remote sensing

MDPI

Article

Ratio of Land Consumption Rate to Population Growth Rate in the Major Metropolitan Areas of Romania

Iulian-Horia Holobâcă [1], József Benedek [1,2,*], Cosmina-Daniela Ursu [1], Mircea Alexe [1] and Kinga Temerdek-Ivan [1]

[1] Faculty of Geography, Babeș-Bolyai University, 5–7 Clinicilor Street, 400006 Cluj-Napoca, Romania
[2] World and Regional Economics Department, University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary
* Correspondence: jozsef.benedek@ubbcluj.ro

Abstract: In 2015, the 2030 Agenda for Sustainable Development was adopted by all United Nations Member States and includes a set of 17 Sustainable Development Goals. The indicator, "Ratio of land consumption rate to population growth rate" (indicator 11.3.1) was proposed for the monitoring of urban development. The present study proposes the analysis of the built-up space evolution in relation to the demographic growth in the main metropolitan areas of Romania using the 11.3.1 indicator. Land consumption rate and population growth rate (LCRPGR) is used to assess the sustainability of urban growth, which takes into account both the change in the built-up area and in the population. LCRPGR is calculated as the ratio of land consumption rate (LCR) and the population growth rate (PGR). The analysis was conducted at the metropolitan area level for the 2006–2009, 2009–2015 and 2015–2020 periods. LCR and PGR proved to be very useful indicators for the monitoring of the intensity of built-up changes in the eight metropolitan areas both in time and in space and are useful for the local and central administrations, in both the context of achieving the sustainable development targets and goals and in conducting urban design and planning.

Keywords: land consumption rate (LCR); population growth rate (PGR); land consumption rate and population growth rate (LCRPGR); major metropolitan areas; Romania

Citation: Holobâcă, I.-H.; Benedek, J.; Ursu, C.-D.; Alexe, M.; Temerdek-Ivan, K. Ratio of Land Consumption Rate to Population Growth Rate in the Major Metropolitan Areas of Romania. *Remote Sens.* **2022**, *14*, 6016. https://doi.org/10.3390/rs14236016

Academic Editor: Tomaž Podobnikar

Received: 12 October 2022
Accepted: 23 November 2022
Published: 27 November 2022

1. Introduction

Cities are considered the "engines" of development, innovation and creativity [1,2]. Accelerated urban growth is a major present challenge. The world's urban population has recorded a rapid growth, from 751 million in 1950 to 4.2 billion in 2018 [3]. While 55.3% of the global population was living in urban areas in 2018 [3], the United Nations report in 2020 showed that the urbanization process would continue, so that over the next decade, an increase was estimated from 56.2% (year 2020) to 60.4% by the year 2030 [4]. In perspective, two thirds of the world's population (68%) will live in cities by the year 2050, which will represent a major challenge for the use of natural resources [5,6]. Almost 73% of the population of the European continent lives in urban areas and it is estimated that this percentage will reach 82% by 2050 [5,7]. The expansion of the built-up areas was noticed in most of the European regions, even in the regions where the population decreased [8,9]. There are also studies [10,11] which focus on the urban shrinkage as an opposite phenomenon to urban growth.

Within the UN Summit of September 2015, the 2030 Agenda for Sustainable Development was adopted. This includes a set of 17 Sustainable Development Goals (SDGs), 169 targets and 232 indicators to measure the progress [12]. Among these, the indicator, "Ratio of land consumption rate to population growth rate" (known as indicator 11.3.1) was proposed for the monitoring of urban development. This indicator is associated with the SDG 11, "Make cities and human settlements inclusive, safe, resilient and sustainable" and to the target 11.3, "enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries" by 2030 [13]. To date, few studies and reports on the monitoring of SDG 11.3.1 have been conducted. According to the report published by the UK Office for National Statistics [14], the land consumption in Great Britain grew more rapidly than the population during the 2013–2016 period; the LCR increased by 4.3%, and the PGR increased by 1.5%. The same report notes that in Wales, the LCR increased by 1.4% and the PGR increased by 1.9%; in Scotland, the LCR increased by 6.1% and the PGR increased by 1.4%; while in England, the LCR increased by 4.4% and the PGR increased by 2.3% over the analyzed period. The study conducted by Nicolau et al. 2019 [15] revealed a growth of the urban area and a decrease in the urban population in Portugal, leading to negative values in the LCRPGR. During the 2007–2011 period, the LCRPGR was 64.4 in Mainland Portugal, while at municipality level its value was negative in 72% of the cases. During the 2011–2015 period, the LCRPGR was −1.3 in Mainland Portugal and recorded negative values in 87% of the municipalities. The results of the Wang et al. (2020) [16] study revealed that out of the 340 analyzed cities in China, the number of cities where urban sprawl was not synchronized with population growth increased from 93 (27%) in 1990–2000 to 186 (54%) in 2000–2010; while in Mainland China, the LCRPGR value increased from 1.69 over the 1990–2000 period to 1.78 in 2000–2010. Zhou et al. (2021) [17] were also concerned with the computation of LCRPGR for the Beijing–Tianjin–Hebei (BTH) region over the 2000–2020 period. A spatial expansion of urban areas located mainly outside the great cities was noticed in Poland and Lithuania over the 2000–2018 period [18]. The average value of the LCRPGR in Poland was 0.115, while in Lithuania it was −0.054. In Poland, the PGR was 0.0132 and in Lithuania it was −0.0067, while the LCR was 0.0462 and 0.0067, respectively. According to Philip's study in 2021 [19], the population growth rate in Hamilton, Canada was higher than the land consumption rate. The values of indicator SDG 11.3.1 were 0.915, 0.841 and 0.783, respectively, during the analyzed periods 2000–2005, 2005–2010 and 2010–2015. Schiavina et al. 2019 [6] underestimated SDG 11.3.1 at several territorial scales for the 1990–2015 interval, at global level, for certain regions and 10,000 urban centers. The results of the study showed that the dense urban centers reported better performances in the efficiency of land use as compared to other types of settlements [6].

In Romania, Benedek et al. (2021) [20] calculated 90 indicators, among which SDG 11.3.1 (land use efficiency) is used in order to measure the progress in reaching the SDG at local and regional level. The present study complements the previous research and provides a grid-level analysis of SDG 11.3.1, by identifying the spatial evolution of the cities inside the administrative territorial units. This is the first study in Romania that uses this set of indicators and aims to provide territorial administrations with tools that allow monitoring progress and developing subnational strategies for SDG 11.3.1.

The urban growth models developed by the urban economy, regional science of human geography focus either on economic development or on demographic development. The novelty of our study is represented by the combination of the socio-economic and the spatial dimensions of urban development, by combining the classical statistical data with those achieved by terrestrial observations. Specifically, the main purpose of the study is the analysis of the built-up space evolution in relation to the demographic growth in the main metropolitan areas of Romania. The main work hypothesis is that the balanced and sustainable urban growth takes place when there is a balanced ratio between the land consumption rate and the population growth rate.

2. Materials and Methods

2.1. Study Area

In Romania, half of the country's population is concentrated in the eight metropolitan areas analyzed in this study (Bucharest, Brașov, Cluj-Napoca, Constanța, Craiova, Iași, Ploiești and Timișoara) [21]. These metropolitan areas have recorded the highest economic and social dynamics over the last two decades, by drawing significant economic and human capital flows [22], but at the same time generating numerous risks and conflicts [23,24].

The composition of the metropolitan areas analyzed in the present study (Figure 1) was obtained from the most recent studies [21,25], but also from the websites of the metropolitan areas that provide official reports. Each study area is composed of different TAUs (Territorial Administrative Units) such as municipalities, cities and communes. We selected the largest metropolitan areas (Figure 1), which are at the same time the areas with the highest economic dynamics. The basic data of the eight analyzed metropolitan areas (Figure 1) are shown in Table 1.

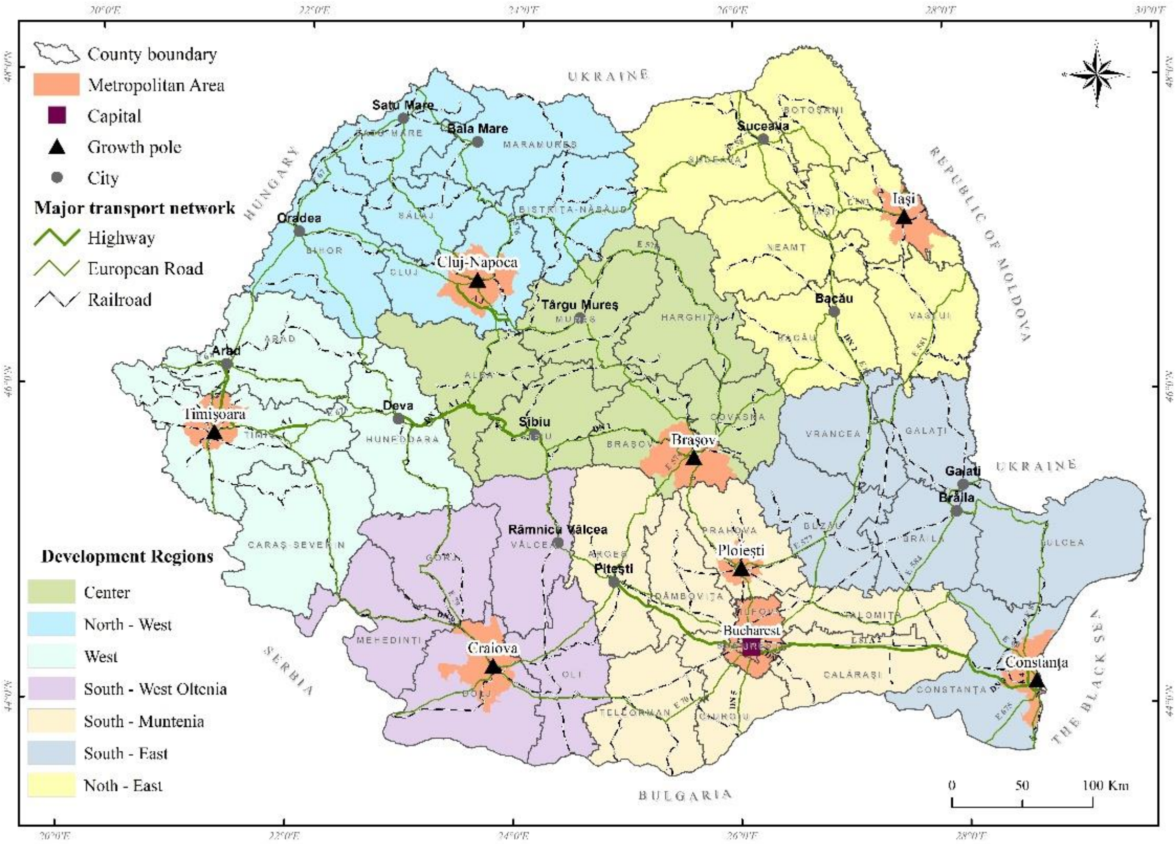

Figure 1. The location of the eight metropolitan areas in Romania.

Table 1. General data on the analyzed metropolitan areas.

Metropolitan Area	Surface (km^2)	Population (2020)	Cities	Communes	Total TAUs
Braşov	1969.52	493,350	7	15	22
Craiova	1822.57	407,312	3	26	29
Bucharest	1804.23	2,612,781	9	32	41
Cluj	1740.7	447,714	1	19	20
Iaşi	1238.64	544,361	1	20	21
Timişoara	1173.23	435,775	1	15	16
Constanţa	1115.62	490,264	6	10	16
Ploieşti	611.77	347,972	4	10	14

Source: National Institute of Statistics [26].

2.2. Data

2.2.1. Spatial Data

The spatial data used for the computation of the LCRPGR come from the official European Union website, GHSL—Global Human Settlement Layer [27], which provides free data and tools to investigate the human presence on Earth. The GHSL data are recommended by UN-HABITAT [13] in the metadata of the LCRPGR index [28] for the computation of this index at grid level. This data were chosen for their quality and for their complete coverage of the study interval.

For the computation of the indices, we used the GHS built-up grid data set [27] at 25 m resolution for the 2000 and 2014 reference years. According to the authors, this data set contains the density of the built-up area aggregated in the set containing the built-up surface at 30 m resolution. The initial data set was obtained by the processing of LANDSAT collections for the reference years.

In the case of the grids rendering the population, the GHS-POP R2019A data set [29] was used for the years 2000 and 2015, at a spatial resolution equal to that of the previous set (250 m). According to the metadata of this index [30], for the building of this data set, estimations of the resident population coming from the University of Colombia were used [31], disaggregated from the level of administrative units to grid cells. From the same source, we find that for this purpose, the built-up space density was considered from the data set for the built-up surface described above.

2.2.2. Built-Up and Population Data

The data referring to the built-up space for the years 2006, 2009 and 2015 were obtained from the Copernicus database, High Resolution Layers (HRL) Imperviousness Density [32]. This includes the spatial distribution of the impervious surfaces, expressed in imperviousness degrees 1–100%, as the result of a semi-automatic classification based on the NDVI index [33]. The database is available in raster format (GeoTiff), with a 20 m resolution, in the ETRS89, LAEA (EPSG:3035) coordinate system.

As the Copernicus database is updated once every 3 years, and the latest available database is 2018, the built-up areas for the year 2020 were obtained based on the overlapping of the set in 2015 with the satellite images in Google Earth.

The data referring to the population of the metropolitan areas for the years 2006, 2009, 2015 and 2020 were downloaded at TAU level, then summed up for each metropolitan area. Their source was the official website of the National Institute of Statistics [26].

2.3. Methods

2.3.1. General Considerations

The indicator, "Ratio of land consumption rate to population growth rate (LCRPGR)" measures the sustainable growth of urban development at the same spatial and temporal scale. The widespread methodology used for the assessment of the indicator 11.3.1 is the one proposed by the UN-Habitat which represents the ratio of land consumption rate (LCR) and the population growth rate (PGR).

Some studies are based on the application of some satellite images classification techniques (Isodata, maximum likelihood classification, object-oriented classification, artificial neural network classification, support vector machines, etc.), regression analysis [34,35] or on the use of various spectral indices such as: NDBI—Normalized Difference Built-up Index [36], IBI—Index-based Built-up Index [37], NDISI—Normalized Difference Impervious Surface Index [38], BCI—Biophysical Composition Index [39], MNDISI—Modified Normalized Difference Impervious Surface Index [40,41], NDII—Normalized Difference Impervious Index [42], RNDSI—Ratio Normalized Difference Soil Index [43], CBI—Combinational Build-up Index [44], CBCI—Combinational Biophysical Composition Index [45], ENDISI—Enhanced Normalized Difference Impervious Surfaces Index [46], etc.

The increase in the mapping accuracy of the urban built-up space resides in the combination of various techniques and types of remote sensing data. Therefore, there are studies combining GaoFen-1 optical images with Sentinel-1 SAR [47], optical images with radar images, Visible Infrared Imaging Radiometer (VIIRS) NTL with SRTM/ASTER DEM data [48], classification of Sentinel-1 SAR images with texture analysis [49] or DMSP-OLS NTL images (night-time light) and Landsat-8 images [50].

2.3.2. LCR, PGR and LCRPGR Computation

Land consumption rate and population growth rate (LCRPGR) is an indicator used to assess the sustainability of urban growth, which takes into account both the change in the built-up area and of the population. The method is based on the change intensity analysis inside the cities. The intensity analysis implies the comparison between a uniform expected growth rate noticed over a certain period of time. This method assumes that a stable growth rate over time characterizes sustainable growth (even if certain authors say that stable growth rate does not implicitly imply sustainable growth) [51].

The initial assumption in computing this sustainable development indicator originates in the claim that the built-up surface growth rate does not match the urban population growth rate according to the power law for the analyzed period. LCRPGR is calculated as the ratio between LCR and PGR (Equation (1)) based on the method of UN-Habitat [13] (Figure 2).

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

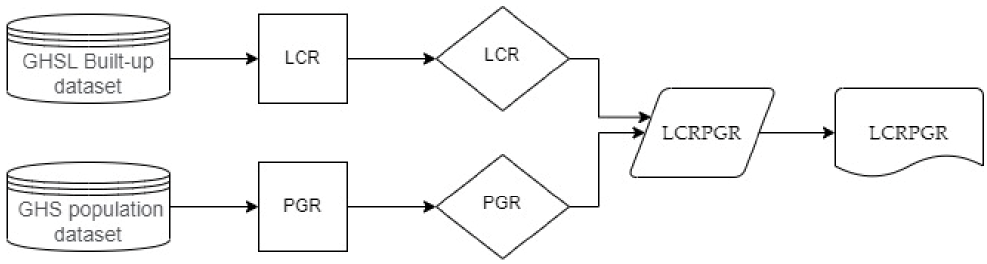

Figure 2. Workflow for calculating the LCRPGR indicator.

LCR indicates the intensity of change of the new built-up space over a period of time in a certain spatial location (Equation (2)).

$$\mathrm{LCR} = \mathrm{Ln}\,(\mathrm{Urb}_{t+n}/\mathrm{Urb}_t)/y \quad (2)$$

where: Ln—the natural logarithm, Urb_t is the built-up space at the beginning of the reference period, Urb_{t+n} is the built-up space at the end of the reference period and y—the number of years of the reference period.

As the LCR is subject to an exponential growth law, it is considered that the built-up surface from the end of the reference period is:

$$\mathrm{Urb}_{t+n} = \mathrm{Urb}_t \times e^{\mathrm{LCR}\ xy} \quad (3)$$

PGR indicates the dynamics of the population (births, deaths, migratory balance) in a certain period of time. This indicator is calculated according to the formula and it is subject, just like LCR, to an exponential growth law:

$$\mathrm{PGR} = \mathrm{Ln}\,(\mathrm{Pop}_{t+n}/\mathrm{Pop}_t)/y \quad (4)$$

$$\mathrm{Pop}_{t+n} = \mathrm{Pop}_t \times e^{\mathrm{PGR}\ xy} \quad (5)$$

where: Ln—the natural logarithm, Pop_t is the population at the beginning of the reference period, Pop $_{t+n}$ is the population at the end of the reference period and y—the number of years of the reference period.

According to the UN-HABITAT documentation [28], the accepted value for LCRPGR is 1. This goal occurs when the development of the built-up surface is coordinated with the increase in the population growth rate. The progress that a city makes for the achievement of this development goal should be analyzed from the perspective of the efforts made to bring this indicator towards the balance value. From this perspective, the UN-HABITAT proposes an interpretation key of the values of this index, which is presented in the Table 2.

Table 2. Classification of the LCRPGR values proposed by UN-HABITAT.

City Urban Extent Density	Indicator Value
10–150 persons/hectare	Below 1: Efficient land use Above 1: Inefficient land use
151–250 persons/hectare	Below 1: Moving toward efficiency Above 1: Moving away from efficiency
Greater than 250 persons/hectare	Below 1: Insufficient land per person Above 1: Moving toward sufficient land per person

Source: UN-Habitat, 2018 [28].

2.3.3. Built-Up Change Rate Computation

For the extraction of the built-up areas at the metropolitan area level, after downloading the raster associated to Romania, the first step was to redesign it in the Stereo 1970 national coordinate system, using the ArcMap 10.6.1 software. After cropping the built-up areas, these were converted into vector and the surfaces were computed in km^2. The present study considered that all polygons with an imperviousness degree higher than 0% were built-up areas.

After achieving the built-up areas in km^2 at the level of each administrative territorial unit, these were inserted in Excel, where the annual average growth rate of the built-up (BU) space was calculated, using the following formula:

$$BU = [(BU_t - BU_{t-1})/BU_{t-1} \times 100]/t - (t - 1) \quad (6)$$

BU_t = built-up area at the time $_t$; BU_{t-1} = built-up area at the previous year $_{t-1}$.

Thus, by dividing the growth rate for the entire period to the number of years corresponding to each interval, an annual average growth rate for each metropolitan area was obtained. Considering that the analyzed intervals are not equal, by relating to the number of years the data compatibility criterion was achieved.

Within this study, the data referring to the evolution of the built-up space have the role of confirming and supporting the observations resulting from the analysis of the LCR, PGR and LCRPGR indicators. In addition, by adding the images from Google Earth in the Discussion section, certain building types can be spatially validated.

3. Results

3.1. The Grid Level Analysis

The identification of the spatial evolution patterns inside the administrative territorial units for the 2000–2014 period was performed on the grid level analysis. The disaggregation of information at grid level enables the identification of land consumption intensity for urbanization and of the changes taking place in the population at a large scale of analysis.

3.1.1. The Spatial Dynamics of the Built-Up Area

Inside the metropolitan areas, but also inside the majority of the localities, the LCR values increased from the center to the periphery, such as the city of Bucharest (Figure 3). The LCR value within the city center was zero, and the LCR values in the suburbs ranged between 0 and 0.2. Where the changes are very intense, the value exceeded 0.2 locally. According to the formula used (Equation (2)), the zero values occur where the values of the built-up areas at the beginning of the analysis period are equal to those at the end of the analysis period (ln(1) = 0). This explains why the values in central areas of the localities, where the space available for new constructions was depleted, were 0, indicating the no-change areas.

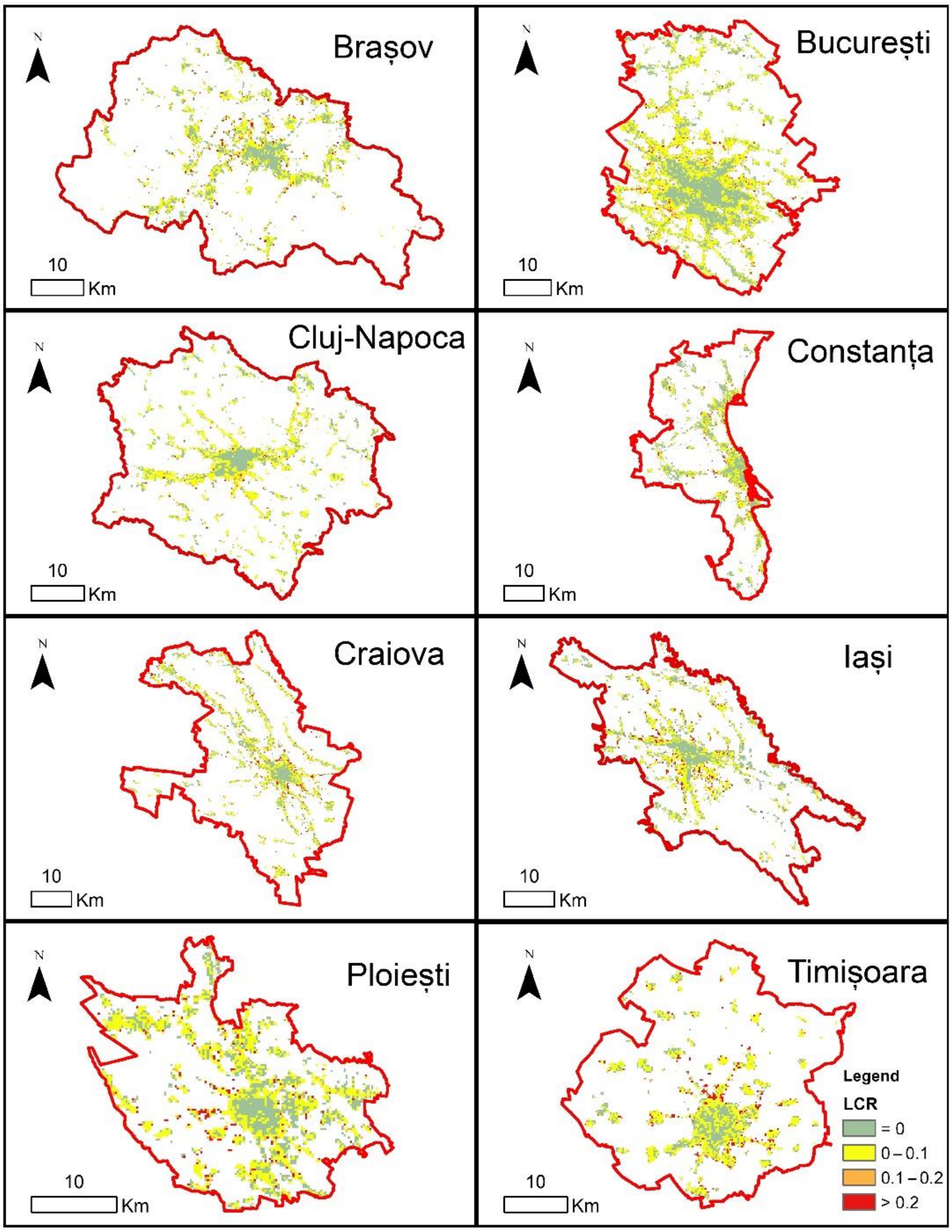

Figure 3. Distribution of the LCR values at grid level for 2000–2014.

However, the city centers are not change-free during the analyzed period, but these are, for all cities, within the 0–0.1 value class, indicating a modest land consumption rate. The most affected by the changes in their central areas are the cities of Timișoara, Ploiești and Bucharest. The other cities and especially Cluj-Napoca have fewer changes in their central part. This class is also very well represented in the localities surrounding the metropolis, especially in those that are further from the center.

The LCR values ranging between 0.1 and 0.2, thus indicating moderate intensity changes, have a much more modest spatial distribution. They occur as islands in the central area of the cities (Bucharest and Timișoara) or make the transition to the high intensity change class (LCR > 0.2).

The highest LCR values could be observed mainly in the immediate proximity of the metropolitan areas, where land was available for urbanization. The distribution analysis of these values gives us a perspective on the preferred development trends. A radial concentric distribution of the LCR > 0.2 values can be noticed in the cities on plains (Bucharest, Craiova and Timișoara) or on development axes in the other cities.

3.1.2. The Spatial Dynamics of the Population

In the case of grid distribution of the PGR values (Figure 4), one can see a completely new distribution of the values as compared to the LCR values in the central area of the cities throughout the 2000–2014 period. Most of these values are negative. According to the computation formula (Equation (4)), this aspect indicates the fact that the population from the end of the period is smaller than the one in the beginning. In all the analyzed localities on the grid data we used, we can notice a decrease tendency of the population in the central area of the metropolises.

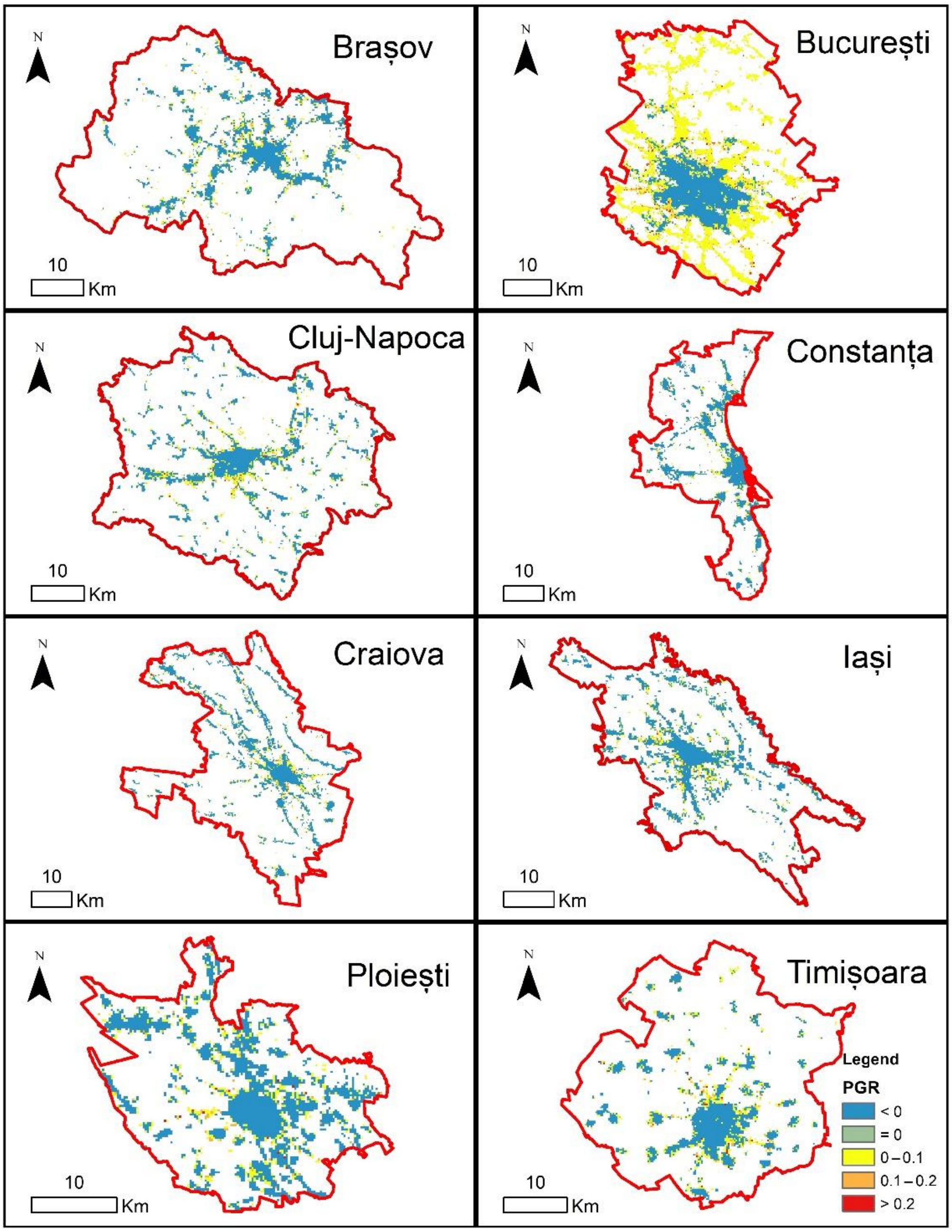

Figure 4. Distribution of the PGR values at grid level for 2000–2014.

This finding is valid also for the localities orbiting around the metropolises, except Bucharest. The positive values of the index predominate in all the localities around the capital. Even if these values are positive, the ones in class 0–0.1 predominate, and these indicate a low change intensity.

The PGR values higher than 0.1 are noticed in the areas around the metropolises that also had a higher land consumption intensity. A part of these higher values can be noticed also in the surrounding localities, with a similar distribution to those of the LCR. We can notice that if we make an exception for the situation in Bucharest, the intensity of changing the PGR values decreases as we move away from the metropolitan center.

3.1.3. Spatial and Temporal Dynamic Changes in LCRPGR

The distribution of the value classes of the LCRPGR index and the percentage share of the classes is presented in Figure 5 and Table 3. For the analyzed period, one may notice that if we take into consideration the entire surface of the analyzed urban areas, the class with the highest share is efficient land use (in green). According to the UN-HABITAT interpretation key, this situation occurs when the analysis period is marked either by a balanced population decrease in relation to the decrease in the built-up area or by a balanced population growth against the increase in the built-up area.

Table 3. The percentage distribution of the LCRPGR classes for the 2000–2014 period. (1—efficient land use, 2—inefficient land use, 3—moving toward efficiency, 4—moving away from efficiency, 5—insufficient land per person, 6—moving toward sufficient land per person).

	1	**2**	**3**	**4**	**5**	**6**
Brașov	72.2	19.6	5.4	0.0	2.7	0.0
Bucharest	56.2	19.2	5.7	0.6	18.1	0.1
Cluj	58.6	27.0	14.3	0.1	0.0	0.0
Constanța	70.4	17.0	11.4	0.2	1.0	0.0
Craiova	70.0	20.4	4.0	0.0	5.6	0.0
Iași	66.2	21.5	6.0	0.0	6.3	0.0
Ploiești	76.1	15.0	8.9	0.0	0.0	0.0
Timişoara	54.1	28.6	16.9	0.1	0.2	0.0

Since there were no decreases in the built-up area recorded during the study period, in our case, we speak about the second situation. For all the analyzed metropolitan areas, this class occupies the percentage values higher than 50% and ranges between 54.1% in Timișoara and 76.1% in Ploiești. However, we can notice the values grouping around 56% (Bucharest, Cluj-Napoca and Timișoara) and 72% (Constanța, Craiova and Ploiești), while in Iași, this is found somewhere around half of the interval (66%). If we analyze the distribution of this class on the grid, we can notice that most of the pixels belonging to this class occur in the localities that gravitate around the metropolis and, to a lower extent, in the periphery of the metropolis.

The second class in terms of frequency is inefficient land use (in brown), which enables the identification of the areas with a growth rate much higher than that of the built-up area against population growth. Considering an average share of 21% for the eight analyzed metropolitan areas, this class ranges between only 15% in Ploiești and over 25% in Cluj (27%) and Timișoara (28.6%).

If we analyze the spatial distribution of this class (Figure 5), we notice that it occurs especially at the periphery of the metropolis and in the near localities where there are extensive residential, commercial and industrial buildings. This aspect is visible mainly around Bucharest and Cluj.

For most of the cities, except Bucharest, moving toward efficiency is the third frequency class (in yellow). This class corresponds to the pixels where population density is average (151–250 persons/ha) and one can notice a population decrease over the analyzed period. This class characterizes the average density parts in the metropolis, where the population grid data indicate an increase in the number of inhabitants throughout the period of study. The largest area percentages are in Cluj and Timișoara (around 15%) and they characterize the central part of the cities. A lower frequency is recorded in Craiova (4.0%) where the city center has a higher population density.

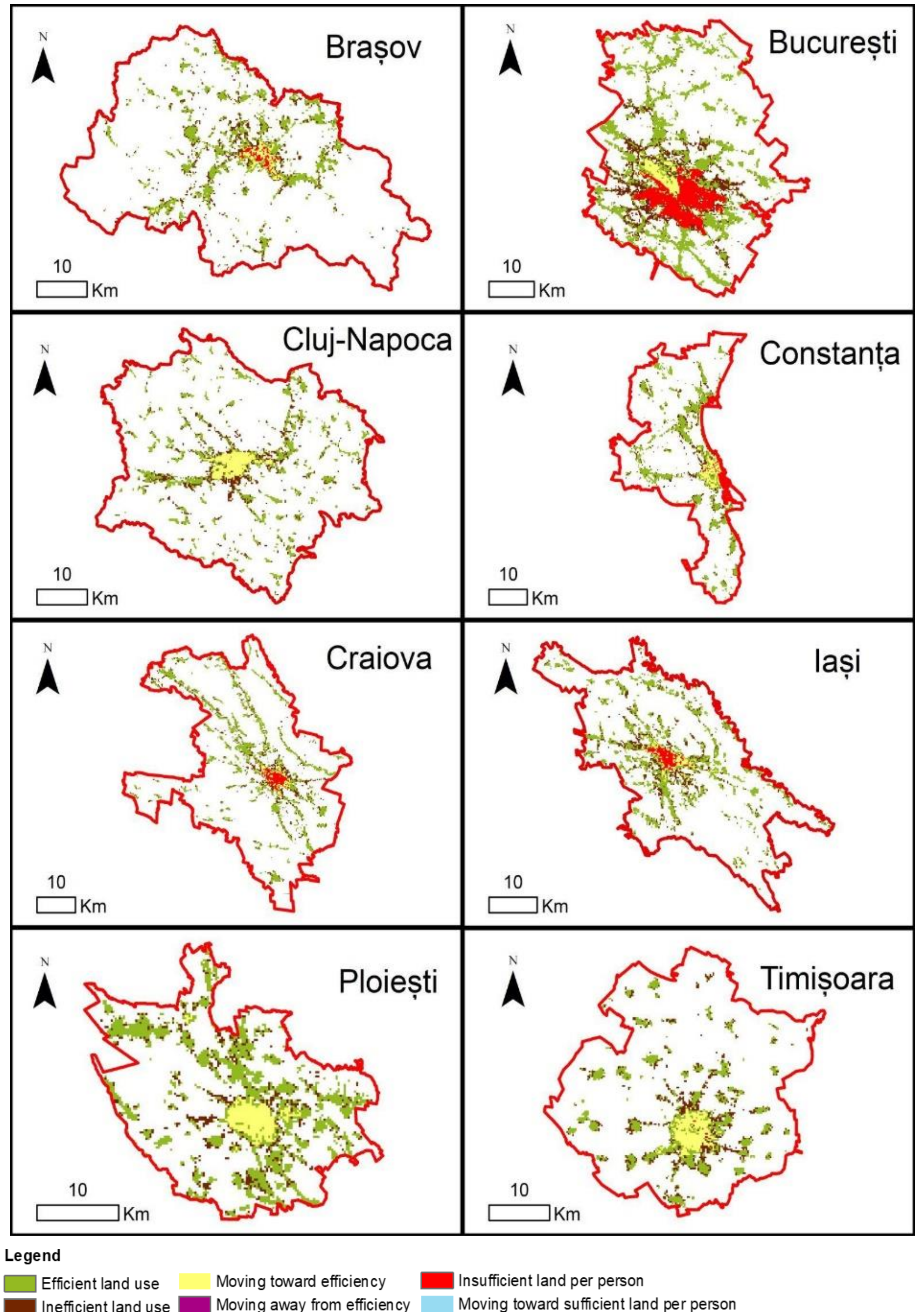

Figure 5. The LCRGR classes at grid level for 2000–2014.

Moreover, if the population density exceeds 250 persons per hectare and the intensity of the built-up area growth is reduced during the analyzed period, then we can consider that there is insufficient land per person (in red). In the case of the analyzed urban areas, such areas have a low share (below 7%) and some cities (Cluj-Napoca) do not have an

LCRPGR class. Bucharest is an exception, as this class occupies 18.1%, with a compact distribution in the central part of the metropolis.

The classes *moving away from efficiency* (urban areas of average density and a higher population growth rate, in purple) and *moving toward sufficient land per person* (densely populated urban areas with a significant growth rate of the built-up area, in light blue) have very low shares in all cities (below 0.7%) and a low impact on the spatial distribution of the LCRPGR values.

3.2. The Metropolitan Area Level Analysis

The overall analysis performed at the metropolitan area level enabled the identification of the temporal dynamics of LCRPGR and the expansion of the analysis until 2020. Even if the spatial information is lost by aggregation, we have the possibility to multiply the analysis periods. In our case, the analysis was conducted for the 2006–2009, 2009–2015 and 2015–2020 periods.

3.2.1. LCR at Metropolitan Area Level

The temporal variability of the metropolitan areas enabled a deeper understanding for us of the temporal dynamics of the built-up change intensity. A general remark is that for all the areas and all the subperiods, the values of the index are positive and different from 0. This aspect suggests that we do not have cities that lose their built-up area and that in all situations we notice an increase in this area at different intensities.

If we analyze the development trajectories of the metropolitan areas, we notice that the city of Cluj-Napoca is an exception (Table 4). The highest intensity (0.55) for all the cities and for all the periods can be noticed here over the first period (2006–2009). The intensity suddenly decreases to a modest value (0.006) over the next period and then we can again notice an increase in intensity corresponding to the moderate class (0.011).

Table 4. Temporal variability of the LCR values at metropolitan area (MA) level (low 0–0.1, moderate, 0.1–0.2 and high > 0.2 intensity, the increasing values are in green).

MA	LCR		
	2006–2009	**2009–2015**	**2015–2020**
Brașov	0.012	0.024	0.010
Cluj	0.055	0.006	0.011
Constanța	0.002	0.009	0.003
Craiova	0.002	0.014	0.002
Iași	0.010	0.013	0.006
Ploiești	0.004	0.004	0.003
Timişoara	0.012	0.016	0.007
Bucharest	0.009	0.011	0.005

For all the other metropolitan areas, the maximum intensity was reached during the intermediate period (2009–2015). These reached a high intensity in Brașov and a moderate intensity in the other four cases. For the last analyzed period, we notice a decrease in change intensity from the built-up area (with the exception mentioned previously) and the reduction in the LCR values toward the low intensities class. For most of the metropolitan areas, a period of at least average change intensity is highlighted. The exceptions are the cities of Ploiești and Constanța, which had a low intensity for all the subperiods.

3.2.2. PGR at Metropolitan Area Level

In terms of the PGR values' variability during the analyzed subperiods (Table 5), we can notice several trajectories. For most of the areas, we can notice a growth trend of PGR values from one period to another and even the transition to a superior class for Iași and Cluj. In the case of Bucharest and Constanța, the intensity decreases during the second period (2009–2015). The third category of cities is represented by those which lost population throughout all three periods (Ploiești and Craiova).

Table 5. Temporal variability of the PGR values at the level of metropolitan area (low 0–0.1, moderate, 0.1–0.2 and high > 0.2 intensity, the increasing values are in green and decreasing values are in red).

MA	PGR		
	2006–2009	**2009–2015**	**2015–2020**
Brașov	0.001	0.002	0.003
Cluj	0.007	0.010	0.013
Constanța	0.003	0.002	0.000
Craiova	−0.001	−0.002	−0.003
Iași	0.006	0.016	0.018
Ploiești	−0.001	−0.003	−0.006
Timişoara	0.006	0.007	0.009
Bucharest	0.004	0.001	0.009

3.2.3. LCRPGR at Metropolitan Area Level

The temporal variability of the LCRPGR classes helps us better understand how the built-up area growth coordinates with the population dynamics for each metropolitan area. Special attention should be paid to the metropolitan areas of Craiova, Ploiești and Brașov, where we noticed either an inefficient land use or a moving away from the efficient use in all the three periods along the time (Table 6).

Table 6. Temporal variability of the LCRPGR classes at metropolitan area level.

MA	LCRPGR		
	2006–2009	**2009–2015**	**2015–2020**
Brașov	Moving away from efficiency	Moving away from efficiency	Moving away from efficiency
Cluj-Napoca	Moving away from efficiency	Efficient land use	Efficient land use
Constanța	Efficient land use	Moving away from efficiency	Inefficient land use
Craiova	Inefficient land use	Inefficient land use	Moving away from efficiency
Iași	Moving away from efficiency	Efficient land use	Efficient land use
Ploiești	Inefficient land use	Inefficient land use	Moving away from efficiency
Timişoara	Moving away from efficiency	Moving away from efficiency	Efficient land use
Bucharest	Moving away from efficiency	Moving away from efficiency	Efficient land use

Constanța is a special case, where there is a transition from an efficient use of the land during the first period toward an inefficient land use over the last period. This continuous degradation of the LCRPGR values can be due to its position on the Romanian seaside of the Black Sea. Located in an important touristic area, it is possible that the extension of the tourism infrastructure or secondary residences is not correlated to the resident population growth.

For Bucharest, Iași, Timișoara and Cluj, we can notice that after one or two periods when the LCR values were not correlated with the PGR, towards the end of the analyzed period the values of the two parameters synchronize and a correlation occurs between the urban population growth intensity and the intensity of the built-up land increase.

3.3. Remarks on the Growth of the Built-Up Area in the Metropolitan Area

For the entire analyzed interval (2006–2020), Cluj had the highest average growth of the built-up area (approx. 2% each year) (Table 7). A significant increase was recorded in the Braşov, as well, with an annual increase of approx. 1.8%. The third place is occupied by Timişoara (1.32%), followed by Iaşi (approx. 1%). Bucharest and Craiova have had a sub-unit growth (between 0.7–0.89%), while Constanţa and Ploieşti come last (below 0.53%).

Table 7. The evolution of the built-up area in metropolitan areas.

Metropolitan Area	Built-Up Space Difference (km^2)				Built Space Change Rate (%)			
	2009–2006	2015–2009	2020–2015	2020–2006	2006–2009	2009–2015	2015–2020	2006–2020
Cluj	11.45	2.68	4.60	18.73	5.96	0.59	1.18	2.09
Braşov	2.44	10.18	3.96	16.58	1.26	2.53	1.03	1.83
Timişoara	2.65	8.12	3.22	13.99	1.17	1.73	0.75	1.32
Iaşi	2.14	5.55	2.34	10.04	1.06	1.33	0.62	1.06
Bucharest	7.94	20.54	8.50	36.97	0.89	1.12	0.52	0.89
Craiova	0.60	7.47	0.84	8.91	0.23	1.44	0.18	0.74
Constanţa	0.61	5.68	1.57	7.86	0.20	0.90	0.28	0.53
Ploieşti	0.97	1.59	1.16	3.72	0.45	0.36	0.31	0.37

Data source: processing based on the Copernicus data [32].

In the three analyzed periods (2006–2009, 2009–2015 and 2015–2020), the eight study areas have occupied various positions in the ranking based on the annual increase rate of the built-up space (expressed in percentages on the vertical axis), with the metropolitan areas represented in ascending order on the horizontal axes in Figure 6. Cluj took the leading position among all metropolitan areas, both during the 2006–2009 period and 2015–2020 period, while Braşov was the first place during 2009–2015 period. A consistent position in the rank was maintained by Iaşi, Bucharest and Timişoara, while Constanţa, Ploieşti and Craiova fell on the last positions in the ranking. Certain types of buildings are considered (residential, industrial areas, communication ways, airport runways or solar parks).

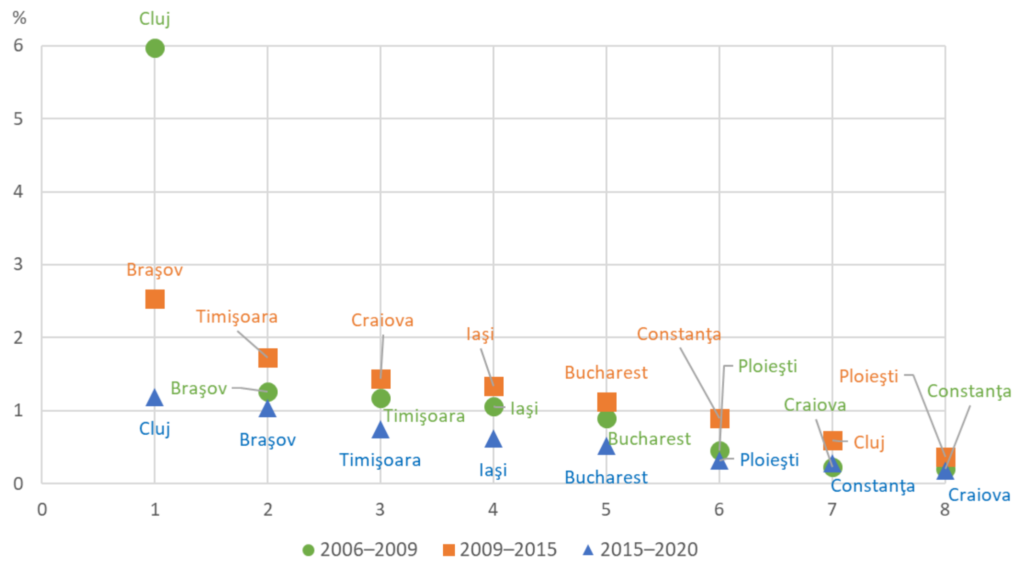

Figure 6. The built-up space average increase rate ranking for the three intervals (Table A1).

Analyzing the annual average rate of the increase cumulated throughout the three intervals (Figure 7), we notice that for most metropolitan areas (except Cluj), the highest increase rate was recorded during the 2009–2015 interval, when major infrastructure elements were built (European and national roads, airport runways) in Braşov, Timişoara, Craiova and Constanţa. However, in Iaşi, Bucharest and Ploieşti, this aspect is not valid; the increase is identified in the residential (Iaşi), industrial (Ploieşti) or mixed (Bucharest) areas. In Cluj, the explosive increase during the 2006–2009 interval is due also to the construction of a highway. During the 2015–2020 interval, the increases are moderated in all metropolitan areas, the highest increases are in the Cluj (1.18%), and the lowest increase is in Craiova (0.28%).

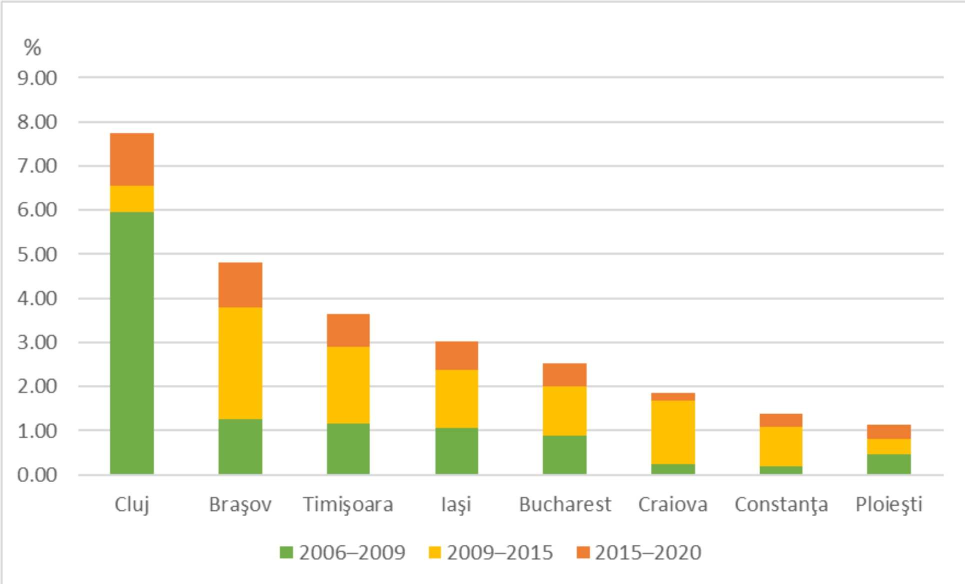

Figure 7. The built-up space increase rate evolution for the three intervals.

4. Discussion

A representative aspect for all metropolitan areas is related to the increase distribution within TAUs comprising the area. At both percentage level (Table 7) and grid level (Figure 3), we can notice that it is not the county seat municipalities that record significant increases in the built-up space. Within the LCR analysis (Figure 3), it is noted that the major urban centers have moderate increases only towards the peripheries. Buildings are constructed in the city built-up areas in few cases (such as Iaşi, Timişoara, Ploieşti and Bucharest). This is due to the lack of free lands, as well as the high prices. Thus, the preferred areas are the nearby communes that have significant space reserves, to the disadvantage of the TAUs located at the periphery of the metropolitan areas, which are not preferred for the expansion of the buildings due to the distance towards the major urban center [52].

From the spatial LCRPGR distribution (Figure 5), it is noted that, generally, the expansion of the built-up areas in the adjacent urban centers are mainly falling in the "Inefficient land use" class, while the existing urban nuclei fall within the "Efficient land use" class. This shows that there were different rhythms between the increase in the built-up space and population growth, as the built-up space grew faster.

The analysis of the built-up space at TAU level, subsequently correlated to images in the Google Earth archive, reveals that each metropolitan area had certain typologies of built-up spaces which have expanded throughout the three intervals. The residential areas have developed mainly in most of the metropolitan areas, especially in the TAUs near the urban centers (Figure 8). The industrial areas are in the same situation (Figure 9). In addition, significant increases in the built-up space in some of the TAUs were due to highway and national roads construction (Figure 10). These were classified by the Copernicus database as built-up spaces. Iaşi is the only one where no infrastructure elements were built. The mixed development is the category which includes both the expansion of the residential areas and of the industrial areas. The touristic infrastructure was developed both in the mountain resorts in Braşov, and in Constanţa (Figure 11). Another category of built-up spaces includes the photovoltaic parks. These are developed in Braşov, Craiova and Ploieşti.

Figure 8. Expansion of the built-up space in Valea Lupului, Iaşi: 2017 (**left**) and 2020 (**right**).

Figure 9. Expansion of an industrial area in Dragomireşti Vale, Bucharest: 2015 (**left**) and 2020 (**right**).

Figure 10. Construction of a sector from the A3 highway Gilău-Nădăşelu: 2013 (**left**) and 2019 (**right**).

Figure 11. Development of the accommodation infrastructure in Năvodari, Constanţa: 2015 (**left**) and 2020 (**right**).

Furthermore, the evolution of the built-up space revealed that the areas where the construction of such residential complexes started in a certain period have subsequently developed and became denser over the next years. Due to the existence of the free space, these have a potential for development in the future as well. Besides the residential complexes, in some TAUs the individual buildings also expanded (for example in the localities of Buftea; Berceni, Bucharest; Agigea, Constanţa; Bârnova; Ciurea, Iaşi; Poiana, Braşov; Predeal; Zărneşti, Braşov). In Braşov, for example, on the Google Earth images, there are many bounded plots in the TAUs near the county seat municipality, which indicates that construction will continue in these areas. The industrial platforms also follow the same trend. Companies that initially had one production hall, have expanded over time and have the potential to do this in the future due to the existence of space reserves.

5. Conclusions

If the LCR values were positive for the locations and for all analyzed periods, indicating an increased pressure on the lands, pursuant to the internal migration and the expansion of social values with preferences to individual households, the PGR values revealed that half of the towns underwent a stagnation period or even a decrease in the population, as a result of population suburbanization.

The grid level desegregation enabled a finer spatial analysis and the identification of the areas where the LCR and PGR values are not correlated. This situation may be noticed especially at the periphery of the metropolises and in their vicinity. These require increased attention for spatial planning, the only tool that enables the public intervention in this regard.

Moreover, the analysis of the LCRPGR values in the metropolitan area enabled a temporal investigation throughout three sub-periods, which identified the development trajectories. While half of the metropolitan areas have made the transition from a LCRPGR value class suggesting moving away from efficiency or even an inefficient use of the lands to an efficient use, the other half had a trajectory towards the inefficient land use. The results described above conclude that urban development is a contradictory process as there is no dominant trend towards a higher sustainability state, but that there are areas of significant progress in this regard.

As mentioned in the article [52], the main limitation of the indicator is the inability to include the vertical dimension of constructions. Another limitation is the uncertainty in the indicator relates to the concept of built-up area in the land-use classification.

LCR and PGR proved to be very useful indicators for the monitoring of the intensity of built-up changes in the eight metropolitan areas, both in time and in space, highlighting the urbanization models both at metropolitan level and at microscale level, where the land consumption relates to population growth. These two indicators are useful for the local and central administrations, both in the context of achieving the sustainable development targets and goals and in conducting urban design and planning. Furthermore, LCRPGR can be a good way to identify the spatial trajectory of the analyzed areas.

Author Contributions: Conceptualization, J.B.; data curation, K.T.-I.; formal analysis, I.-H.H., M.A.; investigation, I.-H.H.; methodology, K.T.-I. and C.-D.U.; software, I.-H.H.; writing—original draft, I.-H.H., J.B. and C.-D.U.; writing—review and editing, M.A., K.T.-I., I.-H.H. and C.-D.U. All authors contributed equally to the research presented in this paper and to the preparation of the final manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by a grant of the Ministry of Research and Innovation, CNCS-UEFISCDI, project number PN-III-P4-ID-PCE-2020-0920, within PNCDI III. The publication of this article was also supported by the 2022 Development Fund of the Babeş-Bolyai University.

Acknowledgments: The authors acknowledge the funding support for this study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The built-up space average increase rate ranking for the three intervals.

Position in the Rank	The Built-Up Space Average Increase Rate (%)		
	2006–2009	2009–2015	2015–2020
1	Cluj (5.96%)	Braşov (2.53%)	Cluj (1.18%)
2	Braşov (1.26%)	Timişoara (1.73%)	Braşov (1.03%)
3	Timişoara (1.17%)	Craiova (1.44%)	Timişoara (0.75%)
4	Iaşi (1.06%)	Iaşi (1.33%)	Iaşi (0.62%)
5	Bucharest (0.89%)	Bucharest (1.12%)	Bucharest (0.52%)
6	Ploieşti (0.45%)	Constanţa (0.9%)	Ploieşti (0.31%)
7	Craiova (0.23%)	Cluj (0.59%)	Constanţa (0.28%)
8	Constanţa (0.2%)	Ploieşti (0.36%)	Craiova (0.18%)

References

1. Florida, R. *The Rise of the Creative Class*; Basic Books: New York, NY, USA, 2002.
2. Glaeser, E. *The Triumph of the City*; Penguin: New York, NY, USA, 2012.
3. United Nations, Department of Economic and Social Affairs. Revision of World Urbanization Prospects. 2018. Available online: https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html (accessed on 21 July 2022).
4. United Nations Human Settlements Programme (UN-Habitat). World Cities Report 2020. The Value of Sustainable Urbanization. Available online: https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf (accessed on 21 July 2022).
5. Ghazaryan, G.; Rienow, A.; Oldenburg, C.; Thonfeld, F.; Trampnau, B.; Sticksel, S.; Jürgens, C. Monitoring of Urban Sprawl and Densification Processes in Western Germany in the Light of SDG Indicator 11.3.1 Based on an Automated Retrospective Classification Approach. *Remote Sens.* **2021**, *13*, 1694. [CrossRef]
6. Schiavina, M.; Melchiorri, M.; Corbane, C.; Florczyk, A.J.; Freire, S.; Pesaresi, M.; Kemper, T. Multi-Scale Estimation of Land Use Efficiency (SDG 11.3.1) across 25 Years Using Global Open and Free Data. *Sustainability* **2019**, *11*, 5674. [CrossRef]
7. European Environmental Agency (EEA). *Urban Sprawl in Europe Joint EEA-FOEN Report 2016*; European Environmental Agency—Swiss Federal Office for the Environment: Luxembourg, 2016; ISBN 978-92-9213-738-0.
8. Haase, D.; Kabisch, N.; Haase, A. Endless urban growth? On the mismatch of population, household and urban land area growth and its effects on the urban debate. *PLoS ONE* **2013**, *8*, e66531. [CrossRef]
9. Rienow, A.; Stenger, D.; Menz, G. Sprawling cities and shrinking region—Forecasting urban growth in the Ruhr for 2025 by coupling cells and agents. *Erdkunde* **2014**, *68*, 85–107. [CrossRef]
10. Zhai, W.; Jiang, Z.; Meng, X.; Zhang, X.; Zhao, M.; Long, Y. Satellite monitoring of shrinking cities on the globe and containment solutions. *iScience* **2022**, *25*, 104411. [CrossRef] [PubMed]
11. Dong, B.; Ye, Y.; You, S.; Zheng, Q.; Huang, L.; Zhu, C.; Tong, C.; Li, S.; Li, Y.; Wang, K. Identifying and classifying shrinking cities using long-term continuous night-time light time series. *Remote Sens.* **2021**, *13*, 3142. [CrossRef]
12. United Nations General Assembly. *Resolution 70/1, Transforming our World: The 2030 Agenda for Sustainable Development*; United Nations General Assembly: New York, NY, USA, 2015.
13. UN-Habitat. Sustainable Development Goal 11+ Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable: A Guide to Assist National and Local Governments to Monitor and Report on SDG Goal 11+ Indicators. Monitoring Framework—Definitions—Metadata—UN-Habitat Technical Support; 2020. Available online: https://www.local2030.org/library/60/SDG-Goal-11-Monitoring-Framework-A-guide-to-assist-national-and-local-governments-to-monitor-and-report-on-SDG-goal-11-indicators.pdf (accessed on 15 March 2022).
14. UK Office for National Statistics. Using Innovative Methods to Report against the Sustainable Development Goals. 2018. Available online: https://www.ons.gov.uk/economy/environmentalaccounts/articles/usinginnovativemethodstoreportagainstthesustainabledevelopmentgoals/2018-10-22 (accessed on 21 July 2022).
15. Nicolau, R.; David, J.; Caetano, M.; Pereira, J.M.C. Ratio of Land Consumption Rate to Population Growth Rate- Analysis of Different Formulations Applied to Mainland Portugal. *ISPRS Int. J. Geo-Inf.* **2018**, *8*, 10. [CrossRef]
16. Wang, Y.; Huang, C.; Feng, Y.; Zhao, M.; Gu, J. Using Earth Observation for Monitoring SDG 11.3.1-Ratio of Land Consumption Rate to Population Growth Rate in Mainland China. *Remote Sens.* **2020**, *12*, 357. [CrossRef]
17. Zhou, M.; Lu, L.; Guo, H.; Weng, Q.; Cao, S.; Zhang, S.; Li, Q. Urban Sprawl and Changes in Land-Use Efficiency in the Beijing–Tianjin–Hebei Region, China from 2000 to 2020: A Spatiotemporal Analysis Using Earth Observation Data. *Remote Sens.* **2021**, *13*, 2850. [CrossRef]
18. Calka, B.; Orych, A.; Bielecka, E.; Mozuriunaite, S. The Ratio of the Land Consumption Rate to the Population Growth Rate: A Framework for the Achievement of the Spatiotemporal Pattern in Poland and Lithuania. *Remote Sens.* **2022**, *14*, 1074. [CrossRef]

19. Philip, E. Coupling Sustainable Development Goal 11.3.1 with Current Planning Tools: City of Hamilton, Canada. *Hydrol. Sci. J.* **2021**, *66*, 1124–1131. [CrossRef]
20. Benedek, J.; Ivan, K.; Török, I.; Temerdek, A.; Holobâcă, I.-H. Indicator-based assessment of local and regional progress toward the Sustainable Development Goals (SDGs): An integrated approach from Romania. *Sustain. Dev.* **2021**, *29*, 860–875. [CrossRef]
21. Ionescu-Heroiu, M.; Cristea, M.; China, A.M.; Butacu, B.C.; Dolean, B.E.; Vinţan, A.D.; Franţ, O.; Mihăilescu, G.M.; Moldovan, S.C.; Sfârlea, E.V. Romania Catching-Up Regions: Metropolitan Romania. *World Bank* **2019**, *145528*, 1–91.
22. Török, I.; Benedek, J. Spatial Patterns of Local Income Inequalities. *J. Settl. Spat. Plan.* **2018**, *9*, 77–91. [CrossRef]
23. Benedek, J.; Varvari, Ș.; Litan, C. Chapter 8: Urban growth pole policy and regional development: Old vine in new bottles. In *Regional and Local Development in Times of Polarization. Re-Thinking Spatial Policies in Europe*; Lang, T., Görmar, F., Eds.; Palgrave/MacMillan: Basingstoke, UK, 2019; pp. 173–196. [CrossRef]
24. Ivan, K.; Benedek, J.; Ciobanu, S. School-age pedestrian-vehicle crashes vulnerability. Case study: Bucharest city, Romania. *Sustainability* **2019**, *11*, 1214. [CrossRef]
25. Kriss, P.; Ivanov, I.; Taralunga, N.; Racoviceanu, S.C.; Stadler, R.L.; Ghintuiala, D.L.; Ionescu-Heroiu, M.; Silimela, Y.T.; Vinţan, A.D.; Moldoveanu, G.A. Romania Catching-Up Regions: Interjurisdictional Cooperation Models. *World Bank* **2019**, *145525*, 1–87.
26. National Institute of Statistics (NIS). Population by Residence. 2022. Available online: http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table (accessed on 23 March 2022).
27. Florczyk, A.J.; Politis, P.; Corbane, C.; Pesaresi, M. GHS-BUILT R2018A—GHS Built-up Grid INPUT DATA, Landsat Multitemporal Collections (1975-1990-2000-2014). European Commission, Joint Research Centre (JRC) [Dataset] 2018. Available online: http://data.europa.eu/89h/jrc-ghsl-10009 (accessed on 2 March 2022).
28. UN Habitat. Land Consumption. Available online: https://www.unescwa.org/sites/www.unescwa.org/files/u593/module_3_land_consumption_edited_23-03-2018.pdf (accessed on 23 March 2022).
29. Florczyk, A.J.; Corbane, C.; Ehrlich, D.; Freire, S.; Kemper, T.; Maffenini, L.; Melchiorri, M.; Pesaresi, M.; Politis, P.; Schiavina, M.; et al. *GHSL Data Package 2019, EUR 29788 EN*; Publications Office of the European Union: Luxembourg, 2019; ISBN 978-92-76-13186-1. [CrossRef]
30. Sustainable Development Goals. SDG Indicators. Metadata Repository. Available online: https://unstats.un.org/sdgs/metadata (accessed on 23 March 2022).
31. Socioeconomic Data and Applications Center (SEDAC). Gridded Population of the World (GPW), v4. Available online: https://sedac.ciesin.columbia.edu/data/collection/gpw-v4 (accessed on 2 March 2022).
32. European Environment Agency (EEA). High Resolution Layer, Imperviousness, Status Maps- Imperviousness Density. 2018. Available online: https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/status-maps (accessed on 20 March 2022).
33. Langanke, T. Copernicus Land Monitoring Service—High Resolution Layer Imperviousness: Product Specifications Document. European Environment Agency, Land Copernicus 2018. Available online: https://land.copernicus.eu/user-corner/technical-library/hrl-imperviousness-technical-document-prod-2015 (accessed on 20 March 2022).
34. Bauer, M.E.; Heinert, N.J.; Doyle, J.K.; Yuan, F. Impervious surface mapping and change monitoring using satellite Remote Sensing. In Proceedings of the ASPRS 2004 Annual Conference, Denver, CO, USA, 24–28 May 2004; Volume 10.
35. Bauer, M.E.; Loeffelholz, B.C.; Wilson, B. Estimating and mapping impervious surface area by regression analysis of Landsat imagery. In *Remote Sensing of Impervious Surfaces*; Weng, Q., Ed.; CRC Press: Boca Raton, FL, USA, 2007; pp. 3–20.
36. Zha, Y.; Gao, J.; Ni, S. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *Int. J. Remote Sens.* **2003**, *24*, 583–594. [CrossRef]
37. Xu, H. A new index for delineating built-up landfeatures in satellite imagery. *Int. J. Remote Sens.* **2008**, *29*, 4269–4276. [CrossRef]
38. Xu, H. Analysis of Impervious Surface and its Impact on Urban Heat Environment using the Normalized Difference Impervious Surface Index (NDISI). Photogramm. Eng. *Remote Sens.* **2010**, *76*, 557–565. [CrossRef]
39. Deng, C.; Wu, C.A. spatially adaptive spectral mixture analysis for mapping subpixel urban impervious surface distribution. *Remote Sens. Environ.* **2013**, *133*, 62–70. [CrossRef]
40. Liu, C.; Shao, Z.; Chen, M.; Luo, H. MNDISI: A multi-source composition index for impervious surface area estimation at the individual city scale. *Remote Sens. Lett.* **2013**, *4*, 803–812. [CrossRef]
41. Sun, Z.; Wang, C.; Guo, H.; Shang, R. A Modified Normalized Difference Impervious Surface Index (MNDISI) for Automatic Urban Mapping from Landsat Imagery. *Remote Sens.* **2017**, *9*, 942. [CrossRef]
42. Wang, Z.; Gang, C.; Li, X.; Chen, Y.; Li, J. Application of a normalized difference impervious index (NDII) to extract urban impervious surface features based on Landsat TM images. *Int. J. Remote Sens.* **2015**, *36*, 1055–1069. [CrossRef]
43. Deng, Y.; Wu, C.; Li, M.; Chen, R. RNDSI: A ratio normalized difference soil index for Remote Sensing of urban/suburban environments. *Int. J. Appl. Earth Obs. Geoinf.* **2015**, *39*, 40–48. [CrossRef]
44. Sun, G.; Chen, X.; Jia, X.; Yao, Y.; Wang, Z. Combinational build-up index (CBI) for effective impervious surface mapping in urban areas. IEEE J. Sel. Top. Appl. Earth Obs. *Remote Sens.* **2016**, *9*, 2081–2092. [CrossRef]
45. Zhang, S.; Yang, K.; Li, M.; Ma, Y.; Sun, M. Combinational Biophysical Composition Index (CBCI) for Effective Mapping Biophysical Composition in Urban Areas. *IEEE Access* **2018**, *6*, 41224–41237. [CrossRef]
46. Chen, J.; Yang, K.; Chen, S.; Yang, C.; Zhang, S.; He, L. Enhanced normalized difference index for impervious surface area estimation at the plateau basin scale. *J. Appl. Remote Sens.* **2019**, *13*, 016502. [CrossRef]

47. Shao, Z.; Fu, H.; Fu, P.; Yin, L. Mapping Urban Impervious Surface by Fusing Optical and SAR Data at the Decision Level. *Remote Sens.* **2016**, *8*, 945. [CrossRef]
48. Zhang, X.; Liu, L.; Wu, C.; Chen, X.; Gao, Y.; Xie, S.; Zhang, B. Development of a global 30 m impervious surface map using multisource and multitemporal Remote Sensing datasets with the Google Earth Engine platform. *Earth Syst. Sci. Data* **2020**, *12*, 1625–1648. [CrossRef]
49. Holobâcă, I.-H.; Ivan, K.; Alexe, M. Extracting built-up areas from Sentinel-1 imagery using land-cover classification and texture analysis. *Int. J. Remote Sens.* **2019**, *40*, 8054–8069. [CrossRef]
50. Goldblatt, R.; Stuhlmacher, M.F.; Tellman, B.; Clinton, N.; Hanson, G.; Georgescu, M.; Wang, C.; Serrano-Candela, F.; Khandelwal, A.K.; Cheng, W.-H.; et al. Using Landsat and nighttime lights for supervised pixel-based image classification of urban land cover. *Remote Sens. Environ.* **2018**, *205*, 253–275. [CrossRef]
51. Sang, X.; Guo, Q.; Wu, X.; Fu, Y.; Xie, T.; He, C.; Zang, J. Intensity and Stationarity Analysis of Land Use Change Based on CART Algorithm. *Sci. Rep.* **2019**, *9*, 12279. [CrossRef]
52. Jalilov, S.-M.; Chen, Y.; Quang, N.H.; Nguyen, M.N.; Leighton, B.; Paget, M.; Lazarow, N. Estimation of Urban Land-Use Efficiency for Sustainable Development by Integrating over 30-Year Landsat Imagery with Population Data: A Case Study of Ha Long, Vietnam. *Sustainability* **2021**, *13*, 8848. [CrossRef]