycling indicators based on LCF from CLC and UA data.

Indicator no	Description of indicators
	General indicators
1	'Grey' land recycling and densification (CLC-based)
2	'Grey', 'green' land recycling and densification (Land recycling in its broad sense, CLC-based)
3	'Grey' land recycling and densification (UA-based)
4	'Grey', 'green' land recycling and densification (Land recycling in its broad sense, UA-based)
Land recycling components	
5	Densification
6	'Grey' land recycling
7	'Green' land recycling
Land recycling components related to urban land management	
8	Densification related to urban land management
9	'Grey' land recycling related to urban land management
10	'Green' land recycling related to urban land management
Land recycling components related to land take	
11	Densification related to land take
12	'Grey' land recycling related to land take
13	'Green' land recycling related to land take

- Soil sealing or imperviousness[15]

The covering of the soil surface with impervious materials as a result of urban development and infrastructure development. The imperviousness indicator or LSI2 indicator is defined as the yearly average imperviousness change between two reference years, as measured by imperviousness change products. The intensity of land take is the proportion of the total built-up surface area that is sealed. See 3.1.3 for more information on the HRL Imperviousness.

- Landscape fragmentation
    - Effective mesh density [10]

The study on effective mesh density quantifies the degree of landscape fragmentation caused by transportation infrastructure and built-up areas. A lower effective mesh size means that the probability

[14] LCF2 is urban residential sprawl; LCF 3 is sprawl of economic sites and infrastructure; LCF13 is development of green urban areas over previously undeveloped land; part of LCF38 is conversion of sport and leisure facilities from previously developed land

[15] https://www.eea.europa.eu/data-and-maps/indicators/imperviousness-change-1

that two points will be connected is lower due to more barriers in the landscape. A low effective mesh size means a higher degree of landscape fragmentation. The degree of landscape fragmentation influences biodiversity and ecological processes and is therefore relevant in regional planning.

- Urban-to-rural gradients analysis [14]

The study by Wadduwage et al. (2017) presents the following four metrics which helps to identify zones of landscape fragmentation:

- Percentage of Land (PLAND) i.e. the proportion of the total area occupied by a particular land-use class.
- Mean Parcel Size (MPS) i.e. measurement of land-use diversity in a cell determined by the distribution of the proportional abundance of different land-use types (parcel richness) extensively.
- Parcel Density (PD) i.e. the average area of all land parcels in the landscape
- Modified Simpson's Diversity Index (MSDI) i.e. the number of land parcels per 100ha.

The percentage of each land-use class in each cell (PLAND) provides data on compositional changes in land use along the gradients. MPS and PD are measurements of key spatial features along the transects. MSDI is a measure of the proportional abundance of land-scape classes in each cell, and is an indicator of land-use diversity.

- Urban sprawl - WUP indicator [12]

The Weighted Urban Proliferation (WUP) is an index to quantify urban sprawl. It is based on the following definition of urban sprawl: "the more area built over (amount of built-up area) and the more dispersed this built-up area in the landscape (spatial configuration), and the higher the uptake of built-up area per inhabitant/jobs (lower utilization intensity, the higher the degree of urban sprawl in the given landscape".

The WUP has three components that correspond to the three dimensions included in the definition of urban sprawl. These dimensions are:

- the percentage of built-up area (PBA)
- the spatial distribution of built-up areas (dispersion, DIS)
- the reciprocal of utilisation density (UD), measuring the number of people working or living in a built-up area (land used per inhabitant or workplace, LUP)

It should be considered that most of the above mentioned indicators are developed and applied on CLC data. However, no major obstacles are foreseen to apply the indicators on UA data.

More extended descriptions of the indicators can be found in the mentioned literature and in the working paper produced in this task [16].

4.2 Grassland

Grassland related indicators may be considered as a subset of a larger group of agri-environmental indicators and are focused on the development of an environmental measuring system to support related policies. In general according to [34] and [353535] indicators should help and support decision makers in the process of assessment of impacts degrading the environment, future sources of danger and for developing sustainable land use systems, help to follow processes related to environment, identify changes in environmental and agricultural practices, help to target programmes that address agri-environmental patterns and understand the linkages between agricultural practices and the environment. Indicators are thus understood as parameters or values derived from parameters, which provide information associated to the above related events. Indicators also contribute to understanding and monitoring of such complex phenomenon in a comprehensive way by reducing the number of measurements and parameters representing the situation. This understanding is based on OECD core indicator definition and was well elaborated already within the IRENA initiative described in [34] and [35]. Among others the demands on indicators should target some of the key attributes such as policy relevancy, analytical soundness, responsiveness to changes and trends, summarizing environmental impacts and must be measurable and controllable at reasonable costs. Indicators then serve as a tool for environmental reporting, international comparison in a harmonised way and support the evaluation of progress in the achievement of goals. [34]

Grassland HRL layer provides (Annex 7) three data layers indicating direct data on grassland or grass covered surface. These include the actual area covered by grassy and non-woody vegetation, the spatial spread of grassland by means of raster dataset with 20 m resolution and additionally the backward tilling activity is available for actually identified grasslands where management activity is present in recent past, disrupting grassland permanency. Regarding its thematic content the HRL grassland layer is suited primarily to contribute to indicator domains related to: agriculture and farming practice, biodiversity, and land use/landscape composition. Secondary it may support the domains of climate change (carbon stock), urban environmental quality (green infrastructure) and soil degradation and erosion risk.

According to relevance of the HRL Grassland specification possible indicators differentiation may be outlined as:

4.2.1 Status and change indicators

- represents basic measures directly derived from HRL Grassland data layer

- Total grassland area (in ha/km2)
- Proportion of grassland on agricultural land (as %)

4.2.2 High Nature Value (HNV)

- The High Nature Value farming concept was established in the early 1990s and describes those types of farming activity and farmland that, because of their characteristics, can be expected to support high levels of biodiversity or species and habitats of conservation concern (Baldock et al., 1993; Beaufoy et al., 1994; Bignal and McCracken, 2000) in [19] In many areas of Europe, semi-natural land cover survives only as smaller patches in a more intensively farmed landscape. These patches may still be of sufficient local value for biodiversity conservation to be considered as HNV farmland. [19] Introduction of HNV farmland concept was closely linked to the aim of integrating environmental concerns into Community policies. In addition the issue of HNV intended to support the discussion on indicators for the integration of environmental concerns into the Common Agricultural Policy (CAP). In general the indicators may help to monitor and assess agro-environmental policies, provide contextual information on rural development, describe and identify environmental issues related to European agriculture and to help to understand the linkages between agricultural practices and the environment. [28] The final report on HNV Indicator further elaborates on conceptual framework as well as the detailed definition of HNV concept, methodology and source types of potential area based on origin in Land Cover (CLC), farming system approach or species approach with several examples of HNV distribution over Europe. [28]

- relevant HRL inputs:
  - Total grassland area (in ha/km2), supplement of CORINE based LC
  - (location, spatial distribution at significantly better resolution, can support minimum/maximum extent of potential HNV location)
  - - deals with coarse CORINE MMU (heterogeneous areas)
  - - HRL does not provide/improve any kind of management system related information (intensity of use), no link to real quality of possible HNV area
  - PLOUGH - identification of disturbed HNV farmland (tilling)
  - extensification/loss of grassland (when change product available)
  - HNV - Type 1 - farmland with a high proportion of semi-natural vegetation identification
  - To confirm farming system approach - e.g. HNV off-farm grazing systems, HNV permanent grassland systems

- The HNV impact Indicator aims to assess changes in the extent and condition of HNV farming and forestry in relation to a baseline established at the start of the programming period. There is no single indicator or data source appropriate for this purpose. The Application of the HNV Impact Indicator document [19] provides extensive description of framework development for possible evaluation of HNV and related indicators setting up Common Monitoring and Evaluation Framework (CMEF), an EU-wide suite of indicators all in accordance with the strategic, programming approach of Pillar 2 of the CAP. As described, rural development programmes and individual measures are monitored and evaluated to assess the extent to which programme objectives are being achieved. These comprises both quantitative (provide information on changes in the extent of HNV farming and forestry or other quantitative measurements, in relation to a baseline) and qualitative indicators (provide information on changes in condition, such as trends in specific farming practices) [19] and rely on grassland and semi-natural area presence.
  - relevant HRL inputs:

    identification of semi-natural grassland

4.2.3 Agro-environmental indicators

- ***PAIS - Proposal on Agri-Environmental Indicators***

    - Landscape related indicator set proposal including grassland monitoring indicators as stock and change of grassland, natural landscape and related diversity indices [36]

        - relevant HRL inputs:

            - Landscape composition - stock and change of grasslands
            - Landscape composition - stock and change of semi-natural land
            - Natural landscape features - extensive managed grassland areas
            - Main agricultural LU type - grassland

- ***IRENA***

    - The IRENA operation (Indicator Reporting on the Integration of Environmental Concerns into Agriculture Policy) is a joint exercise between several Commission directorates-generals (DG Agriculture and Rural Development, DG Environment, Eurostat and DG Joint Research Centre, and the European Environment Agency (EEA) to develop agri-environmental indicators (AEI) for monitoring the integration of environmental concerns into the common agricultural policy (CAP) in the European Union [37] A set of indicators has been identified in a communication from the Commission to the Council and European Parliament (COM(2000) 20), and this set, and the statistics and other information needed to realise the indicators, is the subject of a further Commission communication (COM(2001) 144). [38] Several indicators are considered related to e.g. land use change, intensification/extensification, specialisation/diversification and other. Permanent grassland (and related management) represents one of the key items in farming practices domain. [37][39]

        - relevant HRL inputs:

            - Land Use change related to agriculture (supplement of CORINE)
            - HNV farmland areas (supplement of CORINE)
            - Soil quality
            - Landscape state
            - Impact on landscape diversity

- ***MAES***
  - Action 5 of the EU Biodiversity Strategy to 2020 requires member states to Map and Assess the state of Ecosystems and their Services (MAES). The [40] report provide guidance for mapping and assessment of urban ecosystems. It includes an indicator framework to assess the condition such ecosystems and urban environment.
    - relevant HRL inputs:
      - urban related low-vegetation patterns as lawns, herbs
- ***KIP-INCA***
  - Establishing a sound method of natural capital accounting with a strong focus on ecosystems and their services is a key objective of the 7th Environment Action Programme (EAP) and of the EU Biodiversity Strategy. Integrated system for Natural Capital and ecosystem services Accounting (KIP INCA), where EEA together with the European Commission directorates general for Environment, Research and Innovation, and the Joint Research Centre, Eurostat, are partners in the Environmental Knowledge Community (EKC) are aiming to set up shared infrastructure among the different actors to simplify and foster cooperation toward a jointly production of the Natural Capital accounts at EU level.
  - The integrated accounting system is a shared platform of linked data sets and tools for covering geo-referenced information on ecosystems and their services, allowing to assess their economic importance and value, and which can be linked to the standard national accounts. It also includes layers of data based on earth observation (e.g. on land cover), (further statistical collections, environmental monitoring data, models which quantify ecosystem services such as water, air and soil regulation etc. The shared platform will seek to integrate monetary and non-monetary valuation of ecosystems and their services. Benefits of such a natural capital accounting covers monitoring of the status of natural capital; Show interdependencies and 'trade-offs' between natural capital and economic activities; Indicate specific ecosystems or aspects of biodiversity under particular threat; Allow measurement of the changes in these elements over time; Monitor the effectiveness of various policies; Provide input to economic policies by showing the

dependency of economic sectors on natural capital; Supports the development of macro-indicators for natural capital or the monetary valuation of natural capital. [41][42][43]

- relevant HRL inputs:
    - extensification/loss of grassland (when change product available)

4.2.4 Other related indicators

- ***SEN4CAP***
    - A Grassland mowing product - in brief - related to grassland which is excluded from diversification; permanent grassland identification, by complementing the information about the total area of permanent grassland; catch crop and EFA - nitrogen-fixing crop in relation to annual grasslands or to the consideration of any permanent (multi-year) grassland and other. [44]
        - relevant HRL inputs:
            - grassland location, spatial distribution

5. Indicator development

5.1 Peri-urban areas

5.1.1 Population estimation for FUA based on Copernicus and Eurostat data

Urban and peri-urban monitoring systems are needed to support spatial planning for optimal and sustainable development. Important in the development of such systems is the definition of urban and peri-urban areas on basis of population density estimates.

One of the main objectives of this task was to develop a methodology to define the spatial extend of peri-urban areas (PUAs), i.e. to separate urban and peri-urban areas from each other in Europe's FUAs, by utilizing Urban Atlas (UA) data, High Resolution Imperviousness data (HRL IMD), European Settlement Map data (ESM) made available through the Copernicus Land programme. Also population data made available through EUROSTAT were used to estimate population density estimates per UA polygon. See 3.1 for detailed information on the data used.

The first step in this approach was to develop a method that will provide population estimates for each UA polygon by using EUROSTAT's population data. Taking stock from the JRC report [25] on mapping population densities a methodology was being developed. Different population estimates for 2006 as well as 2012 were produced on basis of a) HRL IMD 2006/2012, b) ESM 2012 (release 2016) and c) 3D information. Results were compared with each other and with the estimates produced by the JRC [25] to get a feeling on the (dis)similarities between the different population estimates.

Large differences exist between newly produced estimates and the results obtained by the JRC. The differences are sometimes incomprehensible. Main difference in both approaches is the use of continuous estimates (new approach) and discrete approach (JRC method). However, the differences are far too big to be caused by this issue. Possible sources for these difference are presented in Table 4. Differences between JRC results and ESM as well as IMD estimates obtained during this work remain unresolved. At the end of the project it became clear that the main reason for the discrepancy seems to have their origin in changed UA2012 geometries. UA2012 has been updated in between the production of the JRC estimates and the estimates produced by us.

Table 4 ***Possible sources for differences between population density estimates [30].***

#	Source for differences	Description	Reasons for or against
1	JRC results must be joined to a different geometry	Incomprehensible JRC examples lead to the conjecture that a different target geometry (or possibly different identifiers) leads to the described results	**Pro:** • Given the magnitude of differences and the fact that for extreme JRC cases population grids from 2006 and 2012 have less population estimates then the single UA polygon under consideration, this option might be reasonable.

			Contra: • It is not clear which UA geometry must be used instead of the UA 2012 data. A joining to the UA 2006 data leads to similar problems.
2	Discrete vs continuous approach	Difference in the modelling approach lead to problems when comparing the data	**Pro:** • This option is a known difference and should lead to differences. **Contra:** • The differences are too big and this option cannot explain the unreasonable examples mentioned earlier.
3	Different population source data	The temporal extent of the data ranges from 2006 to 2012, for modelling the population grid 2012 is used	**Pro:** • Different population input must lead to different results. **Contra:** • Extreme JRC estimations are neither supported by the EUROSTAT population grid 2006 nor by the 2012 population data.
4	Wrong workflow	The workflow used in this approach might differ from the one used by the JRC in unreported details.	**Pro:** • Different workflows lead to different results **Contra:** • Different workflows cannot explain why JRC extreme cases are incomprehensible on their own. • Differences are too big to stem from small differences in GIS operations. As the workflow from [25] was followed closely, this option seems to be unlikely

Leaving the differences between the estimates obtained during this study and the estimates available from the JRC aside, it was found that the dasymetric mapping based on ESM or HRL IMD data leads to reasonable and comprehensible results.

When using ESM or HRL IMD data for dasymetric mapping, one models population distribution on basis of 2D information. The inclusion of 3D data (building heights) for the calculation of population estimates leads to more detailed results. The investigation of population cells with a mixture of polygons with high rise buildings and small to medium height buildings showed that the differences between population estimates based on 2D and 3D modelling approaches are non-negligible. Using 2D information is often seen as an oversimplification which is why the use of 3D information might be desirable. However, at the time of writing this report data availability of 3D information is restricted to core cities of European capitals. This limitation implies that Urban Atlas data cannot be used to its full potential/extent when including 3D data for population estimation.

Based on the population estimates from Urban Atlas and HRL IMD 2006/2012 data population trends between 2006 and 2012 were investigated. It was found that use of down-scaled estimates for population trend calculation leads to detailed pictures of population gain and losses within the FUA.

For more information on the development of an indicator to define PUAs and the results obtained we refer to the report "Population Estimation for European Metropolitan Regions based on Copernicus and EUROSTAT data." [30] produced within this task.

The combination of the population densities downscaled to UA polygons based on the methodology described in detail in [30] and/or produced by JRC with the 6 sub-region entities (urban high and low density areas; peri-urban high and low density areas; rural high and low density areas) as defined in PLUREL [2] shows potential to define PUAs and their dynamics over time. For mapping PUAs and their dynamics the following steps should be considered:

- population data need to be added/downscaled to the UA polygons (several reference years)
- application of PLUREL typology to UA (conversion of UA to CLC classes)
- spatial configuration of polygons should be aligned and prevent "noise", e.g. small isolated peri-urban patches/polygons surrounded by urban patches/polygons

Figure 5 gives a first preliminary impression of how the delineation of urban, peri-urban and rural areas within the FUA of Rotterdam may look like.

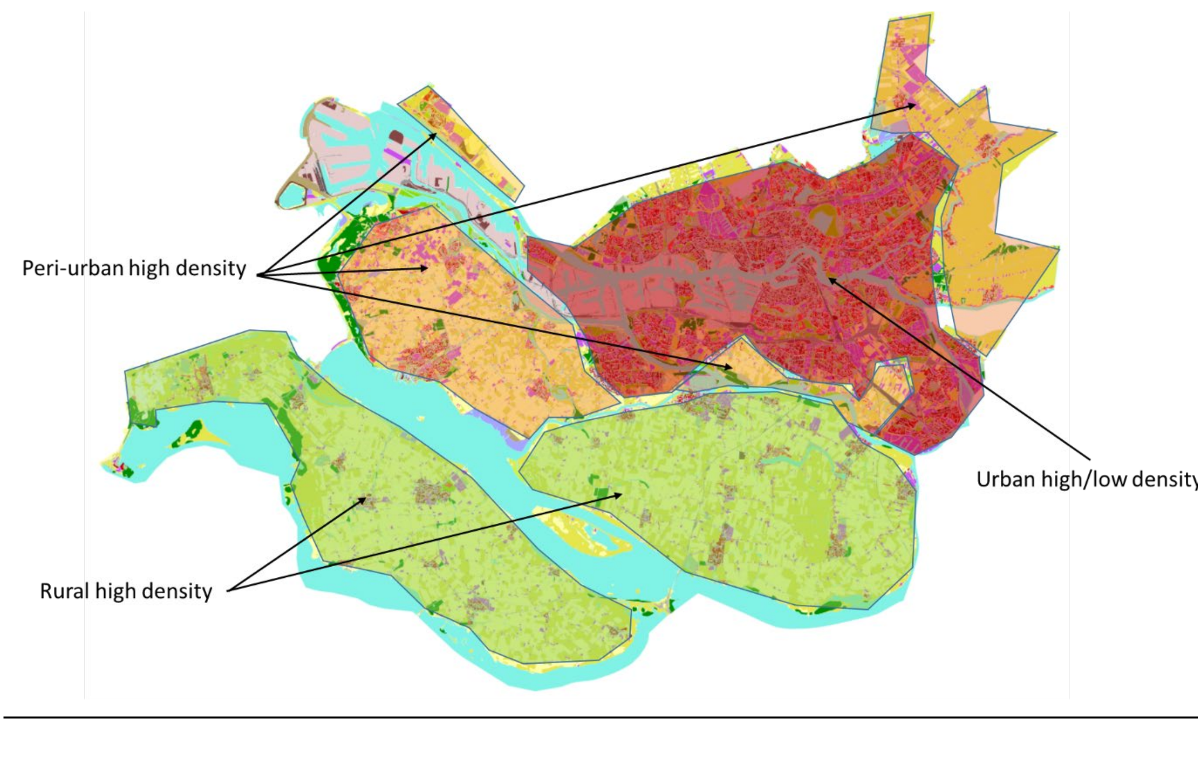

Figure 5 Functional Urban Area of Rotterdam subdivided into clustered PLUREL entities of urban (high and low density), peri-urban (high and low density) and rural (high and low density).

5.1.2 Indicators for monitoring urban development

Table 5 presents an overview of possible indicators to monitor urban development on basis of Copernicus data. Short descriptions, data needs and pro’s and con’s are provided.

Table 5 Overview of possible indicators to monitor urban development on basis of UA data.

Indicator	Methodology	Data needs [1]				Pro's	Con's
		UA 2006, 2012, 2018	IMD 2006, 2009, 2012, 2015, 2018	population data 2006, 2011	Other		
Land take	LCF[2, 3]	X				- apply existing methodology on UA data	- not innovative
Land recycling	LCF[2, 3]	X				- partly already implemented for UA - apply existing methodology on UA data	- not innovative
Soil sealing	imperviousness change[3]		X			- well established methodology - long time series	- only % of imperviousness - changes in % sealing difficult to interpret - aggregation of information
Landscape fragmentation	effective mesh density[3]	X			X	- no population data needed	- especially developed for environmental monitoring
	urban to rural gradient analysis[3]	X				- no population data needed - apply existing methodology on UA data	- meaning of metrics and relationships between metrics needs to be assessed to relate them to urbanisation - robustness of methods needs to be tested
Urban sprawl	WUP indicator[3]		X	X		- well developed and tested for EU - status and change - apply existing methodology on UA data	- availability of harmonised population data over time is limited - limitations like in PUA indicator
PUA	- dasymetric mapping[4] - PLUREL[5]	X		X		- known (experienced) methodology	- overestimation population in city centres, underestimation outside cities - spatial configuration rules for PUA i.e. mapping of PUA to be developed - small transition polygons should be excluded from modelling - availability of harmonised population data over time is limited and should be used with care to deal with unreasonable population losses/gains

Note: [1]data needed for different reference years; UA and IMD for 2018 in production; [2]methodology as defined in land accounting report [29]; [3]see section 4.1.2 for more details; [4]see section 5.1.1 for more details ; [5]methodology as defined in PLUREL project [2]

Table 5 shows indicators possibly relevant to monitor urban dynamics in their readiness to use. Most indicators are developed on basis of CLC data. However, they can in our view be easily converted and applied to UA data.

5.1.3 Characterisation of FUAs on basis of Land Cover Flows

Two different case studies took place to get an idea of relevant process taking place between 2006 and 2012:

- Comparison of Warszawa, Madrid and Munich on basis of LCF between 2006-2012
- Hierarchical cluster analysis on basis of LCFs between 2006-2012 of all Functional Urban Areas (FUAs) in Poland, Germany and Spain

Comparison
The following three cities were selected: Warszawa, Madrid and Munich. The selection of cities was based on metropolitan region data from Eurostat 2006 -> 2012 change data (http://ec.europa.eu/eurostat/web/metropolitan-regions/data/database). The ranking in size and growth per country was used to selected cities (Munich 3rd in size, 11th in growth; Warszawa 1st in size; 3rd in growth; Madrid 1st in size, 7th in growth). As the objective of the case study is to have an idea of different processes taking place in cities, cities were selected in countries where we suppose that city dynamics are different from each other.

Warszawa is characterised with **'Urban diffuse residential sprawl'** as most prominent land cover flow (lcf22 = 35.4%) (see Table 6), which is in contrary to the other two cities that have "Recycling of developed urban land' as most prominent land process. However, within LCF1 the lcf11 'Urban development/infilling' is with 9.1% important compared to the other cities. LCF3 – Sprawl of economic sites and infrastructure are of less importance compared to Madrid and Munich, 35.4% versus 54.3% respectively 53.6%. Main land process within LCF3 is 'Construction' (lcf37) with 16.7%. 'Sprawl of industrial & commercial sites' (9.5%) and 'Sprawl of mines and quarrying areas' (6.6%) are also important processes in Warszawa. The other land cover flows LCF5, LCF7, LCF8 and LCF9 are far less important. Remarkable for Warszawa is the relatively high percentage of 'Semi-natural creation' (lcf911) compared to the other cities. **'Water bodies creation'** (lcf81) is occupying in Warszawa and Munich around 2%.

In Munich the **'Recycling of developed urban land' (lcf12)** is the most important process. The "Urban diffuse residential sprawl' (lcf22) with 10.4% is far less important than in the case of Warszawa (Table 6). Next to the already mentioned process of 'Recycling of developed urban land' with 21.2%, the processes of 'Construction', **'Sprawl of industrial & commercial sites'** and 'Sprawl of mines and quarrying areas' are like in Warszawa important with 14.6%, 18.8% and 10.6%. The process of urban residential sprawl is like in Madrid far less important than in Warszawa. In Munich the **'Conversion from developed areas into agriculture'** (lcf54) with 4.1% and the **'Forest creation, afforestation'** (lcf74) with 2.9% are compared to the other two cities important processes.

Madrid looks like the city of Munich. Most important process is 'Recycling of developed urban land' with 28.9% (Table 6). Also the LCF3 – Sprawl of economic sites and infrastructure is very important like in Munich. However, within this main LCF the **'Construction'** process is by far the largest process (24.8%). In contrary to the other cities lcf13 **'Development of green urban areas'** with 5.5% is important. The other land cover flows LCF5, LCF7, LCF8 and LCF9 are of no importance compared to Warszawa and Munich.

Table 6 LCFs (% of sum of all lcf's) for the cities of Warszawa, Madrid and Munich for the period 2006-2012 based on UA data.

	Warszawa		Madrid		Munich	
lcf11	9.1%		2.1%		2.9%	
lcf12	13.2%		**28.9%**		**21.2%**	
lcf13	0.3%	22.6%	5.5%	36.4%	1.3%	25.4%
lcf21	0.8%		0.8%		0.2%	
lcf22	**35.4%**	**36.2%**	6.3%	7.1%	10.4%	10.6%
lcf31	9.5%		9.6%		18.8%	
lcf32	1.7%		4.2%		6.2%	
lcf33	0.0%		0.0%		0.1%	
lcf34	0.0%		0.3%		0.1%	
lcf35	6.6%		13.3%		10.6%	
lcf36	0.0%		0.0%		0.0%	
lcf37	16.7%		24.8%		14.6%	
lcf38	0.9%	35.4%	2.1%	**54.3%**	3.2%	**53.6%**
lcf51	0.7%		0.0%		0.8%	
lcf53	0.2%		0.0%		0.2%	
lcf54	1.0%	1.9%	0.8%	0.8%	4.1%	5.1%
lcf72	0.0%		0.0%		2.9%	
lcf74	0.0%	0.0%	0.0%	0.0%	0.1%	2.9%
lcf81	1.8%	1.8%	1.0%	1.0%	2.3%	2.3%
lcf911	1.7%		0.4%		0.1%	
lcf99	0.4%	2.1%	0.0%	0.4%	0.0%	0.1%

- For explanation of the LCFs we refer to Annex 2

Hierarchical clustering

Germany, Poland and Spain were selected as countries to analyse the land cover flows based on Urban Atlas (UA) 2006-2012 data. The main objective was to see if similarities between cities (91 in total) can be discovered on basis of the land cover flows that took place. So if there exist groups of cities with more or less the same land cover/land use dynamics. Such a characterization of cities could be used in a later stage to see if these groups of similar cities can be linked to policies that were implemented.

A hierarchical cluster analysis was chosen to identify relatively homogeneous groups of cities. For more detail on the methodology we refer to Annex 3.

Figure 6 shows the diversity within each land cover flow between the cities. The land cover flows in this figure are normalised on basis of the total area occupied by the city to show the relative importance of the land cover flows within a city. Most important land cover flows are lcf12, lcf22, lcf31, lcf35 and lcf37. An intermediate position is for the land cover flows lcf11, lcf13, lcf32, lcf38, lcf54, lcf81. The land cover flows lcf21, lcf33, lcf34, lcf36, lcf51, lcf53, lcf72, lcf74, lcf911, lcf99 are of minor importance. In Annex 4 the land cover flows for cites in Germany, Poland and Spain on basis of Urban Atlas data (ha) are presented.

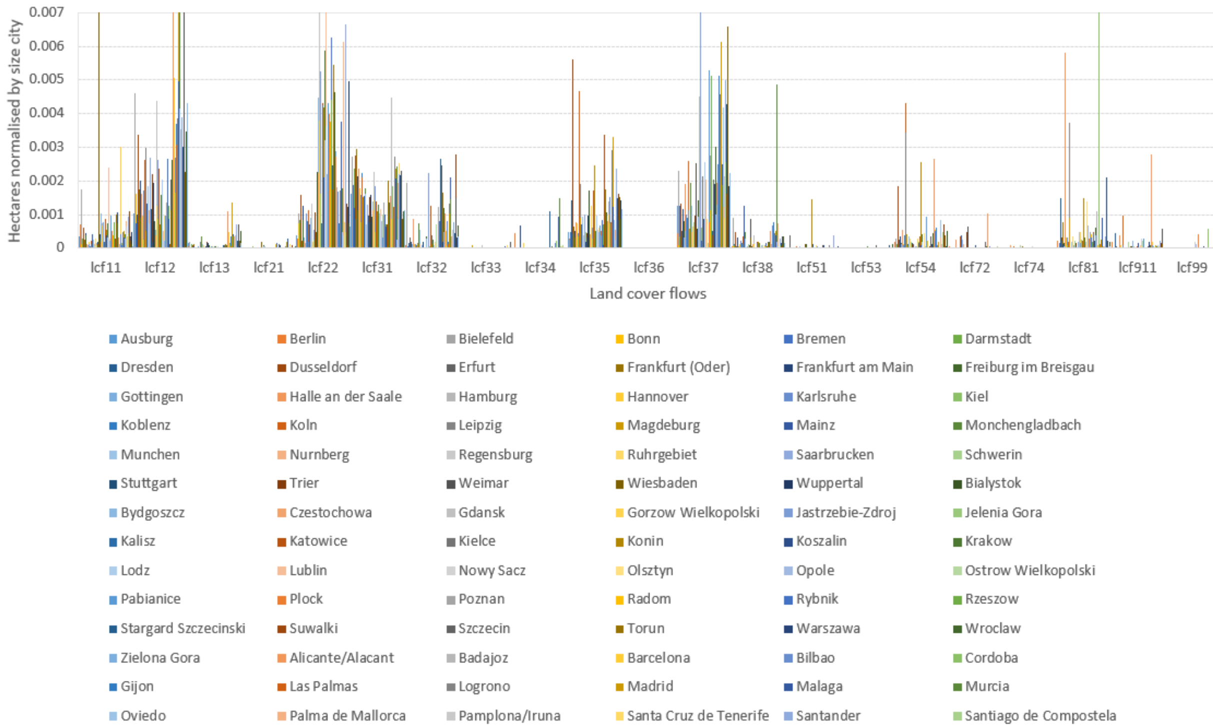

Figure 6 *The area occupied by the 21 different land cover flows for the 91 cities (normalised).*

The clustering of all 91 cities into 10 groups resulted in a cluster dendrogram showing the cities that look similar to each other on basis of the land cover flows present in those cities during the 2006-2012 period (see Annex 5). The clusters are not of the same size as can be seen in Table 7. Cluster 1, 2, 3 and 7 are relatively large clusters with 15 or more cities in each cluster. In those 4 clusters 74 cities out of the 91 are grouped. All other 6 clusters are relatively small having 5 or less cities in it.

Table 7 *Number of cities per country divided over the 10 different clusters.*

Clusters	Dominant LCFs		No. Cities	Germany	Spain	Poland
1	lcf31, lcf12, lcf37	Sprawl of economic sites, recycling, construction	19	17	2	0
2	lcf22, lcf31, lcf12, lcf37	Urban diffuse residential sprawl, sprawl econ. sites, recycling	21	11	0	10
3	lcf37, lcf12	Sprawl of economic sites: construction, recycling	15	1	14	0
4	lcf35	Sprawl of economic sites: mines	2	2	0	0
5	lcf81	Water bodies creation and management	3	2	1	0
6	lcf11	Urban development/infilling	2	2	0	0
7	lcf22	Urban diffuse residential sprawl	19	2	17	0
8	lcf22, lcf37	Urban diffuse residential sprawl, construction	5	0	1	4
9	lcf22	Urban diffuse resisdential sprawl	1	0	0	1
10	lcf12	Recycling of developed urban land	4	0	4	0
			91	37	39	15

From the dendrogam it can be easily seen that clusters 8 and 9 and clusters 1 and 2 look quite similar as they are separated at low height/level. As example in Annex 5 the grouping of cities is presented for only three clusters (combining clusters 1 and 2; clusters 7, 8 and 9; clusters 3, 4, 5, 6 and 10). These clusters are separated at a high level/height in the dendrogram and the cities belonging to one of these main clusters are most distinct from each other. An elaborated characterisation of the clusters is presented in Annex 6. Table 7 gives a short summary of these descriptions. Most of the clusters are dominated by cities from one country. Cluster 4, 6, 9 and 10 having only cities included from Germany, Poland respectively Spain. Cluster 1 is dominated by German cities (17 out of 19), cluster 3 is dominated by Spanish cities (14 out of 15), cluster 7 is dominated by Spanish cities (17 out of 19) and cluster 8 is dominated by Polish cities (4 out of 5). Cluster 2 is the most diverse/balanced cluster in the sense that 11 cities are from Germany and 10 cities from Poland. Cluster 5 is diverse in the sense that 2 cities are situated in Germany and one in Spain. No clusters exist with cities from all three countries.

5.2 Grassland

Indicators for grassland monitoring present a complex topic. As seen from the overview in chapter 4.2 grassland monitoring can be considered ordinarily as a part of broader group of agri-environmental indicators, rather than standalone figure.

In general two main groups can be differentiated, presenting basic **total area of area covered by grassy vegetation** and consecutive **change in time** (Status and change indicators), however different thematic definition(s) of various grassland concepts may be a limitation. Secondly, indicators developed within wider frame, where grassland represents only part of several inputs (**Complex indicators**). In such cases HRL can be rather considered as a spatially homogeneous and qualitatively improved replacement of other data sources as CORINE LC.

5.2.1 Status and change indicators

Status and change indicators gives an overview of quantitative and spatial information about grassland extent and can be considered as standard and trivial. The harmonised Europe-wide extent and unrivalled spatial resolution of HRL Grassland layer is the main advantage. The primary layer contains binary mask of grassy and non woody vegetation. No further qualitative attributes related to grassland management or grassland type are available from HRL Grassland. The dataset contains further expert layers as PLOUGHING INDICATOR, but its potential is limited. This is mainly due to spatially disparate availability of historical EO data, causing inhomogeneity of this layer).

Indicator related to total grassland area

- The total sum of area of grassland (or possibly non woody vegetation) [sq m]
- Spatial distribution at high resolution (raster based, 20m/100m)

Proportion of grassland (e.g. to agricultural land)

- Share of grassland in total area [%]
- Share of grassland in agricultural area (CLC or UAA) [%]

- Share of grassland in complex classes of CLC (like 243)

Change of grassland status in time (HRL Grassland – no change layer yet, but 3 years update frequency expected)

- Change of total sum of grassland area
    - Grassland extensification/loss of grassland [m^2, %]
- Change of grassland share
    - Relative intensity of change (rate of accrual/drop) [%]
    - Share of changed area in total not change grassland area [%]

Fragmentation related indicator (as a result of transforming large grassland habitat patches into smaller, more isolated fragments of grassland habitat). Fragmenting elements may contain elements of specified Land Cover classes (e.g. urban fabric or water bodies), transport network elements (roads, railroads) and elevation barriers.

- Effective mesh size - based on the probability that two points chosen randomly in a grassland area are connected and are not separated by any barriers [km^2]
- Effective mesh density - gives the effective number of meshes per km^2 , in other words the density of the meshes [mesh/km^2]

Other indicators related to geometry and context (aims to distinguish grassland patches based on size, shape or spatial relation)

Average patch size

- The average size of grassland patch [sq m/sq km]

Patch density

- Number of patches to total area [patches/sq km]

Shape index

- Measure of overall shape complexity as a ratio of border length to border length of a square with equal area [1(ideal square) to n(complex object)]

Evenness index

- E.g. Shannons Evenness Index defining evenness of grassland distribution [-]

5.2.2 Complex indicators

HNV Farming Indicator

The contribution of HRL layers may be expected only in domain of targeting specific Land Cover classes, to support the farming system specification. Only partial or indirect details can be extracted as mosaic of habitats or land use. Finally, in general high resolution EO data do not provide any details of species presence or distribution. Thus EO data driven HRL's are suitable only for the Type 1 and Type 2 HNV improvement. The baseline Grassland product offers the most suitable input for possible HNV update, since it includes among managed grassland also semi-natural grassland and natural grassy vegetation. Considering the grassland specification, it may be concluded, that there is primarily a potential for geometrical improvement, where thematic potential is limited. The binary grassland mask does not provide any additional quality of detected grassland, nor any further characteristic that could contribute to HNV farmland identification. The main aim of **HNV improvement by HRL** represents the expected higher geometrical accuracy of HRL Grassland than CLC (spatial resolution, MMU applied). Introducing the grassland mask within the selected CLC classes attempts to reduce commission errors of CLC, where 25 ha MMU is applied (e.g. including LC types not associated with any kind of farming process) or for complex Land Use classes like 243.

Some further possibilities of improvement can be considered as a thematic combination of HRL Grassland with CLC and/or contextual information of Grassland related to other HRLs or in addition the link between CLC and HRL Grassland other High resolution layers may be integrated for HNV update as elaborated in more detail in Task 1.8.4.2 (HNV farmland update) and related Technical note (1.8.4.2: HNV farmland update - Overlay of Copernicus HRL data layers with current European HNV 'map' . Case study on selected countries (AT, BG, CZ, DK, HR, NL, PT) and region Schleswig-Holstein), below a short description is provided.

Latest **High Resolution Layers** provide Europe-wide (EEA39) data at spatial resolution of 20m and aggregated 100m product compatible with HNV dataset. Primarily the Grassland layer accommodates most relevant land cover characteristic for HNV farmland. The contribution of HRL layers may be expected only for HNV farmland Type 1, targeting specific Land Cover classes, to support the farming system specification. Only partial or indirect details can be extracted on mosaic of habitats or land use.

CORINE Land Cover is currently starting point for HNV 'map', providing a selection of specific classes delimiting core areas. However, HRLs data are more detailed then CLC for covered land elements. Two main updates of HNV using HRLs can be considered as most relevant (also see Figure 7):

- Subtraction (-) candidates
  - HRL Forest, HRL Imperviousness - removing non-agriculture areas in mixed classes or due to CLC MMU
  - HRL Water & Wetness - removing non-agriculture areas in mixed classes or due to CLC MMU
- Addition (+) candidates
  - HRL Grassland - adding missing grassland areas due to CLC MMU

The proposed main approach for HNV update comprises a stratified subtraction of selected non-agricultural areas identified by selected HRLs from current HNV map or addition of areas identified within

HRL Grassland and extending current HNV map. Some further possibilities of improvement were considered as a thematic combination of HRL Grassland with CLC and/or contextual information of grassland related to other HRLs. However it turned out, such dependencies are non-trivial, ambiguous and rather complex. As an example, potential HNV patches with special spatial constellation, as areas surrounded by road or a large transport network, or inside other industrial zones are relevant candidates for exclusion.

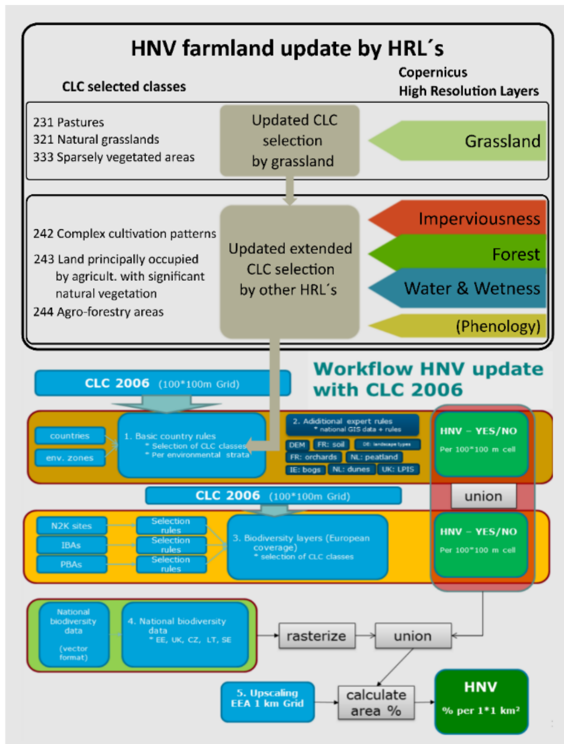

Figure 7 Proposed HNV farmland update by HRLs

The relative share of each HRL within HNV may refer to the relevance for HNV update. Three types of HRLs can be differentiated. One group indicates only binary information of presence of the target feature (Grassland), second group indicates more qualitative categories (such as Water and Wetness – temporary/permanent, Water surface/Humid area) and finally, the third group comprises continuous values (Imperviousness, Tree Cover Density). Since the HRLs are not complementary and overlap may be present, a sequenced assignment was adopted by preference in defined order, based on possible relevancy for improvement. Firstly, the Imperviousness (IMP) layer, followed by Water and Wetness (WAW), Tree cover Density (TCD) and Grassland (GRA). IMP and WAW are considered first, as possible not relevant areas to be excluded from HNV. Their thematic definition and expected reliability indicates areas, that are in most cases in contradiction with HNV because they are not farmland in the 1st instance. Since these layers comprise non-relevant land cover characteristics to farming or management activity, most likely they are suitable for exclusion. Specifically sealed areas resulting from the Imperviousness layer, tree/forest formations identified within the Forest HRL layer and permanent water surfaces from the Water and Wetness HRL can be excluded as non-probable HNV areas. Some of the HRL layers indicate non-binary mask - rather estimating a degree of observed feature. In this case a threshold should be applied, meaning that only areas exceeding a certain value of sealed area (e.g. 30% for imperviousness) will be excluded. Similarly approx. 70% tree cover density exclusion limit may include only real forest areas, leaving areas with scattered tree formations with possible management pattern be part of HNV. Especially for tree cover density, the threshold may vary spatially for different regions or forest types. For Water and Wetness only permanent water surface is considered, since the wetness component is ambivalent regarding the particular definition of included/excluded land cover classes when compared to HNV based definition.

Figure 8 Examples of relevant candidates to be excluded from HNV based on HRLs identification (in red built up areas of Imperviousness, in blue permanent water areas from Water and wetness HRL, in dark green forest areas identified by HRL Tree cover Density)

Considering the thematic content of **HNV and HRL Grassland**, it may be concluded, that there is primarily a potential for geometrical improvement, where thematic potential is limited. The HRL Grassland definition of included/excluded land cover classes differs significantly from the potential CORINE Land Cover classes regarded as potentially associated with agricultural and HNV farm land. As a consequence of this difference, no simple addition or extraction of HRL Grassland towards HNV farmland is feasible, since it may cause substantial thematic inconsistencies e.g. grasslands in urban area (false inclusion) or heathlands (over 10% non-grass cover) (false exclusion). The limitations of additional expert layers of GRAVPI and PLOUGH results in no real asset and use in HNV update within current definition and quality (mainly varying source data availability used for PLOUGHING indicator, causing spatial inconsistency).

HRL Grassland can be eventually utilized in both ways: as a source of additional candidates for HNV map extension, or within current HNV for geometric improvement. Within HNV map, primarily grassy and non-woody covers can be identified more precisely when compared to CLC. However, the Grassland HRL includes further regions not corresponding to HNV definition. Therefore, only areas within selected CLC classes as pastures, natural grasslands and possibly sparsely vegetated areas are relevant for such update. For other CLC classes within HNV map as complex cultivation patterns, land principally occupied by agriculture with significant natural vegetation or agro-forestry areas mainly other HRL's should be applied by means of subtraction as described in previous paragraph. Such improvements may fine-tune geometrical inaccuracies introduced by defined MMU of CLC. Introducing the HRL grassland mask within the selected CLC classes and inside HNV map attempts to reduce commission errors of CLC, where 25 ha MMU is applied (e.g. including LC types not associated with any kind of farming process). To differentiate validity of possible inclusion (areas outside HNV but part of HRL grassland) or exclusion of areas (inside HNV but not inside HRL Grassland) detailed composition of CLC shares were calculated. Such relation may indicate, whether selected grassy patch is a valid candidate. It was observed, that simple LC assignment does not provide unambiguous indication of relevancy and the interpretation may be geographically diverse. For such evaluation further quantification, visual check and comparison with detailed reference data has to be applied. This is characteristic mainly for complex Land cover classes as 243 or 244.

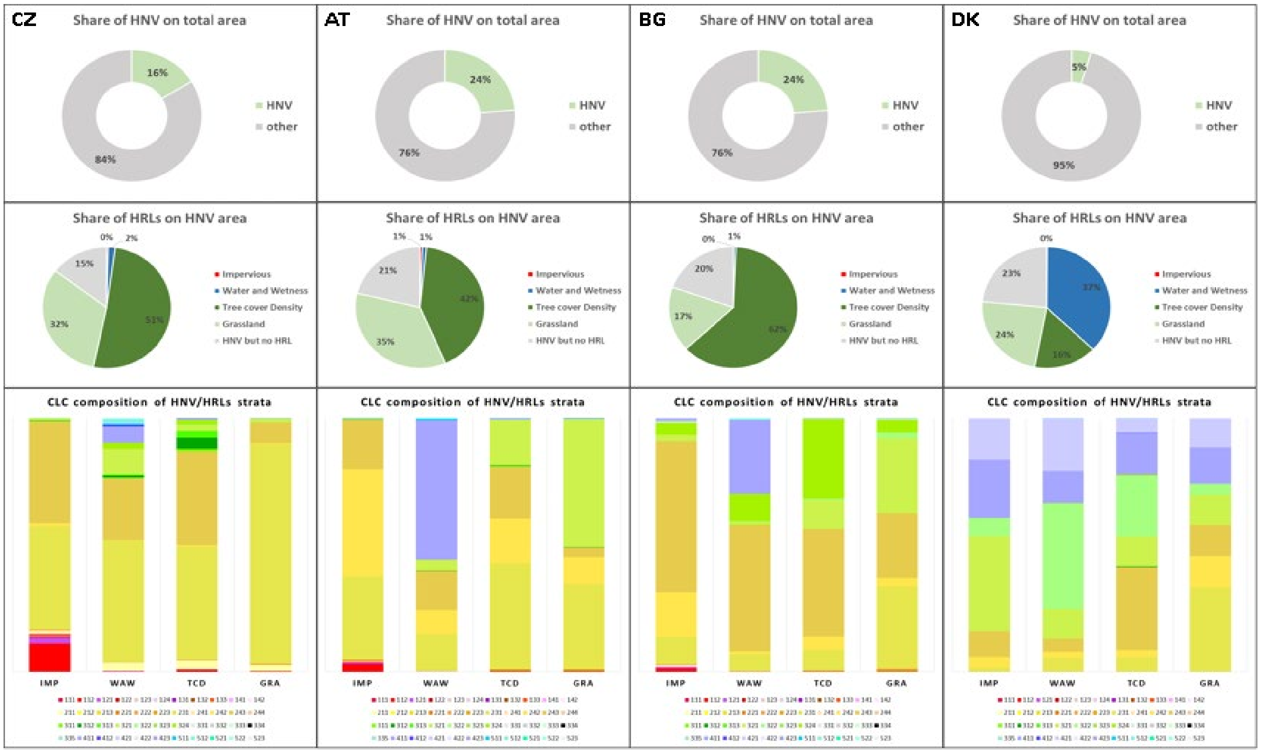

Figure 9 Example of HRL profiles in current HNV map for selected sites

6. Conclusions

6.1 Discussion

6.1.1 Peri-Urban Areas

Policy context
Europe's economic development has put pressures on cities. The role of cities to Europe's economic growth, jobs and competitiveness, while also delivering social and environmental goals, has been addressed extensively by European institutions, regional and local authorities. Sustainable urban development appears prominently in many European policy commitments [45]. Monitoring the effects of land use policies and Structural Cohesion Funds supporting the containment of urban sprawl/dynamics could be supported by indicators based on UA. These indicators could support the analysis of peri-urban land use trends and identify and monitor relevant processes in order to give options for mitigation of negative impacts and highlight the need for action.

The analysis of relevant Land Cover Flows such as "**Urban diffuse residential sprawl"**, **"Recycling of developed urban land**" or "**Sprawl of industrial & commercial sites**" can show evidence of what are the more prominent processes happening in an urban/peri-urban context in different cities across different areas of Europe.

There are a few angles of approach that can be investigated such as:

- Food security: if loss of agricultural area (arable land) in peri-urban areas is detected and agricultural land is fragmented;
- Loss of ecosystem services: if loss of forest or other (semi)natural areas (e.g. green infrastructure) is detected;
- Effects on peri-urban landscapes of urban densification.

Main objective being to enhance **evidence-based** urban/peri-urban policy making.

The relevance of urban/peri-urban aspects can be found in the Amsterdam Pact - response to objective 8 of The Seventh Community Environment Action Programme (7th EAP) - establishing an Urban Agenda for the EU, the newly released (October 2018) SUL-NBS Action Plan of the Urban Agenda [4], as well as, the stakeholder meeting (December 2017) for framing the EEA report Environmental Sustainability in Cities (ESIC) 2020 [6].

Population density estimates
The results presented in section 5.1.1 and [30] showed large difference between the JRC estimates and the estimates provided by the new methodology using either HRL IMD data or ESM data. The estimates based on HRL IMD or ESM data are rather similar. The use of 3D information leads to more realistic estimates per Urban Atlas polygon when buildings of different heights are within on EUROSTAT population grid cell. One important issue in the development of a new method was how to overcome the differences between the JRC estimates and the estimates provided by the new methodology. Estimates for the UA polygon should be in the same order of magnitude to be convincible. After several iterations the differences were still existing.

At the end of the project, however, the reason for the differences between JRC estimates and the new estimates seems to have their origin in changed UA2012 geometries. UA2012 has been updated in between the production of the JRC estimates and the estimates produced by us. In fact JRC's estimates and our estimates could not be compared due to the use of different geometries.

The non-negligible differences between 2D and 3D estimates indicate that the use of building heights is desirable. Building heights should be used in combination with land use data to provide better population estimates. However, building height data is only available for some core cities and the benefits of its European-wide use should be weighed against the increased effort and the limited data availability.

The detailed pictures of population gains and losses by comparing estimates based on 2006 and 2012 data insinuate an exactness which should be dealt with care as it is based on a relatively uncertain downscaling procedure. The integration of different vector data sources (Urban Atlas Polygons & EUROSTAT population grids) together with raster data (ESM, HRL IMD) leads to uncertainties due to boundary effects (e.g. non matching raster grids and borders of vector polygons). A well-known shortcoming is the overestimation of population in city centres and the underestimation outside the cities. The division between detailed visualization and not so detailed source data should be considered. A close examination of modelled population dynamics and reference data would be necessary to make grounded statement about the usefulness of the approach.

Applying the newly developed methodology on UA data for different reference years would make it possible to show the population dynamics over time. Hereby, the availability at regular intervals of population data used for the extrapolation of the population data over the UA polygons needs to be taken into account.

For mapping PUAs and their dynamics the following steps should be considered:

- population data need to be added/downscaled to the UA polygons (several reference years)
- application of PLUREL typology to UA (conversion of UA to CLC classes)
- spatial configuration of polygons should be aligned and prevent "noise", e.g. small isolated peri-urban patches/polygons surrounded by urban patches/polygons

Comparison of cities and cluster analysis on basis of land cover flows

Cities or FUAs can be clustered on basis of land cover flows. One or more land processes expressed as land cover flows are prominent for a specific cluster. The cities within such a cluster show similar patterns in land use/cover changes during the period 2006-2012.

German cities are in majority grouped under clusters 1 and 2 (28 out of 37). Main land cover flows are lcf12, lcf22, lcf31, lcf35 and lcf37 (see Annex 2for explanation of LCF codes). None of the land cover flows is standing out. German cities seems to have a kind of "balanced" development.

Spanish cities are in majority grouped under cluster 3 and 7 (31 out of 39) showing that extension of cities (lcf37 – construction) and diffuse urban sprawl (lcf22) are important processes in Spain. Also recycling of urban land (lcf12) is important in Spain as the complete cluster 10 having lcf12 as most important land cover flow consists of Spanish cities (4).

Polish cities having diffuse urban sprawl (lcf22) as most important land cover flow. Clusters 2, 8 and 9 contain all Polish cities and lcf22 is the most important land cover flow in those clusters.

Overall it can be stated that the most important LCFs in the cities of Poland, Germany and Spain are lcf22, lcf12, lcf37, lcf31, lcf35, lcf11, lcf32, lcf13, lcf54, lcf72 and lcf81. See for Annex 2 explanation of LCF codes.

An inventory of policies implemented and/or provision of background information to explain or clarify the land processes prominent for a specific cluster would be a next step.

6.1.2 Grasslands

The HRL Grassland represents harmonized and consistent pan-European data layer with outlook of regular update in 3-years period at significantly higher resolution than current datasets as CORINE or HNV, providing a good basis for a simple quantitative indicators as amount or share (and their possible change) of grassland. However the thematic definition is rather wide, including both managed and natural grasslands with no further indication of intensity.

On the other hand the HRLs provide valuable information useful for HNV 'map' update. the HNV farmland concept proved to be a valid indicator for estimation of grassland areas relevant for environmental concerns by means of biodiversity and wildlife value of countryside. However, the HNV concept mainly relies on CORINE LC with defined limitation of MMU and complex classes. An enhanced update of HNV layer is proposed using all available HRLs derived from EO data. They provides (similarly to Grassland HRL) pan-European harmonised datasets with outlook of regular 3 year frequency update, related to Land Cover and represents valuable input for HNV farmland, mainly as supplement of CLC. This harmonised datasets also provide better spatial resolution, enabling the reduction of MMU effect of CLC classes.

Imperviousness and Permanent Water surfaces are identified as direct candidates (obvious thematic significance) to be excluded from HNV map. Tree cover density requires further elaboration on proper density threshold, where dense and compact forest formations are candidates for exclusion and scattered trees as landscape elements may be still valid for HNV and integral part of grasslands.

The Grassland HRL product may improve the delineation of HNV by means of geometry, partly thematically (both extension of HNV map or exclusion from current HNV map), but requires further discrimination based on Land Cover and further contextual relations. No simple addition or subtraction is possible without causing thematic inconsistency. Similarly, for other HRLs as Water And Wetness (e.g. Temporary water class), more complex description is needed with regard to Land Cover class, HRLs characteristics (degree, categories) and HNV specific conditions (relevant LC classes, stratification according eco-biogeographical conditions etc.)

The proposed update strategy presents a simple, straightforward and easy to implement process for selected HRLs. The native resolution of HRL's at 20m offers further potential if applied, however such decision may require broader discussion with respect to other inputs (different resolution – 100m) and context of HNV farmland in general. Above HNV methodology upgrade implementation has been already tested for HRL Imperviousness and HRL Forest in the frame of Task 1.8.4.2 - HNV farmland updated.

6.2 Future work

6.2.1 Peri-Urban Areas

Definition of PUA and spatial location within FUAs

The results presented above showed the PLUREL subdivision into urban, peri-urban and rural areas is most promising to monitor urban dynamics i.e. changes between urban, peri-urban and rural areas. The mapping/labelling of UA polygons as urban, peri-urban or rural within UA FUAs on basis of a combination of population thresholds and land use/land cover information (PLUREL method) needs to be defined in more detail to make it suitable for monitoring urban dynamics. For the development of a methodology to monitor the urban dynamics the following steps are foreseen:

- production of newly updated population estimates per UA2012 polygon (UA2012 dataset including West Balkans) by JRC
- disaggregation of population estimates to UA polygons or other representative geometries, e.g. gridded UA LCLU information, for a subset of FUAs for which UA2006 data is available
- mapping of urban, peri-urban and rural areas in the selected FUAs for 2006 and 2012 according to extended PLUREL methodology (population thresholds, land use/land cover information + spatial configuration)
- define the dynamics between urban, peri-urban and rural areas for the period 2006-2012

The data needed for the development for such a methodology are EUROSTAT population data and UA data for at least two reference years e.g. 2006 and 2012. Also ESM or IMD datasets for those reference years are needed as population covariates (POPCOV**)** indicating what fractions of the covered ground are made up of artificial surfaces.

The calculation of population estimates by JRC on stable UA2012 datasets (including West Balkan) will be using the methodology of dasymetric mapping to downscale population density data to UA polygons. The methodology has his disadvantages but is at the moment the only proven methodology. As for the subdivision between urban and peri-urban areas within the FUAs population density information at the level of UA polygons is indispensable. To exploit the full potential of UA data in defining PUA and their dynamics population density information for the years 2006, 2012 and 2018 are needed.

The downscaling of 2006 population data to UA2006 polygons could be produced on basis of 2018 experiences by the ETC/ULS team for a limited number of FUAs. These estimates could be used to define the methodology to define PUA and monitor urban dynamics in more detail.

The final outcome of this work could be an estimation of efforts needed to apply the methodology for all FUAs where UA data is available for both reference years.

The 2018 work revealed also some suggestions or considerations:

- population estimates could be improved by up-sampling sealing layers to higher resolutions and excluding small transition polygons from modelling to avoid the mitigation of boundary effect when adding population covariates to the transition geometries.

- a close examination of the EUROSTAT data is necessary and unreasonable population gains/losses must be investigated when modelling of population dynamics
- the PLUREL method to make a division within FUAs between urban, peri-urban and rural areas using the estimated population densities needs to be figured out/further detailed (the extended PLUREL method). E.g. combining population density thresholds with a measure for contingency of UA polygons to label polygons as PUA (i.e. adapt spatial configuration avoiding "noise", e.g. small isolated peri-urban patches/polygons surrounded by urban patches/polygons)
- define a way to monitor the dynamics in urban development on basis of EUROSTAT population grid data of different reference years. E.g. the extension of urban areas at the expense of PUA or shrinking of rural areas due to extending PUA.

Clustering

Some suggestions for future work regarding the clustering of FUA:

- clustering of cities on basis of all FUAs for which land cover flows (LCFs) are available
- a more complex clustering of cities using land cover flows between 2006-2012 and between 2012-2018 when UA2018 data becomes available
- spatial representation of cluster by showing a map of EEA39 with the clusters of FUAs

6.2.2 Grasslands

Complex patterns

For thematically rich and/or categorical HRLs (Grassland, Water and Wetness) extended evaluation is needed to differentiate various clusters of possible positive or negative candidates for inclusion or exclusion.

Such evaluation may lead to

⇒ **Complex rule based description -** considering Land Cover class, HRLs characteristics (degree, categories) and HNV specific conditions (relevant LC classes, stratification according eco-biogeographical conditions and other)

Ancillary layers

Use of additional/ancillary layers may be considered to refine or stratify the selection for possible update of HNV 'map'. Further information can be extracted from DEM data (HNV grasslands in higher altitudes), expert layers of HRLs if relevant, bio-geographical stratification (different grassland types) or specific land cover classes.

Quantitative comparison with reference data

Since above mentioned complex rules may lead to non-trivial relations, detailed quality assessment of possible updates may be of benefit for evaluation of improvement.

Intensity of use

One of the main characteristics important for grassland areas assessment and valuation is intensity of grassland use. There are no data currently available on European scale to really consistently provided input to such characteristic. Synergy of HRL grassland and HR phenology services is expected to finally contribute in this context. Methodological framework for such a synergy will be explored.

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8. Annexes

Annex 1 Indicators related to urban/peri-urban areas exploited in Portugal (source Portuguese NRC LUSP).

Source	Indicator	Methodology	Datasets	Data resolution	Data coverage	References
Directorate-General for Territory (DGT)/National Statistical Institute (INE)	Urban land use (%)	Land classified as urban/ total area	Directorate-General for Territory: Planned Land Use Map (CRUS) Official Portuguese Administrative Map (CAOP)		National	Statistical Council, Portugal 2020 Context and Result Indicator System (GT PT2020) (June 2016)
	Urban land use density	Present population/ Land classified as urban	Directorate-General for Territory: Planned Land Use Map (CRUS) Official Portuguese Administrative Map (CAOP) Statistics Portugal (INE): Census Population data		National	
	Change of artificial territory areas	% of change of artificial territory area by municipality taking into account the initial and last referenced years	Land Use Land Cover Map (COS) COS is a vector data model national product under the responsibility of the Directorate-General for Territory (NMCA Portugal) and corresponds to polygonal maps that represent homogenous land use/cover units.	The reference mapping unit corresponds to 1 hectare, with a defined distance between lines equal or higher than 20 meters and a percentage equal or higher than 75% of a given land use/cover thematic class.	National (Continental) Data series of COS is available for t reference years - 1995, 2007,2010. COS 2015 is currently under production.	National Spatial Development Policy Program (PNPOT, 2018) (Diagnosis Document, currently under development, 20 September 2017)
	Percentage of land use classified as artificial territories		COS 2010	The reference mapping unit corresponds to 1 hectare, with a defined distance between lines equal or higher than 20 meters and a percentage equal or higher than 75% of a given land use/cover thematic class.	National (Continental)	National Spatial Development Policy Program (PNPOT, 2018) (Diagnosis Document, currently under development, 20 September 2017)
	Ratio of land consumption rate to population growth rate	Currently testing the implementation of this indicator by following the UN SDG metadata with some adaptations Some other indicators may derivate from this one (e.g.Total of urban expansion in km^2)	COS 1995-2007-2010 CLC 1990-2000-2006-2012	The reference mapping unit corresponds to 1 hectare, with a defined distance between lines equal or higher than 20 meters and a percentage equal or higher than 75% of a given land use/cover thematic class.	COS - National (Continental) CLC - National	

Annex 2 Definition of relevant Land Cover Flows.

LCF 1: Urban land management:

- lcf11 - Urban development/infilling;
- lcf12 - Recycling of developed urban land;
- lcf13 - Development of green urban area.

LCF 2: Residential sprawl:

- lcf21 - Urban dense residential sprawl;
- lcf22 - Urban diffuse residential sprawl.

LCF 3: Sprawl of economic sites and infrastructure:

- lcf31 - Sprawl of industrial & commercial sites;
- lcf32 - Sprawl of transport networks;
- lcf33 - Sprawl of harbours;
- lcf34 - Sprawl of airports;
- lcf35 - Sprawl of mines and quarrying areas;
- lcf36 - Sprawl of dumpsites;
- lcf37 - Construction;
- lcf38 - Sprawl of sport and leisure facilities.

LCF 5: Conversion from forest to agriculture:

- lcf51 - Conversion from forest to agriculture;
- lcf53 - Conversion from wetlands to agriculture;
- lcf54 - Conversion from developed areas to agriculture.

LCF 7: Forest creation and management:

- lcf72 - Forest creation, afforestation;
- lcf74 - Recent felling and transition.

LCF 8: Water bodies creation and management:

- lcf81 - Water bodies creation.

LCF 9: Changes of land cover due to natural and multiple causes:

- lcf911 - Semi-natural creation;
- lcf99 - Other changes and unknown

Annex 3 Methodology cluster analysis on basis of land cover flows for cities in Germany, Poland and Spain.

The UA change 2006-2012 data of all available cities in Germany (35), Poland (32) and Spain (24) were used to derive the different land cover flows:

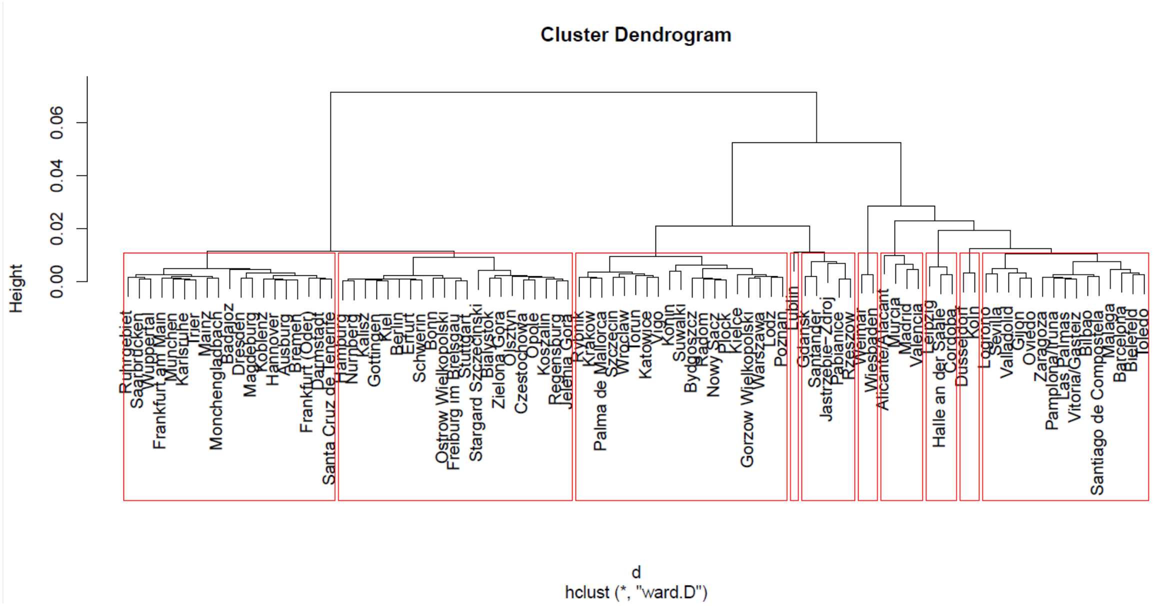
- Downloading UA change layers for 2006-2012 (xxx_Change_2006_2012.shp) from EEA.
- Derivation of land cover flows [in ha] from change matrix between UA 2006 ad 2012, according to definitions described in [10]. The results are presented in Annex 3.
- Rescaling of lcf's based on the areal extent of the FUA for 2012 (Boundary2012_DE001L1_xxxx.shp downloaded from EEA). This was done in order to avoid that the cluster analysis would create groups based on the magnitude of the lcf's.

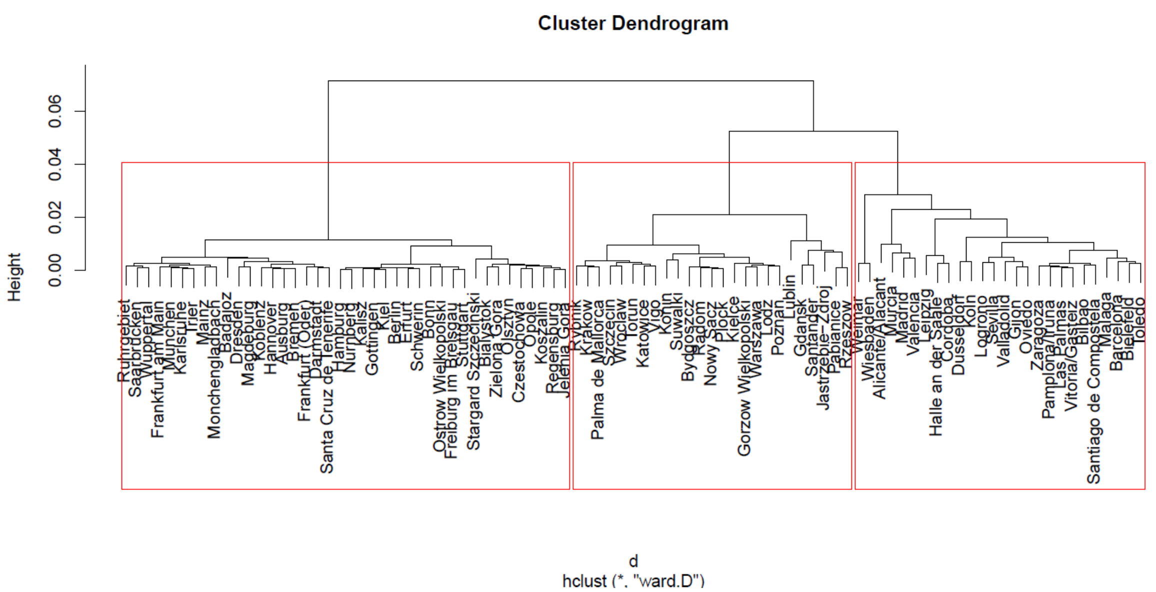
The next step was to cluster the re-scaled lcf's with the intention to cluster cities that show similar behaviour based on the lcf's (so-called lcf-signature or pattern). A hierarchical cluster analysis (HCA) was chosen and performed in R (function hclust). The resulting HCA dendrogram is shown in Annex 4.

Annex 4 Land Cover Flows (ha) for cites in Germany, Poland and Spain on basis of Urban Atlas data.

Country	City	Area_City	lcf11	lcf12	lcf13	lcf21	lcf22	lcf31	lcf32	lcf33	lcf34	lcf35	lcf36	lcf37	lcf38	lcf51	lcf53	lcf54	lcf72	lcf74	lcf81	lcf911	lcf99
Germany	Ausburg	199777	70	204	28	0	74	325	7	0	0	97	0	253	7	0	0	31	1	0	10	0	0
Germany	Berlin	1748392	1240	1311	84	22	483	1175	164	0	796	485	0	802	95	25	0	344	91	31	407	334	5
Germany	Bielefeld	25910	46	120	5	0	27	71	50	0	0	7	0	60	23	1	0	8	0	0	0	0	0
Germany	Bonn	129380	14	211	0	0	96	178	1	0	0	12	0	13	7	0	0	0	0	0	0	4	0
Germany	Bremen	589486	100	435	10	1	366	1110	27	1	0	285	0	745	79	2	0	52	5	0	101	6	0
Germany	Darmstadt	78151	22	67	9	0	67	184	6	0	0	17	0	27	6	0	0	9	0	0	7	0	0
Germany	Dresden	583338	62	586	19	7	247	692	95	0	0	822	0	98	37	2	0	22	0	0	862	261	0
Germany	Dusseldor	120243	73	405	11	4	189	330	25	0	0	676	0	161	59	4	0	222	0	0	37	0	3
Germany	Erfurt	285672	22	185	8	0	37	246	87	0	0	130	0	147	16	109	5	76	4	0	59	13	0
Germany	Frankfurt	14782	4	26	2	0	3	44	0	0	0	10	0	6	0	0	0	0	0	0	11	0	0
Germany	Frankfurt	430299	192	859	31	14	545	926	76	0	284	223	0	502	144	2	2	154	7	0	51	9	0
Germany	Freiburg i	221118	83	200	6	1	185	250	28	0	0	71	0	180	12	0	0	34	0	0	34	1	0
Germany	Gottingen	238866	6	133	2	0	80	114	32	0	0	47	0	79	11	0	1	32	0	1	11	2	0
Germany	Halle an d	157611	17	254	5	4	33	374	136	3	0	120	0	299	8	0	0	88	38	15	915	61	0
Germany	Hamburg	734196	70	604	28	1	123	321	32	1	0	189	0	386	27	2	0	55	0	0	46	5	2
Germany	Hannover	297359	54	289	4	2	244	532	41	0	49	219	0	295	40	0	0	38	0	0	92	23	0
Germany	Karlsruhe	125841	16	217	7	3	131	198	14	0	0	56	0	126	29	2	0	12	0	0	41	0	0
Germany	Kiel	338165	10	89	0	21	57	267	8	2	0	119	0	78	8	0	0	21	0	0	33	0	0
Germany	Koblenz	92262	6	48	1	1	73	205	7	0	0	94	0	84	14	0	0	35	2	0	6	1	0
Germany	Koln	162615	37	429	7	4	186	340	11	3	0	758	0	423	56	8	3	701	58	7	29	157	0
Germany	Leipzig	397600	55	1182	74	1	71	577	64	0	2	763	0	451	45	7	5	1372	1	0	1483	39	0
Germany	Magdebur	416932	42	208	11	2	150	635	53	42	0	375	0	234	47	17	3	177	0	0	379	3	0
Germany	Mainz	70320	28	94	16	0	49	109	4	0	0	50	0	106	90	0	0	8	26	0	0	0	0
Germany	Moncheng	17094	4	25	6	0	12	31	12	0	0	5	0	33	8	0	0	2	0	0	0	0	0
Germany	Munchen	549936	138	1010	64	8	496	898	298	3	4	508	0	697	152	38	10	195	137	3	111	4	0
Germany	Nurnberg	293432	35	328	12	0	70	177	40	0	0	53	0	145	10	0	0	4	33	0	6	2	0
Germany	Regensbu	253818	23	190	15	2	336	179	4	0	0	100	0	155	10	0	0	8	0	0	20	0	0
Germany	Ruhrgebie	443910	132	809	34	0	82	229	15	6	0	213	0	284	28	10	0	131	11	0	151	0	0
Germany	Saarbruck	153762	24	412	2	0	84	201	13	0	0	154	0	100	9	3	0	20	6	0	12	2	0
Germany	Schwerin	489831	40	160	14	8	127	447	75	0	0	241	0	375	66	0	0	85	16	47	104	95	0
Germany	Stuttgart	365423	70	430	25	8	274	358	71	0	0	65	0	340	31	13	0	56	42	0	5	6	0
Germany	Trier	121069	15	265	24	0	130	185	4	0	0	53	0	117	7	0	0	16	59	0	21	0	0
Germany	Weimar	88880	947	16	14	9	42	69	2	0	0	29	0	224	76	0	0	12	57	0	4	0	0
Germany	Wiesbade	101580	921	90	1	18	50	36	0	0	0	15	0	64	32	14	0	1	0	6	0	4	0
Germany	Wupperta	16848	7	33	3	0	13	27	0	0	0	16	0	9	0	0	0	0	0	0	0	0	0
Poland	Bialystok	223576	65	178	23	18	507	211	78	0	0	385	0	318	15	29	2	6	0	0	19	15	0
Poland	Bydgoszcz	210060	218	118	3	9	938	289	61	0	0	81	0	198	11	0	0	10	0	0	39	47	0
Poland	Czestocho	193828	38	74	2	1	431	217	2	0	0	79	0	35	23	4	0	6	0	0	9	12	0
Poland	Gdansk	263215	194	1154	10	12	1845	601	7	24	1	279	0	1184	97	0	0	16	0	0	125	14	0
Poland	Gorzow W	97517	67	123	1	0	369	140	102	0	0	124	0	163	13	2	0	29	0	0	47	0	0
Poland	Jastrzebie	29479	23	77	2	1	155	55	66	0	0	18	0	283	0	0	0	0	0	0	5	0	0
Poland	Jelenia Gc	83442	16	71	6	0	136	40	5	0	0	25	0	52	3	0	1	15	0	0	21	0	0
Poland	Kalisz	149071	27	115	2	1	111	133	5	0	0	33	0	35	4	0	1	25	0	0	6	2	0
Poland	Katowice	394555	350	927	10	5	1701	542	498	0	5	671	0	378	81	5	6	137	11	0	84	18	0
Poland	Kielce	224313	72	115	14	3	950	171	87	0	0	532	0	479	37	0	0	0	0	0	62	0	0
Poland	Konin	118231	64	83	2	3	495	130	15	0	0	291	0	73	21	174	2	302	0	0	176	13	0
Poland	Koszalin	129659	49	63	4	0	272	67	4	0	0	39	0	114	5	15	1	10	11	0	5	22	0
Poland	Krakow	375774	279	602	19	4	2204	489	97	0	6	197	0	740	58	0	22	154	4	0	123	12	8
Poland	Lodz	169455	56	346	5	1	545	173	15	0	0	162	0	433	5	0	0	30	0	0	32	0	0
Poland	Lublin	322692	779	170	5	6	3834	379	11	0	0	164	0	655	2	0	0	4	8	0	29	27	0
Poland	Nowy Sac	130375	106	32	7	0	475	121	25	0	0	73	0	44	4	0	5	12	0	6	69	37	25
Poland	Olsztyn	202623	56	197	2	3	358	36	29	0	0	124	0	174	8	20	4	89	2	0	284	14	0
Poland	Opole	176656	39	40	7	3	390	145	15	0	0	86	0	21	18	0	0	5	0	0	118	25	22
Poland	Ostrow W	84697	7	58	0	1	80	84	61	0	0	36	0	14	7	0	0	4	0	0	2	19	0
Poland	Pabianice	32996	32	32	0	0	142	10	1	0	0	23	0	175	1	2	0	31	0	0	7	10	0
Poland	Plock	170997	89	71	2	5	684	172	40	0	0	90	0	131	2	0	0	1	0	0	47	7	71
Poland	Poznan	309258	79	415	7	2	1051	421	383	0	0	115	0	856	29	1	1	48	0	0	146	0	0
Poland	Radom	68049	27	29	2	9	257	55	0	0	0	57	0	76	3	0	1	16	0	0	29	0	0
Poland	Rybnik	14831	7	39	0	2	93	15	12	0	0	13	0	29	3	0	0	0	0	0	5	0	0
Poland	Rzeszow	229194	178	289	15	1	1015	160	7	0	0	162	0	1173	16	0	0	1	10	0	43	0	0
Poland	Stargard S	36697	2	32	4	0	90	23	97	0	40	3	0	19	0	0	0	0	0	0	1	1	0
Poland	Suwalki	72182	21	8	0	4	127	51	4	0	0	244	0	28	5	0	0	4	0	0	35	0	0
Poland	Szczecin	112891	80	232	11	14	533	111	279	0	0	76	0	230	21	9	9	40	22	0	52	5	0
Poland	Torun	158957	157	179	21	16	868	320	261	0	0	279	0	179	23	0	2	20	0	0	28	0	0
Poland	Warszawa	861464	905	1313	33	75	3521	941	174	0	0	658	0	1660	86	69	18	103	1	0	181	168	37
Poland	Wroclaw	264810	196	692	21	8	1226	363	320	0	17	284	0	799	51	4	2	119	13	0	159	27	0
Poland	Zielona Gc	169480	16	151	2	2	488	136	82	0	0	87	0	172	15	0	0	0	0	0	63	1	0
Spain	Alicante/A	35582	11	516	39	1	97	56	37	0	0	29	0	69	19	0	0	94	37	0	3	99	0
Spain	Badajoz	218871	28	229	6	2	394	980	37	0	0	305	0	285	24	0	2	3	0	0	243	5	0
Spain	Barcelona	244051	737	1232	114	2	86	214	129	0	3	242	0	461	82	2	0	136	0	0	23	46	0
Spain	Bilbao	148089	60	398	22	5	251	221	119	0	24	224	0	369	98	5	0	74	6	0	1	12	0
Spain	Cordoba	186907	29	306	23	1	100	344	10	0	40	139	0	103	11	0	8	43	2	8	1419	14	108
Spain	Gijon	52733	5	194	19	0	40	28	10	0	0	35	0	270	41	0	0	33	0	0	0	1	0
Spain	Las Palma	75384	10	233	5	0	48	93	9	0	0	58	0	110	7	0	0	0	0	0	9	0	0
Spain	Logrono	46141	23	179	26	2	80	125	61	0	0	134	0	211	20	5	0	4	0	0	1	0	0
Spain	Madrid	682634	352	4871	922	131	1062	1622	715	0	43	2249	0	4187	351	0	0	133	0	0	175	64	0
Spain	Malaga	152185	49	754	62	42	574	314	320	9	145	186	0	379	60	0	0	0	0	0	136	2	0
Spain	Murcia	119886	50	949	42	5	212	293	174	0	179	56	0	226	584	0	0	3	0	0	8	8	0
Spain	Oviedo	93391	28	388	21	0	46	23	10	0	0	79	0	391	19	3	0	79	2	0	0	10	0
Spain	Palma de	201844	165	455	71	3	1238	392	71	1	0	108	0	247	149	0	0	64	0	0	9	6	6
Spain	Pamplona	126789	81	448	49	1	49	109	70	0	8	31	0	270	9	0	0	16	0	0	6	0	0
Spain	Santa Cru	61346	22	94	8	7	47	155	24	5	4	29	0	56	2	0	0	0	0	0	0	3	0
Spain	Santander	68499	64	266	49	1	456	152	52	0	0	162	0	343	19	27	0	18	0	0	24	16	13
Spain	Santiago c	126309	56	303	9	1	59	48	40	0	12	110	0	322	12	3	0	59	6	0	0	5	0
Spain	Sevilla	340128	116	1028	79	6	261	738	154	0	0	502	0	1451	55	0	31	113	0	0	719	27	51
Spain	Toledo	93445	103	428	35	8	123	130	261	0	0	151	0	150	5	0	0	66	2	0	10	14	0
Spain	Valencia	104553	38	961	76	1	127	240	155	20	0	88	0	330	38	0	0	35	0	3	22	59	0
Spain	Valladolid	115657	24	261	24	0	12	101	7	0	1	175	0	761	14	0	0	44	0	0	0	14	0
Spain	Vigo	134783	64	300	6	1	669	142	44	1	0	190	0	248	15	7	0	10	0	0	1	4	3
Spain	Vitoria/Ga	159393	22	554	83	8	118	176	110	0	0	138	0	235	57	0	22	81	0	0	31	4	6
Spain	Zaragoza	276158	13	1189	41	1	178	313	99	1	0	325	0	618	42	0	0	0	7	0	15	2	3

Annex 5 Cluster dendrogram: clustering of German, Polish and Spanish cities into 10 clusters (upper graph) and 3 clusters (lower graph).





The horizontal axis of the dendrogram represents the distance or dissimilarity between clusters.

Annex 6 Descriptions of 10 clusters based on land cover flows (ha normalised by the size of the city).

Cluster 1: A large cluster containing 19 cities mainly situated in Germany (17) and two in Spain (Badajoz and Santa Cruz de Tenerife). The cluster is characterized by a group of land cover flows. There is not one land cover flow standing out. Mainly land cover flows sprawl of industrial & commercial sites (lcf31), recycling of developed urban land (lcf12) and construction (lcf37) are characteristic for this cluster. Also sprawl of mines and quarrying areas (lcf35) is of importance.

Cluster 2: The largest cluster with 21 cities included. Eleven German cities, 10 Polish cities and no Spanish cities are included. Also in this cluster not a specific land cover flow is standing out. Most important land cover flow is urban diffuse residential sprawl (lcf22), directly followed by sprawl of industrial & commercial sites (lcf31), recycling of developed urban land (lcf12) and construction (lcf37).

Cluster 3: The cluster contains 15 cities of which 14 are situated in Spain (+ Bielefeld in Germany). Most important land cover flows are construction (lcf37) and recycling of developed urban land (lcf12). Land cover flows urban diffuse residential sprawl (lcf22), sprawl of industrial & commercial sites (lcf31), sprawl of transport networks (lcf32) and sprawl of mines and quarrying areas (lcf35) are of minor importance. The land cover flow sprawl of transport networks (lcf32) is popping up in this cluster (and in the cluster 7 and 10). In the other clusters the land cover flow is nearly present.

Cluster 4: Only the cities of Dusseldorf and Koln (both German) are included in this cluster. Main land cover flow is sprawl of mines and quarrying areas (lcf35) which is not so astonishing they are situated in the "Ruhrgebiet" a mining area in Germany. Other (less) important land cover flows are lcf12, lcf22, lcf31, lcf37 and lcf54 (conversion from developed areas to agriculture).

Cluster 5: A cluster of only three cities (Halle an der Saale, Leipzig (both German) and Cordoba (Spain). Main land cover flow is water bodies creation (lcf81). Of minor importance are the land cover flows lcf12, lcf31, lcf35 and lcf37.

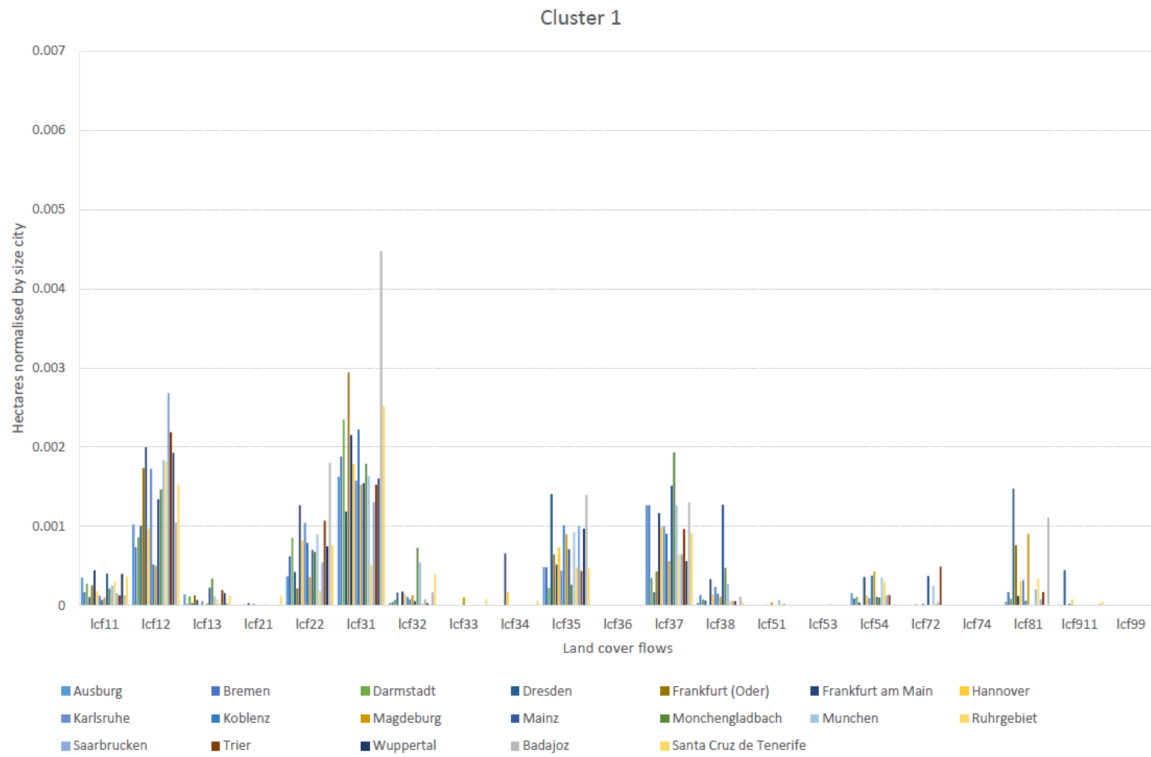
Cluster 6: A very small cluster with only two German cites (Weimar, Wiesbaden) included. The cluster is characterised by the land cover flow urban development/infilling (lcf11). Lcf 37 is of minor importance.

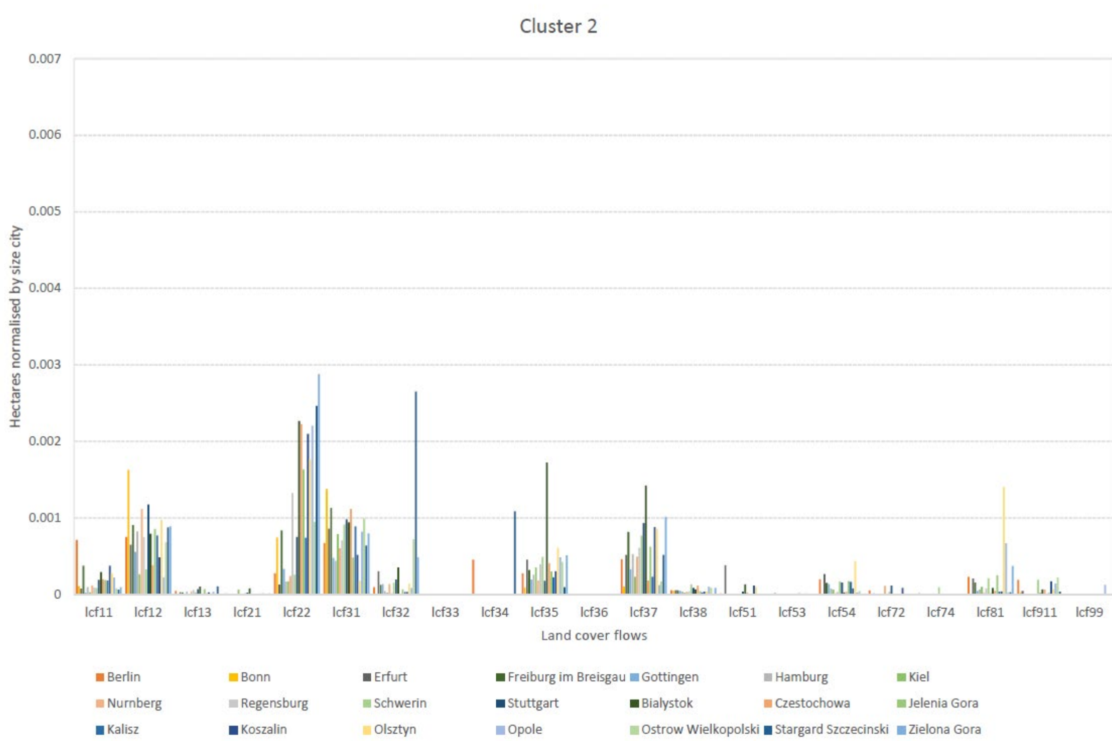
Cluster 7: A group of 19 cities, mainly situated in Spain (17) and 2 cities in Germany. The main land cover flow is urban diffuse residential sprawl (lcf22). Other land cover flows that are important but less extended are lcf12, lcf31, lcf32, lcf35 and lcf37.

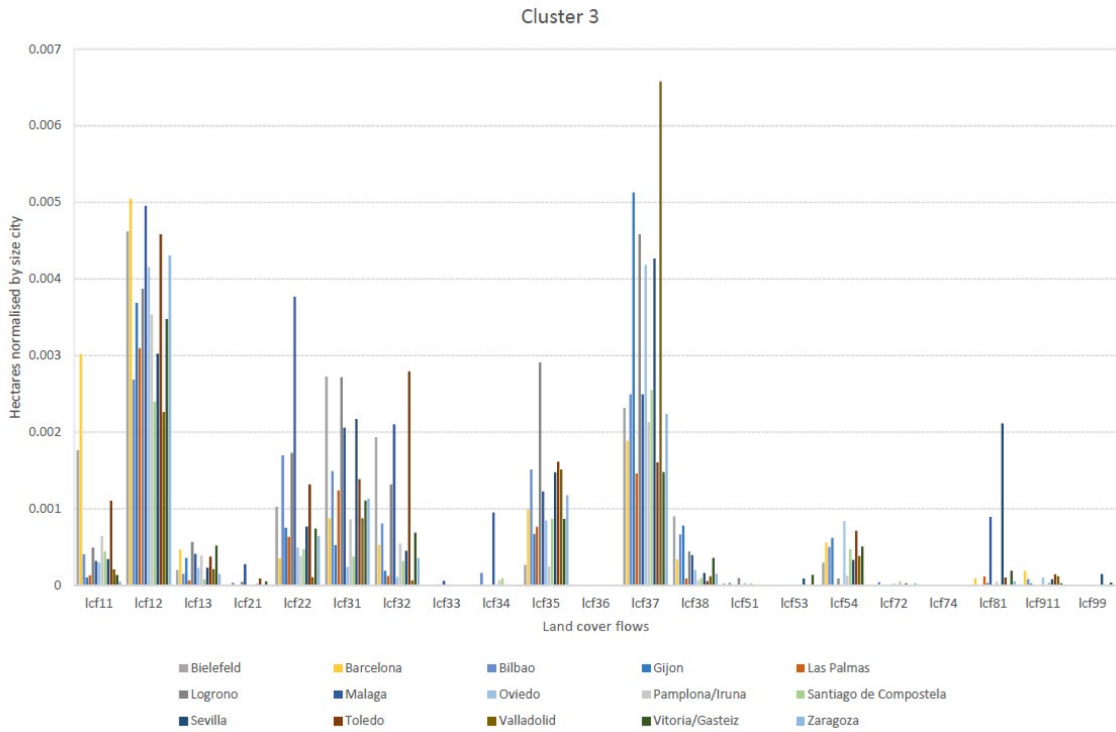
Cluster 8: Also this cluster is relatively small with only 5 cities included (4 from Poland and 1 from Spain). Most important land cover flows are land cover flow urban diffuse residential sprawl (lcf22) and construction (lcf37). Land cover flows of less importance are lcf12, lcf31 and lcf35. Main difference with cluster 7 are the higher importance of lcf37, and that lcf32 and lcf35 are less prominent.

Cluster 9: Only the city of Lublin in Poland is included in this cluster. The cluster is characterised by the land cover flow urban diffuse residential sprawl (lcf22). Lcf11, lcf31 and lcf37 are of minor importance.

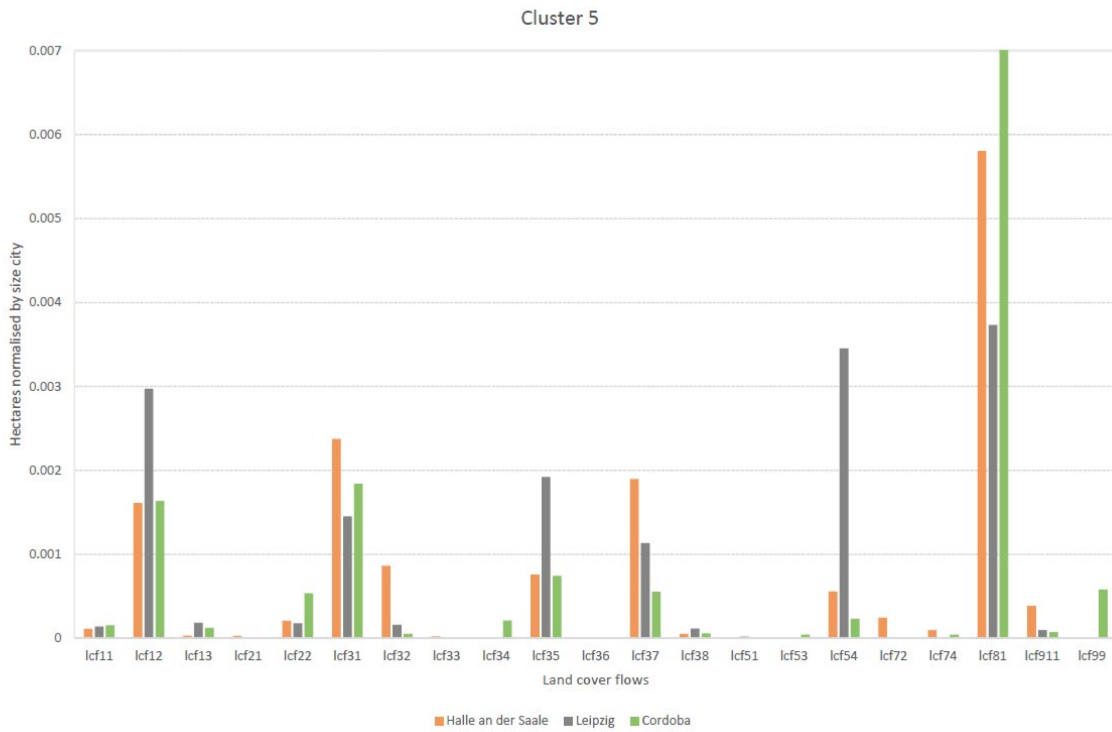
Cluster 10: The cluster contains only 4 cities that are all situated in Spain. By far the most important land cover flow is recycling of developed urban land (lcf12). Land cover flows of minor importance are lcf22, lcf31, lcf32, lcf35 and lcf37.


Cluster 1
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Ausburg
Bremen
Darmstadt
Dresden
Frankfurt (Oder)
Frankfurt am Main
Hannover
Karlsruhe
Koblenz
Magdeburg
Mainz
Monchengladbach
Munchen
Ruhrgebiet
Saarbrucken
Trier
Wuppertal
Badajoz
Santa Cruz de Tenerife


Cluster 2
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Berlin
Bonn
Erfurt
Freiburg im Breisgau
Gottingen
Hamburg
Kiel
Nurnberg
Regensburg
Schwerin
Stuttgart
Bialystok
Czestochowa
Jelenia Gora
Kalisz
Koszalin
Olsztyn
Opole
Ostrow Wielkopolski
Stargard Szczecinski
Zielona Gora


Cluster 3
Hectares normalised by size city
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Bielefeld
Barcelona
Bilbao
Gijon
Las Palmas
Logrono
Malaga
Oviedo
Pamplona/Iruna
Santiago de Compostela
Sevilla
Toledo
Valladolid
Vitoria/Gasteiz
Zaragoza


Cluster 4
Hectares normalised by size city
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Dusseldorf
Koln


Cluster 5
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0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
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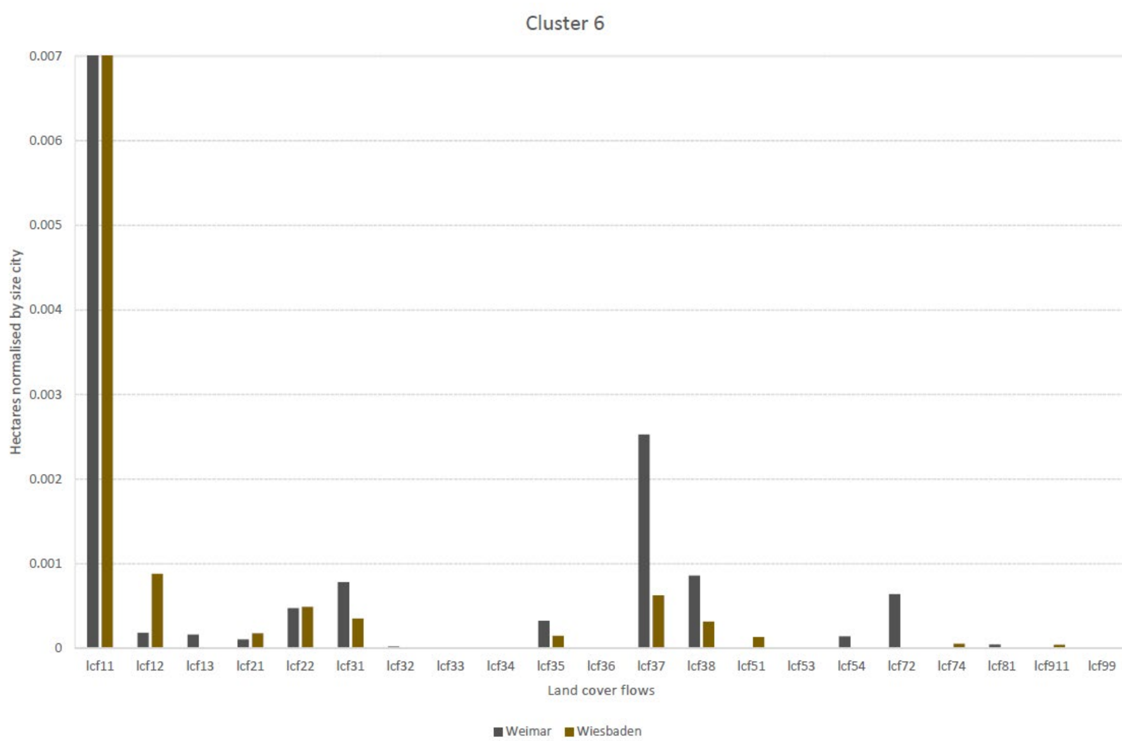
Land cover flows
Halle an der Saale
Leipzig
Cordoba


Cluster 6
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0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
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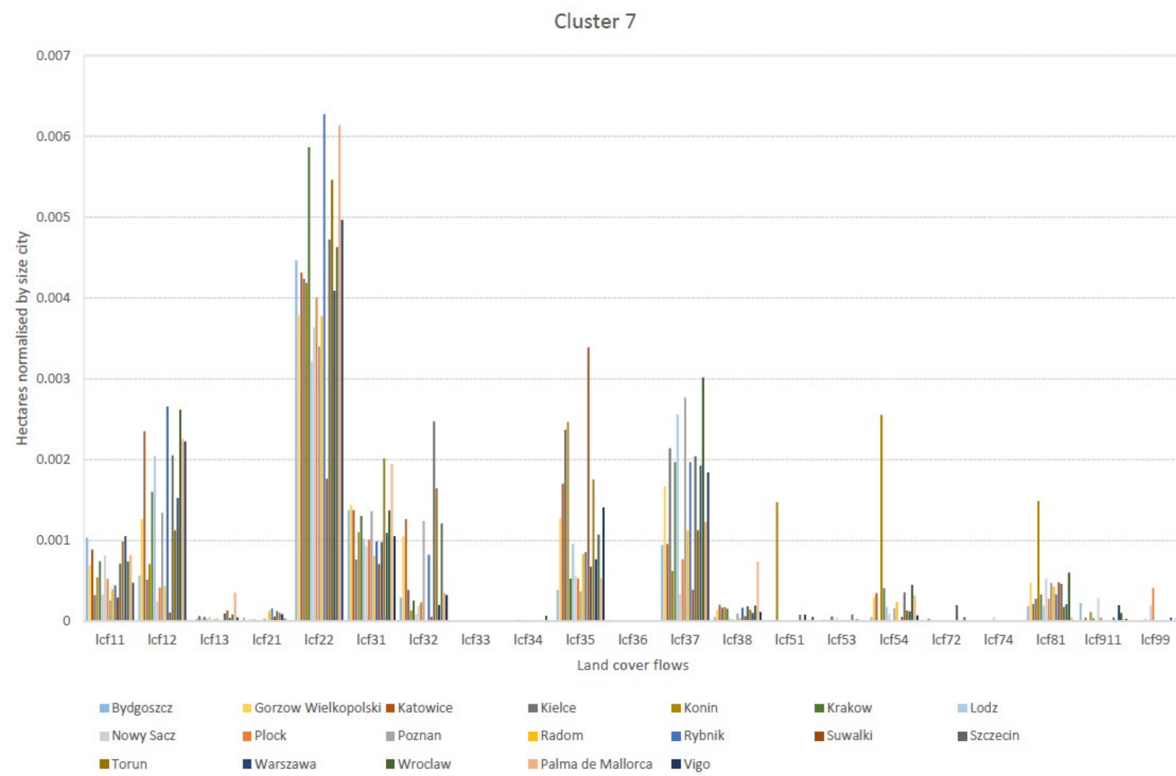
Land cover flows
Weimar
Wiesbaden



Cluster 7
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
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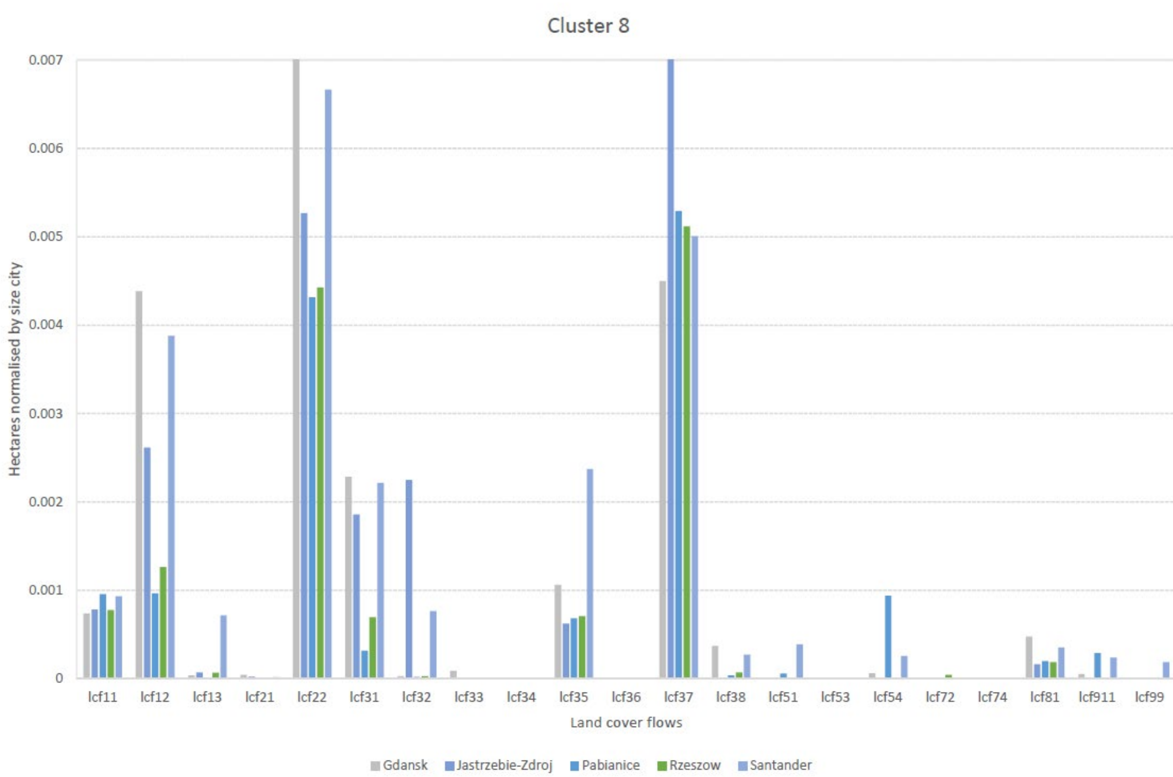
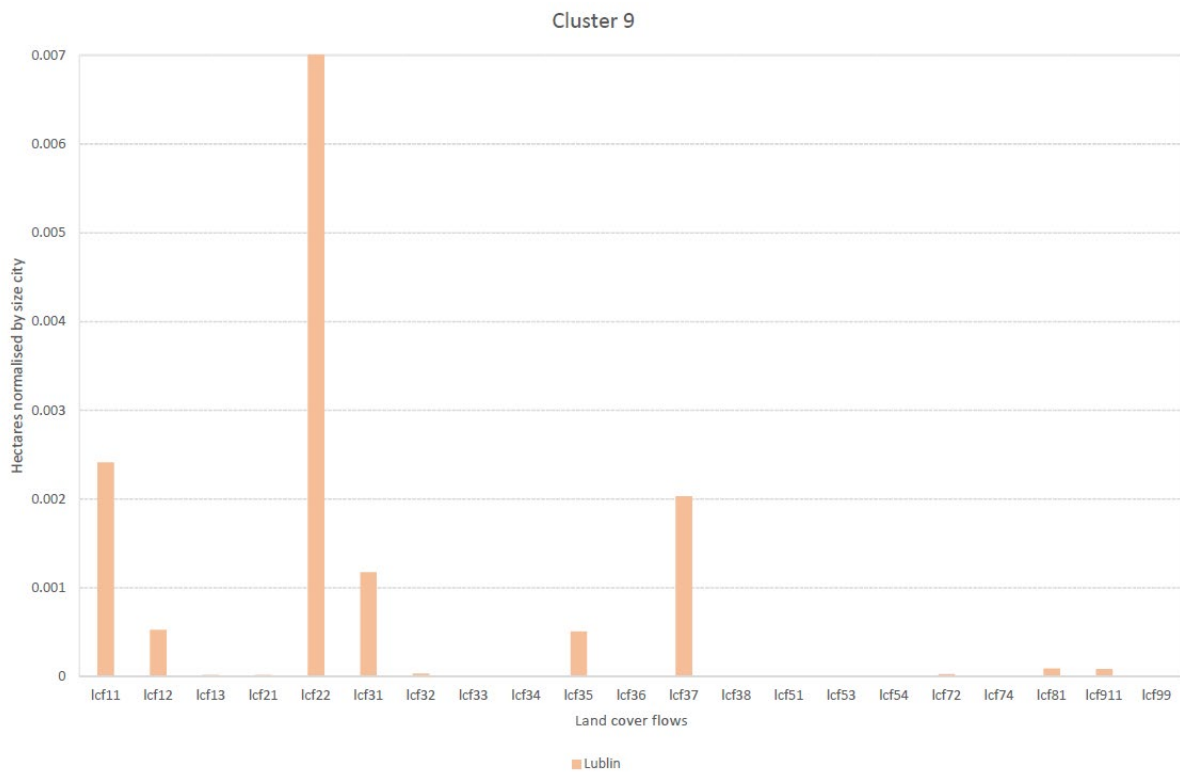
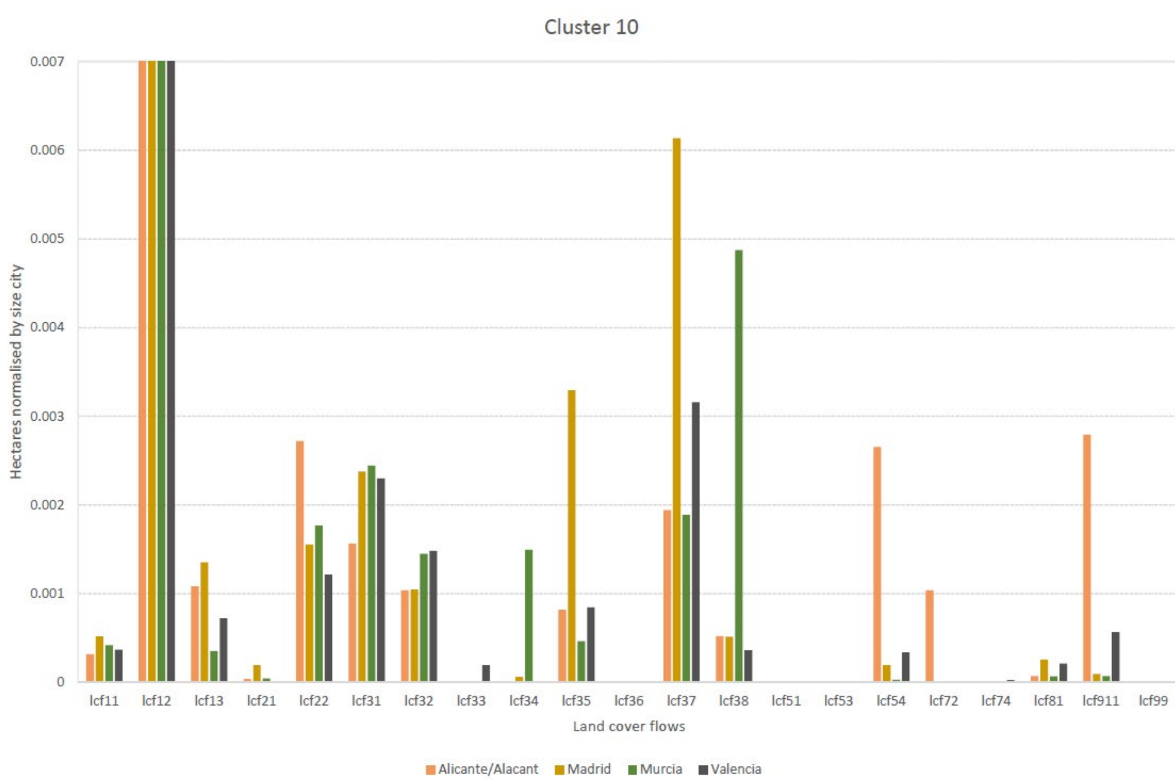
Land cover flows
Bydgoszcz
Gorzow Wielkopolski
Katowice
Kielce
Konin
Krakow
Lodz
Nowy Sacz
Plock
Poznan
Radom
Rybnik
Suwalki
Szczecin
Torun
Warszawa
Wroclaw
Palma de Mallorca
Vigo



Cluster 8
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Gdansk
Jastrzebie-Zdroj
Pabianice
Rzeszow
Santander



Cluster 9
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Lublin



Cluster 10
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Hectares normalised by size city
lcf11 lcf12 lcf13 lcf21 lcf22 lcf31 lcf32 lcf33 lcf34 lcf35 lcf36 lcf37 lcf38 lcf51 lcf53 lcf54 lcf72 lcf74 lcf81 lcf911 lcf99
Land cover flows
Alicante/Alacant
Madrid
Murcia
Valencia

Annex 7 Abstract of current Grassland HRL specification

The pan-European HRL Grassland 2015 product consists of three different layers:

- **Grassland (GRA)**

  A *grassland/non-grassland mask for the EEA39 area. This grassy and non-woody vegetation baseline product includes all kinds of grasslands: managed grassland, semi-natural grassland and natural grassy vegetation*

  Grassland HRL represents herbaceous vegetation with at least 30% ground cover, of which at least 30% graminoid species such as Poaceae, Cyperaceae and Juncaceae. It can include additional non woody plants such as lichens, mosses and ferns scattered trees and shrubs may be present, covering a maximum 10 %.

- **Grassland Vegetation Probability Index (GRAVPI)**

  Provides a measure of classification reliability

  Describes the reliability of the multi-seasonal optical grassland classification for the reference year 2015. Indicates to which degree grassland could be separated from other vegetated land cover types.

- **Ploughing Indicator (PLOUGH)**

  Represents historic land cover features with the aim to indicate ploughing activities in preceding years

  Estimates the temporal extent since last ploughing activity. PLOUGH is derived from historical bare soil time series (up to 6 years) of multi-temporal optical HR imagery. Each pixel value represents the latest bare soil indication (number of years prior to the target year) within the grassland mask.

The HRL2015 Grassland Layer was produced by using a combined optical/SAR data analysis approach based on data from the reference period 2015 +/-1 year. A variety of high resolution satellite images with multiple spatial resolutions were utilized for the production of the HRL Grassland layers. These include primarily the dense time series of the Sentinel 1 and Sentinel 2 archives of the Copernicus programme. Furthermore, Earth observation (EO) data from the USGS Landsat programme and Copernicus DWH HR_IMAGE_2012 datasets were used as supplementary data sources. [*all based on* 26]