Land Use Efficiency in Poland: A Change Analysis from the Point of View of Sustainable Development Goals

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Key words: land use efficiency, sustainable development goals, LUE

SUMMARY

Sustainable development represents a guiding principle for the advancement of numerous countries and regions in the 21st century. It emphasizes the need to consider the long-term wellbeing of the environment, society, and economy, to ensure a balanced approach to progress and the enhancement of living standards. Identifying areas where land consumption exceeds demographic growth encourages public authorities to initiate recovery strategies. This study focuses on Poland as the case study, based on data about land use from Central Statistical Office data alongside population statistics to analyze shifts and regional variations in land use efficiency from 2007 to 2021. The assessment was based on the SDG11.3.1 indicator, which evaluates the ratio of land consumption rate to population growth rate (LUE). The findings reveal that land consumption patterns were more varied during 2007–2014 compared to 2014–2021. These variations pertain both to the indicator values and the spatial disparities between regions. From 2007 to 2014, ten out of sixteen regions exhibited a more balanced population increase relative to urban expansion, whereas in 2014–2021, land consumption surpassed demographic growth in twelve regions. The observed trends in land consumption were shaped by efforts under EU and Polish policies aimed at achieving territorial cohesion and fostering the development of less central regions. Rapid urbanization exert significant pressure on natural resources, hindering improvements in living conditions. Therefore, sustainable development requires an alignment between population dynamics and the ecosystem's evolving productive capacity. Ultimately, sustainable development is not a static state of equilibrium but an ongoing process of adaptation, where resource use and investment priorities must be harmonized to safeguard the environment, society, and economy for present and future generations.

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1. INTRODUCTION

The United Nations estimated that by 2050, 70% of the global population will reside in major urban centers, which means a significant rise compared to earlier decades. This trend predicts an increase in the urban population from 3.4 billion in 2009 to 6.3 billion by mid-century. Urbanization is regarded as a continuous process of urban growth and transformation (Scott and Marshall, 2000), which started with the formation of the earliest cities and persists in the modern era. The study of urbanization, as defined by Sustainable Development Goal 11 and its indicator SDG 11.3.1, involves examining the relationship between the land consumption rate (LCR) and the population growth rate (PGR). The LCR serves as a measure of land use efficiency and the level of urban compactness in the areas under study, while the PGR reflects demographic trends to assess the sustainability of urban development in specific locations, along with other sub-indicators of SDG 11. Recent research on SDG 11.3.1 has employed diverse approaches and data sources. Population growth is calculated based on demographic shifts, using data collected over decades at local, national, regional, and global scales. In contrast, the assessment of land consumption requires an understanding of the spatial expansion of human settlements, which depends on remote sensing and the interpretation of spatial data (Mudau et al., 2020). Earth observation data, offering global coverage at regular intervals and relatively low costs, has been identified as a critical resource for SDG 11 monitoring (Paganini et al, 2018; Anderson et al, 2017; Schiavina et al. 2022). Numerous global datasets are now available, including the Global Human Settlement Layer (GHSL) and GHS-Built, maintained by the Joint Research Centre of the European Commission; the Atlas of Urban Expansion, created by New York University; and the Global Urban Footprint (GUF), compiled by the German Aerospace Center (DLR) (Esch, et al., 2017; Schlomo et al. 2016; Belward et al. 2015). At the European level, resources such as the pan-European Urban Atlas, managed by the European Environment Agency, provide consistent high-resolution data on land cover and land use. However, the limited temporal coverage of these datasets—available only for 2006, 2012, and 2018—restricts analyses of urban compaction to recent years. Studies by Schiavina et al. (2020) and Zhou et al. (2021) utilized GHS-Built data to evaluate land use efficiency . Similarly, Wang et al. (2020) applied China's Land-Use/Cover Datasets (CLUDs) and nighttime light data

from the Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS) to identify built-up areas in China. Nicolau et al. (2019) analyzed the relationship between LCR and PGR in Portugal using the COS vector map ("Carta de Ocupação e uso do Solo") and CORINE Land Cover (CLC), derived from computer-aided photointerpretation of imagery from Landsat, IRS, SPOT, and RapidEye satellites.

This study focuses on the computation and examination of the SDG 11.3.1 indicator, defined as the "ratio of land consumption rate to population growth rate," hereinafter referred to as LUE, within Poland, focusing on voivodeships during the periods 2007–2014 and 2014–2021. Identifying areas where land use expands faster than population growth is crucial, as it calls for public administration to implement recovery strategies. Moreover, the study highlights the importance of visualizing these processes—land consumption and population growth rates—through thematic maps and associated graphs. Such visual tools are critical for the formulation of national or regional development policies aimed at achieving sustainable social, economic, and environmental growth. Aligning population growth with the expansion of built-up areas is essential, as it fosters positive synergies while mitigating issues related to environmental degradation, biodiversity loss, and climate impacts at both local and global levels. The paper is structured as follows: the next section details the study area, the methodology, and data utilized, followed by a presentation and discussion of the findings, concluding remarks, and recommendations.

2. STUDY AREA, DATA AND METHODS

Study area

This study focuses on Poland, a Central European country depicted in Figure 1. The country is divided into 16 administrative provinces (voivodeships). It spans an area of 312,696 km². With a population exceeding 37.6 million, Poland ranks as the fifth-most populous member of the European Union. Urban areas are home to 61.5% of the population, with an average density of 123 residents per km². In the first half of 2024, a negative population growth of -77.7 thousand was recorded. The urban population decline amounted to -4.8‰, while in rural areas, it was -3.1‰ (GUS, 2024). Warsaw, the capital and largest city, has approximately 1.77 million inhabitants. Additionally, four cities in Poland have populations exceeding 500,000. The Silesian Voivodeship is characterized by one of the highest population densities in the country, at around 372 inhabitants per km², more than three times the national average. The most densely populated areas are located mainly in the southern and central parts of the country, driven by the extensive economic development of these areas. In contrast, the north-western and north-eastern regions are sparsely populated, characterized by large forested areas and fewer cities.

Currently, Poland faces certain demographic challenges including a declining birth rate and negative population growth, which may have significant socio-economic consequences in the future (Calka et al. 2022).

Fig.1. Study area – Poland in Europe
(https://mapy.geoportal.gov.pl/imap/Imgp_2.html?gpmap=gp0)

Methodology

The methodology for calculating the SDG 11.3.1 indicator is presented and documented in the SDG Indicators Metadata Repository, managed by UNDESA (https://unstats.un.org/sdgs/iaeg-sdgs/metadata-compilation). The LUE indicator is determined as the ratio between the land consumption rate (LCR) and the population growth rate (PGR) (Calka et al, 2022, Bielecka and Calka, 2022). The PGR indicator (Equation 1) represents the change in population over a defined period, while the LCR indicator (Equation 2) reflects the extent of land development during the same timeframe (Schiavina et al, 2020; Anderson et al., 2017). Together, the LUE indicator measures the efficiency of land use in relation to the demographic growth of urban areas. In this study, the indicator was calculated for the voivodeships of Poland for the years 2007, 2014, and 2021 (Equation 3).

$$PGR = (ln\frac{Pop_{t+n}}{Pop_t})/\ t \qquad (1)$$

Where:
Pop_t - the total population in the initial year for a spatial unit,
Pop_{t+n} - the total population in the final year for a spatial unit, and
t is the number of years between the two measurement periods.

$$LCR = (ln\frac{Urb_{t+n}}{Urb_t})/\mathrm{t} \quad (2)$$

Where
Urb_t - the total area extent of the built-up area for a spatial unit for the initial year using,
Urb_{t+n} - the total area extent of the built-up area for a spatial unit for the final year,
T - is the number of years between the two measurement periods.

$$LUE = \frac{\mathrm{LCR}}{\mathrm{PGR}} \quad (3)$$

Where:

LCR - the land cover ratio and PGR is the population growth ratio.

LCR is an indicator of land area expansion, while PGR describes demographic changes. Positive values of the first one indicate an increase in built-up area, and positive values of the second one indicate population growth. Negative values may indicate a decrease in either built-up area or population. The LUE value may be less than zero, indicating that one of these indicators (LCR or PGR) is negative.

Data used

Data on the population of cities and the extent of built-up areas, aggregated by voivodships for the reference years 2007, 2014, and 2021, were obtained from the Central Statistical Office (GUS 2024).

Between 2007 and 2021, according to the available data, the artificial areas in Poland expanded at varying rates across different voivodeships. In the period 2007–2014, the highest increase in urban areas was recorded in Małopolskie (68%), Podkarpackie (50%), and Mazowieckie (41%). However, in the subsequent period (2014–2021), the rate of urban expansion slowed in most regions, with the highest growth observed in Małopolskie (30%), Podkarpackie (35%), and Kujawsko-Pomorskie (26%). At the same time, some regions, such as Opolskie and Mazowieckie, experienced a significant drop in urban expansion rates, from 19% to 7% and 41% to 16%, respectively. In contrast, Podlaskie saw an increase from 4% to 14%, indicating a shift in urban development patterns across Poland (Figure 2).

Between 2007 and 2014, Poland's population exhibited diverse demographic trends. Population growth was recorded in six voivodeships, with the highest increase in Pomorskie (4%), followed by Mazowieckie and Małopolskie (3% each). The demographic situation remained stable in Dolnośląskie (0%), while the largest population declines were observed in Łódzkie (-

2%), as well as Opolskie and Podlaskie (-3%). Between 2014 and 2021, depopulation intensified in most voivodeships (Figure 3).

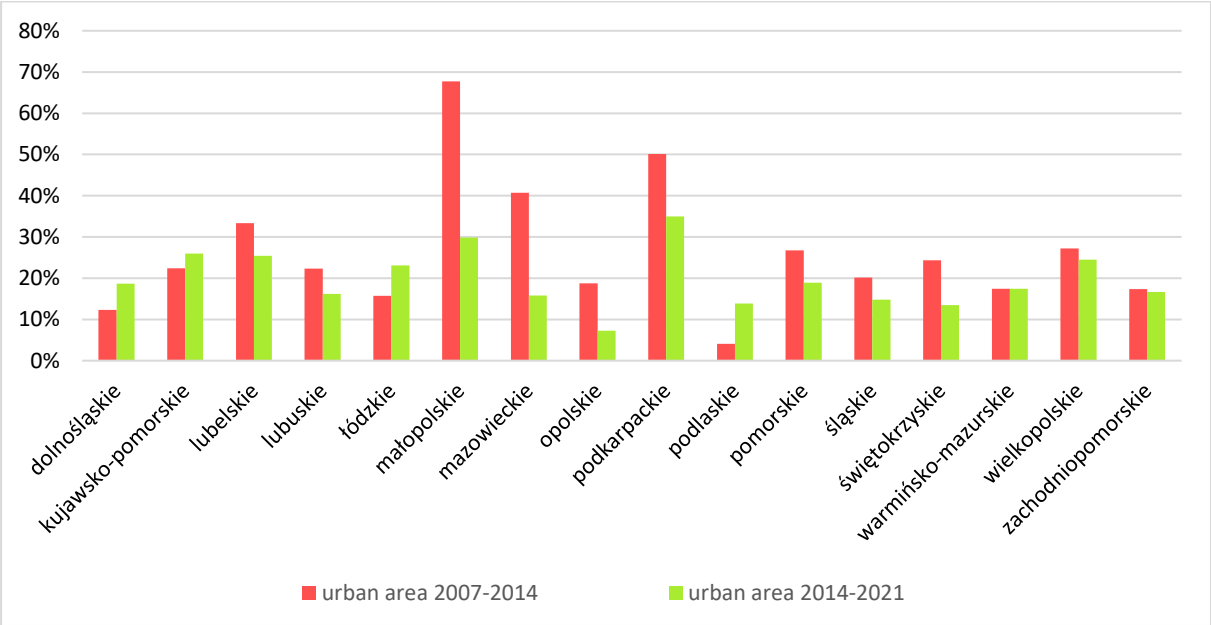

Fig.2. Changes in urban areas in Poland a) 2007-2014 b) 2014-2021

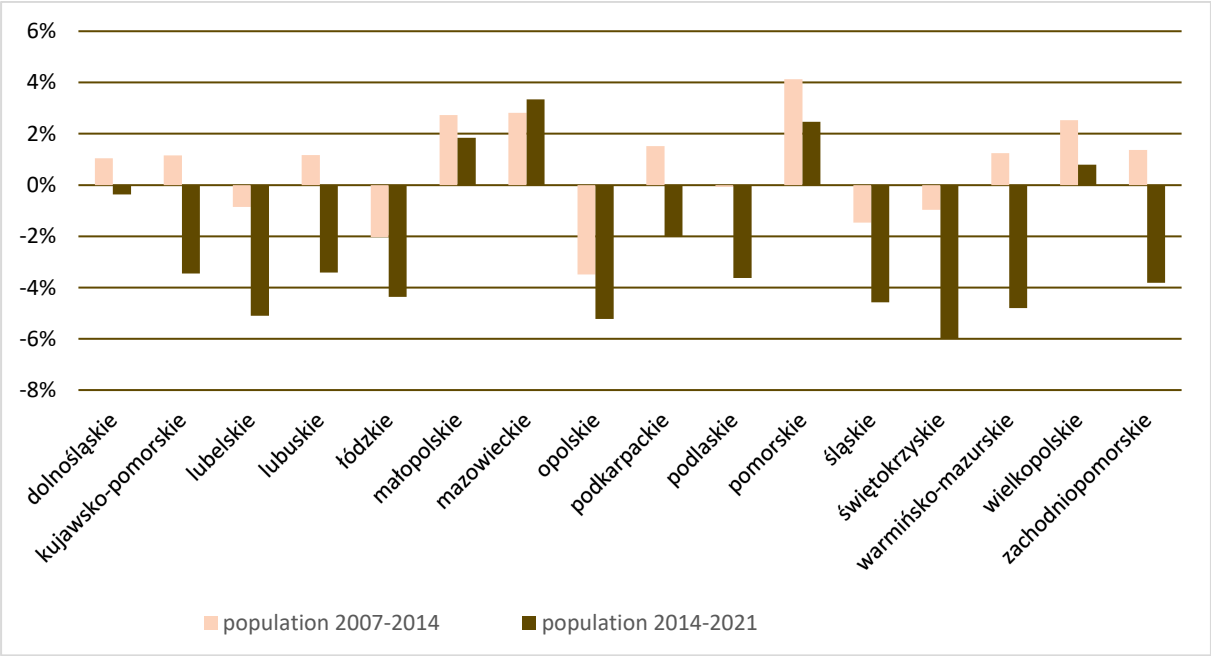

Fig.3. Changes in population in Poland a) 2007-2014 b) 2014-2021

The greatest population decline occurred in Świętokrzyskie (-6%), followed by Lubelskie, Opolskie, and Śląskie (-5% each). Population growth was recorded in only three voivodeships: Mazowieckie (3%), Małopolskie (2%), and Pomorskie (2%). In other regions, the number of inhabitants decreased by 2–5%. This trend indicates the continuation of depopulation in most regions of Poland, except for a few dynamically developing voivodeships, mainly in the central and northern parts of the country.

3. RESULTS AND DISCUSSION

Between 2007 and 2014, the PGR coefficient took negative values in six voivodeships. In the years 2014-2021, however, the majority of voivodeships experienced a negative PGR, with 12 voivodeships showing a decline, indicating depopulation. The population decline between 2014 and 2021 was significantly greater than in the 2007-2014 period, as shown in Figure 5.

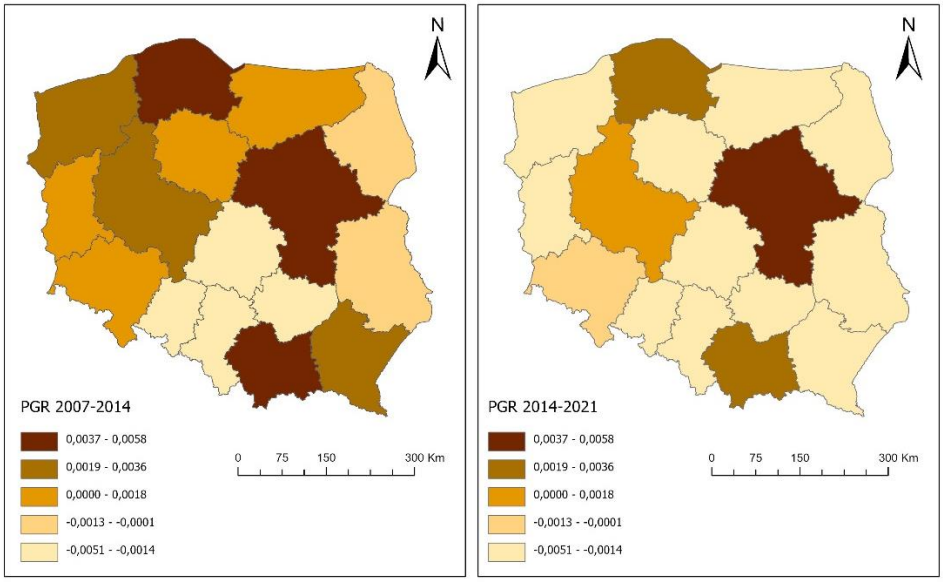

Fig.4. Population Growth Ratio (PGR) in Poland a) 2007-2014 b) 2014-2021

Land consumption, as shown in Figure 5, has led to an increase in sealed surfaces, more scattered settlement, intensified mixed land use, and the loss of peri-urban agro-ecosystems. These changes impact the structure of urban green spaces and limit their ability to provide ecosystem services, such as erosion control, air quality improvement, and outdoor recreation. Larger changes in the Land Consumption Rate (LCR) were observed in the 2007–2014 period, although for both time intervals, the LCR values remained positive.

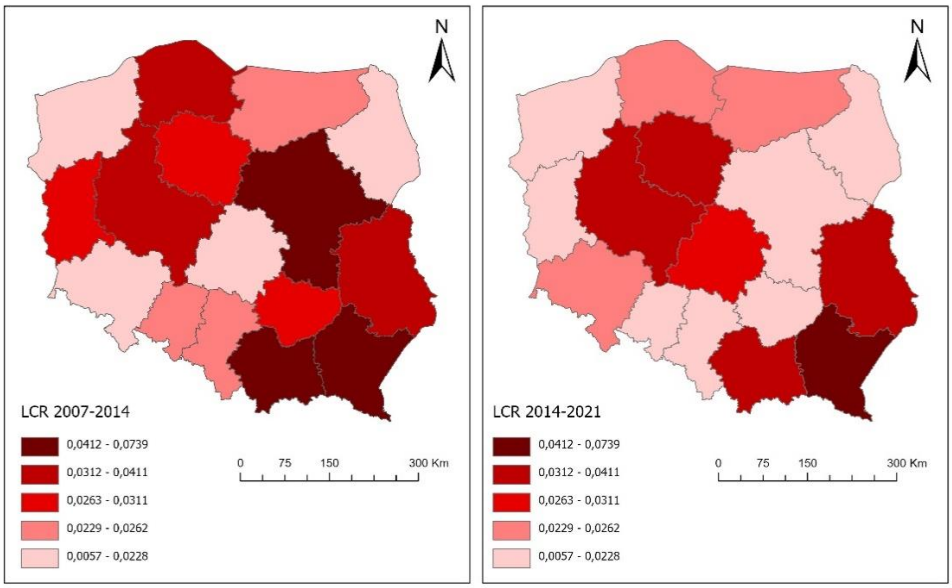

Fig.5. Land Consumption Ratio (LCR) in Poland a) 2007-2014 b) 2014-2021

The cartographic presentation of the Land Use Efficiency (LUE) index for the periods 2007–2014 and 2014–2021 (Figure 6) illustrates significant regional variations in spatial and demographic dynamics across Polish voivodeships. The LUE index helps identify areas where the rate of land consumption surpasses population changes (LUE > 1) as well as regions where demographic decline coincides with continued spatial expansion (LUE < 0).

In the period 2007–2014, several regions demonstrated notably positive LUE values, indicating a disproportionate increase in land consumption compared to demographic changes. The Kuyavian-Pomeranian (17.61) and Subcarpathian Voivodeships (26.94) are examples where land use expanded at a higher rate than population growth. On the other hand, regions such as Podlaskie (-63.98) and Lublin Voivodeships (-33.63) showed negative LUE values, suggesting population decline or minimal changes in land use. In the subsequent period (2014–2021), changes in LUE dynamics were evident. The Greater Poland (27.83) and Lesser Poland Voivodeships (14.32) presented significant positive LUE values, indicating better-aligned spatial and demographic growth. Conversely, regions such as the Lower Silesian (-46.32) and Subcarpathian Voivodeships (-14.61) experienced negative LUE values, highlighting a mismatch between land consumption and demographic trends. These observations align with broader spatial development patterns in Poland, where metropolitan areas such as Greater Poland and Lesser Poland continued to attract growth, while peripheral and less economically vibrant regions struggled with demographic decline. The presented LUE analysis underscores the need for sustainable spatial planning and highlights the importance of ongoing policy

interventions, including strategic documents like "Polska 2030" (2012) and the "Strategia na rzecz Odpowiedzialnego Rozwoju" *[Strategy for Responsible Development]* (2017).

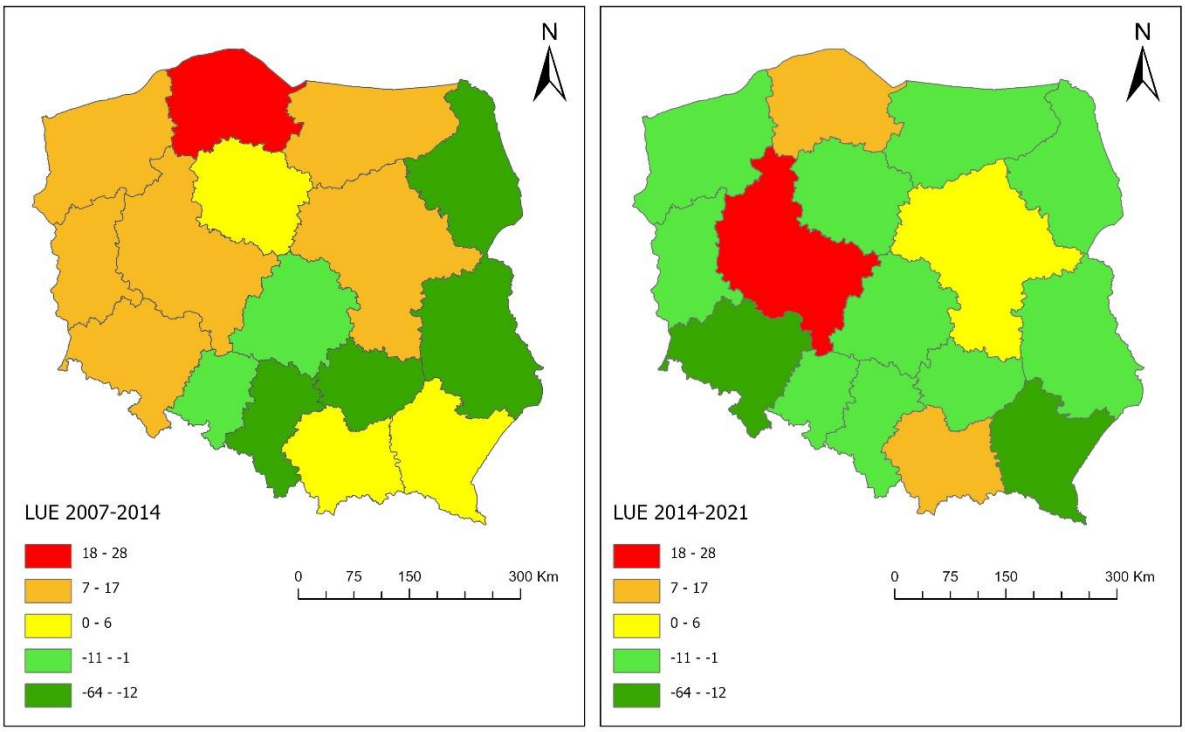

Fig.6. Land use efficiency in Poland a) 2007-2014 b) 2014-2021

4. CONCLUSIONS

The findings indicate that during the years 2007-2014 land consumption patterns were more varied compared to the 2014-2021 period. Differences were observed both in the indicator values and in the spatial distribution across regions. Between 2007 and 2014, ten out of sixteen regions experienced more balanced population growth relative to the expansion of built-up areas. However, in the period from 2007 to 2021, land consumption surpassed demographic growth in twelve regions. The declining population is the main factor influencing such values of the LUE index. Excessive urban development also exerts pressure on resources and hinders improvements in living standards. Despite this, current actions under EU and Polish policies aim to improve territorial cohesion and support the development of peripheral areas. Achieving sustainable development requires aligning population size and growth with the evolving productive capacity of ecosystems. Nevertheless, sustainable development is not a fixed state of equilibrium but an ongoing process where resource exploitation and investment choices need to be balanced to safeguard the environment, society, and economy for present and future generations. It should also be highlighted that the LUE calculation method involves some

uncertainty when population numbers or built-up areas remained stable during the studied period (with PGR = 0 and/or LCR = 0).

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