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Exploratory research project interim report

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Contents

Abstract

ENACT ("ENhancing ACTivity and population mapping") is a JRC Exploratory Research Project involving various units at the JRC, and spanning 2 years (2016-2017).

Current knowledge of population distribution is still very limited even for Europe. Existing spatial datasets refer only to 'residential' population distribution, and more complete datasets reflecting spatiotemporal population variations are still lacking. Yet, this type of information is essential for multiple purposes such as analysis of human exposure, regional and urban planning and impact assessment of new investments or infrastructures.

ENACT aims at contributing to fill the existing knowledge gap by producing consistent, seamless, multi-temporal and high-resolution population distribution grid maps for Europe that take into account major daily and seasonal population variations. Most of ENACT's tasks consist of exploring and combining new and unconventional datasets which can be useful to map spatiotemporal population distribution.

In the herein interim report we describe with some detail ENACT's scope, objectives and workflow, and make an account of the state of the work conducted so far, with highlight to the tasks related to the literature review, activity mapping, and collection of population statistics at regional level.

1 Introduction

ENACT ("ENhancing ACTivity and population mapping") is an Exploratory Research Project awarded in 2015 by the JRC Scientific Committee, following a selection procedure. It has a duration of 2 years (2016-2017), and involves three units at the JRC:

- JRC.B.3, Territorial Development,
- JRC.B.6, Digital Economy, and,
- JRC.E.1, Disaster Risk Management.

ENACT fulfils the overall requirements of the 2015 call for Exploratory Research Projects at the JRC: a) it is an innovative project with ambitious goals, b) links multiple units and directorates within the JRC and, c) builds new scientific competences for future policy demands, not necessarily linked to existing policy support. Additionally, the expected outputs in terms of intermediate and final produced geo-datasets are expected to be useful to other activities at the JRC, namely for the territorial modelling community dealing with issues such as transport, land use, regional economy, etc., and for disaster risk assessment and management.

The project has been granted dedicated human resources both from existing personnel (partially dedicated to ENACT) and new recruits (i.e. three new recruits, one for each unit involved, fully dedicated to ENACT). The project officially kicked-off in January 2016. The first recruit joined unit JRC.B.3 on the 1st of August 2016. A second recruit joined unit JRC.E.1 on the 1st of November 2016, and third recruit is expected to join unit JRC.B.6 in 2017. Therefore, for most of 2016, the project ran understaffed, with impact on the schedule. Despite these limitations, significant progress has been accomplished throughout 2016.

In this project's interim report, we make an account of the state of the work conducted so far with highlight to the following tasks: literature review (chapter 2), activity mapping, and collection of population statistics at regional level (chapter 4). A thorough description of the project (objectives, product specifications, workflow and schedule) is provided in chapter 3. The report concludes with a discussion of the main risks and challenges identified for the remainder of the project. A number of relevant annexes complement the information provided throughout the report.

2 Background and state-of-the-art

The JRC has a long and recognized experience in population mapping and modelling. Since the early 1990's it has contributed to revolutionize the way population is represented and mapped at European level. From the early works of Gallego and Peedell (2001) to most recently Gallego et al. (2011) and Batista e Silva et al. (2013a), methods to map population have been experimented and refined, allowing the creation and update of maps representing residential population across Europe. Thanks to these early efforts, rudimentary – and to large extent ineffective – maps showing population density per administrative unit have been replaced by more realistic and useful depictions of population distribution at regular grid cell level, typically with a 100x100 meters resolution and usually referred to as 'population grids'. The data structure and high resolution of population grids allowed wider integration with other datasets in Geographical Information Systems (GIS), and thus have become indispensable datasets among both social and environmental researchers and spatial planners.

The main principle underlying the construction of such maps relies on the combination of two inputs: population counts usually available per administrative units or census zones, and a covariate of population distribution at higher spatial resolution, for example residential areas extracted from land use maps, building footprints, impervious surfaces, road network or even night-time lights from remote sensing imagery (for an extensive review of population estimation methods using GIS and Remote Sensing, see Wu et al. 2005). Using similar approaches, population estimates for the Urban Atlas polygons[1] have also been created at the JRC at the request of DG REGIO (Batista e Silva et al. 2013b, Batista e Silva and Poelman 2016). In addition, the JRC has achieved to model future population distributions at European level under different scenarios using the LUISA territorial modelling platform, given demographic projections, within-region migration and local potential for urbanization (Batista e Silva et al. 2013c, Lavalle et al. 2016).

Despite the many improvements introduced by different researchers over the years, European population grids are – still nowadays – essentially static maps of 'residential population'. Residential population refers to the number of people who declare to reside in a given location. As such, when mapping residential population we are essentially mapping the distribution of population during the night time, assuming that most people stay in their declared places of residence during the night for shelter and rest, and excluding the fraction of people who work outside their residences during night time. Maps of residential population have developed quicker due to easier access to data: all European National Statistical Institutes (NSI), at least once every 10 years, count systematically the number of residents per census zone.

Residential population grid maps, although sufficient for a range of purposes, describe only a fraction of reality. The spatial distribution of people during the daytime or where people stay in different seasons is practically unknown for any spatial scale. Yet, such information is essential to an all range of applications (Martin et al. 2010). The location of population during the day is determined by the location of economic, social and leisure facilities which pull population off their residences, driving commuting flows and other forms of daily trips. Daytime population distribution thus varies greatly from night-time distribution. Contrary to night-time population – which, as already mentioned, can be straightforwardly inferred

[1] Urban Atlas, http://land.copernicus.eu/local/urban-atlas/urban-atlas-2012/

by official statistics on residential population – it is much more challenging to infer daytime population distribution.

Addressing the needs of emergency response, compatible day- and night-time population grids have been produced in the mid-2000s for the USA (McPherson et al. 2004; Bhaduri et al. 2007). In Europe, such datasets have been mostly lacking, with only a few countries systematically collecting base data and modelling population distribution on the daily cycle (e.g. Ahola et al. 2007). More recent research (Martin et al. 2015; Martin et al. 2010; Aubrecht et al. 2014; Smith et al. 2016) has been increasing the resolution of the temporal component and/or including a seasonal dimension for limited regional areas by mining conventional data. Other authors have explored the contribution of non-conventional data such as mobile phone activity records (Deville et al. 2014; Tatem et al. 2014) or 'geotweets' (Patel el al. 2016) for population mapping in selected countries, a task which is not without shortcomings and challenges. A relatively straightforward approach was proposed to estimate day- and night-time population distribution at high resolution for the cities in Urban Atlas (Freire et al. 2015); yet its quality depends largely on that of ancillary datasets and availability of local parameters, and its accuracy is still uncertain.

The challenges posed by spatiotemporal mapping and modelling of population distribution cannot be addressed effectively by conventional data sources alone (e.g. official statistics and reference land use datasets). Significant advances in this field can only be attained if data from conventional data sources are combined with data from emerging, non-conventional data sources in a coherent methodological framework. Non-conventional data sources may include volunteered geographical information (Goodchild 2007), web-based social networks (Aubrecht et al. 2016), thematic proprietary databases, mobile phone operator data, or even navigation systems.

Data mining from such (big) data sources is becoming a common task in many geospatial applications. Craglia and Granell (2014) reviewed a range of projects leveraging citizen science or crowd sourcing in the area of environmental monitoring and smart cities application. There are several projects that demonstrate the benefits of combining official and non-official sources. These include for example the GEO-Wiki project focusing on global land cover validated by local people in a game-inspired apps, and its urban application Cities Geo-wiki2 whose aim is to map the physical geography of all major cities in the world to link to weather and climate models. Another approach to augment local land use and building use databases with crowd-sourced information is documented by Spyratos et al. (2014) who used data from 'Foursquare' to monitor the dynamic changes in building use in commercial areas. Other studies have also shown that thematic geospatial layers can be obtained from disparate data sources and integrated with existing land use maps for improved detail (Batista e Silva et al. 2013d; Jiang et al. 2015). One of the most promising data sources to estimate population density comes from mobile network operators. Several studies have documented the importance and usefulness of this data source (see for example Steenbrugger et al. 2014, and Deville et al. 2014), but one key problem remains data access, which is normally negotiated with the data providers by individual researchers for specific projects.

Until a few years ago, population grids were almost unknown to most researchers even in domains with a strong spatial dimension. But population grids gained momentum very rapidly, and have become mainstream input for many analyses. Eurostat, which was initially reluctant to publish population figures using non-conventional zoning systems, kicked-off the GEOSTAT project in 2010[2] to promote the production, dissemination and use of 'gridded' population among NSIs. But despite all the referred advances, Europe is still lacking a wall-to-wall, spatiotemporal model of population distribution. Given its experience in population mapping and big data mining, as well as its fast track connection to Eurostat and NSIs, the JRC, through the ENACT project, is in good position to expand upon the state of the art and fill the existing gaps in population mapping.

Box 1, below, summarizes the main challenges associated with spatiotemporal population mapping.

Box 1. Why mapping spatiotemporal population is a big challenge?

Fast population dynamics	People commute, travel, and migrate faster than ever before.
Multifaceted concept	While during the night most of us are 'resident population', during the day our (multiple) occupations relate to the (multiple) locations of probable presence.
Data availability issues	No official statistical sources exist. Daytime population needs to be inferred from multiple, indirect, and perhaps, *new* data sources.
State-of-the-art	Few case studies, often incomparable due to the use different methodologies and input data of different nature[3].

2 GEOSTAT initiative, http://ec.europa.eu/eurostat/web/gisco/gisco-activities/integrating-statistics-geospatial-information/geostat-initiative

3 See Annex 1 for an overview of previous efforts in spatiotemporal population modelling using conventional data sources.

3 Project description

3.1 ENACT in a nutshell

Population is a crucial variable for the social sciences, the geosciences and for policy support in many domains. Yet, our knowledge of its spatial distribution is still nowadays very incomplete. Population is a temporally dynamic variable, with major shifts in its distribution occurring in daily and seasonal cycles, resulting in rapidly changing densities.

Spatially detailed representations of residential population exist at EU level since several years. While these maps can be used as proxy for night-time population distribution, the distribution of population for other time frames is practically unknown at almost every spatial scale. Consequently, all applied sciences and policy support that require spatially detailed information on population distribution are based on only a fractional and static representation of reality. Overcoming this large knowledge gap is the main goal of the ENACT exploratory research project.

Several methodological challenges and data limitations have hindered progress in this field in the past. This project aims at addressing the challenges that are required to obtain (1) the amount of people per type of activity, per time-frame, and per region, and (2) their likely location at a high spatial resolution. The first element requires regional data on residents, employees per sector of activity, students and tourists, which can be derived mostly from official sources. The second element requires spatial data on the location of activities (e.g. manufacturing, retail, health, education, leisure/tourism), which will be sought from various conventional (e.g. remote sensing imagery, land use maps) and unconventional data sources (e.g. volunteered geographical information, large proprietary geo-databases, and web-services). The final challenge is to validate the produced multi-temporal population distribution grid maps. ENACT's output will be compared against reference data from independent sources such as multi-temporal population grids derived from mobile phone operator data or other sources (e.g. produced by other researchers), and micro-data from National Statistical Institutes (NSIs) on location of employment.

Ultimately, this project aims at developing and implementing a consistent and validated methodology to produce multi-temporal (i.e. including daily and seasonal variations) population distribution grids for Europe. Such datasets will expand the knowledge base of spatiotemporal population patterns across the continent. Moreover, multi-temporal population grids can be a useful and straightforward (i.e. easy to integrate) input to several models developed and run at the JRC, particularly transport, land use, economic and environmental models, and exposure to hazards, with potential positive impact on the reliability of assessments.

In addition to fostering a range of applications across Europe, the forthcoming public dissemination of ENACT's final outputs may increase awareness among national authorities on the importance of collecting good quality data on population and location of activities.

Box 2. ENACT's methodology in brief

The following questions define the main methodological aspects that need to be addressed by ENACT in order to produce multi-temporal population grids for Europe:

Question 1a: How many people are inside and outside their residences during the day in each region?

Action: To estimate total population per type of main activity, per NUTS3 region.

How: By assembling official data from Eurostat on the no. of workers per sector of economic activity, no. students per main educational levels, no. of tourists, and number of inactive population (and thus likely to be at home during the day) per region.

Question 1b: What is the seasonal variation of total present population in each region?

Action: Seasonal variation of total present population in a region is mostly due to touristic flows. Therefore, inbound and outbound tourist flows of each region per season (or per month) must be taken into account by ENACT.

How: By first downscaling total yearly nights-spent per NUTS2 to NUTS3 using the no. of beds per NUTS3. Then, breaking down the NUTS3 yearly nights-spent per month using, as proxy, monthly flight traffic information from Eurostat. Monthly nights-spent per region can then be easily converted to average no. of tourists present in a given month by dividing total nights-spent in a month by the total no. of days comprised in that month. Finally, the number of tourists present in given a region in a given month are removed from their likely regions of origin.

Question 2: Where do people spend their time during the day and night?

Action: There is no one-stop shop for such multi-sector, highly detailed locations of activities. ENACT needs to resort to various sources, proprietary and open-source, conventional and non-conventional. Specific population sub-groups then need to be allocated to locations of probable presence.

How: By extracting relevant activity-location data from multiple sources, namely conventional (e.g. LULC maps, remote sensing), volunteered geographic information (e.g. OpenStreetMap), web-based services, and proprietary sources (e.g. TomTom, PLATTS, GISCO-EuroGeographics, etc.). At night-time, residents will be located to residential areas, and tourists to touristic accommodation facilities. At daytime, the various population sub-groups (e.g. students, workers per sector of activity, tourists) will be allocated to the relevant activity types based on a probability matrix.

Question 3: How accurate are ENACT's multi-temporal population grid maps?

Action: To compare ENACT's outputs with other reference data.

How: By resorting in particular to emerging population density grid maps derived from mobile phone operator data, but also to existing employment grids produced by some NSIs. Comparing ENACT's grids with grids from other researchers is an additional option.

3.2 Specific objectives of ENACT

The ultimate objectives/outputs of ENACT are as follows:

— In terms of data production:

- To produce a set of multi-temporal population grid maps that take into account the main seasonal and daily variations of population, consistent with the most recent census data (2011), and covering the largest possible number of EU28 countries. ENACT aims at least 6 population grid maps, covering 3 main seasons of the year (summer, winter, spring/autumn), for both night- and daytime.

— In terms of dissemination of methods and results:

- To write a scientific paper summarizing the methodology and results and submit it to a high-impact geographical science journal;
- To disseminate the final multi-temporal population grids following the INSPIRE directive standards, using JRC web channels.

To fulfil the above objectives, the following intermediate objectives/outputs of ENACT are expected:

- To review the most recent and significant scientific literature on daytime (or multi-temporal) population mapping;
- To build a database of population stocks at regional level (NUTS2/3) with no. of residents, employed population per main sector of activity, nr. of students, nr. of tourists and inactive population. The database must have a temporal dimension (seasonal or monthly);
- To build a geodatabase with land use and activity information at the highest possible thematic and spatial resolution by assembling data from both conventional and non-conventional sources;
- To produce an enhanced version of the CORINE Land Cover Map 2012, with improved spatial resolution (minimum mapping unit of 1 hectare instead of 25) and thematic resolution (further breakdown for specific CLC's LULC classes);
- To compare ENACT's multi-temporal population grids with other independent sources, namely multi-temporal population grids derived from mobile phone operator data or other sources (e.g. produced by other researchers), and micro-data from National Statistical Institutes (NSIs) on location of employment[4].

3.3 Main specifications of output datasets

As per the above objectives, two sets of data will be produced, (a) geodatabase with land use and activity information, and (b) multi-temporal population grid maps. The former item comprises individual datasets with location of specific activities, plus an overarching land-use map herein referred to as CLC-R 2012. CLC-R 2012 is a refined version of CLC 2012, with increased spatial and thematic resolution, and built by integrating geodata from multiple sources (see Annex 4). Because CLC-R contains the location of many types of activities, it will be the backbone for the subsequent production of the multi-temporal population grid maps.

[4] The comparison exercise, however, may only be feasible for selected regions or countries in Europe, depending on the amount of reference data the project is able to collect and handle.

Table 1 summarizes the main specifications (spatial coverage, spatial, thematic and temporal resolutions, reference dates) of the two sets of data. Figure 1 shows the area of interest of ENACT.

The multi-temporal population grid maps have a more limited spatial coverage than the CLC-R because they require, as input, statistical data which is not fully available from Eurostat for countries outside EU28. The spatial resolution is also somewhat more limited for the final multi-temporal population grid maps due to the inability to validate these maps at a resolution below 1 Km. The temporal resolution is yet to be defined, but ENACT aims at least 6 maps (summer, winter, spring/autumn x day- and night-time). The possibility to have higher temporal resolution (e.g. 24 maps, each month x day- and night-time) is currently under consideration depending on whether we will be able to break down yearly tourist stocks per month.

Table 1. Main expected specifications of output datasets.

	Land use and activity data (CLC-R)	**Multi-temporal population grid maps**
Spatial coverage	EU28 + EFTA + Balkan countries + Turkey (see figure 1)	EU28 (see figure 1)
Spatial resolution	100 m	100 m (production) 1 Km (dissemination)
Temporal resolution	Single year	Monthly or seasonal x day- and night-time
Thematic resolution	~ 10 separate land use categories relevant for population mapping (see Annex 2)	Population per various sub-groups (residents, employees per sector of activity, students, tourists, inactive)
Reference date	2012	2011

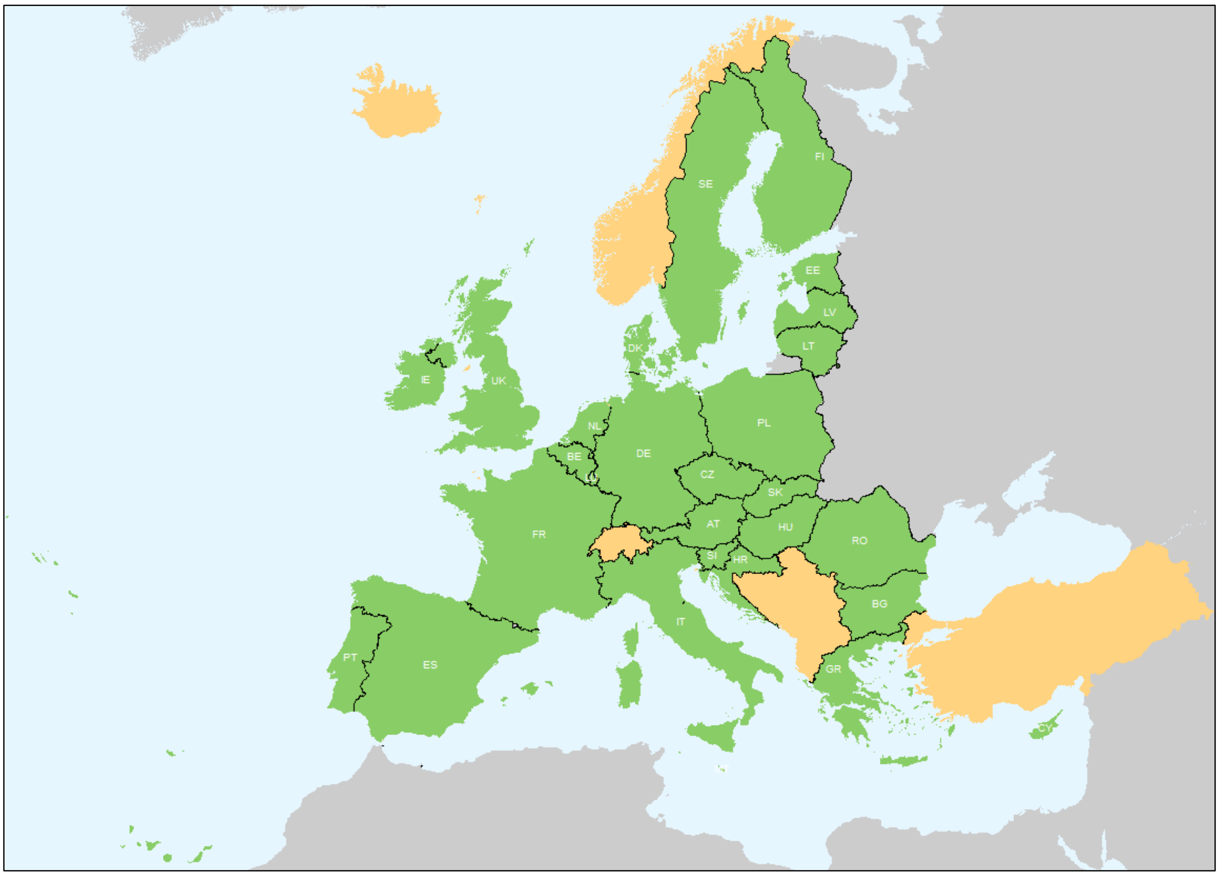

Figure 1. Area of interest of ENACT. Legend: Green: area of interest for the multi-temporal population grids (EU28); Yellow: area of interest for land use and activity data; Grey: outside area of interest.

3.4 Workflow and schedule

The main phases and tasks of the project are mapped in the Gantt chart of Figure 2, with an approximate schedule of the work. The herein project planning is a revision of the original schedule included in the project proposal. It has a slightly revised arrangement of the main phases, and divides each of the 6 mains phases into sub-activities or tasks. The green bars correspond to the originally scheduled duration of each task. The grey bars correspond to the revised duration. For many tasks, the duration was prolonged for additional months as the project ran significantly understaffed for most of 2016. The flowchart in Figure 3 shows how the main phases of the project (in square brackets) are interconnected.

The first, crucial phase of the project ('Preparation') paves the way for a structured and solid kick-off. It includes a literature review of the most recent and relevant work in the field, as well as an inventory of the data needs and potential data sources. In addition, linkages between the nomenclatures used in the various data sources will be established, using the NACE rev.2 as pivotal nomenclature.

The second phase ('Regional flows and stocks of people') includes the collection of statistical data primarily from official sources (Eurostat and NSIs). The statistical data will be worked in order to produce seasonal or monthly regional balances of various population sub-groups, namely: residents, workers per 6 sectors of economic activity, students, tourist and inactive population.

The third phase ('Activity mapping') goes in parallel with the second phase, and consists of collecting land use and activity location data from all available data sources. These data will be combined to improve both the spatial and thematic resolutions of CLC 2012, and thus generate the 'CLC-R'. The CLC-R will be the base map for the allocation of population sub-groups in different land use and activity categories for different time-frames (seasons or months and night-time and daytime). The spatial allocation, or disaggregation, of population will be carried in the fourth phase of the project ('Modelling spatiotemporal population distribution').

In the fifth phase of the project ('Validation') a comparison will be made between ENACT's main outputs (i.e. multi-temporal population grid maps) and reference data from independent sources, namely multi-temporal population grids derived from mobile phone operator data or other sources (e.g. produced by other researchers), and micro-data from National Statistical Institutes (NSIs) on location of employment. With the comparison exercise, we expect to assess the validity of ENACT's outputs. Although the ENACT's outputs may not be fully comparable with the independent sources used in the validation (e.g. due to differences in total estimated population within a given spatial unit of analysis), appropriate indicators will be established to check the degree of agreement in terms of relative difference of population between various time frames (e.g. night-time vs. daytime, or season/month 'A' vs. season/month 'B'). The comparison exercise may only be feasible for selected regions or countries in Europe, depending on the amount of reference data the project is able to collect and handle. The validation is indispensable for the 'Reporting and dissemination' of ENACT's outputs (phase 6 of the project).

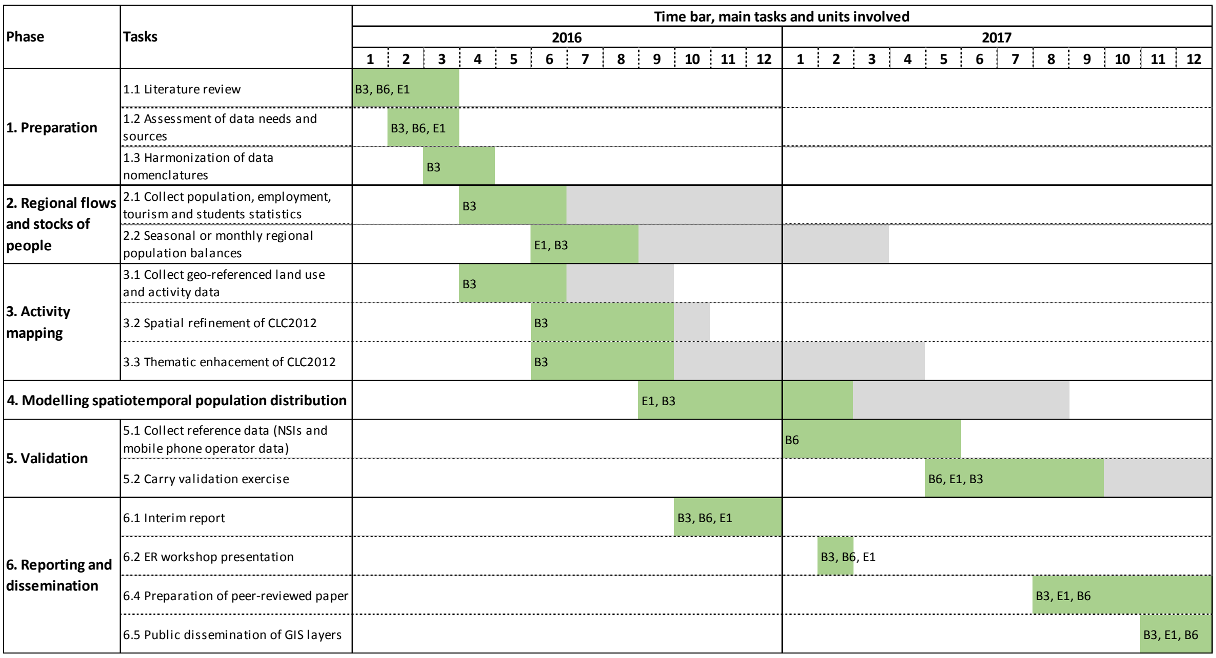

Figure 2. Schedule of main phases and tasks and units involved.

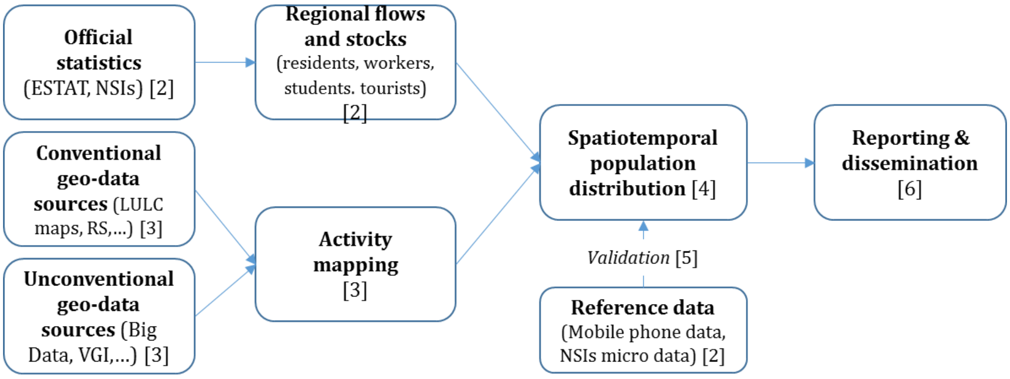

Figure 3. Workflow and interlinkages between the project's main phases.

4 State of the work

So far we have mostly focused on phases 1, 2 and 3 of the project, although some preparatory tasks for the subsequent phases have also initiated. Below we list and describe the main tasks completed, on-going and forthcoming.

Table 2. State of the work.

Phase/task	Description	Actors	Dependencies	Status
1. Preparation				
1.1 Literature review	'First round' of literature review of multi-temporal population mapping to steer the kick-off of the project. 'Second round', complementary literature review to done by the time of the writing of the final paper.	B3, B6, E1	None	'First round' of review complete. See summary in chapter 2 of the herein report + annex 1.
1.2 Assessment of data needs and sources	List of potentially useful sources of geographical and statistical data to be used in different stages of the project.	B3, B6, E1	1.1	Complete. See annex 5.
1.3 Harmonization of data nomenclatures	Check data nomenclatures and classifications from the different sources of data useful to the project. Make the necessary correspondences between classifications.	B3	1.2	Complete.
2. Regional flows and stocks of people				
2.1 Collect population, employment, tourism and students statistics	Collection of raw statistical data from Eurostat on number of residents, employees per sector of economic activity, students per main educational levels, number of nights-spent by tourists, per NUTS2/3, and flight data per airport, unemployment rates.	B3	1.2	On-going (close to completion).
2.2 Seasonal or monthly regions population balances	Production of seasonal or monthly tables of population balances per NUTS3 and per the following population categories: resident population, employees (per sector of activity), students (per main educational levels), tourists, and non-active population, taking into account outbound tourism and to avoid double counting of population.	E1, B3	2.1	On-going (just initiated).
3. Activity mapping				
3.1 Collect geo-referenced land use and activity data	Collection and preparation of available data on land use and activities locations from multiple sources (open/proprietary, conventional/non-conventional).	B3	1.2	Complete.
3.2 Spatial refinement of CLC 2012	Improvement of the spatial resolution of CLC 2012. Reduction of minimum mapping unit (MMU) from 25 ha to 1 ha for all 'artificial surfaces' group of LULC classes. See Annex 4 for a more complete description.	B3	3.1	Complete.
3.3 Thematic refinement of CLC 2012	Improvement of the thematic resolution of CLC 2012. Add additional breakdown ('level 4') to some 'artificial surfaces' LULC classes.	B3	3.1, 3.2	On-going.

4. Modelling spatiotemporal population distribution				
Modelling spatiotemporal population distribution	Downscaling of multi-temporal population balances per NUTS3 (task 2.2) to grid cell level, based on the location of land uses and activities.	E1, B3	2, 3	On-going. First prototype scripts under constructi on.
5. Validation				
5.1 Collect reference data (NSIs and mobile phone operator data)	Establish methods to estimate population density distribution from network-based mobile phone data[1]. Obtain data on population densities derived from mobile phone operator data (MPOD). The sample should ideally include more than one European region/country, and have both daily and seasonal resolution. Obtain employment grids for a sample of European regions/countries.	B6	1.2	On-going. Data for Belgium collected (see figure 4).
5.2 Carry validation exercise	Define a methodology for the validation exercise. Preparation of MPOD for the comparison with ENACT's multi-temporal population grids. Construct indicators of agreement between the reference grids and ENACT's multi-temporal population grids.	B6, E1, B3	4.1, 5.1	To be initiated.
6. Reporting and dissemination				
6.1 Interim report	Interim report describing the project's objectives and progress of the work.	B3, B6, E1	n.a.	Complete.
6.2 Exploratory research workshop presentation	Oral presentation of the project's progress to the JRC Scientific Committee.	B3, B6, E1	n.a.	To be scheduled.
6.3 Preparation of peer-reviewed paper	Scientific paper describing the newly produced datasets.	B3, B6, E1	4, 5	To be initiated.
6.4 Public dissemination of GIS layers	Public dissemination of GIS layers, possibly using JRC web channels.	B3, B6, E1	4, 5	To be initiated.

Notes:
[1] Published journal article "Estimating population density distribution from network-based mobile phone data" PUBSY JRC96568.

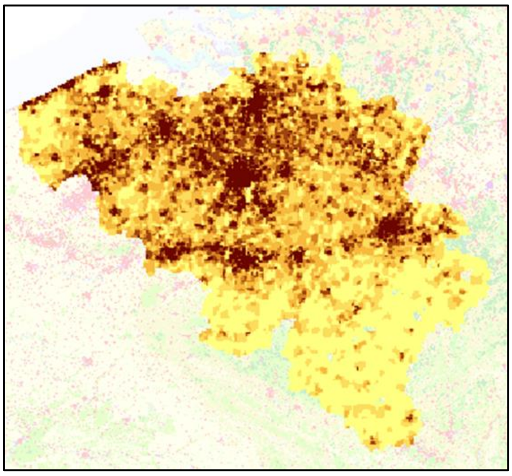

Figure 4. Population density in 8/10/2015, derived from mobile phone operator data (Proximus), in Belgium at 1 km resolution.

4.1 Participation in events

The ENACT project has already been presented in the following occasions/events/working groups:

- 10-12 November 2015: European Forum for Geography and Statistics (EFGS) 2015 Conference, Vienna, Austria.
    - Presentation by Filipe Batista e Silva titled ”The ENACT project: Towards spatiotemporal population mapping”.
- 12 February 2016: 1st JRC-Eurostat workshop on Big Data, Ispra, Italy.
    - Presentation by Filipe Batista e Silva titled ”The ENACT project: Towards spatiotemporal population mapping”
- 1-2 September 2016: JRC Big data for science and policy workshop, Ispra, Italy.
    - Presentation by Filipe Batista e Silva titled ”Big data for 'Enhancing activity and population mapping'”.
- 22 November 2016: ERSA/REGIO/UCL joint international workshop ”How can regional policy benefit from Big Data?”, Louvain-la-Neuve, Belgium:
    - Presentation by Filipe Batista e Silva titled ”Spatiotemporal population mapping in Europe”.
- Participation in the work of the European Statistical System Big data Task Force chaired by ESTAT which is the forum in which collaboration with statistical agencies and some mobile phone operators takes place that can assist in the validation of the ENACT outputs (Massimo Craglia).
- Participation in collaborative work between ESTAT, the Belgian Statistical agency, and Proximus mobile phone operator[5] (Massimo Craglia).

[5] See description here: http://economie.fgov.be/fr/binaries/Carrefour_economie_2016_10_tcm326-280315.pdf pages 38-53

5 Conclusions, main risks and challenges ahead

The work is progressing well given the stated limitations (project running considerably understaffed for most of 2016). Nonetheless, significant progress has been made (see summary in chapter 4). As main milestones achieved, we highlight the conclusion of the spatial refinement of CLC-R 2012, and the collection of most data inputs necessary for the detailed mapping of activities and construction of regional population balances.

At project proposal stage, we had identified the following main risks:

1. The collection of land-use relevant VGI has not been assessed at EU scale: addressing redundancy between data sources and assessing data quality (i.e. completeness, consistency, update…) at EU level are key challenges.
2. The accuracy levels of the resulting population grids will determine the appropriate spatial resolution of the final layers for public dissemination. A low spatial resolution (e.g. cell size > 1 Km) can limit the range of potential applications.
3. The delivery schedule and sample size of the mobile phone data are not fully known at this stage.
4. Potential delays in the production of the CLC 2012 for some countries could lead to gaps in the spatial coverage of the CLC-R 2012.

Risks 2 and 3 remain open at the current stage of the project. Risk 1 will be address by applying Machine Learning methods to classify CLC-R polygons into a more detailed a set of discrete LULC classes. Risk 4 is now obsolete. CLC 2012 has been completed and is available at the Copernicus Land Monitoring Service website. The spatial refinement of CLC 2012 has been already accomplished for the entire extent of the CLC mapped area. The thematic refinement of CLC is on-going and progressing as expected so far.

However, as the work progressed, we identified additional challenges:

— Related to the construction of NUTS3 population balance tables:

- Tourism and student data only available at NUTS2 for some countries – downscaling to NUTS3 possibly using proxies;
- Breakdown of yearly NUTS3 tourists per season/month necessary. Method based on using monthly flight traffic as proxy still under testing phase;
- Workers in one NUTS3 region can be resident in another NUTS3 region (commuting between NUTS3). Commuting data between municipalities or even NUTS3 seems to be completely inexistent at EU-level. Pragmatic assumptions might be necessary;
- Statistics for active/inactive population and unemployment available only at NUTS2. Downscaling to NUTS3 might be necessary using proxies available at NUTS3 (e.g. total population and population per age-groups).
- Inbound tourists in one NUTS3 have other NUTS3 as regions of origin which need to be identified. Method still to be defined;
- Construction of NUTS3 consistent population balance tables that avoid double counting of total population.

— Concerning the disaggregation of population stocks from regional to pixel level:

- The relationship between certain population sub-groups (e.g. employees per sector of economic activity or tourists) and the land uses is of 'one-to-many'. In other words, a population category can occur in more than one land use type. This will inevitably call for additional parametrization of the downscaling algorithms, possibly using probability matrices defining the probability of land use class holding population from the various sub-groups.

— Related to the use of 'Big Data' sources:

- Extraction/mining/scrapping of data from the web is sometimes challenging (a dedicated procedure needs to be constructed for each website);
- The big data sources screened for the ENACT project are mostly proprietary, with strict terms and conditions of use;
- Dialogue with individual data providers would be required to gain legal access;
- Quality of data unknown: difficult to measure accuracy and completeness of bottom-up generated data;
- Methodological challenges: making sense out of the multiple big data sources for our specific needs.

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List of abbreviations and definitions

CLC	CORINE Land Cover
CLC-R	CORINE Land Cover – Refined
EC	European Commission
EFTA	European Free Trade Association
EPRTR	European Pollutant Release and Transfer Register
ESM	European Settlement Map
GIS	Geographical Information Systems
JRC	Joint Research Centre
LULC	Land use/land cover
MMU	Minimum Mapping Unit
MPOD	Mobile Phone Operator Data
NACE	Nomenclature Statistique des activités économiques dans la Communauté européenne
NSI	National Statistical Institute
NUTS	Nomenclature of Territorial Units for Statistics
OSM	OpenStreetMap
VGI	Volunteered Geographic Information

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Annexes

Annex 1. Literature review

The table below provides an overview of previous efforts in spatiotemporal population modelling using mostly conventional data sources (i.e. excluding studies using mobile phone data, social media and other 'big data' sources).

Publication (Authors and year)	**Main application / objective**	**Temporal resolution**	**Spatial resolution**	**Study area**	**Proxies for population allocation**	**Method**
McPherson & Brown, 2004	Emergency response (manmade disaster - release of hazardous material)	Night-time / Daytime	250 m	USA	StreetMap USA ESRI/GDT 1998; NAVTEC Premium Streets Data; State Business Directory	Night-time population: disaggregation of census data based on road network; Daytime population: worker population disaggregated based on State Business Directory + residual residential population
Ahola et al. 2007	Risk assessment and damage analysis (fire and rescue services)	14 time periods	Vector based (building level)	Helsinki (centre), Finland	Buildings; Enterprise and agency data related to buildings; Person traffic data; Shopping centres; Kindergartens; Schools; Central traffic buildings	Disaggregation into point locations using a matrix of weights (per population subgroup and time period), includes expert knowledge based weights
Bhaduri et al. 2007	Enhancing the temporal resolution of population distribution data in the US (general purpose)	Night-time / Daytime	3 arc seconds (~90 m)	USA	Roads, Railroads; Airports; Large Area Landmarks; Water; Recreation Areas; Retail Centers; National Land Cover Data; Elevation Data; Education; Employment; Jails and prisons; Aerial imagery	Disaggregation into cells based on modelled cumulative weights. Methodology includes extensive manual checking and refinement
Aubrecht et al. 2014	Social impact evaluation in crisis management	Quasi continuous (1 hour step)	100 m	Baden, Austria	Land use / Land cover (national data, CORINE, Urban Atlas); Street network; Building layer	DynaPop model – three components of population (Home, Commuting, Work), disaggregated from census zone level to grids using a set of spatial and temporal weights
Freire et al. 2015	Assessment of human exposure to volcanic hazard	Night-time / Daytime	50 m	Naples, Italy	Urban Atlas; European settlement map; LandScan; Census tracts	Night-time population: disaggregation of census data based on land use; Daytime population: derived using commuting ratios + estimated

						residual residential population
Martin et al. 2015	Proposal and implementation of a flexible framework for spatiotemporal population modeling	Quasi continuous (15 min. step)	200 m	Southampton, UK	Residential locations; Prisons; Care homes; Workplaces; Schools; Universities; Hospitals; Roads	SurfaceBuilder 247 – variable kernel density estimation; several age/activity based population subgroups are redistributed across space subject to a series of weights, constraints and temporal profiles
Smith et al. 2015	Assessment of human exposure to flood risk in a coastal touristic region	Quasi continuous (1 h step)	100 m	St Austell area, UK	Centroids representing residential locations; Centroids representing places of work, study, leisure, healthcare and retail; Roads	
Smith et al. 2016	Assessment of urban exposure to flood risk	Quasi continuous (2 h step)	200 m	Southampton, UK		

Annex 2. CLC-R nomenclature for 'Artificial surfaces'

Level 1	Level 2	Level 3	Level 4	Brief description / examples
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric	1111 Dense urban fabric	Predominantly residential areas at different degrees of horizontal building density. High density areas, particularly in the centre of cities may be characterized by mixed land uses (e.g. residential, commercial, public services).
		112 Discontinuous urban fabric	1121 Medium density urban fabric	
			1122 Low density urban fabric	
			1123 Very low density or isolated urban fabric	
	12 Industrial, commercial and transport units	121 Industrial or commercial units	1211 Industry	Manufacturing facilities, refineries, large farm buildings.
			1212 Energy production, water supply, waste management.	Power plants (non-renewable and renewable), water supply, waste management and treatment plants.
			1213 Commerce and private services	Wholesale, retail and business areas, office buildings, exposition sites, research facilities, food and beverage services (e.g. bars and restaurants).
			1214 Public administration, defense and social facilities	Large facilities related to health care, education, public administration, security, law and order services, military barracks.
			1215 Cultural facilities	Arts and cultural facilities (e.g. museums, libraries, theaters), monuments, places of worship.
		122 Road and rail networks and associated land	1221 Road network	Main road network (consisting of motorways and other main national links).
			1222 Rail network	Wide rail segments.
			1223 Train or ferry station	Train or ferry stations / terminals.
			1224 Other road and rail associated land	Eg. rest areas, service stations.
		123 Port areas		See CLC nomenclature illustrated guide.
		124 Airports	1241 Airport terminals and associated buildings	Airport terminals and associated buildings.
			1242 Airport runway and associated land	Airport runway and associated land.
	13 Mine, dump and construction sites	131 Mineral extraction sites		See CLC nomenclature illustrated guide.
		132 Dump sites		
		133 Construction sites		
	14 Artificial, non-agricultural vegetaged areas	141 Green urban areas		
		142 Sport and leisure facilities	1421 Sport and leisure green	Other artificial green areas (typically surrounding sport and leisure facilities). Includes golf courses.
			1422 Sport and leisure built-up	Built-up areas related to sports and leisure activities (e.g. stadiums, sports halls, zoos, luna parks).
			1423 Touristic accomodation	Hotels and similar accomodations; camping/trailer sites.

Present in CLC-R v1
Present in CLC-R v2
Presence in CLC-R v2 to be determined
No further level 4 expected

Annex 3. Classification of economic activities (NACE rev. 2)

6 sectors	
A	Agriculture, forestry and fishing
B-E	Industry
F	Construction
G-J	Wholesale and retail trade; transport; accommodation and food service activities; information and communication
K-N	Financial and insurance activities; real estate activities; professional, scientific and technical activities; administrative and support service a…
O-U	Public administration and defence; compulsory social security; education; human health and social work activities; arts, entertainment and recreation.

11 sectors	
A	Agriculture, forestry and fishing
B,D,E	Mining and quarrying; electricity, gas, steam and air conditioning supply; water supply, sewarage, waste, management and remediation activities
C	Manufacturing
F	Construction
G,H,I	Wholesale and retail trade; transport and storage; accomodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate
M,N	Professional, scientific and technical activities; administrative and support service activities
O,P,Q	Public administration, defence; education; human health and social work activities
R,S,T,U	Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies

21 sectors	
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Transportation and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
T	Activities of households as employers; u0ndifferentiated goods- and services-producing activities of households for own use
U	Activities of extraterritorial organisations and bodies

Annex 4. Short description of the CLC Refined 2012 (v1.0)

Prepared by Filipe Batista e Silva and Konstantin Rosina

Document version: November 2016

Introduction

The CORINE Land Cover (CLC) is a European land use/land cover (LULC) mapping project initiated in the mid-1980's. The first inventory was released for the reference year 1990, and subsequent updates have been produced for the reference years 2000, 2006 and 2012[6]. The CLC is produced under the coordination of the European Environment Agency (EEA), using a common LULC nomenclature, mapping specifications and methodologies, meant to ensure a high degree of comparability across time and countries covered, thus making it a reference and widely used data source for LULC information in Europe.

CLC, however, is characterized by a relatively coarse minimum mapping unit (MMU) of 25 hectares for all LULC categories, which is a limiting factor for applications requiring a finer detection of LULC patterns. Another key limitation, particularly, for applications related to urban areas, population and economic activity, concerns the low thematic resolution for artificial LULC classes. The European Commission Joint Research Centre (JRC) has been engaged in developing and implementing a methodology to address the above-mentioned limitations of CLC, so to release an enhanced European LULC map, labelled "CLC refined" (CLC-R). This work is conducted by JRC's own initiative, as an element of its work programme.

As its name indicates, the CLC-R 2012 (v1.0) is an enriched version of CLC 2012, with a significantly higher spatial resolution of 1 hectare for artificial LULC categories and at least 5 hectares for non-artificial ones. The methodology is based on the integration of LULC-relevant information from multiple CLC 2012-compatible geodata sources (particularly the Copernicus "High Resolution Layers", amongst others). A forthcoming version of CLC-R 2012 (v2.0), expected by mid-2017, will address the improvement of the thematic detail of CLC 2012, namely by breaking down CLC's LULC category "121 – Industrial or commercial sites" into various sub-classes linked to specific socio-economic sectors. The work herein referred follows and expands upon previous experience of refining the CLC 2006[7].

The remainder of the document covers the main objectives concerning the production of CLC-R 2012, its main characteristics, input data and methodological steps. A more thorough description of the methodology is under preparation and will be published as a JRC Technical Report.

Objectives

The main objective set for CLC-R 2012 (v1.0) was the increase of CLC's spatial resolution (i.e. reduction of the minimum mapping unit) while preserving the thematic detail and definitions of CLC. Another objective was to attain a more detailed and consistent

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[6] For more info on CLC family of products: http://land.copernicus.eu/pan-european/corine-land-cover/

[7] Batista e Silva F, Lavalle C, Koomen E (2013) A procedure to obtain a refined European land use/cover map. Journal of Land Use Science 8(3): 255-283.

classification of the 11X - Urban fabric classes, using an unambiguous, quantitative approach to identify urban fabric of different densities.

The immediate usage of the CLC-R 2012 within the JRC is twofold:

- To be used as base map in LUISA's territorial modelling platform[8];
- To be used as input to the ENACT JRC exploratory project aiming at the enhancement of activity and population mapping.

The CLC 2012 refined (v1.0) can, in addition, be used for a wide range of other purposes and applications, within the JRC and elsewhere.

Main characteristics of CLC-R 2012

<u>Spatial resolution</u>: Minimum mapping unit of ~5 hectares (1 ha for artificial surfaces and for all LULC classes in areas covered by the Urban Atlas dataset – European Functional Urban Areas (FUAs) above 50,000 inhabitants). Width of linear features of ~20 m. Cell size = 100 x 100 metres.

<u>Thematic resolution</u>: Same as in CLC 2012, with the following additional LULC classes: 410 - Inland wetlands (a union of 411 - Inland marshes and 412 - Peatbogs); 113 - Urban fabric low density (10-30% built-up); 114 - Urban fabric very low density and isolated (<10% built-up); 143 - Leisure and touristic built-up.

<u>Geographical coverage</u>: EU28 + EFTA + Western Balkans + Turkey, including Islands, Azores, Canary Islands, Madeira, Ceuta, and Melilla and excluding French overseas territories.

<u>Reference year</u>: 2012

<u>File format</u>: Unsigned 8-bit raster file (available as GeoTIFF and File GeoDatabase Raster Dataset)

Input Data

The CLC-R 2012 (v1.0) is a composite map whereby information from multiple geodata sources has been integrated with the original CLC 2012 in a sequential order, following certain rules and criteria (see methodology section below). Input data sources have been harvested from and selected based upon the compliance with following criteria:

- Compatibility with CLC's LULC nomenclature (LULC class definitions);
- Reference year 2012 +/- 2;
- Higher spatial resolution than CLC 2012;
- Pan-European geographical coverage;
- Preferably free, open and documented data.

The input data sources are listed below:

- <u>CLC products</u>: CLC 2012 v 18.5, CLC Changes 2006-2012 and CLC Changes 2000-2006;

[8] For more info on LUISA territorial modelling: https://ec.europa.eu/jrc/en/luisa/

- Copernicus high resolution (HR) layers 2012: HR layer Forest type + Tree cover density, HR layer Permanent water bodies, HR layer Wetlands;
- TomTom Multinet 2014: Land Use layer + Built-up layer;
- JRC's European Settlement Map (ESM) (10m version, aggregated to 100 m reference grid);
- Urban Atlas 2012: All available FUAs by October 2016 (580).
- OpenStretMap (OSM) and TomTom Multinet 2014 as source of road network data.

Methodology

The methodology consisted of a sequential integration of LULC information from multiple geodata sources into the original CLC 2012 map. At each step of the sequence, specific input data layers were used to recode the grid cells with which they overlaid spatially, following pre-established decision rules. Each step typically deals with the integration of one particular data input from the above mentioned sources.

The order of the sequence is determined by the degree of spatial detail and accuracy of the data source at hand (the more detailed and accurate, the later in the sequence), or by other logical considerations (e.g. linear features are added later in the process due to less strict MMU). Each step is automatized as a separate GIS tool. The table below describes the main steps of the workflow:

Step	Input data source	Description of procedure	Affected LULC classes
1	CLC change maps	Selected CLC change patches that were not included into CLC2012 map due to generalization rules are added.	All
2	Copernicus High resolution layers	A threshold of 50% is applied to the continuous pixel values (i.e. the respective class must cover the majority of pixel to be considered). A MMU of 5 contiguous pixels is applied.	31X, 41, 51X
3	TomTom Multinet 2014 – Land Use layer	Land use information from TomTom are added. A look-up table is used to establish the relationship between the TomTom and CLC nomenclatures. Vector polygons are rasterized using Maximum Combined Area criterion. Applied MMU = 1 pixel, i.e. individual pixels are included.	121, 122, 123, 124, 141, 142
4	European Settlement Map	First, a 100 m raster coincident with EEA reference grid is derived from the original 10 m version. Pixels overlapping non-residential artificial classes are excluded, as are the pixels under minimum building density threshold (empirically derived value of 5%). Applied MMU = 1 pixel, i.e. individual pixels are included.	11X
5	Urban Atlas 2012	Vector polygons are rasterized using Maximum Combined Area criterion; a decision matrix (original CLC class vs. urban atlas class) is used to establish	All

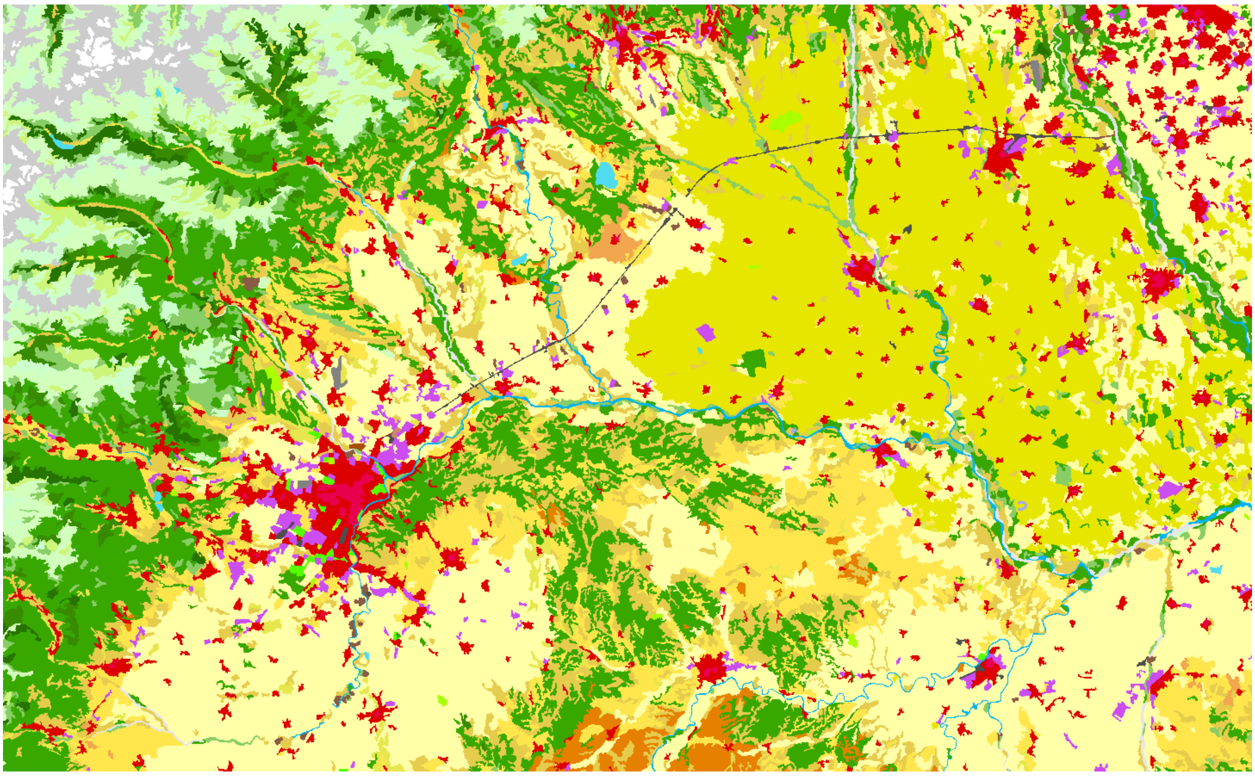
		the final classification of overlapping pixels. Applied MMU = 1 pixel, i.e. individual pixels are included.	
6	European Settlement Map	The general 11X class 'urban fabric' is differentiated into 4 classes according to the underlying building density (based on ESM data) – 111 - dense, 112 - medium density, 113 - low density, 114 - very low density or scattered built-up.	11X
7	HR layer Permanent water bodies + OSM and TomTom Multinet 2014 – Road networks	Linear features such as rivers and mains roads are included. The inclusion of linear features obeys to less restrictive thresholds of within-pixel cover so to preserve as much as possible the spatial contiguity of these features (in view of their distinct function and importance in structuring and fragmenting the territory). However, within artificial areas, linear features are included only when the percentage covered is larger than that of building cover.	122, 51X
8	European Settlement Map	Built-up areas in the class 142 - Sport and leisure facilities are extracted as a separate class 143 - Leisure and touristic built-up.	142, 143
9	TomTom Multinet 2014 – Built-up layer	Areas pertaining to Local Administrative Units (LAU2) for which the amount of built-up is significantly lower than expected (given an empirical relationship between size of the population and urban fabric surface) are refined by adding built-up areas from the TomTom built-up layer. Added built-up areas are coded as 114 - very low density or isolated built-up.	114

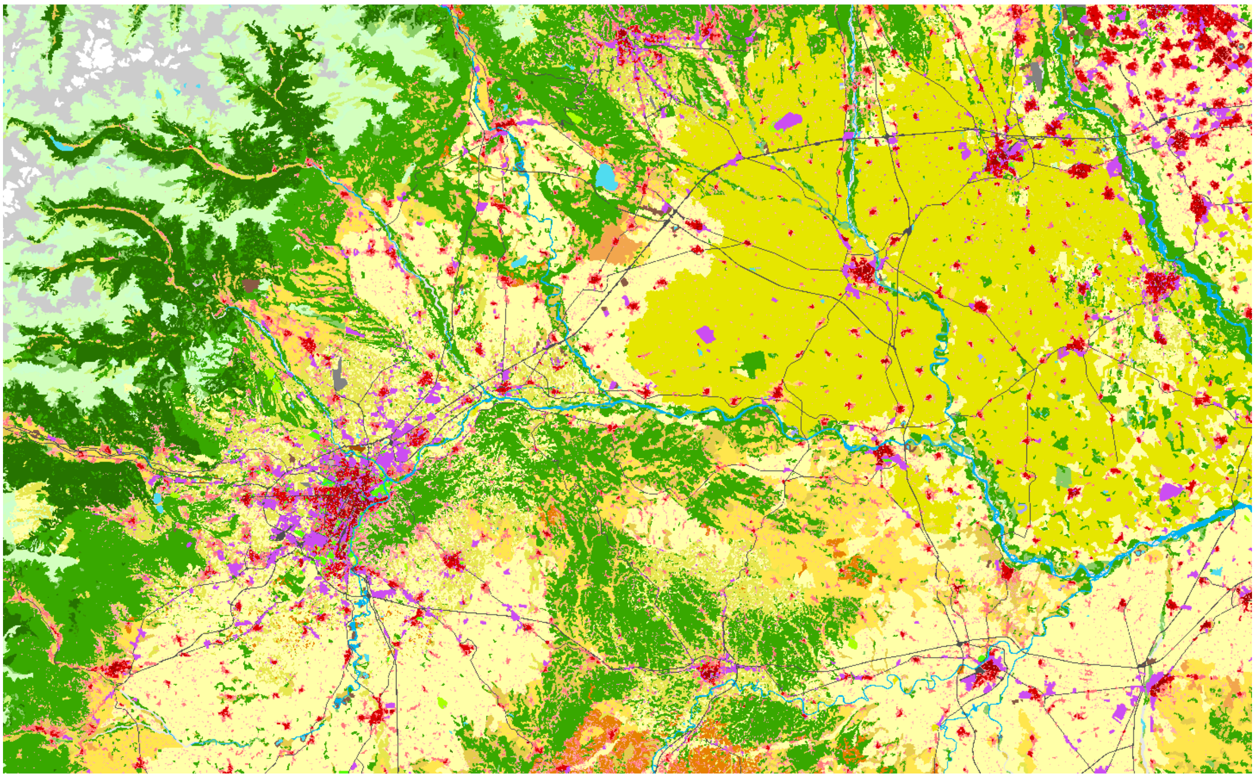
Nomenclature

Value	Label
111	Urban fabric dense (> 50% built-up)*
112	Urban fabric medium density (30-50% built-up)*
113	Urban fabric low density (10-30% built-up)*
114	Urban fabric very low density and isolated (<10% built-up)*
121	Industrial or commercial units
122	Road and rail networks and associated land
123	Port areas
124	Airports
131	Mineral extraction sites
132	Dump sites
133	Construction sites
141	Green urban areas
142	Sport and leisure facilities
143	Leisure and touristic built-up*
211	Non-irrigated arable land
212	Permanently irrigated land
213	Rice fields
221	Vineyards
222	Fruit trees and berry plantations
223	Olive groves
231	Pastures
241	Annual crops associated with permanent crops
242	Complex cultivation patterns
243	Land principally occupied by agriculture, with significant areas of natural vegetation
244	Agro-forestry areas
311	Broad-leaved forest
312	Coniferous forest
313	Mixed forest
321	Natural grasslands
322	Moors and heathland
323	Sclerophyllous vegetation
324	Transitional woodland-shrub
331	Beaches, dunes, sands
332	Bare rocks
333	Sparsely vegetated areas
334	Burnt areas
335	Glaciers and perpetual snow
410	Inland wetlands*
421	Salt marshes
422	Salines
423	Intertidal flats
511	Water courses
512	Water bodies
521	Coastal lagoons
522	Estuaries
523	Sea and ocean

* New or redefined classes.

For illustration purposes, the figures below show the differences between the original CLC 2012 (top) and CLC-R 2012 (v1.0) (bottom) for the area surrounding the city of Turin, Italy.





Annex 5. List of land use and activity data sources

Data source name	Type	Reference date	Description / content	Use in ENACT
Booking.com	Web-service	2016	Location of hotels.	To reveal locations of probable tourist presence (night-time).
Copernicus High resolution layers	Open / public	2012	Spatial raster layers describing forests, wetlands and water bodies.	Spatial refinement of CLC.
CORINE Land Cover	Open / public	2012	Land use/cover map with 44 classes.	Base map for activity mapping.
European Pollutant Release and Transfer Register (EPRTR)	Open / public		Location of polluting industries and waste treatment plants.	Thematic refinement of CLC.
European Settlement Map	Open / public	2012	Density of built-up.	Spatial refinement of CLC.
EuroRegionalMap	Proprietary		Location of activities (points of interest).	Thematic refinement of CLC.
National land use maps	Public or proprietary	2007-2012	Detailed land use maps for the following countries/regions: Portugal, Spain, Wallonia, Lombardia, The Netherlands.	Provide training and test subsets for the thematic refinement of CLC.
OpenStreetMap	Open, VGI	2016	Location of activities (points of interest).	Thematic refinement of CLC.
PLATTS	Proprietary		Location of power plants.	Thematic refinement of CLC.
TomTom	Proprietary	2013	Location of activities (land use polygons and points of interest). Road and rail networks.	Spatial and thematic refinement of CLC.
TripAdvisor.com	Web-service	2016	Location of hotels, restaurants, and tourist attractions.	To reveal locations of probable tourist presence (day- and night-time).
Urban Atlas	Open / public	2012	Land use maps for European Functional Urban Areas.	Spatial refinement of CLC.

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