T U R A S
TRANSITIONING TOWARDS URBAN
RESILIENCE AND SUSTAINABILITY

FORMS OF URBAN GROWTH IN SOUTHEAST EUROPE:

TRANSITIONING TOWARDS URBAN RESILIENCE AND SUSTAINABILITY

VOLUME 2

Edited by

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THE ROLE OF MARKET AND STRATEGIC PLANNING AND GOVERNANCE IN URBAN GROWTH AND DEVELOPMENT: THE CASE OF THE METROPOLITAN AREA OF BELGRADE (SERBIA)

Compendium of contributions of the IAUS team to the Project TURaS

Content

3.2. Indicators of urban sprawl and urban land policy

Slavka Zeković, Tamara Maričić and Miodrag Vujošević

3.2.1. Introduction

The **key aim** of this contribution is to present the *indicandum* (the indicated issues, that is, urban sprawl and urban land) which are usually measured by a number of indicators, the criteria for selection variables, the identification and classification of the key indicators (quantitative) and their description. Also, a **concomitant aim** is to derive some quantitative indicators critical for urban sprawl and urban land policy.

As for the **methodology** used here for the preliminary identification of the indicators in question, the criteria are derived from standard evaluation of limit values and goals of, while the indicators are derived from measurements. Both concepts define the means or tools which have been used for the collection, analysis, evaluation and comparison of information about different issues, as well as tools for the integrated impact analysis of urban processes on urban land-use and policy.

We start here from the common finding that land-use indicators are important in the identification, better planning, governance and prevention/limitation of urban sprawl and urban land use. For example, Needham (2006) pointed to the significance of three criteria, viz., the effectiveness in realizing democratically chosen goals, economic efficiency and distributional effects. In addition to this, we will corroborate our arguments by including the majority of the criteria that have already been put forth by the TURaS partners (see Report by La Sapienza, 2012), supplemented by introducing a number of new criteria. In this respect, some of the general recommendations of the TURaS project have been used here, with the aim to develop a **syncretic approach** which includes the following five segments:

- A short analysis of the specific theoretical and global contextual framework for urban sprawl and urban land policy;
- Defining a perspective and the classification of groups of indicators;
- Deriving, describing and quantifying key quantitative indicators;
- Deriving preliminary criteria for the valuation of indicators; and

- Deriving a tentative matrix of indicators, paralleled by their "brief-and-rapid" valuation, based on a provisorial heuristic analysis of the above topic (no. 4).

As early as at this stage, it should be pointed out that suburbs are areas of changes, implying that some indicators can vary, even considerably, in accord with the changing dynamics and characteristics of various urban or rural territories. As for the application of the chosen indicators, they should be selected taking into account that their respective roles and usage may well differ between **sustainability indicators**, **indicators for potential scenarios** and different **spatial scales**.

As for the lessons from numerous international practices and experiences (i.e., from the global context), here we utilize some general findings that form a common ground in this field. For example, EEA (2006) defined urban sprawl as "… low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas." Urban sprawl includes various phenomena such as: strip development, scattered development, and leap-frog development. According to Bolund and Hunhammar (1999), urban sprawl can support the environmental quality in cities but with the consumption of more energy and occupation of a large amount of land. Analogously, the high demand for residential area per person and decreasing household size represent some of the key reasons (sources) for urban sprawl (Camagni et al., 2002). It was Ewing (1997) who argued that a better way to identify urban sprawl was to use indicators because this was a more flexible and less arbitrary method. We, also, have recently pointed out the importance of some sprawl indicators, like urban land consumption, consumption of agricultural land, etc. (Zeković, Vujošević, Maričić, 2015).

With the aim to implement the sustainable development goals of *UN Habitat* (2015) related to cities and human settlements as inclusive, safe, resilient and sustainable, here we suggest some pertinent recommendations, viz.: ensuring access to affordable housing and basic services, and upgrading life in the suburbs by expanding public transport to provide access to transport systems; reducing the adverse environmental impact of cities/suburbs per capita; providing access to public spaces; supporting the economic, social and environmental connections among sub/urban, peri/urban and rural areas by strengthening urban planning& governance and indicators; supporting sustainable and resilient buildings; and limiting urban sprawl in suburbs. This accords with the implementation of the *New Urban Agenda, Sustainable Development Goals and the Strategy for Sustainable Housing and Land Management in the ECE Region 2014-2020*, which suggest the prevention and limitation of urban sprawl because "ongoing urbanization has led to the continuing expansion of urban areas and urban sprawl, thus reducing the land available for other uses", as well as the *Strategy for Sustainable Housing and Land Management in the ECE Region 2014-2020*, its key objectives comprising: balancing the increasing demand for urban land and the limited supply of available land; minimizing the loss of rural land; increasing the efficient use of urban land; and realizing compact, inclusive and green cities. Finally, according to the *Prague Declaration for the UN conference on Housing and Sustainable Urban Development* (Habitat III, March 2016), planned strategic urban development can promote economic, social and environmental sustainability and prevent urban sprawl, with

urban sprawl featuring as one of the key challenges of urban development. In this context, risk reduction and urban resilience may also play prominent roles.

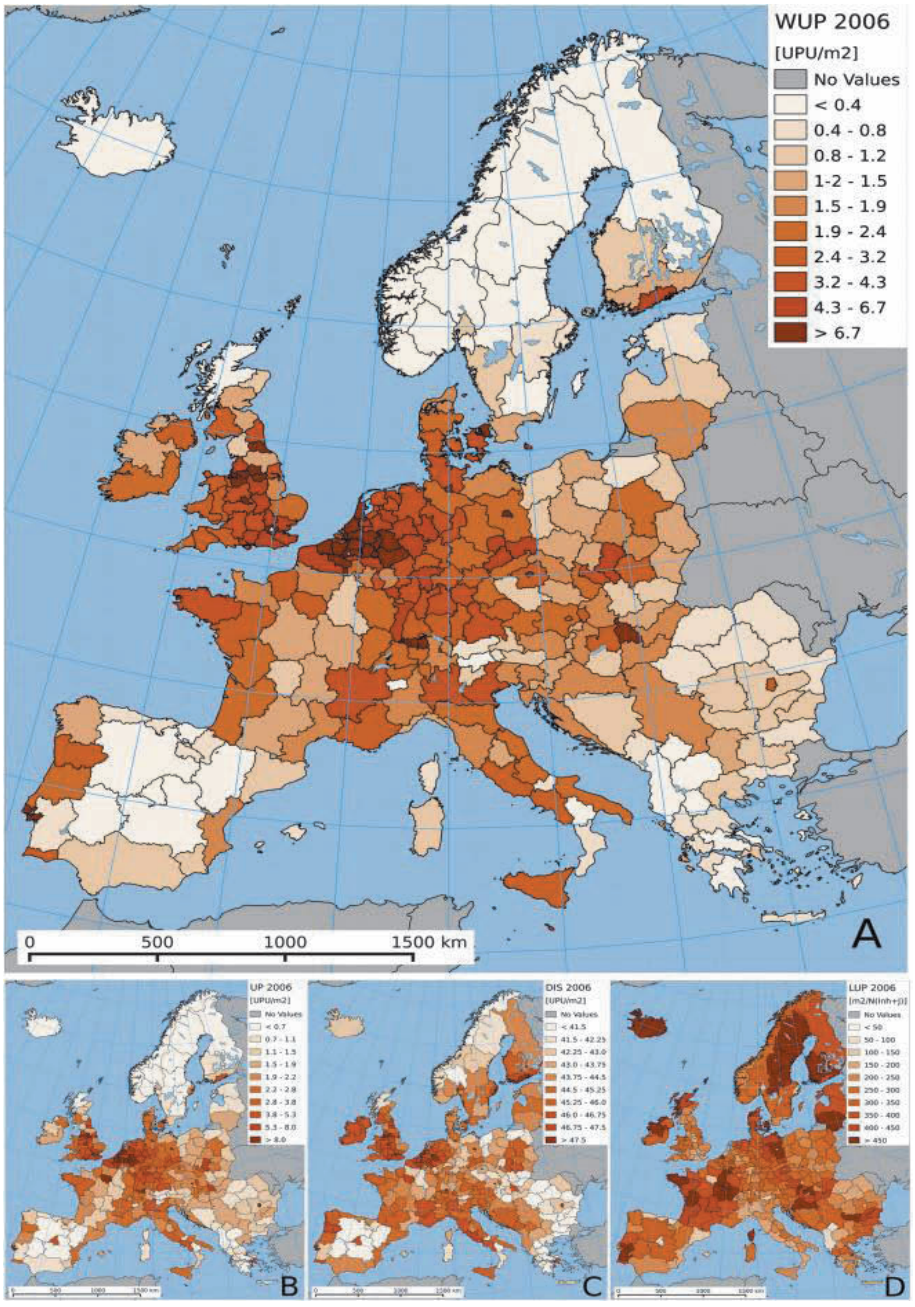
As for the **practical implementation of the general schemes and guidelines**, according to Normandin et al (2009), comparative analysis between the resilience indicators and the sustainable development indicators for cities (273 indicators) showed that only a small number of them were identical, which also contradicted a common belief that sustainable development equaled resilience. This phenomenon points to the fact that uncontrolled urban growth can lead to urban sprawl, thereby generating a number of negative impacts (e.g., lack of public spaces, transport, services, jobs, and so on). Also, the lack of affordability renders various impacts on urban sprawl, especially on low cost housing. In this respect, compact urban forms, supported by appropriate public transport infrastructure and access to public services, are better suited to sustainability. In limiting and preventing urban sprawl, different costs of urban land equipment/utility, associated costs and the costs of urban densification of the existing urban structure play the most important role.

In the same context, it should be pointed out that the **neoliberal urban policy** resulted in a switch from prosperous "boom scenarios" (in the era of financial "bubbles") to subsequent "doom scenarios", sprawling to an enormous number of cities and towns, both in some of the most developed countries, post-socialist countries and other places, thereby devaluing their respective urban assets and territorial capital. In sum, the so-called "New urbanism", directed by the slogan "this time is different" (cf. Reinhart&Rogoff, 2009), resulted in disastrous losses of capital and asset value, but also introduced new arrangements of risk dissemination, transfer and redistribution. Namely, the real estate bubble/property bubble (housing bubble, urban-land bubble, and so on) is a form of economic bubble in local or global markets. These bubbles are characterized by the fast growth of property values (houses, flats and land) until they reach an unsustainable level – and then they rapidly decline. In the case when the bubble bursts, the property value decreases, which is, however, not paralleled by the equivalent debt of their "owners".

In **macro-regional terms**, some European regions feature very prominently regarding the control and limitation of urban sprawl. Hennig at al. (2015) identified European regions with the highest and of the lowest levels of urban sprawl, respectively, and proposed a European de-sprawling strategy, including the implementation of targets and limits, and a set of concrete measures to control urban sprawl and to use land in an efficient way (Figure 1). They used the so-called method of Weighted Urban Proliferation (WUP) for measuring urban sprawl, which combined three components (after Jaeger et al, 2010) and determined urban sprawl at the country level, *NUTS 2* level and Land and Ecosystem Accounting, with a grid/cell size of 1 km^2 (Fig.1). They ascertained that large parts of Europe are affected by urban sprawl, with an average WUP value of 1.56 UPU/m^2 (UPU/Urban Permeation Units). Jaeger at al. (2010) argued that for urban sprawl, the ideal case would be that one indicator quantifies the degree of urban sprawl, while an additional indicator measures the relevant causes, consequences, and attributes of urban sprawl. They suggest the use of three measures, viz., the size of urban area, proximity and contagion. Feng et al. (2015) demonstrated the use of

multidimensional **indicators** to effectively measure **urban sprawl as well the u**se of integrated **indicators.**

Figure 1. WUP index in European urban sprawl in UPU/m^2 (Hennig et al., 2015)



Suggested categories and types of indicators

Starting from the above mentioned and some other cases and experiences, also in accord with the aim stated at the beginning of this report, we now define **a preliminary set of indicators for urban sprawl, urban land-use and concomitant policy**, grouped into five categories, viz.:

- Key indicators of urban sprawl and urban land;
- Anticipatory indicators of urban sprawl;
- Basic market indicators of urban land and real estate;
- Indicators of multi-functional urban land-use; and
- Composite indicators (indices).

The above listed categories are defined and described in more detail below.

3.2.2. The key indicators of (limiting) urban sprawl and urban land

Out of the large number of indicators that have been suggested for usage and/or have already been utilized, we focus here on some of the standard indicators of the kind that could also be applied to the three cities which are the main theme of the research within WP5 (following their general description in Table 1).

The urban sprawl index measures the growth in built-up areas over time, adjusted for population growth. In accord with *Cities and climate changes: key messages from the OECD* (OECD, 2013), when the population changes, the index measures the increase in the built-up area over time relative to a benchmark where the build-up area would have increased to in line with the population growth. The index is equal to zero when both population and the built-up area are stable over time. It is larger (smaller) than zero when the growth of the built-up area is greater (smaller) than the growth of the population, i.e., the density of the metropolitan area has decreased (increased). The suburbs have grown faster than the urban core in 66 of 78 metropolitan regions in the OECD countries.

The gross rent multiplier (GRM) is applicable for the market value analysis for any purchased property. Despite the fact that the GRM may not be precise enough for the assessment of value, it may well be useful as a "first and fast" value assessment tool. In this respect, it may be of importance for a general appraisal of the ratio between market movements, for example, regarding building new floor areas and the sale/purchase and rent of existing floor areas. The GRM indicator can probably indicate the over-pricing – or under-pricing – of properties, as well as a certain level of **resilience** of investment property policies (as they develop and accommodate over time).

According to the EU (2011), EU policies take into account the direct and indirect impact of land use in the EU and globally, and the rate of land take is on track with the aim of achieving no net land take by 2050.

Table 1: The key indicators of urban sprawl and urban land

Indicator	Description	Note
1. Urban sprawl index	Change in urban area vs. change in population (relation in % or index)	
2. Urban sprawl indicator	Total population/distance from the city centre (determination of a threshold value where the amount of artificial surface reaches the national mean value)x(1/Distance from the city centre where the natural surfaces exceed the artificial surfaces)x100	PLUREL project (2009) developed this indicator of urban sprawl using the land cover structure (gradients) and the population number-value decrease with increase of urban sprawl
3. Urban land consumption (urban land-take)	m2 /p.c.	
4. Land development multiplier	Relationship between the average price of adjusted p/lots/parcels in urban boundaries and the average price of unadjusted/undeveloped land in non-built/undeveloped areas	
5. Gross rent multiplier (GRM)	Market value/Annual gross Income – rent	This indicator is suitable as a rough general assessment tool of over-pricing – or under-pricing – properties, to serve as a measure of resilience of investment property policies over time, both for existing and newly constructed units.
6. Urban densities	Number of inhabitants/ha of urban land	
7. Relation of rates core urban/ peripheral growth of inhabitants	In %	
8. Index of demand for land and supply of urban/building land	The relation between the average annual volume of demand for land and supply of	

	urban/building land (ha/yr)	
9. U-Index/ Human use index or Corridor index	As % of human land use in an area (urban, suburban and agricultural land)	Larger values indicate the main disturbance of natural land area, while lower values show less deviation of natural land cover.
10. FSI (Floor Space Index/Floor area ratio or Floor space ratio)	The ratio of a building's total floor area (gross floor area) to the size of the piece of land upon which it is built	
11. Increment of built areas	In % or m2	As "cost"
12. Increment of green areas	In % or m2	As "benefit"
13. Agglomeration index as alternative measure of urban concentration	Based on three factors - population density, population of a 'large' city centre, and travel time to the large city centre	Source: Uchida and Nelson (2011)
14. Availability and access to public transport	Frequency of service/ number of departures per hour in an urban area: no access, low (4 departures/h), medium (4-10 departures/h), high (>10 departures/h), very high ((>10 departures and metro with >10 departures/h)	Source: EC (2015)
15. Commuting distance	As % of inhabitants in the radius zone 5-10km, 15-20km, >20km or over time-trip	Commute is a journey from home to work and back
16. Land use intensity	Km2/GDP	EC (2011) suggested this indicator concerns "resource use intensity".
17. Rate of conversion of agricultural land into urban over a particular period	In %	

3.2.3. Anticipatory indicators of urban sprawl

The idea behind the urge to define appropriate anticipatory indicators is to be able to foresee, in a timely manner, the impact of some of the expected determinants ("signals") which may influence the key course of future events (1), as well as to outline an appropriate policy framework in the urban land-use market, the real-estate market and housing market (2). In particular, they would indicate the predictable outburst of "rent bubbles" (or similar phenomena) in the markets in question. The indicators assume an especially important role under the circumstances of unstable financial flows in this sphere. They are summarized in Table 2. The indicators in question signify the importance of the impact of high-risk mortgage loans (that is, loans which are given to people without credit potential or without connection with their incomes, totaling about 10% of the value of outstanding mortgages, cf. Mayer and Hubbard, 2008). According to the mentioned authors, real house prices were 82% higher in 2007 than in 1999, rising 70% relative to household income. (In accord with data from Goldman Sachs, 2008, a 1% increase in mortgage lending rates would reduce the market price of houses by 8%.)

A simple theoretical framework between house prices and interest (mortgage) rates was considered as early as at the beginning of 1960s, within the so-called "Gordon growth model". In this model, the asset price = dividend/interest rate – dividend growth rate (Gordon, 1962). The reinterpretation of Gordon's growth model for housing (house price = rent/Interest rate – rental growth rate) implies a convex relationship between house prices and interest rates: the lower the level of the interest rate - the greater the elasticity of house prices (Mayer, Hubbard, 2008), especially in long-term series comparisons.

Table 2: Anticipatory indicators of urban sprawl and real estate market.

Indicators	Description	Notes
1. Price of urban development/ building land	Price in (€/ m^2)	
2. Urban sprawl index	Change in urban area vs. change in population, in % or index	
3. The annual gross rental yield for a housing unit	Annual rent/ house price x 100% or $\text{Gross Rental Yield} = \frac{\text{Monthly Rent x 12}}{\text{House Price}} \text{ x } 100\%$	Used in the United Kingdom.
4. Price of dwellings/houses/ flats	House Price = Rent/(Interest Rate – Rental growth rate), in €/ m^2 of houses/flats	In accordance with the Gordon growth model the Asset price = dividend /interest rate – dividend growth rate (Gordon, 1962).
5. Ratio of housing to family income	As %, or as annual income	

6. Affordability Index	Measures the ratio of the actual monthly cost of the mortgage to take-home income	
7. Median Multiple	Ratio of the median house price to the average annual household income	This measure pitches around a value of 3 or less, but rose dramatically, especially in markets with severe public policy constraints on land and development.
8. Number of buildings under mortgages	Number of buildings under mortgages (loans) or in % of total buildings	In Serbia there are 1.04 million buildings under mortgages, out of a total number of 4.69 million buildings.

3.2.4. Basic market indicators of urban land and real estate

- We conclude this presentation of various multi-purpose indicators by resuming standard indicators that are used in the sphere of urban land market and real estate analysis, viz.:
- Land development multiplier;
- Annual volume of demand for land (for industrial, commercial and residential uses, in ha per year;
- Elasticity of demand for urban land construction (correlating change in prices and change in demand);
- Number and volume of transactions, which expresses the annual number of plot transactions for commercial and/or residential purposes (it could be expressed as the ratio of the number of sales and purchase agreements to the total housing stock, i.e., as the turnover rate);
- Annual number of dwelling transactions (sales and purchases) and rented dwellings;
- Average annual volume of supply of urban (construction) land (for industrial, commercial, residential, public and other purposes, in ha per year);
- Median, and extreme, prices of urban (construction) land (€/m2);
- Level of informal land transactions;
- Availability of information on land prices;
- Lost agricultural land for conversion into other uses;
- Changes in the amount of inaccessible (impervious) areas;
- Prices of various types of dwellings (flats, housing units, houses, etc.), in €/m2;
- Number of housing starts (per year);

- Number of permits issued (per year);
- Change in urban land vis-à-vis change in population (as %, or as index);
- Annual gross rental yield per housing unit (annual rent/house pricex100%);
- Annual gross rental yield for commercial properties (AGRYCP=Annual rent per m2 of floor spacexm2 of built space/Value of built space, expressed in %);
- Gross rent multiplier (GRM=Market value/Annual gross income-rent);
- Buy-rent gap as the ratio of the costs of purchasing a flat to the rental costs, which compares the costs of owning a flat in relation to renting it;
- Vacancy rent of built floor space or unit (Effective number of occupied units, in m2/Total number of units, in m2 in a certain zone and/or building category);
- Quantitative indicators for the formal land administration system, which comprise: security, transferability, clarity, simplicity, timeliness, fairness, accessibility, costs and sustainability (after Burns, 2007); etc.

3.2.5. Indicators of multi-functional urban land-use

According to Bhatta et al (2010), the degree to which different land uses are mixed together is often indicative of concrete urban sprawl, which, however, may well differ among the key spatial patterns of land-use, that is, to be mono-functional on the one hand, and multi-functional on the other, and also in a different way impact **urban resilience**. In this respect, **Beinat** and Nijkamp (1998) emphasize that the multi-functional utilization of urban land is a preconditioned in the following way:

- An intensified utilization of urban land may drive its more effective usage;
- Mixed uses are typical within an area;
- This also introduces a third physical dimension (under-surface and above-surface) of its multi-functionality; and
- The fourth dimension reiterates the importance of multi-dimensionality over time.

These characteristics, in particular, point to the importance of introducing appropriate approaches to standard planning models, with a view to better accommodate both space and time dynamics. This is of particular relevance from the standpoint of keeping an urban system **resilient** to various changes, vis-à-vis the fact that the vulnerability of the system grows with the versatility of its uses. (Of course, this may well apply to other similar categories, that is, **urban adaptability**, **urban resistance**, and **urban stability**.) Namely, introducing new functions into an urban area, in parallel with diminishing the sizes of pertinent mono-functional sub-areas, will most predictably render an impact on the adaptability of the system in question, including its resilience, as well as on the **quality of its territorial capital**. Apart from the so-called "soft parts" of the territorial capital of an area (e.g., institutions, human resources, dominant models of communication and interaction, etc.), here its more conventional characteristics are of special relevance, that is, efficacy, effectiveness, sustainability, synergy (of functions and activities), and so on. This, of

course, drives us to the more politico-economic aspects of urban development. As for the narrower and specific aspects of the utilization of urban land, we will resort here to the key factors of effective land utilization (after Harvey, 2000), viz.: accessibility, agglomeration economies, development, physical characteristics, and technological growth and development. Following this line of thinking, below we define a framework for a better understanding of the factors that determine the selection of multi-dimensional utilization of urban land, viz.:

- The importance of an appropriate integrated planning-and-market/market-and-planning approach for controlling land use in terms of diversification, dispersion, concentration, multi-functional interweaving, territorial cohesion, etc.;
- Striking a balance between different approaches for defining the systems of indicators (e.g., complementarity between the sets of indicators that have been suggested in this contribution – vis-à-vis those that have been developed by other TURaS partners, for example, La Sapienza within T5.2);
- Defining a common set of criteria for specific multi-functional uses of urban space;
- Defining typologies of multi-functional use of urban land, harmonized with other approaches, methods and tools (e.g., those developed within TURaS, CORINE LAND USE, ESPON, new approaches in controlling urban sprawl in post-socialist countries, etc.);
- Undertaking research and evaluation of the impact of multi-functional land use on the selection, construction and usage of urban land-use indicators; etc.

Starting from the above listed assumptions, as well as from the research goals as defined for tasks T5.5&T5.10, we outline below a **set of indicators which seem to be of relevance for multi-funcional urban land-use**:[32]

- **The land development multiplier**, which expresses the relationship between the average price of a spatially arranged and organized plot (lot, site, parcel, and so forth) in a developed (or built up) area and the average price of undeveloped land in a non-built up (non-developed) area;
- **The diversity index**, as a quantitative measure, expresses the different land use functions (or "planned destinations") that could simultaneously exist in the project area. Apart from its general form (Diversity=Actual number of functions/Maximum number of feasible functions), it also has a number of variants (True diversity index, Shannon entropy index, and so forth) - see Hannan (1997);
- **The dispersion index** (derived from the HHI, Herfindahl-Hirschman Index, measuring the size of firms in relation to an industry, as an indicator of the

[32] To note, in the earlier phases of the TURaS research, we already mentioned this category of indicators.

amount of competition among them)expresses the variability of functions in a given area in urban land management, as in the formula:

$$D = \frac{1}{l \cdot \sum_{i=1}^{l} \left(\frac{M_i}{S}\right)^2},$$

where: i=1, Mi - the amount of m^2 land used by a single function i (input), S - the total amount of m^2 land use of the project area, l - the actual number of functions (l has a maximum value according to the number of land use functions in a plan or other documents). Also, the **index of dispersion**, **dispersion index/coefficient of dispersion or relative variance** are measures of the dispersion of a probable distribution (including a standard statistical model); and

- **Index of efficiency and intensity of land use** (FSI, etc.), as a standard measure of the utilization of an area (space).

Composite indicators (indices)

Composite indicators may be developed for various explorative and planning/policy purposes aimed at getting a better insight into a number of issues, viz.: urban expansion patterns; the degree of compactness of urban land (compendious development, linear/corridor development, "leapfrog" development, cluster space development, etc.); the degree of urban sprawl; the agglomeration index, etc. Of necessity, they would have to measure specific multi-dimensional concepts applied to a concrete situation, e.g., the level of competitiveness, resilience, environmental quality and territorial cohesion, as these concepts cannot be captured and expressed by a single indicator. Along this approach, and based on the appropriate theoretical framework and methodology, **composite indices** would be selected and combined in a way which is most suitable to express the concept in question (i.e., compactness, urban sprawl, urban resilience, cohesion, etc.), as well as to support research on the optimal degree of aggregation and measurement of the mentioned urban phenomena.

3.2.6. Ecological indicators for reducing urban sprawl

There has been a common stand among commentators that urban sprawl may induce a number of negative environmental and energy-related outcomes. For example, Oueslati et al. (2015) claim that the most compelling examples of the kind are air pollution and greenhouse gas emissions (indirectly contributing to urban heat island phenomena). According to a study in Norway (Sørlie, 2008 in Christiansen and Loftsgarden, 2011), the environment is among the top five reasons for moving, after family causes, housing and location (while work was the most important reason for moving in 1972). As a motive for sprawl, a study from 2011 (Christiansen and Loftsgarden) also mentioned access to green space and having a good environment for children.

Referring to various ecological (environmental) consequences of urban sprawl in a number of European countries, the European Environment Agency (EEA, 2006) pointed to four broad main categories of environmental consequences of urban sprawl, viz.:

- **Natural resources and energy**, which includes: increased consumption of numerous natural resources (farmland, raw materials, etc.) and energy (household and transport, increased emission of CO_2 to the atmosphere, etc.), transformation of soil properties (soil sealing, etc.), and hydrological changes (impairment of small watersheds, reducing groundwater recharge);
- **Natural and protected areas**, which includes: stress on ecosystems and species through noise and air pollution, fragmentation of habitats (degradation of ecological networks), loss of agricultural and natural land, particular impacts on ecologically sensitive areas located in coastal zones and mountain areas;
- **Rural environments**, referring to urban growth on former agricultural land; and
- **Urban quality of life, hazards and health**, which include both the direct impacts, e.g., poor air quality (resulting in an increase in respiratory problems linked to air pollution) and high noise levels, and indirect impacts, e.g., greenhouse gas emissions that have major implications for global warming and climate change, causing severe weather events and increased incidences of river and coastal flooding, or soil erosion due to the reworking and removal of the soil surface by construction.

A large number of researchers (Burchfield et al., 2006; Deng et al., 2008; *Laidley, 2016;* Oueslati et al., 2015; Stone 2008; Wu, 2006; Hasse& Lathrop, 2003; etc.) highlight the importance of environmental factors for inducing and regulating urban sprawl. In the sequel the most significant factors are briefly pointed out, paralleled by the concomitant suggested indicators, all belonging to five large groups, as they have been put forth by some authors.

- **Ground water availability**. According to Burchfield et al. (2006), sprawl increases substantially with the presence of water-yielding aquifers in the urban fringe, as they allow people to dig a well far away from any other development without financing the extension of the municipal water infrastructure.

Suggested indicator: % of urban fringe overlying aquifers

- **The role of the temperate climate**. According to Burchfield et al. (2006) and Oueslati et al. (2015), the temperate climate represents one of the main factors that increase the value of open space and sprawl.

Suggested indicators:

Mean cooling degree days

Mean heating degree days (The idea behind this is to define whether a city has an extremely hot or cold climate. A standard measure of extreme heat is cooling degree days, a concept used by engineers to calculate the demand for air

conditioning. Extreme cold can be similarly measured through heating degree days, used to calculate fuel demand for heating, cf. Burchfield et al., 2006.)

Thenumber of rainy days per year (cf. Oueslati et al., 2015)

Temperature (referring to the average temperature of the warmest months on the year, cf. Oueslati et al., 2015)

- **Rugged terrain**. According to Burchfield et al. (2006), while high mountains close to a development hinder urban expansion and tend to make development more compact due to higher costs, hills and small-scale terrain irregularities encourage scattered development. Analogously, Oueslati (2015) showed that the effect of altitude is positive, implying that cities located in urban areas at higher altitudes are likely to be more fragmented.

Suggested indicators:

Elevation range in the urban fringe (m)

Terrain ruggedness index in the urban fringe (m) (Burchfield et al. 2006)

Median city centre altitude above sea level (m) (as a partial indicator for the ruggedness)

- **Ambient air quality and local particulate pollution**. Stone (2008) showed that large metropolitan regions ranking highly on a quantitative index of sprawl experience a greater number of ozone exceedances than more spatially compact metropolitan regions.

Suggested indicators:

Particulate Pollution Emissions per Capita, lbs. (PW), measuring the total per capita emissions in pounds of hazardous pollutants, the sum of volatile organic compounds, NO_x, sulfur dioxide, carbon monoxide, ammonia, and small and large particulate matter, i.e., particles less than 2.5 and 10 μm in diameter, respectively (cf. Laidley, 2016)

Exceeding emissions of pollution particulates, measuring the number of days per year when concentrations/emissions of pollution particulates exceed the statutory level, namely: hazardous pollutants, the sum of volatile organic compounds, NO_x, sulfur dioxide, carbon monoxide, ammonia, and small and large particulate matter, that is, particles less than 2.5 and 10 μm in diameter, respectively

CO_2 Emissions per Capita from Onroad Sources, kg (CO_2), measuring the total per capita on-road carbon dioxide emissions in kilograms from highway sources (cf. Laidley, 2016)

- **Loss of natural habitat**. Forests and wetlands have been recognized as crucially important for the ecological health of a landscape and its biodiversity. The loss of wetlands has implications for the water quality/quantity and wildlife habitat. The loss of natural habitats and construction of roads also induces habitat fragmentation (according to Vos et al, 2001, this has two principal components: decrease in habitat area and increase in the isolation of the remaining habitat patches.)

Suggested indicators:

Percentage of forest habitat loss, normalizing the area of forest core loss by the area of previous forest core for each unit of analysis. (This can also be expressed as **Per capita forest loss**, generated by normalizing the area of forest core loss by the population increase for each unit of analysis, cf. Hasse& Lathrop, 2003.)

Percent of natural wetlands loss, generated by normalizing the area of wetlands that become urbanized by the original area of wetlands. (This can also be expressed as **Per capita natural wetlands loss**, generated by normalizing the area of wetlands lost to urbanization by the population growth within the unit area of analysis, cf. Hasse& Lathrop, 2003.)

3.2.7. Conclusions

Based on our preliminary analyses, suburban areas with more urgent social needs or structural economic difficulties should be recognized as immediate planning entities for further research, starting from the suggested types of quantitative indicators. We suggest the integration of several indicator groups into the TURaS tools, relating to completion of urban sprawl, urban land use and other parameters (social, economic, environmental, demographic, etc.) into a common framework of integrated urban strategy, as well as further research into the optimal degree of aggregation, and the measurement of different urban phenomenon by composite indicators (urban sprawl, urban competitiveness, urban compactness, urban resilience, etc.). Apart from this purpose, they should also serve another important purpose, namely, helping define a future research agenda in this field. Indeed, it is now very difficult to prepare planning and development regulations and indicators for urban sprawl because of a lack of guidance for their adaptation to the global challenges, uncertainties, disturbances and limitations in different and complex contextual conditions. Appropriate and suitable indicators may help to that end, that is, to get better insights into the key and related matters of controlling and directing urban development.

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3.2.8. Appendix

The ideas behind the proposals in this contribution are twofold: first, to preliminary identify those criteria and derive those quantitative indicators that critical for urban sprawl and urban land policy, to be ruther developed for comparative analysis; and second, to help define a new research agenda, focused on the efficiency of the indicators in use.

Table 1. Preliminary criteria for the benchmarks of the urban sprawl and urban land

Transparency	Term should be clear and simple to understand to general public. It should alco satisfy the condition of being transparent.
Accessibility	The quality of being available when needed. In conditions of uncertanties and challenges, indicator should be able to providing access to all users
Sustainability	The ability to continue a defined behavior indefinitely. Sustainability implies the organizational and institutional arrangements, governance procedures, educational and professional levels for the particular jurisdiction, understanable and affordable to the inhabitants and users.
Security	The state of being free from danger or threat. Land markets have to operate effectively and efficiently with protection of the property rights to all. Financial institutions should be informed to mortgage property/ land.
Efficiency	The state, action or quality of being efficient.

To note, a number of other indicators of some relevance have not been includedin the above table, for example, the criteria of accuracy, simplicity, cost, utility, flexibility, validity (based on official statistics or data), etc.

Table 2. A Matrix of links beetwen quantitative indicators of urban sprawl&urban land and criteria

Indicators	Transparency	Accessibility	Sustainability	Security	Efficiency
Urban sprawl					
1. Urban sprawl index		+		+	
2. Urban sprawl indicator		+	+		
3. Urban land consumption		+	+		+
4. Land development multiplier	+	+	+		+
5. Gross rent multiplier	+			+	+
6. Urban densities			+		
7. Relation of rates core urban/ peripheral growth of inhabitants			+		
8. Index of demand for land and supply of urban/building land		+	+		+
9. U-Index/ Human use index		+	+		
10. FSI- Floor space index	+		+	+	+
11. Increment of built areas			+		
12. Increment of green areas		+	+		
13. Agglomeration index		+	+		
14. Availability and access to public transport	+	+		+	
15. Commuting distance		+			
16. Land use intensity	+				+
17. Rate of conversion of agricultural land into urban		+	+		

Urban land use					
1. % of total parcels registered	+	+		+	
2. % of transfers of rights that are registered	+			+	+
3. Annual registered transactions as % of registered parcels	+	+		+	+
4. Annual registered transfers as % of registered parcels	+	+			+
5. Annual registered mortgages as % of registered parcels	+			+	+
6 Annual registry running costs/ registered parcels					+
7. Number of registred parcels/ 1 million residents		+			
8. Number of registred parcels/ km^2		+			
9. Public/budgete income/p.c.	+				+
10. Equitable taxation of property	+				+
11. Blighted or substandard flats	+			+	