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European cities: territorial analysis of characteristics and trends

An application of the LUISA Modelling Platform (EU Reference Scenario 2013 - Updated Configuration 2014)

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Abstract

Cities and towns are at the core of the European economy but they are often also the places where problems related to the quality of life of citizens such as unemployment, segregation and poverty are most evident.

To curtail the negative impacts and foster the positive effects of ongoing urban processes in Europe, policies have to be adjusted and harmonised to accommodate future urbanization trends. Such an analysis of the evolution of European cities requires the evaluation of impacts of continent-wide drivers and, at the same time, assessment of the effect of national and local strategies.

As a contribution to this analysis of the current and future evolution of European territories (countries, macro-regions, regions or urban areas), the Directorate-General Joint Research Centre (DG JRC) of the European Commission (EC) has developed the Land-Use-based Integrated Sustainability Assessment (LUISA) Modelling Platform. Based on the concept of 'dynamic land functions', LUISA has adopted a novel approach towards activity-based modelling and endogenous dynamic allocation of population, services and activities.

This report illustrates how European cities could potentially evolve over the time period 2010-2050, according to the reference configuration of the LUISA modelling platform, on the basis of a collection of spatial indicators covering several thematic fields. These spatial indicators aim to improve our understanding of urbanization and urban development processes in Europe; explore territorial dimensions of projected demographic and economic changes, and finally examine some key challenges that urban areas are or may be exposed to. Some of the key findings of this report are given below:

- The proportion of the population living in cities, towns and suburbs is higher in the EU than in the rest of the world. According to the LUISA forecasts, the urban proportion will continue to increase up to 2030; subsequently slow down, and reach a relatively steady state by 2050.
- In 2010, 65% of the EU population were living in Functional Urban Areas (FUA, the city and its commuting zone). This figure is expected to reach 70% by 2050. The total EU-28 population is expected to grow by 4.6%. Most of this population growth will occur particularly in FUA which will grow by an average 14%.
- As of 2010, the amount of artificial areas per inhabitant in the EU-28 was estimated as 498 m^2: it becomes 539 m^2 in 2050 with an 8% increase. Although there is not a unique spatial pattern, land take tends to start peak at 5 km distance from the city centre. This is due to the fact that land is often less available for development within city centres and that the majority of land take therefore will occur firstly in the suburbs and then in rural areas.
- By 2050, potential accessibility – as measure of economic opportunities - will be higher in the urban areas of north-western Europe, while it will not improve in lagging European regions. Urban form has a considerable impact on average travelled distances and thus potentially on the energy dependence of transport.
- Green infrastructure is mainly located at the periphery of urban areas. Its share per person is generally low or very low in most of the European cities, with few exceptions. Green infrastructure per capita in FUA shows a general trend towards a decrease across the EU-28 (by approximately 13%) between 2010 and 2050.
- Larger cities tend to have higher average flood risk, especially due to the higher sensitivity in terms of potential human and physical losses.

The analysis herein presented is part of a wider initiative of DG JRC and DG REGIO aiming to improve the management of knowledge and sharing of information related to territorial policies, such as those concerning urban development. In this framework, the work will be further developed, covering the following main elements:

- Development of the European Urban Data Platform, providing a single access point for data and indicators on the status and trends of European urban areas;

- Updates of the LUISA configuration, to account for new socio-economic projections;
- Support to the development of the EU Urban Agenda and related initiatives;
- Provision of evidence-based support for the evaluation of territorial policies in particular to proof the role of cities in the implementation of EU priorities.

1. Introduction

Cities lead economic growth and innovation in Europe. They host the majority of the population, providing opportunities for employment and an abundance of social and cultural activities. At the same time, cities are also confronted with important environmental, social and economic problems such as: air pollution, flooding, congestion, risk of segregation and poverty, unemployment, and inadequate social services. European institutions, national and local authorities set policies for the sustainable development of cities and urban areas. These aim at maintaining economic productivity and innovation in cities, improving the quality of life and addressing the main environmental and social problems. Beforehand evaluation of the potential implication of such policies at the city and EU level is becoming increasingly important. This report aims to contribute to this effort by introducing a set of spatial indicators to assess the current state of European cities and their possible future development following a baseline reference scenario resulting from a territorial modelling approach.

The Land-Use based Integrated Sustainability Assessment (LUISA) Modelling Platform is designed for the evaluation of EC policies with direct or indirect territorial impacts (Lavalle et al., 2011; 2013a). It provides a comprehensive, harmonised and consistent spatial analysis of environmental and socio-economic changes in Europe. LUISA is based on the concept of 'land functions' for cross-sector integration. It is an activity-based model, based on an endogenous dynamic process of population, services and activities allocation. It has coherent linkages with other Europe-wide macroeconomic and biophysical models and derives information from several European thematic databases and scenarios. LUISA produces territorial indicators that can be grouped together according to the 'function' of interest and/or the sector under assessment (LUISA, 2015).

The core of LUISA is a computationally dynamic spatial model that allocates population, activities and services based on biophysical and socio-economic drivers. LUISA generates three primary outputs at 100 meters spatial resolution: (1) land use/cover, (2) population and (3) accessibility. Several other spatial indicators are derived from these three main outputs to assess policy effects on various themes such as resource efficiency, urban and regional development, and the provision of ecosystem services (Batista et al., 2013; Baranzelli et al., 2014b).

This technical report introduces a collection of spatial indicators to assess the present and future state of European cities and regions. These can be grouped in 10 categories:

- Degree of urbanization – the projected degree of urbanization,
- Urbanization – the urban proportion and annual rate of urbanization,
- Land use and urban development – the land take and land use intensity analysis,
- Population –the analysis of total population changes,
- Population weighted density – the population weighted-density analysis,
- Recreation opportunities – the nature based recreation opportunities and demand,
- Air quality –analysis of NO_2 and PM_{10} concentrations and exposure,
- Accessibility – the potential accessibility and average travelled distances,
- Green infrastructure – the share of green infrastructure (GI) and GI per capita,
- Urban flood Risk – the flood risk assessment index.

These urban indicators serve to characterise the processes of urbanization and urban development in Europe; explore the territorial dimensions of projected demographic and economic changes, and finally, examine key environmental challenges that urban areas need to address. For a wider assessment, all these indicators are designed to be able to highlight similarities / dissimilarities of countries and regions; to capture the main directions of land use / land cover based changes and their likely impacts; and to explore differences between urban and rural areas in Europe.

The report is also aimed at providing a base for further work which would establish clear links between these assessments and policy implementations for the future of cities and sustainable urban development.

The following section provides a description of the LUISA Modelling Platform, its drivers and assumptions. Section 3 focuses on the assessment of the present and future state of European cities and urban areas based on the LUISA urban indicators. Section 4 provides a summary of the main findings and section 5 contains the concluding remarks.

2. The LUISA Modelling Platform

2.1 Description of the model

The Land-Use based Integrated Sustainability Assessment (LUISA) Modelling Platform is a model framework simulating land-functions. It is developed by the Joint Research Centre (JRC) of the European Commission (EC), and used for the ex-ante and ex-post evaluation of EC policies with direct or indirect territorial impacts (Lavalle et al., 2011).

The core module of LUISA allocates population, services and activities to the most optimal 100m grid cells, given predefined suitability maps, regional demands and the supply of resources in a region. Grid cell population counts are linked to the allocated land uses, which are modelled separately prior to the land-use allocation. The platform's starting point is a refined version of the CORINE land cover data for 2006, and population levels that are consistent with that data source. LUISA simulates the dynamic process of population and land use change on an annual basis, starting in 2006 and continuing until 2050. The resulting annual output serves as direct input for the calculation of the subsequent year.

The three primary outputs that LUISA generates are land use / cover, population and accessibility distributions. The thematic detail of the land use / cover projections is particularly fine and discerns classes such as industrial and urban at various densities, as well as various agricultural land uses. Abandonment processes in urban and rural areas are also simulated. Over 50 indicators of land functions are derived from LUISA's main outputs providing valuable information on various themes such as resource efficiency, sustainable urban development, ecosystem services and accessibility.

A detailed description of LUISA and its reference scenario can be found in Lavalle et al. (2013a) and Baranzelli et al. (2014a). A description of the projected changes under the 2014 reference scenario can be found in Baranzelli et al. (2014b) and Barbosa et al. (2014).

2.2 The reference scenario, main drivers and assumptions

LUISA can be configured according to various socio-economic and policy scenarios. The results produced in this report are obtained from the LUISA's 2014 reference configuration; for which the main drivers and assumptions are outlined in this section.

LUISA is composed of three separate modules that are tasked with: (1) the management of regional sectoral trends and associated demands for resources and commodities; (2) the allocation of activities, services and population expectations to fine resolution rasters; and (3) the computation of various indicators needed to determine policy effects. The structure of the model including the urban indicators is illustrated in Figure 1.

The allocation module is driven by future trends supplied by upstream models or other sources (e.g. projections or results from EUROSTAT, ECFIN, GEM-E3 and CAPRI). For instance, the evolution of the artificial land uses is driven by the official demographic projections produced by Eurostat EUROPOP 2010 (residential and other urban classes) and the Gross Value Added (GVA) projections from the GEM-E3 model (for industry/commerce/services). Figure 2 shows, the regional GDP and population projections included in the reference scenario and the population distribution downscaled from regional level to 100 meters resolution. In general, those models provide outputs at various geographical scales that range from NUTS2 to the national level. Because of the large differences in detail and typology of input data, additional information (Table 1) are used in LUISA to ensure consistency in used data projections. For more information we refer to Baranzelli et al. (2014b).

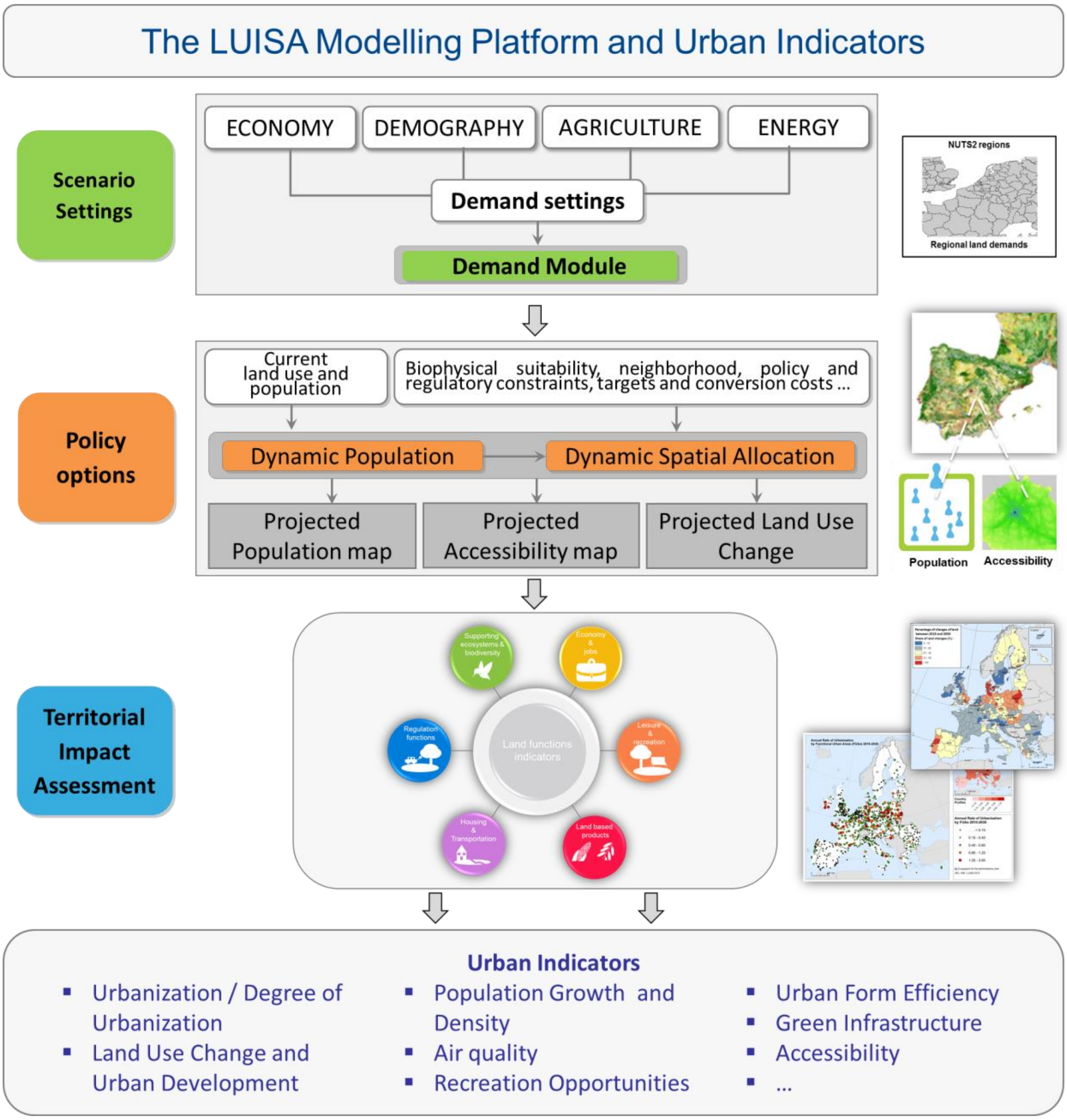
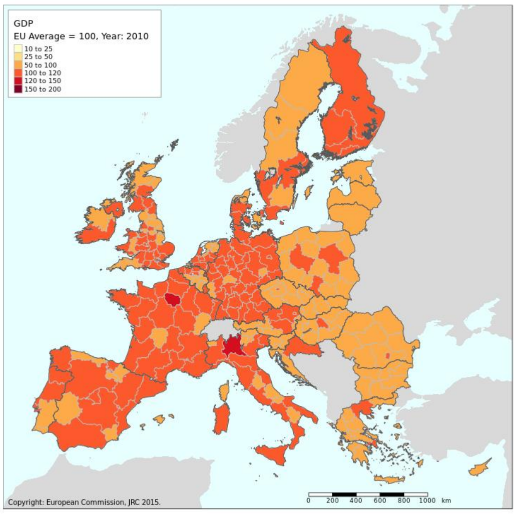


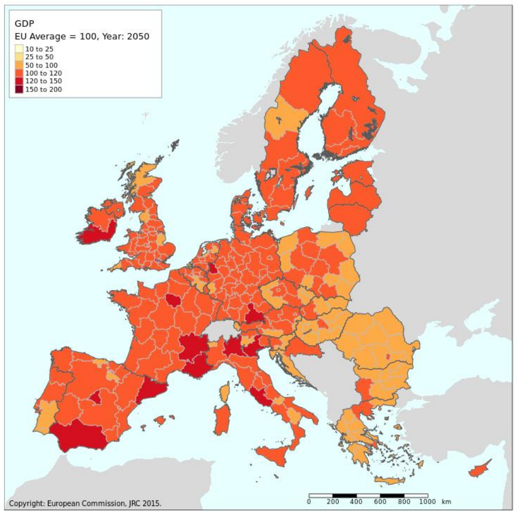
Figure 1: The LUISA Modelling Platform and urban indicators.

Table 1: Regional and national socio-economic drivers in the LUISA Configuration 2014.

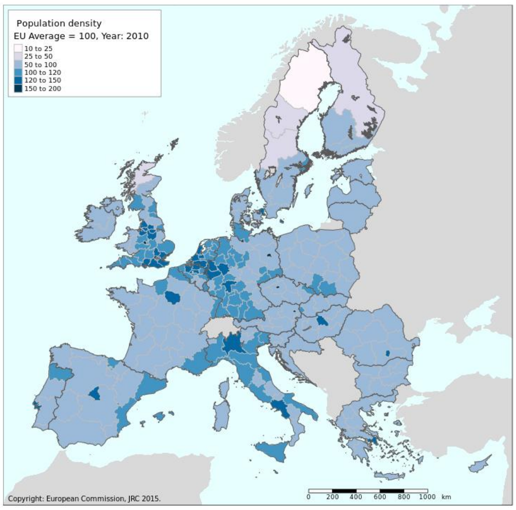
Data and land use type	Source	Geographical Unit
Population	Externally downscaled national projections EUROPOP 2010 (EUROSTAT)	NUTS2
Urban	Population	NUTS2
	Historical household sizes (EUROSTAT)	
	Tourism land use intensity (Data Hub for the Energy Performance of Buildings)	
	Tourism growth rates (UNWTO)	
Industrial	GVA projections (GEM-E3)	NUTS2
Forest	Extrapolation of historical national forest accounts (UNFCC)	National
Agriculture	Agricultural commodity projections (CAPRI)	CAPRI-particular regions



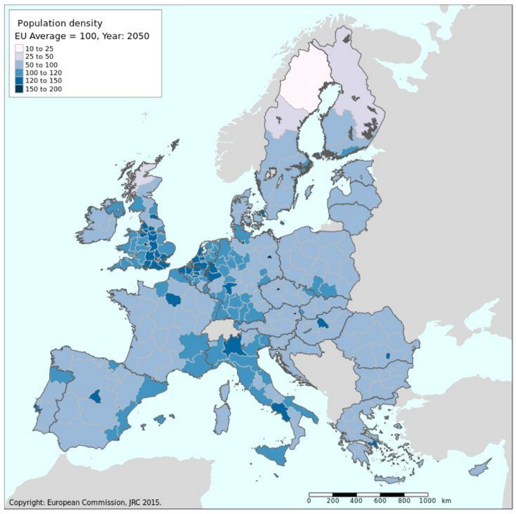
GDP in 2010



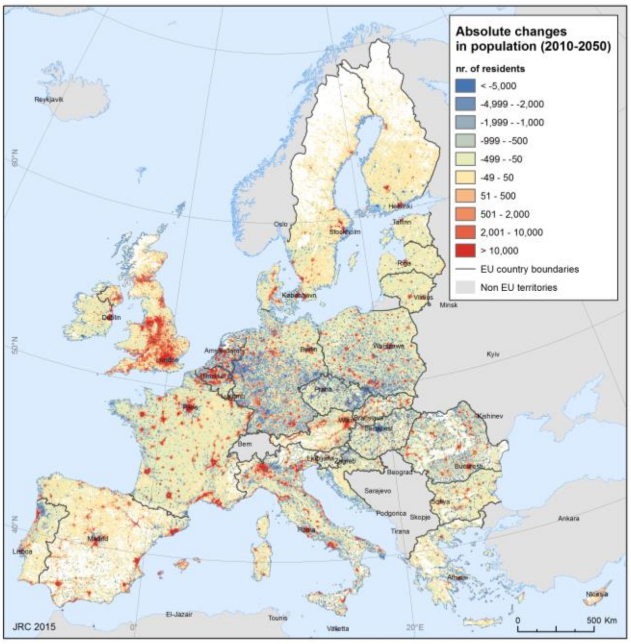
GDP in 2050



Population density in 2010



Population density in 2050



Change in Population between 2010-2050

Figure 2: Regional GDP and population projections as macro drivers of the model

The projected land use demands are allocated to 100m grid cells by means of a two-step procedure. In the first step, regional changes in population plus an additional 10% of the existing population are allocated to grid cells. This is based on a function that defines the attractiveness of each pixel for residence. Any grid cell that subsequently holds at least six people is converted into urban land use; any currently urban grid cell that subsequently holds less than two people is flagged as abandoned urban land use. This method is constrained by a routine that does not allow a decimal number of people in any grid cell; some iterations are done to ensure that whole people are allocated everywhere. The method is furthermore constrained to ensure that urban conversions always match the expected number of urban grid cells.

In the second step, all non-urban land uses are allocated assuming competition between those uses. Land use specific functions define how attractive a grid cell is for a given land use. Land uses are assumed to maximize their utility; a simulated bidding process is used to determine final land use patterns. This method is constrained by the land use demands that are determined upstream; the method is furthermore constrained by the supply of land in a region. A large number of factors determine the attractiveness of a grid cell for a certain land use. The most important factors are listed in Table 2.

Table 2: Selection of factors driving the attractiveness of grid cells for land uses and population in the LUISA model.

Factor	Variable	Affects
Suitability factors	Potential accessibility	Population + land uses
	Slope	Population + land uses
	South-facing slope	Land uses
	Distance to water body	Land uses
	Distance to roads	Population
	Travel time to towns	Population
Neighbourhood factors	Land uses in immediate neighbourhood	Land uses
	People in immediate neighbourhood	Population
Prior land use	Matrix of conversion costs between land uses	Land uses
	Estimated effect of prior land use on attractiveness	Population
Policies	CAP through location-specific incentives or restrictions	Agricultural land uses
	NDA through location-specific restrictions	Population + land uses
	TEN-T through potential accessibility changes	Population + land uses
	Energy directive through new energy crop incentives	New energy crops land use type
	Cohesion policies-location specific incentives	Population + land uses

2.3 LUISA land function indicators

The ultimate product of LUISA is a set of territorial indicators that can be grouped and combined according to the 'land function' of interest and/or the sector under assessment. A land function (Lavalle et al., 2015) can, for example, be physical (e.g. related to hydrology or topography), ecological (e.g. related to landscape or phenology), social (e.g. related to housing or recreation), economic (e.g. related to employment or production or to an infrastructural asset) or political (e.g. the consequence of policy decisions). This section briefly presents the land function indicators developed within LUISA. The indicators are projected in time until typically 2030 or 2050, and can be represented at various geographical resolutions (national, regional or other). Table 3 illustrates how the indicators are thematically grouped. A catalogue of land function indicators is available in Lavalle et al. (2015).

Table 3: LUISA land function indicators

Land function	Division	Sub-division	Indicator Code	Unit
Provision of work	Employment	Industrial / Commercial/ Services	Employment in Industrial, commercial, Services	% of total population
		Agricultural	Employment in Agriculture	% of total population
	Economy	GDP	GDP	(million EUR)
			GDP / capita	(million EUR/capita)
Provision of leisure and recreation	Recreational and cultural services	Physical and experiential interactions	Recreation potential	Dimensionless (9 categories)
Provision of land and water based products	Water	Water flows	Water consumption	(m^3)
			Water productivity	(EUR per m^3)
	Food and Biofuels	Food and Feed Crops	Food and feed production	(1000t/ha/a)
			Energy content of produced food and feed	(MJ/ha/a)
		Energy Crops	Biomass harvested from energy crops	(1000t/ha/a)
			Energy content of dedicated energy crops	(GJ/ha/a)
	Wood Biomass	Forest	Biomass harvested for material and energy uses	(t/ha/a)
			Energy content of wood production	(MJ/ha/a)
Provision of housing and transport	Settlements	Residential areas	Share of residential areas over the total land area	% of total land
			Residential areas per inhabitant	(m^2/person)
			Population Density	Inhabitants/km^2
		Industrial areas	Share of industrial / commercial/ services areas	km and %
			Industrial economic output per unit of industrial / commercial area	(euro/ha)
		Built-up areas	Share of built-up areas over the total land	km and %
			Productivity of built-up areas	(EUR per km^2)
			Built-up per person	(m^2/capita)
		Transport	Potential accessibility	(dimensionless)
			Network efficiency	(dimensionless)
			Local accessibility	(dimensionless)
			Daily accessibility	(dimensionless)
Provision of regulation by natural physical structures and processes	Mediation of waste, toxics and other nuisances	Mediation by ecosystems (Capacity of ecosystem to remove air pollutants)	NO_2 removal by urban vegetation	(t/ha/year)
			Urban population exposed to PM_{10} concentrations exceeding the daily limit value on more than 35 days in a year	%
			Urban population exposure to air pollution by particulate matter	μg/m^3
	Mediation of flows	Mass flows (Capacity of the Land Cover to prevent soil erosion)	Capacity of ecosystems to avoid soil erosion	(dimensionless)
			Soil retention	(t/ha)
		Liquid flows (Capacity of coastal ecosystem to protect against	Ratio between capacity and demand for coastal protection (under development)	(dimensionless)

		inundation and erosion from waves, storm or sea level rise)		
		Liquid flows (Capacity for retention of water in the landscape)	Water Retention	(dimensionless)
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Relative pollination potential	(dimensionless)
		Soil formation composition	C- Stock changes	(t/ha)
	Atmospheric composition and climate regulation	Global climate regulation by reduction of GHG concentrations		
		Micro climate regulation (Capacity of ecosystems to regulate urban)	Cooling effect	(dimensionless)
Provision of Land supporting ecosystems and biodiversity	Biodiversity conservation	Habitat conservation	Habitat conservation Status	(dimensionless)
		Habitat quality indicator	Habitat quality based on the species distribution of all common birds included in the Common Bird Index	(dimensionless)
			Habitat quality based on the species distribution of forest birds included in the Common Bird Index	(dimensionless)
			Habitat quality based on the species distribution of farmland birds included in the Common Bird Index	(dimensionless)
	Maintaining ecosystems	Structural Green Infrastructure	Proportion of land area covered by green infrastructure (GI)	%
		GI fragmentation	Effective mesh density	(Number of meshes - 1000 km²)
		Landscape fragmentation by artificial areas	Effective mesh density	(Number of meshes - 1000 km²)

Source: Lavalle et al., 2015, LUISA Dynamic Land Functions Catalogue of Indicators – Release I, Luxembourg, Publications office of the European Union.

The assessment of land functions related to ecosystem services is performed with ESTIMAP (the Ecosystem Services Mapping tool), which is a consistent and flexible set of spatially explicit models all developed following the CICES classification (http://cices.eu/) and implemented in LUISA as one of the set of thematic indicators (Zulian et al. 2013, Maes et al. 2015). For this report, only the capacity of ecosystems to remove air pollutants has been compiled and used at Functional Urban Areas (FUA) scale.

2.4 A complete list of LUISA indicators for the analysis of urban areas

A set of specific indicators are defined and computed for the analysis of European cities and urban areas. Because of their high original spatial resolution, the LUISA urban indicators can be aggregated to any administrative level (e.g. municipality, NUTS3 etc.), or available definition of urban areas, such as Functional Urban Areas (FUA), or core cities as defined in the Urban Audit, or the OECD-EC defined 'degree of urbanization'[1]. Composite

[1] A detailed description of spatial units used in the report is given in section 3.

indicators can in turn be derived from combinations of indicators. Table 4 gives an extended list of LUISA urban indicators classified under the following thematic fields: urbanization, land use and urban development, population, urban form and efficiency, environmental impacts, green infrastructure and accessibility.

Table 4: List of LUISA indicators for the analysis of urban areas (FUA: Functional Urban Areas; LAU2: Local Administrative Units - 2)

Indicator Code	Indicator Name	Measurement Unit and Min. Spatial Resolution	Reporting Unit
Urbanization			
URBAN1	Degree of Urbanization - Projected	Dimensionless – 100m pixel	LAU2
URBAN2	Urban Proportion by Population	Percentage – 100m pixel	FUA
URBAN3	Urban Proportion by Area	Percentage – 100m pixel	FUA
URBAN4	Annual Rate of Urbanization	Percentage – 100m pixel	FUA
Land Use and Urban Development			
LAND1	Total Built-up Areas	Hectare – 100m pixel	FUA and LAU2
LAND2	Total Residential Built-up Areas	Hectare – 100m pixel	FUA and LAU2
LAND3	Total Industrial/Commercial Areas	Hectare – 1000m pixel	FUA and LAU2
LAND4	Share of Built-up Areas	Percentage – 100m pixel	FUA and LAU2
LAND5	Share of Residential Built-up Areas	Percentage – 100m pixel	FUA and LAU2
LAND6	Share of Industrial/Commercial Areas	Percentage – 100m pixel	FUA and LAU2
LAND7	Land Annually Taken for Built-up Areas	LAU2 in ha/year FUA Km/year	FUA and LAU2
LAND8	Land Annually Taken for Built-up Areas per Person	m^2/person – 100m pixel	FUA and LAU2
LAND9	Land Use Intensity (artificial areas per inhabitant)	m^2/person – 100m pixel	FUA and LAU2
LAND10	Tourism Activity/Land Use Intensity	Coordinates – any regional level	FUA
LAND11	Total Number of Industrial Facilities	Coordinates – any regional level	FUA
LAND12	Total Number of Energy Infrastructure Facilities	Coordinates – any regional level	FUA
Population Growth and Density			
POP1	Total Population	Number of Inh. – 100m	FUA and LAU2
POP2	Population Density	Inhabitants / ha – 100m	FUA and LAU2
POP3	Population Weighted Density	Inhabitants / ha – 100m	FUA and LAU2
POP3	Population Growth Rate- Projected	Percentage – 100m pixel	FUA and LAU2
POP4	Population Growth Rate - Historical	Percentage – LAU2	FUA and LAU2
Urban Form and Efficiency			
FORM1	Compactness of the Largest Patch	Dimensionless - various	FUA
FORM2	Urban Compactness	Dimensionless - various	FUA
FORM3	Urban Sprawl	UPU/m^2 – 100m pixel	FUA
FORM4	Urban Form Efficiency via ease of access to PT services	Dimensionless - various	FUA
Environmental Impacts			
ENV1	Amount of Agricultural Land Uptake by Built-up Areas	Hectare – any regional level	FUA and LAU2

ENV2	Amount of Forest/Semi-Natural Areas Uptake by Built-up Areas	Hectare – any regional level	FUA and LAU2
ENV3	Atmospheric Emissions	q/y – 100m pixel	FUA and LAU2
ENV4	NO_2 concentration	$\mu g/m^3$ – 100m pixel	FUA and LAU2
ENV5	PM_{10} concentration	$\mu g/m^3$ – 100m pixel	FUA and LAU2
ENV6	Urban population Exposed to NO_2 Concentrations Exceeding the EU Legislation Limits	Percentage – 100m pixel	FUA and LAU2
ENV7	Urban Population Exposed to PM_{10} Concentrations Exceeding the EU Legislation Limits	Percentage – 100m pixel	FUA and LAU2
ENV8	Water Use/Consumption	m3 – 100m pixel	FUA and LAU2
ENV9	Flood Risk Assessment Index	Categories - 100m pixel	FUA and LAU2
ENV10	Habitat for Bees – capacity of landscape to sustain wild pollinators' activity	Dimensionless – 100m pixel	FUA and LAU2
ENV11	Capacity of Ecosystems to Avoid Soil Erosion	Dimensionless -100m pixel	FUA and LAU2
ENV12	Soil retention	t/ha/year	FUA and LAU2
Green Infrastructure			
GREEN1	Nature based recreation opportunities	Dimensionless – 100m pixel	FUA
GREEN2	Recreation Opportunity Spectrum (ROS)	Categories - 100m pixel	FUA
GREEN3	Proportion of Potential Trips per ROS Category	Percentage – 100m pixel	FUA
GREEN4	Proportion of Green Infrastructure	Percentage – 100m pixel	FUA and LAU2
GREEN5	Fragmentation of Green Infrastructure	Mesh density – 100m pixel	FUA and LAU2
GREEN6	Green Infrastructure fragmentation per capita	Number of meshes – 100m pixel	FUA and LAU2
GREEN7	Connectivity of Green Infrastructure	Percentages – 100m pixel	FUA
GREEN8	Access to Green Urban Areas	Dimensionless – 100m pixel	FUA
GREEN9	Removal capacity of NO_2 by vegetation	T/ha*Y – 100m pixel	FUA and LAU2
GREEN10	Removal capacity of PM_{10} by vegetation	T/ha*Y – 100m pixel	FUA and LAU2
GREEN11	Land surface emissivity	Dimensionless – 100m pixel	FUA and LAU2
GREEN12	F-evapotranspiration	Dimensionless – 100m pixel	FUA and LAU2
GREEN13	Total number of sports/cultural/health-care facilities	Coordinates - any reg. level	FUA
GREEN14	Fragmentation by artificial areas	Mesh density – 100m pixel	FUA
Accessibility			
ACCES1	Accessibility – Population Potential	Dimensionless – 100m pixel	FUA and LAU2
ACCES2	Accessibility – Daily Population Potential	Dimensionless – 100m pixel	FUA and LAU2
ACCES3	Accessibility – Local (Nearest Town)	Dimensionless – 100m pixel	FUA and LAU2
ACCES4	Average Travelled Distances	Kilometres – 1km	FUA

It is worth mentioning here that not all indicators available within the LUISA Platform are used in this report; only a set of relevant urban indicators have been selected. The list of indicators is continuously being extended. For instance, a range of indicators concerning the production and consumption of energy at the municipal and regional level are being defined and computed at the time of writing this report.

3. Assessing the present and future state of European cities – the LUISA urban indicators

3.1 The main concept of the assessment

This section of the report introduces a selection of LUISA urban indicators developed in several thematic fields to assess the present and future state of European cities and regions. These indicators highlight the main dynamics of urbanization and urban development and explore significant changes in land use / land cover, population patterns, recreation potentials, green infrastructure, air quality, food risk and accessibility. These indicators and the type of analysis can be shortly listed as following.

- Degree of urbanization – with the projected degree of urbanization analysis,
- Urbanization – with urban proportion and annual rate of urbanization analysis,
- Land use and urban development – with land take and land use intensity analysis,
- Population – with the analysis of total population changes,
- Population weighted density – with population weighted density analysis,
- Recreation opportunities – with the analysis of nature based recreation opportunities and demand,
- Air quality – with the analysis of NO_2 and PM_{10} concentrations and exposure,
- Accessibility – with the analysis of potential accessibility values and average travelled distances,
- Green infrastructure – with the analysis of share of green infrastructure (GI) and GI per capita,
- Urban flood risk – with the flood risk assessment index.

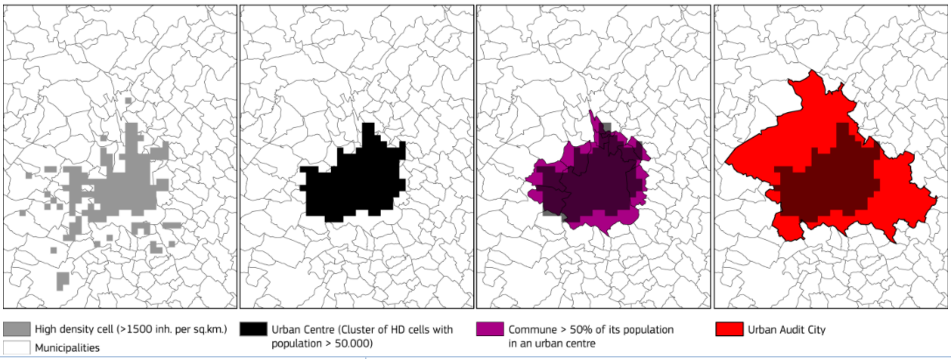
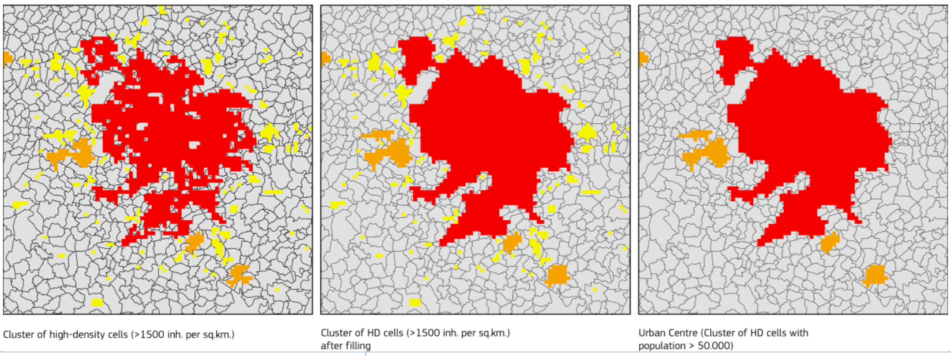
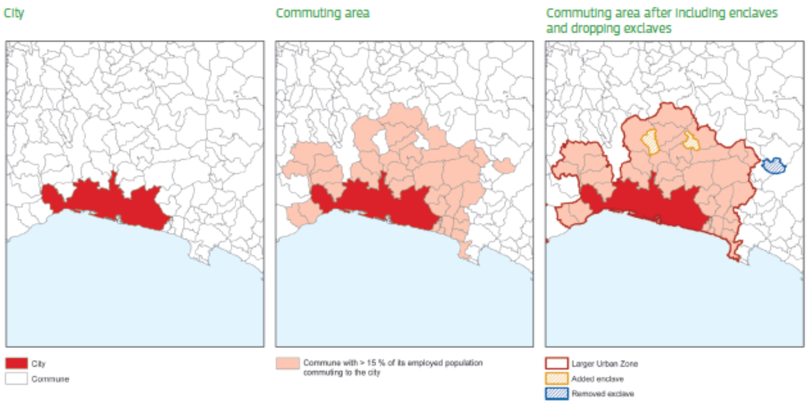
The LUISA urban indicators aim to improve our understanding of urbanization and urban development processes in Europe; to explore territorial dimensions of projected demographic and economic changes, and to examine some key environmental challenges that urban areas are or may be exposed to.

These indicators are designed to be able to highlight similarities and dissimilarities between countries and regions; to capture the main direction of land use / land cover based changes and their likely impacts, and explore differences between urban and rural areas in Europe. The subsequent sections present the assessment of the state of European cities and urban areas with the above mentioned indicators.

The production of LUISA high resolution projection maps on land use and population from 2010 to 2050 constitutes the primary step in the assessment. In the second step, in order to analyse urbanization, urban development and territorial dimensions of change in other themes, several GIS-based spatial and statistical techniques were applied for each indicator.

The results are summarized at the EU-28, Member State and Functional Urban Areas (FUA) level. In the majority of cases the results are also disaggregated by degree of urbanization. The spatial units used throughout the report are summarized in Table 5. Furthermore, specific cities have been selected and further analysed to illustrate local characteristics and trends.

Table 5: Description of the spatial units

<table>
<tr><th>Spatial Units</th><th>Description</th></tr>
<tr><td>Population grid</td><td>A grid composed of 1 km² cells, each containing a population counts.</td></tr>
<tr><td>City
Technical term: densely populated area</td><td>A local administrative unit (LAU) where the majority of the population lives in an urban centre of at least 50 000 inhabitants.</td></tr>
<tr><td colspan="2">High density cells, urban centre and city (Toulouse)
</td></tr>
<tr><td>Urban centre
Technical term: High-density cluster</td><td>High density cluster of contiguous grid cells of 1 km² with a density of at least 1500 inhabitants per km2 and a minimum population of 50 000.</td></tr>
<tr><td colspan="2">Steps in the creation of Urban Centres (the case of Paris)
</td></tr>
<tr><td>Commuting zone</td><td>A commuting zone contains the surrounding travel-to-work areas of a city where at least 15 % of their employed residents are working within the urban area.</td></tr>
<tr><td>Functional Urban Area</td><td>The functional urban area consists of a city plus its commuting zone. This was formerly known as LUZ (larger urban zone).</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Degree of urbanization	The new degree of urbanization indicates the character of the area where the respondent lives. Three types of area have been identified: thinly populated areas, intermediate density areas and densely populated areas.
Rural area Technical term: thinly populated area	An area where more than 50 % of the population lives in rural grid cells, as used in the degree of urbanisation.
Town and suburbs Technical term: Intermediate density area	Areas where less than 50 % of the population lives in rural grid cells and less than 50 % live in high-density clusters, as used in the degree of urbanisation.
Urban area	The sum of cities, towns and suburbs.
Local administrative unit (LAU)	The local administrative units, abbreviated as LAUs form a system for dividing up the economic territory of the European Union (EU) for the purpose of statistics at local level. They have been set up by Eurostat and they are compatible with NUTS. At local level, two levels of LAU have been defined: ▪ The upper level (LAU1, formerly NUTS level 4) is defined for most, but not all, of the countries. ▪ The lower level (LAU2, formerly NUTS level 5) consists of municipalities or equivalent units in the 28 EU Member States.

Source: EUROSTAT (2015a), Regions and cities glossary, http://ec.europa.eu/eurostat/statistics-explained/index.php/Category:Regions_and_cities_glossary – access date 15/12/2015; EUROSTAT (2015b), European cities – the EU-OECD functional urban area definition, Authors: Lewis Dijkstra and Hugo Poelman (European Commission, DG Regio), http://ec.europa.eu/eurostat/statistics-explained/index.php/European_cities_%E2%80%93_the_EU-OECD_functional_urban_area_definition - access date 15/12/2015.

3.2 Degree of urbanization

The concept of degree of urbanization was introduced in 1991 to indicate the character of a populated area. It distinguished three types of areas: densely, intermediate and thinly populated areas. This definition was based on the population size and density and spatial contiguity of level 2 - Local Administrative Units (LAU2). It is important to note that LAU2 vary considerably in areal size, and that this may reduce the comparability of results between countries with large LAU2 and those with small LAU2. In 2010, a new urban-rural regional typology was published in the Eurostat regional yearbook to be used by all Commission services. This typology was derived from the Organisation for Economic Cooperation and Development (OECD) method. While the OECD method defines rural regions based on the share of population in rural LAU2 and their population density, the new method is based on grid cells of 1 km^2. As the grid cells are identical in size, this new method eliminates the distortions of using LAU2 that vary in size. The two main advantages of this method are greater comparability and a harmonisation of spatial concepts (Dijkstra and Poelman, 2014).

3.2.1 The degree of urbanization classification

The concepts of urban and rural areas are widely used by policymakers, researchers, national administrations and international organisations such as the OECD, the United Nations (UN) and the European Commission (EC). These two terms are well known by the public, but a clear definition at the international level has remained elusive. The degree of urbanization developed by the OECD and DG REGIO provides a shared definition of the concepts which also increases the coherency and availability of data.

A growing number of countries in the EU have created population grids based on population registers or other detailed sources of where people live (the so-called bottom-up method). This provides much more detailed and accurate information about the population distribution within a country and within Local Administrative Units (LAU2).

By using a population grid (1 km^2), it is possible to classify each pixel into 3 distinct classes according to the methodology described below:

Grid cell classification:

1. High-density clusters (or urban centres): Contiguous grid cells of 1 km^2 with a density of at least 1500 inhabitants per km2 and a minimum population of 50000.
2. Urban clusters: Clusters of contiguous grid cells of 1 km^2 with a density of at least 300 inhabitants per km^2 and a minimum total population of 5000.
3. Rural grid cells: Grid cells outside high-density clusters and urban clusters, where the density stands for the population divided by land area.

The classified population grid is then used to create a three-way classification of LAU2, according to the following thresholds:

LAU2 classification:

The new degree of urbanization creates a three-way classification of LAU2 as follows:

1. Cities (Densely populated areas): At least 50% of the population living in high-density clusters (alternative name: urban centre).
2. Towns and Suburbs (Intermediate density areas): (alternative name: towns and suburbs). Less than 50% of the population living in rural grid cells; and • Less than 50% living in a high-density cluster.
3. Rural Areas (Thinly populated areas): More than 50% of the population living in rural grid cells.

3.2.2 Degree of urbanization projections for the EU-28

The degree of urbanization was calculated for the years 2010, 2020, 2030, 2040 and 2050 based on the LUISA population projections. The outputs for 2010 and 2050 are presented in Figure 3 and Figure 4. Figure 5 illustrates changes in the degree of urbanization over this time period and Figure 6 and Figure 7 represent aggregated graphical results of the trends in the degree of urbanization.

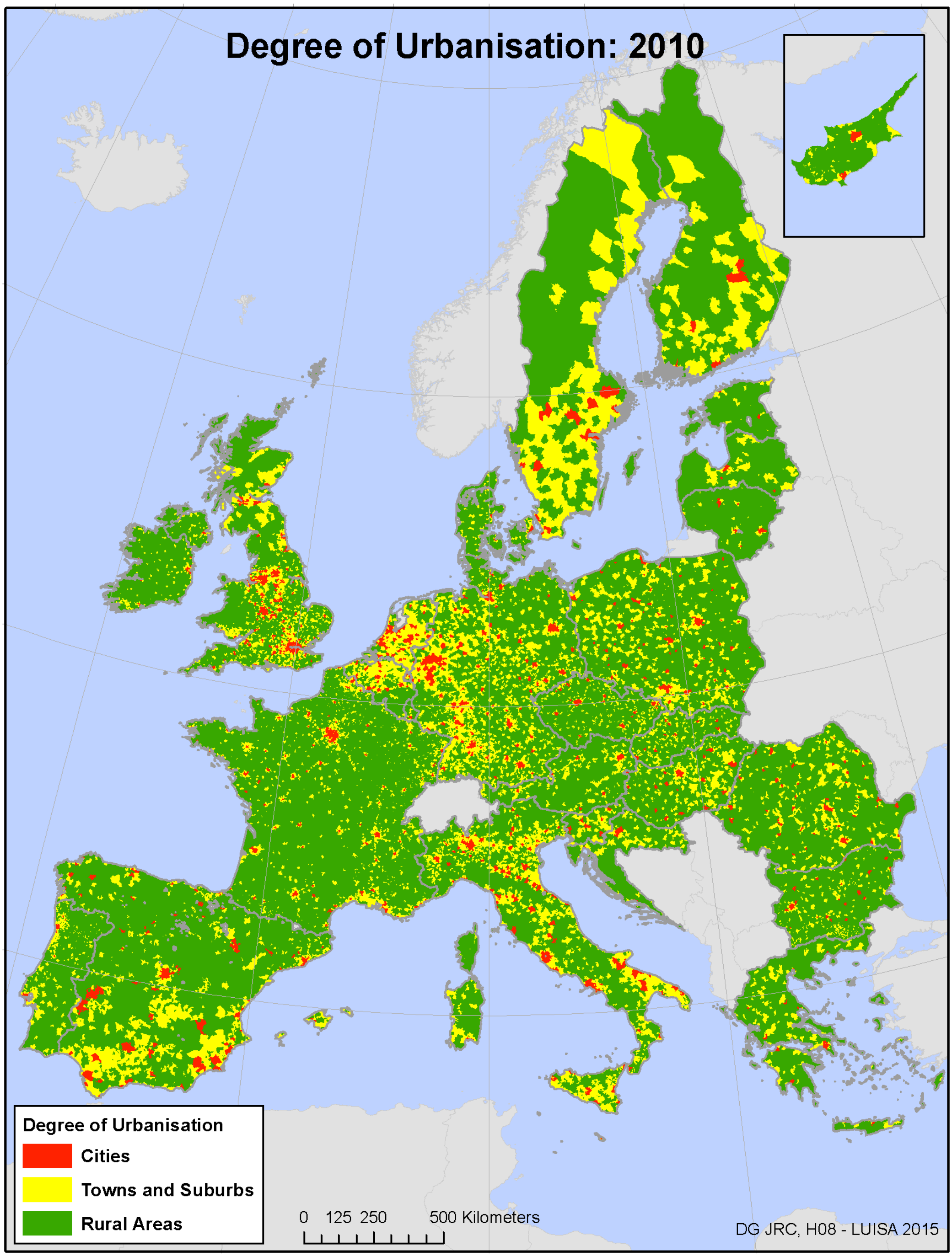


Figure 3: Degree of urbanization for EU-28 in 2010.

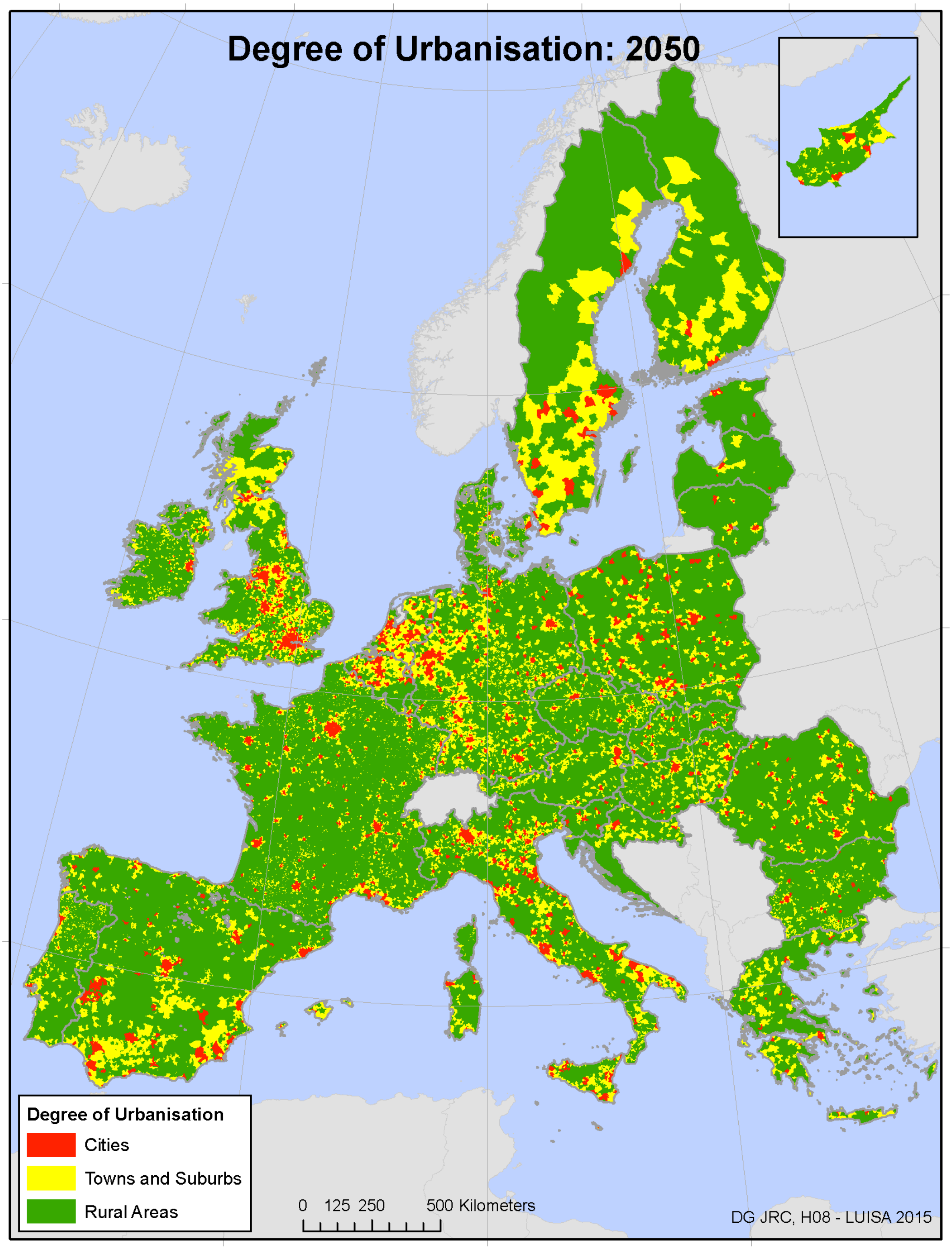


Figure 4: Degree of urbanization for EU-28 in 2050.

Although the changes do not follow a particular spatial pattern, the majority of changes in the United Kingdom, France, Austria and Czech Republic are towards an increase in the number of urban areas, whereas several parts of Germany, Romania and Poland show a reduction in number urban areas over time (Figure 5).

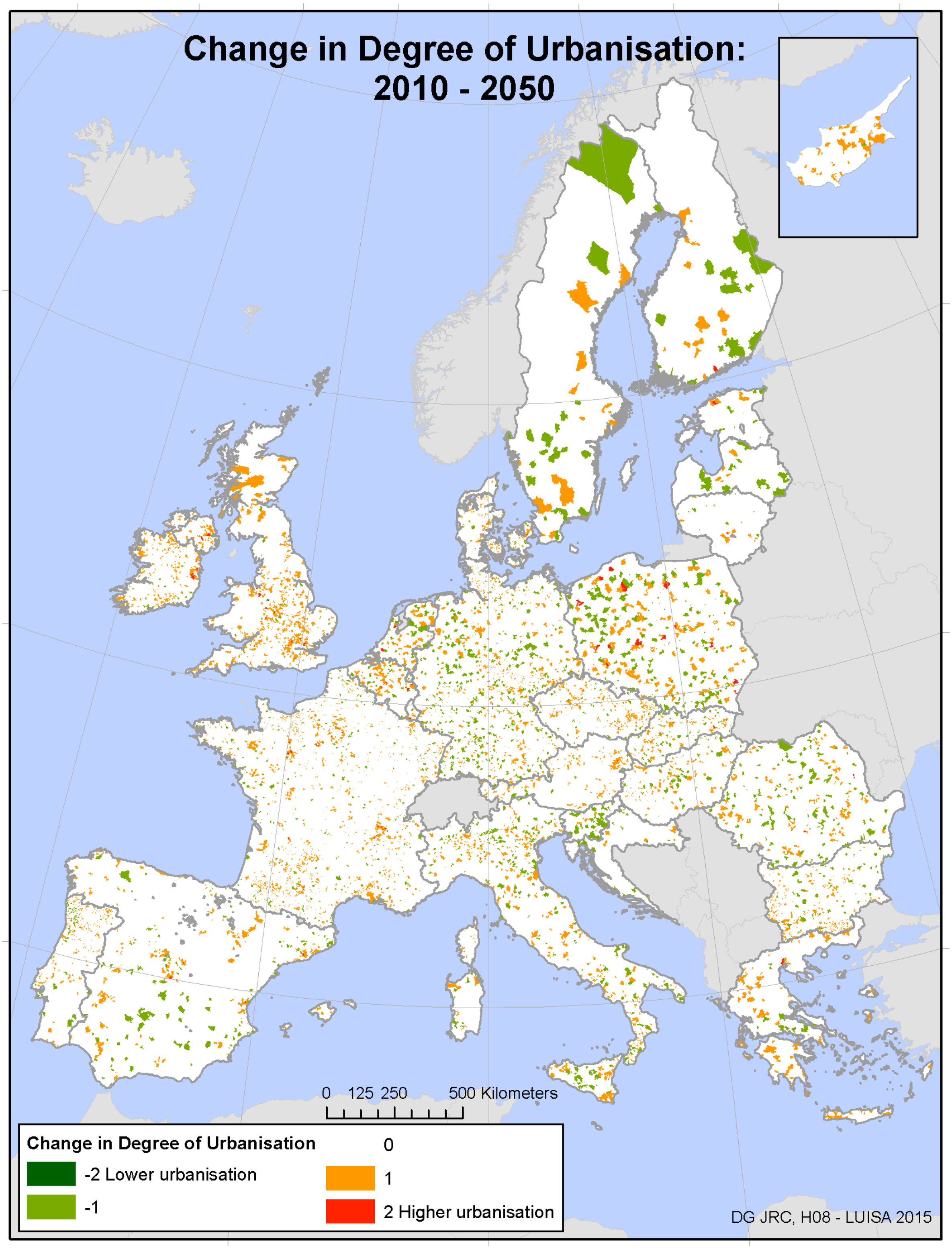


Figure 5: Change in degree of urbanization between 2010 and 2050.

As indicated in Figure 6, the large majority of LAU2 are classified as rural areas (thinly populated), followed by towns and suburbs (intermediate). The number of LAU2 classified as rural areas are expected to decrease until 2020 then increase until 2050, although not reaching 2010 levels again. The number of towns and suburbs decreases slightly between 2010 and 2050, while the number of cities (densely populated) increases in the same period.

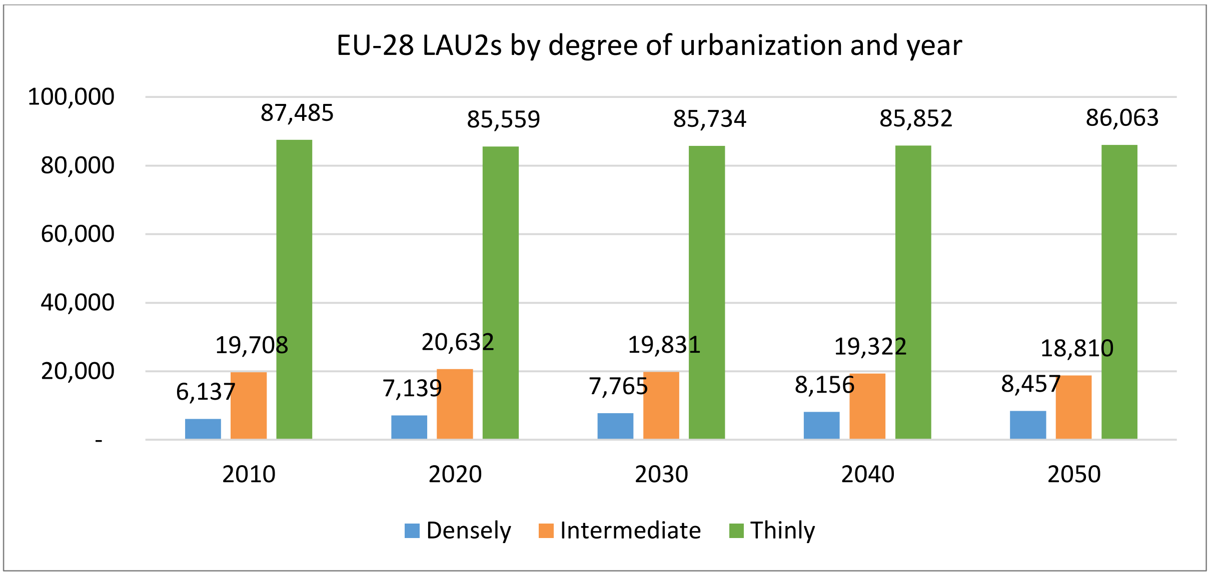


Figure 6: EU-28 number of LAU2 by degree of urbanization between 2010 and 2050.

Since LUISA also produces projected population grids, it is possible to visualise population changes according to the degree of urbanization classification. As shown in Figure 7, the EU-28 population is mainly located in cities. There is an increase in total population within cities while there is a decrease in towns and suburbs and rural areas, most notably between 2010 and 2020. These results, together with the previous analyses, indicate higher urbanization rates in Europe during the coming decades.

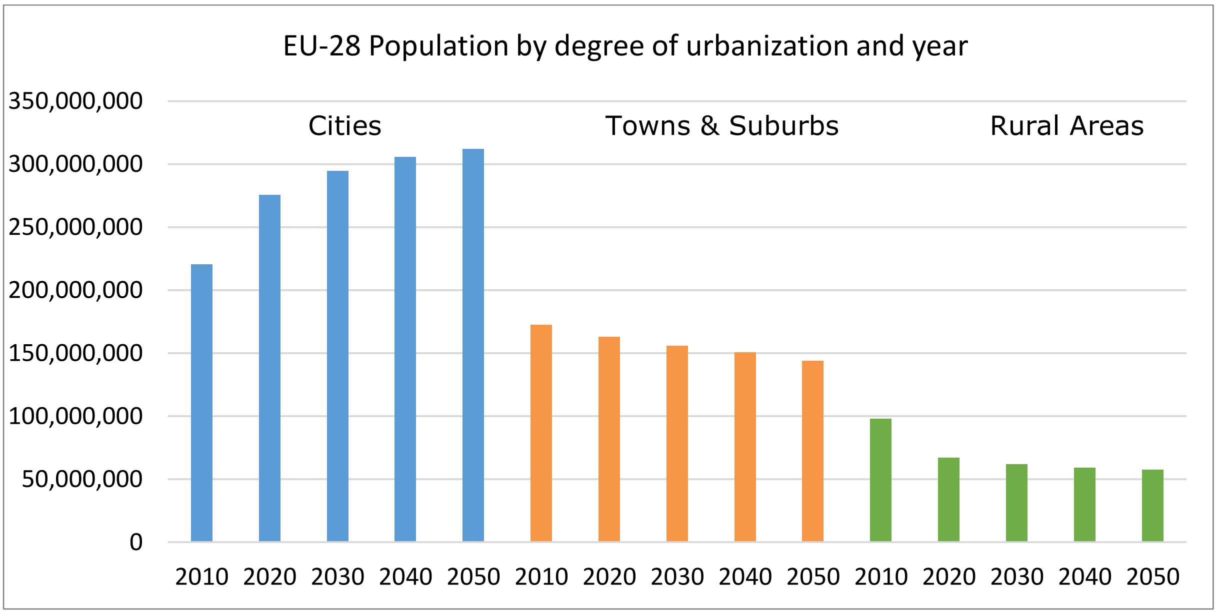


Figure 7: EU-28 population by degree of urbanization between 2010 and 2050.

3.3 Urbanization

3.3.1 Urban proportion

According to the UN World Urbanization Prospects (UN, 2014), as of 2010, 52% of the total world population lives in urban areas and it is supposed to increase linearly up to 2050 where the average urban proportion is estimated to reach 60% by 2030 and 66.5% by 2050. The European Union has a more urbanized structure as compared to the rest of the world, with an urban proportion of 74% according to the UN 2010 values. The urbanization rate is therefore lower than the rest of the world where the urban proportion in the EU-28 is supposed to reach 78% by 2030 and 83% by 2050 as indicated in Figure 8.

LUISA proposes an original methodology, to measure urban proportion in Europe using the new degree of urbanization classification based on the population grids[2]. According to the results of this new technique, as of 2010, the urban proportion (proportion of the population in cities, towns and suburbs) within the EU is almost 80%. This proportion varies significantly from the UN estimates reaching to 87% in 2030 and 88% in 2050, with a higher growth rate within the first 20 years period and a decreasing growth rate within the second (Figure 8).

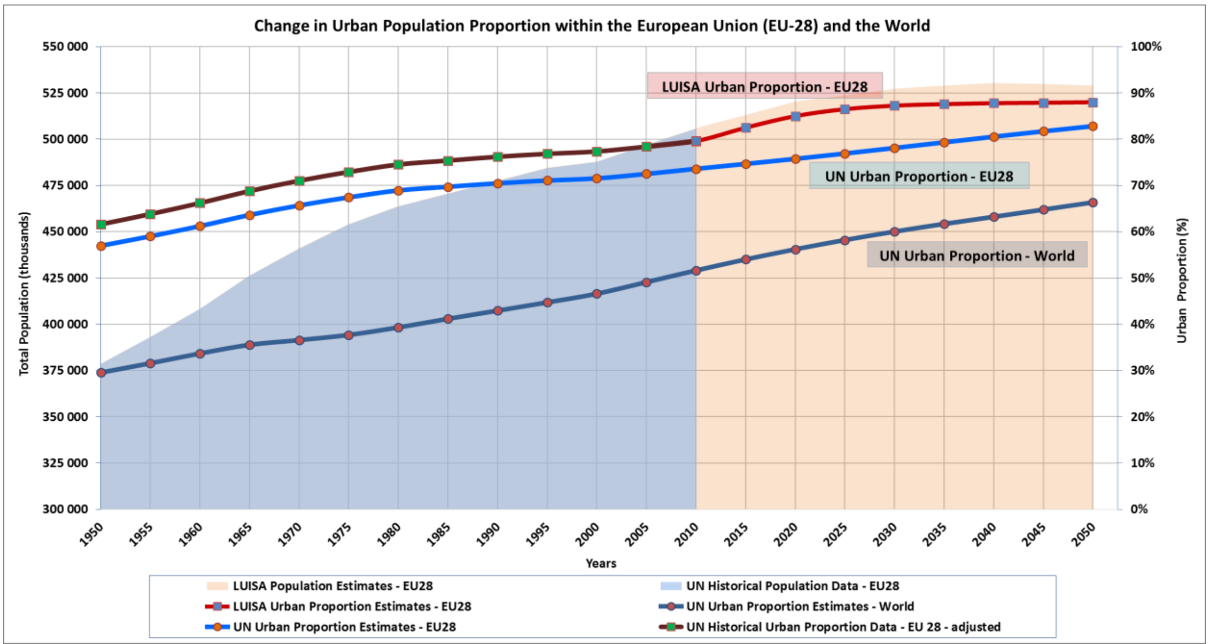


Figure 8: Change in urban proportion within the European Union and the World. [3,4]

At country level, Malta, the Netherlands, the United Kingdom and Belgium have the highest urban proportions with 98%, 94%, 90% and 87% respectively. The countries which have

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[2] Urban proportion for the EU-28 is calculated based on the OECD-EC degree of urbanization methodology that uses 1 km^2 population grids (Dijkstra and Poelman, 2014). These grids are clustered into three classes based on the projected population: 1) Cities, 2) Towns and suburbs, and 3) Rural Areas; and are then used to classify Local Administrative Units (LAU2) under these three classes. Urban proportion calculations in this study use total LAU2 populations classified under cities, towns and suburbs as urban areas.

[3] The source for the historical population data and the UN urban proportion data for the World and EU-28 is the report entitled 'World Urbanization Prospects: The 2014 Revision' (UN, 2014). The EU-28 total population and the urban proportion from 2010 to 2050 are based on the LUISA population projections.

[4] The UN definition for urban areas depends on the various definitions by national statistical institutes. Hence, LUISA urban proportion estimated from 2010 to 2050, using the population grids based on the new degree of urbanization, slightly differs from the UN numbers for urban proportion. In order to remove this difference for comparability and maintain consistency with the historical data, the UN urban proportion value for 2010 was matched with the LUISA urban proportion estimate for 2010 and then the proportion between these values was applied to the urban proportion data going back from 2010 to 1950.

the lowest share of people living in cities, towns and suburbs are Croatia, Slovakia, Austria and Romania with 60%, 63%, 65% and 66% respectively. As indicated in Figure 9, less urbanized countries close the majority of the gap between them and the more urbanized countries up to 2050. From 2010 to 2050, Ireland, Luxembourg, Romania, Lithuania, Estonia and Poland record the most remarkable changes in urban proportion.

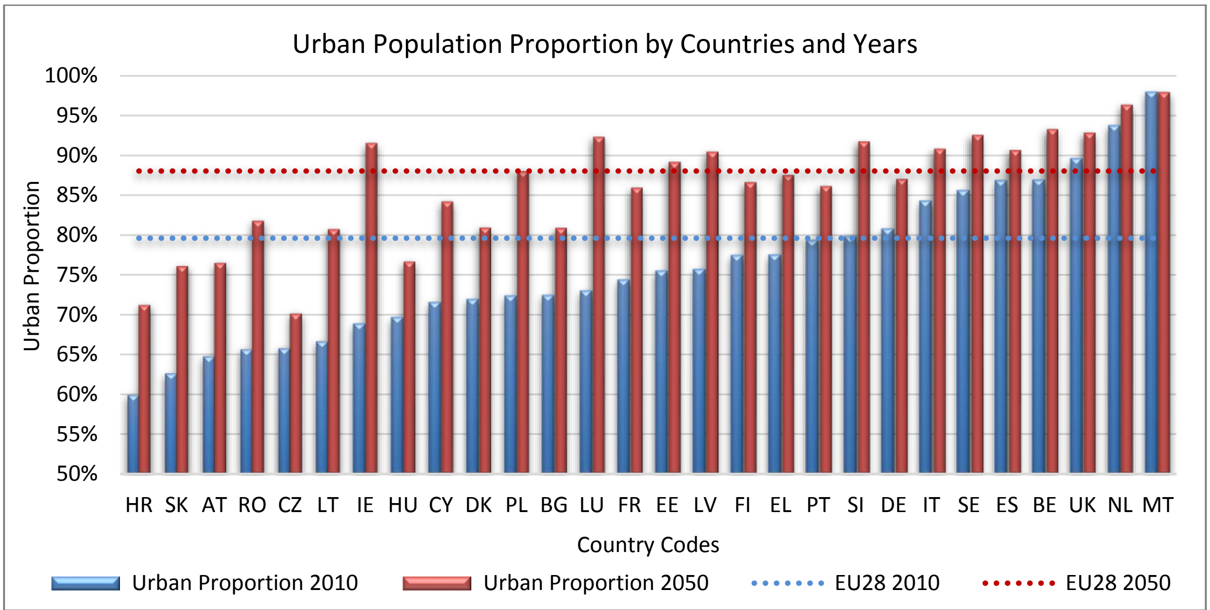


Figure 9: Urban proportion by countries and years.

Considering all 672 Functional Urban Areas (FUA) in Europe, the average urban proportion is 90% in 2010, and it becomes 93% in 2030, and 94% in 2050. The urban proportion in FUA of countries like the UK, Greece, the Netherlands, Spain and Romania is above 95%, as indicated in Figure 10. On the contrary, countries such as Czech Republic, Slovakia, and Denmark have urban proportions of less than 80% when only the FUA are taken into consideration.

3.3.2 Annual rate of urbanization

Another important indicator in monitoring urbanization process is the annual rate of urbanization, in other words the annual rate of change in urban population proportion. The average annual rate of urbanization across the World is 0.82% from 2010 to 2030, it decreases to 0.53% between 2030 and 2050. Over the whole period, the average rate is 0.72% (UN, 2014)[5].

The LUISA estimate for the average annual rate of urbanization across the EU-28 is almost half of the World average with only 0.48% between 2010 and 2030. It decreases almost ten times in the consequent 20 years to reach 0.05%; the average rate for the whole forty-year period is 0.27%.

Considering the country specific annual rate of urbanization as indicated in Figure 11, in the first twenty-year period countries such as Ireland, Lithuania, Romania, and Poland leave the EU-28 average behind with the highest urbanization rates. This is also the case for some countries like Luxemburg, Austria, Slovenia, Slovakia and Denmark, which have with lower annual rates of urbanization but remain above the EU-28 average in the subsequent twenty years.

[5] Since the numbers indicate the projection of the annual rate of change in urban proportion, there is no inconsistency in comparing them with the LUISA estimates for the EU-28.

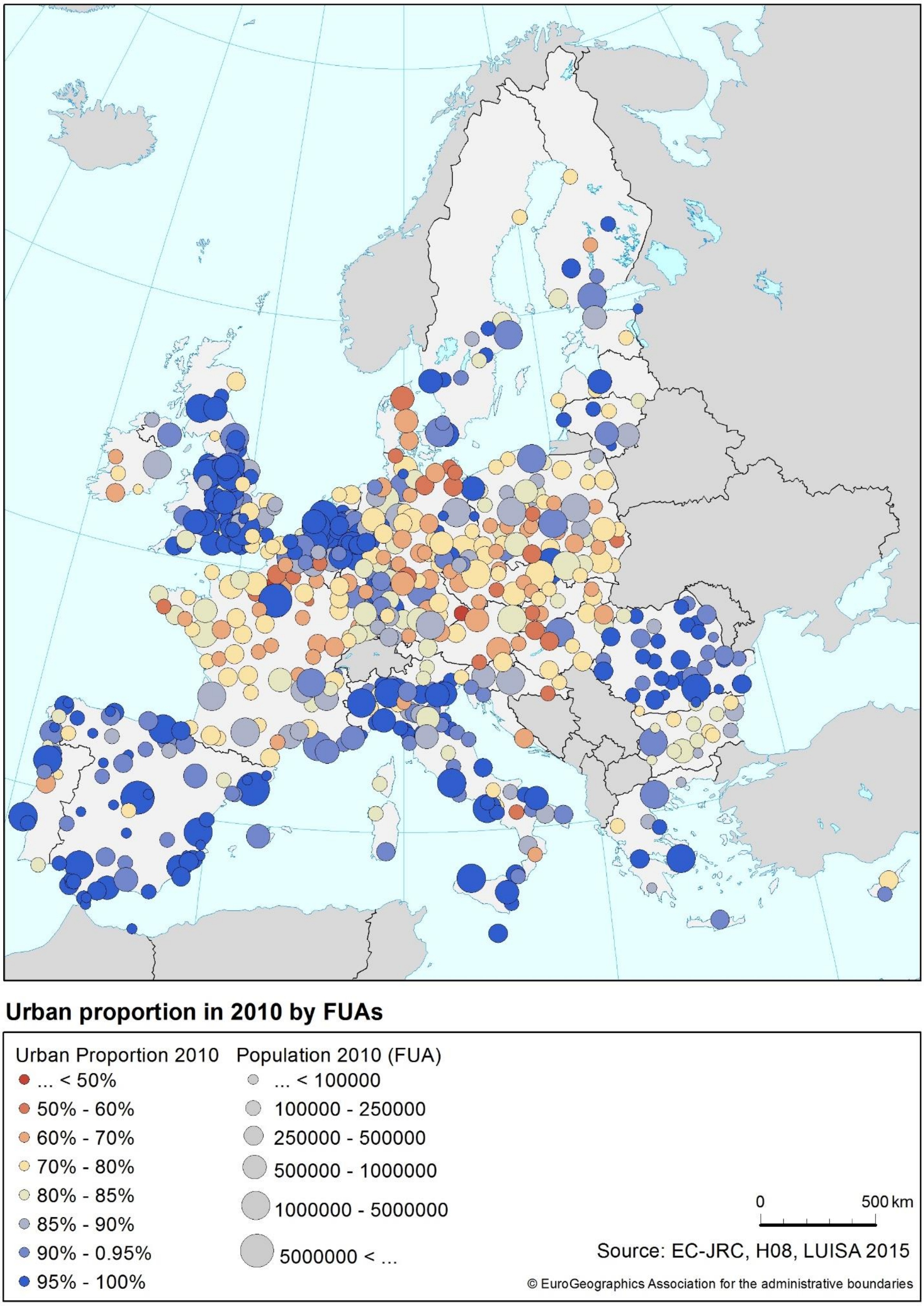


Figure 10: Urban proportion by Functional Urban Areas (FUA).

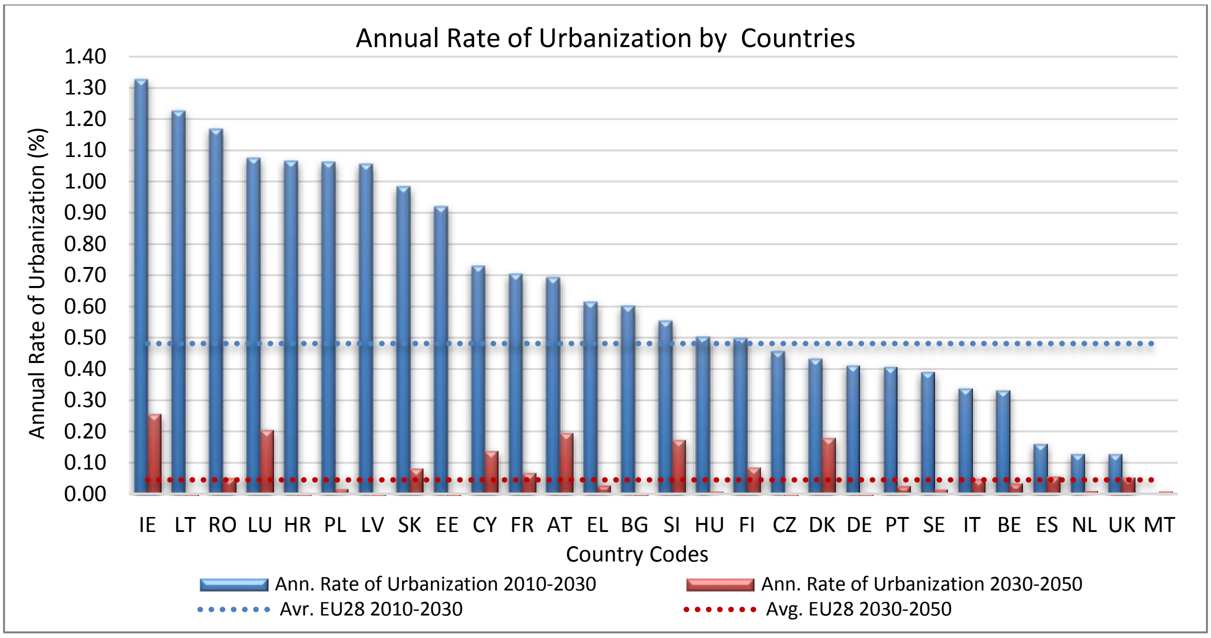


Figure 11: Annual rate of urbanization by countries.

With an average of 90% urban proportion, FUA have much lower annual rate of urbanization values. The EU-28 average annual rate of urbanization for FUA is 0.21%; less than half of the EU average. This rate decreases to almost zero with a value of 0.02% within the 2030-2050 period. As indicated in Figure 12, for some FUA such as the ones in Spain, United Kingdom, Portugal and Netherlands, it can easily be stated that no further increase in urban proportion is foreseen in the next twenty years.

On the other hand, the urbanization process within the FUA of countries like Slovakia, Ireland, Poland and Croatia is continuing. However, the annual rate of urbanization for FUA in these countries is still lower than for the country itself. The results imply that in the next twenty to forty years, urbanization in Europe will continue with lower rates. Besides this, urbanization will not mainly take place only in the FUA as it is in the past, but smaller cities/towns and also rural areas will be the subject of urbanization, since most of the FUA have already reached certain thresholds.

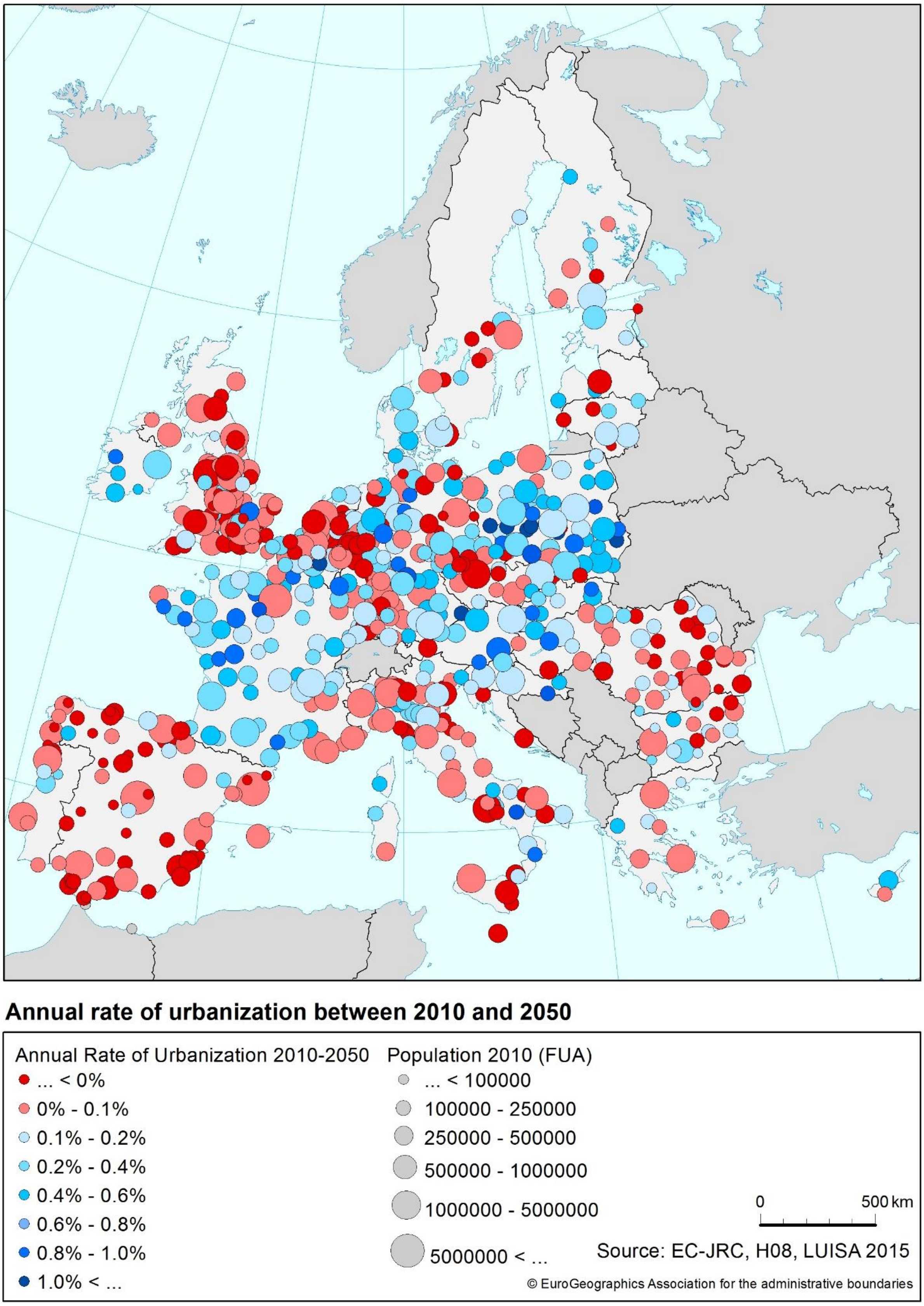


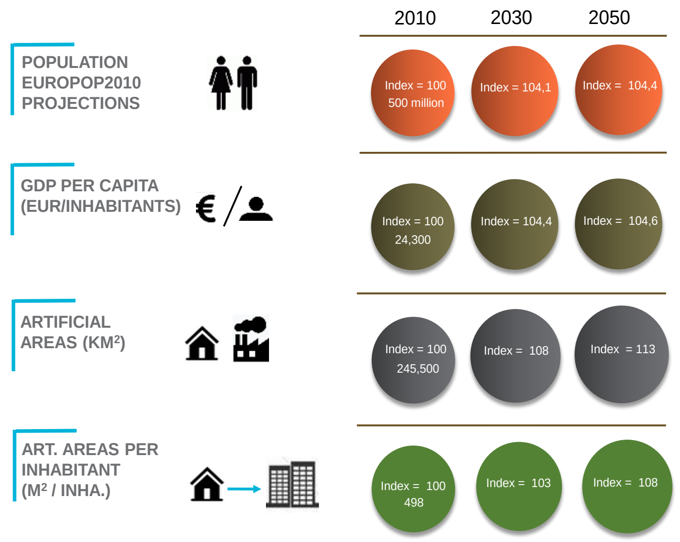
Figure 12: Annual rate of urbanization by Functional Urban Areas (FUA).

3.4 Land use and urban development

Cities generate around 75% of the global revenue and attract people that are looking for opportunities for a better future. The more people live in cities, the higher the demand for housing, jobs, transport, and recreation and leisure sites. When cities grow fast and planning instruments fail to respond adequately to the new challenges faced, both the quality of life and the supporting ecosystem can be significantly affected (UN HABITAT, 2014).

One measure of urban development is the 'land take' (i.e. the amount of land converted into artificial or built-up areas) and the intensity of land used (i.e. the actual amount of artificial land per inhabitant) (European Commission, 2014). Land take results in land degradation; in Europe it has caused high habitat fragmentation in 30% of the land area. Adopting limitations to this land take is already a priority policy target at national and sub-national level. Land-recycling, compact urban development, place-based management and the protection of green infrastructure in urban areas are seen as positive urban development policies in Europe (European Environment Agency, 2010).

In this section, the future land take and artificial areas per inhabitant were estimated according to a reference scenario (Baranzelli et al., 2014b). As indicated in Figure 13, the simulation with the reference scenario shows how the land use and population distribution would look like in 2050 according to the climate and energy policies in Europe. The methodological framework relies on the integrated modelling approach of the LUISA Modelling Platform.



Note: Economy and demography are important macro drivers of land-use change. In the reference scenario, the economic and demographic assumptions are consistent with the 2012 Ageing Report (EC, 2012). The demographic projections (EUROPOP2010), were produced by Eurostat, whereas the long-term economic outlook was undertaken by DG ECFIN and the Economic Policy Committee.

Figure 13: Some macro figures on demographics and land use dynamics.

3.4.1 Annual land take per inhabitant - land take intensity

The LUISA land take intensity indicator (Lavalle et al., 2013b) measures how much land initially covered by agriculture, forests and semi-natural areas is converted into housing, commercial, industrial and service areas over time. Coupling the amount of land take with the amount of population informs us on the intensity of the land take; a higher amount of land take per inhabitant means lower efficiency in using land resources.

The annual land take between 2010 and 2050 at EU-28 level is approximately 1.6 m^2/capita/year. As indicated in Figure 14, it is less than 1 m^2/capita/year in Bulgaria, Germany, Latvia, Croatia and Greece and more than 3m^2/capita/year in Ireland, Finland, Belgium, Cyprus, Luxemburg and Sweden. The annual land take per inhabitant in Spain, Slovenia, United Kingdom and Lithuania is close to the EU-28 average.

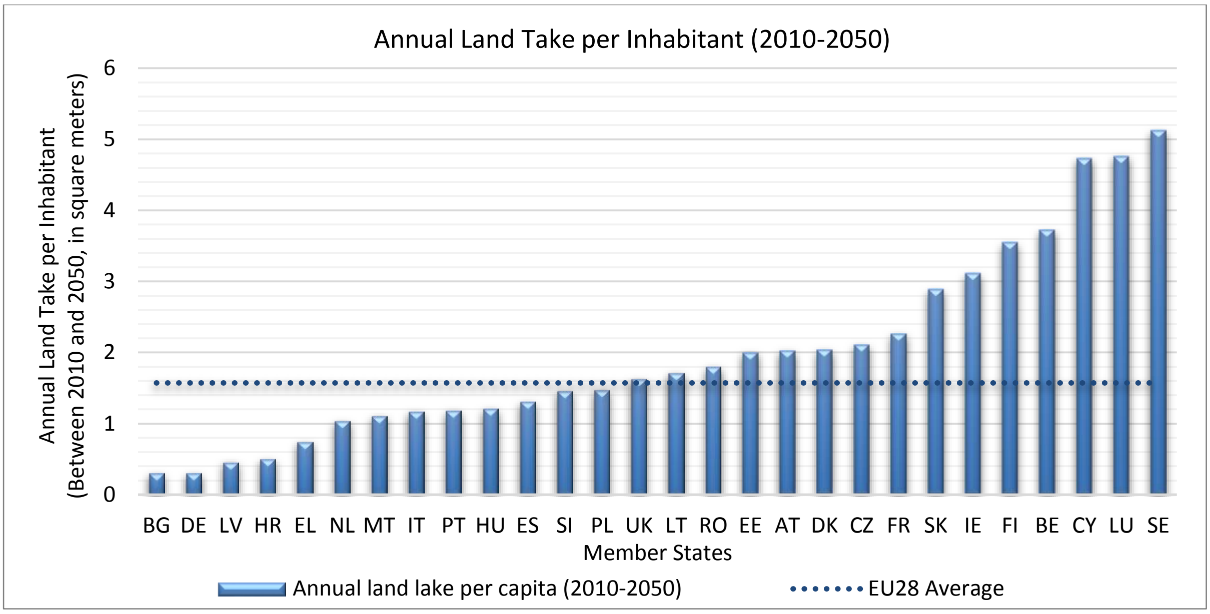


Figure 14: Annual land take per capita (land take intensity) between 2010 and 2050 by countries.

The annual land take per inhabitant in square meters varies throughout the EU-territory (Figure 15). The regions in red hues are those classified with the highest land take between 2010 and 2050. In these regions, the amount of land converted in residential, industrial/commercial/ services are above 8 m^2 per inhabitant per year. On the contrary, regions in blue hues expect no net land take (dark blue) or a land take that is lower than the EU-28 average (light blue).

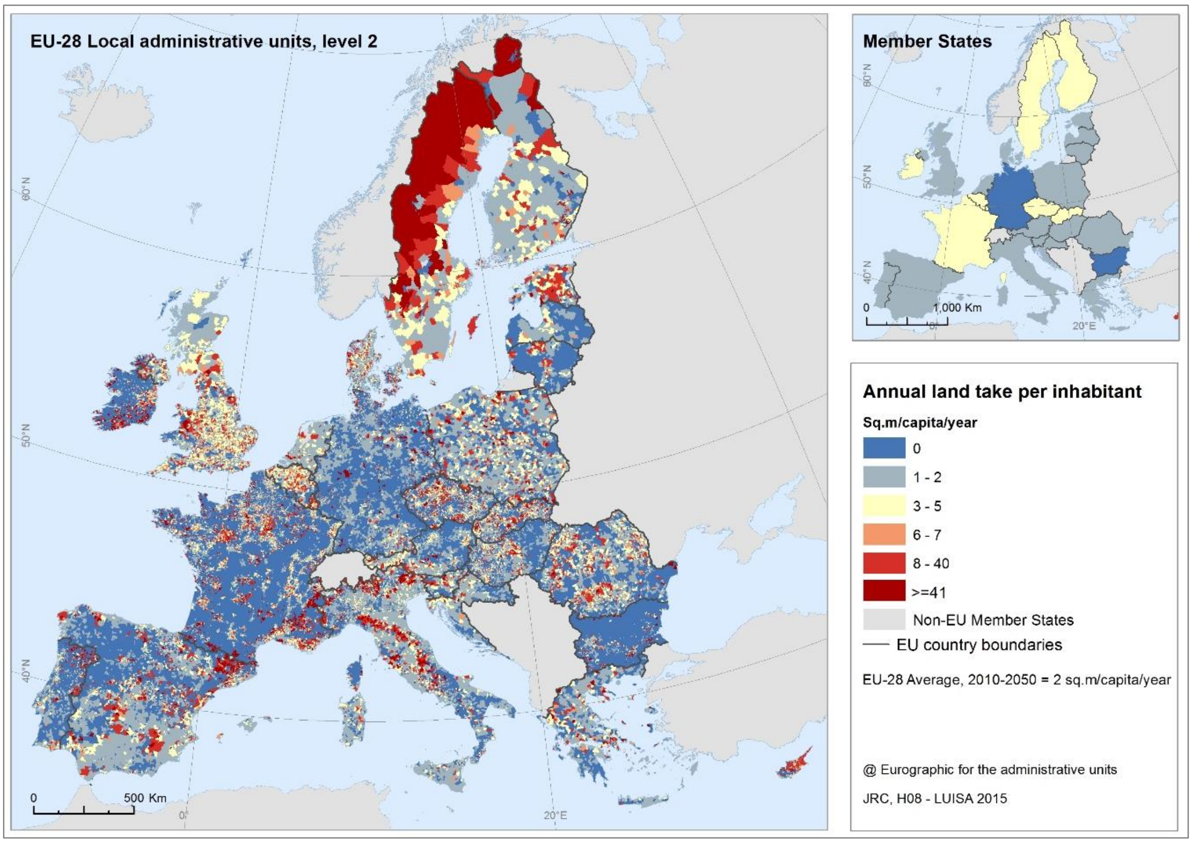


Figure 15: Annual land take per inhabitant (land take intensity) between 2010 and 2050 at municipality level (LAU2).

The average annual land take per inhabitant also varies depending on the degree of urbanization. Most cities already have a high proportion of built-up areas, i.e. land in these regions is intensely occupied and virtually all available land has already been developed. As a consequence, land take is higher in the surrounding suburbs and rural areas than in the cities, and is expected to increase in the future. Under the reference scenario, the annual land take between 2010 and 2050 is approximately 0.80 m^2/capita/year in cities, 1.93 m^2/capita/year in suburbs and towns, and 3.08 m^2/capita/year in rural areas. Figure 16 allows the comparison of this figure by country. If overall ratio per degree of urbanization is compared, the share of cities in annual land take per inhabitant is 14 %, it is 33% for suburbs and towns and 53% for rural areas, as indicated in Figure 16 with stacked bars. This last figure is even higher in rural areas of Denmark, Ireland, the United Kingdom and Sweden.

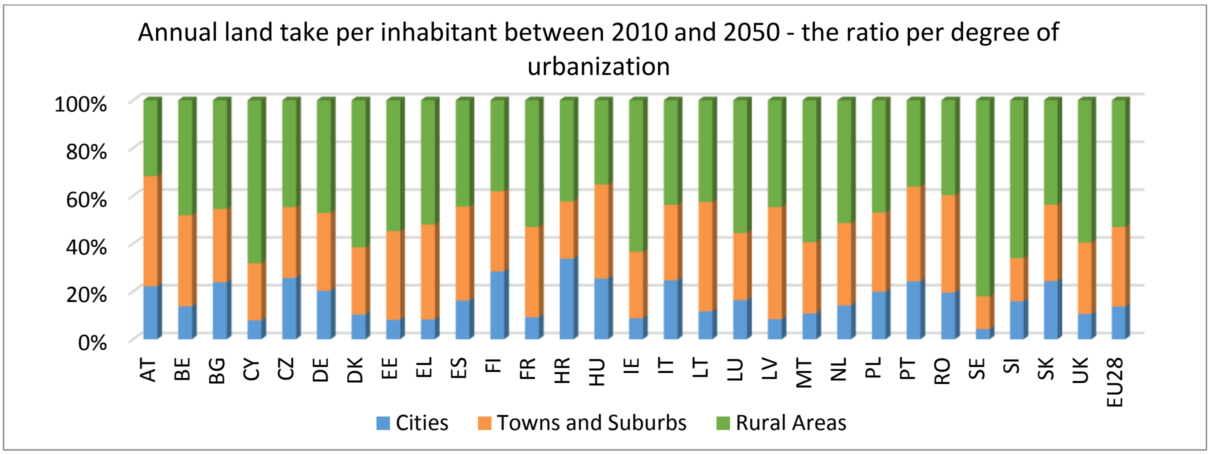


Figure 16: Annual land take per inhabitant between 2010 and 2050 – the ratio per degree of urbanization.

Figure 17 shows the annual land take per inhabitant in the Functional Urban Area of Brussels. In Brussels city centre, the land take is almost zero, meaning that the land available for built-up areas has already been taken in the past. The farther you go from the city centre, the higher the observed annual land take per inhabitant. A similar pattern is noticeable in the majority of FUA in Europe.

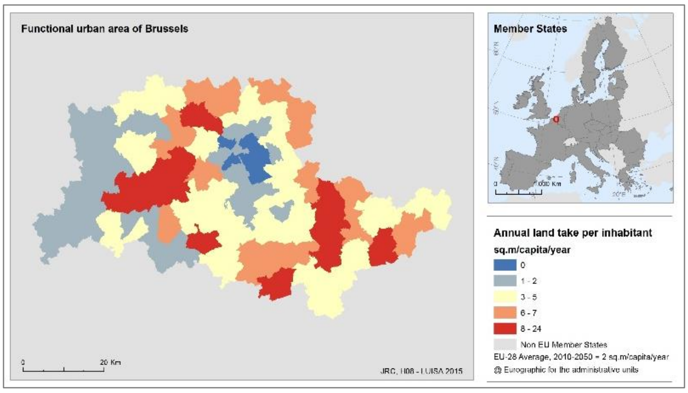


Figure 17: Annual land take per capita in the Functional Urban Area (FUA) of Brussels between 2010 and 2050 at Local Administrative Units (LAU2) level.

The average annual land take per inhabitants in FUA is slightly lower than that for the whole EU-28, with 1.5 m^2/capita/year. As indicated in Figure 18, it is below the EU average in FUA of Latvia, Germany, Bulgaria, Croatia, Italy, and Spain; and above the average for instance in France, Finland, Denmark, Belgium, Ireland and Sweden. Figure 19 shows the annual land take per km^2 in a range of 30 km distance from the city centre for six cities in Europe. The land take tends to start peaking after a distance of 5 km from the centre. The general pattern can be explained by the fact that the land available for built-up within city centres has already been developed, meaning that land take is mainly in the suburbs followed by the rural areas. Despite this general trend, highest land take occur between 5 and 20 km distant from the city centre, the land take profiles after 5 km distance otherwise differ significantly across the cities. The highest amount of annual land take per km^2 is seen in Bucharest and Brussels at 8-12 km distances with around 7000 to 9000 m^2/year.

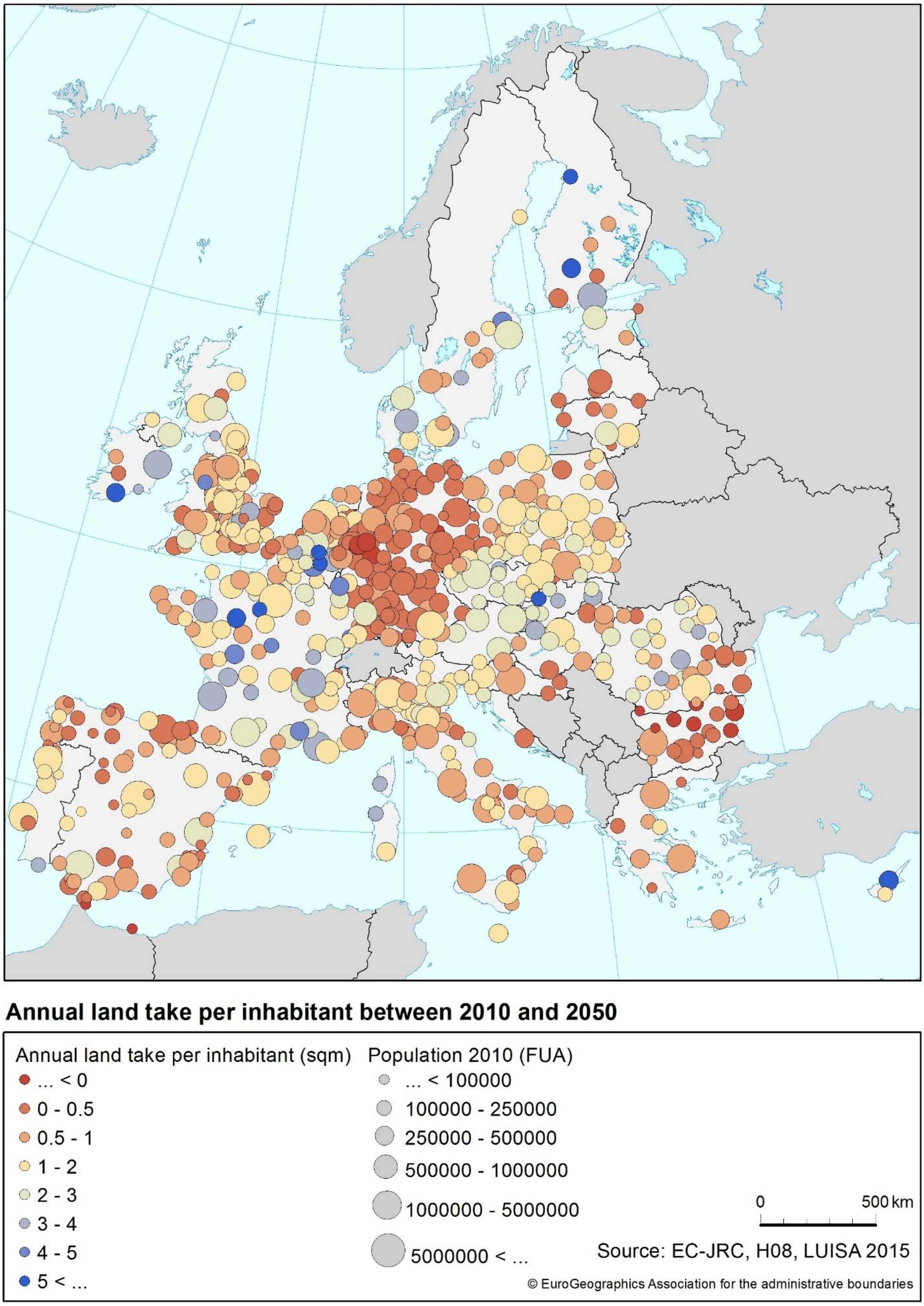


Figure 18: Annual land take per inhabitant between 2010 and 2050 by Functional Urban Areas (FUA).

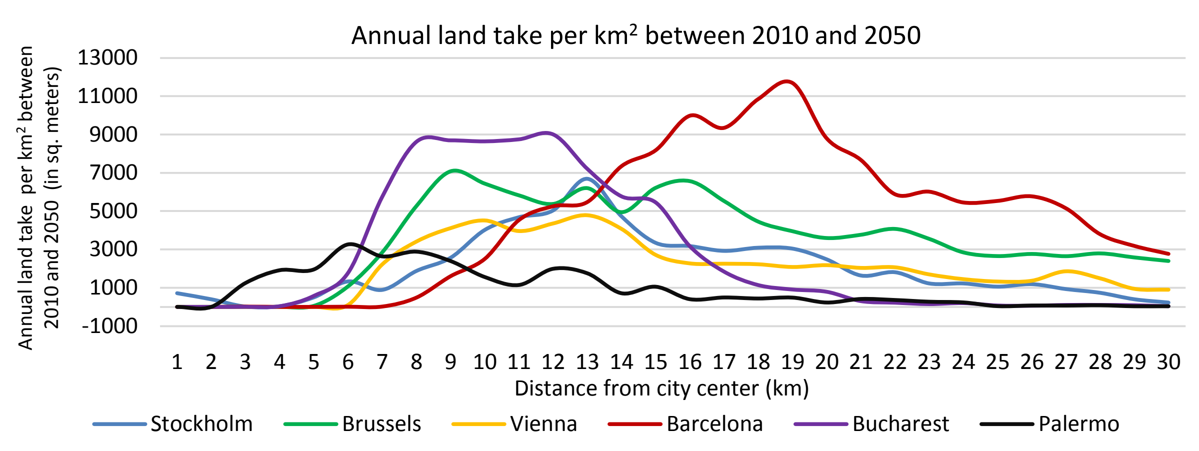


Figure 19: Annual land take per km^2 between 2010 and 2050 – the profiles for Stockholm, Brussels, Vienna, Barcelona, Bucharest and Palermo.

Figure 20 shows the land take per inhabitant for the same sample of cities in Europe. For example, in Barcelona and Vienna land take per inhabitant gradually increases up to 4 m^2/capita/year at 30 km distance from the city centre. Stockholm shows a similar pattern, however, the land consumed per inhabitant is even higher with 8 m^2/capita/year at the 30 km distance from the city centre, meaning a more dispersed built-up area development. Palermo has a more homogenous distribution in terms of land take with distance; always less than 3 m^2/capita/year due to the natural thresholds. In Brussels the land take per inhabitant gradually increases up to 6 m^2/capita/year until 17 km and then drops down to 4 m^2/capita/year. Bucharest has a similar profile, however it peaks at 12 km and has a stronger decline down to 1 m^2/capita/year at 30 km distance from the city centre.

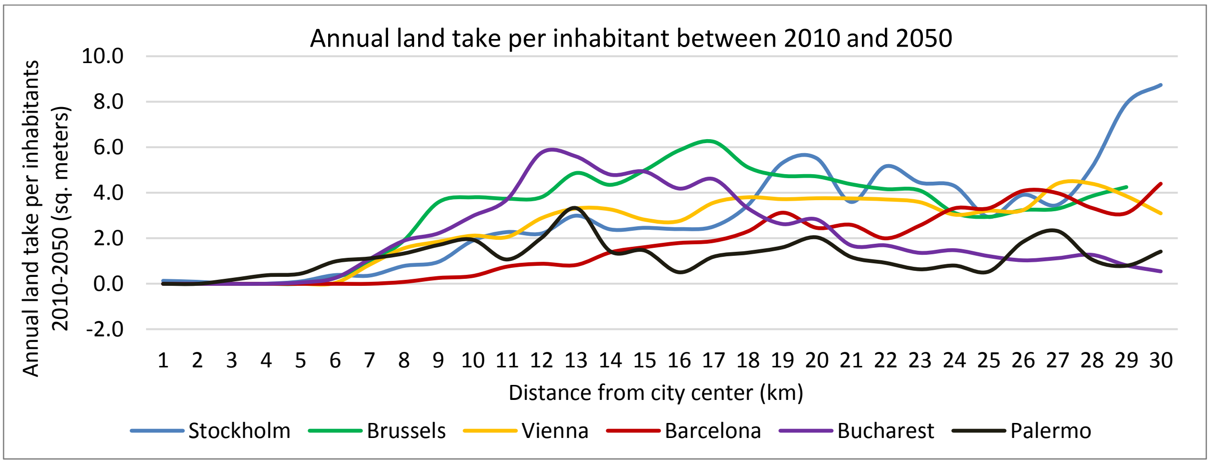


Figure 20: Annual land take per inhabitant between 2010 and 2050 – the profiles for Stockholm, Brussels, Vienna, Barcelona, Bucharest and Palermo.

3.4.2 Artificial areas per inhabitant - land use intensity

The land use intensity indicator measures the land consumption or the size of actual artificial areas per inhabitant, expressed in square meters per inhabitant. It provides useful information on the efficiency of land used for residential, sport and leisure, economic activities and infrastructures[6]. An additional analysis compares the growth rate of artificial

[6] Infrastructures (road and rails networks, ports and airports, mineral extraction, dump and construction sites) were taken into account in the calculation, however, in the LUISA framework they are non-simulated land use classes and thus remain static over time in terms of quantity and location.

areas with the total population growth rate between 2010 and 2050. The land use intensity trend increases when the urban growth rate is lower than the population growth rate, whereas if the rate of urban growth is higher than the growth rate of the population, the land use intensity shows a negative trend in terms of efficiency, resulting in an increased land consumption.

As shown in Figure 21, the average amount of artificial areas per inhabitant in the EU-28 as of 2010 is 498 m^2. This value is less than 400 m^2 mainly in the southern countries like Malta, Greece, Italy and Spain and less than the European average in some northern countries, with more compact urban development, like the United Kingdom, the Netherlands and Germany. On the contrary, the artificial areas per inhabitant in 2010 are above 800 m^2 in most of the northern countries, with a more dispersed use of land, like in Sweden, Lithuania and Finland.

The artificial areas per inhabitant in EU-28 increase by 8% to 539 m^2 in 2050. Croatia, Romania, Bulgaria, Latvia, Slovakia, Ireland and Poland record the greatest amount of change between 2010 and 2050 in terms of artificial areas per inhabitant. Not only the additional land consumed but also the decrease in population plays an important role in these changes during the following decades, as is the case in Romania and Bulgaria.

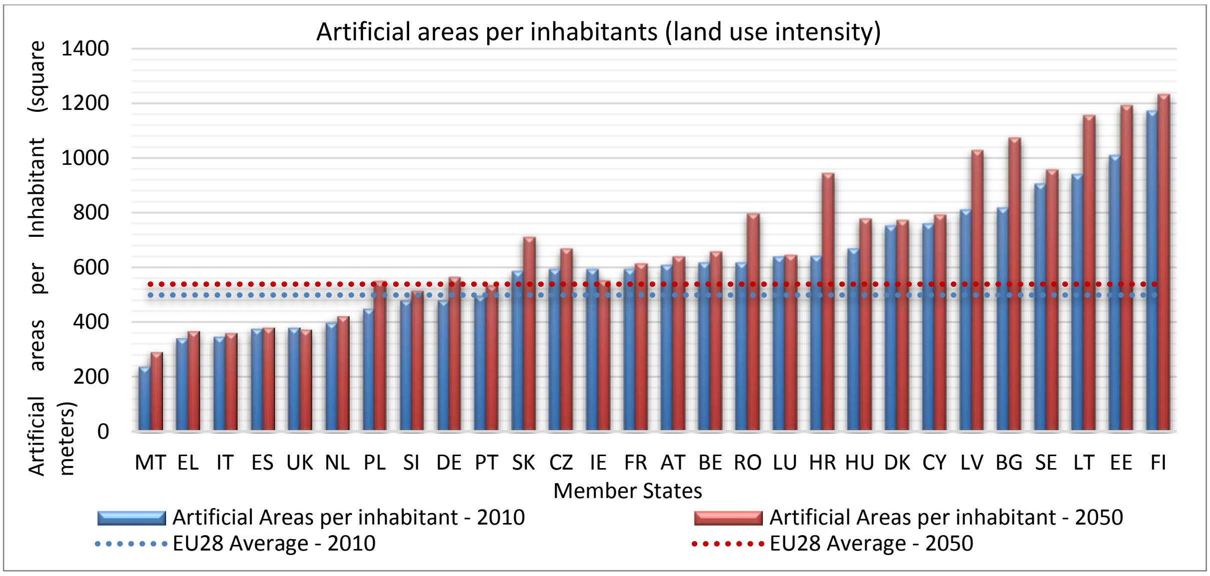


Figure 21: Artificial areas per inhabitant (land use intensity) by countries.

Figure 22 shows the amount of artificial areas per inhabitant by Functional Urban Areas (FUA). Considering only the FUA, in 2010 the average amount of artificial areas per inhabitant is 373 m^2, and becomes 388 m^2 in 2050 with a 4% increase. This is only half of the increase rate within the whole EU-28, meaning that there is less land consumption per inhabitant in FUA. As mentioned earlier, in Southern Europe this value is lower (light yellow/yellow hues) than for the regions in Western, Central, Eastern and Northern Europe (light red/red hues).

The low land use density patterns (red hues) in those FUA can be justified by the need for more space per inhabitant, the development of commercial and transport services, the preference for single houses over blocks of flats, and the influence of land use policies, either towards compact or sprawled cities (Kasanko et al., 2006). The high population density in artificial areas (yellow hues) can be attributed to a different origin. Cities located in the southern part of Europe are historically more compact than in the rest of Europe. Capital cities such as London, Paris and Brussels are already saturated with buildings but remain attractive to people since they supply employment, opportunities for learning, accessibility to health care facilities, and a variety of social and cultural activities.

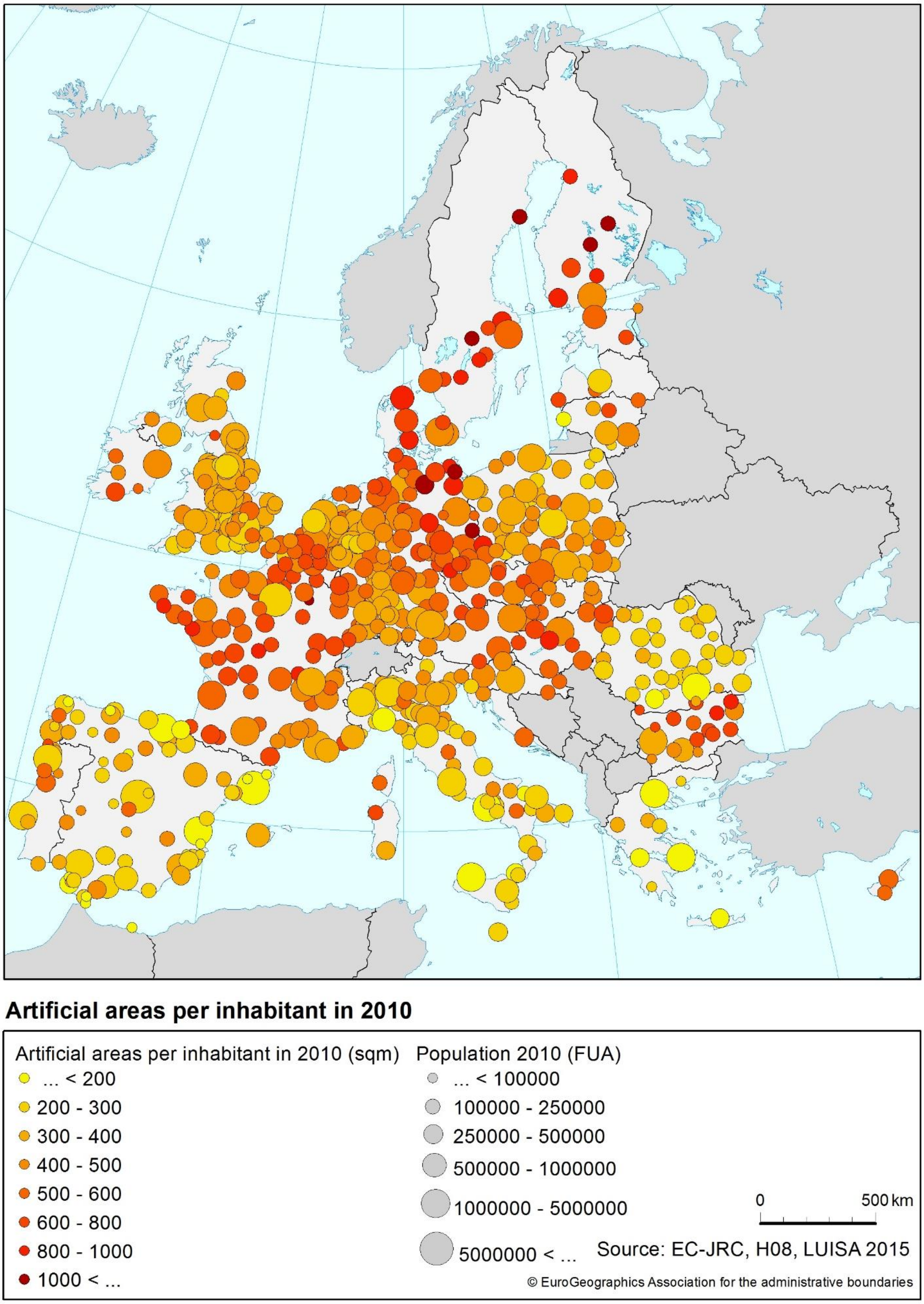


Figure 22: Artificial areas per inhabitant (land use intensity) by Functional Urban Areas in 2010.

As expected, the land use intensity/artificial areas per inhabitant also varies depending on the degree of urbanization. In general, the local administrative units (LAU2) classified as cities use land more efficiently (228 m^2/capita), than towns and suburbs (501 m^2/capita) and rural areas (1084 m^2/capita). Figure 23 shows how the ratios per degree of urbanization differ among countries. On average, cities account for 12% in artificial areas per inhabitant whereas towns and suburbs make up 27% and rural areas 60% of the total.

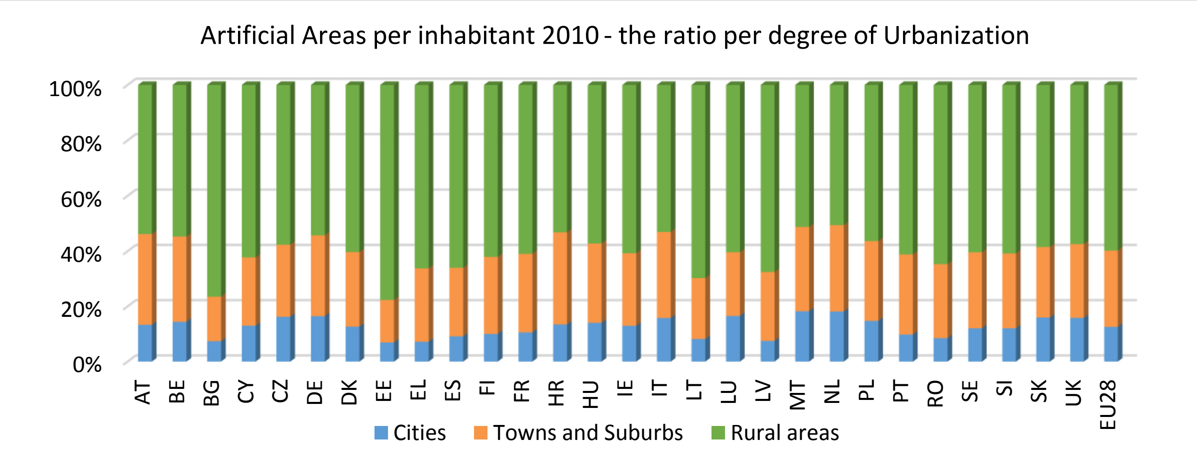


Figure 23: Artificial areas per inhabitant (land use intensity) in 2010 - the ratio per degree of urbanization.

Towards 2050, the amount of available artificial areas per inhabitant tends to increase in almost all Member States, particularly in the rural areas as indicated in Figure 24.

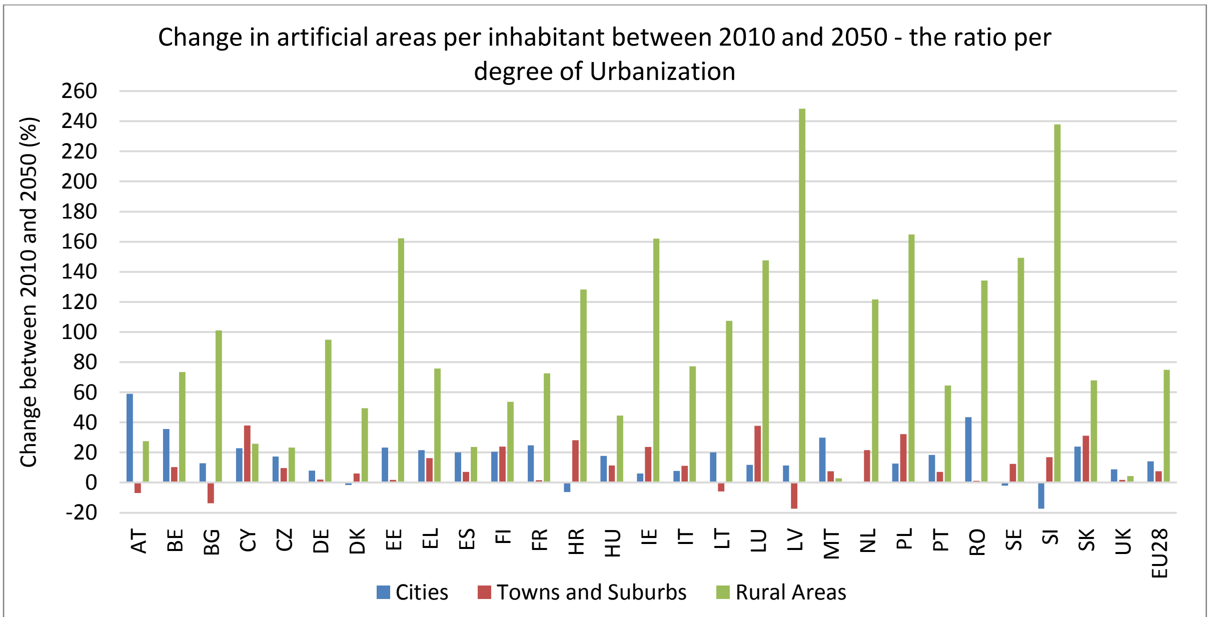


Figure 24: Percentage of changes in artificial areas per inhabitant (land use intensity) between 2010 and 2050.

Figure 25 shows how FUA are expected to change in terms of land use intensity between 2010 and 2050. This figure compares the growth in population (x axis) and the growth in artificial areas (y axis) in the reference scenario between 2010 and 2050. The colours split the urban areas into two groups with different land use intensity patterns. The FUA placed in the green area of the figure are those where the population growth exceeds the growth in artificial areas (right side of x-axis). Dublin, Cambridge, Pisa and Stockholm are few examples of urban areas that will use the artificial areas more efficiently since the predicted amount of land consumed per capita decreases over the period of analysis.

The second group corresponds to urban areas where the amount of artificial areas is expected to increase faster than their population (dark and light red hues). Within this group, two profiles can be identified. The first profile is related to the urban areas such as, Dusseldorf, Lleida and Perpignan where the population is expected to decrease by 2050 (left side of y-axis) while the growth in artificial areas remains positive. As a result, the area consumed by each resident is increasing. The second profile of FUA includes cities like Barcelona, Naples, Brussels and Vienna, where the population is expected to have a positive growth but the amount of artificial areas is growing faster than the population.

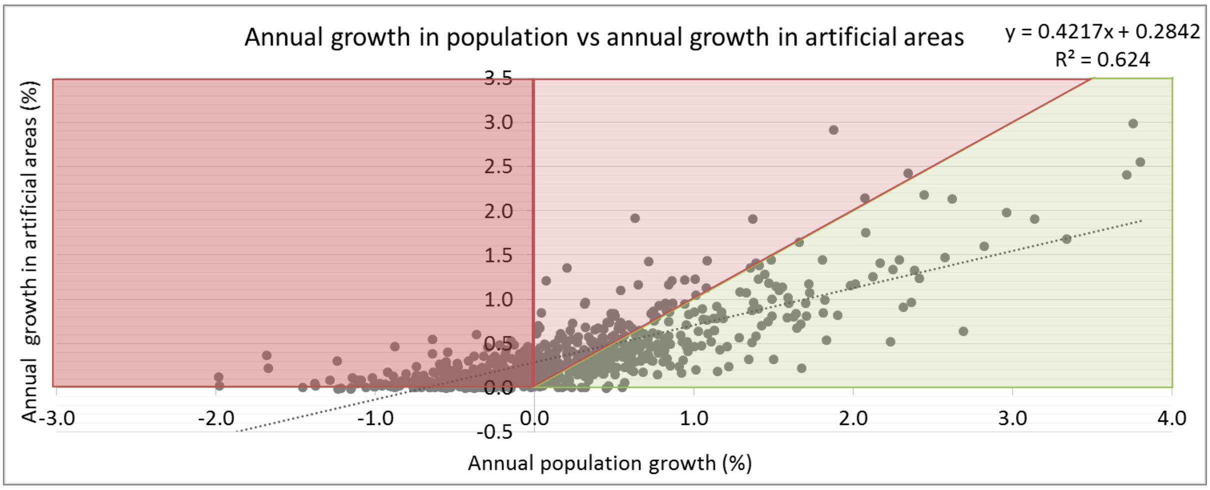


Figure 25: Annual growth in population vs. annual growth in artificial areas between 2010 and 2050 by FUA.

In Figure 26 and Figure 27, the distribution of artificial areas per inhabitant in a range of 30 km distance from the city centre is given for the 6 cities introduced earlier. Similarly to the land take indicator, a pattern with an intense use of land in the city centres (in this example up to 200 m^2/per inhabitant) is noticeable in all selected cities. After 10 km distance from the city centre the amount of artificial areas per inhabitants tends to increase first to 400-600 m^2/inhabitant and then to 600-1000 m^2 /inhabitant.

In comparison with the other cities Barcelona has a more intense use of land at all distances whereas Stockholm has a less intense use of land especially beyond 20 km from the city centre. As indicated in figure 14, a similar pattern for the year 2050 can be observed with slightly more artificial areas per inhabitant farther than 3-4 km from the city centre.

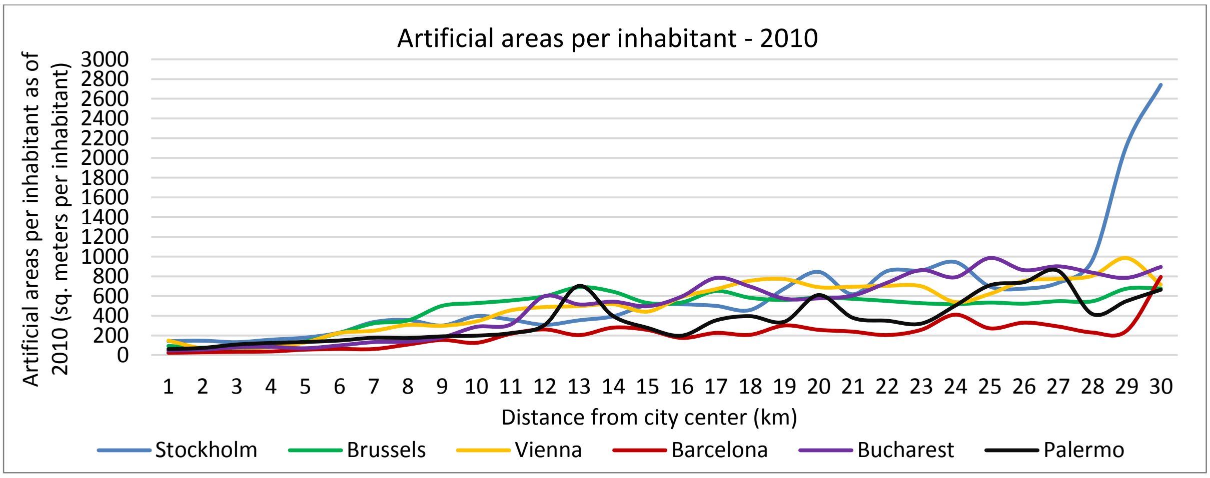


Figure 26: Artificial areas per inhabitant (land use intensity) at increasing distances from the city centre, for selected European cities in 2010.

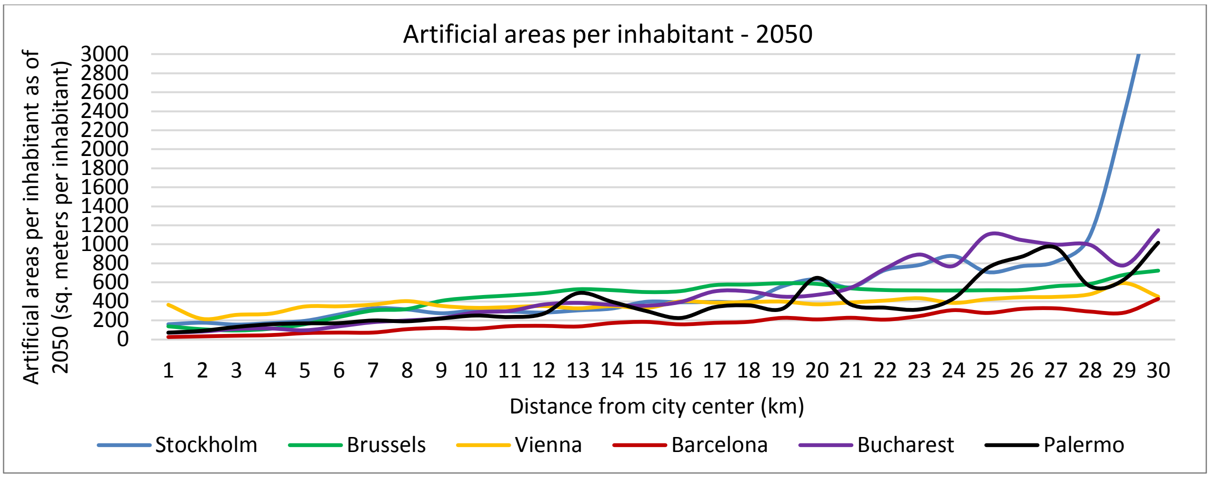


Figure 27: Artificial areas per inhabitant (land use intensity) at increasing distances from the city centre, for selected European cities in 2050.

3.5 Population growth

3.5.1 The EU-28 population in 2010

In 2010, 65% of the total EU-28 population, approximately 320 million people, live in the 672 Functional Urban Areas (FUA). The proportion of population living in FUA varies across EU countries from 100% in Luxembourg to 35% in Slovakia (Figure 28).

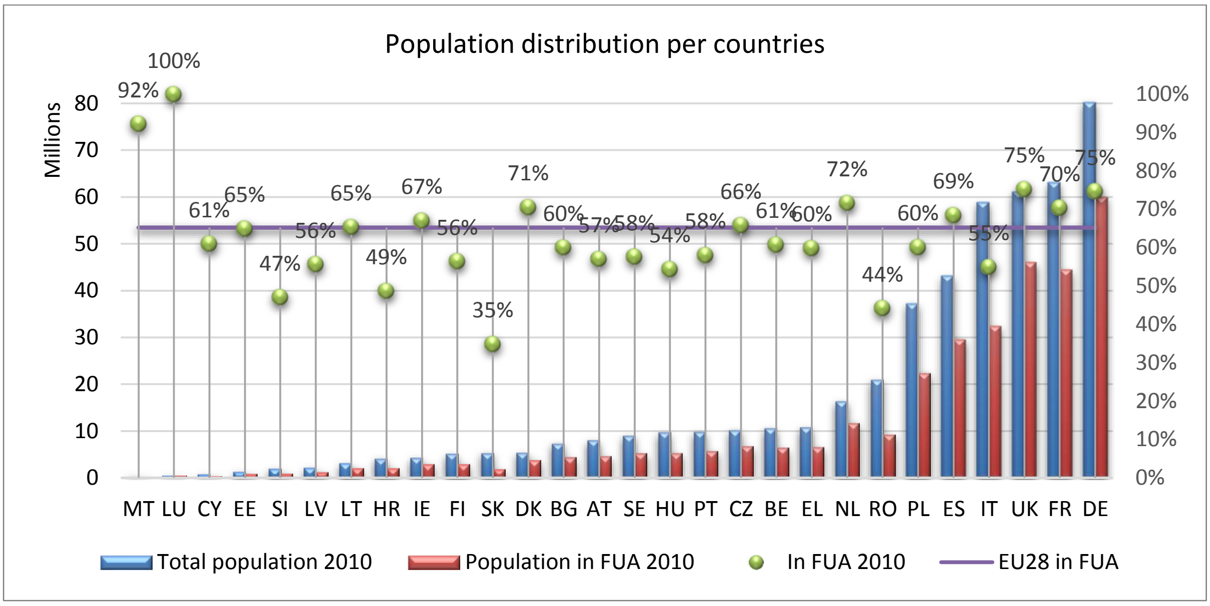


Figure 28: Population distribution for the EU-28 in 2010.

FUA with total populations greater than 1.5 million account for 39% of the population while FUA with fewer than 200 thousand people account for 12% of the population.

In the EU-28, 45% of the population live in local administrative units (LAU2) which are considered as cities, 35% in towns and suburbs and 20% in rural areas. The highest proportion of LAU2 population living in cities can be found in Malta (68%) whilst the lowest proportion can be found in Slovakia (21%) (Figure 29).

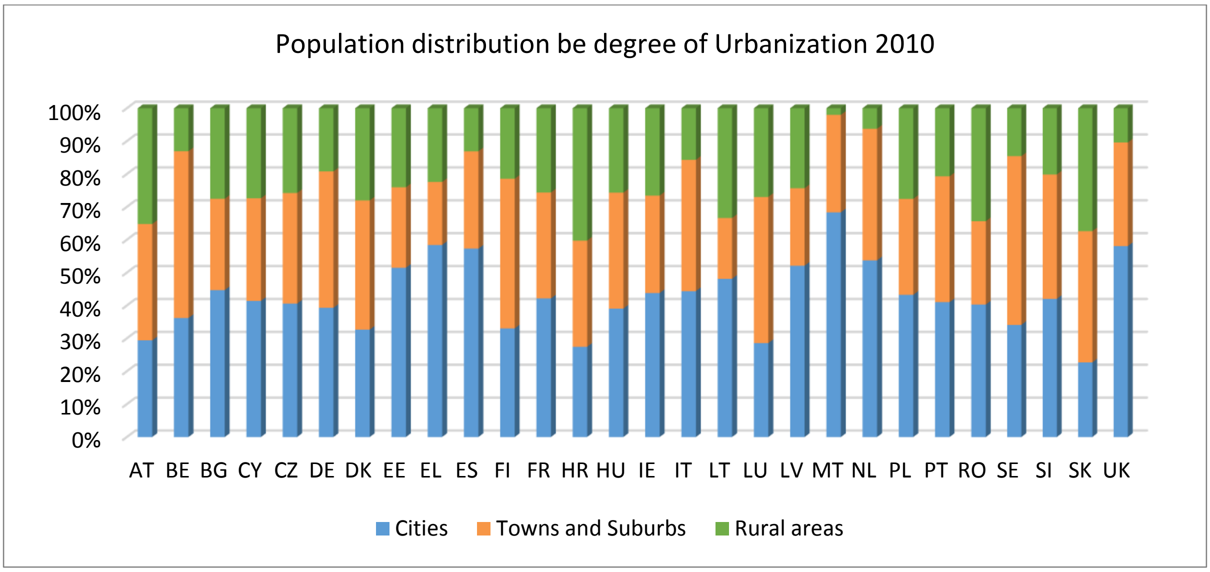


Figure 29: Population distribution per degree of urbanization in 2010.

3.5.2 Projected changes in population

The amount and spatial distribution of population for the year 2050 were obtained from the LUISA platform reference scenario for 2014 (Baranzelli et al., 2014b). Under this scenario, the global trend in urbanization is likely to increase in the future (Figure 30), and 70% of EU the population is expected to live in FUA by 2050.

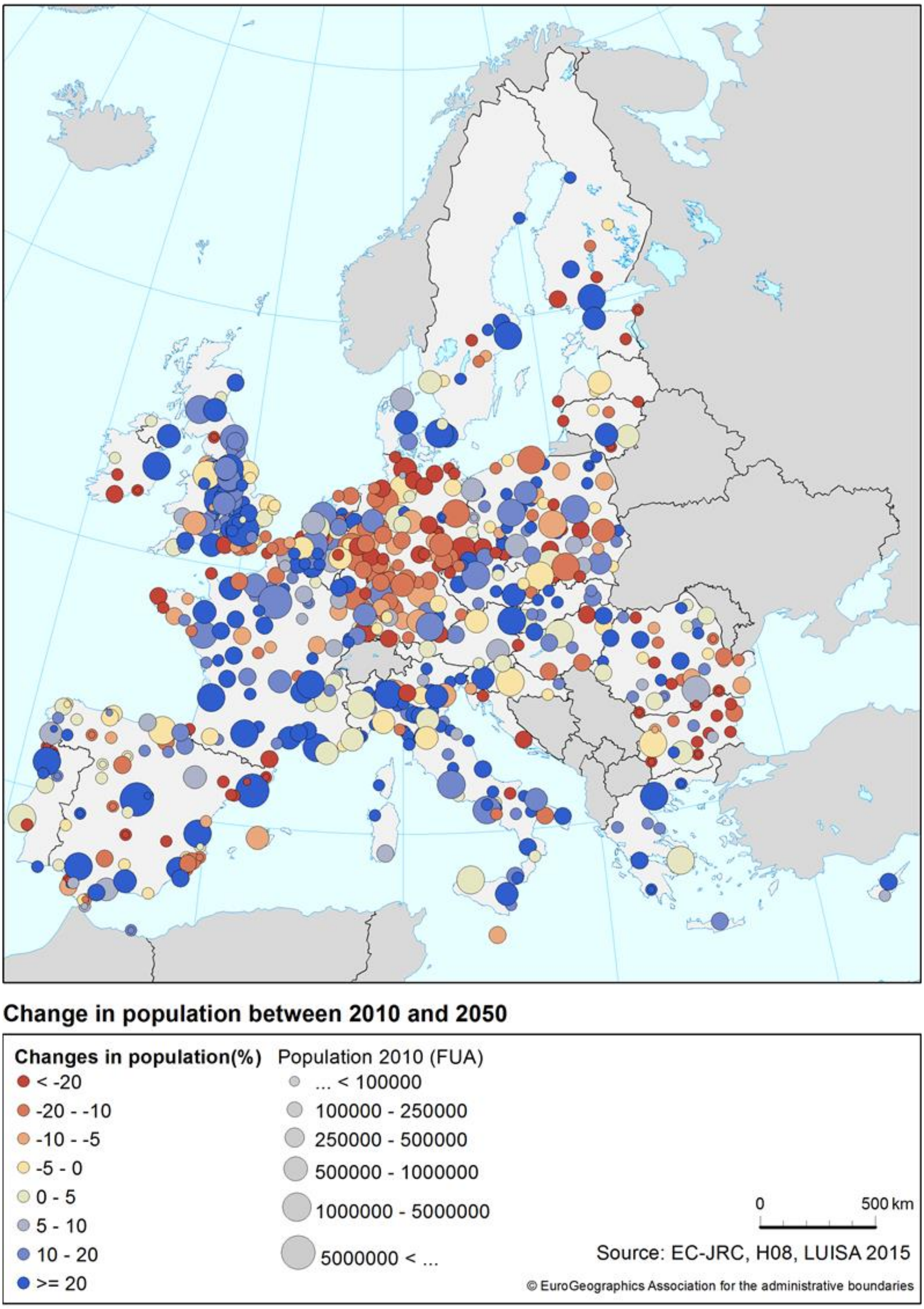


Figure 30: Changes in EU population between 2010 and 2050 at FUA level.

The EU-28 population is expected to grow by 4.6% between 2010 and 2050. Most of this population growth will occur in FUA (which will grow by an average 14%) while the rest of the European landscape is expected to lose population (-12%, by 2050). This change will however be uneven across Europe.

Changes in FUA population are likely to be heterogeneous across Europe (Figure 31). Countries such as Germany, Bulgaria and Hungary will lose population, whilst others will experience strong gains (France, United Kingdom, Italy and Spain). The highest growth rates (>40%) in FUA populations are expected in Luxembourg, Ireland and Finland.

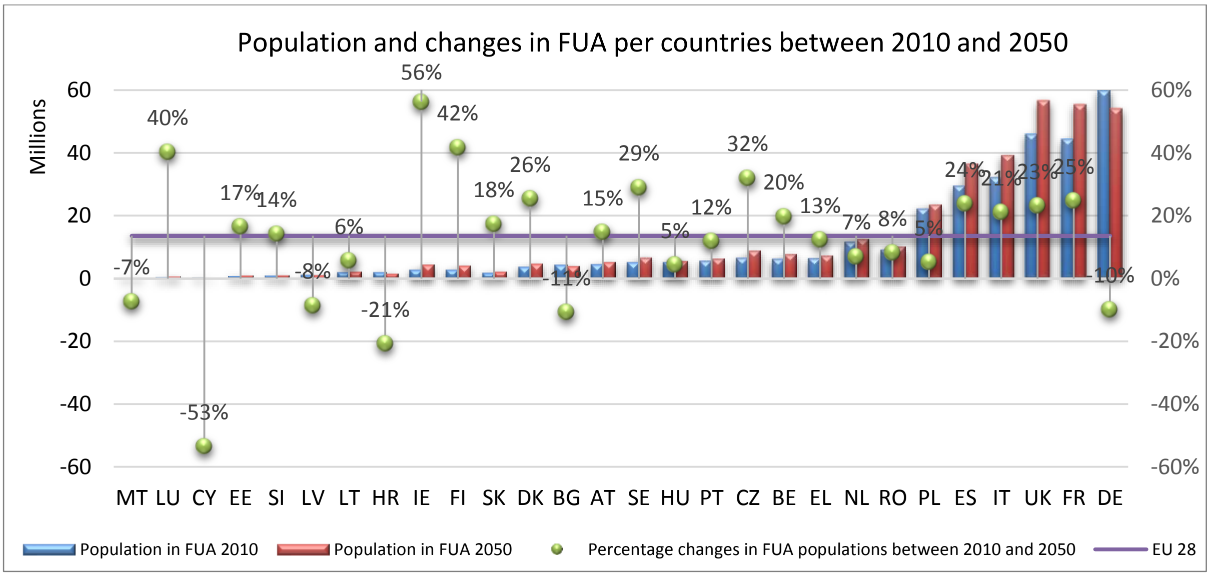


Figure 31: Population changes in FUA between 2010 and 2050.

Within FUA, we will also observe a change in population distribution with more people living in LAU2 considered as cities (+30%) and less living in suburbs and towns as well as rural areas (Figure 32). Globally, we expect a decrease in the proportion of population living in towns and suburbs except from Malta, Estonia, Slovakia, Lithuania, Bulgaria, Austria, Romania and Poland. This indicates a densification of the urban habitat. This densification effect is, however, positively biased by the fact that LAU2 classified as towns and suburbs and rural areas are reclassified into cities in 2050 which leads to a 22% increase in the number of LAU2 considered as cities between 2010 and 2050.

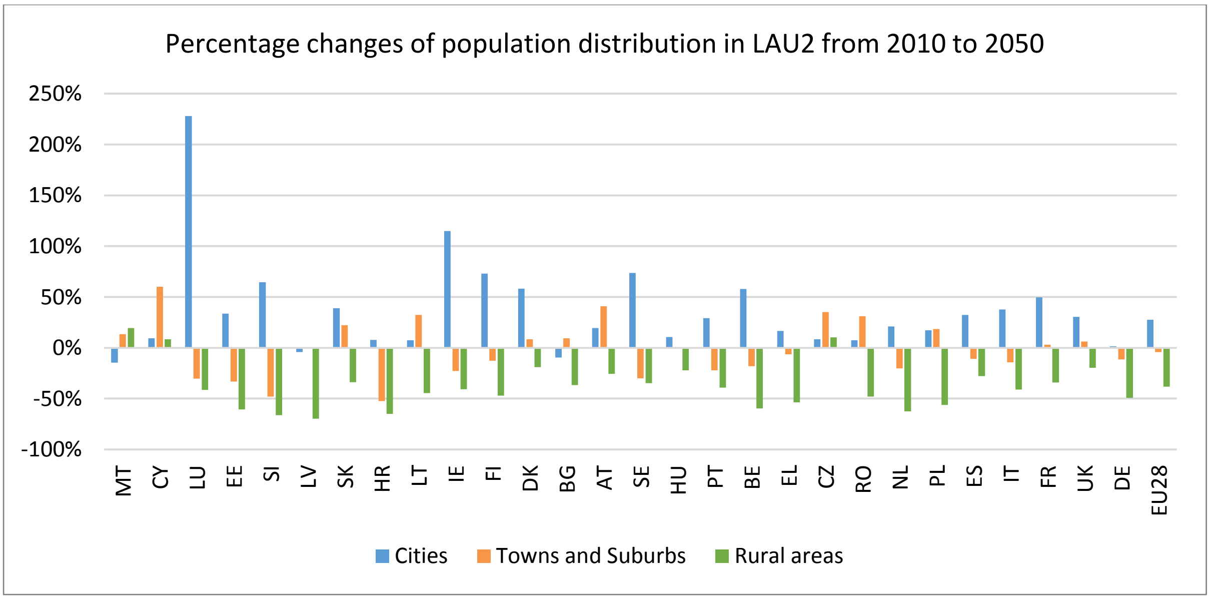


Figure 32: Percentage changes in population distribution between 2010 and 2050.

3.5.3 Population changes in selected European cities

Figure 33 illustrates the changes in population density as a function of distance to city centre for 6 selected cities in 2010. We observe a similar profile for all selected cities where most of the population is located near the city centre, the density then decreases and plateaus around 14 km distance.

Future changes in population across the selected cities (shown Figure 34) indicate that overall, city centres are likely to lose people (particularly Vienna), while the city outer rings, from 8 to 22 km, will see an increase in population. This population increase outside city centres is particularly notable for Bucharest, which will see its population more than triple in the 12-13 km ring surrounding the city centre (mostly due to the development of new built-up areas).

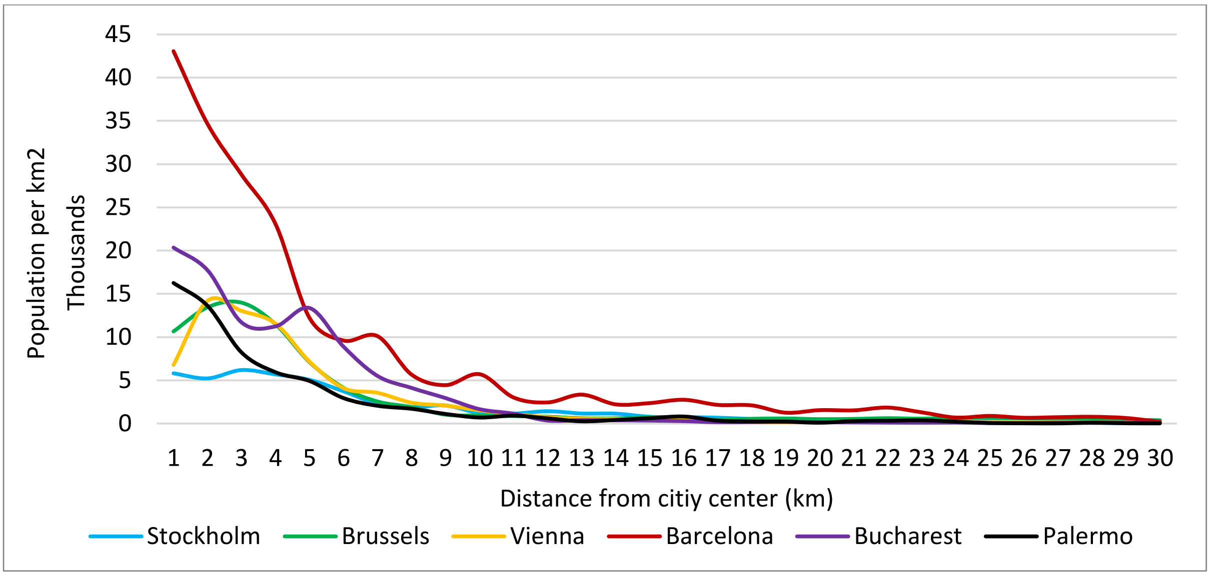


Figure 33: Population profile of selected cities in 2010.

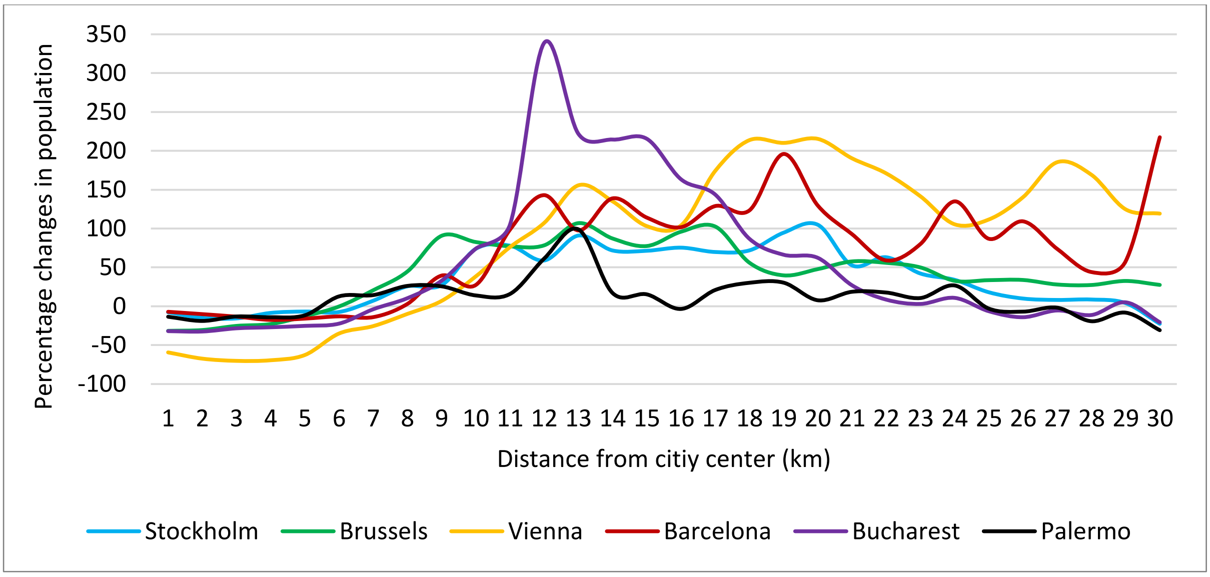


Figure 34: Percentage change in population, for selected cities between 2010 and 2050.

Figure 35 illustrates these potential changes for the city of Bucharest (Romania). We observe that LAU2 making up the Bucharest city centre will lose about 20% of their population, while the LAU2 on the outer edges of the FUA will strongly increase (more than double) their population, to the point to which some LAU2 currently considered as suburbs at the outer SW and NW corner of the FUA are reclassified as cities.

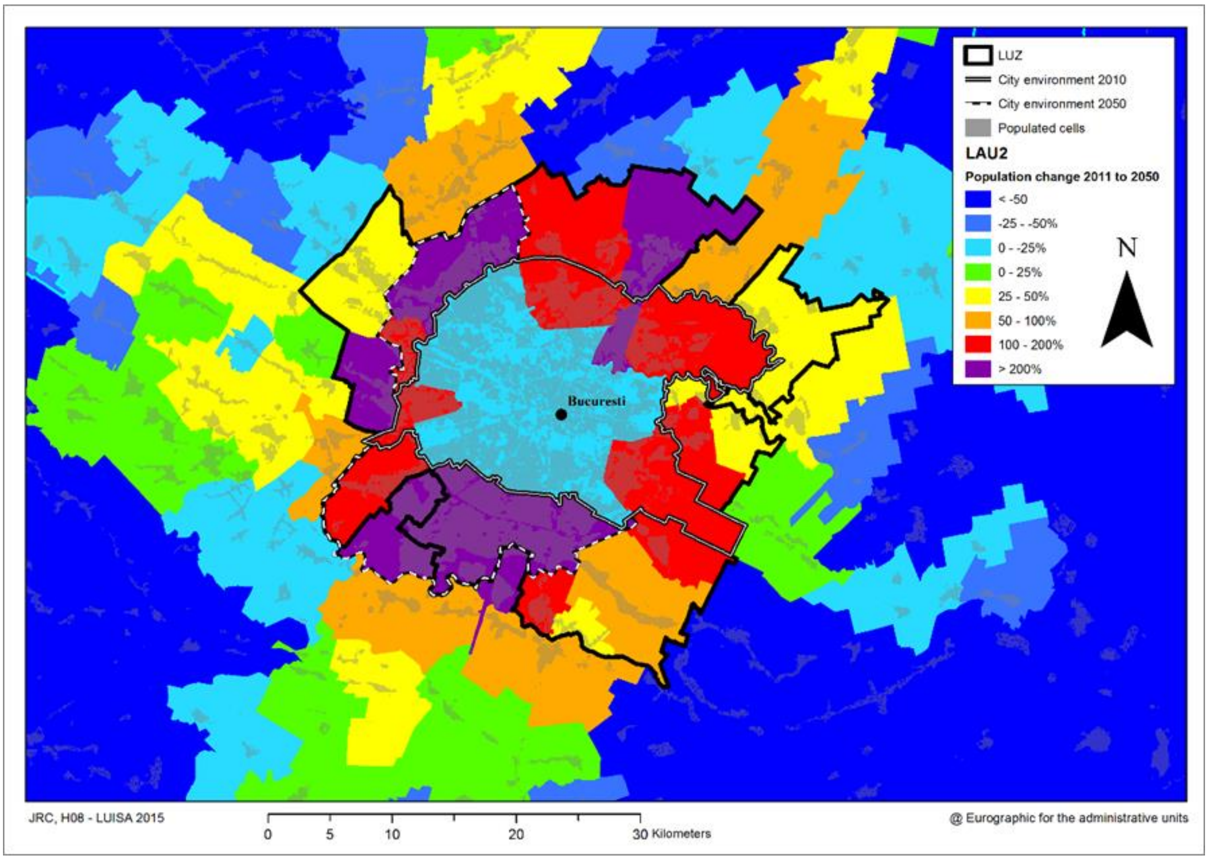


Figure 35: Changes in population between 2010 and 2050 for Bucharest (LAU2 level).

3.6 Population weighted density

3.6.1 The population weighted density in the EU-28

The standard measure of population density (population / total area) may be heavily affected by the size of geographical units. Population weighted density, measuring simply the average residential densities, removes this effect. It takes the smallest (residential) units of a city or region and computes their weighted densities where each unit is weighted according to its population and the population of the other units. The main formula of population weighted density is, $D=\Sigma(P_i d_i)/\Sigma P_i$, where D is the population-weighted density of a superior or covering area and Pi and di the respective population and density of each "parcel". A short explanation of population weighted density and an application of it can be seen in the report by the U.S. Census Bureau and Wilson (2012).

In this indicator, we applied the population weighted density concept to larger geographical boundaries (at LAU2, FUA, and country levels) and considered 1 ha pixels as "parcels". The results are presented at various levels including countries, degree of urbanization and cities.

In 2010, the average population weighted density across all EU countries was approximately 70 persons/ha. Within FUA, this density reaches almost 95 person/ha. The population weighted density in FUA varies across the EU countries from 278 in Spain, to 35 in Cyprus (Figure 36). The difference in density within and outside FUA also varies greatly among countries, for instance it shows high difference in Romania (average density of FUA is 1.75 times higher than the average density of the country), and no difference in Luxembourg.

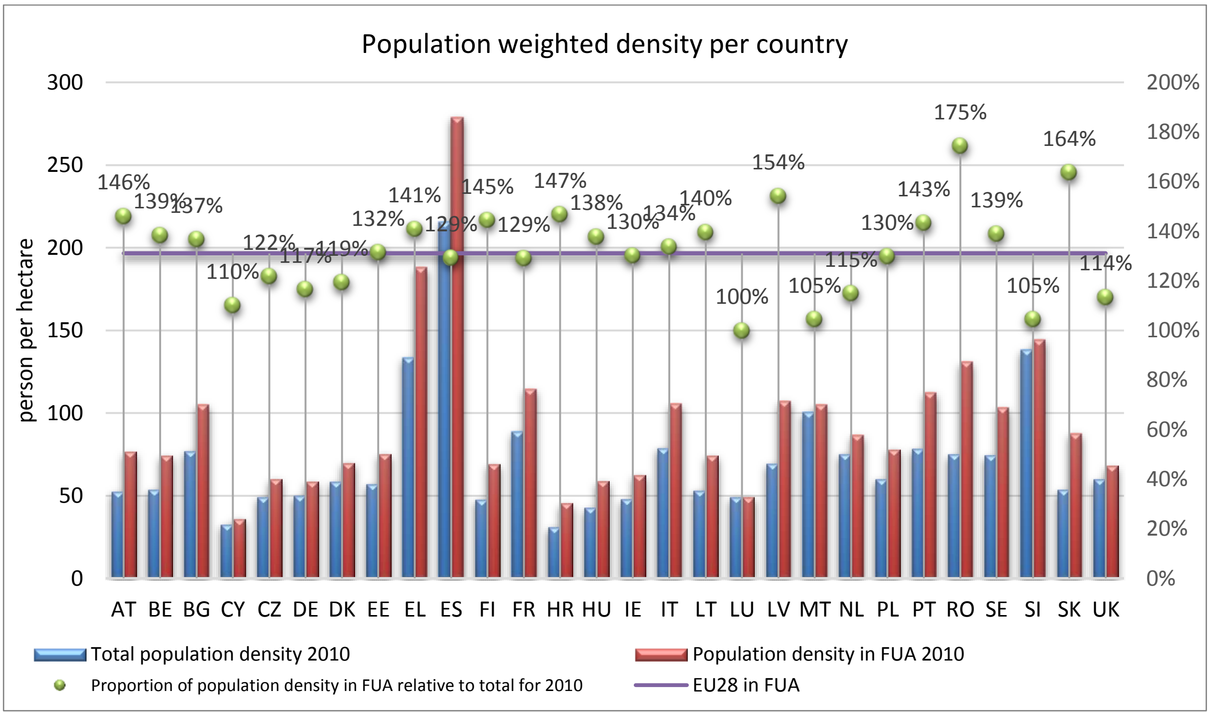


Figure 36: Population weighted density distribution within FUA and all municipalities for EU-28 in 2010.

Population weighted density also differs across different degrees of urbanization. The average EU-28 population weighted density is roughly 120 persons/ha in cities; 45 persons/ha in suburbs and towns and 20 persons/ha in rural areas. The highest average densities in cities (LAU2 level) can be seen in Spain with 320 persons/ha, and in Greece and Slovenia with almost 200 person/ha while Cyprus presents the lowest density in cities with only 45 persons/ha. Figure 37 represents population weighted density by country and degree of urbanization.

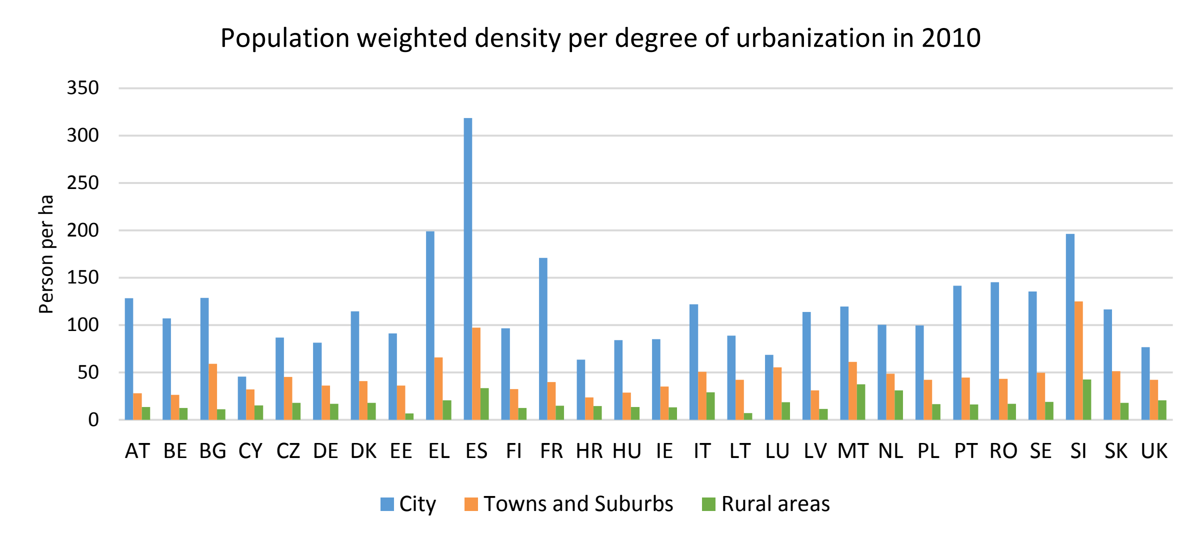


Figure 37: Population weighted density per degree of urbanization for the EU-28 Member States.

3.6.2 Projected changes in population weighted density

The amount and spatial distribution of population for the year 2050 were obtained from the LUISA platform reference scenario (Baranzelli et al., 2014b). Under this scenario, the average population weighted density is likely to decrease slightly across the EU-28 in the future. The average population weighted density in FUA is also expected to decrease to 85 by 2050. However, these changes in population weighted density are likely to be spatially heterogeneous (Figure 39). Population weighted density in FUA across most of Spain, Sweden and Bulgaria will increase, it will mainly decrease in Germany and Croatia.

Changes in population weighted density in FUA are likely to be heterogeneous across EU member states (Figure 38), with most countries seeing decreases in FUA, particularly in Austria (-55%), Finland (-52%) and Scandinavia (-42%), while others will strongly increase (Slovenia in particular by +188%).

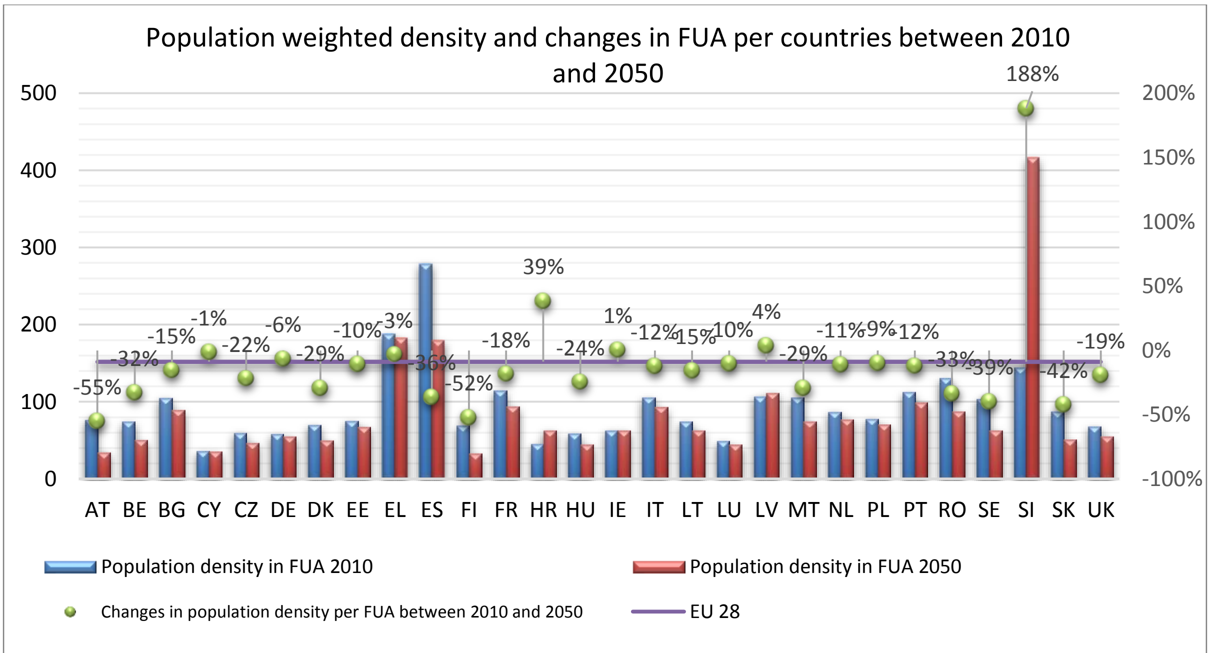


Figure 38: Changes in population weighted density of FUA, per country between 2010 and 2050.

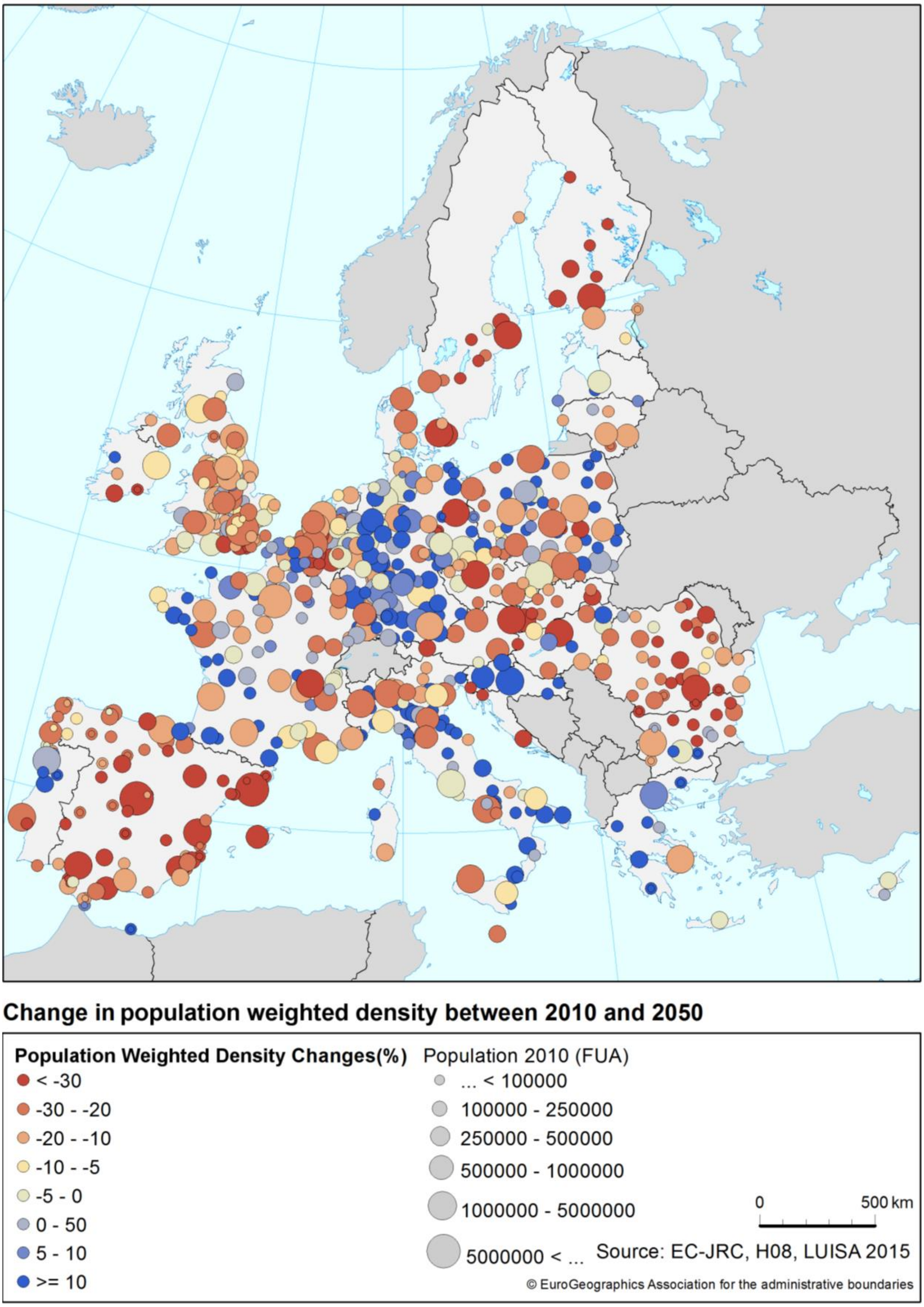


Figure 39: Changes in EU population weighted density between 2010 and 2050 at the level of FUA.

We can also observe large differences in changes of population weighted density as a function of the degree of urbanization (Figure 40). Overall, across the EU-28 we observe a decrease in population weighted density in both cities (-10%) and rural areas (-1%), and an increase in suburbs and towns (2%). This general trend in population weighted density across different degrees of urbanization is more or less pronounced and can be noticed across all Member States. Austria, Finland, Belgium and Sweden will show a strong density decrease in LAU2 considered as cities (<-50%). However, the population weighted density in Slovenia is expected to increase in cities by almost 300%. Finally, population weighted density across all degrees of urbanization will decrease in other Member States, such as in Luxembourg, Denmark, Scandinavia and Romania.

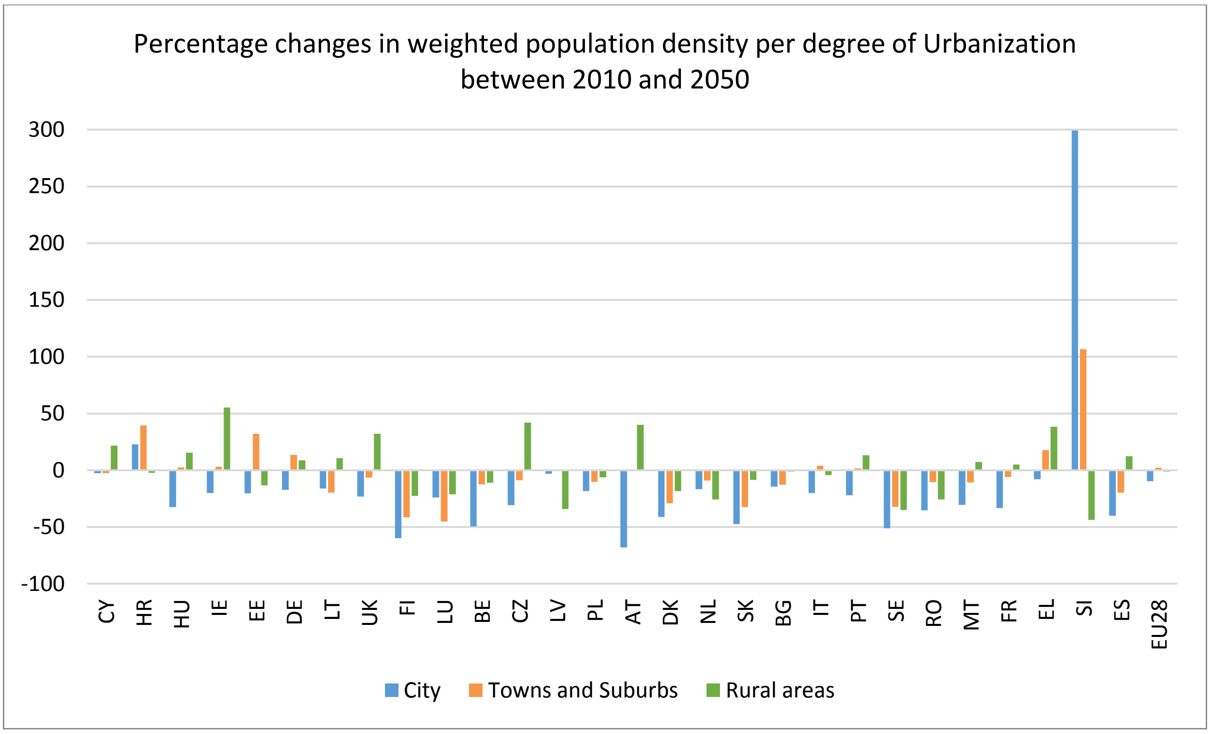


Figure 40: Percentage changes in population weighted density per degree of urbanization between 2010 and 2050.

3.6.3 Population weighted density changes for selected European cities

Figure 41 illustrates the variations in population weighted density as a function of its distance to city centre (concentric rings) for 6 selected cities. For 2010, we observe a similar profile for all selected cities where high population weighted density in the centre decreases and plateaus around 12 km. The city of Barcelona has much higher weighted density than the other cities, reaching almost 600, as compared to a 280 maximum for the others. It also shows a decrease from 1 to 4 km followed by a strong increase until 7 km from the city centre. Future changes in population weighted density for the selected cities (Figure 42) indicate a general decrease for Stockholm and Barcelona at all distances and a decrease in the city centre followed by an increase beyond 10 km from the city centre for Palermo, Vienna, and Bucharest.

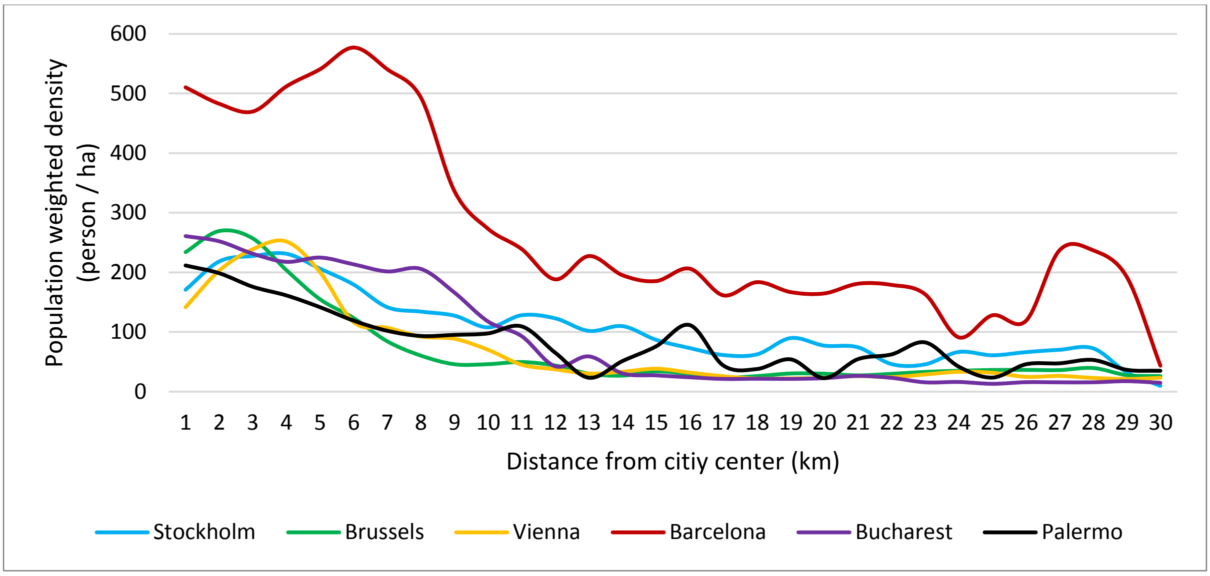


Figure 41: Population weighted density for selected cities in 2010.

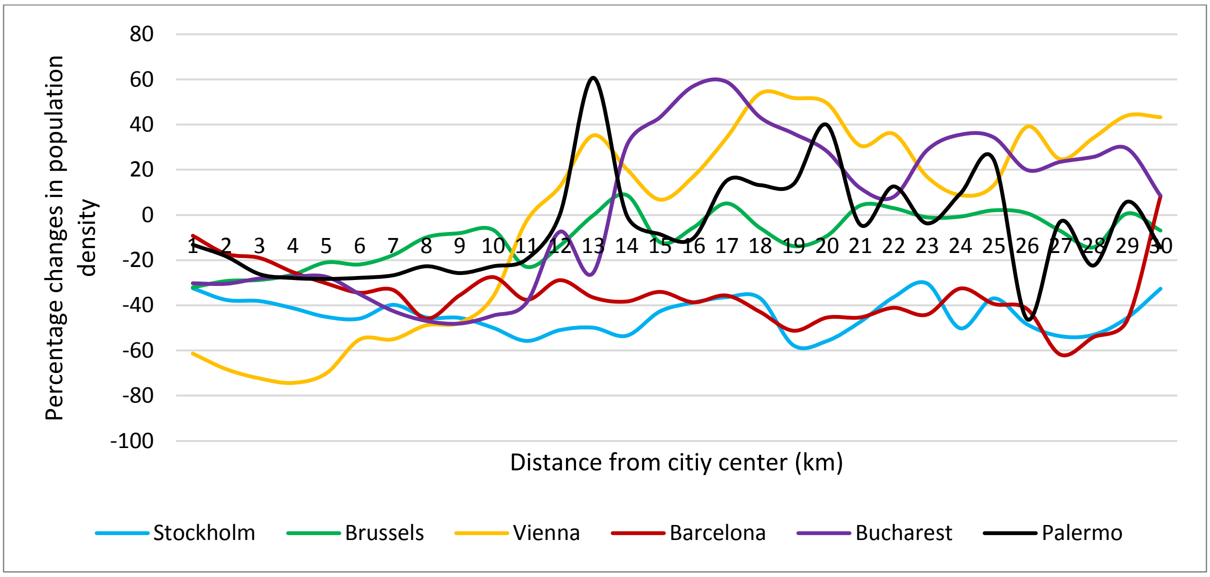


Figure 42: Change in population weighted density for selected cities between 2010 and 2050.

Finally, Figure 43 illustrates these potential changes for the city of Vienna (Austria). We observe that the population weighted density at LAU2 level corresponding to Vienna city centre will strongly decrease, while the density in LAU2 on the outer edge of the FUA will increase. This increase will be particularly strong in the LAU2 located directly south of Vienna city centre where population weighted density will be more than doubled.

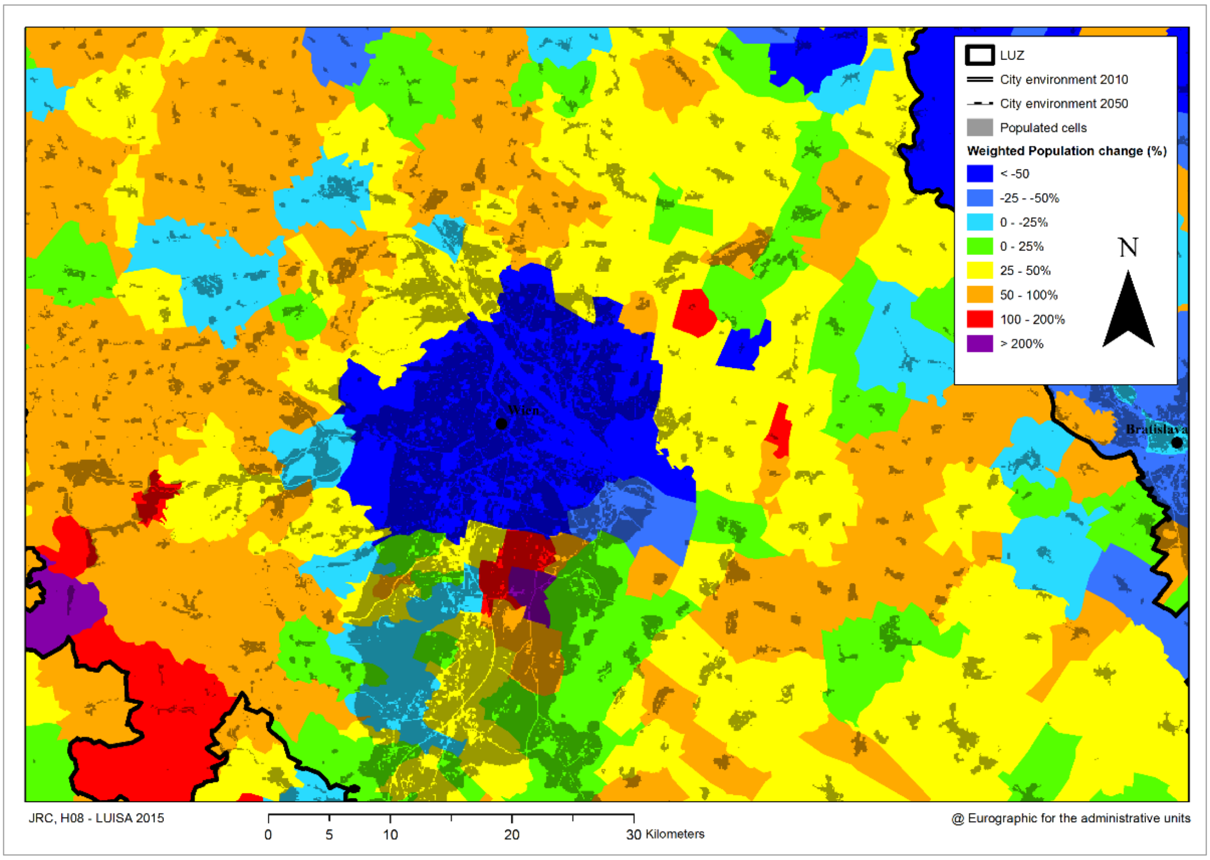


Figure 43: Changes in population weighted density between 2010 and 2050 for Vienna.

3.7 Nature based recreation opportunities

3.7.1 Nature based recreation opportunities in cities

Public, local, nature based, outdoor recreational activities include a wide variety of practices ranging from walking, jogging or running in the closest green urban area or at the river/lake/sea shore, bike riding in nature after work, picnicking, observing flora and fauna, organizing a daily trip to enjoy the surrounding beauty of the landscape, among a myriad of other possibilities. These activities have an important role in human well-being and health. The ESTIMAP-recreation model (Zulian et al., 2014) assesses the capacity of ecosystems to provide nature based outdoor recreational opportunities which can be enjoyed on a daily basis, i.e. mainly by people living in the area of interest (Zulian et al., 2013; Paracchini et al., 2014). It computes a composite dimensionless indicator that estimates the provision of the service as the potential capacity of a group of identified landscapes and features to provide opportunities for local outdoor recreation.

The provision varies according to four main components (1): the suitability of land to support recreational activities; (2) the blue-green infrastructure in urban areas; (3) the presence of natural areas, and 4) the presence and quality of water bodies and coastal areas (inland and sea). Table 6 shows the list of components and inputs of the model. The availability of a recreation service is strictly related to its accessibility; the model therefore takes into account the road network structure at different scales. Each component of the indicator depends on a number of sub-components and related inputs that are considered in terms of their capacity to provide potential nature based recreation opportunities.

Table 6: Components and inputs for recreation potential model.

Component	Inputs	Expected effects on recreation potential
Suitability of Land to support recreational activities	Land use	Land use types capacity to support recreational activities
Urban	Green Urban Areas Natural riparian areas Bathing water quality Semi-natural vegetation (grassland and woody vegetation)	Blue-green infrastructures play a key role in supporting nature based recreational activities in Functional Urban Areas
Natural Features influencing the potential provision NATURE	Natural protected areas	The presence of protected areas increase the availability of recreation opportunities and the quality of the sites
	Semi-natural vegetation (woody vegetation and grassland)	Increase of vegetation heterogeneity in agricultural areas
Water	Geomorphology of coast Marine protected areas Bathing water quality Blue flags Lakes Natural riparian areas	The presence of water provides different opportunities for recreation. Four key aspects were considered: the distance from inland coast and sea coast; geomorphology of the sea coast; bathing water quality, and presence of natural riparian areas
Proximity	Road network Built-up areas	The road network and built up areas allow the computation of a proximity index, the types of roads considered depend on the scale of the assessment, When focusing at a local scale, i.e. metropolitan, only pedestrian and local roads are used.

The model provides a spatially explicit assessment of recreation opportunities at a pan European scale. Figure 44 provides an overview of the potential availability of recreational sites. Besides that, what plays a key role is the societal demand for this service. It appears clear that the areas that provide the highest opportunity level are the least accessible and therefore cannot be enjoyed on a daily basis.

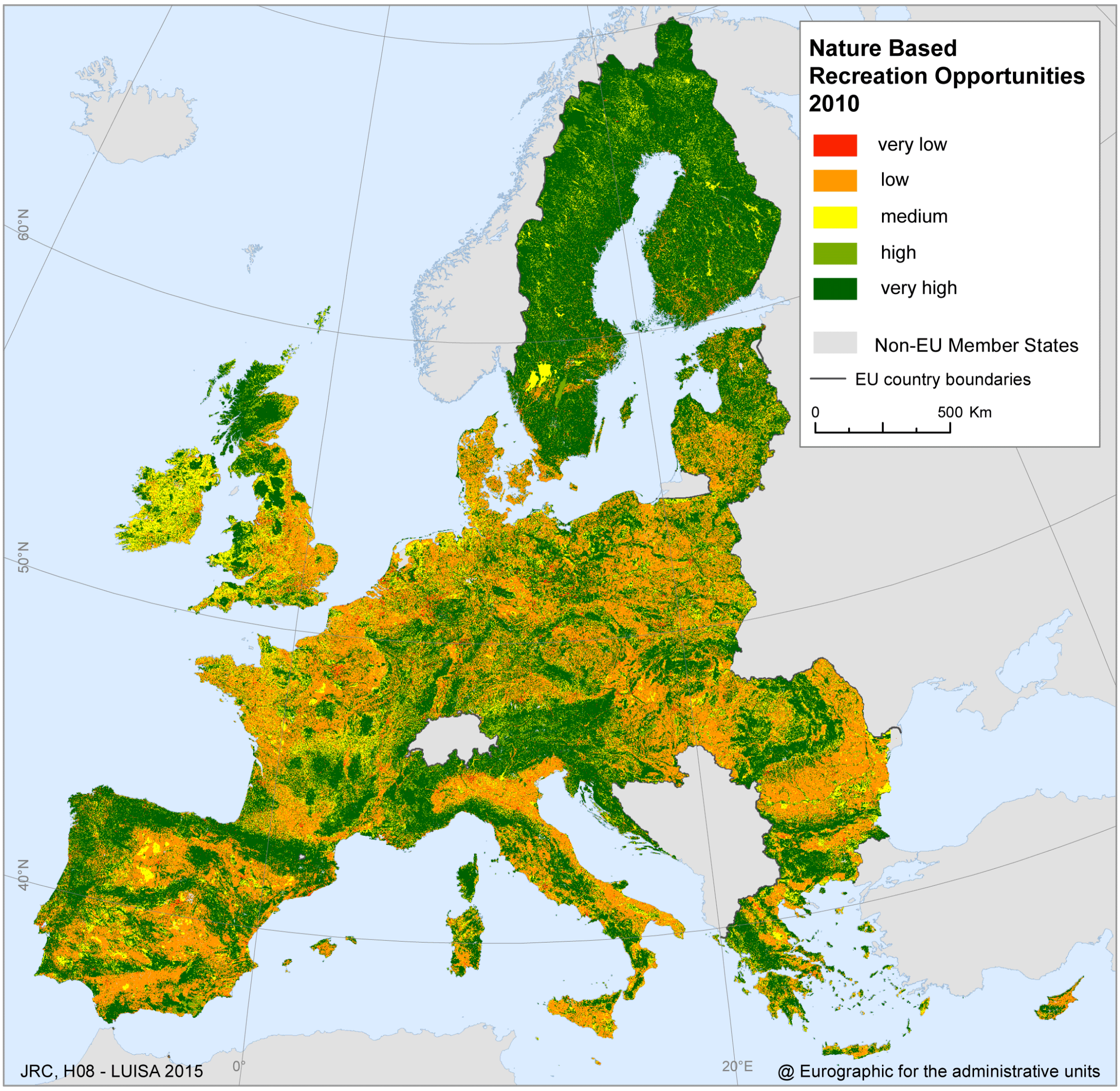


Figure 44: Map of Nature Based Recreation Opportunities in Europe for EU-28 in 2010.

In 2010, almost 320 million people live in the 672 Functional Urban Areas (FUA) within the EU-28, which accounts for 65% of the population. The access to daily opportunities for recreational activities is therefore becoming more and more important, especially around urbanized areas. We estimate the demand for nature based recreation opportunities as percentage of population that lives in the proximity of low provision areas and the percentage of potential short trips (less or equal to 5 km) to areas with low recreation opportunities. A high percentage represents a strong demand for recreational sites.

Figure 45 shows the relative percentage of recreation opportunities (RP) available per LAU2 in 2010 classified by degree of urbanization. The rural zones in Europe provides higher levels of opportunities, but, as in Figure 46, cities (cities + towns and suburbs) generate a high amount of potential short trips to recreational sites of low level that we consider in high demand.

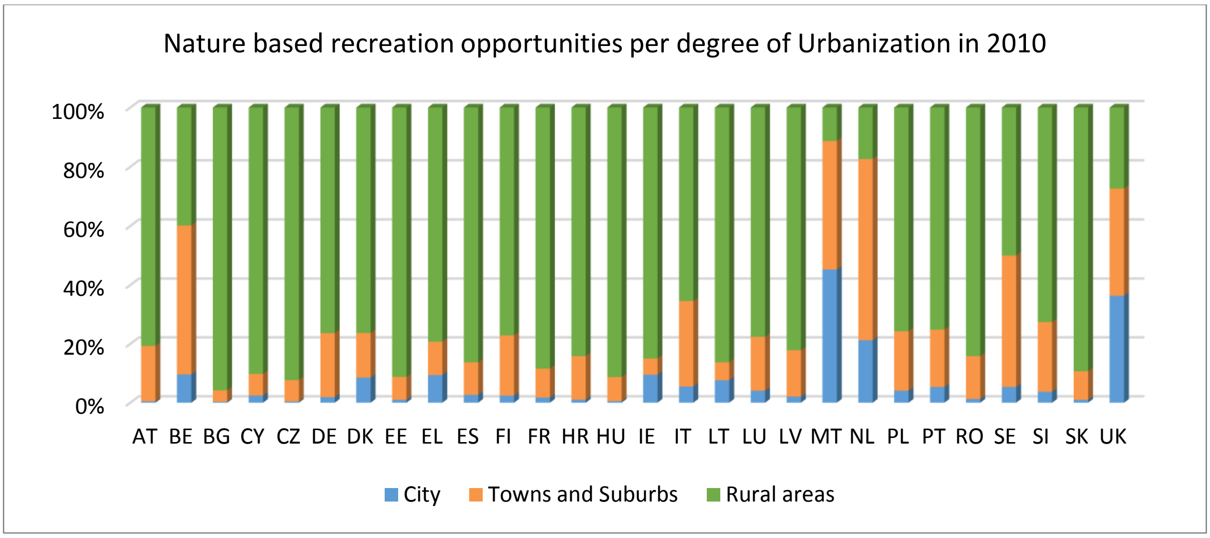


Figure 45: Proportion of Nature Based Recreation Opportunities per degree of urbanization in 2010.

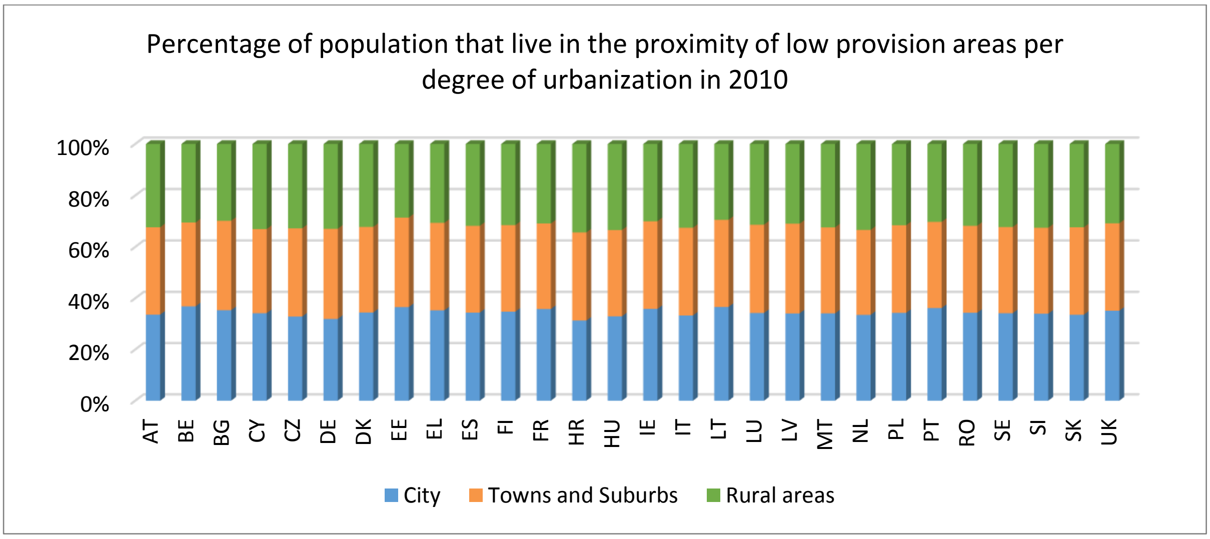


Figure 46: Percentage of population that live in the proximity of low provision areas per degree of urbanization in 2010.

3.7.2 Projected changes in nature based recreation opportunities

The global trend in opportunities for nature based recreation provision is likely to decrease in the future (Figure 47), with an average of -30% by 2050. Figure 47 shows the spatial trends of changes that mainly depend on transitions from natural to artificial land uses. The demand for recreation varies according to the availability of opportunities and the number of people that live in the proximity of low provision of nature based recreation opportunities.

Figure 48 shows the spatial pattern of the changes of recreation demand for LAU2 in Europe between 2050 and 2010. We note a clear similarity in the pattern of Figure 48 and Figure 49 (which shows the change in population in between 2010 and 2050 at FUA level). The demand increases in areas with an already high population density. This means that besides a population growth we do not expect an increase of opportunities for nature based recreation.

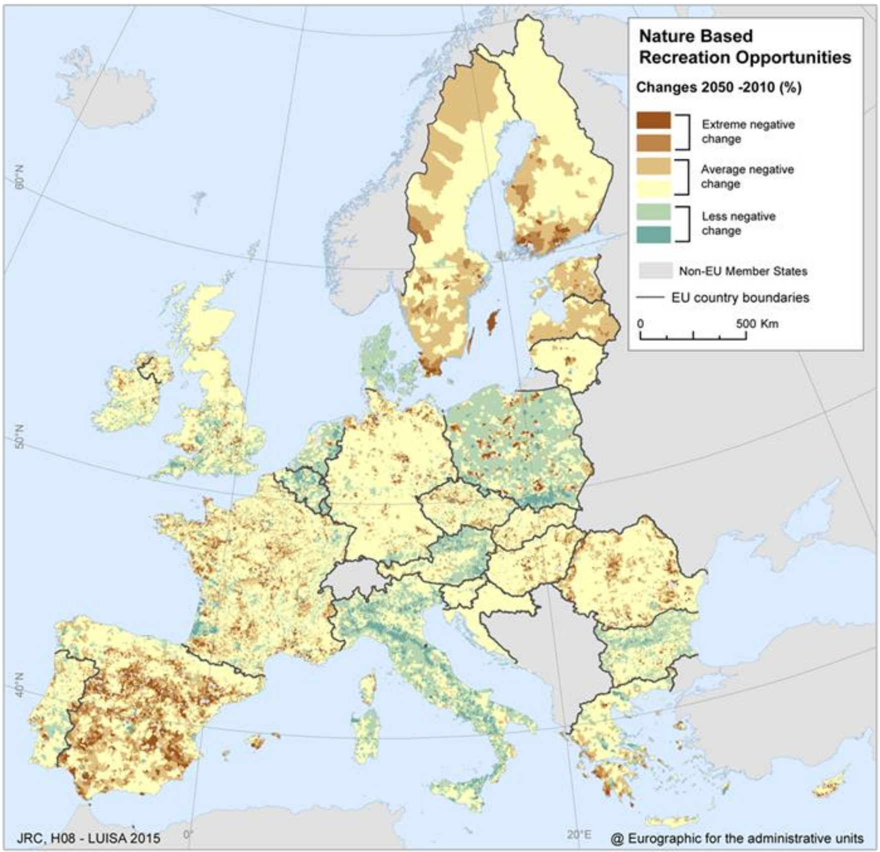


Figure 47: Changes in EU recreation provision between 2010 and 2050 at LAU2 level.

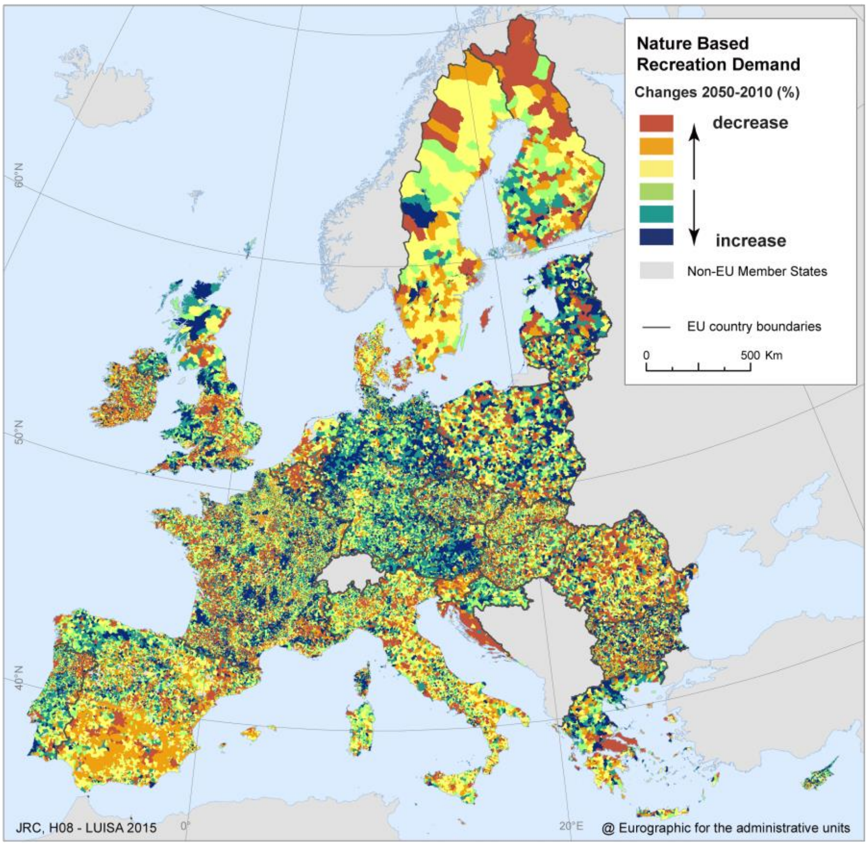


Figure 48: Changes in recreation demand for LAU2 between 2010 and 2050.

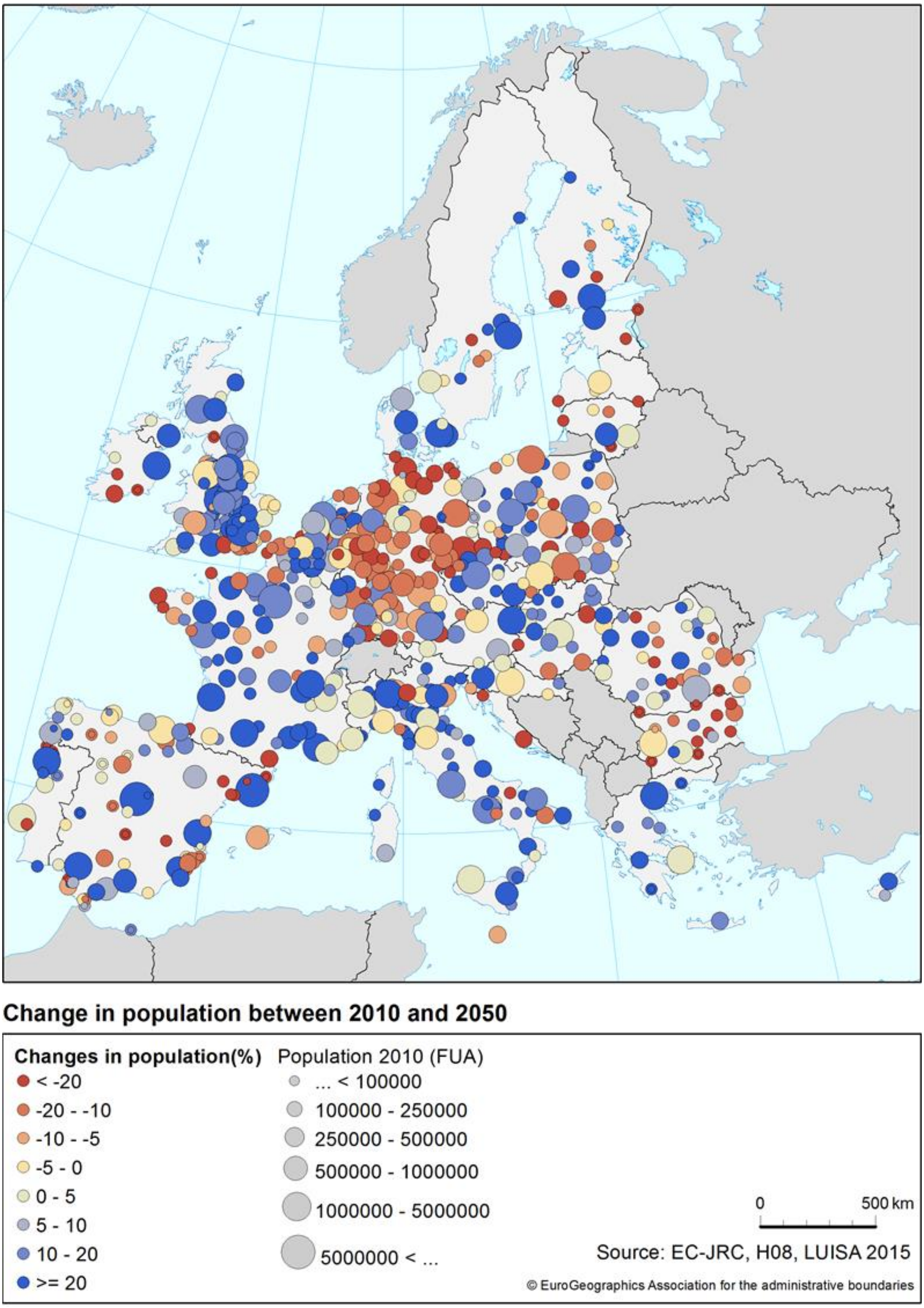


Figure 49: Changes in EU population between 2010 and 2050 at FUA level.

3.7.3 Recreation opportunities in selected European cities

Figure 50 and Figure 51 illustrate the amount of recreation potential in six European cities moving from the city centre to a distance of 30 km, first as a relative recreation capacity in 2010 and then in terms of changes between 2010 and 2050.

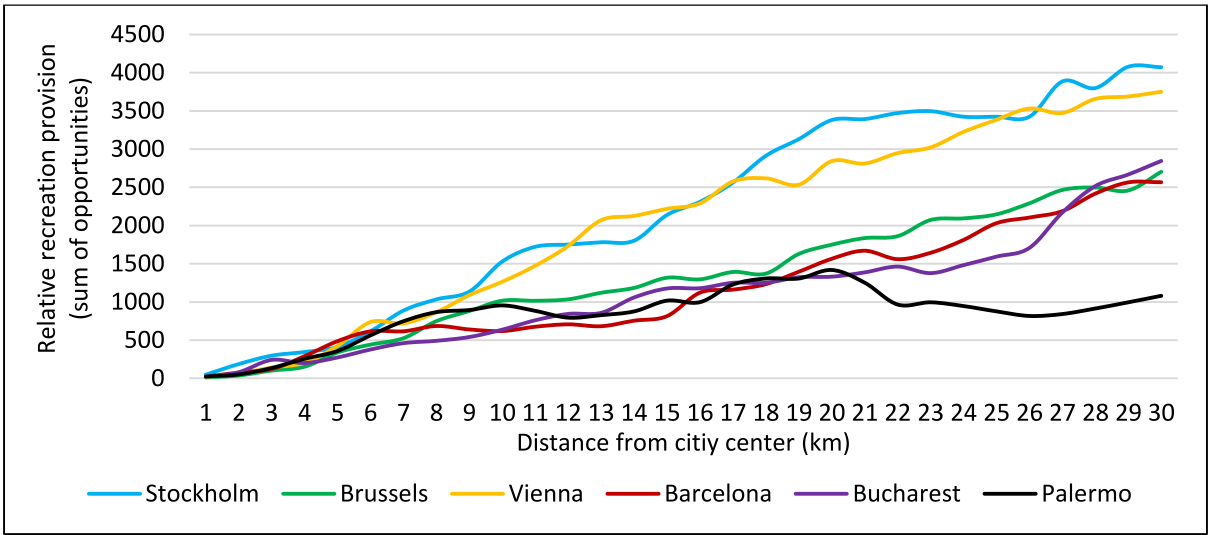


Figure 50: Relative amount of recreational opportunities in six European cities at FUA level from the city centre to a distance of 30 km.

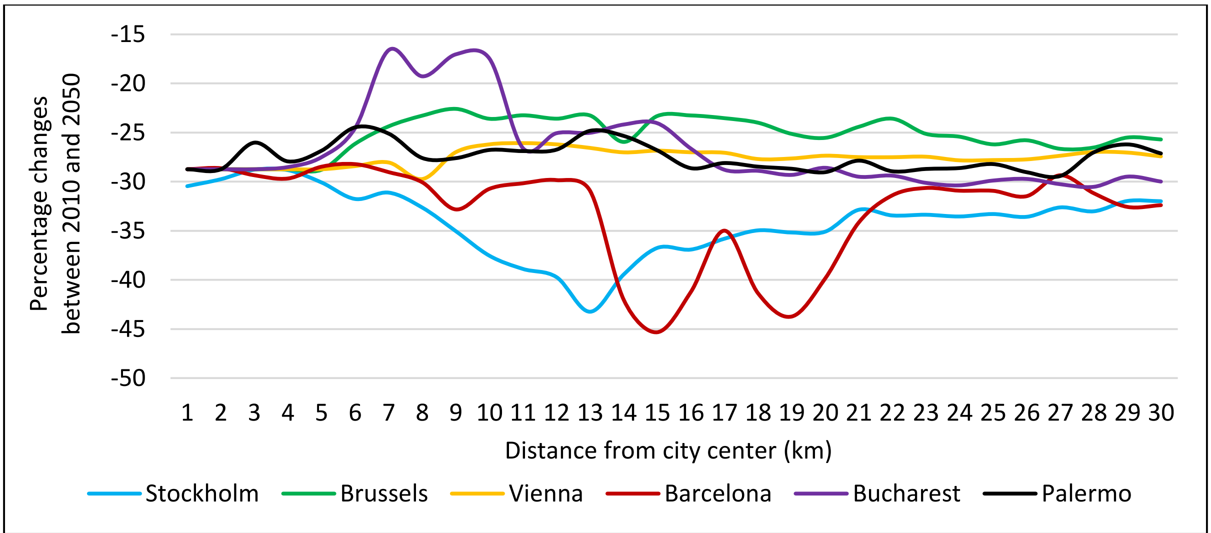


Figure 51: Changes in the recreation provision in six European cities at FUA level from the city centre to a distance of 30 km.

Figure 52 shows the actual recreation opportunities in Barcelona and Vienna in 2010 and the population demand for the service in terms of percentage of potential short trips to low opportunity destinations. Vienna provides very low opportunities for nature based recreation only in the core city centre. Natural protected areas cover 24% of the FUA. Elements like the Biosphärenpark Wienerwald (labelled as 1 in A.2, designated as a biosphere reserve by UNESCO, in 2005 to protect natural and cultural elements), the Donauauen National Park (2 in A.2) or the Natural Park Rosalia -Koglberg (3 in A.2) are inside the FUA and relatively close to populated areas. Barcelona functional urban area lacks opportunities for nature based recreation, and more than 50% of the urban population lives in areas with low provision of opportunities. The natural protected areas cover 20 % of the FUA, including areas like Conreria-Sant Mateu-Céllecs (labelled as 2 in B.2) or the National Park of Sant Llorenç del Munt i l`Obac (2 in B.2), but these areas lack local and easily reachable opportunities.

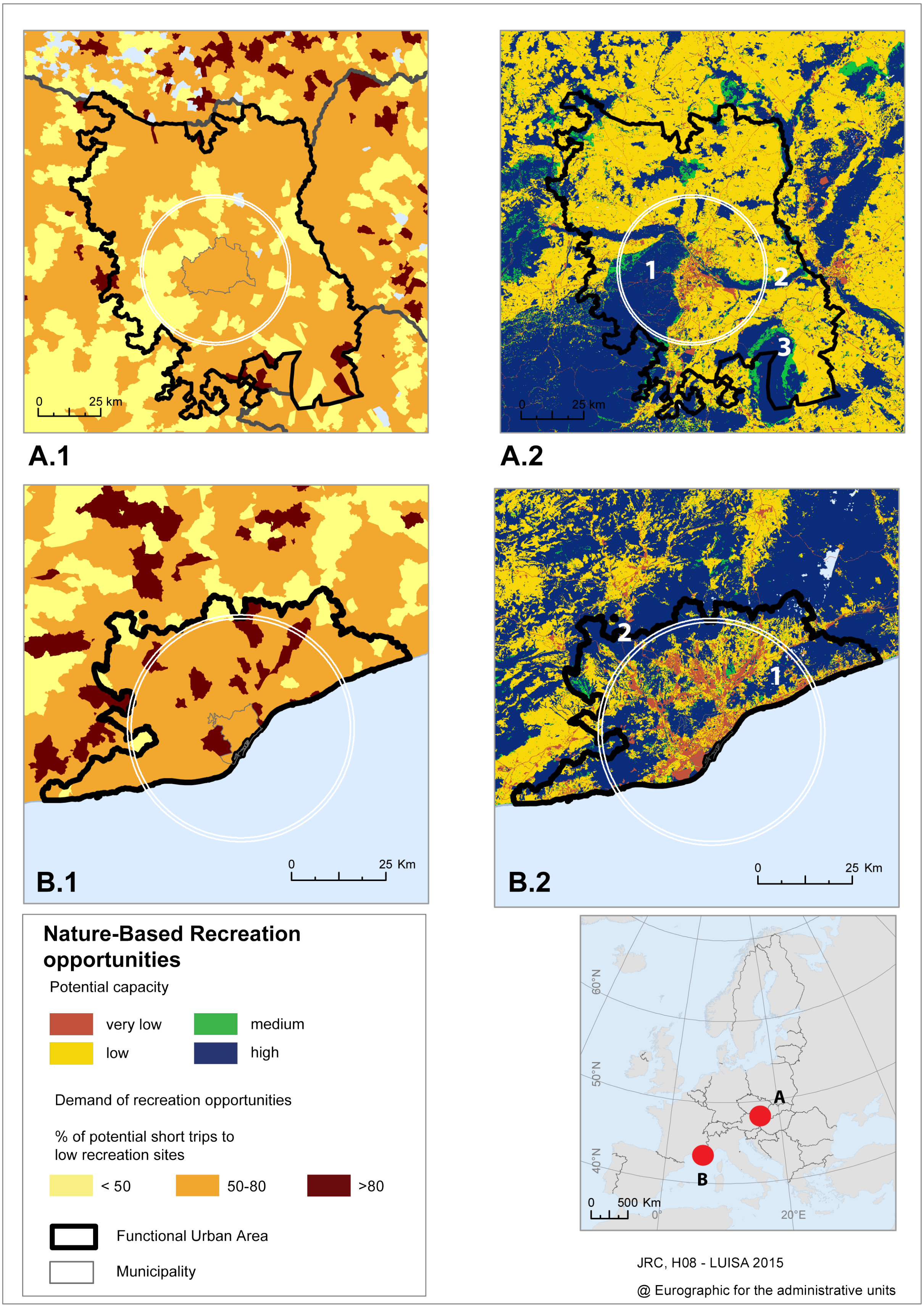


Figure 52: Provision and demand of nature based recreation opportunities in the Functional Urban Areas (FUA) of Vienna (A) and Barcelona (B).

3.8 Air quality

Air quality is the principal environmental factor linked to preventable illness and premature mortality and has significant negative effects on much of Europe's natural environment. Thus, in the EU, air quality has been of high concern since the 1970’s and several strategies have been implemented to improve it in the last decades. Recently, in 2013, the Commission adopted a Clean Air Policy Package reviewing existing EU air legislation. This policy package includes:

- a new Clean Air Programme for Europe with measures to ensure that existing targets (included in the EU Air Quality Directive; European Commission, 2008) are met in the short term, and new air quality objectives for the period up to 2030;
- a revised National Emission Ceilings Directive with stricter national emission limits for six main pollutants;
- a proposal for a new Directive to reduce pollution from medium-sized combustion installations, such as energy plants for street blocks or large buildings, and small industry installations.

3.8.1 Atmospheric emissions

An assessment of the atmospheric emissions over Europe has been implemented gridding the data from the **G**reenhouse Gas and **A**ir Pollution **In**teractions and **S**ynergies (**GAINS**) model (http://gains.iiasa.ac.at/models/index.html). The gridding procedure is based on the LUISA modelling platform data under the reference scenario (Baranzelli et al, 2014b). The GAINS model (routinely used also by the European Commission for impact assessment studies) has been developed by the International Institute for Applied Systems Analysis (IIASA) and “provides a consistent framework for the analysis of co-benefits reduction strategies from air pollution and greenhouse gas sources” (Amann et al., 2011).

The model considers, among other things, emissions of different compounds: carbon dioxide, methane, nitrogen oxides, nitrous oxide, particulate matter, sulphur dioxide, volatile organic compounds. Emissions of pollutants are estimated for each country, with five-year intervals up to 2030. Further information on the method is also available in Trombetti et al. (2014).

Figure 53 shows NOx emissions in year 2010. Most of the emissions occur in the most densely populated areas with a significant impact also coming from the road network. Hot spots are also visible in the sea, due to a higher density of the vessels. The expected reductions in 2030 will most significantly benefit the urban areas, which will see significant decreases.

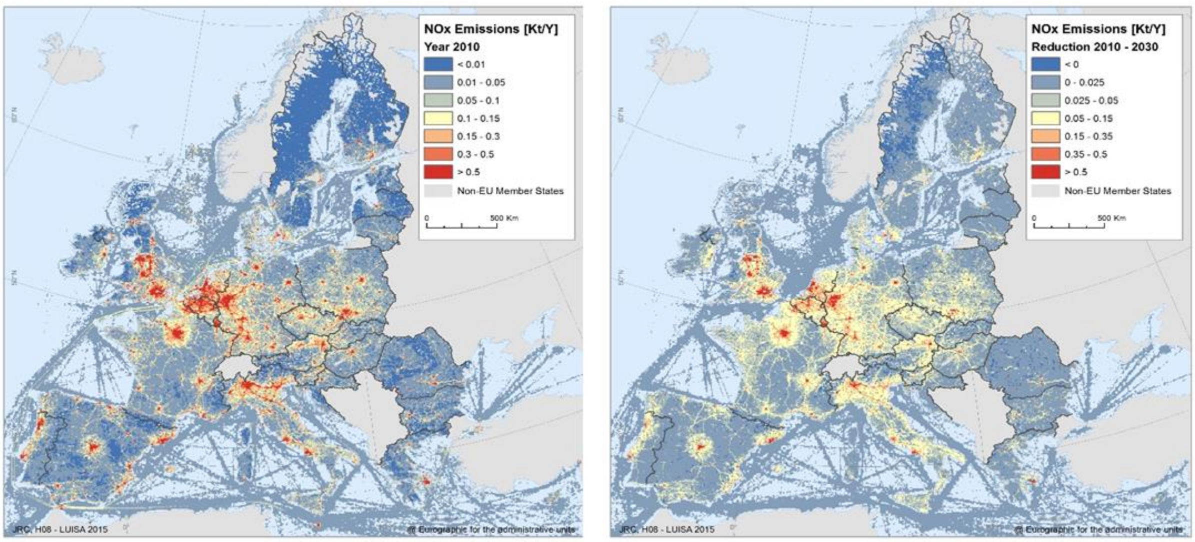


Figure 53: NO_x emissions in 2010 and expected reduction in 2030.

PM_{10} emissions are shown in Figure 54. In this case, emissions are more widespread and affecting urban, sub-urban and industrial areas more evenly. The expected reduction in emissions by 2030 will still mainly affect the urban areas even if, in this case, the trend is less visible and the most drastic reductions affect a more restricted area. It is also important to note an increase in emissions in extensive areas in Spain, the United Kingdom and Sweden.

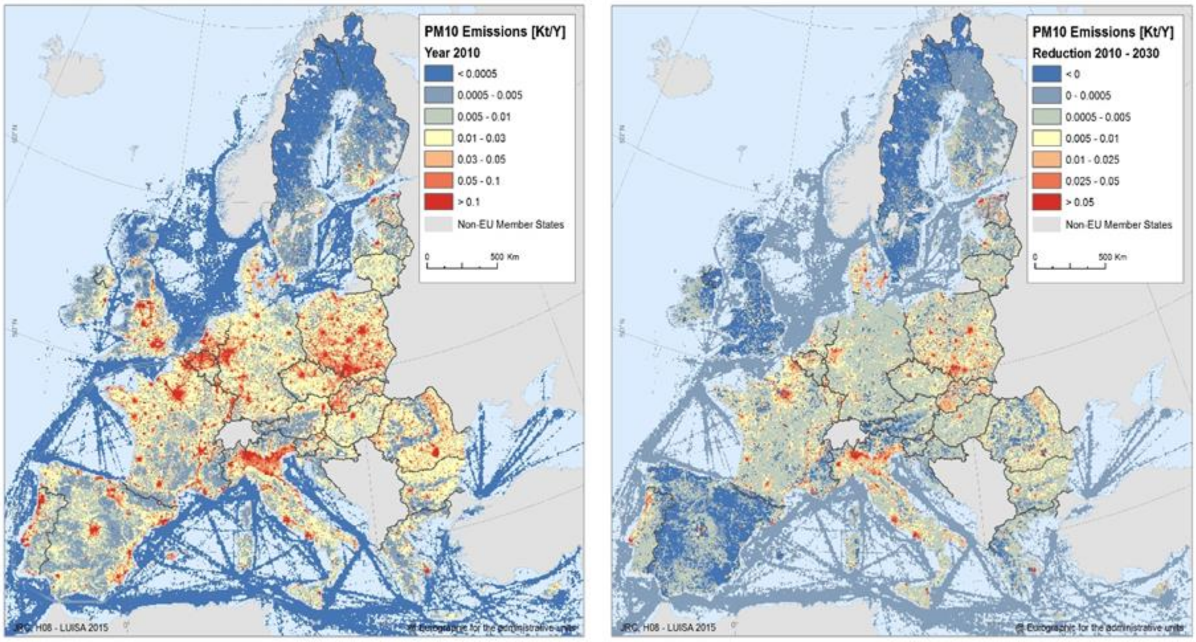


Figure 54: PM_{10} emissions in 2010 and expected reductions by 2030.

3.8.2 NO_2, PM_{10} and $PM_{2.5}$ concentrations

We followed two different modelling approaches to derive pollutant concentrations at European scale:

- a Land Use Regression model (LUR) to simulate NO_2 and PM_{10} at very high resolution (100 m) built using pollutant concentrations for 2010 from monitoring sites as dependent variable, and several parameters (independent variables) defined within a Geographic Information System (GIS). The LUR model was developed using Random Forest regression techniques (Breiman, 2001) and it was used to predict evolution of concentrations of pollutants from 2010 to 2050, according to predicted changes in land use and population density data taken from LUISA (Baranzelli et al, 2014b). The modelling exercise did not consider for the prediction of future concentrations specific measures or policies implemented in order to reduce emissions. NO_2 and PM_{10} were analysed with this method. These pollutants were chosen due to the high impact that they have on human health, and because their concentrations are highly correlated to human activities (road transport for NO_2 and residential combustion for PM_{10}) and consequently the higher concentrations are expected to occur in cities. Besides this, we also considered the availability of concentration data from the monitoring stations for the base year 2010. Limit values for concentrations of both pollutants have been set within the Air Quality Directive for different time scales.
- a source-receptor model approach, to simulate $PM_{2.5}$ at coarser resolution (7km), identified starting from a set of deterministic air quality model simulations. This approach is implemented through the RIAT+ (Regional Integrated Assessment Tool, Carnevale et al., 2012) and SHERPA (Screening for High Emission Reduction Potential on Air Quality, Clappier et al., 2015) models. This different approach for the calculations was crucial since the LUR model requires a sufficient number of measurement stations, which were not available for $PM_{2.5}$.

For 2010, average values of concentrations of NO_2 within FUA are lower in every country than concentrations of PM_{10}; and for both pollutants, concentrations remain below the limits established by the EU Air Quality Directive. However, if the maximum average values per FUA and per country are considered, some FUA present average values close to the permitted limits. Comparing the maximum and average values per FUA per country, the different trends of the curves show the different spatial distribution of concentrations within countries, especially noticeable in bigger countries like Germany, Poland or Italy, as indicated in Figure 55.

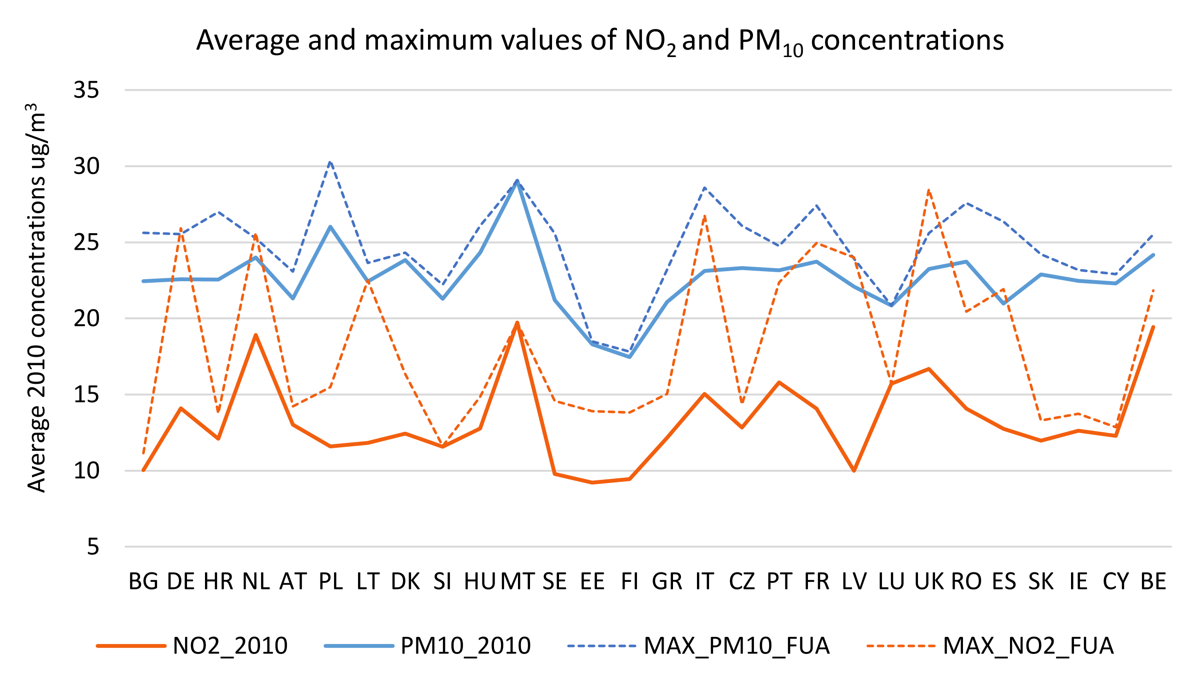


Figure 55. Average and maximum concentrations of NO_2 and PM_{10} at FUA level per country in 2010.

Figure 56 and Figure 57 present the results calculated following the LUR approach. Both pollutants present greater concentrations in urban areas reflecting the linkage to human activities. NO_2 presents higher values close to main roads, and PM_{10} has higher concentrations in densely populated areas. At European scale, the regions most affected by high NO_2 are the urban areas in the north-west of Europe and in the Po valley in Italy. For PM_{10} the regions most affected are the urban areas in southern Poland, Slovakia, Bulgaria and the Balkan region (in these areas high concentration values are linked to traditional heating systems).

Results of $PM_{2.5}$ are presented in Figure 58. The pattern simulated for $PM_{2.5}$ is quite similar to that of PM_{10}, as both pollutants present a similar behaviour.

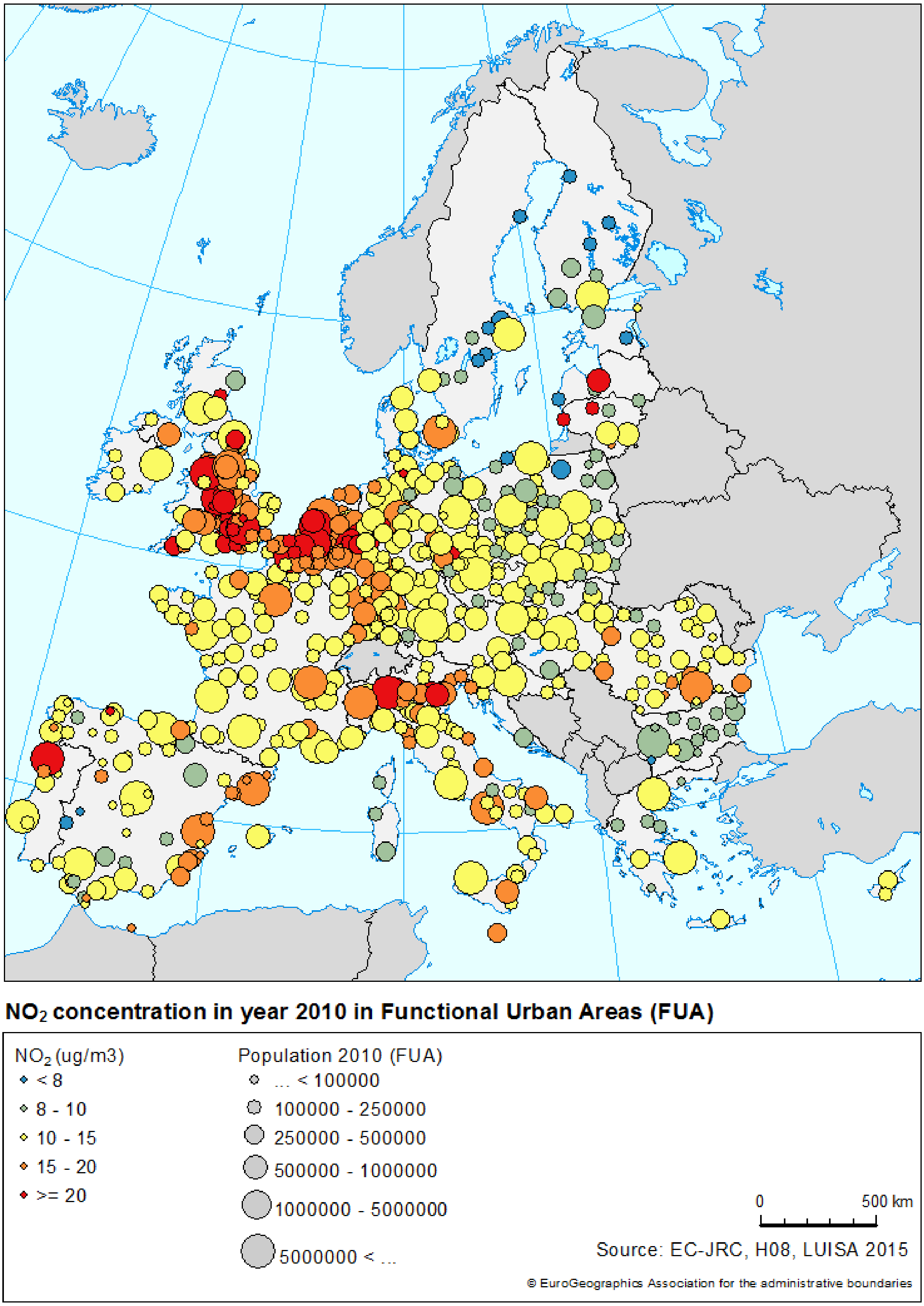


Figure 56. NO_2 concentration in 2010 by FUA according to LUR modelling techniques.

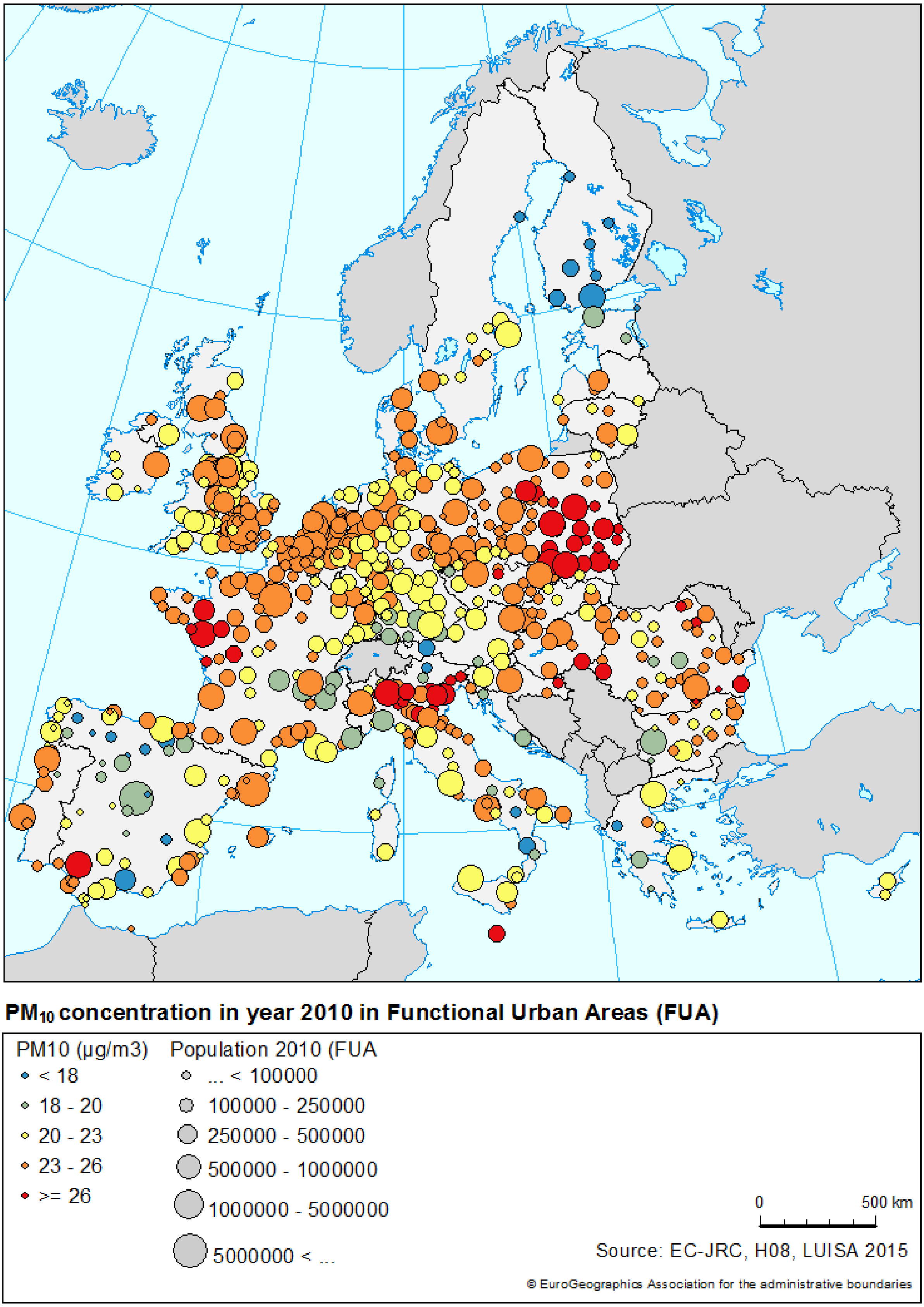


Figure 57. PM_{10} concentration in 2010 by FUA according to LUR modelling techniques.

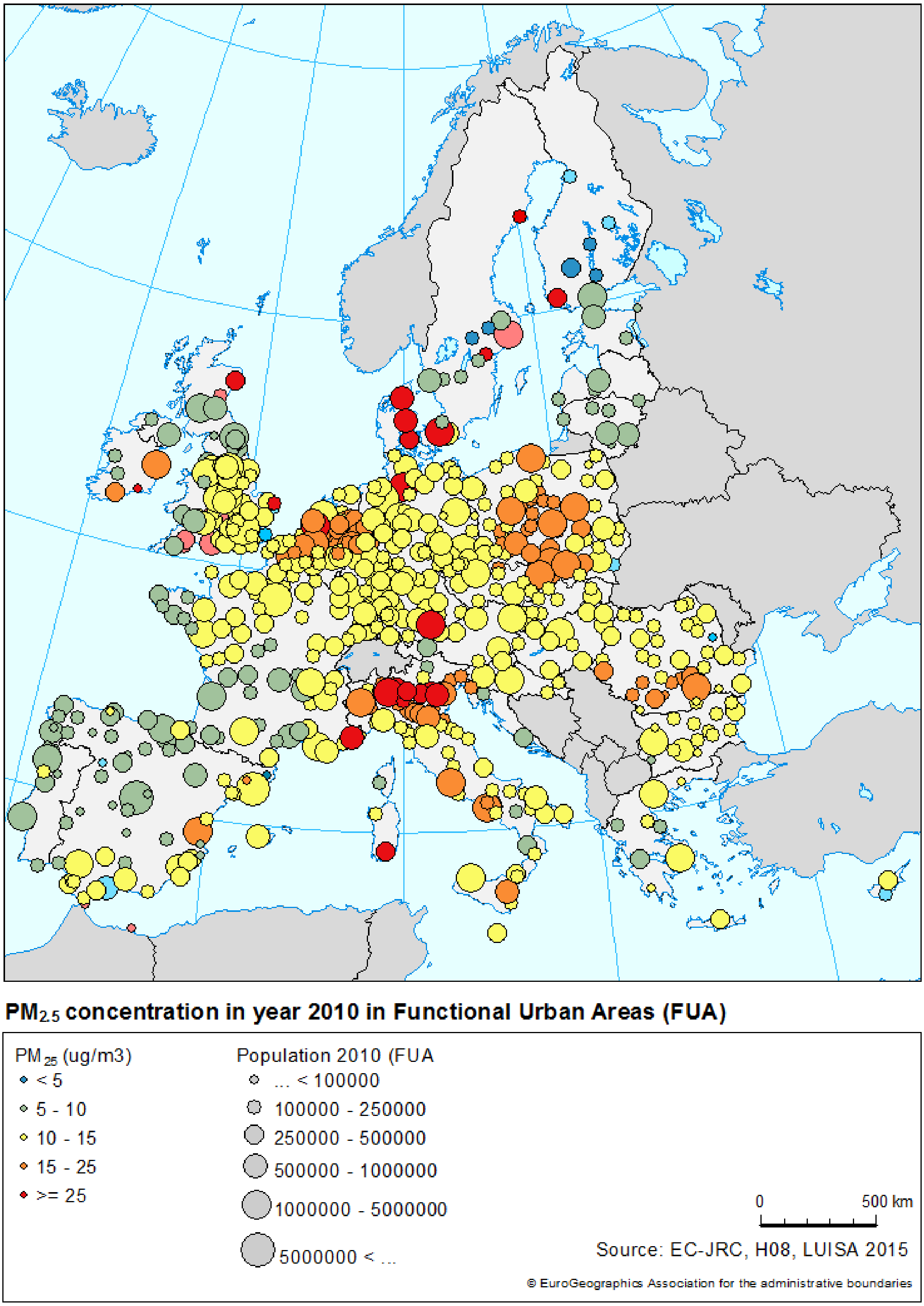


Figure 58. $PM_{2.5}$ concentration in 2010 by FUA according to RIAT+/SHERPA models.

Average percentage changes in concentrations of pollutants in FUA predicted with LUR methods (and considering only land use policies) are relatively low between 2010 and 2050. In most of the countries, absolute changes in NO_2 concentrations will be higher than changes in PM_{10} concentrations for which changes of less than 1% are expected in most of the countries. NO_2 concentrations will increase in most countries between 1% and 5%, and average decreases will occur only in FUA of Germany and Bulgaria (Figure 59).

It is worth noting that the greatest changes in NO_2 concentrations are expected in countries with the highest values in 2010 at FUA level. In most cases, this means an increase in concentrations, and as a consequence of this, that the air quality status in these FUA will get worse in 2050.

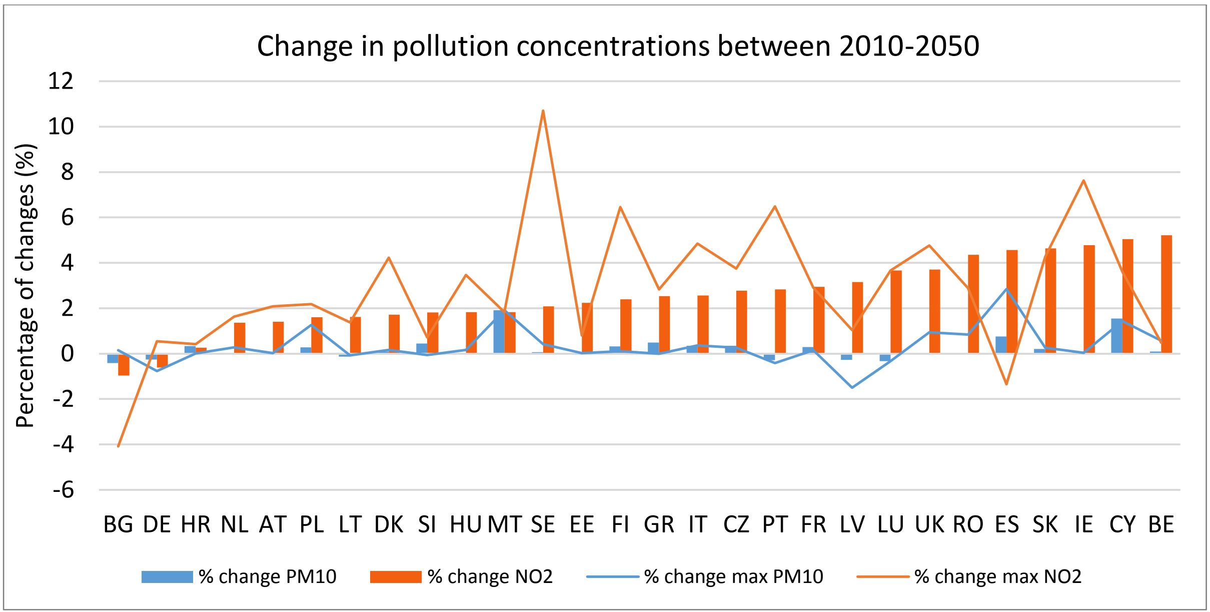


Figure 59. Average percentage of changes in pollution concentrations between 2010 and 2050.

3.8.3 Human health

As shown in Figure 60, most of the people affected by concentrations of NO_2 over the recommended limit (an annual average of 40 µg/m^3) live in cities, close to places where emissions are produced. For PM_{10}, due to the greater travelling distances of this pollutant, high concentrations are found further from the city centre. People living in suburbs are therefore affected by concentrations exceeding the limit (a daily value of 50 µg/m^3, not to be exceeded more than 35 times per year; equivalent to an average annual value of 30 µg/m^3 according to Kiesewetter et al. (2014)).

"Months of lost life" due to yearly $PM_{2.5}$ concentrations were computed using the methodology presented in Anenberg et al. (2010) (Figure 61). In particular, $PM_{2.5}$ yearly concentration has been simulated for the 2010 "current legislation" and 2030 "maximum feasible reductions" scenarios, using the GAINS (Amann et al., 2011) emission reduction estimations and the SHERPA (Clappier et al., 2015) air quality model.

Other input data used for the calculation are derived from LUISA (population), from the HRAPIE project (WHO, 2013; concentration response function/ $PM_{2.5}$ relative risks) and from the European Mortality Database (baseline mortality values).

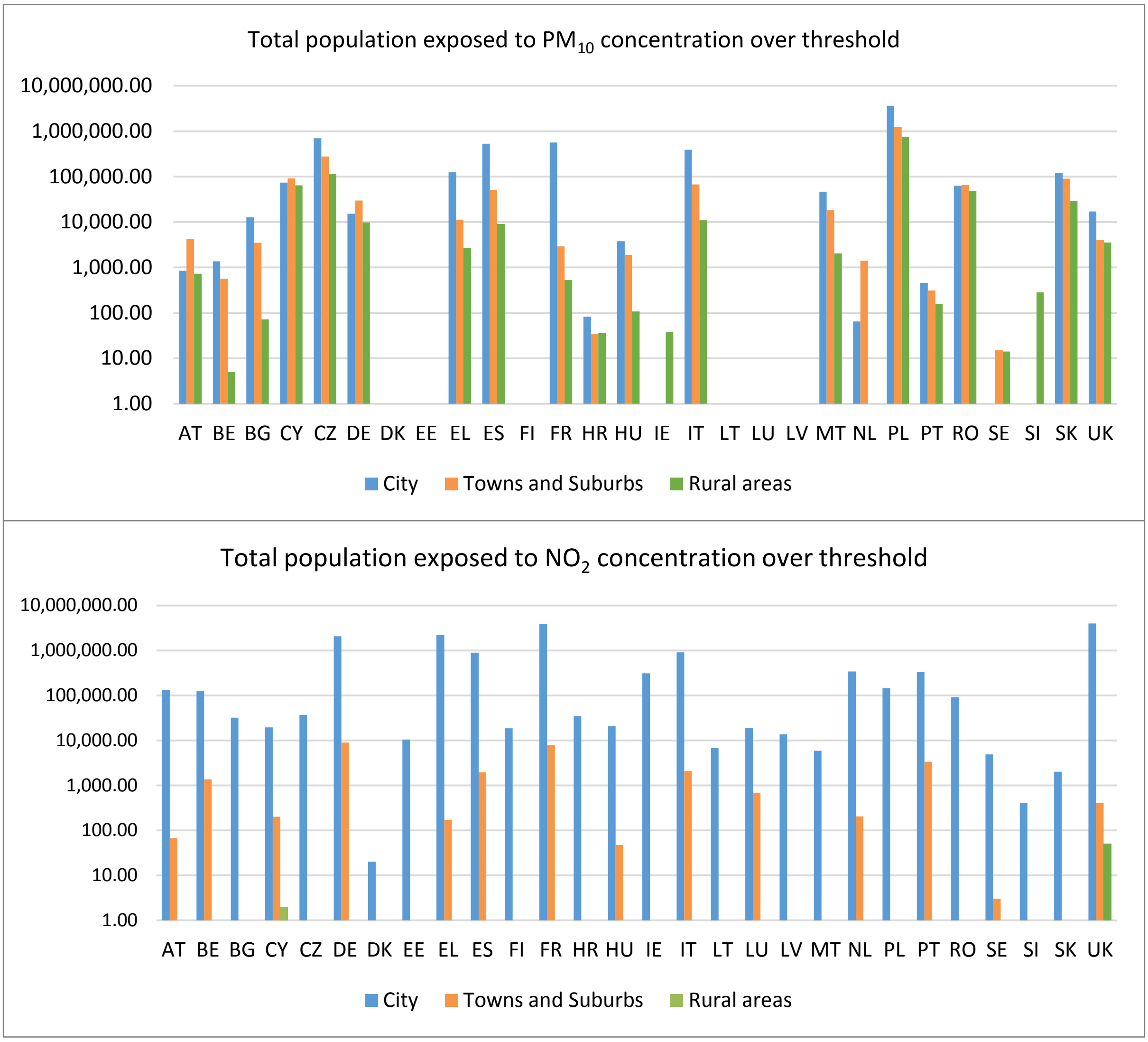


Figure 60: Distribution of people exposed to concentrations of PM_{10} (above) and NO_2 (below) over the limits imposed by the Air Quality Directive - by degree of urbanization, in 2010.

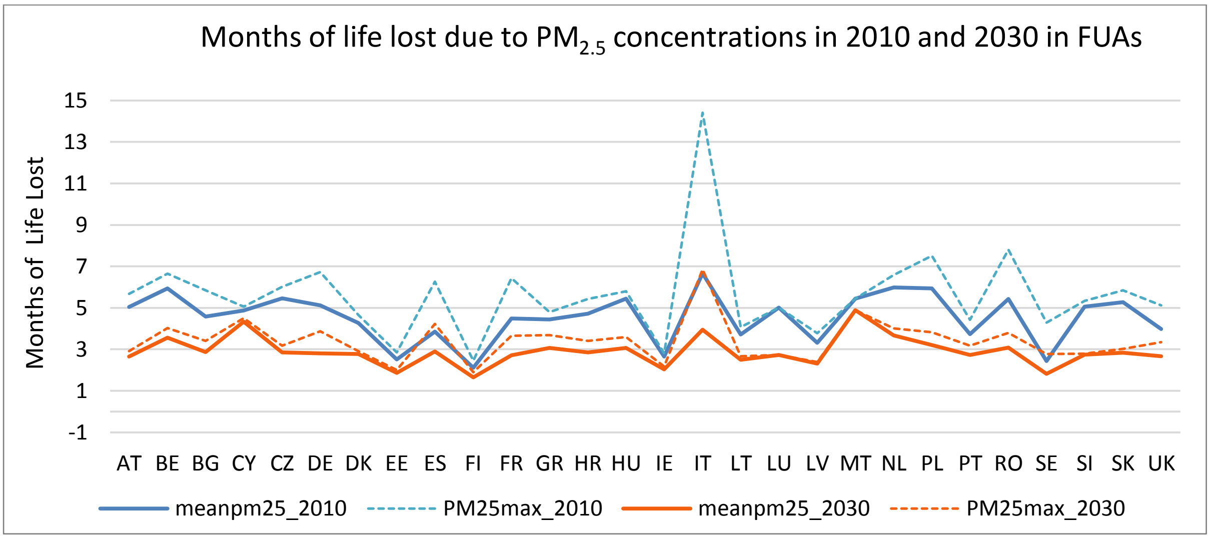


Figure 61. Months of life lost due to $PM_{2.5}$ concentrations in 2010 under current conditions and in 2030 considering maximum feasible reduction measurements applied.

3.8.4 Concentration of NO_2 and PM_{10} for selected European cities

Figure 62 and Figure 63 reflect the behaviour of the different indicators of air quality with increasing distance from the city centre. Figure 62 presents spatial trends in concentrations of NO_2 (above) and PM_{10} (below) and reflects the different nature of the pollutants. NO_2 is most concentrated in areas where emissions occur and decays fast over short distances, whereas PM_{10} dispersion rates are higher and consequently concentrations remain more constant with distance.

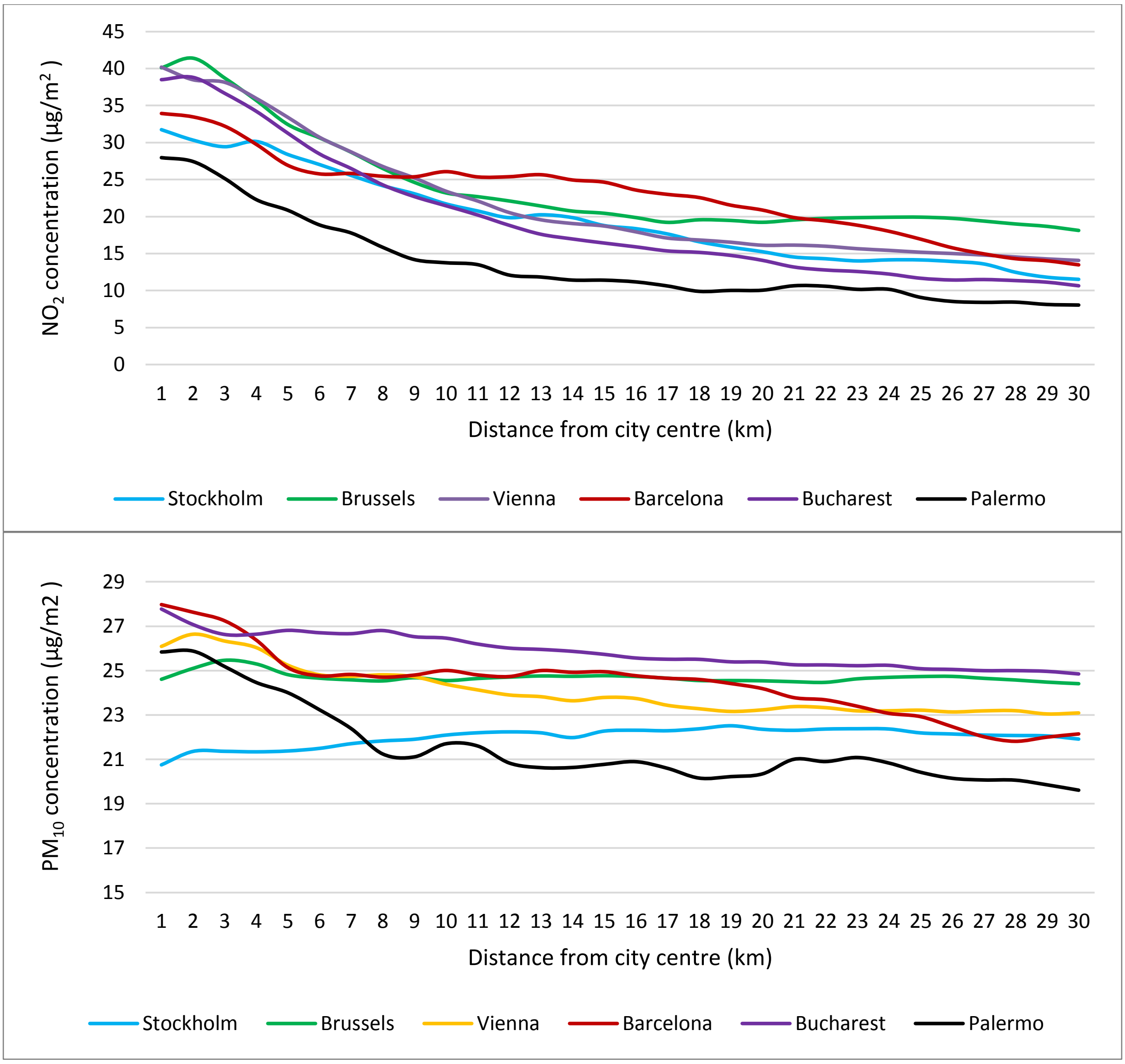


Figure 62: Change in air quality indicators with an increasing distance from the city centre, for selected cities.

Figure 63 shows the removal capacity of pollutants by vegetation, expressed as a function of pollutant concentration. The morphology of the curve reflects the morphology of the city and the surface occupied by vegetation reflects the nature of the fate of the pollutant. In this way, the removal of PM_{10} is higher at greater distances from the city, where green areas are more abundant but concentrations of the pollutant remains relatively constant (Figure 63). However, removal of NO_2 is relatively high close to the city centre where there is vegetation, and still relatively high values of NO_2.

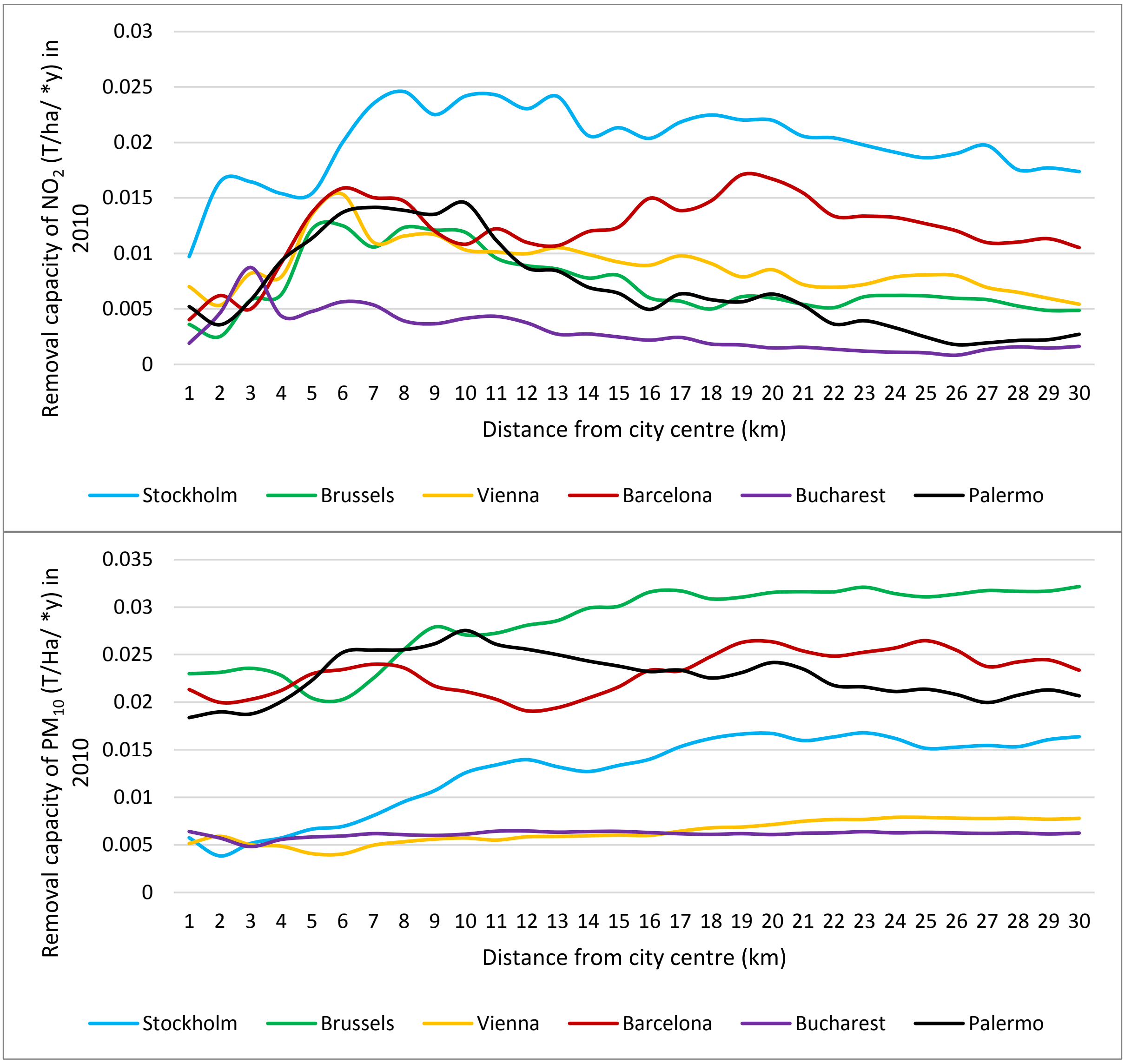


Figure 63: Change in removal capacity of air quality indicators with an increasing distance from the city centre, for selected cities.

3.8.5 Air quality management

Air Quality Management is a complex task, as it involves decisions at multiple administrative levels (international, European, national, regional…) and different stakeholders (policy makers, citizens, industries, etc.). This complexity is reflected well by the structure of the legislation in place to improve air quality that considers both "source-based mitigation controls", fixing binding targets of emission reductions for the future years and "local air quality standards", fixing air quality concentration thresholds for certain pollutants. The legislation for "air quality management" is of vital importance.

In principle the task of designing these plans has been delegated to regional / local authorities; in practice there are plenty of concrete challenges to be tackled, i.e. how competences are split between different decision levels (state / region / municipality); lack of management and assessment capacity at local scale, and public acceptance of local measures.

However, a clear message can be conveyed in this context: in various situations, the local authority / city cannot tackle the air quality issue by itself, but needs to coordinate with higher decision levels (region / national level). A recent study (Thunis et al., 2015) has clearly shown this aspect, analysing three regional areas in Europe (Benelux, South of Poland and the Po Valley, Figure 64). Specific indicators have been developed, to analyse the possibility to improve air quality through local actions, using 0 for no possible improvement, and 1 for full improvement.

In all three cases considered (Figure 65), the potential for local action is limited: to a maximum of 25% of improvement in the case of Benelux, and higher values for the other two domains (up to 50% for long-term improvement, in blue, and 75% for short-term improvement, in red). This study was done for regional level actions; at city scale this behaviour is even more pronounced. Hence, in order to improve air quality, different decision levels would need to team up.

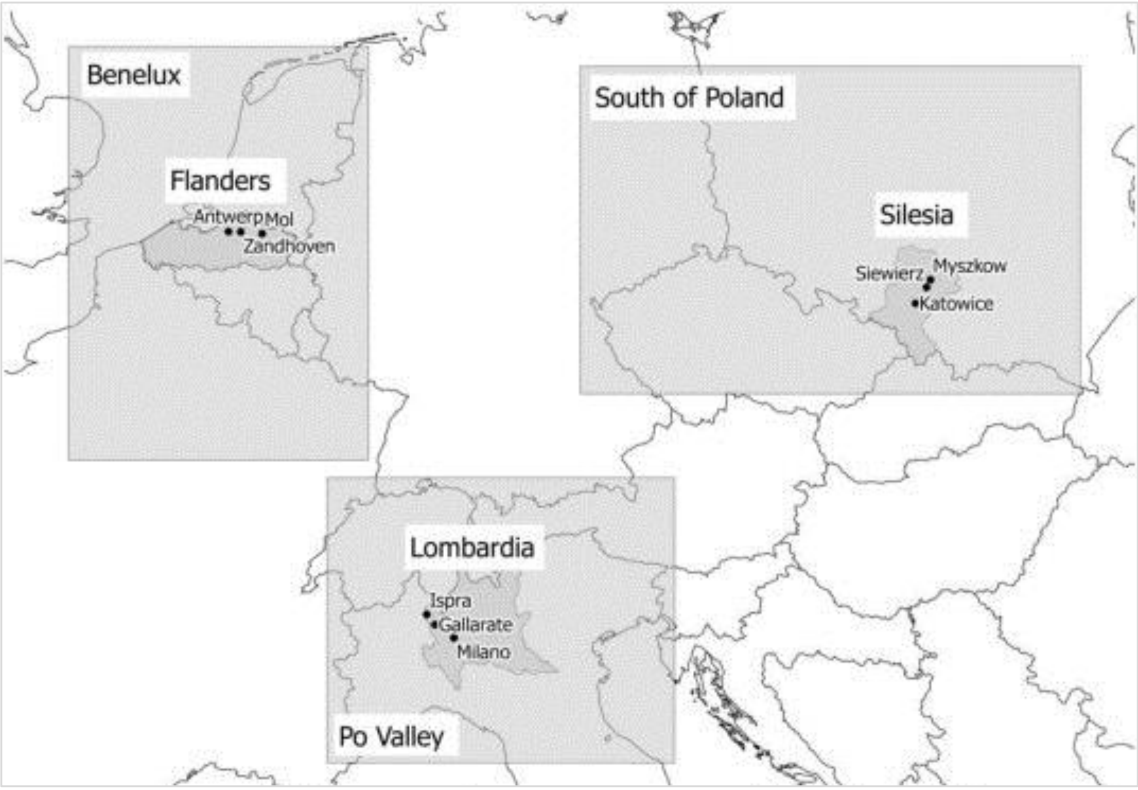


Figure 64: Map of the three simulated areas in Thunis et al. (2015, p.187).

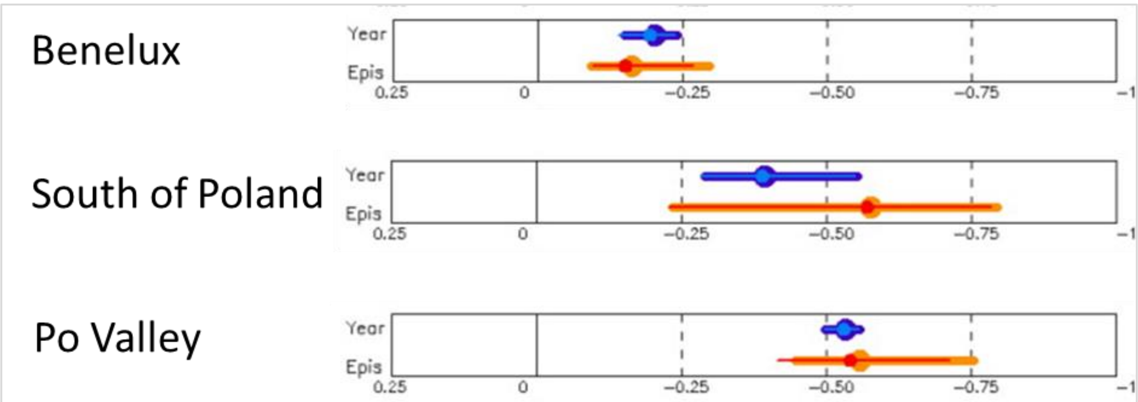


Figure 65: Analysis of potential for local actions, for long term (blue) and short term (red) air quality legislation objectives.

3.9 Accessibility

This section will focus on potential accessibility measures and a newly developed indicator in which potential average Euclidean travel distances are estimated. The potential accessibility measure essentially indicates the opportunity for interaction that transport infrastructure provides; for more information see Jacobs-Crisioni et al., 2014. The measures computed here are based on road travel times and population distributions in such a way that shorter travel times and/or higher population counts lead to higher levels of accessibility. The average Euclidean distances are computed by using a spatial interaction model from all populated 1 km grid cells to all other 1 km grid cells within 30 minutes of travel time. This model assumes that every inhabitant only makes one trip to an inhabitant in any destination grid cell.

3.9.1 Potential accessibility

Accessibility levels vary significantly between the various member states. The highest accessibility levels are found in north-western Europe, while the newest member states and the Scandinavian countries generally have much lower accessibility levels (see Figure 66). In most cases, accessibility values are higher within Functional Urban Areas (FUA) than in the country average due to higher population numbers and potentially higher levels of service of the road network. Only a handful of countries form an exception to this rule, where evidently some FUA have relatively low accessibility levels. This is presumably an effect of the existence of FUA in peripheral areas, and in the case of Greece even on islands. These peripheral FUA cause a predominance of low accessibility values in the averaged FUA values.

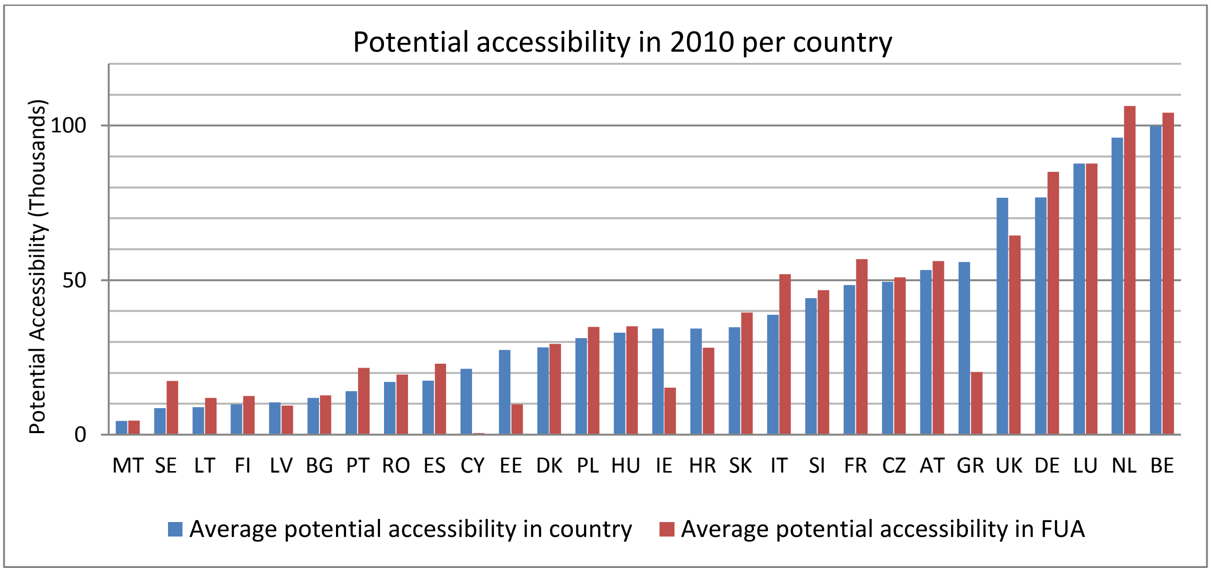


Figure 66: Average accessibility values per country in 2010.

An indicator that serves as a proxy of motorized road transport dependencies has been introduced for this report. For this indicator the average travel distances are computed assuming that all inhabitants in a zone make one trip by personal car to a destination within 30 minutes of driving. A straightforward spatial interaction model between all the populated 1km grid cells in a region is subsequently employed. The result of this method is a matrix with the likely number of trips for every combination of origin and available destinations. This method assumes that people select destinations for their one trip only from the set of destinations that are available; within that set of destinations they are more likely to go to those that have more inhabitants or that are closer to them (for further information, see Jacobs-Crisioni et al., 2015). The trips are distributed based on car travel times; later additions to this method may also include public transport travel times and then distribute trips based on the shortest travel time, regardless of transport mode.

Finally, to proxy energy consumption independent of transport modes, the as-the-crow-flies distances for each trip are measured. We assume this gives a simple approximation of potential energy dependence for each origin pixel. The results of this indicator are currently being validated.

When looking at the aggregate results of this indicator, it becomes abundantly clear that more densely populated areas (cities) are associated with smaller average travel distances (see Figure 67). In most cases, rural areas or thinly populated municipalities close to cities have the highest average distances, highlighting that those areas have an especially high dependence on main cities and potentially consume a relatively large amount of energy for transport. Remote, thinly populated (remote rural) areas are mostly associated with lower average travel distances, indicating that those municipalities are probably more autonomous with less variations due to a limited choice of destinations. Lastly, the high average values of Germany, France, Netherlands and Belgium are noteworthy: apparently, notwithstanding compact or spread urban development, the highly developed road networks in those countries and the associated higher potential accessibility values cause generally higher average distances.

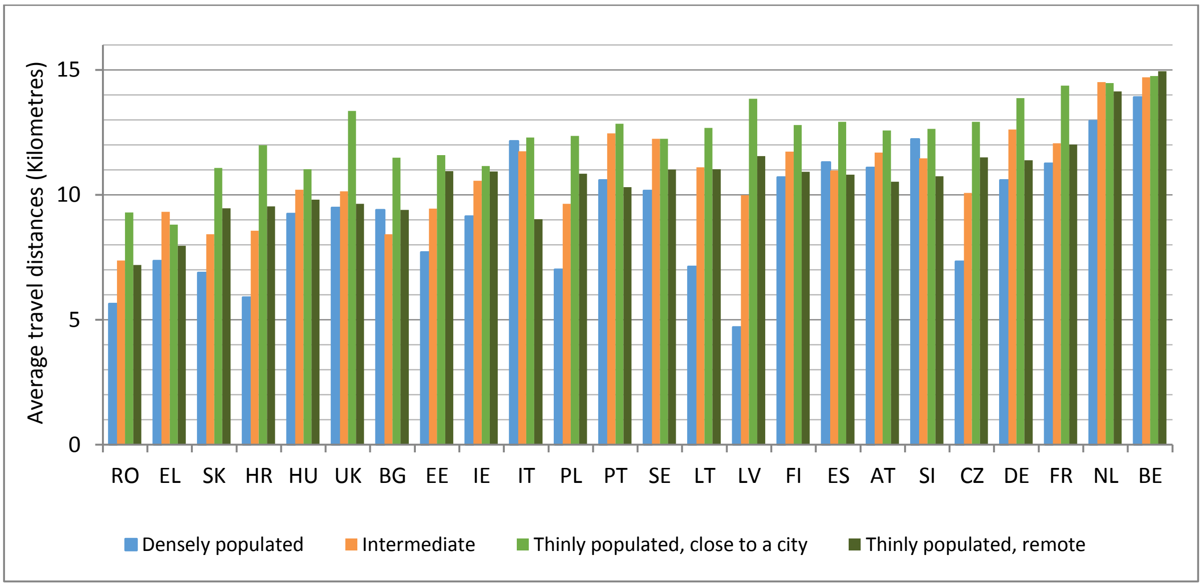


Figure 67: Modelled travel distances averaged by degree of urbanization using the EUROSTAT 2011 population grid (EUROSTAT, 2015c).

3.9.2 Projected changes in potential accessibility

The amount and spatial distribution of accessibility for the year 2050 has been obtained from the LUISA platform reference scenario for 2014. Under this scenario, substantial changes in population levels as well as substantial road network improvements are foreseen. As a result, potential accessibility levels are expected to increase particularly in western Europe. Nevertheless, expected mass emigration from new member states may cause substantial declines in accessibility levels regardless of the sizeable investments from EU cohesion policies to improve transport infrastructures in those states (see Figure 68).

When comparing modelled changes in average country accessibility levels with those changes at the FUA level, it becomes clear that in most cases, according to the LUISA outputs, FUA perform better than the modelled countries as a whole (Figure 69). Where accessibility values decrease, the average country level mostly decreases more than the average of FUA (notably in Lithuania, Romania, Hungary and Slovakia); where national accessibility values increase, the FUA average increases even more (notably in Denmark, Italy, the United Kingdom and Ireland).

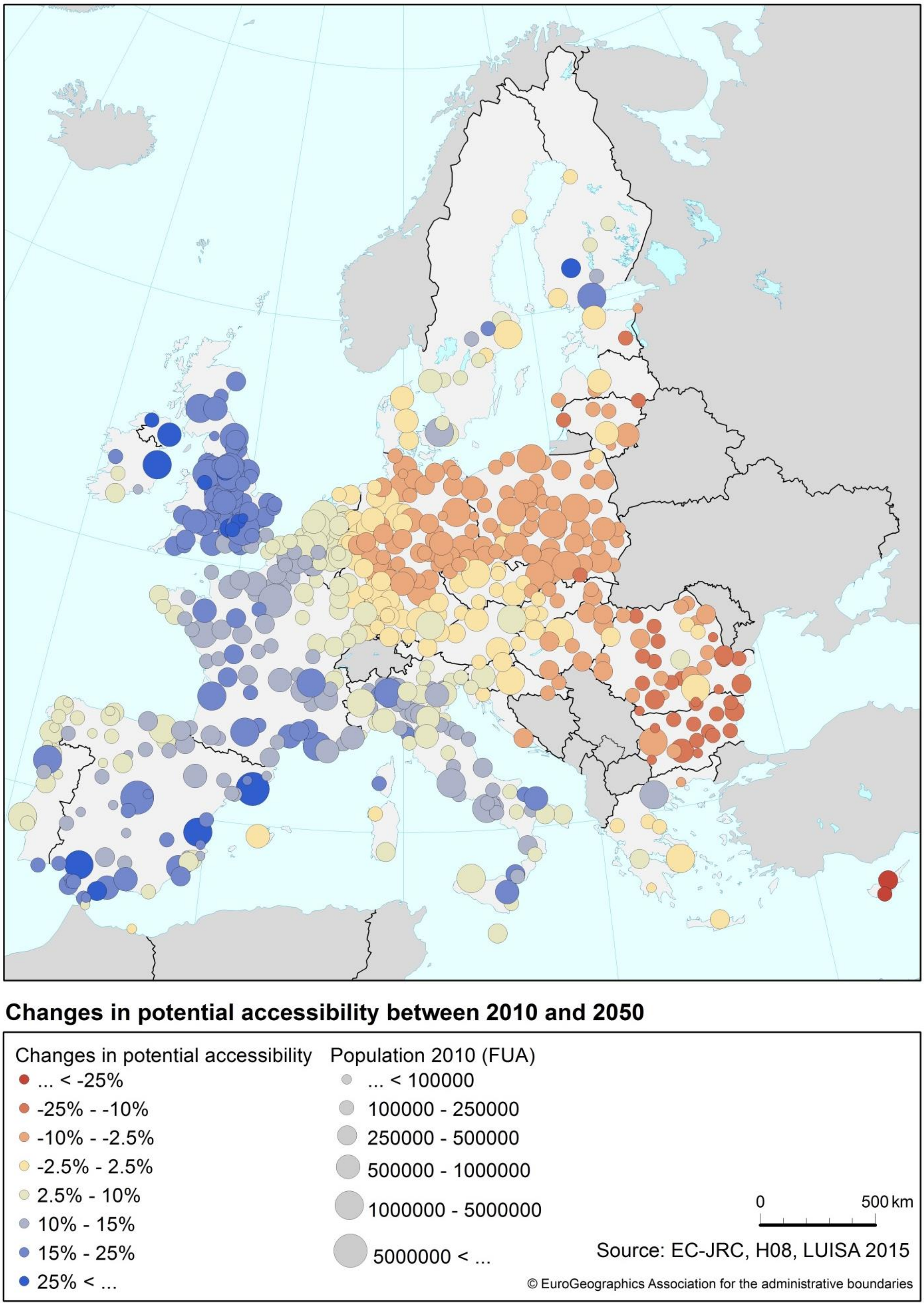


Figure 68: Changes in EU accessibility levels between 2010 and 2050.

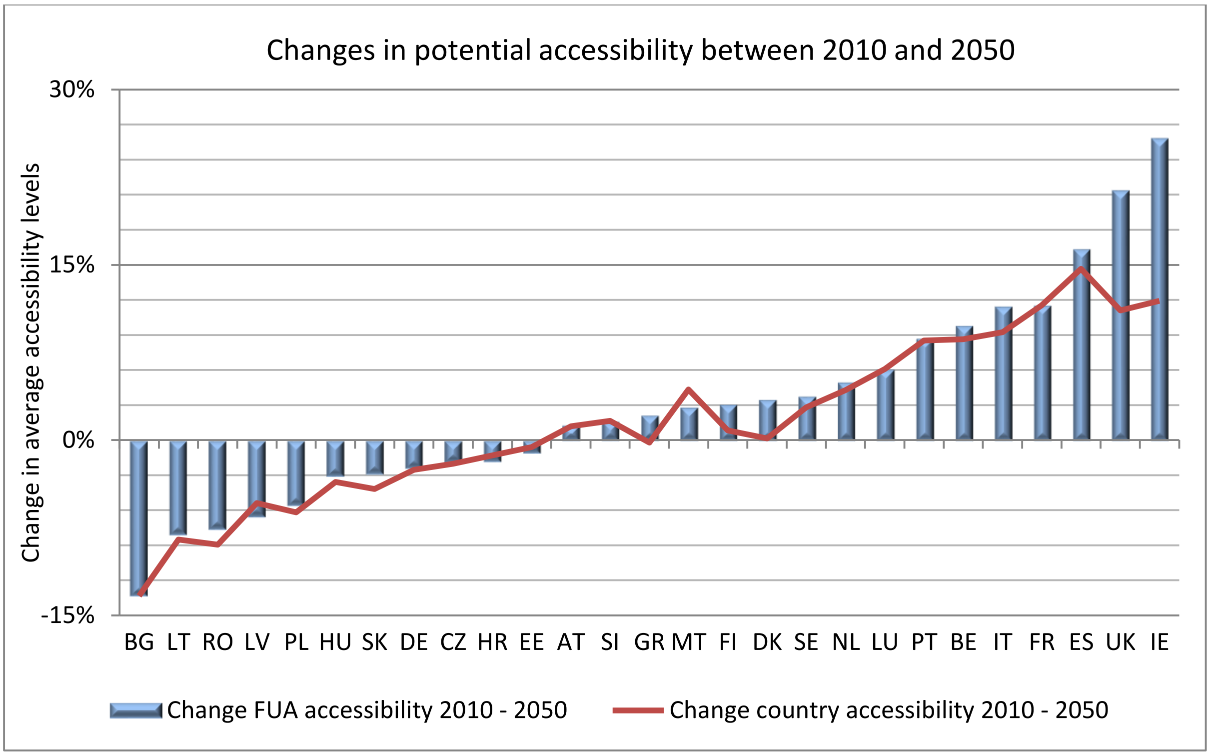


Figure 69: Changes in accessibility values 2010 - 2050 at the FUA and national level.

3.9.3 Average travel distances in selected European cities

It is worth having a closer look at the results on estimated average travel distances and potential accessibility measures for 6 selected metropolitan areas, as indicated in Figure 70. Logically, average travel distances increase when moving away from the city centre, while accessibility values generally get lower. Close to the city centre population densities are generally higher. The accessibility results presented here indicate that those higher population densities provide a much larger selection of destinations in the immediate vicinity, so that, on average, people make trips to destinations which are closer by, reducing the average travel distance close to the city centre.

Despite the overall trend of increasing average travel distance with greater distances to the city centre, strong differences between the selected metropolitan areas can be observed. For example, the difference between Barcelona and Stockholm is highly noticeable. Both cities have roughly similar average distances in the city centre. While the case of Barcelona shows consistently and sharply increasing average travel distances away from the city centre, average travel distances in Stockholm vary much less with distances from the centre.

The differences between Barcelona and Stockholm are no doubt caused by differences in their urban structure. As can be seen in Figure 71, the city centre of Barcelona, with its very high concentration of people, will no doubt attract much more traffic from the metropolitan zone, thus causing steadily increasing average travel distances further from the centre. The underlying large disparities in terms of destination choice are underlined by Barcelona's sharply decreasing accessibility profile. In contrast, the metropolitan area of Stockholm not only has a considerable concentration of people in the city centre, but also in compact sub centres in the city's periphery. This causes a much smaller decline of accessibility levels with distance, and seems to cause a much gentler increase of average travel distances away from the city centre.

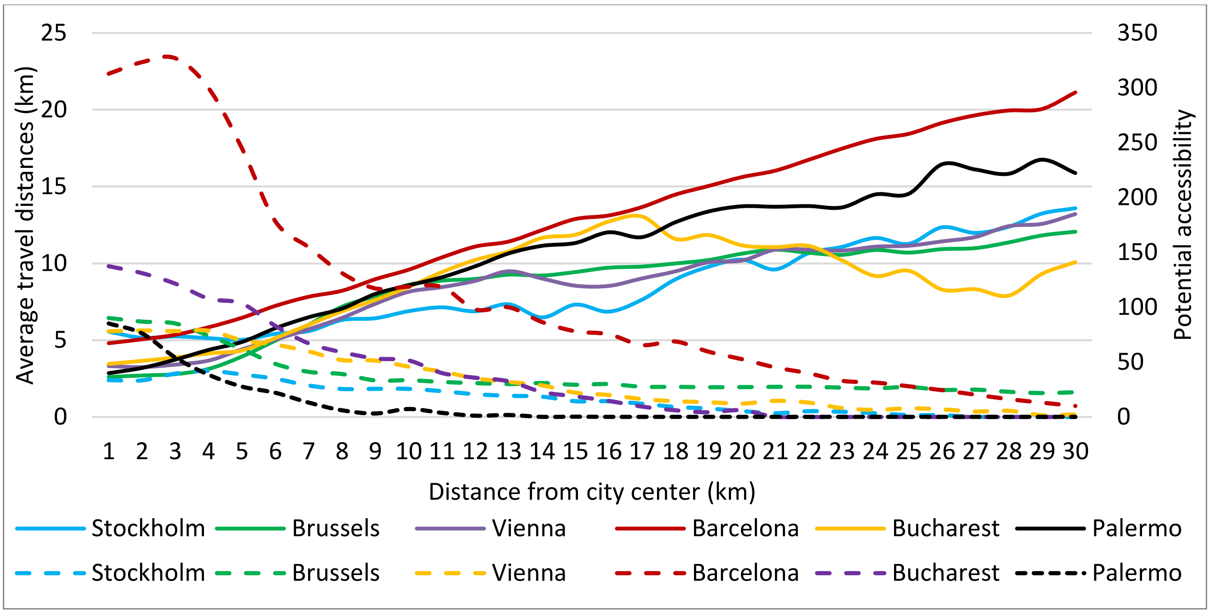


Figure 70: Average Euclidean travel distances (solid lines) and potential accessibility values (dashed lines) with increasing distance from the city centre in selected European metropolitan areas, based on the EUROSTAT 2011 population grid (EUROSTAT, 2015c).

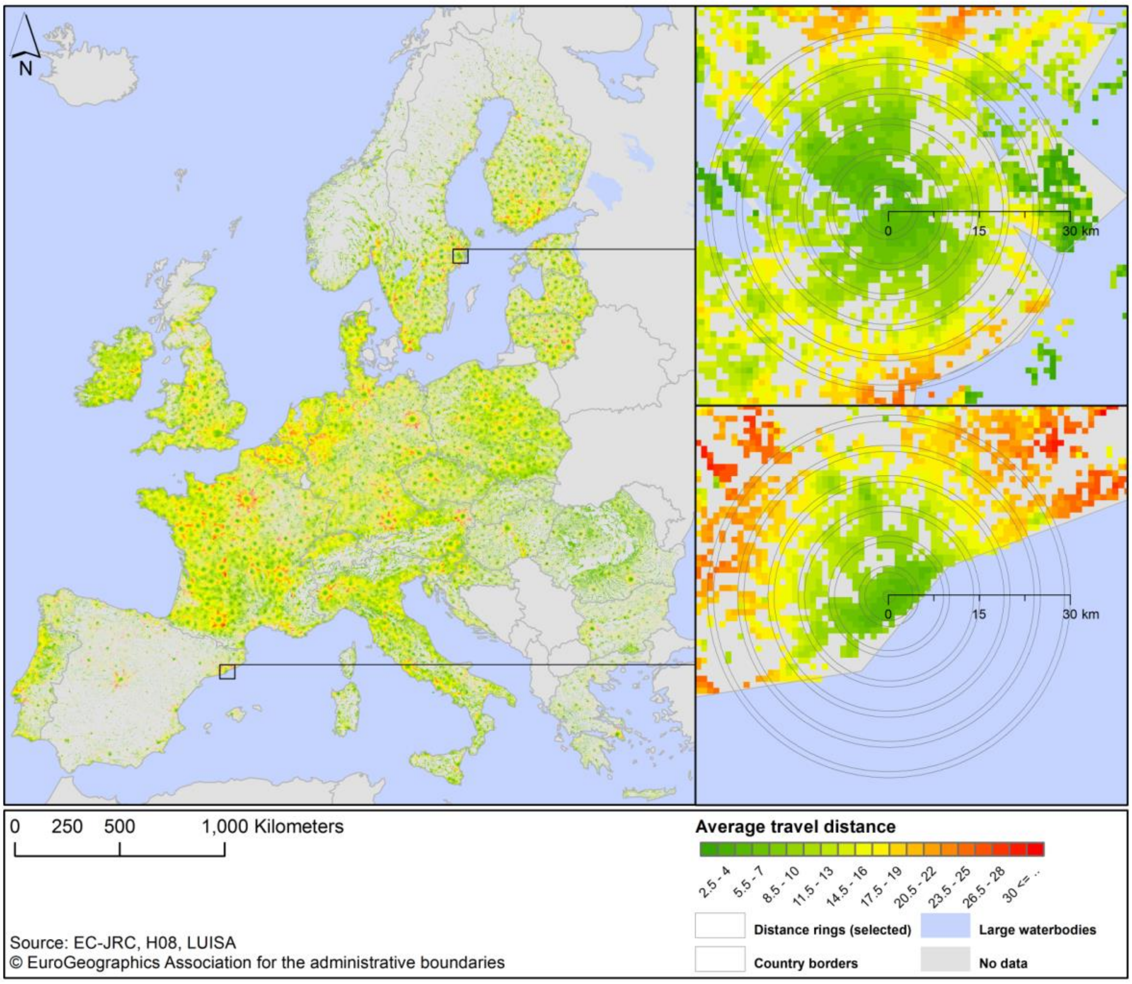


Figure 71: Modelled average travel distances (km) in Europe, with detailed overviews of Stockholm (top right) and Barcelona (bottom right), based on the Eurostat 2011 populaton grid (EUROSTAT, 2015c).

3.10 Green Infrastructure

Green Infrastructure (GI) is defined as a strategically planned and delivered network of high quality green spaces and other environmental features (European Commission, 2013). These areas are structurally and functionally "interconnected and therefore bring added benefits and are more resilient". GI includes natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas. Table 7 describes the land uses considered as part of the GI network.

Table 7: Land use classes included in the definition of Green Infrastructure (GI).

LU Classes	**Green Infrastructure**
Other Arable	GI Only if HNV[1]
Permanent Crops	GI Only if HNV[1]
Pastures	GI Only if HNV[1]
Forests	GI
Transitional woodland-shrub	GI
Cereals	GI Only if HNV[1]
Maize	GI Only if HNV[1]
Root crops	GI Only if HNV[1]
Abandoned Arable Land	GI Only if HNV[1]
Abandoned Permanent Crops	GI Only if HNV[1]
Abandoned pastures	GI Only if HNV[1]
Natural land[2]	GI
Other Nature[2]	GI
Wetlands[2]	GI
Water Bodies[2]	GI
Urban green leisure[2]	GI

[1] HNV: from Paracchini et al., 2008, High Nature Value Farmland in Europe: An estimate of the distribution patterns based on land cover and biodiversity data.

[2] These land use classes were not simulated in the reference scenario (they are kept constant over time).

As pointed out in the Territorial Agenda of the European Union 2020 (European Commission, 2011), changes in land use such as urbanization, agricultural intensification, infrastructure development, etc., threaten cultural assets and landscapes. They may lead to a decrease in ecological value and environmental quality that are crucial to human well-being and to economic prospects which offer unique development opportunities.

GI networks, integrating ecological systems, aim to promote ecosystem health and resilience, contribute to biodiversity conservation and provide other benefits to human populations. They contribute to the maintenance and enhancement of ecosystem services and to long term sustainable development. Therefore, quantification of the availability of GI (i.e. the share of total area and hectares of GI per capita) is important, especially in areas where sprawl of artificial land uses may compete with natural and semi-natural land uses, such as in Functional Urban Areas (FUA). The availability of GI in urban areas is indicative of the environmental quality, which should be protected and developed according to the Territorial Agenda of the European Union 2020.

3.10.1 Share of green infrastructure

GI availability, expressed as the share of GI, is quite heterogeneous throughout the EU-28 territory. At country level, it varies from almost 95% in Finland to 12% in Malta (Figure 72). On average, FUA have a lower share of green infrastructure (green bullets in the figure, 100 means FUA average equal to country average) than the whole territory, with the exception of Cyprus, Denmark, Malta, Lithuania and the Netherlands. The largest difference in the share of green infrastructure among FUA and the country as a whole can be seen in Belgium and the United Kingdom, where GI in FUA represents less than 60% of the country averages.

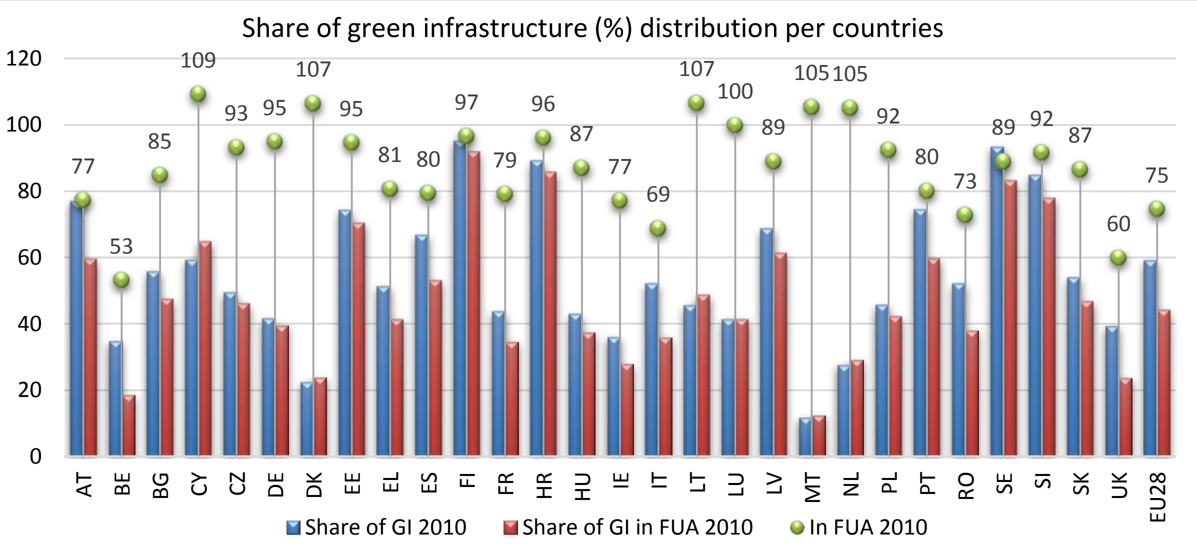


Figure 72: Share of Green Infrastructure inside and outside FUA per member states.

The average share of GI for all municipalities (LAU2 level) is almost 60%, while this average decreases to 45% when only the municipalities within FUA are considered (Figure 72). The majority of capitals show a low (< 40%) or very low (<20%), GI with the exception of cities such as Helsinki, Zagreb and Bilbao.

Across most of the EU-28 (Figure 73), the largest share of green infrastructure is found in rural areas. Notable exceptions are the Netherlands and Malta where suburban municipalities present the largest share of GI, as well as the United Kingdom where GI seems almost uniformly distributed across cities, towns and suburbs and rural areas.

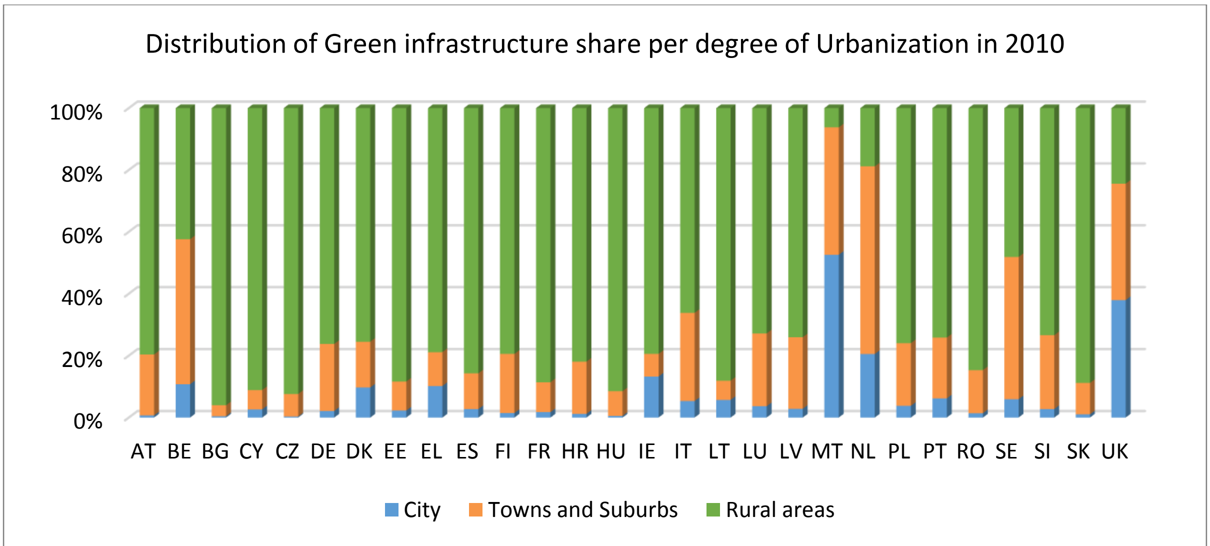


Figure 73. Distribution of Green Infrastructure share per degree of urbanization.

Figure 74 indicates that a general pattern of low share of GI in FUA with large built-up areas are visible in Belgium and the United Kingdom but also in some regions dominated by agricultural areas like south of Italy. FUA in Sweden, Finland, Spain and Croatia have higher share of GI.

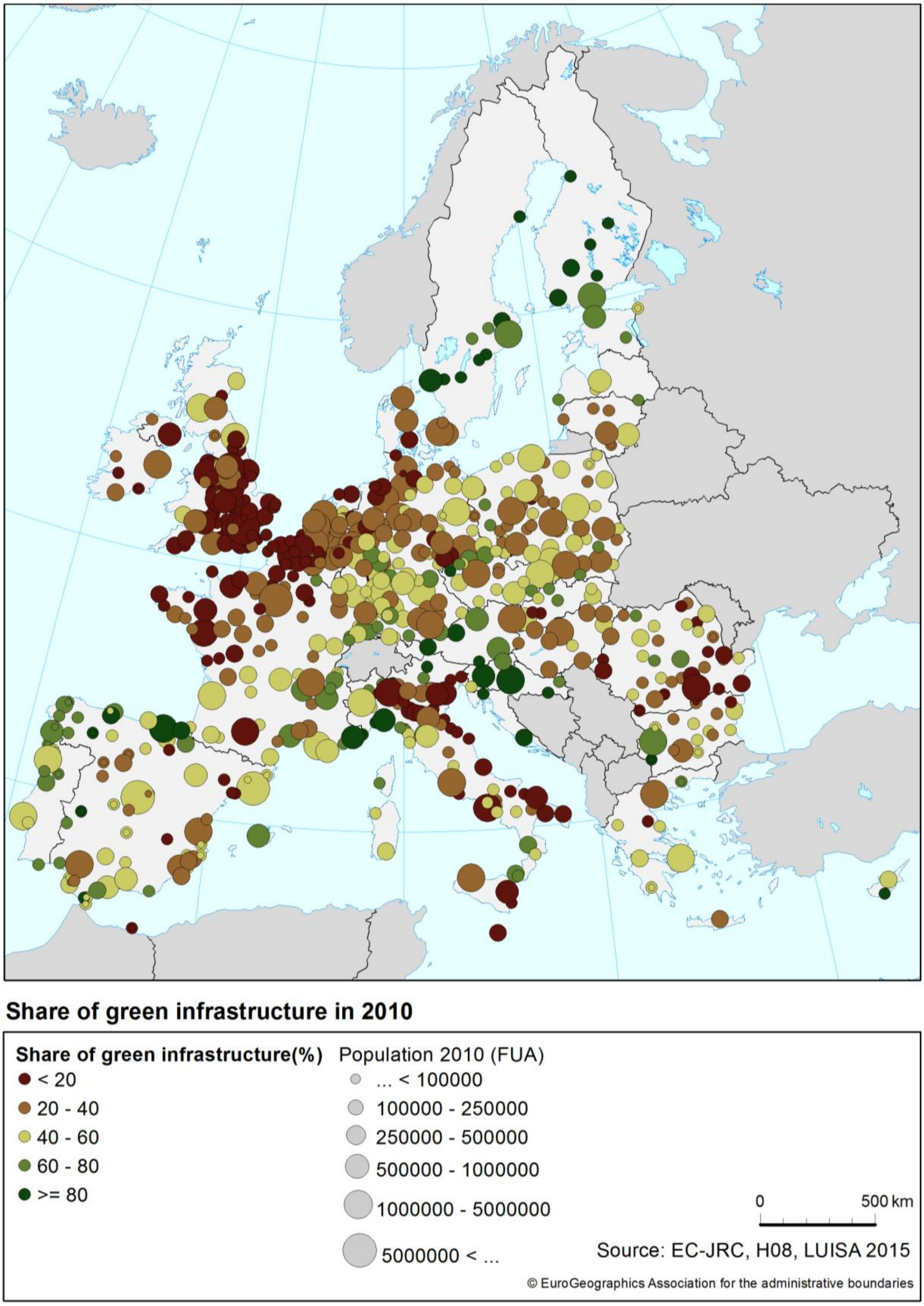


Figure 74. Share of Green Infrastructure in 2010 by Functional Urban Areas (FUA).

3.10.2 Green infrastructure per capita

The availability of GI per capita, is on average 0.79 ha per person in FUA. This value is likely to decrease in the future (Figure 75), particularly in areas where natural and semi-natural areas are competing with other land uses such as urban, industrial and commercial. Figure 75 shows a general trend towards a decrease in GI per capita in FUA across most of the EU-28 (by approximatively −13%) between 2010 and 2050.

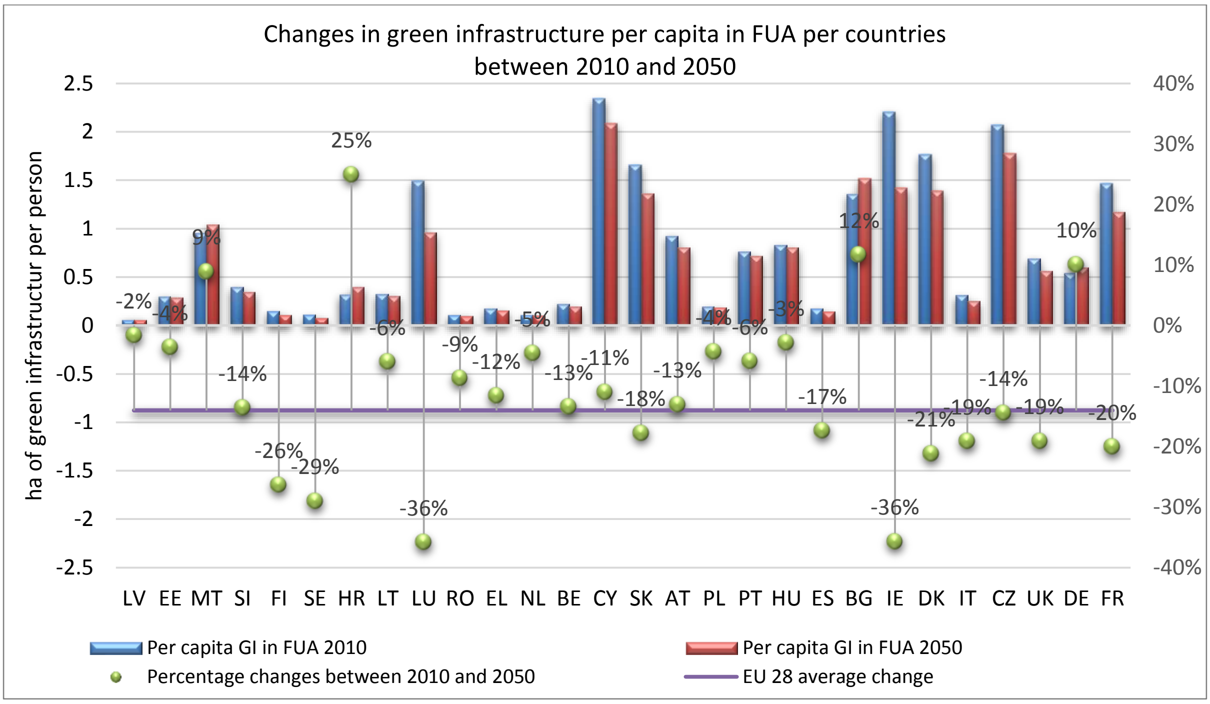


Figure 75. Changes in GI per capita between 2010 and 2050 in Functional Urban Areas (FUA).

On average, the countries where FUA are expected to undergo the greatest decrease in GI per capita are Luxembourg (-36%), Ireland (-36%), Sweden (-29%) and Finland (-26%). On the other hand, FUA in Hungary (+25%), Bulgaria (+12%), Germany (+10%) and Malta (+9%) are expected to show increases in GI per capita between 2010 and 2050. This is most likely associated with expected population decreases in these countries rather than an increase in the amount of green infrastructure.

3.10.3 Changes in green infrastructure per capita in selected European cities

Figure 76 illustrates the current state and projected changes in GI per capita as a function of its distance to the city centre for 6 selected cities. For 2010, we observe a relatively similar profile between cities, with low levels of GI per capita near to the city centre, rapidly increasing (exponential) values between 5 to 10 km, and plateauing values after 15 to 25 km.

Stockholm presents the highest GI per capita values in the city centre while Barcelona presents the lowest values (principally because of its lack of green areas and high population density). Palermo also displays very low values of GI per capita near the city centre, but this value sharply increases between 2 and 15 km distance to reach the highest values among the selected cities.

Projected changes between 2010 and 2050 in per capita GI indicate little changes across all cities between 1 and 10 km from city centre. Green infrastructure per capita is expected to decrease in Vienna and Stockholm between 15 and 30 km and increase in Palermo and Bucharest after 25 km distance from the centre.

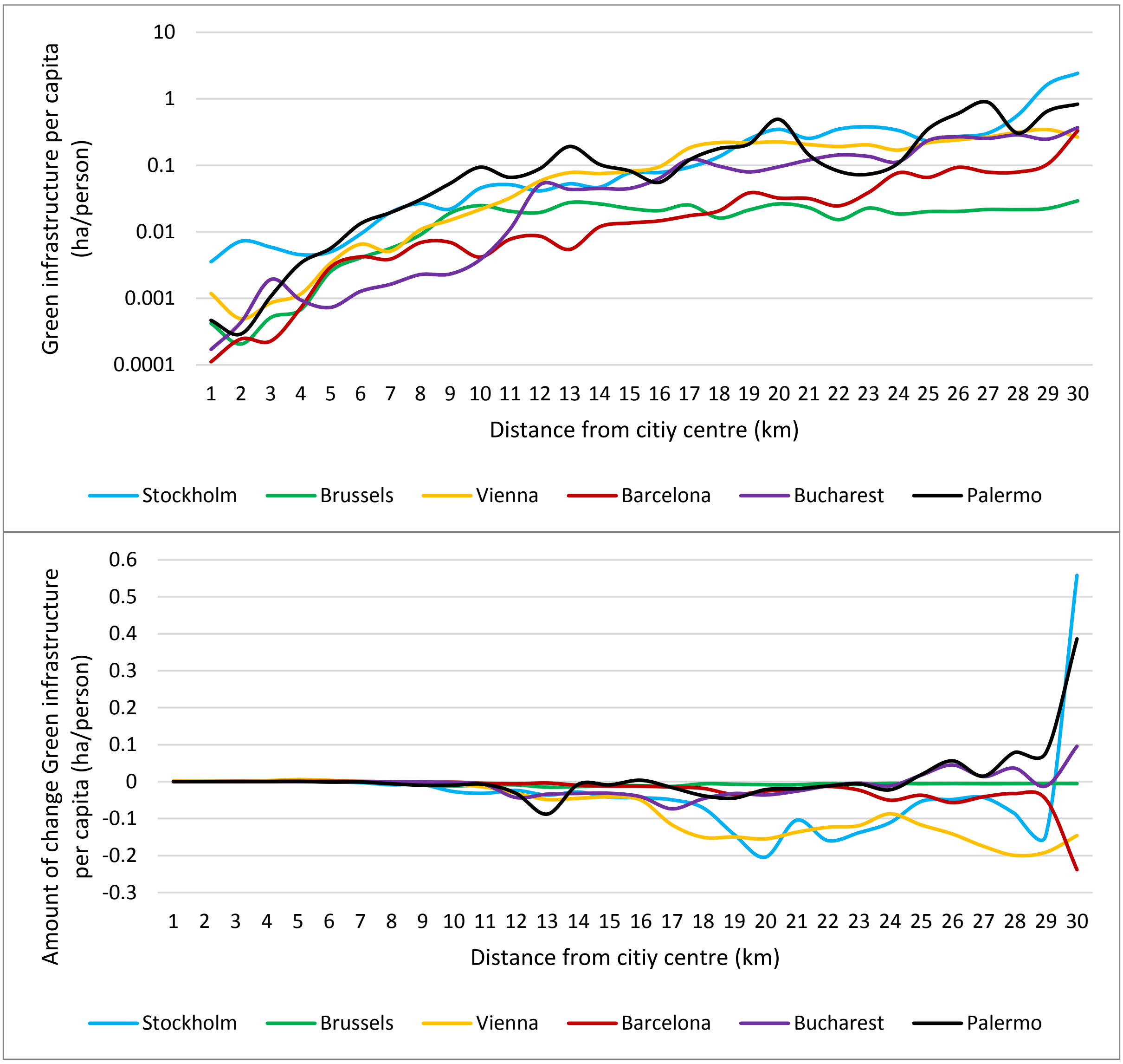


Figure 76: Green infrastructure (person/ha) profiles for selected cities in 2010 (above) and the amount of change between 2010 and 2050 (below).

3.11 Urban flood risk

3.11.1 River flooding in Europe

River flooding is a frequently-occurring natural hazard in Europe. It occurs when rivers overflow their banks and inundate the surrounding area, with an accumulation of water especially in down-stream, flatter areas; meaning that often cities are at high risk of flooding. The impact of flooding on human activity are especially high in urban areas due to the density of the population and physical assets/infrastructure.

We used the flood impact indicator (Lung et al., 2013) to assess the current impacts of flooding in Europe's major cities. The methodology takes into account both the exposure of the city to river flooding, and the associated sensitivity in terms of potential human and physical losses resulting from a flood event.

3.11.2 Quantifying urban flood risk

The risk associated with urban flooding depends firstly on the natural exposure of the city to flooding. This can be measured based on past and predicted flood extent and depth. The EU flood simulation model LISFLOOD (Van Der Knijff et al., 2010) was used to derive the inundation extent and water depth of a 100-year return level of river discharge (Feyen et al., 2012; Alfieri et al., 2013). The model uses current and projected climate conditions in conjunction with a Pan-European hydrological model to characterize future flood events. The map of flood extent and depth was used to derive parameters describing the exposure to flooding (flood area and mean depth for each city).

The sensitivity of the city to flooding is reflected by the potential physical and human losses. In order to quantify these parameters at the urban scale we estimated the population density and area of physical assets affected by flooding according to the flood extent map. The population potentially affected by flooding was computed using a detailed population density map (Batista e Silva et al., 2012); the acreage of commercial and industrial areas was extracted from the current and projected land use maps of LUISA. The parameters used are summarised in Table 8.

Table 8: Parameters taken into consideration when computing the river flood impact indicator.

Component	Description	Temporal coverage	Data source
Flood exposure	Flooded area [%]	1961–1990; 2040-2070	LISFLOOD (Feyen et al., 2012; Alfieri et al., 2013)
	Mean water depth of flooded area [m]	1961–1990; 2040-2070	LISFLOOD (Feyen et al., 2012; Alfieri et al., 2013)
Flood sensitivity	Population density within flooded areas	2010; 2050	Population density map (Batista e Silva et al., 2013)
	Commercial & industrial areas flooded [%]	2010; 2050	CORINE refined (Batista e Silva et al., 2012) & LUISA

The parameters calculated were combined to give a composite indicator taking into account both the exposure and sensitivity of the city. This final index was calculated for the years 2010 and 2050 at both Functional Urban Area (FUA) and municipality level (LAU2). The 2010 calculations used land use and population density data for 2010 and flood extent based on the current climate (1961-1990), while projected land use and population density maps were used for the 2050 index, along with a flood extent map calculated based on an average of 5 climate scenarios for the period 2040-2070.

3.11.3 Urban flood risk in 2010

The urban flood risk index was calculated for the EU-28 countries for both the Functional Urban Areas (FUA,), and municipality level (LAU2). The results are highly variable at the FUA level (Figure 77), with especially high flood risk in central Europe, Romania and Spain. Also notable is that cities with larger populations tend to have a higher flood risk, except in the Scandinavian countries, northern UK, Ireland and Greece.

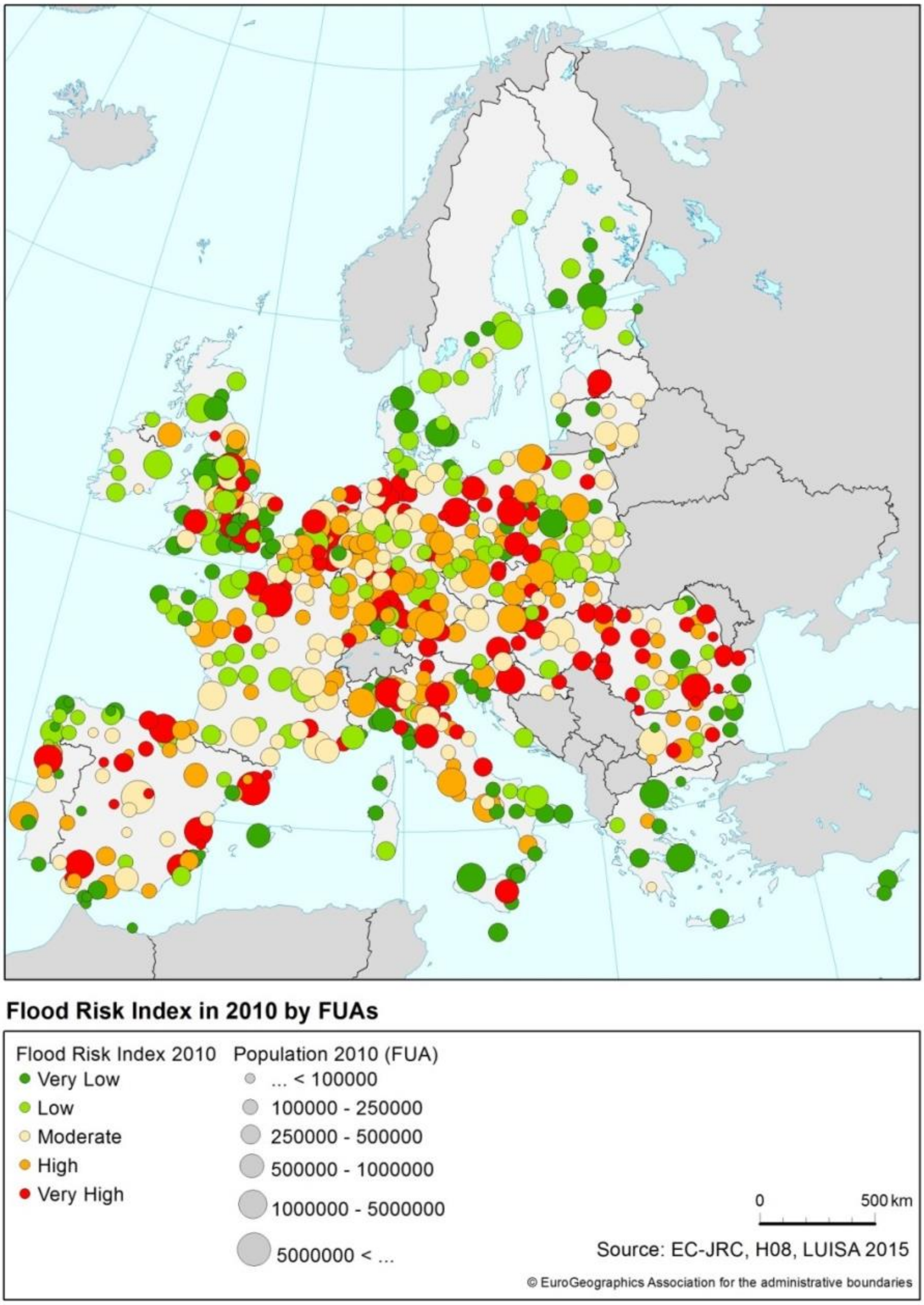


Figure 77. Urban flood risk by FUA for 2010.

The average index per country is summarized in Figure 78 by degree of urbanization (based on the LAU2 calculations). With the exception of Hungary and Sweden, all countries have the highest relative flood risk in areas designated as cities, followed by towns and suburbs, and lowest in rural areas. The highest flood risk for cities is found in Latvia, Portugal, and Lithuania, with the lowest flood risk for cities in Sweden. Whilst the exposure of cities to flood risk is highly dependent on their geographical location (ie. proximity to major waterways and topography), the sensitivity to flooding will logically tend to be higher due to the dense population and abundance of commercial and industrial areas potentially at risk.

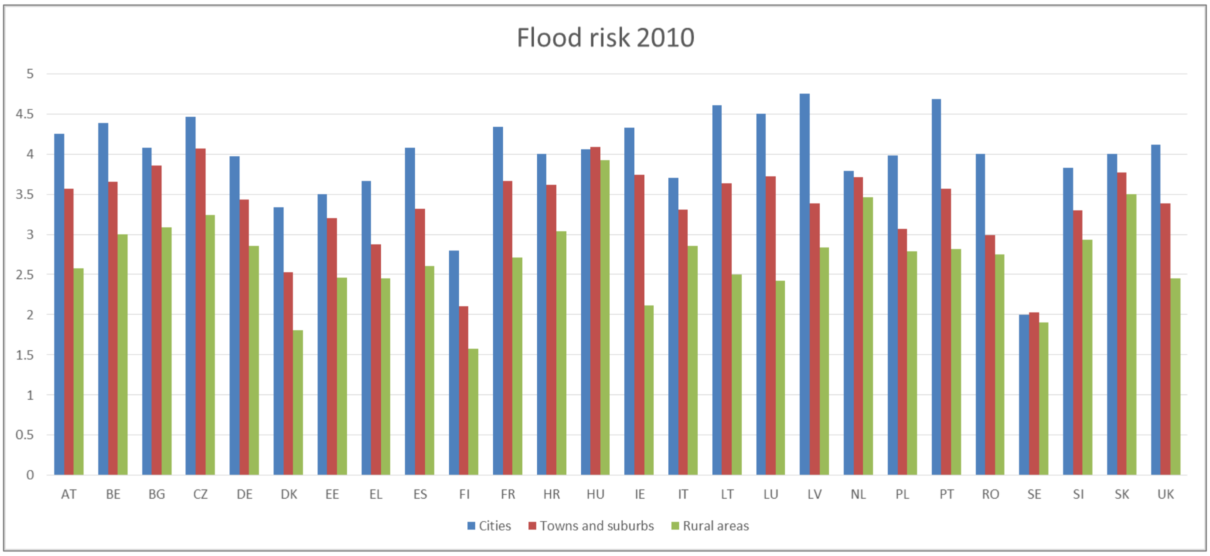


Figure 78. The average urban flood risk per country per degree of urbanization for 2010.

3.11.4 Projected change in urban flood risk 2010 - 2050

The urban flood risk index was projected to the year 2050 for the EU28 countries for both the Functional Urban Areas (FUA), and municipality level (LAU2). Figure 79 gives the resulting change in the index at FUA level between 2010 and 2050. Although most urban areas maintain the same index score, several areas show improvements, especially in Germany and Poland. Other urban areas showed increased flood risk over time, notably those in the UK, France, northern Italy, eastern Poland and Belgium.

3.11.5 Summary of the findings

The results show a high variability in flood risk both spatially across Europe, but also according to the size of the urban agglomeration. Larger cities tend to have higher average flood risk, especially due to the higher sensitivity in terms of potential human and physical losses.

The overall index shows some notable changes over time in urban areas, due both to climate variability (resulting in a varied predicted flood extent), and to the growth or de-population of the agglomeration. Although flood risk increases in numerous urban zones in the UK, France, Poland, Belgium, the Netherlands and Romania, there are also several improvements seen in central and eastern Europe.

It should also be noted that regions such as the Netherlands, Germany, and Northern France may experience high flood risk, but also have the highest protection levels against flooding. The indicator has also been computed taking into account only river flooding, and therefore is not fully representative for the flood hazard experienced in cities along the coastlines, which may in addition experience coastal flooding.

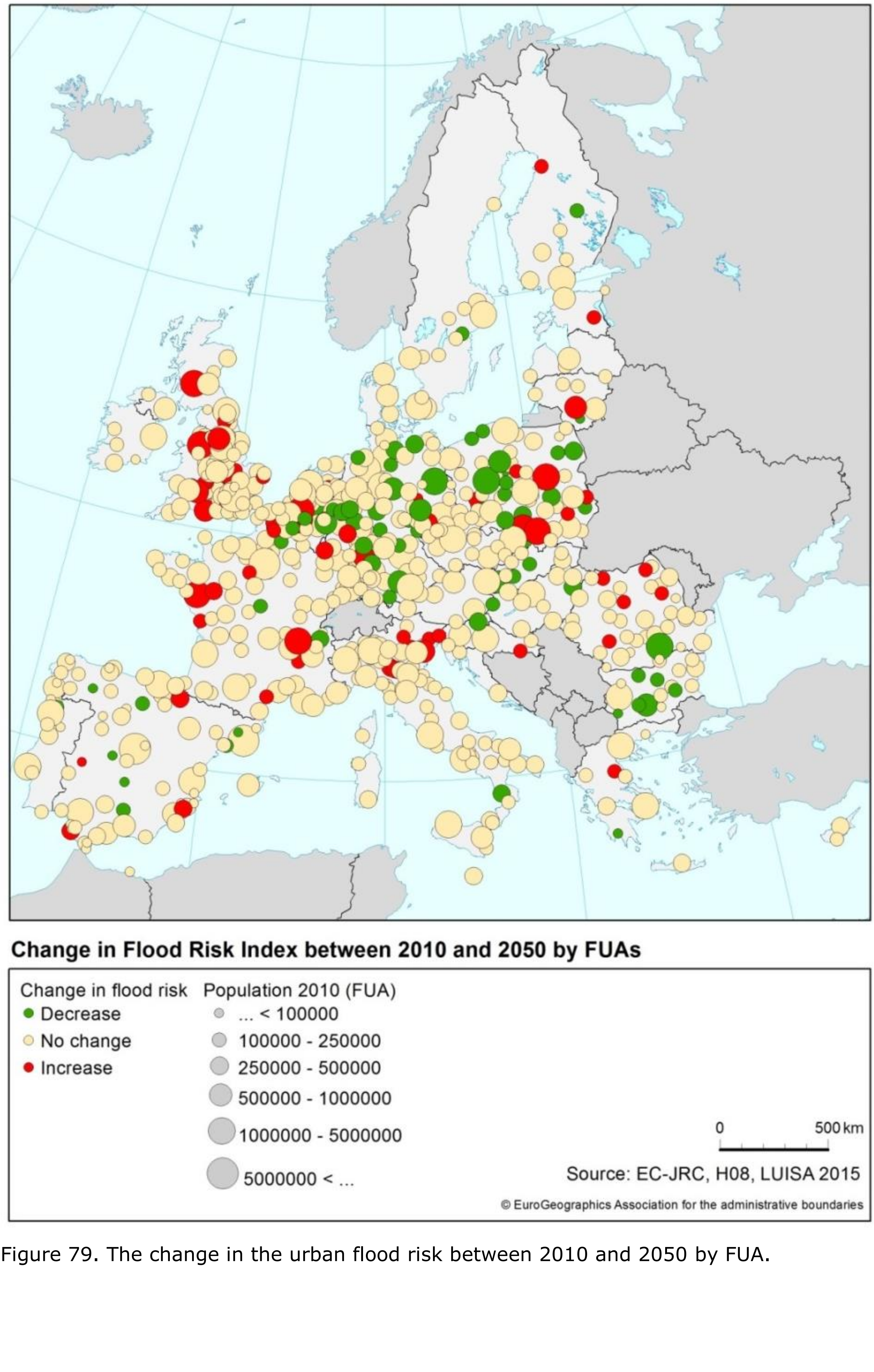


Figure 79. The change in the urban flood risk between 2010 and 2050 by FUA.

4. The Present and future of European cities: summary of the main findings

In the previous sections, the results of urban indicators were presented in detail at the EU level for all relevant thematic fields. Territorial and temporal dimensions of future changes were given; regional differences and trends are elaborated upon, and characteristics of urban and rural areas were highlighted. Finally, in this section, the dominant patterns and/or most likely changes for each thematic field are summarised:

Degree of urbanization:

These results demonstrate that, although in the EU-28 no considerable shifts in degree of urbanization are forecasted at the LAU2 level, the population is increasing mainly in densely populated areas. There is, however, not a clear spatial pattern of urbanization. Within each country, it is possible to find both regions that are becoming more densely populated and regions where the opposite phenomenon takes place.

Urbanization:

As of 2010, the proportion of the population living in cities, towns and suburbs within the European Union was higher than the rest of the world with almost 80%. The forecasts imply that in the next twenty years, the urban proportion will continue to increase as in the past few decades; it will then slow down and reach its limit at 88% by 2050. Since most of the Functional Urban Areas (FUA) have already reached their thresholds, with 90%-95% urban proportion levels, smaller cities/towns and also rural areas will be the main subject of urbanization in the future.

Land use and urban development:

The annual land take between 2010 and 2050 at EU-28 level is approximately 1.6 m2/capita/year. It is less than 1 m^2/capita/year in Bulgaria, Germany, Latvia, Croatia and Greece and more than 3m^2/capita/year in Ireland, Finland, Belgium, Cyprus, Luxemburg and Sweden. The annual land take per inhabitant is much higher in rural areas with 3.08 m^2/capita/year than the cities with 0.80 m2/capita/year and the towns and suburbs with 1.93 m^2/capita/year. With a focused analysis, the land take tend to start peaking after a 5 km distance from the city centre, which means the land available for built-up within city centres has already been developed in the past, and that the majority of land take therefore will occur first in suburbs and then in rural areas.

As of 2010, artificial areas per inhabitant in EU-28 were 498 m^2 and become 539 m^2 in 2050 with an 8% increase. Croatia, Romania, Bulgaria, Latvia, Slovakia, Ireland and Poland record the greatest amount of change between 2010 and 2050 in terms of artificial areas per inhabitant. Considering only the FUA, in 2010 artificial areas per inhabitant are 373 m^2 and become 388 m^2 in 2050 with a 4% increase. This is only half of the average increase rate for the whole EU-28, and means that less land is consumed per inhabitant in FUA. Finally, in general, the local administrative units (LAU2) classified as cities use land more efficiently (228 m^2/capita), than the towns and suburbs (501 m^2/capita) and the rural areas (1084 m^2/capita).

Population growth:

In 2010, 65% of the EU population were living in Functional Urban Areas (FUA). This number is expected to reach 70% by 2050. While the overall EU population is expected to grow by 4.6%, most growth will occur in FUA. The rest of the European territory (including many FUA in central Europe) is expected to lose population. Within FUA, more people will be living in municipalities classified as cities, towns and suburbs.

Population weighted density:

In 2010, the average population weighted density in FUA across all EU countries was approximately 95 persons/ha. By 2050, most countries will see decreases in population weighted density in cities and rural areas and increases in suburbs and towns if the FUA are taken into consideration.

Nature based recreation opportunities:

The indicator allows the spatially explicit assessment of: 1) the capacity of ecosystems to provide recreation opportunities, and 2) the demand for this important service. The rural zones in Europe provides higher levels of opportunities, but, urban areas (cities + towns and suburbs) generate a high amount of potential short trips to recreational sites of low level that we consider in high demand. The global trend in opportunities for nature based recreation provision is likely to decrease in the future with an average of -30% by 2050. Due to the spatial trends of changes that mainly depend on transition from natural to artificial land uses.

Air quality:

The Land Use Regression model (LUR) and source receptor methods were used to derive PM_{10} and NO_2 and $PM_{2.5}$ concentrations respectively in FUA throughout Europe, allowing the quantification of their impact on health. Results of concentrations for specific pollutants show high variability in FUA between and within countries. LUR methods also allow the prediction of future air quality patterns and the results show that, in general terms, concentrations will slightly increase between 2010 and 2050 if only land use related parameters (no specific air quality measures) are considered. If suitable measures are not taken, those slight increases can be further augmented by increased emissions from, for example, traffic and industries.

Accessibility:

Potential accessibility values are higher in particular in the urban areas of north-western Europe. Despite substantial investment in Europe's new member states, accessibility is expected to increase in particular in Western Europe, Great Britain and Ireland. Apart from this, it is obvious that urban form has a considerable impact on average travelled distances and thus potentially on the energy dependence of transport within cities.

Green infrastructure:

Green infrastructure is mainly found at the periphery of European urban areas. Green infrastructure per person is generally low or very low in most European cities at the exception of cities such as Helsinki, Zagreb and Bilbao. Green infrastructure per capita shows a general trend towards a decrease in FUA across the EU-28 (by approximatively –13%) between 2010 and 2050. This decrease is expected to be particularly significant where natural and semi-natural areas are competing with other land uses such as urban, industrial and commercial.

Urban flood risk:

Larger cities tend to have higher average flood risk, especially due to the higher sensitivity in terms of potential human and physical losses. The overall index shows some notable changes over time in urban areas, due both to climate variability (resulting in a varied predicted flood extent), and to the growth or de-population of the agglomeration. Although flood risk increases in numerous urban zones in the United Kingdom, France, Poland, Belgium, the Netherlands and Romania, there are also several improvements seen in central and eastern Europe. It should also be noted that regions such as the Netherlands, Germany, and Northern France may experience high flood risk, but also have the highest protection levels against flooding.

5. Conclusion

Given its approach developed for territorial modelling, and its high resolution land use and population data outputs, LUISA is an efficient method to measure the performance of European cities and to explore key spatial parameters that shape urban areas. Previous territorial impact assessment practices had difficulties in measuring the EU-wide performance of cities and urban areas against specific policies. Europe-wide spatial models are generally designed to produce projections at the country level and/or for NUTS2 and NUTS3 regions. Moreover, other more fine-resolution spatial analyses cover only a limited number of cities or urban regions, implying intrinsic difficulties in making comparisons between different regions and in monitoring EU-wide impacts of urban policies.

At this point, the approach developed by LUISA creates an important opportunity to fill this gap in territorial impact assessment practice. The high resolution land use, population and 'land function' data output by LUISA provide useful complementary indicators to measure the performance of European cities and to explore the key spatial parameters that shape urban areas in Europe.

This study, as a recent exercise of the LUISA modelling platform, investigated the present and future state of European cities and regions. It applied several urban indicators that analyse the main dynamics of urbanization and urban development through changes in land use / land cover, population growth, recreation potential, green infrastructure, air quality, flood risk and accessibility in Europe.

The results were demonstrated in detail for a number of thematic fields at the spatial extent of the entire EU. Territorial and temporal dimensions of future changes were explored; regional differences and trends are elaborated upon, and characteristics of urban and rural areas are highlighted. Finally, the dominant pattern and/or most likely change in each thematic field were summarised in an overview.

The results achieved within this report indicates that the patterns and trends seen are spatially different among countries and among regions which demonstrates the added value of territorial modelling for the assessment of policies related to urban areas. To allow full exploitation of these outcomes by urban policy, next efforts should focus on establishing clear links between this assessment and policy implementations for Europe's cities.

The analysis herein presented is part of a wider initiative of DG JRC and DG REGIO aiming to improve the management of knowledge and sharing of information related to territorial policies, such as those concerning urban development. In this framework, the work will be further developed, covering the following main elements:

- Development of the European Urban Data Platform, providing a single access point for data and indicators on the status and trends of European urban areas;
- Updates of the LUISA configuration, to account for new socio-economic projections;
- Support to the development of the EU Urban Agenda and related initiatives;
- Provision of evidence-based support for the evaluation of territorial policies in particular to proof the role of cities in the implementation of EU priorities.

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List of abbreviations and definitions

CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CICES	The Common International Classification of Ecosystem Services
CLC	Corine Land Cover
DG ECFIN	Directorate-General for Economic and Financial Affairs
DG ENER	Directorate-General for Energy
DG ENV	Directorate-General for the Environment
DG JRC	Directorate-General Joint Research Centre
DG REGIO	Directorate-General for Regional and Urban Policy
EC	European Commission
ESTIMAP	The Ecosystem Services Mapping tool
EU	European Union
EUROSTAT	Statistical Office of the European Communities
FUA	Functional Urban Areas
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies Model
GDP	Gross Domestic Product
GEM-E3	General Equilibrium Model for Economy - Energy - Environment
GHG	Greenhouse Gas
GI	Green Infrastructure
GVA	Gross Value Added
ha	Hectares
IES	Institute for Environment and Sustainability
JRC	Joint Research Centre
LAU2	level 2 - Local Administrative Units
LUISA	Land-Use-based Integrated Sustainability Assessment Modelling Platform
LUR	Land Use Regression Model
MS	Member States
NDA	Non-disclosure agreements
NUTS	Nomenclature of Territorial Units for Statistics
OECD	The Organisation for Economic Cooperation and Development
TEN-T	The Trans-European Transport Networks
UNFCC	The United Nations Framework Convention on Climate Change
UNWTO	The United Nations World Tourism Organization

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