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Assessing the Negative Effects of Suburbanization: The Urban Sprawl Restrictiveness Index in Romania's Metropolitan Areas

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Abstract: Urban sprawl is widely considered to be a major issue for the functioning of urban areas, threatening long-term sustainability and affecting the quality of living. The aim of this research is to develop a methodology for assessing the negative effects of uncontrolled suburbanization in metropolitan areas through a multicriterial approach. Based on the existing body of knowledge, we have defined a set of indicators for assessing the impact of suburbanization, covering themes such as land use, water, biodiversity and economy or social issues. A questionnaire was applied to experts in the field in order to find out the final set of indicators and their perceived importance. The product of our research is an urban sprawl restrictiveness index at the local level, tested on five of the most dynamic metropolitan areas in Romania. The results highlight the concentration of negative effects of urban sprawl in the areas most accessible from the city core, where additional in-depth analyses were performed for validation. This study thus proposes a novel method for assessing the negative impacts of urban sprawl. The index could be used in other comparative studies at the national or international level while also aiding policymakers in better managing metropolitan areas.

Keywords: suburbanization; urban sprawl; metropolitan planning; spatial analysis; land cover and use changes; Central and Eastern Europe

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1. Introduction

Urban sprawl is most commonly understood as a suburban development characterized by low density, automobile dependency and segregated land uses around the periphery of cities [1–3]. It is widely considered to be a pattern of urbanization with complex economic, social and ecological impacts [4–8] that threaten the functioning of urban environments [9].

The emergence of the urban sprawl debate is mostly linked with the development of suburbia in the USA in the early years of the twentieth century. In Europe, the equivalent debate is centered around concepts such as suburbanization or peri-urbanization [2]. Both concepts describe a process of urban expansion and decentralization [10], with peri-urbanization referring to the development of intermediate areas between suburbs and typical rural areas [11]. Consequently, as sprawling areas may be located well beyond the administrative boundaries of cities, metropolitan areas become a more appropriate area of study. These urbanization patterns in the form of low-density discontinuous development pose specific challenges for planners and policymakers [12], as the lack of interjurisdictional land use planning makes it difficult to manage suburban development [13].

There is some debate regarding the definition of urban sprawl, regarded as a multidimensional phenomenon with various determinants [14–16]. Urban morphology (scattering of development, connectivity and availability of open space), as well as a density, decentralization and land use mix, are considered among the dimensions of urban sprawl [15]. The focus on urban morphology dimensions is evident from previous attempts at measuring urban sprawl. Examples include weighted urban proliferation [17], which considers the dispersion of built-up areas and building density, and different urban sprawl indices containing variables such as shape irregularity and fragmentation [18] or spatial configuration indicators [19]. Some authors suggest that it is difficult to distinguish urban sprawl from other urban growth patterns, opting to focus more on urban sprawl as a process of urban change [2] made undesirable because of its impacts [20].

Urban sprawl is generally compared to an ideal type of compact city, regarded as a sustainable urban form [2,21–23]. However, individual residential preferences appear to be directed towards lower-density housing areas [20,24,25]. Consequently, some authors point out the social injustice of urban containment policies, which affect housing affordability and push residential areas even further away from the city [26]. Others suggest that, in time, sprawling areas can develop into complex suburban areas with mixed and various land uses [27,28]. The ecological value of interstitial spaces resulting from urban sprawl developments has also been discussed [29]. While acknowledging these various perspectives on the urban sprawl–compact city debate, our research focus is nevertheless on the negative impacts of urban sprawl. Three main categories are considered in the scientific reports prepared by the European Environmental Agency: (1) environmental impacts, (2) economic impacts and (3) social impacts and quality of life [30,31].

An important topic when analyzing the environmental consequences of urban sprawl is represented by land cover and land use change. Urbanization-driven changes in land cover affect ecological systems and may lead to landscape fragmentation and natural landscape degradation [1,32]. Other effects of land cover and land use change include the decrease of local biodiversity [33], the loss of agricultural land [34–36] and the sealing of soil surfaces [37,38].

Urban sprawl is also linked to energy and climate change issues, as well as air pollution [39–43]. Land cover changes, mentioned above, also lead to a decrease in carbon dioxide uptake as a result of vegetation removal [44,45]. The growth of transport emissions has been linked to the absence of specific urban planning policies that could limit the increase of artificial land [46]. Other environmental impacts of urban sprawl include increased water consumption per capita [47,48] and higher risk of leakages as the network of pipes increases [49].

As far as economic impacts are concerned, urban sprawl determines higher costs for transport due to increased daily commuting [50–52], as well as more material use for construction per housing unit [53]. Land conversion related to suburban development and changing land use regulations lead to rapid increases in real estate prices [54]. The reduction of cities' touristic attractiveness is also regarded as a negative economic consequence of unplanned suburban development [55].

Among the social impacts of sprawl, the most often discussed are the effects of the segregated land uses, with unequal distribution and accessibility of public infrastructure and services such as schools, healthcare and leisure facilities [20,56–58]. In this context, there is a perceived social vulnerability of suburbs lacking adequate social infrastructures [59,60]. The higher proportion of single households in urban sprawl developments [61] also leads to a more resource-intensive lifestyle [31]. Social interactions are also made difficult by the decentralization, fragmentation and long commutes associated with urban sprawl [62].

Considering the debates in the scientific literature related to the definition of urban sprawl, this paper focuses on urban sprawl as a process of change impeding the sustainable development of cities and metropolitan areas. While useful in establishing gradients of urban sprawl, the indices developed so far [17–19] do not explain the scale of the ecological, social and economic effects of suburban development. Other research in this area has focused on developing systems of indicators in order to explain the drivers and impacts of urban sprawl [63], while other authors have opted to quantify impacts in monetary terms [64]. However, little attention has been given to temporal approaches and the integration of environmental, economic and social issues when discussing urban sprawl impacts. In order to fill in this gap, this paper proposes a novel method for measuring urban sprawl based on the impact assessment of suburbanization from 2006 in the selected metropolitan areas. By combining analyses using different scales and different datasets, it also provides new insights regarding the use of CORINE Land Cover and Urban Atlas data.

Hence, the aim of this paper is to develop a methodology for assessing the negative effects of urban sprawl in metropolitan areas through a multicriterial approach, taking into account the environmental, economic and social dimensions. After defining a set of criteria and possible proxy indicators, we applied a questionnaire to experts in spatial planning in order to determine a final set of indicators and their perceived importance. The product of our research is an urban sprawl restrictiveness index at the local administrative unit (LAU) level tested on five of the most dynamic metropolitan areas in Romania. In spite of data availability constraints, we believe that our method opens new research directions, including the possibility of in-depth comparative studies at the national or international level. The proposed index represents a solution for metrics-based monitoring, which can help the integrated assessment of urban sprawl's environmental, economic and social impacts. The fact that the assessment is done at the LAU level can support policymakers in better managing and planning metropolitan areas. The preliminary analyses done for the local administrative units with the highest index values suggest the need for updated planning instruments that are regulated across administrative boundaries and specific urban policies tackling the poor coverage of public infrastructure and services.

2. Materials and Methods

Our case study, Romania, is a Central and Eastern European country that has undergone similar urbanization patterns to other post-socialist countries in Europe [35,58,65,66]. After a communist regime where suburbanization processes were limited and cities compact, Romanian urban areas have been characterized by uncontrolled suburbanization after 1990 [67,68]. The main driver has been property restitution after the fall of communism [69,70] and the subsequent conversion of agricultural land into built land [71–73]. This has also been supported by a decentralization of responsibilities regarding land use planning to local public authorities and a lack of spatial planning instruments, land use policies and institutional arrangements needed to coordinate suburban development [74]. Along with the impacts determined by land use changes, one of the most pressing issues with sprawling developments in Romania is the lack of basic public infrastructure and services [75,76]. The new suburban developments became dormitory suburbs, where people often remain dependent on the infrastructure and public services offered by the main city. Recent research has highlighted the fact that population changes in peri-urban areas are closely linked to the nature of core cities' labor markets [77].

The five metropolitan areas selected for our analysis were Brașov, Cluj-Napoca, Constanța, Iași and Timișoara–see Figure 1. All selected metropolitan areas were designated as national growth poles by the Romanian government in 2008, thus having access to important funding from the European Regional Development Fund within the 2007–2013 Regional Operational Programme [78]. Apart from their designation, the selection of the metropolitan areas was based on previous research showcasing that sprawl processes are more dynamic in the largest Romanian cities [21,71,79].

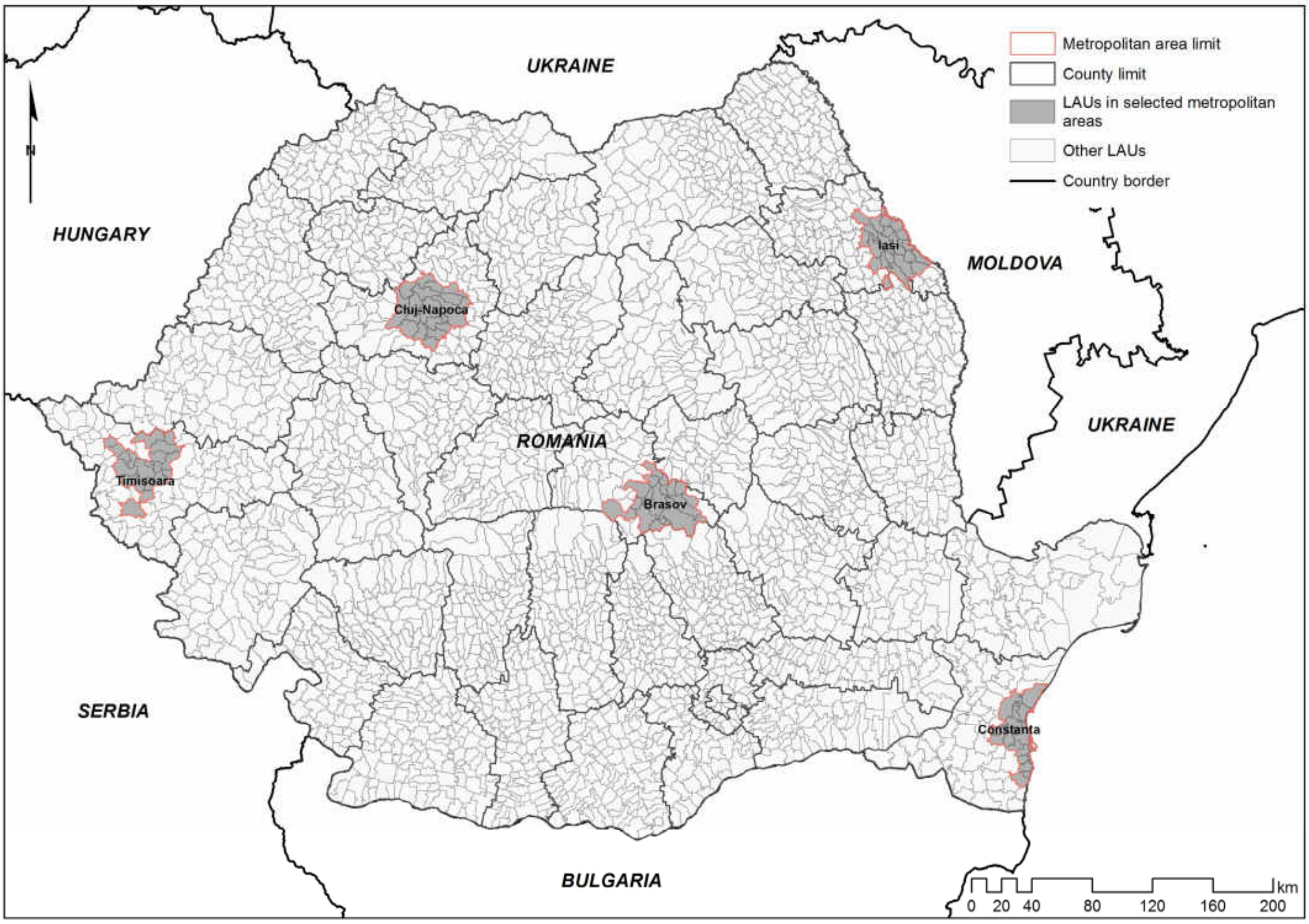

Figure 1. The five Romanian metropolitan areas selected for the study (gray color fill and red contour): Brașov, Cluj-Napoca, Constanța, Iași and Timișoara.

Figure 2 offers an overview of the methods used for constructing the urban sprawl restrictiveness index. In brief, these are:

- Literature review for compiling a list of urban sprawl consequences that could be measured using impact indicators;
- Questionnaire applied to experts in the field for ranking each urban sprawl consequence according to its perceived negative impact, as well as selecting the indicators considered to be most relevant for measuring urban sprawl impacts. The 50 experts who answered the questionnaire were urban planners, geographers, architects, landscape architects, engineers, sociologists, economists and ecologists, mostly working in universities or research centers but also in private companies or public administration. The questionnaire was disseminated through the Romanian Professional Association of Urban Planners;
- Building a database containing the values of the selected indicators at the LAU level for the five metropolitan areas. Realizing the spatial analysis using GIS software for deriving indicators from CORINE Land Cover datasets;
- Statistical analysis for identifying redundancies in the database indicators;
- Computing the urban sprawl restrictiveness index and analyzing its distribution at the LAU level in the five metropolitan areas;
- Using the Urban Atlas dataset for additional analyses for the two local administrative units with the highest index values.

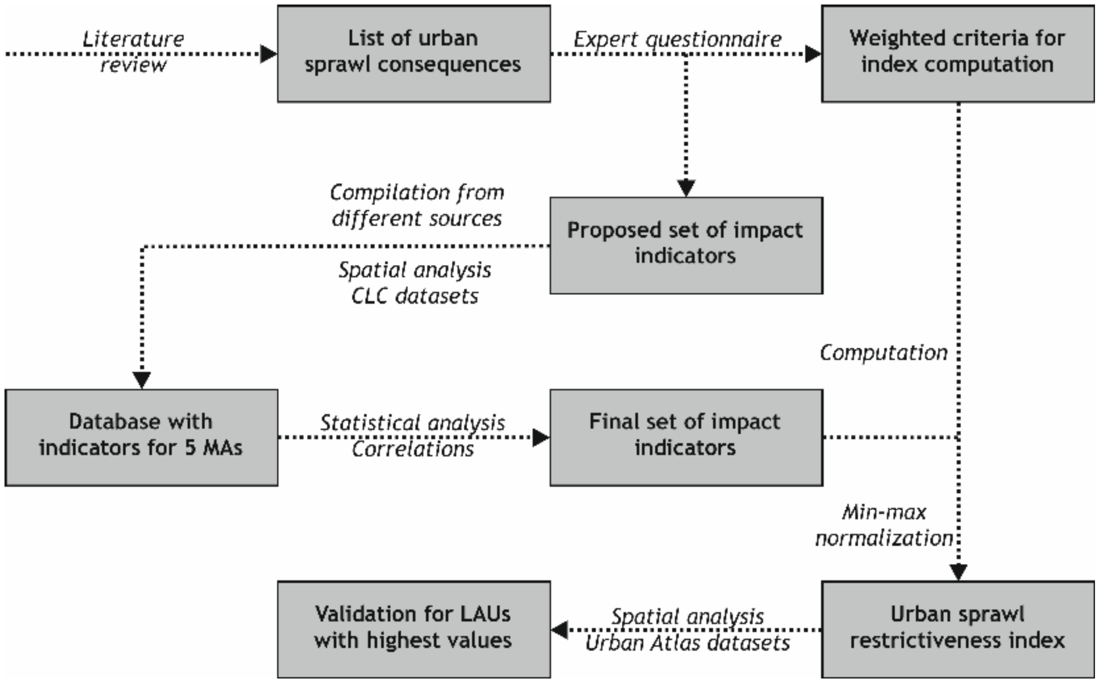

Figure 2. Research flow. MA–metropolitan area.

Based on the analyzed literature, we have compiled a list of urban sprawl consequences on themes such as land use, energy and climate change, air pollution, water, flora and fauna, the economy and social issues–see Table 1. This list represented the preliminary set of criteria for assessing urban sprawl impact. A questionnaire was then applied to 50 experts in the field of urban and territorial planning who were asked to rank each impact category (environmental, economic and social), as well as each criterion from the preliminary list, from 1 (little negative impact) to 6 (significant impact). The scale from 1 to 6 was chosen in order to avoid median values. Criteria obtaining an average rating below 4.00 were considered as consequences without an important negative impact and thus removed from the analysis.

Table 1. The first column presents the environmental, economic and social themes considered, and the second one lists the consequences of urban sprawl as a preliminary set of criteria compiled from the literature review, while the third one contains the references.

Theme	Urban Sprawl Consequences	References
Environmental impacts		
Land use	Loss of farmland	Grigorescu et al. 2021 [34] Petrisor et al. 2020 [35] Van Vliet et al., 2017 [36]
	Sealing of soil surfaces	Naumann et al., 2019 [37] Barbero-Sierra et al., 2013 [38]
Energy and climate change	Higher energy consumption and higher greenhouse gas emissions	Navamuel et al., 2018 [40] Jones & Kammen 2014 [41]
	Removal of natural vegetation	Carpio et al., 2021 [44] Hutyra et al., 2011 [45]
Air pollution	Rise in air pollution caused by road traffic	Bart 2010 [46] Stone Jr et al., 2007 [43]
	Rise in air pollution caused by residential sources	Cocheci 2014 [80] Johnson 2001 [1]

Table 1. *Cont.*

Theme	Urban Sprawl Consequences	References
Water	Increased water consumption per capita	Heidari et al., 2021 [47] March & Saurí 2010 [48]
	Higher risk of leakages per capita	Pauliuk et al., 2014 [49]
	Water pollution from residential sources	Dong et al., 2014 [81] Schleich & Hillenbrand 2009 [82] Tu et al., 2007 [83]
Flora and fauna	Increased fragmentation of landscape	Alberti et al., 2020 [32] Johnson 2001 [1]
	Natural habitat degradation	Wu et al., 2021 [84] Chin 2002 [20]
Economic impacts		
Economy	Higher costs for transport associated with commuting for households	Di Bartolomeo et al., 2021 [50] Lee 2020 [51] Travisi et al., 2010 [52]
	Higher material use for construction per housing unit	Roy et al., 2015 [53]
	Economic loss in touristic areas due to landscape degradation	Rusu et al., 2020 [55]
Social impacts		
Social	Higher proportion of single households leading to a more resource-intensive living style	Díaz-Pacheco & García-Palomares 2014 [61]
	Difficult access to social infrastructure	Halbac-Cotoara-Zamfir et al., 2021 [75] Suditu et al., 2012 [76]

Source: Own studies, derived from the EEA-FOEN report [31].

For each criterion, the experts were given the possibility to select one proxy indicator that they considered to be the most relevant for quantifying each negative urban sprawl consequence. In certain cases, explained in the Results section, we have opted not to consider the questionnaire results due to problems regarding data availability or consistency.

The proposed proxy indicators were selected according to the available data from sources such as the National Institute for Statistics database, CORINE Land Cover and Use datasets and other public databases or reports. Whenever possible, the indicators were defined to measure the dynamics between the baseline year (2006) and the most recent available year. The baseline year (2006) was established according to the availability of CORINE data but also according to previous research that illustrated the emergence of significant suburbanization processes in Romania in the 2006–2012 period.

While acknowledging the limitations of using CORINE data [85,86], its coverage of the entire national territory made it the most suitable dataset for analyzing urbanization patterns. The Urban Atlas dataset, also used in urban sprawl studies at the European level [67,87], was also considered for its greater precision but did not cover the whole territory of the selected metropolitan areas, so was used only for validation.

In order to extract the surfaces derived from the analysis of CORINE datasets, an ArcGIS model was run using as input the 2006 and 2018 CORINE Land Cover raster data, the polygon features of the local administrative units in Romania and the polygon features representing the limits of the five selected metropolitan areas, derived from the latter–see Table 2.

Table 2. The first column presents the datasets used in the spatial analysis, and the second one specifies the data type for each dataset, while the third one mentions each dataset's source.

Dataset	Type	Source
CORINE Land Cover 2006	Raster	Copernicus Land Monitoring Service
CORINE Land Cover 2018	Raster	Copernicus Land Monitoring Service
LAU limits	Vector (polygon)	National Agency for Cadastre and Land Registration
Metropolitan area limits	Vector (polygon)	Derived from LAU limits

A reclassification of the CORINE Land Cover (CLC) datasets was carried out in order to extract artificial surfaces (separating road and rail networks and associated artificial land from the rest of land uses: urban fabric; industrial; commercial and transport units; mine, dump and construction sites and artificial, nonagricultural vegetated areas); agricultural areas and natural and semi-natural areas (which included forests and semi-natural areas, wetlands and water bodies). The reclassification was used to analyze land use dynamics between 2006 and 2018 and extract the geometrical areas for each local administrative unit, needed for computing the final set of indicators. Figure 3 illustrates the model run with ArcGIS software in order to compute the indicators derived from CLC datasets.

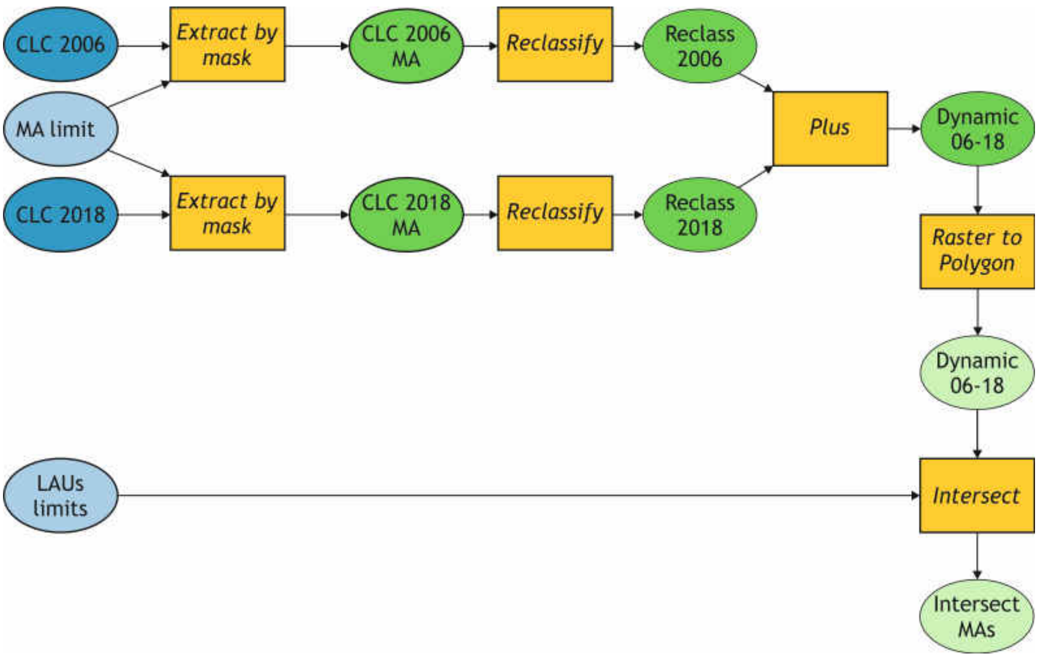

Figure 3. The figure illustrates the GIS spatial analysis model for CLC datasets, which was used to extract indicators referring to urbanized area for the five selected metropolitan areas. MA–metropolitan area. Blue–input data (dark–raster data and light–vector data). Green–output data (dark–raster data and light–vector data). Yellow–GIS operations.

Descriptive statistics and paired correlations were analyzed for all selected indicators using SPSS Statistics Version 20 in order to identify possible redundancies. Kendall's tau_b rank-based parameter, appropriate for variables measured on an ordinal or continuous scale, was used for the correlation analysis [88].

The urban sprawl restrictiveness index was computed for each local administrative unit in the five metropolitan areas as a weighted average of three intermediary indices regarding the environmental, economic and social impacts of urban sprawl. These intermediary indices were computed as the weighted average of each indicator in the corresponding category, using min–max normalization in order to ensure data compatibility.

Since there were no major differences between the average scores obtained by each criterion, as mentioned in the Results section, the urban sprawl restrictiveness index (USRI) was computed as a simple arithmetic average:

$$USRI = \frac{I_{env} + I_{eco} + I_{soc}}{3} \tag{1}$$

where I_{env}, I_{eco} and I_{soc} are the intermediary indices for the environmental, economic and social impacts, respectively. These intermediary indices were computed as averages of the normalized indicators in each of the three categories using min–max normalization:

$$I_{env} = \frac{\sum_{i=1}^{8} \frac{V_i - V_{i\ min}}{V_{i\ max} - V_{i\ min}}}{8} \tag{2}$$

$$I_{eco} = \frac{\sum_{i=1}^{2} \frac{U_i - U_{i\ min}}{U_{i\ max} - U_{i\ min}}}{2} \tag{3}$$

$$I_{soc} = \frac{\sum_{i=1}^{2} \frac{W_i - W_{i\ min}}{W_{i\ max} - W_{i\ min}}}{2} \tag{4}$$

For the two local administrative units with the highest urban sprawl restrictiveness index, additional analyses based on Urban Atlas datasets for the years 2006 and 2018 were realized. The results of the Urban Atlas analyses were used as a basis for discussing the suitability of CORINE Land Cover datasets for research at the metropolitan level.

3. Results

3.1. Constructing the Urban Sprawl Restrictiveness Index (USRI)

Due to limited territorial coverage of air pollution data in the national network of air quality monitoring, the two criteria related to air pollution were not included in this research. Moreover, because of inconclusive results in the preliminary analysis of the data, the economic losses in touristic areas were also not included as a criterion. For the last criterion (difficult access to social infrastructure), only the relation between the scholar population and teaching personnel was analyzed, as the available data regarding the number of medical personnel did not cover all local administrative units in the selected metropolitan areas. Table 3 illustrates the proposed impact indicators for the final set of criteria included in the analysis.

Table 3. The table lists the proposed set of indicators for the final set of criteria included in the urban restrictiveness index computation, along with the average scores obtained by each criterion according to the experts who answered the questionnaire. A code was given to each indicator.

Category	Criteria	Average Score	Proposed Indicator (Proxy)	Source	Indicator Code
Environmental impacts	Loss of farmland	4.64	Agricultural land transformed into built land, 2006–2018 (%)	CORINE	111
	Sealing of soil surfaces	4.76	Percent of newly urbanized surfaces from the total surface of the Local Administrative Unit, 2006–2018 (%)	CORINE	112
	Higher energy consumption and higher greenhouse gas emissions	4.64	Estimation of the growth in energy consumption for residential use, based on the growth in residential surfaces, 2006–2021 (tons of oil equivalent)	NIS *	121
	Removal of natural vegetation	4.76	Land covered by natural and semi-natural vegetation transformed into built land, 2006–2018 (%)	CORINE	122

Table 3. *Cont.*

Category	Criteria	Average Score	Proposed Indicator (Proxy)	Source	Indicator Code
Environmental impacts	Increased water consumption per capita	4.06	Growth in water distributed for residential use, per capita, 2006–2018 (cubic meters)	NIS *	131
	Higher risk of leakages per capita	3.98	Extension of water and wastewater networks, 2006–2021 (km)	NIS *	n.a.
	Water pollution from residential sources	4.86	Estimation of growth in municipal wastewater, based on population growth, 2006–2021 (cubic meters)	NIS *	132
	Increased fragmentation of landscape	4.88	Growth in land surface occupied by major road and railway networks, 2006–2018 (ha)	CORINE	141
	Natural habitat degradation	5.04	Loss of land covered by natural and semi-natural vegetation, 2006–2018 (ha)	CORINE	142
Economic impacts	Higher costs for transport associated with commuting for households	4.72	Percent of active population commuting to an urban center for work (1–5 ordinal scale according to World Bank data)	World Bank	211
	Higher material use for construction per housing unit	4.16	Growth in the number of housing units, 2006–2021 (%)	NIS *	212
Social impacts	Higher proportion of single households leading to a more resource-intensive living style	4.64	Percent of single-family residential units in the total number of building permits issued, 2006–2021 (%)	NIS *	311
	Difficult access to social infrastructure	5.00	Growth in number of students per teacher, 2006–2021	NIS *	312

* National Institute for Statistics–TEMPO Online Database.

The average scores obtained by category, according to the ratings of the 50 experts that answered the questionnaire, were 4.70 out of a maximum possible of 6.00 for environmental impacts, 4.14 for economic impacts and 4.68 for social impacts. Hence, the social impacts of urban sprawl were considered by experts to be almost as important as the environmental impacts. The average scores obtained by each criterion were between 3.98 and 5.04. Only the criteria regarding difficult access to social infrastructure and natural habitat degradation obtained average scores above 5.00. As a result, given the relatively narrow distribution of the average scores, all categories and criteria were weighted equally when computing the urban restrictiveness index. The extension of water and wastewater networks was not considered in the index, as the higher risk of leakages per capita criterion obtained an average score under 4.00 in the questionnaire.

The statistical analysis showcased a significant relation ($R = 0.841$) between the loss of farmland and sealing of soil surfaces–see Table 4. This relation can be explained by the fact that almost 90% of the growth in urban areas during 2006–2018 was determined by the urbanization of former agricultural lands. There are also important links between the estimated growth in energy consumption, the estimated growth in municipal wastewater and the growth in the number of housing units ($R > 0.50$). These correlations were expected, given the methods used for estimating the impact indicators. Consequently, all indicators were used in the computation of the urban restrictiveness index.

Table 4. The table shows the paired correlations between the proposed indicators using Kendall's tau coefficient. There is a significant relationship between the loss of farmland (111) and the sealing of soil surfaces (112) and also important links between the estimated growth in energy consumption (121), the estimated growth in municipal wastewater (132) and the growth in the number of housing units (212).

Indicator Code	111	112	121	122	131	132	141	142	211	212	311	312
111 Correlation Coefficient	1.000	**0.841** **	0.352 **	0.158 *	−0.034	0.257 **	−0.030	0.010	0.358 **	0.273 **	0.037	0.187 **
112 Correlation Coefficient		1.000	0.336 **	0.264 **	−0.021	0.233 **	−0.036	0.015	0.295 **	0.287 **	0.002	0.148 *
121 Correlation Coefficient			1.000	0.194 *	−0.039	**0.527** **	0.006	0.030	0.486 **	**0.532** **	0.142 *	0.167 *
122 Correlation Coefficient				1.000	−0.020	−0.013	−0.112	0.412 **	0.163	0.042	−0.064	0.038
131 Correlation Coefficient					1.000	0.125	0.026	−0.054	0.119	0.121	0.091	−0.188 **
132 Correlation Coefficient						1.000	−0.060	−0.095	0.442 **	**0.570** **	0.234 **	0.152 *
141 Correlation Coefficient							1.000	−0.063	0.040	−0.101	−0.030	−0.134
142 Correlation Coefficient								1.000	−0.006	−0.091	−0.096	0.027
211 Correlation Coefficient									1.000	0.379 **	0.153	0.240 **
212 Correlation Coefficient										1.000	0.254 **	0.171
311 Correlation Coefficient											1.000	−0.014
312 Correlation Coefficient												1.000

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

The urban sprawl restrictiveness index was computed for 96 local administrative units in five metropolitan areas, its values ranging from 0.14 (Petreștii de Jos commune, Cluj-Napoca metropolitan area) to 0.74 (Dumbrăvița commune, Timisoara metropolitan area)–see Table 5. Only in three metropolitan areas did the local administrative units register index values above 0.70: Brașov (Sânpetru commune, 0.62), Cluj-Napoca (Florești commune, 0.72) and Timișoara (Dumbrăvița commune, 0.74 and Giroc commune, 0.62). Higher standard deviations were usually associated with metropolitan areas comprising more than 20 local administrative units.

Table 5. The table lists descriptive statistics (number of entries, mean values, standard deviation and minimum and maximum values) for the urban sprawl restrictiveness index in each of the five selected metropolitan areas.

Metropolitan Area	No. of LAUs	Mean	Std. Deviation	Minimum	Maximum
Brașov	17	0.41	0.10	0.25	0.62
Cluj-Napoca	20	0.39	0.12	0.14	0.72
Constanța	16	0.38	0.07	0.28	0.51
Iași	23	0.35	0.11	0.22	0.58
Timișoara	20	0.39	0.14	0.18	0.74

3.2. Territorial Distribution of the USRI

Most of the local administrative units registering urban sprawl restrictiveness index values in the highest quintile (15 out of 17) are located in the first ring of settlements around the core cities, with the only exceptions being Zărnești Town and Tărlungeni Commune in the Brașov metropolitan area–Figure 4. This tendency of higher urban sprawl restrictiveness indices around the core cities is also evident when analyzing the second highest quintile, with only four cases located beyond the first ring of settlements (Vulcan in the Brașov metropolitan area, Murfatlar Town in the Constanța metropolitan area and Pădureni and Bucovăț Communes in the Timișoara metropolitan area).

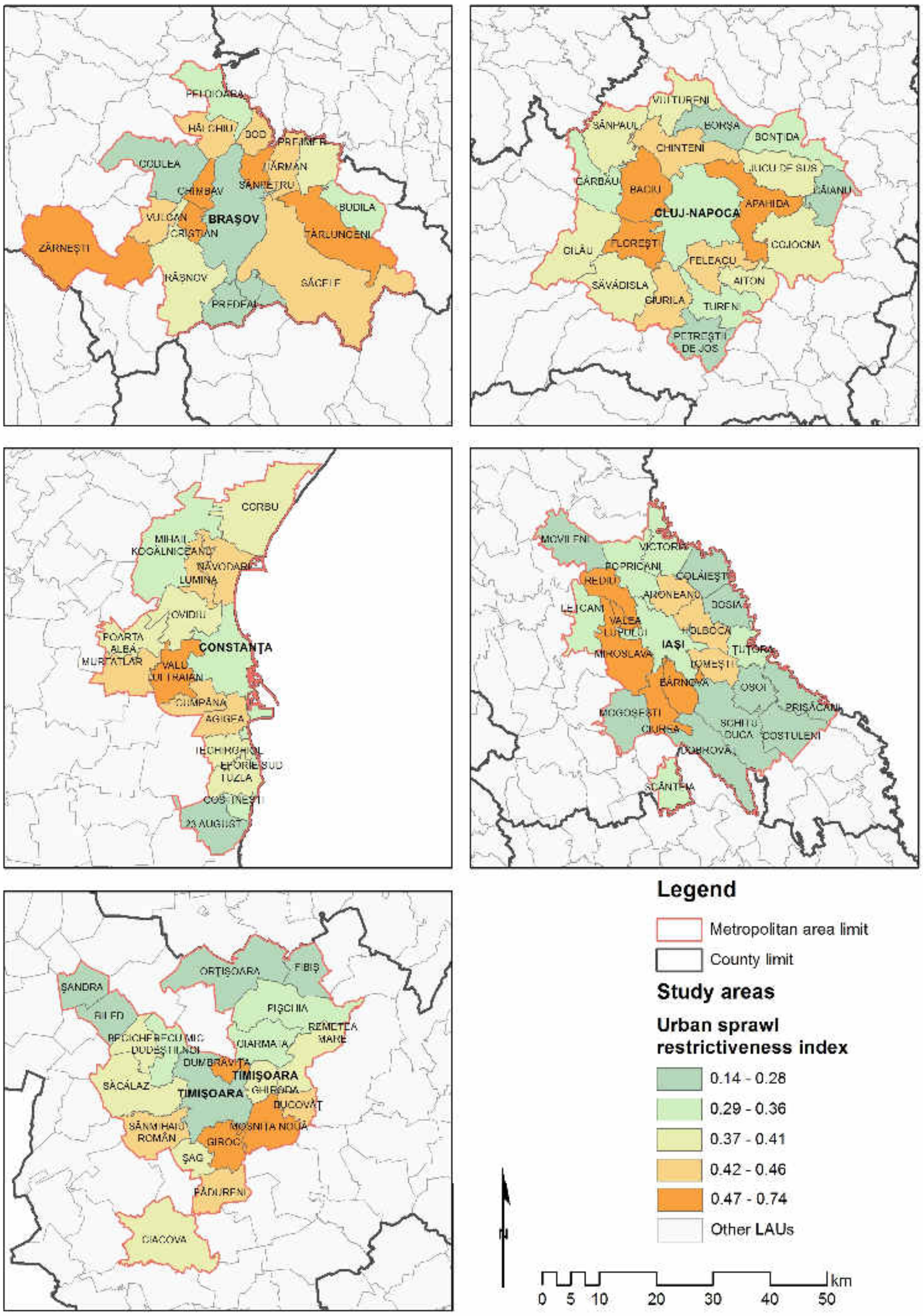

Figure 4. The figure illustrates the spatial distribution of the urban sprawl restrictiveness index, with the highest values (orange) mostly located in the first ring of settlements around the core cities and the lowest values (green) mostly located towards the fringes of the metropolitan area.

These exceptions can be explained by the commuting patterns related to overall accessibility, as well as investment in the extension of water infrastructure and the residential preferences of the inhabitants. The six local administrative units mentioned above all had a high percent of active population commuting to the main city, as well as an important growth in water distributed for residential use and a very high proportion of single-family houses in the building permits issued between 2006 and 2021.

All five core cities in the analyzed metropolitan areas have registered values within the lowest two quintiles, suggesting that most of the urbanization is actually taking place outside of the cities' administrative borders.

As far as the LAUs with the lowest index values are concerned, most of them are located at the border of their respective metropolitan areas. In some cases, the limit of the metropolitan area is also a county limit (Predeal Town in the Brașov metropolitan area and Orțișoara and Fibiș Communes in the Timișoara metropolitan area) or even the country's national border (Golăiești, Bosia and Prisăcani Communes in the Iași metropolitan area).

Two communes have registered index values above 0.70: Dumbrăvița in the Timișoara metropolitan area (0.74) and Florești in the Cluj-Napoca metropolitan area (0.72). Both of them are part the urban agglomeration of the metropolitan areas' core cities–Figure 5.

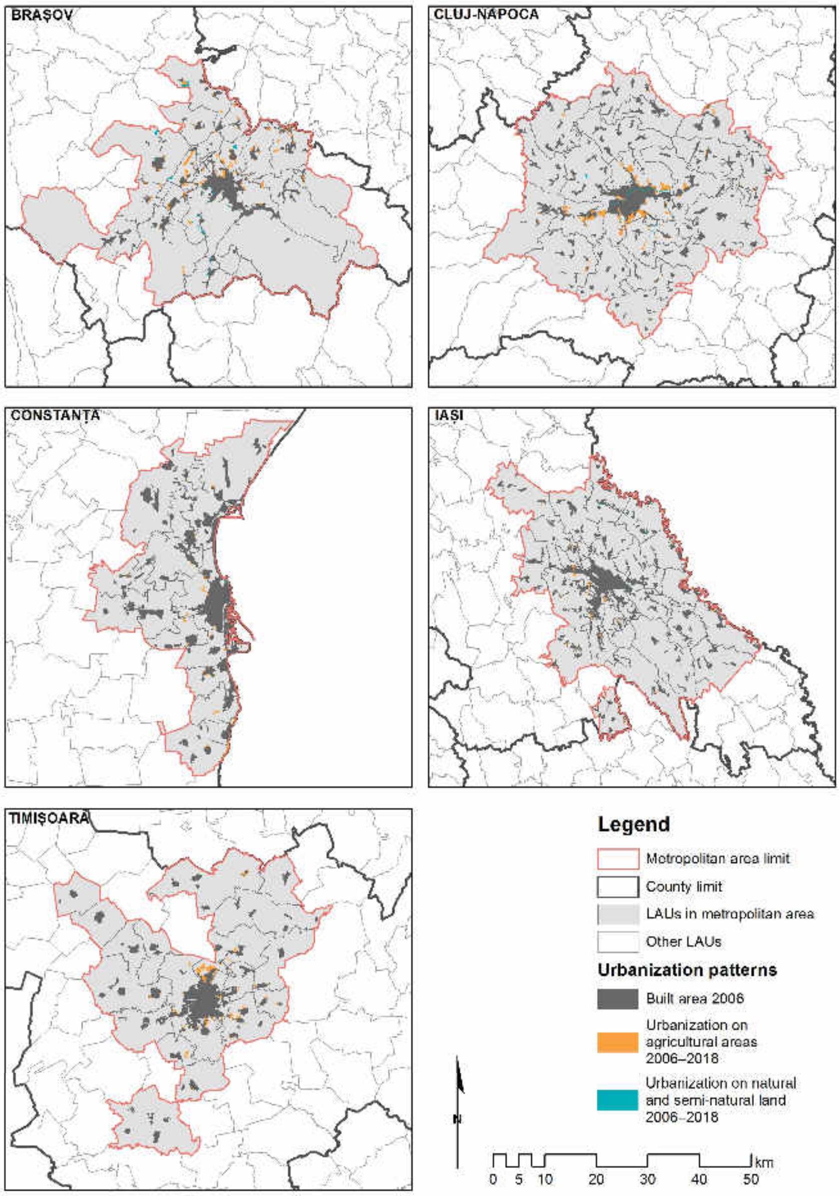

Figure 5. The figure shows urbanization between 2006 and 2018 in the five metropolitan areas (light gray), on agricultural land (orange) and on natural and semi-natural areas (green). In some cases, (Cluj-Napoca and Timișoara) urbanization patterns extend the existing urban agglomerations.

3.3. Comparison with Urban Atlas Data

Figure 6 illustrates the urbanization patterns in the two communes with the highest urban sprawl restrictiveness index. The superposition between urbanization data according to the CORINE Land Cover dataset and the data from the Urban Atlas highlight the differences in precision between the two datasets, which are also presented in Table 6. The greater area values resulting from the CLC datasets are determined by the raster data's original resolution (minimum mapping unit of 25 hectares). On the one hand, this minimum mapping unit means that smaller patches of agricultural land remaining between new built-up areas are also considered to be artificial surfaces, such as in the case of the new developments in the western part of Dumbrăvița. On the other hand, smaller patches of urbanized land can be omitted, such as in the case of linear developments in the southern part of Florești.

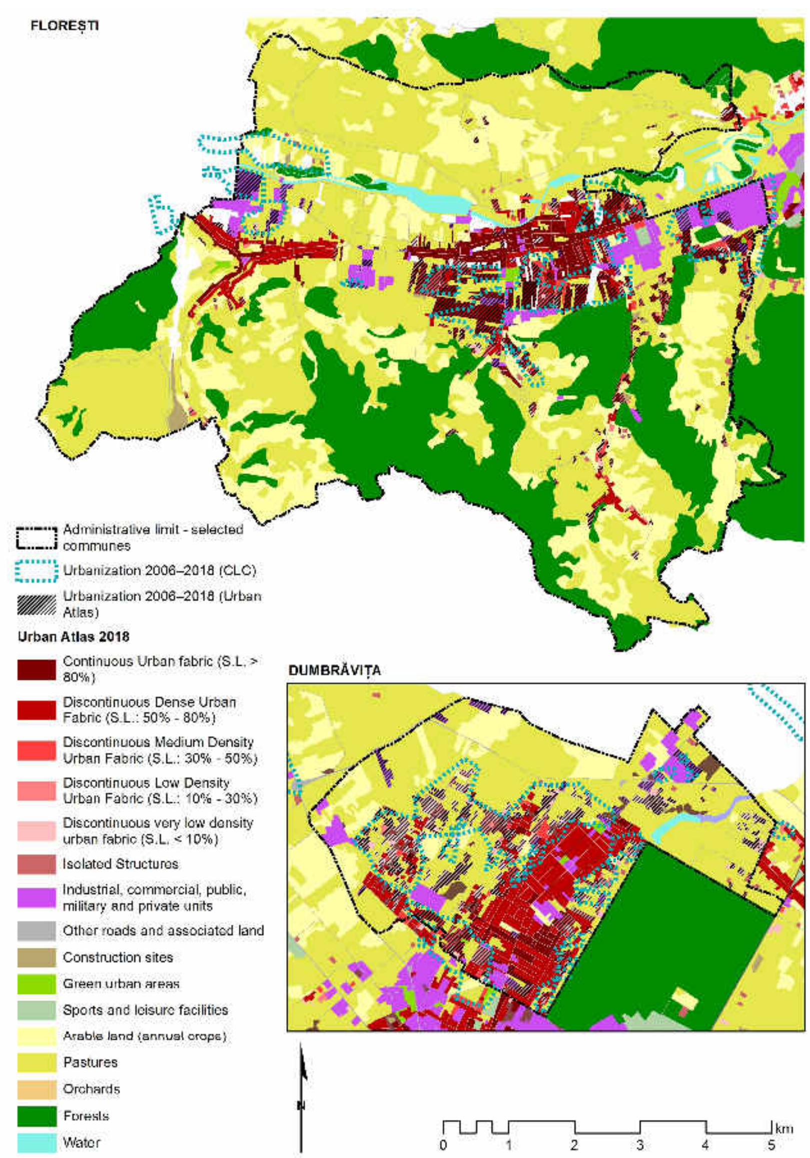

Figure 6. Urbanization in Florești and Dumbrăvița according to CORINE Land Cover (CLC–light green dotted contour) and Urban Atlas data (black line pattern fill). The figure highlights the differences between the two datasets starting from the Urban Atlas 2018 situation.

Table 6. The comparison between CLC and Urban Atlas datasets in the two communes with the highest urban restrictiveness index values illustrates the greater area values resulting from the CLC data.

Commune	Urbanized Area 2006–2018–CLC (ha)	Urbanized Area 2006–2018–Urban Atlas (ha)
Dumbrăvița	433.16	275.87
Florești	433.42	332.52

4. Discussion

4.1. Highlights of Urban Sprawl Impacts in a Post-Socialist Country

The ratings given by the 50 experts in spatial planning answering the questionnaire suggest significant awareness regarding not only the environmental impacts of urban sprawl but also the social and economic ones. Out of the thirteen proposed criteria, ten obtained an average score above 4.50, highlighting the perceived importance of urban sprawl impacts such as landscape fragmentation, difficult access to social infrastructure or transport costs associated with commuting. This is in line with other research pointing out the general consensus of planners over sustainable urban development [89].

The strong links between the sealing of soil surfaces and the loss of farmland confirm previous findings regarding the urbanization of former agricultural land in post-socialist countries [35,69], with land abandonment as a precursor [73]. Albeit weaker, the correlation between loss of agricultural land to urbanization and the percent of active population commuting to an urban center for work suggests that new suburban developments remain dependent on the main city for jobs. This dependency is also suggested by the relation between the commuting active population and the increased number of students per teacher, which highlights the fact that existing public educational services in suburban areas are lagging behind.

The territorial distribution of the urban sprawl restrictiveness index illustrates the fact that suburbanization has a higher impact on the local administrative units situated closest to the main city. In all of the five selected metropolitan areas, there are significant territorial disparities in the values of the urban sprawl restrictiveness index, with the local administrative units located at the fringes of the metropolitan areas registering the lowest index values. This confirms previous research on Romanian cities with over 200,000 people, which found out that the highest pressure of urban sprawl is around 8–10 km from the main city [90]. The territorial distribution also highlights the fact that topography can still be a barrier to suburban development, as seen in the cases of the local administrative units located south of Brașov or Cluj-Napoca. Overall, the lower values of index in core cities, coupled with the distribution of the highest values in the first ring of settlements around these cities, suggest the need to approach the management of suburbanization at the metropolitan level. Such as in the case of other post-socialist countries, urban sprawl in Romania is a process mostly taking place beyond the administrative borders of cities, supported by the lower prices of land in rural areas and entrepreneurial approach of some local public authorities for attracting new housing.

The fact that the two local administrative units with the highest urban sprawl restrictiveness index were Florești and Dumbrăvița is not a surprise. The former is Romania's biggest commune in terms of population, a fact highlighted by the recent preliminary results of the 2021 national census but also by different researchers illustrating the commune's population growth, mostly based on young people [91]. The latter, also with a significant growth in population in the last two decades, is considered to be one of the most developed communes in Romania [92]. Consequently, the results obtained through the computation of the urban sprawl restrictiveness index are consistent with the reality of the territorial dynamics in Romanian metropolitan areas, in spite of the problems in data availability and consistency, discussed below.

4.2. Possible Contribution of the Urban Sprawl Restrictiveness Index to Metropolitan Planning

Metropolitan areas were first defined in Romanian law in 2001 as voluntary associations of local administrative units that could be created in the areas surrounding the most important twelve urban agglomerations in the country [93]. In 2008, a spatial plan for peri-urban areas was introduced as planning instrument in the Romanian law [94]. However, as the number of cities that could form a metropolitan area gradually increased to 41 in 2019 [95] and 103 in 2022 [96], the national planning law changed in 2011 [94], replacing the spatial plan for peri-urban areas with the territorial metropolitan/peri-urban development strategy, which had limited effects on land use.

As a result, the planning of land use in metropolitan areas is the result of general urban plans developed by each local administrative unit, with little incentive or pressure for coordination at the metropolitan level. The adoption of new general urban plans often leads to the increase of built area limits, as this extension is an important means for increasing local budget revenue [76]. Moreover, when the general urban plan becomes outdated, such as in the cases of Florești and Dumbrăvița, suburban development becomes possible through private-led zonal urban plans, which allow the extension of built area limits and are approved by each local public authority.

Given the environmental, social and economic impacts of urban sprawl, there is a clear need for developing planning instruments and spatial policies that could aid in better managing suburbanization. In this context, the urban sprawl restrictiveness index could become an important tool for policymakers by highlighting the local administrative units that have become restrictive [97] due to the negative environmental, social and economic impacts of suburbanization. On the one hand, the index provides means to highlight the local administrative units that have been most affected by suburbanization not only in terms of urbanized area but also in terms of landscape fragmentation, increased commuting among the active population or insufficient social infrastructure. On the other hand, the index can be used as a monitoring tool to assess the progress made by local authorities in tackling urban sprawl issues. As the index is computed using exclusively publicly available data, it could be used for monitoring and computed every six years, when new CORINE or Urban Atlas data become available.

Such as in the case of other indices trying to integrate multiple dimensions, the urban sprawl restrictiveness index cannot provide a full picture of the different impacts of urban sprawl if discussed separately from its components. However, the index provides a synthesis of urban sprawl issues at the LAU level and could be especially useful in determining the areas where specific planning instruments are needed to ensure a better coordination in the development of multiple local administrative units. Our findings suggest that these areas include, in most cases, the core city and parts of the first ring of settlements around the latter. In addition to land use regulations across administrative boundaries, specific policies are needed for ensuring the necessary social infrastructures (especially kindergartens and schools) in the new suburban areas.

4.3. Research Limits and Further Research Directions

The most important limits of this research were related to the availability of data at the LAU level covering the entire territory of the selected metropolitan areas, also pointed out by other studies [8]. Firstly, the limited coverage of the national network for air quality monitoring, with stations often located only in the core cities of metropolitan areas, made it impossible to assess the potential impact of urban sprawl on air quality for each local administrative unit. This could be solved in the future by having access to air quality data from other monitoring sources covering the entire metropolitan territory.

Secondly, the validation realized by comparing the urbanization areas resulting from CORINE Land Cover and Urban Atlas datasets suggests that the values obtained from the former are higher than in reality. This was an expected limitation due to the original resolution of the CORINE raster data, which minimum mapping unit of 25 hectares makes it improper for more detailed analyses, also pointed out before [35,98]. While Urban Atlas data offers higher precision than CORINE, its coverage is limited to the local administrative units within the urban agglomeration of larger cities, i.e., the continuous urbanized area around core cities in a metropolitan area [7]. This coverage limitation meant that Urban Atlas data could not be used for all local administrative units within a metropolitan area. While the analysis of CORINE datasets resulted in higher values than the ones obtained from the Urban Atlas, the use of the former ensured that the same datasets were used for all 96 local administrative units.

The proposed urban sprawl restrictiveness index could be used in other analyses at the LAU level. The methodology could be replicated in the case of other metropolitan areas in different European countries, with the condition that data regarding the population and number of dwellings dynamics, building permits, number of students per teacher and commuting patterns are publicly available.

The quantitative method proposed in this paper could also be completed, in a multi-scalar approach, with a qualitative approach (see, for example, [8]). The latter could be used to better understand the impacts of urban sprawl from perspectives such as urban morphology, quality of living in relation to infrastructure access or landscape quality. The relation with existing urban planning regulations could also be explored in-depth, as it would greatly aid in discovering the potential causes that have led to uncontrolled suburbanization in the first place.

5. Conclusions

This paper proposes a novel method for the integrated assessment of urban sprawl in metropolitan areas through the computation of an urban sprawl restrictiveness index comprising indicators related to environmental, economic and social issues. The urban sprawl restrictiveness index is based on publicly available data and could thus become an important tool for monitoring urban sprawl issues in metropolitan areas. Used by policymakers, the index is useful for highlighting areas with the greatest suburbanization dynamic, which should become an object of specific planning instruments regulating land use and proposing interventions for improving the quality of living. The spatial distribution of index values in a given metropolitan area can become the first step before more thorough analyses are made to determine the best spatial planning approaches for confronting suburbanization in different local administrative units.

In the case of Romanian metropolitan areas, the spatial distribution of the urban sprawl restrictiveness index shows that the territories most affected by suburbanization are located in the first ring of settlements around the main cities. This suggests that new planning instruments or spatial policies targeting quality of life improvements in territories affected by uncontrolled suburbanization should focus on a territory that is smaller than the metropolitan area.

If available, other indicators could be added in the computation of this index, such as data on air pollution or more precise data on urbanized areas. The proposed methodology could be used for comparative studies between post-socialist countries or even countries belonging to other spatial planning systems, opening new research directions regarding the scale of urban sprawl impacts in different territories and their implications for spatial planning.

The quantitative approach presented in this paper could benefit from more in-depth analyses focusing on smaller areas within a single local administrative unit. These analyses could point out the relation between urban sprawl and existing planning regulations, as well as additional impacts that cannot be assessed at the LAU level.

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