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Urban sprawl in Europe – identifying the challenge

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1 ABSTRACT

In Europe, research on urban sprawl is largely limited to case studies of selected metropolitan areas in a national context. In addition, the literature to date does not present comprehensive empirical evidence as to what exactly constitutes urban sprawl. Accordingly, the European Environment Agency describes urban sprawl as the "The ignored challenge" in the subtitle to its 2006 report on urban sprawl (European Environment Agency, 2006). This article aims to deliver a contribution for identifying the "challenge": it provides a consistent overview for the area-wide distribution and characterisation of urban sprawl in Europe, based on CORINE land cover data and a set of GIS-based indicators. The indicators are built upon a framework that allows for the differentiation of distinct types of urban sprawl, including measures that compare land cover change over time. The results are presented as continuous maps of Europe for different indicators of urban sprawl, and interpreted in the context of their characteristics and distribution.

2 INTRODUCTION

During the 1990's, the phenomenon of urban sprawl received growing attention in the international planning debate. However, a survey of the literature yields no agreement in terms of defining and measuring urban sprawl (Galster et al. 2001). Previous attempts of measurement significantly vary in terms of data sources used, land use characteristics focused on, the impacts sprawl might hold responsible for, and the spatial scales of observation (national, metropolitan, city, neighbourhood). Simply spoken, it is obvious that sprawl means different things to different people. The same applies to similar terms like compactness, compact growth, or sustainable urban form (Tsai 2005; Jabareen 2006). However, politicians and planners aiming to contain unwanted patterns of urbanisation must have an agreed-upon way to define and measure land use patterns in order to track their progress.

Furthermore, previous research on urban sprawl is largely limited to case studies of selected metropolitan areas in a national context. The lack of internationally comparative research on the intensity and spatial coverage of urban sprawl constrains the understanding of sprawl's economic, social and political drivers as well as the different implications of alternative urban form. While demographic and economic trends are usually well-documented, few work exists on the per capita amount of urbanised land, the rates of growth and the spatial patterns of urban expansion (EEA 2006; Schneider/Woodcock 2008; Kasanko et al. 2006). We simply do not know how industrialized countries and their metropolitan areas compare internationally in terms of sprawl patterns.

With this background, we present a methodological framework for the comparative measurement and assessment of similarities and differences in urban sprawl that has occurred across 26 European countries. The implementation of this measurement concept in a Geographic Information System (GIS) is based on the assumption that urban sprawl is a multidimensional phenomenon which can only be measured with a multiple-indicator approach. We introduce indicators that refer to specific impact dimensions of urban sprawl, namely the composition of land use (addressed as the proportion of certain land use types) and the spatial pattern or urbanised areas. The main part of this paper presents the findings of the implementation of the proposed sprawl indicators based on CORINE land cover data. In order to avoid scaling issues and allow for comparability of indicators, we used a reference grid for analysis. All outputs for indicator calculations were then scaled to this grid.

3 APPROACH AND RELEVANCE

Our conceptual framework takes into account that different dimensions of sprawl correspond with environmental, social and economic impacts of urban land use change (Siedentop et al. 2007; Siedentop 2007). At first, sprawl-type developments contribute to declining urban densities (density dimension). Declining densities are an outcome of low density development at the urban fringe and density losses within the urbanised area as an effect of household dynamics and rising affluence. Among outher negative implications “low density sprawl” imposes pressure on the economic efficiency of technical infrastructures and increases transportation demand (Burchell et al. 1998).

A second dimension of sprawl refers to the change of land use pattern (pattern dimension), operationalized with geometric measures. According to this dimension, sprawl describes the transition of a compact urban form to a dispersed urban land use pattern. A typical feature of this sprawl dimension is an irregular, discontinuous urban form with a highly fragmented mosaic of different land uses. “Pattern sprawl” can typically be found in suburban and exurban parts of metropolitan areas. Researchers claim that “pattern sprawl” is responsible for efficiency losses of urban services such as road infrastructure or sewer systems (Burchell et al. 1998, Doubek/Zanetti 1999). There is also evidence that spatially dispersed urban functions contribute to larger travel distances (Cervero 1996, Naess 2003). Furthermore, pattern sprawl is one crucial contributor to landscape fragmentation characterized by a process of perforation, dissection and isolation of habitat areas and natural or semi-natural ecosystems (Jaeger 2000). Many scholars regard fragmentation as a major cause of the alarming loss of species all over the world (Cieslewicz 2002).

Furthermore, sprawl can be characterized by its change of land use composition. We address this as the “surface dimension” of sprawl. From this point of view, urban sprawl describes a large scale conversion process of natural or semi-natural surfaces to urban uses with a high share of artificial, impervious surfaces and complex effects on ecological systems (Arnold/Gibbons 1996). “Surface sprawl” usually affects the core areas of metropolitan areas and their near surroundings. Next to the amount of urbanized land or impervious surfaces, the quality of land that became urbanized within a specific period of time has to be taken into account (e.g. soil quality, habitat quality). Of particular concern is the loss of open spaces important for recreation, wildlife and water quality.

The dimension-oriented measurement concept presented here intends to overcome some of the empirical limitations of previous sprawl studies. Firstly, we work with different indicators to indicate different impacts caused by sprawl. Secondly, our approach can deal with the static and process nature of urban sprawl. Therefore, we suggest operational indicators that characterise the conditions of land use and use others to address land use changes over time. Thirdly, our indicators can be used for all spatial units (administrative or non-administrative units such as river basins or air pollution sheds) and various geographical scales above the neighbourhood level (city, metropolitan, national). However, due to limitations of CORINE land cover data and the scarcity of fine-scaled population data we couldn’t implement density indicators in this paper.

4 DESCRIPTION OF INDICATORS

4.1 Data

We used two data sets in order to implement all indicators that are presented in the subsequent chapter. Information regarding administrative areas (country borders) was sourced from the European Unions’ NUTS classification system (EUROSTAT). Land cover data comes from the European Union’s CORINE project (Coordination of Information on the Environment). Comparable data is available for the years 1990 and 2000 for 26 countries of the European Union[1]. The next release (2006) is scheduled to be available at the end of 2009. For our analysis we selected nine out of ten available “artificial surface” land cover classes (except mineral extraction sites) as urbanized area. As a reference map for data checks, we used satellite images from the arcgisonline map server, provided by the Environmental Systems Research Institute (ESRI) to scales of about 1:100,000 for Europe. As explained above, we could not implement density related urban sprawl indicators. This would require disaggregated, continuous population data for all countries, which we only had available for the larger urban zones (LUZ) that participate in the Urban Audit project of the European Union. However, since our focus was to provide continuous information on urban sprawl indicators, we had to discard all density-related indicators for this study.

In terms of data accuracy, it is important to note the limitations of CORINE land cover data. Smaller urban areas (< ~ 25 ha, depending on the type of adjacent features) in rural areas are unaccounted for. Similarly, smaller non-urban features are not represented within urban area compounds. Based on our experience, the

[1] Data for Sweden and Finland is only available for 2000.

urban area is under-represented compared to official statistics, and more so in predominantly rural regions than in urbanised regions (see also European Environment Agency 2006, Meinel et al. 2007).

4.2 Indicators

Table 1 gives an overview over the selected indicators, including essential aspects for implementation (units, year of data capture). The framework described above is reflected in the categorisation of sprawl indicators in the surface and pattern groups.

		Indicator	Description	Units	Year
Surface	Static	Share of urbanised land	Percentage of urbanised land to a cell's total area	Percent	2000
	Dynamic	New consumption	New urban area in CORINE land cover data	Hectares	1990, 2000
		Conversion of sensitive areas	Ratio of new urban area converted from forest and semi-natural areas, wetlands and water bodies	Percent	1990, 2000
Pattern	Dynamic	Openness	Measures integration of new urban areas into existing urban areas	Index	1990, 2000
	Static	Total Core Area Index	Ratio of summarised core area to urbanised area of a cell	Index	2000
		Jaggedness	Ratio between the perimeter of an urban area and a square of the same size	Index	2000

Table 1: Overview of selected sprawl indicators

We implemented three indicators for the pattern and three for the surface dimension. One pattern and two surface indicators describe processes of sprawl, i.e. they are dynamic. The rest fall under the category "static indicators" as they describe the 2000 situation only.

The "share of urbanised land" is a simple percentage of a cell's area that is classified as urban in the CORINE land cover nomenclature. Although it might not be considered an indicator for urban sprawl as such, it is the base from which urban development, including sprawl, occurs. It is therefore a "surface" indicator, providing the surface configuration of the research object we analyse.

The second surface indicator ("new urban area consumption") measures the amount of land that was converted into urban use from the base year 1990 to the target year 2000. It is therefore a dynamic indicator that looks at the process of relevant land use change over time. We measure it in hectares for each cell. As with the share of urbanised land, it is not necessarily an indicator for urban sprawl. However, as a main quantitative measure for urban growth it is an important factor in urban sprawl research.

The "conversion of sensitive areas" is also a dynamic surface indicator. It describes the pre-existing land cover conditions where new development has taken place. In detail, it measures the percentage of new urban area that was previously classified as forest and semi-natural areas, wetlands and water bodies. As a surface measurement, it delivers an impact-oriented control variable for urban land use conversion.

The dynamic pattern indicator we present here is called "openness index". It was first conceptualised by Burchfield et al. (2000), based on the assumption that the integration of new developments into the existing urban area compound is more efficient than isolated developments far from existing infrastructures. The index is calculated as the proportion of existing urban area that falls within a 1 kilometre radius of newly developed urban areas, thus depicting the spatial proximity to existing infrastructure and urban services. The "openness index" ranges from 0 to 1, with values closer to 0 showing a lower level of integration of new developments. In contrast, values closer to 1 can be said to be less "open" towards its surrounding land features, i.e. more integrated into the urban fabric. The settlement patterns in the corresponding cells are therefore considered less sprawl-like.

The "Total Core Area Index" introduced by McGarigal and Marks in 1994 compares the summarised core area of a cell to the total urbanised area. The core area is defined by a 500 meter buffer from an urban area's boundaries, i.e. it follows the boundaries at a 500 meter offset on the inside of the settlement polygon. The index can range from a value of 0 (no core area) to a value close to 1, where the core area covers large amounts of the total settlement area. From a geometric perspective, more compact urban forms will yield a higher core area index. The total core area index summarizes the individual values for the whole cell, thus giving a measure for the compactness of urban forms. In addition, the total core area index will decrease if there are many small settlements with no corea area (core area index of 0), thus giving an indication of the level of centrality for an area. The lack of compactness and centrality are usually seen as aspects of urban sprawl (Galster et al. 2001).

The "jaggedness" indicator (Tinh 2004) sums up the values for all urban area perimeters within a cell, and relates the result to the perimeter of a square of the same size. This measurement concept is derived from the shape-index – also–, and adapted to produce summarised shape index results for all urban areas within a cell. The more an urban area resembles a compact geometric form (square, circle, hexagon), the lower the indicator value will be. In general, lower results are therefore an indication for the presence of compact urban forms, with less negative sprawl-like settlement patterns. Higher values, in contrast, appear where settlements have irregular shapes. These are generally considered to be served less efficiently by urban services and infrastructure, and thus classified as "sprawling".

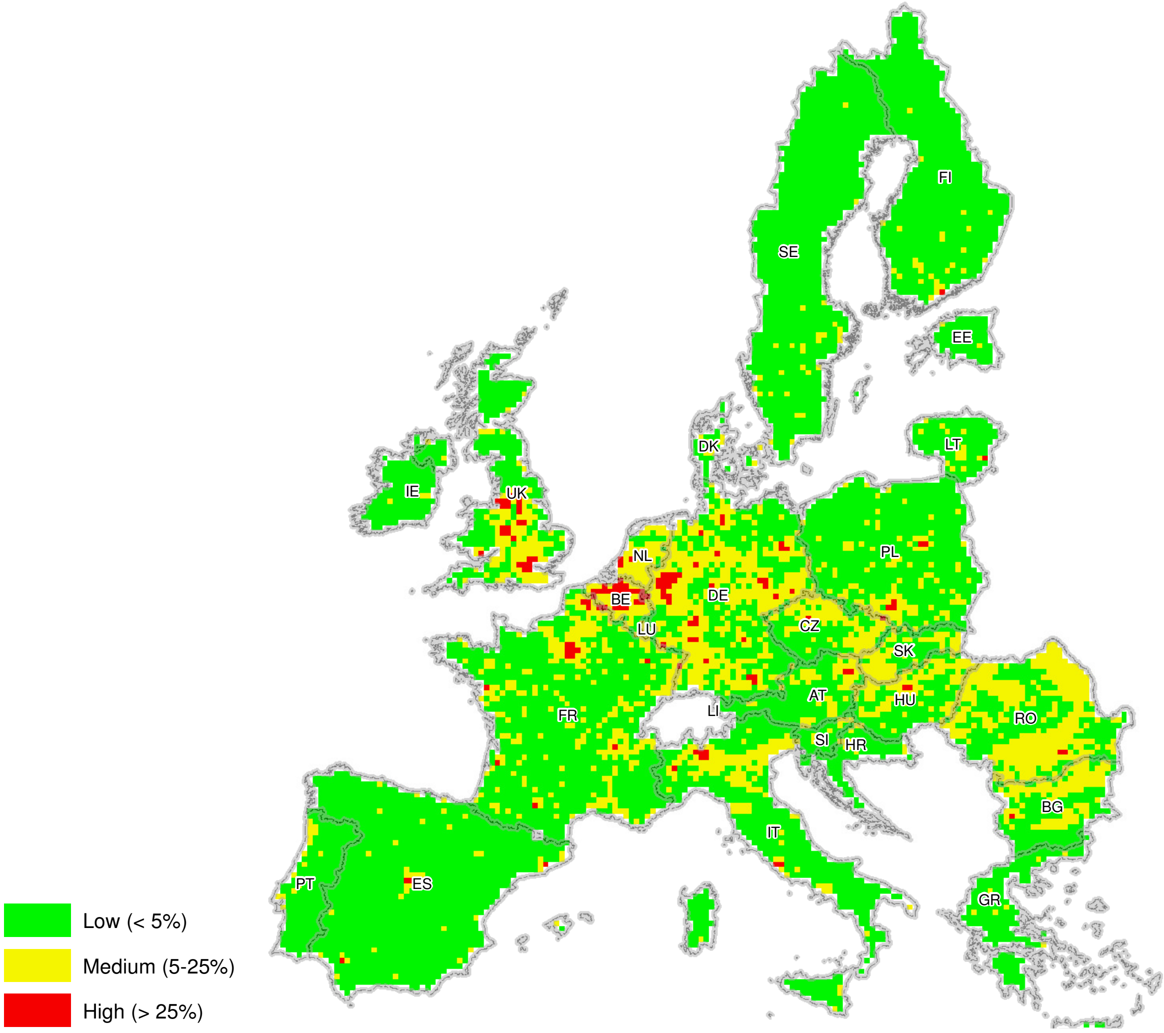
4.3 Methodology

Geographic Information Systems (GIS) were fundamental in analysing land cover data, and in the calculation of the indicators as described above. CORINE land cover data provides continuous features for 26 European countries. Accordingly, the data volumes are quite large. All methods for data extraction and processing needed to take processing time and efficiency of geoprocessing routines into account. As mentioned above, we used a reference grid for analysis. This polygon layer contained 20 x 20 km squares for the land area of the studied countries. All outputs for indicator calculations were then scaled to this grid. As most of the indicators used land area as a reference, all cells covering sea were removed from the analysis layer. This had the side effect that some main urban centres could not be considered in this analysis. The methods for the calculation of indicators were adjusted from textbook formulaes to GIS compatible attribute functions. The final results of our analysis were then visualised as maps, using standardisation and normalisation techniques where appropriate. In some cases, the calculations produced null values due to missing data. This was especially the case for the dynamic indicators that used new urban area as an input. As a consequence areas without any new urban area are presented with blank cells in the resulting maps.

5 RESULTS

The main results of our studies can be found in the maps on the following pages. Each country that participated in the CORINE project is labelled with the 2-digit country code according to the NUTS classification system. Please note that data for Sweden and Finland on new urban area is not available. The colours in the classification systems are built around a bipolar scale, ranging from green to red. Generally, we used red colours to present urbanised, growth and sprawl like spatial patterns, and greens for rural, non-sprawl and non-growth like values.

The first figure presents the distribution for the indicator "share of urbanised land" for the European Countries that we had land cover data for. As explained above, this indicator gives the percentage of urbanised land within each 20 x 20 km grid. Yellow and red colours show where medium to high shares of urbanised area can be found, green represents shares of less than 5%. The value of this map is to provide the base information for interpreting the indicators that follow. Moreover, it also confirms that CORINE land cover data is suitable to conduct urban area analyis on a European scale. The map is consistent with aerial photography we used as a reference (arcgisonline map server, world imagery, ESRI, 2008). It shows the high shares of urban land in Southern England, Northwestern and Central Europe, Northern Italy, and to some degree also in the Eastern European countries Czech Republic, Slovakia, Hungary, and Romania. Additionally, the main cities are usually red, with some exceptions where individual cities were excluded from analysis due to their proximity to the sea (for example Athens).



Country codes: Austria (AT), Belgium (BE), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU), Netherlands (NL), Portugal (PT), Spain (ES), Sweden (SE), United Kingdom UK), Bulgaria (BG), Cyprus (CY), Czech Republic (CZ), Estonia (EE), Hungary HU), Latvia (LV), Lithuania (LT), Poland (PL), Romania (RO), Slovakia SK), Slovenia (SI), Croatia (HR), Liechtenstein (LI)

Figure 1: Share of urbanised land

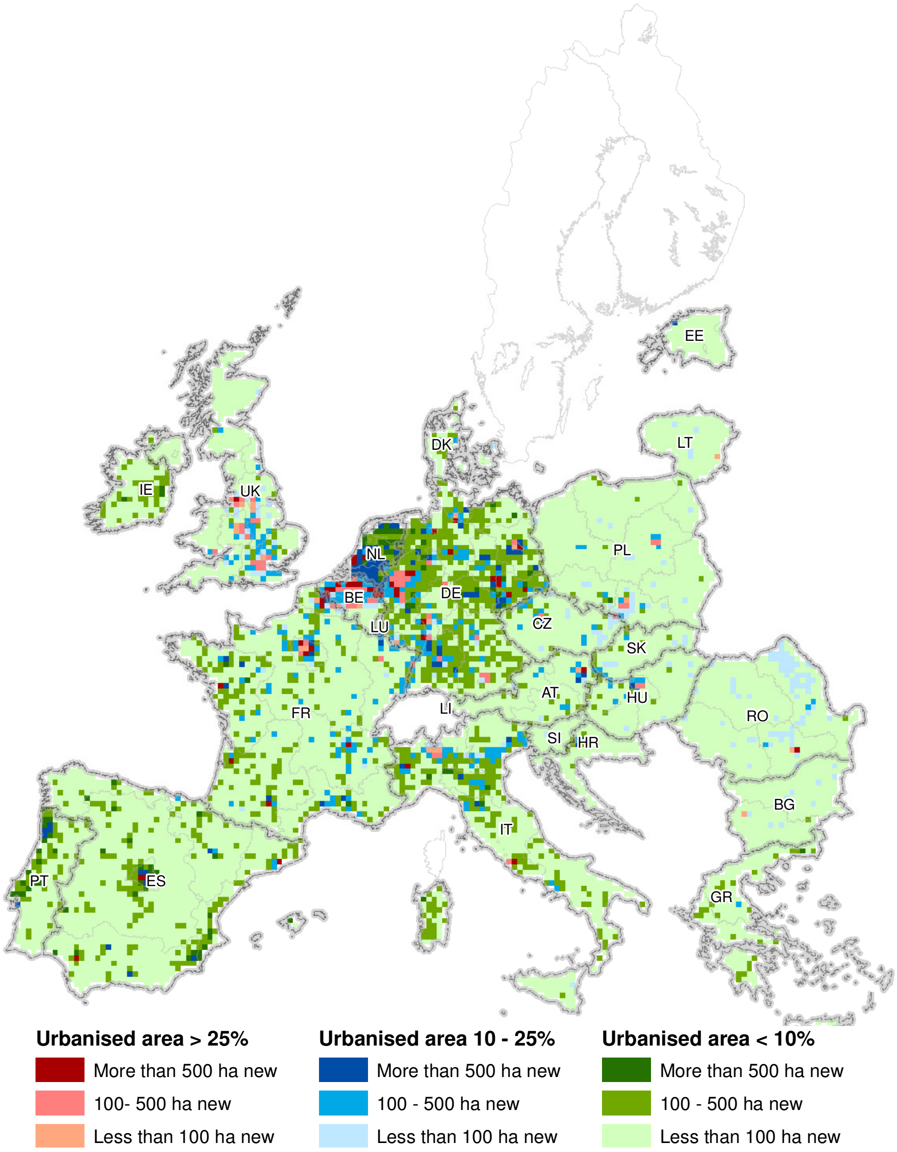


Figure 2: Urban area types

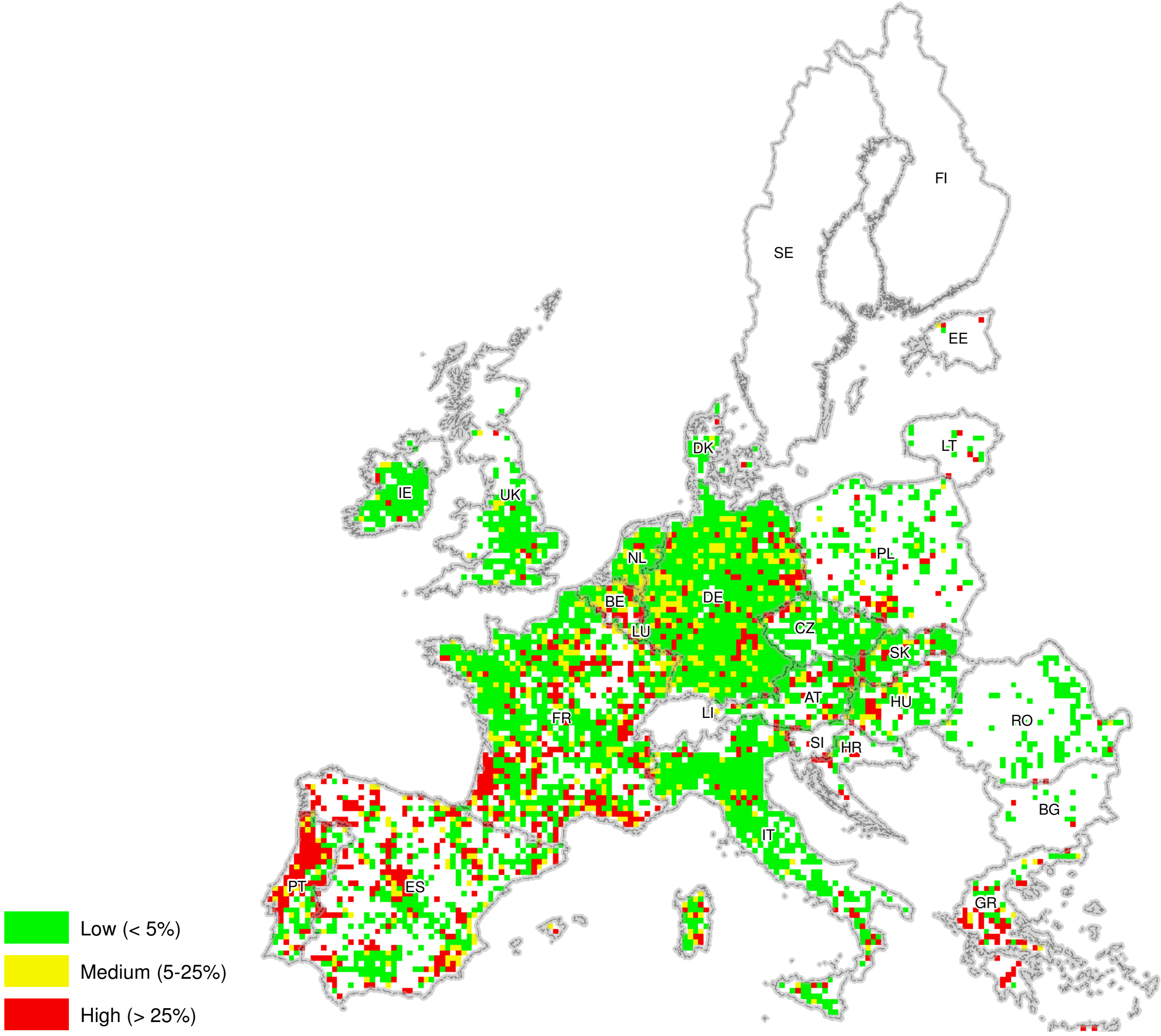


Figure 3: Conversion of sensitive areas

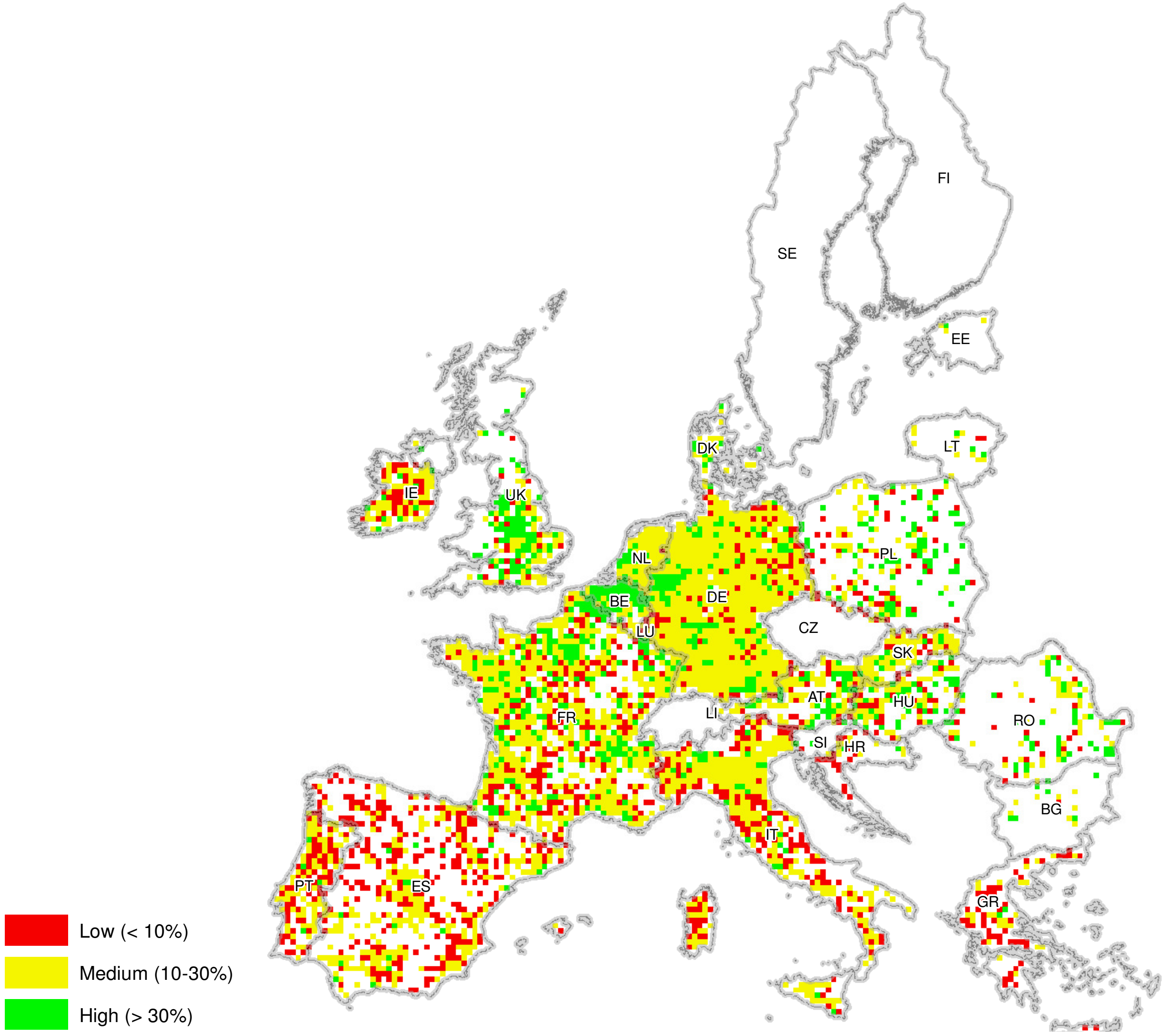


Figure 4: Openness index

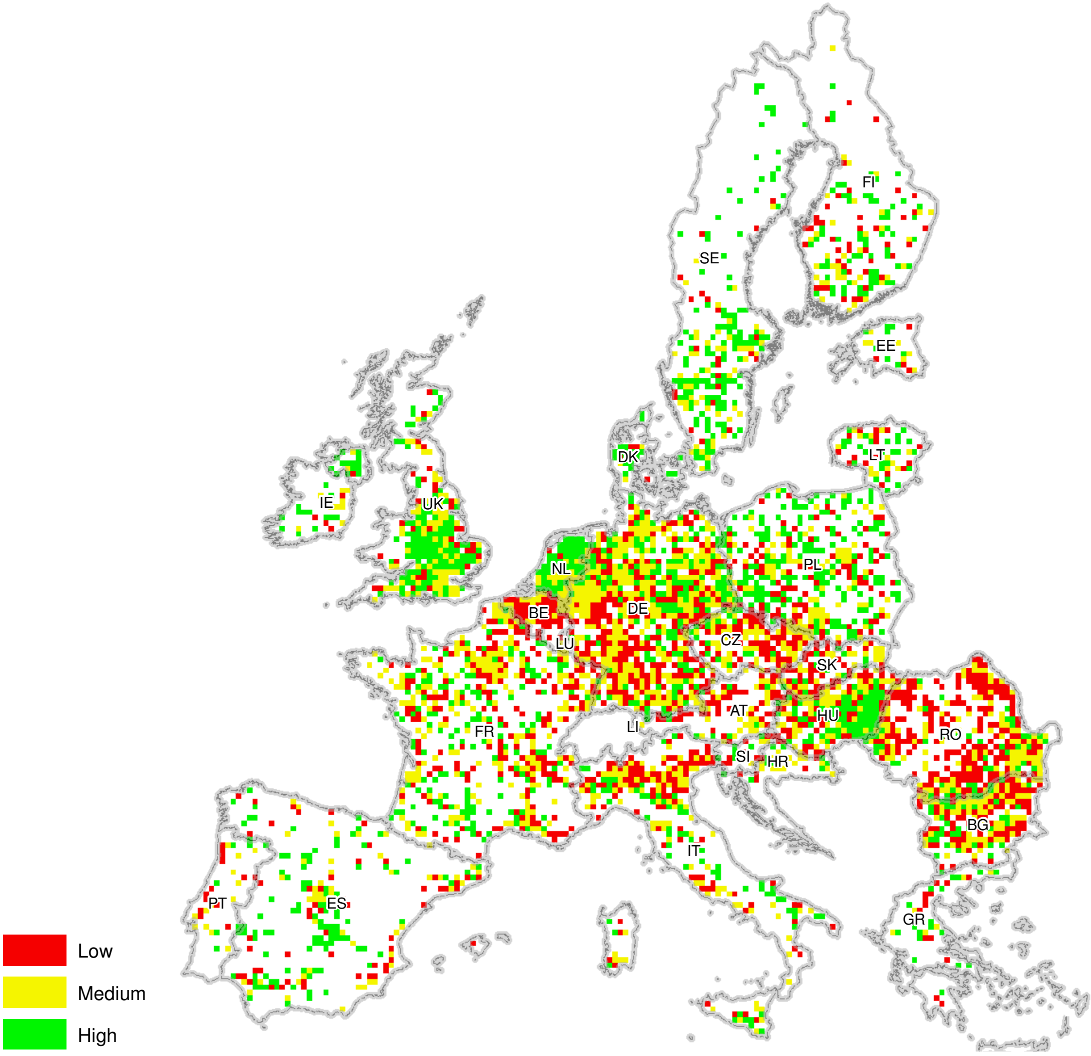


Figure 5: Total core area index as a measure for compact urban forms

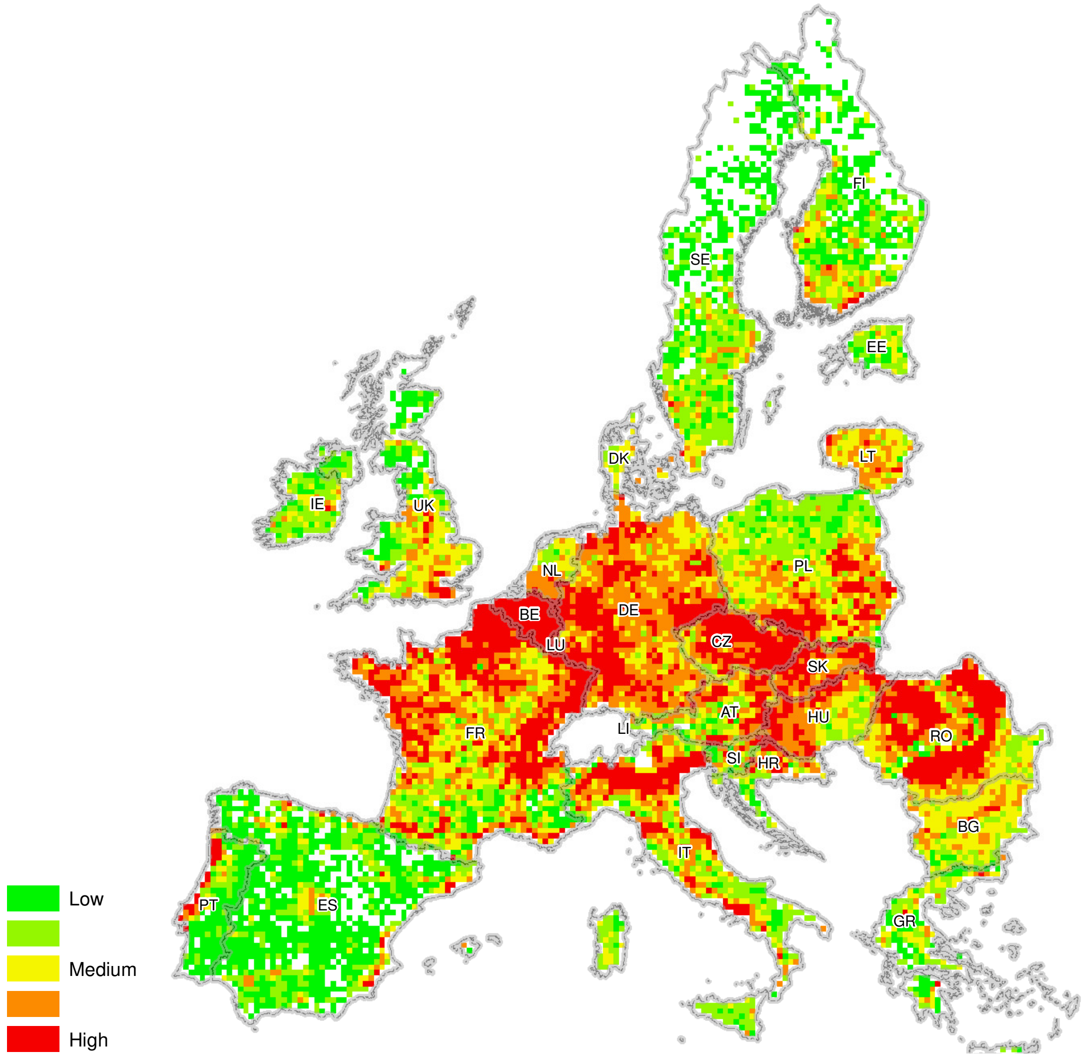


Figure 6: Jaggedness index

The data presented in figure 2 is a composite between "share of urbanised land" and the "new consumption of urban area". This approach provides added value as the static and dynamic aspects of urban area growth can be visualised together. The definition of urban area types based on these aspects helps in interpreting the patterns. We defined three types for share of urbanised area (0-10%, 10-25%, more than 25%), using green, yellow, and red, respectively. The new consumption values are than categorised in three classes (less than 100 ha, 100-500 ha, more than 500 ha), and presented through shading values. According to the resulting distribution, high levels of urban area consumption appear in the Benelux countries, in Germany, Northern Italy, in Spain, and along the Atlantic coast in Portugal. In parts of Belgium, the Netherlands, Germany, and some core metroplitan areas (Paris, Toulouse, Lyon, Madrid, Seville, Manchester, Vienna, Bucarest, Torino, Rome) this new consumption is taking place in the vicinity of the main urban areas (dark red). To the largest degree, however, significant new consumption occured in areas that had less than a 10% share of urbanised area in 2000 (dark green). From 1990 to 2000, particularly Germany, Northern Italy, Portugal, and and in some parts also Ireland, France and Spain had large amouts of new urban area developped in rural areas.

Figure 3 depicts how much of this newly consumed land was previously covered by forest and semi-natural areas, wetlands and water bodies. We consider these types of pre-use ecologically sensitive areas. Prinicipally, the loss of such areas as a result of urban growth is regrettable, more so if these growth patterns are a result of urban sprawl. Due to the lack of urban density data we are not in a position to relate the loss of ecologically sensitive areas to the sprawl context comprehensively. Nevertheless, we present this map as an initial research finding with the stated limitations in mind. As such, there are two marked clusters where more than 25% of the converted area can be classified as sensitive: in large parts of Portugal, and in the Southwest of France (red colours). Other concentrations can be seen along the mediterranean coast in France, in Greece, and also around some large metropolitan areas (Madrid, Berlin, Lyon, Krakow, Budapest).

Figure 4 shows the Openness-Index. As described above, this indicator reflects the level of integration of new urban areas into the existing urban compound. Naturally, the resulting values for this indicator can be expected to be higher in areas with large shares of existing urban area (see figure 1, England, Benelux, Paris, Rhine-Ruhr area in Germany, Warsaw, Vienna, Madrid, Rome, and other urban centres). However, scatter plots showed that low levels of openness do not necessarily coincide with low shares of urbanised area. From a geographic point of view, they appear to be more frequent in Southern European countries, including the south of France, and in Ireland. In the sprawl context, areas with a high openness index are likely to suffer from “leapfrogging” patterns, where new developments are disconnected from the existing urban area.

In figure 5 we present the total core area index as a measure for compactness of settlement forms. For this representation, the calculated values for the total core area index were normalised by the share of urban area for each cell, i.e. the effect of the size of an urban area was eliminated. We also excluded all settlements that did not have a core area according to the definition, thus focusing on what this index has to offer for measuring compactness. The final result highlights three areas that have almost continuously compact settlement patterns: Central England, the Netherlands, and Eastern Hungary (green). In contrast, large parts of Belgium, southwest Germany, Northern Italy, and in Romania have more irregular settlement patterns (red). It is also evident from the map that the Southern European countries had large parts of its area excluded from this analysis, due to settlement patterns that were not large enough to produce a core area with the chosen definition (500 meter offset from the settlement boundary)[2]. In this context, there may be a signficant correlation between settlement size on one hand, and the high openness index for Southern Europe as seen in figure 4. This assumption could not be researched fully within the timeframe of this study.

Finally, figure 6 shows the visualised results for the “jaggedness” indicator. As with the total core area index, this measure mainly aims at quantifying compactness of urban patterns. Due to the calculation it delivers a more concise picture in map format as the total core area index does. At the first glance, the share of urbanised land seems to be a pre-determining factor for the distribution of high jaggedness values (orange, red). However, scatterplots and a more detailed analysis provide evidence that the correlation between the two is not significant, although present. As for low values (green), this indicator confirms what has already been said for the total core area index: that The Netherlands, and some parts of Hungary have distinctly compact settlement forms. It also confirms that settlement patterns in Southern Europe are very compact as well. However, the jaggedness indicator also reveals an obvious exception to this observation along the coasts of Portugal, Spain, France, and Italy, where high values are present. In terms of medium ranged values we found that a more refined classification system with five classes provided additonal insights. For example, the jaggedness values in Central Europe are quite diverse. The highest values are concentrated along semi-circles running from Belgium, Southwest Germany along the French Rhone valley to the Mediterranean Sea. Another cluster is evident around the Czech Republic, including the South of Saxony in Germany, Western Slovakia, and the areas around Krakow (Poland), Vienna (Austria), and some parts of Croatia. Northern Italy is another cluster of high values, as is most of Romania except the Carpathian Mountains and the coastal areas west of the Black Sea. Urban forms in the north of Poland and in the largest parts of Scandinavia are very compact. As for the Baltic states, Lithuania appears with higher values than Estonia.

Figure 7 summarises the two impact dimensions we have discussed in this paper. Each of the indicators contributed with its most urban sprawl- or growth-like features towards the classification in this map. According to this, surface sprawl / growth is particularly evident in Spain, Greece, and The Netherlands. Pattern sprawl is significant in the Benelux countries, in some areas of England, Germany, France, Poland, Austria, and Hungary. Overall, we identify these areas to be risk areas for urban sprawl for future research to focus upon.

[2] This is a result that we found confirmed by the calculation of the patch density index. This index measures the number of patches (settlements) and compares it to the amount of urbanised land. Due to the limited length of this article, we have not included patch density as a map.

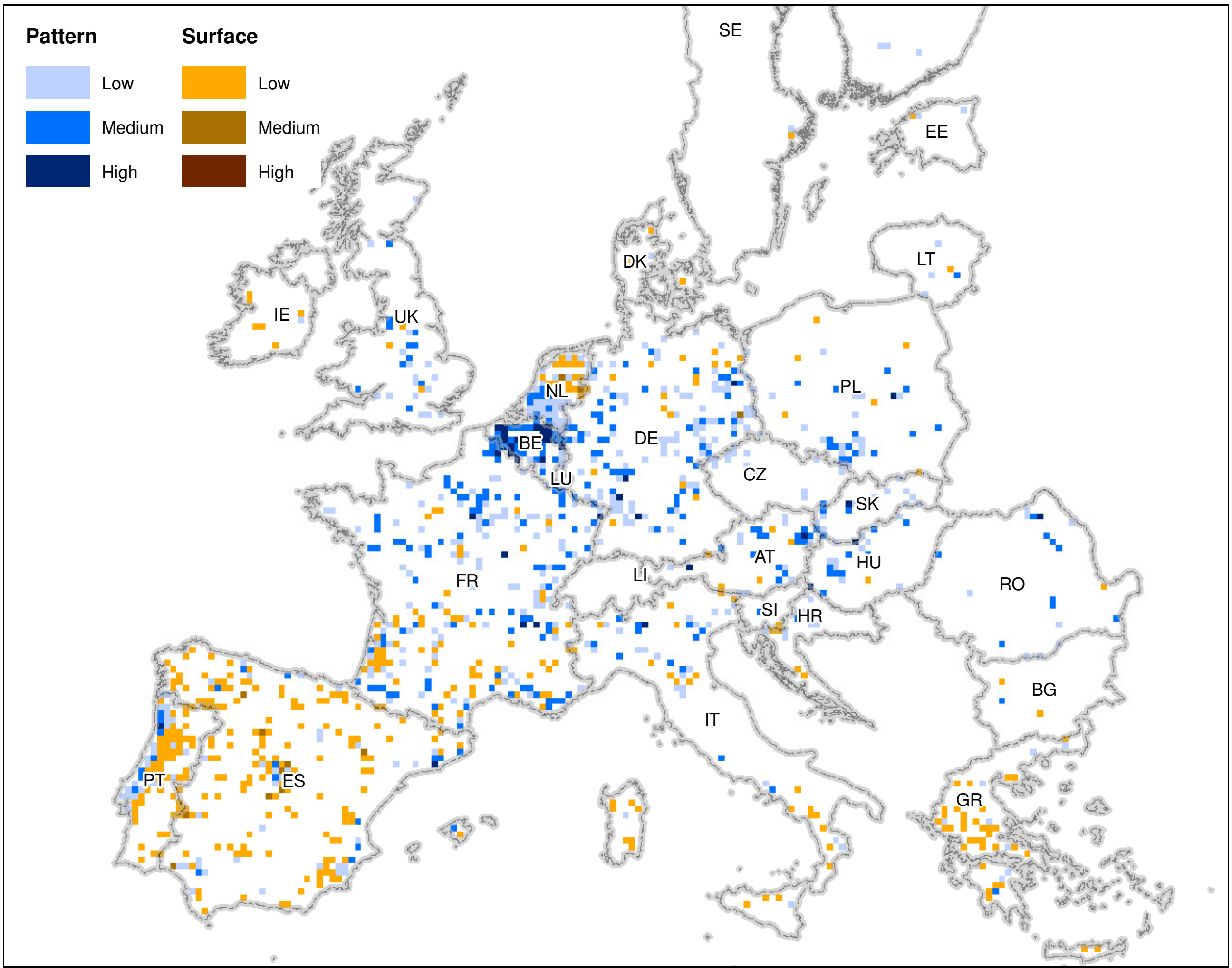


Figure 7: Focus areas for urban sprawl research (areas with the highest values of pattern / surface–related urban sprawl indicators)

As a final remark for this chapter we would like to acknowledge some of the inherent difficulties in the interpretation of our results. Firstly, we are aware that the methodology could be enhanced with statistical analysis procedures. The results show that an in-depth analysis of the correlative effects between variables is required. Initial tests with simple normalisation techniques were not conclusive. We therefore suggest further research using factor analysis, and in a next step an evaluation of each indicator to produce robust, dimension-specific measures for urban sprawl.

6 CONCLUSION

Our maps presented in chapter 5 display areas with an "above average risk" of adverse land use related impacts. Areas with a high share of urban land experience significant hydrologic and mesoclimatic changes (excessive urban runoff, heat island effects) due to the spatial concentration of impervious surfaces. These areas are also characterized by a scarcity of valuable open space – both in absolute terms and per capita – and a quantitative loss of prime agricultural land and wildlife habitats. Regions or subregions with an irregular, dispersed and discontinuous urban form may be affected by a reduced efficiency of public transport systems and urban infrastructures (roads, water supply, sewer systems) and a higher per capita energy consumption (as an effect of larger travel distances). Furhtermore, areas with significant "pattern sprawl" as indicated in figure 7 witness higher risks of threats to endangered species due to landscape fragmentation and the high level of habitat disturbance.

At the same time, our analysis depicts "success stories" of implementing sustainable land use policies across the European Union. Examples refer to the relatively compact urban form and growth in parts of The Netherlands and the United Kingdom notwithstanding a high level of population density and urbanisation in both countries. Figure 3 gives evidence of a significant South-North divide in the use of ecologically sensitive areas for urban purposes. More effective or established landscape planning schemes and higher standards of environmental impact assessement in Northern Europe may explain this observation.

Furthermore, the relatively low degree of urbanisation in large parts of Scandinavia, Spain, Greece, Scotland, Ireland and southern Italy must be seen as an important ecological resource to be carefully managed in the future.

The measurement concept presented in this paper creates a methodological framework for evaluating the success of future land use policies and landscape protections programs. We deliberately avoided developing a composite sprawl index that aggregates the impact dimensions discussed above. The problem we see is that different sprawl indicators tend to outweigh each other in the process of aggregation. Therefore we recommend the use of dimension related sprawl types attributed with a specific profile of environmental and economic problems (see figure 7). Taking this into account, type-specific anti-sprawl strategies and instruments could be implemented.

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