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Towards sustainable development exemplified by monitoring land use efficiency in Europe using SDG 11.3.1

Abstract
Monitoring land use efficiency (LUE) is of great importance for the sustainable development of each country. The identification of regions where land consumption prevails over demographic growth should prompt public administrations to act and establish a recovery programme. This paper took Europe as the research area, and CORINE Land Cover and statistical population data to assess changes and spatial diversity of the LUE status from 2006 to 2018. Results show that, during the 2006–2012 period, LUE was more diversified than in 2012–2018. The differences concern both values of the indicator and the spatial differentiation between regions. Between 2012 and 2018, the number of countries moving towards efficient land use doubled compared to 2006–2012. Great progress towards achieving SDG 11.3.1 was seen in Portugal and Germany, and almost all Balkan countries are moving towards more efficient land use.

Keywords
SDG 11 • population growth • land consumption • urbanization • spatio-temporal analysis • LUE

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Introduction

Sustainable development is a paradigm that shapes the development of many countries and regions in the 21st century. The idea of sustainable development – that is, thinking about the future environment, society and economy that balance the pursuit of development and improvement of the quality of life – has been of key importance since 1987 when the World Commission for Environment and Development presented its report 'Our Common Future' (UN 1987). The UN Report defines sustainable development as development that 'seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future'. Pieloch-Babiarz et al. (2021) noted that it is the most common definition, despite many critical comments regarding its vagueness and interpretation difficulties. The problem of sustainable socio-economic development has become so important that in 2000 at the UN summit in New York, eight Millennium Development Goals were defined, which should have been achieved by member states by 2015, among them goal 7 – 'Ensure Environmental Sustainability' and target 7.A – 'Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources' directly refer to the sustainable development definition given by the report 'Our Common Future'. Fifteen years was too short a period to solve all the problems listed in the MDGs; therefore, in 2015, at the UN summit in New York, the 2030 Agenda for Sustainable Development (2030 Agenda) was adopted, and 17 Sustainable Development Goals were defined (UN 2017). One of the goals of the 2030 Agenda, namely goal 11, is related to the sustainable development of cities and settlements. Achieving this goal is especially important considering that the modern world is urbanized, and urbanization as a complex and continuous process has for years been the main trajectory of land cover changes around the world – changes that generally do not lead to sustainable development (Gerten et al. 2019; Keil 2018; Bielecka 2020). Scientists and environmental protection agencies have long warned that urbanization is irreversible, leads to landscape fragmentation, reduces the potential of ecosystems to provide ecological services (Antrop & Eetvelde 2000), causes irreversible loss of fertile soil (EEA 2018), contributes to climate change and, socially, to the deterioration of the living conditions and health of the population (Easterlin et al. 2011). However, urbanization should not be solely perceived in terms of negative and irreversible effects on the environment. Urban expansion is inextricably linked with population growth and migration to cities, and is thus an engine of economic growth and poverty reduction (Shaker 2015). An analysis of urban expansion conducted by the OECD indicated the ever-growing importance of urban areas in the economic development of regions (OECD 2011).

The SDG 11.3.1 indicator (marked as LCRPGR or LUE) seeks for balanced growth of urban areas and population counts by calculating the ratio of the land use rate to the population growth rate. The indicator is defined by the very general methodological framework given by UN-Habitat (UN 2021) in metadata. Metadata describes components of the indicator, namely the land consumption rate (LCR) and population growth rate (PGR), provides an explanation of newly built-up (developed) areas, gives key data sources, a formula for index calculation, and a reporting procedure. The rationale for undertaking this research lies in the lack of official LUE monitoring statistics in Europe at the country level. Instead, Eurostat reports the settlement area per capita (Eurostat 2021). The main research question in relation to the SDG 11.3.1 indicator concerns diversity and variability over space and time, and in particular the trajectories of land use change as a function of population and developed land changes. Research issues concern the trend of the of LCR, PGR, LUE indicators' values over the years 2006–2012 and 2012–2018, the spatio-temporal pattern, and regional disparities in the implementation

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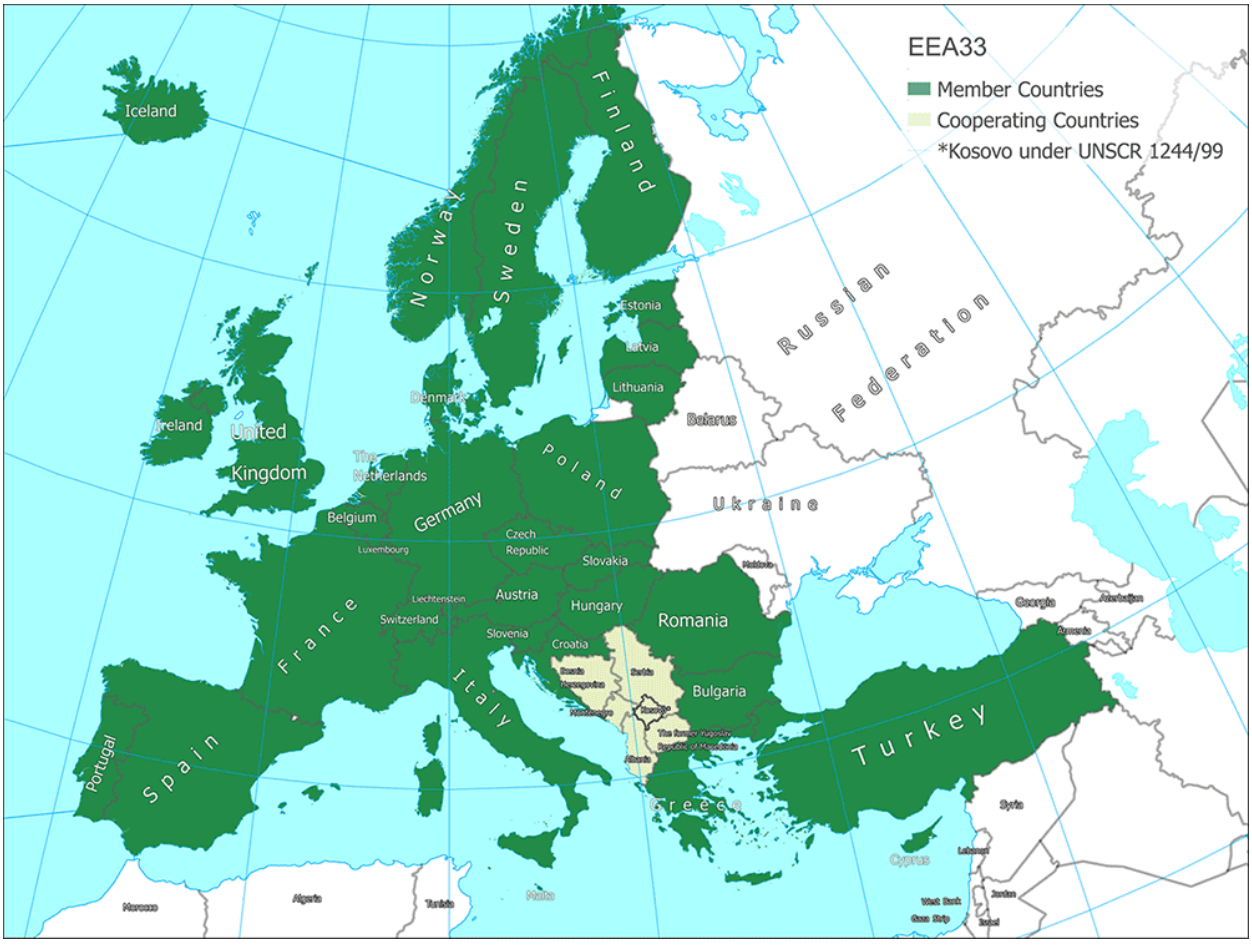


Figure 1. Research area
Source: EEA 2018

of SDG 11.3.1, using cartographic modelling supported by spatial analysis and statistical reasoning. Furthermore, the challenges of determining LUE due to established methodological framework is discussed. The presented result of SDG 11.3.1 monitoring in Europe is demonstrated for the first time and will therefore benefit researchers, planners and policymakers who thoroughly analyse a country's progress. The outcomes are based on open and publicly available data – namely, population statistics and CORINE land Cover datasets.

Data and methodology

Data collection and research flowchart

The empirical investigation of SDG 11.3.1 comprises 39 Eionet (European environment information and observation network) countries, both member (32 nations) and cooperating (seven nations) countries (Fig. 1).

Information on urbanized areas was derived from the CORINE land Cover (CLC) datasets of 2006, 2012 and 2018 via Copernicus Land Services. The population counts at the country level referred to the years 2006, 2012 and 2018, and were obtained from the Eurostat web page. The countries' boundaries (NUTS 0) at the scale 1:60,000,000 came from CISCO data repository maintained by the Eurostat.

The methodological framework of cartographic modelling was the basis of LUE computing, analysis and mapping. Cartographic modelling provides a standardized procedure for data integration, spatial operations, and analyses, along with the results visualization in the form of thematic layers, maps, tables and reports by means of GIS tools. The study was conducted in four consecutive phases (Fig. 2).

Phase 1 comprised data acquisition and pre-processing, including selection by attributes of artificial area from CORINE Land Cover (land cover type indicated as the artificial surfaces at the level 1), overlay analysis of CLC artificial surfaces and countries' polygon, and spatial join with descriptive population data. Phase 2 relied on LCR, PGR, and LUE computation according to the formula given in the next section, while statistical analysis of data trends (the Mann-Kendall *tau*), statistical dispersion (i.e. standard deviation, interquartile range, variance to mean ratio), and spatial pattern by Global Moran's I was undertaken in phase 3. Finally, in phase 4, the results were presented in the form of choropleth maps.

Methodological framework

The LUE indicator is calculated using the formulas 1–3:

$$\mathrm{LUE} = (LCR)/(PGR) \quad (1)$$

$$\text{Land consumption rate: } LCR = (ln\frac{B_{t+n}}{B_t})/\mathrm{t} \quad (2)$$

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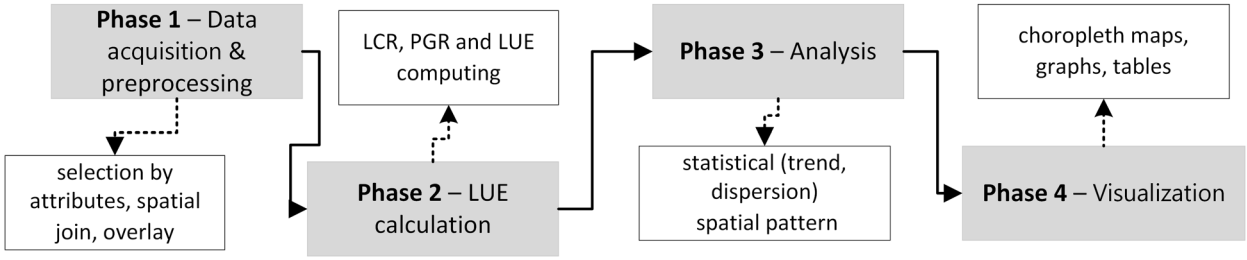


Figure 2. Flow diagram of the cartographic modelling approach to LUE calculation
Source: authors' elaboration

$$\text{Population growth rate: } PGR = (ln\frac{Pop_{t+n}}{Pop_t})/t \quad (3)$$

where: *ln* denotes the natural logarithm; B_{t+n} B_t indicate the built-up area in the final year and initial year of the measurement, and Pop_{t+n} and Pop_t specify the total population within the built-up area in the final and initial year; while *t* defines the number of years between the final and initial years, LCR indicates built-up area enlargement, and PGR illustrates the changes in demography.

LUE equal to or lower than −1 implies inefficient land use; a level in the −1<= LUE <0 and above 1 range, it is moving away from efficiency; while in the range of 0< LUE <=1, it points to efficient land use or moving towards efficiency. SDG 11.3.1 is achieved when land use and population growth rate are in balance, as indicated by a LUE value close to 1 (Melchiorri et al. 2019; Calka 2021).

The Mann-Kendall *tau* examines whether the regular time series show monotonic upward or downward trends. It is an inferential statistic, where the null hypothesis: H0: ô = 0 states that there is no observed trend between analysed data series. An alternative hypothesis is tested for HA: ô < 0 or HA: ô > 0. The Kendall *tau* is calculated based on numbers of concordant and discordant pairs based on formula elaborated by Brossart at al. (2018):

$$\tau = \frac{n_c - n_d}{\frac{1}{2}n(n-1)} \quad (4)$$

where: n_c, n_d denote the number of concordant and discordant pairs, respectively, and *n* indicates the total number of observations in the series. The τ values are bound between −1 and +1; negative values of τ implies that the data series are inversely related (negative monotonous), while positive values show positive monotonous relations.

Statistical dispersion was analysed by standard deviation (σ), interquartile range ($IQR=Q_1-Q_3$), and variance to mean ratio ($VMR=\sigma^2/\mu$).

The geographical pattern of the countries' LUE value was investigated by Global Moran's I statistics, which measures spatial autocorrelation based on feature locations and feature quantitative values concurrently throughout a whole dataset. The null hypothesis of complete spatial randomness says that the attribute being investigated (LUE values) is randomly distributed among the features (countries) in the whole study area. A detailed description of Global Moran's I is given in ESRI ArcGIS Help or in Moran (1950).

The geovisualization of the results was the final stage of the research. Choropleth maps with six class intervals were adopted to portrayal the land use efficiency in Europe in the analysed periods. Class 1 takes LUE values greater than or equal to 2, emphasizing that the LCR is twice the PGR, while class 2 represents an LUE in the range (1, 2] showing the LCR slightly greater than the PGR. Class 3, with index values in the range 0 < LUE ≤ 1, indicate a population growing at a higher rate than the built-up area. Classes 4–6 present decreasing population, with −1 <LUE ≤ 0 (class 4) showing the negative pace of population is faster than built-up area rate; class 5 and 6, with −2 < LUE ≤−1 and LUE ≤ −2, where the negative pace of population or slower than the built-up rate. The colour scheme was chosen so that warm (orange–red) colours indicate faster population growth than built-up areas, while cold (blue) colours indicate that LCR is preferred over PGR.

Results

Statistical analysis

Both the PGR and LCR show monotonic upward trends, with the Mann-Kendall *tau* equal to 0.800 and 0.247 (with significance p ≤ α = 0.05) for two consecutive analysed data series (2006–2012 and 2012–2018), which results in a similar trend in the LUE data series (*tau* = 0.570, p ≤ α = 0.05). A decline in the population growth rate in both periods was observed in 14 countries, 13 of which belong to Central and Eastern Europe. Changes in land consumption pace were also small; the country average annual increase in built-up land in 2006–2012 was 67.8 km^2, while in 2012–2018, it was 16.6 km^2. Selected measures of descriptive statistics show the greater statistical dispersion of the LUE values in 2006–2012 than 2012–2018 (Table 1). In the years 2006–2012, the standard deviation is more than twice as high as in the years 2012–2018, and the quartile range is even four times higher. Also, VMR indicates a greater degree of LUE disparity in 2006–2012 than 2012–2018, taking the value of 145.96 and 129.62, respectively.

In both analysed periods, LUE values reached extremes in five countries: in 2006–2012, they were Portugal, Poland, Greece, Bosnia and Herzegovina, and Croatia; in 2012–2018, they were Poland, Estonia, Spain, Macedonia and Montenegro. Very slight decreases in the rate of land consumption were recorded in Finland, Ireland and San Marino, which, with modest population growth, suggested a trajectory of compacted land change and synergies between the country's development policy and the EU's 'no net land take by 2050' strategy (COM 2011). Former post-communist countries, both Central European and Balkan, were characterized by a decline in the number of inhabitants with a large increase in the built-up area, which ultimately indicated that the country's development policy, supported by EU funds, was not fully in line with the Efficient Europe strategy. However, changes in the LUE between 2012 and 2018 finally suggested some trade-off between national and EU development policies. The remaining countries are characterized by both population and built-up area growth, indicating a sprawl-type development trajectory, also

Vol. 26 • No. 4 • 2022 • pp. 208-214 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2022-0015

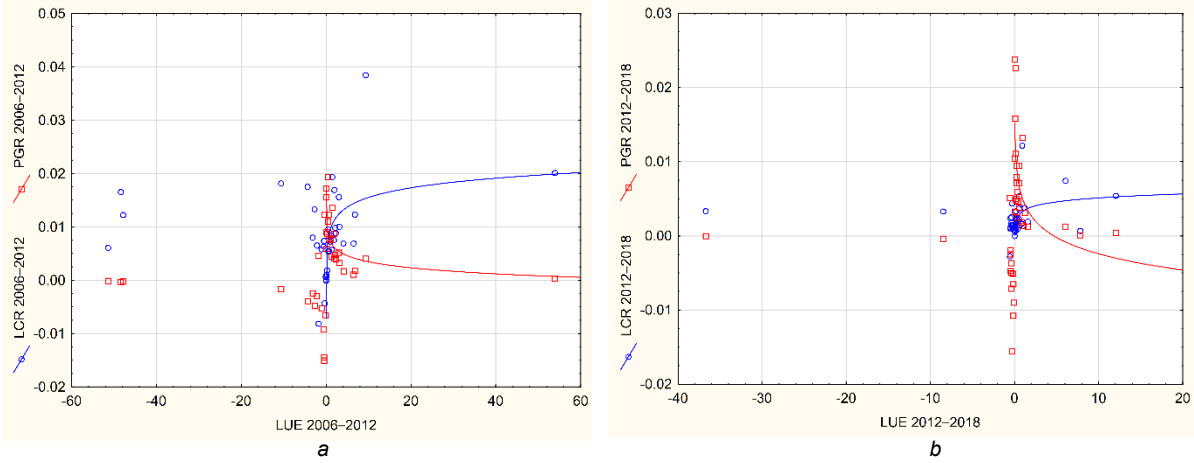


Figure 3. Relation of LCR and PGR to LUE 2006–2012 (a) and 2012–2018 (b)
Source: authors' elaboration

Table 1. LUE statistical parameters

Statistics	LUE 2006–2012	LUE 2012–2018
Mean	−1.88	−0.34
Median	0.22	0.15
Minimum	−51.38	−1.11
Maximum	53.95	12.05
Q1	−1.11	−0.28
Q3	1.95	0.57
Range	105.33	48.77
Quartile (Range)	3.06	0.85
Std.Dev.	16.57	6.63
Variance to Mean VMR	145.96	129.62

Source: authors' elaboration

Table 2. Number of countries in particular LUE classes

LUE	Number of countries	
	2006–2012	2012–2018
LUE≤−2	8	2
−2<LUE≤−1	2	0
−1<LUE≤0	6	13
0<LUE≤1	9	18
2≥LUE>1	5	3
LUE>2	9	3

Source: authors' elaboration

quite distant from the EU strategy. The dependence of LUE on LCR and PGR is shown in Figure 3.

Geographical distribution

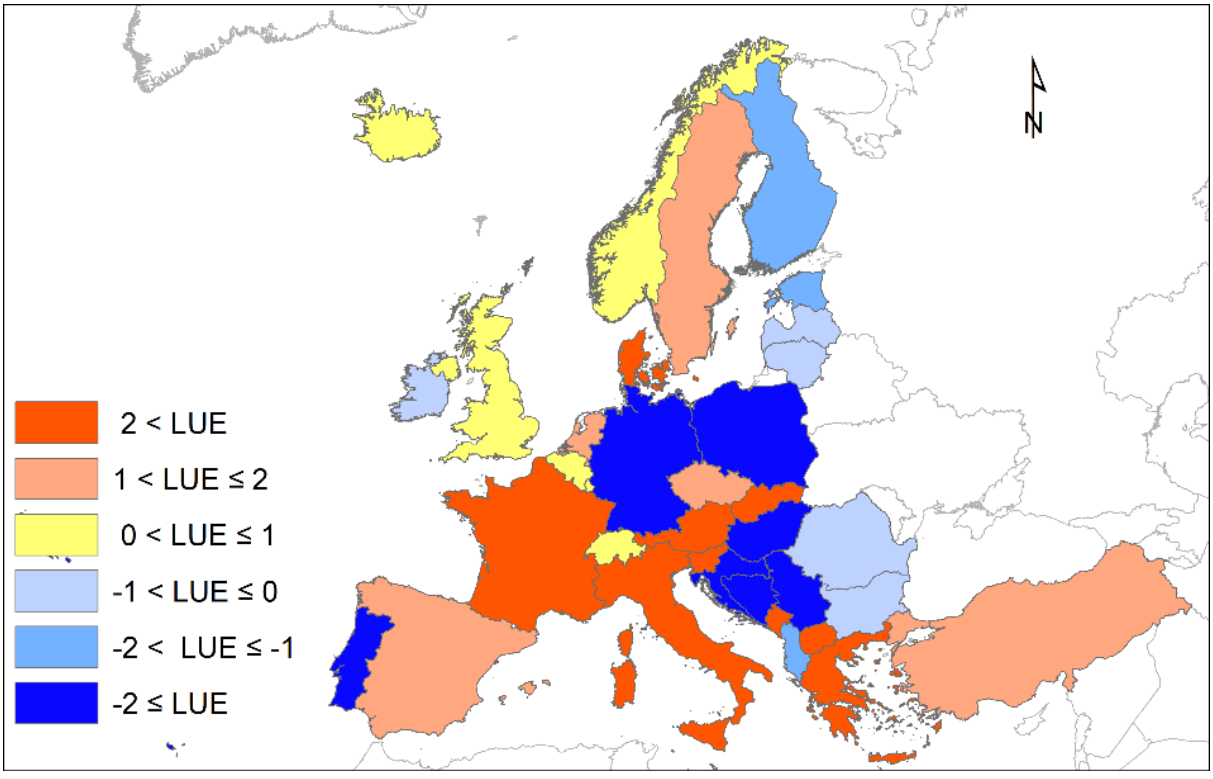
Considering all 39 analysed countries, the Global Moran's I analysis shows that in both periods the spatial pattern of land use efficiency in the areas of nations did not appear to be significantly different from the random one, yielding the z-score of 0.0367 (p-value: 0.97069) in 2006–2012 and 1.266 (p-value: 0.205549) in 2012–2018. Also, the land consumption rate showed a random distribution, while the population growth ratio in both periods revealed a cluster pattern, with a z-score of 5.578 and 4.422 (p-value: 0.00001), successively.

In 2006–2012, the land efficiency index reached a value close to 1 in Liechtenstein (0.96) and Sweden (1.07), and in 2012–2018 in Turkey (0.92) and Slovenia (1.03), indicating significant land use efficiency, with a comparable increase in land consumption and population growth rate. As many as eight countries made little progress towards efficiency (LUE <−2 in 2006–2012); in 2012–2018 there was still an insufficient increase in urbanized area in relation to population growth, although it was less than in the period 2006–2012 (Table 2). Relatively large progress in achieving SDG 11.3.1 was observed in Portugal and Germany (see Fig. 4). Almost all Balkan countries are moving towards more efficient land use. Poland was characterized by an increase in urban areas and a decline in population, which manifested itself in ineffective land use. Estonia showed both a PGR growth and an LCR reduction, which indicates an insufficient increase in built-up area in relation to population growth, with the result that the LUE values for both periods were below −2. Therefore, both countries are shown in the choropleth map in dark blue (Fig. 4).

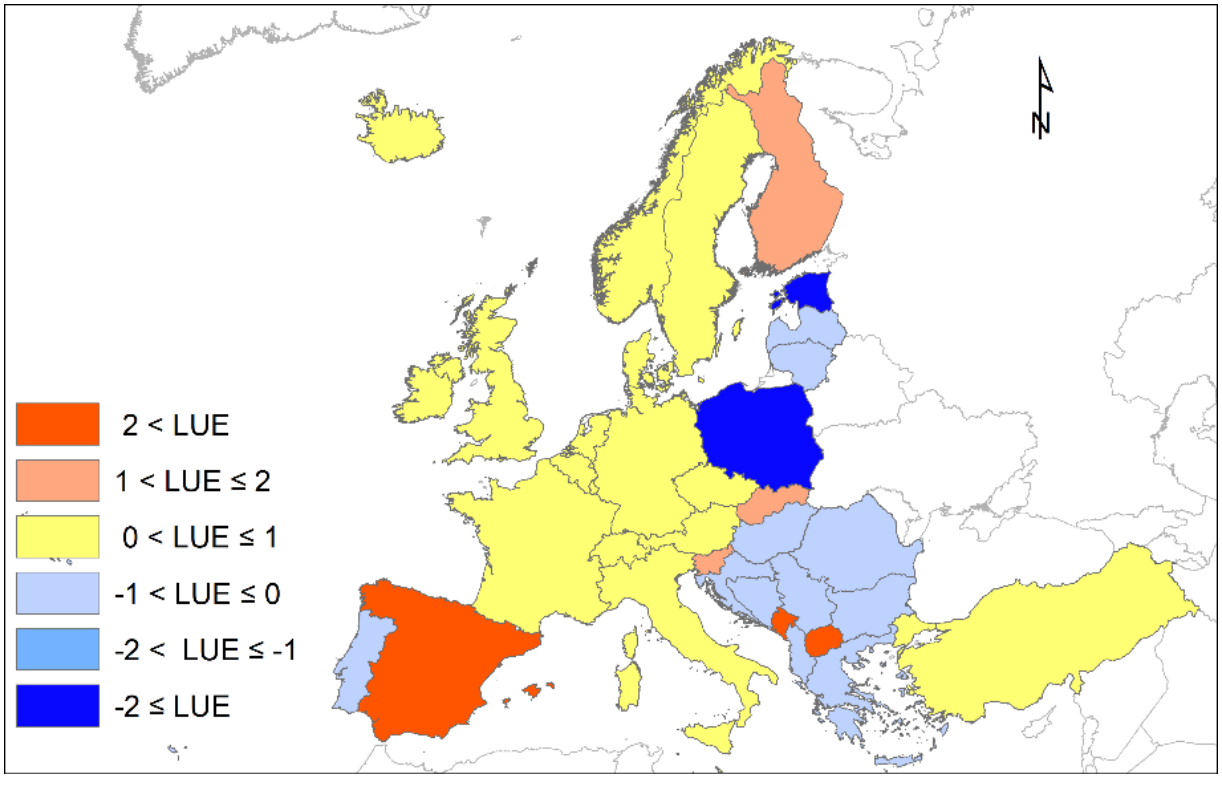
Discussion

The LUE indicator is directly related to geographic space; therefore, geographic datasets are required for land cover and spatial distribution of the population. The UN-Habitat has classified SDG 11.3.1 indicator to Tier II, which means that the methodology for indicator calculation is established, but data for some regions may be unavailable, unreliable, or have insufficient spatial resolution. Moreover, there is some confusion about the definition of the built-up areas covered by SDG 11.3.1 as there is no consensus on its definition yet. Further problems are related to the LUE calculation formula – when the PGR is set to 0 (no change in the analysed period), the LUE value is undetermined.

Vol. 26 • No. 4 • 2022 • pp. 208-214 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2022-0015



a) 2006–2012



b) 2012–2018

Figure 4. LUE values in 2006–2012 (a) and 2012–2018 (b)
Source: authors' elaboration

Vol. 26 • No. 4 • 2022 • pp. 208-214 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2022-0015

An attempt to solve this issue is given in the studies of Calka et al. (2022).

Compared with other regions, Europe is characterized by good access to data on land cover and spatial population distribution. In this regard, fine-scale data with six-year temporal resolution is commonly available from the global, raster land cover products, namely CORINE Land Cover vector. And even though researchers report some confusion about the methodology of land cover classes delineation, the CLC datasets are still widely used in many urban-related applications (Cieślak et al. 2020), including LUE monitoring (Nicolau et al. 2019). In terms of population data, Europe is also covered by many gridded datasets, with both worldwide and European geographic coverage with the spatial resolution of 1 km. Only recently the European Joint Research Centre has released a detailed (up to 250 m) dataset on the spatial distribution of the gridded population (GHS-POP) and the Global Human Settlement Layer (GHSL) depicted urban area. Both datasets cover the years 1975, 1990, 2000 and 2014; therefore, no up-to-date datasets on a fine scale are available yet.

The availability and quality of data needed to monitor land use efficiency is widely discussed in the literature. Researchers noted that the SDG 11.3.1 values depend on the data used (Nicolau et al. 2019), which, linked with the various monitoring periods, makes the results incomparable. At the global level, this was discussed by Melchiorri et al. (2019); it was also considered at the national (Schiavina et al. 2019), regional (Cai et al. 2020), and local (Wiatkowska et al. 2021; Sharma et al. 2012) levels. Furthermore, Akuraju et al. (2020), based on analysis carried out in 1990–2006 for selected European counties, found that 'association between the scaling and the country-wide area growth rate to population growth rate' is not seen.

Finally, the complex nature of the SDG 11.3.1 indicator should be emphasized. This is because the 2030 Agenda is seen as a system of interacting elements that is more than a collection of goals, targets and indicators. Achieving land use efficiency contributes to monitoring some other goals. Sustainable population and urban growth make a positive impact on water quality (goal 6), affordable access to clean energy (goal 7) and, consequently, on climate change (goal 13).

Conclusions

Undoubtedly, urbanization has a substantial impact on land use efficiency. Hence, LUE monitoring is of utmost importance in supporting decision-making and promoting land use in an efficient way. Although SDG 11.3.1 is defined in the official UN document, the conceptualization of its calculation is not yet clear enough.

It was noticed that European countries are characterized by considerably varying population and urbanization. The analysis of LUE revealed that, in the analysed periods, land use change and population growth were not aligned. Although built-up areas are generally growing faster than the population, some countries are not following this trend, more notably Poland and Estonia. Moreover, in 2006–2012, land use efficiency varied more than in 2012–2018, which clearly indicates that more efficient land use is underway.

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Vol. 26 • No. 4 • 2022 • pp. 208-214 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2022-0015

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