Built-up areas are expanding faster than population growth: regional patterns and trajectories in Europe

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ABSTRACT
Human settlements typically expand to accommodate additional housing demand from a growing population and their socio-economic activities. This implies consumption of land, a limited resource necessary for many other services. The efficiency of this exploitation in relation to demographic trends is key to preserve land and natural capital that could otherwise be degraded. Here, we assess patterns of population and built-up area growth over the period 2000–2015, using demographic statistics and remote-sensing data. We find that on average, in the EU27, built-up areas grew at a faster pace than population and that they expanded even in regions where population has declined. We quantify the impact of future population growth under different assumptions on future built-up efficiency. Keeping current built-up per capita fixed could preserve up to 9,000 km² of land until 2030, especially outside predominantly urban regions, where land use efficiency is generally low and has been declining.

Introduction

Land surface on Earth is a finite resource, whose management has progressively entered the discourse on sustainability (Turner et al., 2020; Wu, 2019). Through expansion of built-up areas, human settlements increasingly compete for available land with other vital uses, such as agriculture, conservation, and other ecosystem services (Haberl et al., 2014). Over the last 100 years, rapid urbanisation has emerged as a key process of global environmental change shaping anthropogenic impacts on the planet (Grimm et al., 2008). Such unprecedented land urbanisation process was accompanied by an enormous population increase (i.e. world population almost tripled since 1920; United Nations, Department of Economic and Social Affairs, Population Division, 1999, 2015). Although human settlements, in recent years, take up only about 0.5% of the global landmass (Florczyk et al., 2019), their impacts extend well beyond their nominal spatial footprint, also due to expanding range of activities by settlers (Seto et al., 2012).

Demographic dynamics and land urbanisation are two intertwined processes: typically, human settlements expand their built-up footprint to accommodate a growing population and their activities (Duncan et al., 1962). However, at times these two elements decouple with diverging trajectories of demography and land consumption (Kroll & Kabisch, 2012). When population growth outpaces built-up expansion, settlements become denser on average (i.e. more housing units or more people per built-up land). Conversely, when land consumption outpaces population growth, human settlements become less dense, which is often associated with urban dispersal, urban sprawl or suburbanisation.
These processes can be assessed by quantifying built-up area changes and demographic dynamics over time by means of specific data and indicators (Sharma et al., 2012; Wolff et al., 2018). Target 11.3 of the Sustainable Development Goal 11 (aiming to ‘enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries by 2030’) can be monitored with an indicator (SDG indicator 11.3.1: Land Use Efficiency; UN Statistical Commission, 2017) designed to estimate the efficiency of land use as a consequence of population growth and new land consumed (Cai et al., 2020). Based on the 2019 formulation of such an indicator, the relationship between built-up area expansion and population variation, measured as the ratio of the built-up area growth rate between two years and the population growth rate in the same time interval, showed disparities that vary across regions of the world and income classes (Schiavina et al., 2019). However, this internationally agreed indicator, even after the 2021 update (i.e. land consumption rate computed as percentage increase), has some drawbacks, especially in its interpretation and comparison, which are not intuitive, and can be problematic when dealing with population and/or land consumption growth rates that are negative: positive values of the indicator are the result of growth in both built-up area and population but also of decrease in both factors, while negative values are obtained with opposite signs of the ratio components without any discrimination between population decline or land restoration cases (Schiavina et al., 2019). In some cases (Melchiorri et al., 2019), simpler indicators, such as the built-up per capita change and the Marginal Land Consumption (MLC) between two epochs, as suggested by Wolff et al. (2018) and Schiavina et al. (2019), simplify the analysis and interpretation of evolving patterns of land consumption efficiency, enabling comparisons among different values. These indicators are spatially explicit metrics to relate a quantitative amount of land consumed per unit of demographic change, and they could still effectively detect the potential occurrence of urban dispersal, urban sprawl or suburbanisation whenever a built-up area growth outpaces population growth in a region.

The European Union (EU), through its ‘Urban Agenda’, is particularly committed to supporting sustainable land use and urban development. The European context is characterised by lower demographic growth and more dispersed built-up patterns compared to other world regions (Alvarez Alvarez et al., 2021; Florczyk et al., 2019; Vollset et al., 2020). The study of urbanisation and population dynamics in Europe has focused mostly on limited areas, such as individual countries, regions or cities (Hoymann, 2012; Pontarollo & Serpieri, 2020; Salvati & Zambon, 2019; Salvati et al., 2018; Wolff et al., 2018), according to data availability. There is a lack of comprehensive studies that conduct detailed and comparable pan-European analyses for the contemporary period across the whole urban/rural continuum and explore prospective scenarios, despite this appearing crucial to implement more localised policies of sustainable land use (Salvati et al., 2018), to raise the awareness of best practices and directions to mitigate and compensate soil sealing in Europe (European Commission, Directorate General for the Environment, 2012).

The Global Human Settlement Layer (GHSL) is part of a new generation of geospatial land use information that meets such requirements (Melchiorri et al., 2018). The GHS-BUILT (Corbane et al., 2018) is a GHSL-family product representing built-up areas globally at an unprecedented spatial and temporal resolution, and adopting a consistent definition of built-up area compliant with the definition of ‘building’ as per the ‘Infrastructure for Spatial Information in Europe’ (INSPIRE) directive. The global spatial extent of GHS-BUILT allows the monitoring and comparison of global land consumption trends (Shelestov et al., 2020). Recent studies relied on GHS-BUILT or showcased its application to estimate built-up area per capita and its change over time, also in the context of the Sustainable Development Goals (Maes et al., 2020; Siragusa et al., 2020).

The objective of this study is to assess the trends of built-up growth and the related land use efficiency in Europe (EU27) based on observational data for the period 2000–2015, and on modelling scenarios for the period 2015–2030. We do this by combining built-up data from GHSL and demographic data from official statistics at NUTS3 level. To analyse the 2000–2015 period, we propose the
MLC indicator, relating changes in population with consumption of land due to built-up area expansion. In addition, we relate the observed landuse efficiency trends with an urban-rural regional typology on a per country basis, in a comparable manner. With regards to the period 2015–2030, we develop three scenarios of built-up growth based on demographic projections and assumptions regarding changes to built-up per capita.

Our results contribute to the knowledge base and the vibrant debate around land consumption and urban land uptake ongoing at both EU and global level (Marquard et al., 2020). Looking beyond Europe, our analysis may provide insight for other world regions that still display expansion of built-up areas despite their decreasing population growth rates and projected population decline.

Materials and methods

This study relies on three types of input data and on the current NUTS3 subdivision of EU27 (version 20163): (i) the built-up areas to quantify the expansion of human settlements between 2000 and 2015 (observed data); (ii) the demographic component to quantify total population change over the same period and projections for the year 2030; and (iii) the urban-rural typology of NUTS3 regions.

Built-up areas

Several spatial layers mapping land use or built-up surface have been developed specifically for the European extent (e.g. European Settlement Map, ESM; Corbane & Sabo, 2019; CORINE Land Cover and CORINE Land Cover refined; Pigaiani & Batista E Silva, 2021; Rosina et al., 2018). However, these layers do not have a consistent multi-temporal component or lack precision for small scale assessment (Decoville & Schneider, 2015). The multi-temporal component of the global built-up area grids GHS-BUILT (Corbane et al., 2018) along with its detailed spatial resolution are fundamental to analyse changes in time using consistent data. The definition of ‘built-up area’ according to the GHSL framework is ‘the union of all the satellite data samples that corresponds to a roofed construction above ground which is intended or used for the shelter of humans, animals, things, the production of economic goods or the delivery of services’ (Pesaresi et al., 2013). These multi-temporal layers are obtained by processing Landsat data collections plus Sentinel-1 and GlobeLand30 learning sets with a symbolic machine learning process (Corbane et al., 2019) and are available at a resolution of 250 m and 1 km in World Mollweide projection (ESRI:54009). These 250 m and 1 km built-up density layers are obtained from an aggregation of an original binary layer produced at sensor resolution (30 m) mapping the physically observable built-up area markers via optical remote sensing. Therefore, the land consumption at NUTS3 level assessed in the analysis is based on the built-up area component extracted from the 2000 and 2015 layers at 250 m resolution of the GHS-BUILT dataset and summed for each NUTS3 using a ‘zonal statistics’ geoprocessing function.

Demographic data

The Eurostat database is the official source for demographic information at NUTS3 level for EU27. Resident population totals are reported for all years since 1990 at several aggregation levels. These data are collected annually by Eurostat as part of the Unified Demography (Unidemo) project and rely on statistics sent annually by each country (Member States plus other countries in the project for a total of 37 countries). Eurostat annually publishes the demographic data broken down by NUTS 2 and 3 levels according to the NUTS 2016 classification, which subdivides the territory of the European Union into 104 regions at NUTS level 1; 281 at NUTS level 2; and 1348 at NUTS level 3. For the purpose of this analysis, only the years 2000 and 2015 for EU27 NUTS3 level population were selected from the database.
With regard to future population developments, we used the baseline scenario of the EUROPOP2019 demographic projection by Eurostat and released in mid-2020. These projections take 2019 as the base year, and projects population until 2100, covering the whole EU27 with subnational detail, and considering natural and migration dynamics. From these projections, we used the total population per NUTS3 until 2030.

**Territorial typology**

Urban and rural developments are central concepts used by a wide range of policymakers, researchers, national administrations and international organisations. The European Commission developed a definition of territorial typologies, built on work already done by the OECD, to provide a consistent basis for the description of predominantly rural, intermediate and predominantly urban regions (Eurostat, 2019).

The urban-rural typology is applied by Eurostat to 2016 NUTS3 level regions and it is available on the GISCO portal. It identifies three types of regions based on the share of the urban and rural population, according to the Degree of Urbanisation (Dijkstra et al., 2020) applied to the GEOSTAT population grid 2011:

- ‘predominantly urban regions’, NUTS3 regions where more than 80% of the population live in urban clusters;
- ‘intermediate regions’, NUTS3 regions where more than 50% and up to 80% of the population live in urban clusters;
- ‘predominantly rural regions’, NUTS 3 regions where at least 50% of the population live in rural grid cells.

In our analysis, we used such classification to discuss potential relationships present on the EU27 territory between the efficiency of land consumption and the urban/rural classification of each NUTS3. To identify different development trajectories between different territorial typologies, summary statistics and indicators are computed by aggregating built-up and population data available at NUTS3 according to their urban–rural typology.

**Built-up per capita and marginal land consumption**

The main focus of this study is to assess efficiency in land consumption at NUTS3 level between 2000 and 2015. To do so we use two metrics, the Built-up per capita change, and the Marginal Land Consumption as indicators of efficiency of development trajectories. The first metric, Built-up per capita change ($BpC_t$) is computed by evaluating the Built-up per capita ($BpC$) in each epoch $t$ (2000, 2015 and 2030) for each NUTS3 region as follows:

$$BpC_t = \frac{BU_t}{POP_t}$$

where $BU_t$ is the built-up surface at time $t$ (expressed in $m^2$) and $POP_t$ is the population at time $t$ in a given NUTS3; we then compute the difference between the two epochs of interest (2000 and 2015, observed; 2015 and 2030, observed and scenario).

The second metric, the Marginal Land Consumption ($MLC_{dt}$), as introduced by Pileri (2017) and applied at global level by Schiavina et al. (2019), is also computed for the same intervals as follows:

$$MLC_{dt} = \frac{BU_{t2} - BU_{t1}}{POP_{t2} - POP_{t1}}$$
with \( t1 \) corresponding to the first epoch (2000, observed; 2015, scenario) and \( t2 \) to the second epoch (2015 observed; 2030 scenario). The study separately analyses NUTS3 regions showing positive and negative population changes. The MLC provides limited insight in situations of negative population growth (i.e. population decrease), therefore, in depopulating NUTS3, we replace the MLC metric by built-up area change.

Finally, we analyse the relationship between land efficiency and the classification of NUTS3 according to the urban–rural territorial typology.

### Projecting built-up expansion until 2030

To project built-up growth until 2030, we resorted to the ‘land use intensity’ approach described by Batista e Silva et al. (2014), and which was used to develop three scenarios. All three scenarios are constructed around assumptions related to future built-up per capita, as defined in Eq. 1. Built-up per capita in the past (2000, 2015) is assessed per NUTS3 using the already mentioned sources: population from official Eurostat statistics, and built-up area from the GHSL time series. Future population growth is given by the EUROPOP2019 demographic projections, as mentioned above. Future built-up is calculated according to Eq. 3, as follows:

\[
BU_{t3} = POP_{t3} \times BpC_{t3}
\]

where \( BU_{t3} \) is calculated according to Eq. 3, as follows:

\[
BU'_{t3} = \begin{cases} 
BU_{t2} \text{ if } BU_{t3} < BU_{t2} \\
BU_{t3} \text{ if } BU_{t3} \geq BU_{t2}
\end{cases}
\]

where \( t2 \) and \( t3 \) denote years 2015 and 2030, \( BU'_{t3} \) corresponds to the final estimate of built-up area, and \( BpC_{t3} \) is estimated according to three scenarios, as follows:

- Scenario 1, ‘Containment’: built-up per capita as measured in 2015 remains fixed until 2030 in each NUTS3.
- Scenario 2, ‘Trend’: built-up per capita in 2030 is linearly extrapolated from the observed trend in the period 2000–2015.
- Scenario 3, ‘Business as usual’: built-up per capita in 2030 is predicted based on a multiple linear regression analysis considering the following predictor variables: observed built-up per capita, the log of the per capita amount of available land for urban development,\(^8\) the urban–rural typology,\(^9\) and country fixed effects (to control for land use planning regulation, for instance). This model has been estimated first for the cross-section period 2000–2015, and then it was used to project built-up per capita in 2030 based on predictor variables observed in 2015.

In all scenarios, built-up area is not allowed to decrease (Eq. 4). While existing brown fields or abandoned urban areas can occasionally be converted to ‘green’ land cover, at higher spatial aggregation such interventions are almost negligible, and overall reduction of built-up areas do not appear even in regions with declining population.

### Results

In this section, we summarise the results by depicting the trajectories of the whole EU27 and the pattern across the EU27 by NUTS3 identifying possible relationship with their territorial typology classification. A separate section is dedicated to the analysis of NUTS3 experiencing a decrease in their population. We ultimately show the results of the future scenarios of built-up area growth based on population projections to 2030, in order to identify potential issues and policy implications.
EU27 displays continuing and fast built-up land expansion despite low demographic change

In the period 2000–2015, built-up surface in EU27 expanded by almost 1,000 km² per year (from 106,091 km² of 2000 to 120,877 km² of 2015; 0.87% average annual growth), while population grew about 1 million people every year (from about 429 million people in 2000 to more than 444 million people in 2015), corresponding to an average population growth rate of 0.24% per year. Despite the population growth rate in EU27 being one fifth of global one (1.22% per year; United Nations, Department of Economic and Social Affairs, Population Division, 2015; between 2000 and 2015 the region registered a MLCdt value of 962 m² per new inhabitant, more than nine times the global value (101 m² per new inhabitant; as derived from Table 2 in Schiavina et al., 2019). This low demographic change accompanied by a fast built-up expansion led to an increase of built-up per capita in the same period of about 25 m² per inhabitant (BpCd).

In half of the NUTS3, the land consumption related to a new inhabitant was more than six times the new built-up area of another new inhabitant on the planet

Figure 1 shows the variability of the MLCdt among EU27 NUTS3: 57% (664) of all NUTS3 experienced population growth between 2000 and 2015; conversely 43% (504) were shrinking in population and only built-up expansion is considered in the analysis. About 250 NUTS3 (21%) developed along a less efficient trajectory than the general EU27 trend (MLCdt > 962 m² per new inhabitant). Half of the growing NUTS3 showed a marginal land consumption (MLCdt) greater than 600 m² per new inhabitant, more than six times the average built-up area allocated for each new inhabitant of the world (global MLCdt = 101 m² per new inhabitant; as derived from Table 2 in Schiavina et al., 2019).

The overall pattern shown in the EU27 regions confirms the heterogeneity of the European territory. In particular, there is a general East-West gradient with many depopulating regions in Eastern Europe (i.e. almost entire Bulgaria, Estonia, Hungary, Latvia, Lithuania and Romania), but also some more localised geographical contrasts can be identified:

- North-South disparities in Spain, Italy and Sweden;
- East-West in Poland;
- Depopulating internal regions of Croatia, Finland, France, Germany and Portugal.

Only 52 NUTS3 (4% of total) expanded along very efficient land consumption paths (i.e. lower than global average). These areas usually contain large urban centres (Table 1) and generally have high population densities (e.g. Paris 21,000 inhabitants/km²; Bruxelles 7,300 inhabitants/km²; München 4,600 inhabitants/km²; Wien 4,400 inhabitants/km²) or big population size (e.g. Madrid 6.4 M inhabitants; Barcelona 5.4 M inhabitants; Roma 4.3 M inhabitants). These NUTS3 have on average 2.5 times higher population density than the EU27 average (350 inhabitants/km² and 137 inhabitants/km², respectively), and two times higher population size than EU27 NUTS3 average.

One third of the new EU27 built-up land between 2000 and 2015 is detected in depopulating NUTS3

Figure 2 shows the amount of built-up land expansion per country between 2000 and 2015 in NUTS3 regions that experienced a population decline in the same period. Despite the population decline, these regions, representing 43% of all NUTS3, contributed with more than 4,000 km² to the total built-up land expansion (i.e. 30%) between 2000 and 2015. In 10 countries, this contribution exceeded half of the total national built-up land expansion with Bulgaria, Romania and Lithuania reaching 86%, 95%
Figure 1. Marginal Land Consumption per new inhabitant (MLC in m²/inhabitant) per NUTS3 between 2000 and 2015.

Table 1. Selection of NUTS3 with an efficient development trajectory (below the global land consumption path). ΔPop represents the population variation between 2000 and 2015; ΔBU the built-up area expansion between 2000 and 2015. (Islands and enclaves NUTS3 excluded from selection).

| NUTS code | NUTS Name | ΔPop (inhabitants) | ΔBU (km²) | MLC_dT (m²/inhabitant) | BpC_dT |
|-----------|-----------|--------------------|----------|------------------------|--------|
| FR101     | Paris     | 77,295             | 0.25     | 3                      | −3%    |
| BE100     | Arr. de Bruxelles-Capitale / Arr. van Brussel-Hoofdstad | 227,599 | 2.04 | 9                      | −18%   |
| DE212     | München, Kreisfreie Stadt | 241,651 | 5.34 | 22                      | −14%   |
| DK011     | Byen København | 158,387 | 3.72 | 23                      | −18%   |
| AT130     | Wien      | 260,545            | 6.34     | 24                      | −12%   |
| ES300     | Madrid    | 1,042,857          | 71.68    | 69                      | −7%    |
| ITI43     | Roma      | 637,375            | 44.93    | 70                      | −8%    |
| DE111     | Stuttgart, Stadtbezirk | 32,720 | 2.36 | 72                      | −3%    |
| DEA22     | Bonn, Kreisfreie Stadt | 14,301 | 1.09 | 76                      | −3%    |
| ITC4C     | Milano    | 268,941            | 25.02    | 93                      | −4%    |
| ES511     | Barcelona | 650,190            | 60.94    | 94                      | −4%    |
and 100% of national built-up expansion, respectively. Germany is the country with the highest absolute land consumption in shrinking NUTS3, about 1,000 km² (44% of national expansion), followed by Poland and Romania, with about 800 km² (54%) and 500 km² (95%), respectively.

**Predominantly urban regions show a more efficient land consumption pattern**

The average built-up per capita in 2000 ($BpC_{2000}$) varied from 200 m² in predominantly urban regions, to 286 m² in predominantly rural regions, with intermediate regions close to predominantly rural regions (271 m²). Starting from these initial observations, the trajectories of the three groups diverge in the period under analysis. The average built-up per capita variation is quite narrow in predominantly urban regions ($BpC_{dt} = +8.9$ m²/inhabitant). Conversely, built-up per capita increased substantially more in both intermediate regions ($BpC_{dt} = +33$ m²/inhabitant) predominantly rural regions ($BpC_{dt} = +55$ m²/inhabitant). The statistical distribution of these changes across the three territorial typologies is shown in Figure 3. All distributions display long tails towards high MLC values, as shown

![Figure 2](image-url)  
*Figure 2.* National built-up land expansion in shrinking NUTS3 as absolute area (black bars) and relative to total national expansion (gray dots). Numbers topping bars indicate number of shrinking NUTS3 by country.

![Figure 3](image-url)  
*Figure 3.* Distribution of Marginal Land Consumption (MLC) by territorial typology. Box represents the interquartile range with median (line); whiskers represent 90% interval and cross is the average MLC.
by the average values close to or even greater than 75% of the regions in the group. However, predominantly urban regions have lower variability, with 90% of NUTS3 below 1,500 m² of new built-up land per new inhabitant (75% for intermediate regions and few more than 50% for predominantly rural areas). In particular, 50% of predominantly urban regions accommodate a new inhabitant in less than 300 m² of new built-up land, while this value more than doubles for intermediate regions (MLCdt = 700 m²/inhabitant) and triples for predominantly rural regions (about 1,200 m²/inhabitant).

The more efficient use of built-up land in predominantly urban regions is also confirmed in Figure 4, which relates the change in built-up per capita with the population growth rate per region. Figure 4 indicates that built-up per capita variation is negatively correlated with population growth rate. In other words, higher population growths correspond to lower increase in built-up per capita.

Looking at predominantly urban regions, only a few cases of increase in built-up per capita (BpCdt > 0) along with an increase of population are recorded. Conversely, the built-up per capita change in predominantly rural areas is dominated by the loss of population combined with increase in built-up per capita (BpCdt > 0, lower right quadrant of the chart of Figure 4). On the other hand, intermediate regions show frequency distributions that cross those from the other typologies: from the typical

**Figure 4.** Heat maps of NUTS3 frequency distributions according to built-up per capita change (BpCdt) in square metres per inhabitant and population compound annual growth rate (%) between 2000 and 2015, by territorial typology.
predominantly urban region pattern, as for Guadalajara (ES424), to the usual shrinking pattern of predominantly rural regions, such as in Bpaqa (Vratsa, BG313). However, even in those cases where the growth rate is strongly negative, the increase of built-up per capita is generally lower than in predominantly rural areas.

**Scenarios of future built-up expansion**

Three scenarios of built-up expansion for the year 2030 were developed, considering population projections and assumptions regarding future built-up area per capita. Scenario 1 assumes that the average built-up per capita in each NUTS3 observed in 2015 remains fixed until 2030. As documented above, built-up area per capita has been increasing overall in the EU27 in the period 2000–2015. Therefore, scenario 1 can be seen as a containment baseline to which the other scenarios can be compared with. Scenario 2 is a trend-following approach. It assumes that the measured change in built-up per capita between 2000 and 2015 in each NUTS3 will continue through to 2030.

Scenario 3 is based on an explanatory approach, whereby future built-up per capita in each NUTS3 is a function of past built-up per capita, per capita amount of land available for urban development, the urban-rural typology and country. A multiple linear regression model was estimated using 2000–2015 data, obtaining an $r$-squared of 0.951, with all coefficients significant at the 99% confidence level. The regression results (Table 2) show that there is an overall tendency to increase the built-up per capita in the period 2000–2015, as indicated by the coefficient $>1$ for the variable built-up per capita in 2000. In addition, a large amount of available land for development per capita in 2000 contributed to a higher built-up per capita in 2015, whereas being an intermediate or predominantly urban region contributed to lower the built-up per capita. The estimated coefficients were then used to project built-up per capita in 2030, based on independent variables observed in 2015.

Table 3 summarizes the results of the built-up projection exercise for the EU27 and per urban-rural regional types. In all scenarios, the future built-up growth is estimated to be lower than in the period 2000–2015. This is due to a projected population growth more than 3 times

| Table 2. Regression results. |
|-------------------------------|
| Variables | Coefficient |
| Dependent: Built-up per capita in 2015 | |
| Independent: | |
| Built-up per capita 2000 | 1.077 | *** |
| Log of available land for development per capita in 2000 | 20.315 | *** |
| Intermediate and predominantly urban region dummy | -14.456 | *** |
| Country fixed effects | Yes | |
| Intercept | -60.007 | *** |
| $R^2$ | 0.951 | |

***p < 0.01

| Table 3. Summary results of the built-up area projection exercise for the EU27 and per urban-rural typology. Population growth is obtained from official Eurostat data (population data 2000 and 2015; population projections 2030). |
|-----------------------------------------------|
| Population growth (million inhabitants) | Built-up area growth (km²) |
| EU27 | Rural | Intermediate | Urban | EU27 | Rural | Intermediate | Urban |
| 2000–2015 | 15.4 | (+3.6%) | 4.8 | (+1.6%) | (+2.9%) | (+7.4%) | 12.1 | (+13.9%) | 14,787 | (+18.4%) | (+14.4%) | 6,593 | (+9.6%) | 3,175 |
| 2015–2030 (S1) | 4.9 | (+1.1%) | 3.8 | (-4.1%) | (+0.0%) | (+4.9%) | 4.052 | 425 | 1,564 | 2,063 |
| 2015–2030 (S2) | 13,307 | (+11.0%) | 4,640 | (+14.3%) | (+11.3%) | (+7.6%) | 5,922 | 2,745 |
| 2015–2030 (S3) | 12,725 | (+10.5%) | 3,961 | (+12.2%) | (+10.8%) | (+8.6%) | 5,659 | 3,104 |
smaller than in 2000–2015. Scenario 1 (‘containment’) entails an average built-up growth of only 3.4% (0.22% annual compound growth), while scenarios 2 and 3 (‘trend’ and ‘business-as-usual’) point to a built-up growth between 10.5% and 11.0% (0.67% – 0.70% annual compound growth) on average for the whole EU27. If we consider the urban-rural typology, scenarios 2 and 3 project a much higher built-up growth in predominantly rural and intermediate regions than in urban regions in both absolute and relative terms, and this despite the negative or near-zero population growth in the latter regions. In fact, of the roughly 13,000 km² additional built-up projected for the period 2015–2030, more than 75% are associated with predominantly rural and intermediate regions combined. Conversely, in the containment scenario, only 4,000 km² of additional built-up are projected, of which roughly 50% are attributed to predominantly urban regions. The higher proportion of built-up growth in urban regions in the ‘containment’ scenario is due to the fixed built-up per capita which does not allow for some efficiency gains, expected especially in predominantly urban regions, if the conditions set in scenarios 2 and 3 were to hold. Figure 5 indicates that the vast majority of countries would observe a growth of built-up areas around or below 5% if built-up per capita were to remain fixed at the observed levels in 2015 (scenario 1). Conversely, the ‘trend’ and ‘business-as-usual’ scenarios project a built-up area growth twofold or more than that of the ‘containment’ scenario for the majority of countries. Cyprus, Luxembourg, Malta and Ireland are the only countries where scenarios 2 and 3 project less built-up growth than the containment scenario 1. This is explained by the fact that built-up per capita in the period 2000–2015 had been increasing in these countries: a trend that continues through to 2030 in scenarios 2 and 3, leading to lower relative increases of built-up area. These are relatively small and very urbanized countries, with most of the population concentrated in one or few large cities, which explains the pressure to increase land use efficiency.

Considering scenarios 2 and 3, the countries with the highest projected built-up growth are Finland, Estonia, Lithuania, Sweden, Poland, Ireland and Romania, where at least one of the scenarios project a growth of 15% or more. Conversely, the smallest projected built-up area growth is expected in Cyprus, Italy, Spain, Luxembourg, Greece, Belgium and Croatia, where both scenarios project a growth of 7% or less. Although scenarios 2 and 3 point to similar aggregate built-up growth prospect for the EU27, higher differences between these scenarios are apparent at country level (see Figure 5).

Figure 5. Percentage growth of built-up areas between 2015 and 2030 in the EU27 member states according to different scenarios.
Finally, Figure 6 shows, for each NUTS3 region, the maximum projected built-up area growth between 2015 and 2030 based on the ‘trend’ and ‘business-as-usual’ scenarios and the difference in relation to the ‘containment’ scenario, highlighting the regions with potentially more room to control future built-up expansion.

**Discussion**

Land consumption and land use efficiency by human activities are increasingly under discussion especially in the European context. Although the outpace of land consumption in relation to population growth is a known global phenomenon (Huang et al., 2021; Li et al., 2022; Seto et al., 2012), recent global studies focusing on land use efficiency (Cai et al., 2020; Estoque et al., 2021) identified a specific behaviour of Europe driven by the modest demographic growth and the continuous expansion of built-up areas. The EU has set very ambitious goals in this domain with the objective of ‘no net land take in EU by 2050’ (European Commission. Directorate General for the Environment. & University of the West of England (UWE). Science Communication Unit, 2016). In this study, we examined European trends of built-up expansion and land use efficiency using state-of-the- art data and meaningful indicators. Our results confirm a negative outlook on the intermediate objective of reducing the pace of land consumption to an annual average of 800 km² by 2020 (European Commission, 2011; Mourelatou & European Environment Agency, 2018). Moreover, the efficiency of land take has further decreased as the population growth between 2000 and 2015 was lower than the previous 15 years (Eurostat Population Database, DEMO_PJAN¹⁰), leading to an increase of MLC and built-up per capita.

It is still under discussion how to identify and adopt a common methodology to assess the effectiveness and results of this policy (Decoville & Schneider, 2015). The land use efficiency indicator agreed at the international level for the Sustainable Development Goals (SDG 11.3.1), used to monitor progress towards the policy objective, is affected by several drawbacks, as discussed in previous research studies (Schiavina et al., 2019). A recent update of the indicator’s metadata¹¹ by its custodian agency (UN Habitat) in March 2021 did not comprehensively solve such issues, increasing
concerns on its interpretation and usefulness (see Supplementary material). However, this update recognizes some of these limitations and proposes the use of ‘secondary’ metrics in regions where population and/or built-up are declining.

In our analysis, we incorporate the suggested dimensions by developing a methodology that can be applied to the whole European context for the estimation of land take. Results indicate that between 2000 and 2015 the marginal land consumption in more than half of EU NUTS3 was more than six times the global average and that more than 30% of land consumption in the same period happened in areas experiencing a decline in their population. In addition, our scenario exercise indicates that without containment policies, and if recent observed trends hold until 2030, built-up areas will continue to grow at a much faster pace than population, especially outside predominantly urban regions. These results are coherent with findings by Huang et al. (2021) using different data sources, hence confirming the observed trend and the thesis of generalized increase of land use per capita.

A comparison of scenarios suggests that about 9,000 km\(^2\) of additional built-up areas could be avoided in the period 2015–2030 under a ‘containment’ objective in comparison with a ‘trend’ or ‘business-as-usual’ situation, and almost all located in predominantly rural and intermediate regions, where also most of the natural capital is located. The differential between scenarios varies significantly on a per-country basis, with countries like Finland, Poland and Lithuania standing out as the ones with more room for containment. Conversely, built-up growth in countries like Spain, Italy, Greece and Belgium should not be of major concern if future built-up per capita does not deviate too much from current levels, as the trend and business-as-usual scenarios suggest. The same is true for countries like Luxembourg, Malta, Ireland and Cyprus as long as the on-going urban densification trends continues.

In the patterns identified by the analysis, efficiency of land consumption displays significant variation with territorial typology. Predominantly urban regions, already displaying more efficient land use (i.e. accommodating more people in less built-up surface), usually maintain or even improve their efficient land consumption, which in some cases is comparable to the global MLC average. Rural areas, already less built-up land use efficient, are becoming even less efficient over time. Conversely, agglomeration effects of cities, reflected in innovation and higher growth and productivity, is drawing more people and, in particular, younger population (Goujon et al., 2021). To accommodate this increasing population and activities, urban areas need to also become more land use efficient, which is achieved by higher horizontal and vertical built-up densities. Such economies of scale extend to resource use beyond land, like energy and materials, thus contributing to sustainability (Bettencourt & Lobo, 2016; European Commission. Directorate General for Regional and Urban Policy, 2014). However, a recent trend detected in major urban areas may partially reduce this efficiency, as an increasing number of households in some European capital cities, reaching about 50% of the total, are composed of single residents (Eurostat, 2018).

These results, confirming recent findings based on a different definition of urban area (Li et al., 2022), point out the need for discussing the possible approaches to achieve sustainable urbanisation, efficiently manage built-up area expansion and to find alternatives to urban sprawl that represent the dominant mode of urban growth (ESPON, 2020b; Hersperger et al., 2020), but also the areas experiencing population decline. So, while the analysis herein identifies countries and regions where excess built-up growth is expected, and where room exists to contain further growth, land use planning and policies conducive to containment should not come at the cost of reducing housing supply. Adequate supply levels are important to ensure access to quality and affordable housing. Housing supply growth may coexist with urban land use containment policies by increasing density of urban fabric, both horizontally and vertically, as well as through urban renewal.

The approach developed in this work can be easily applied in other contexts and at a global scale given the availability of multitemporal global datasets on built-up areas and associated population (e.g. the GHS-BUILT and the GHS-POP). According to Jiang et al. (2021), as the world saw an overall
rise of the SDG indicator 11.3.1 from 1.68 in 1990–2000 to 1.74 in 2000–2015, meeting SDG Target 11.3 by 2030 requires slowing down the decline in compactness. This suggests that the compactness should be maintained or increased over time as also evidenced in the global detailed analysis at city level (Melchiorri et al., 2019; Schiavina et al., 2019; Schiavina et al. 2022).

Land use efficiency is closely related to socioeconomic development. To better understand policy implications of the observed trends, it is essential to take into consideration the relationship between not only land and population but also the economic urbanisation. Only when the comparisons across countries, regions or cities take into account also the differences among socioeconomic zones, population sizes together with different levels of GDP per capita it could then be possible to shed light on differences in urbanization patterns and hence contribute to decision-making in a spatially explicit manner.

Nevertheless, EU policies could take advantage of the classification here proposed by addressing demographic dynamics and land consumption issues with the appropriate action. The trends identified in our analysis and related policy implications are not unique to Europe, despite its early urbanization. China has experienced increasing urbanization rates despite slowing population growth overall and depopulation in rural areas and some cities (Wang et al., 2021). Development control, siting and strategic spatial planning could be applied to rural regions with continued built-up area expansion. Building stock refurbishment to achieve more energy efficient housing, brownfield redevelopment in de-populating predominantly urban regions or the implementation of other smart shrinkage policies (Yang, 2019) are examples of diversified place based interventions. The effectiveness of these latter actions are evident in the experiences of Detroit and Leipzig where population decline was an opportunity to decrease further sealing of open areas, avoiding abandoned buildings and unclaimed land areas (see Serbia and Japan), thus increasing the sustainability of land use (Segers et al., 2020; Wang et al., 2021). The set of possible actions can be further extended by considering interventions like densification, containment, regeneration, or more process related interventions like governance and sectoral policies (ESPON, 2020a). The efficiency of land use could also be achieved by looking at the other component of the equation, the demographic dynamics. The major aspect of demographic transitions in EU influencing land use changes are related to ageing and decline of population in remote areas and internal migration. These aspects should be targeted by specific policies addressing migrants integration and fertility rate support.

As possible limitations of our study, we consider built-up area as the single driver of land consumption. However, the consumption of land and the anthropization of the environment is not limited to the construction of buildings, especially in the context of the ‘no net land take in EU by 2050’ objective. In this sense, the transformation of natural areas into arable land or transportation infrastructures could also be included into the computation of land consumption (Decoville & Schneider, 2015).

A possible limitation of our study is that it does not differentiate between residential and non-residential built-up areas. In fact, it could be argued that a measure of the efficiency of land consumption in relation with population growth taking into account the residential component of built-up penalizes regions where services, transport, industrial, commercial or other infrastructures have been allocated to support socioeconomic development. In this respect, the lack of consistent data (i.e. in resolution, extent and temporal coverage) discriminating the nature of built-up area suitable for the analysis conducted in this study prevents the disentangling of such drivers in a comparable manner over time. Finally, this study relies on built-up areas mapped from optical decametric satellite imagery. Despite all the advantages and advances of this data source for mapping large areas, it is not devoid of limitations or uncertainties. However, the consistency in data and methodology used in mapped epochs (2000, 2015) and the fact that we analyse changes in built-up area, limits the effects of temporal biases. While the observed patterns provide evidence of known processes, their specific magnitude may be estimated more precisely in future due to progress in technology (i.e. use of Sentinel-2 imagery), or in the availability of time series, and change detection products for Europe (Corbane et al., 2021).
Forthcoming releases of the GHS-BUILT, especially through the Copernicus programme, or futures updates of the ESM (Corbane & Sabo, 2019) and LUISA Base Maps (Pigalani & Batista E Silva, 2021) should help in filling these gaps too.

Notes
1. https://www.urbanagendaplatform.org/european_union
2. The NUTS (Nomenclature of Territorial Units for Statistics) is the Eurostat’s official regional subdivision for collection and reporting of statistical data. It is structured in four hierarchical levels, from NUTS-0 (countries) to NUTS-3 (sub-regions).
3. https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units
   /nuts#nuts16
4. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset = demo_r_pjanaggr3&lang = en
5. https://ec.europa.eu/eurostat/cache/metadata/en/proj_esms.htm
6. https://gisco-services.ec.europa.eu/distribution/v1/nuts-2016.html
7. https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat
8. The amount of available land for urban development in each region is the surface area of the region minus the area that is already developed (LUISA basemap) and the areas where it is legally or technically impossible or very costly to develop: protected areas (NATURA 2000); high slopes (EU-DEM v1.1); glaciers, water surfaces, wetlands (LUISA basemap).
9. Dummy variable for NUTS3 regions classified as ‘Predominantly Urban’ or ‘Intermediate’.
10. https://ec.europa.eu/eurostat/databrowser/bookmark/f4ac31b4-e6a9-4fa6-ad33-83187d8834c1?lang=en
11. https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf
12. https://www.copernicus.eu/en

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Disclosure statement
No potential conflict of interest was reported by the author(s).

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Data availability statement
- GHS Built-up surface layer: GHS_BUILT_LDSMT_GLOBE_R2018A DOI:10.2905/jrc-ghsl-10,007: https://ghsl.jrc.ec.europa.eu/download.php
- Eurostat NUTS3 2016 boundaries: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts#nuts16
- Eurostat NUTS3 Population data 2000-2015: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_pjanaggr3&lang=en
- Eurostat NUTS3 Population data 2030: https://ec.europa.eu/eurostat/cache/metadata/en/proj_esms.htm
- Eurostat NUTS3 territorial typologies 2016: https://gisco-services.ec.europa.eu/distribution/v1/nuts-2016.html
- Artificial surfaces, water, wetlands, glaciers: LUISA basemap https://data.jrc.ec.europa.eu/dataset/93a3385d-624a-46fe-9138-9b5bc55a8f0a
- Protected areas: NATURA 2000 https://www.eea.europa.eu/data-and-maps/data/natura-11/natura-2000-spatial-data/natura-2000-shapefile-1
- Slopes: EU-DEM v1.1 https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=metadata
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