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Multi-criteria analysis of urban policy for sustainable development decision-making: A case study for Warsaw city, Poland

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Abstract

In order to track how cities develop and grow, multidimensional systems of urban development indicators taking into account the balance between economic, social, and environmental aspects are the best solution found so far. However, there is no unique measurement system that would be widely accepted and applied within various urban areas to verify whether a given city is developing in a sustainable way. The aim of this paper is to apply the TOPSIS algorithm on the basis of selected urban indicators, in order to evaluate the progress of a single city towards the concept of sustainable development observed over a longer period of time. A capital city of Poland, Warsaw, faces several challenges associated with development policy evaluation, thus confirming the need for this research. We meticulously selected 48 indicators from the economic, social and environmental areas as an input for TOPSIS algorithm, which allowed us to calculate a new proposed aggregated index for evaluating urban policy on the example of Warsaw. Research has shown usefulness of applied TOPSIS algorithm in assessing the long-run development of an urban area towards the concept of a sustainable city. The results of our analysis indicated that over a period of ten years, during 2008-2017, the urban policy decision-making has been balancing the socio-economic and environmental aspects and the city of Warsaw has been developed in a sustainable manner.

Keywords: multi-criteria decision analysis; sustainable urban development; TOPSIS algorithm; urban sustainability indicators

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1. Introduction

Sustainability in cities seeks to successfully meet present needs without compromising the future ones and to work together for a vibrant economy, in an inclusive society and a healthy natural environment. Cities constitute centers of the economic and social development for their countries and regions, but they also contribute to huge devastation of the natural environment. The concept of a sustainable city refers directly to the Brundtland report [12] and brings the definition of sustainable development into the urban level. Thus, a sustainable city is one in which environmental and social goals are fully integrated with economic goals, and the needs of the city's inhabitants are satisfied without diminishing the opportunities of future generations.

Theoretical framework and indicative targets set by international agreements and declarations for sustainable development decision-making encounter numerous practical problems during their implementation. The operationalisation of the concept of sustainable development at the city level is difficult because the criteria of a sustainable city remain diverse. Currently there is no single sustainability measurement system that is widely accepted and applied among various urban areas. Meanwhile, more and more cities are prioritising the assessment of sustainability and many of them are making efforts to develop detailed measurement and evaluation programs including environmental, social and economic aspects.

We have examined current state-of-the-art decision-making models for sustainable development, and we propose to apply the TOPSIS algorithm in order to calculate a new proposed aggregated index that evaluates the progress of sustainable development of Warsaw observed over a 10-year period of time. The study was based on data provided by the Central Statistical Office of Poland. The decision to use database of statistics provided publicly was dictated by the desire to ensure full transparency and reproducibility for application of the TOPSIS algorithm and calculation of the aggregated index.

This paper is organised as follows. Section 2 presents the review of available methods for decision-making in the context of urban policy. Section 3 describes our proposed selection of urban development indicators for Warsaw. Section 4 addresses data preprocessing for TOPSIS algorithm. Section 5 reveals application of TOPSIS algorithm and calculation of a new proposed aggregated index that we named Sustainable Urban Development Index (SUDI). The paper ends with discussion of research ideas in Section 6 and final conclusions in Section 7.

2. Multi-criteria analysis methods in the urban policy decision-making

A group of Multi Attribute Decision Making (MADM) methods focuses on problems in which the set of all acceptable solutions is a discrete set containing a finite number of possible decision alternatives [5]. In MADM, the alternatives can be described in terms of value, in arbitrary units, or qualitatively (point scale). As a result of normalisation of differentiated ratings for individual characteristics, it is possible to reduce them to comparability and, as a result, synthetically evaluate the options. Due to the high frequency of occurrence of such problems, various methods have been developed to solve them [9], such as: AHP (Analytic Hierarchy Process), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), ELECTRE (Elimination Et Choix Traduisant la Realite), TOPSIS (Technique for Order Performance by Similarity to Ideal Solution), SMART (Simple Multi Attribute Rating Technique), ANP (Analytic Network Process).

On the grounds of the wide variety of available MADM methods, each of which has specific advantages, disadvantages and limitations, it is necessary to select a technique appropriate for the decision problem under consideration. In a multivariate study of urban sustainability, the number of criteria and variants is considerable, so great difficulties can be encountered using methods based on the superiority relation, such as the ELECTRE and PROMETHEE methods, which require pairwise comparisons of decision variants due to successive criteria. These methods are used for small sets of alternatives in cases where the comparison is made between values lying on compatible scales and where the decision alternatives are characterised by similar attribute values [10]. The AHP method, on the other hand, is based on the utility function and can also be applied to large sets of alternatives. However, the essence of this method is the decomposition of the problem into a hierarchy of criteria. In this study we chose deliberately the TOPSIS algorithm in order to reduce subjectivity and obtain a comprehensive evaluation with a large set of criteria and variants.

The TOPSIS algorithm has been used in comparative analyses of sustainable development of countries, regions and cities, made on the basis of a selected set of indicators. Sen [8] evaluated states in India based on the UN Sustainable Development Indicators using various methods including TOPSIS. Alptekin [1] applied this algorithm to evaluate 28 countries of the European Union and Turkey. Also Balcerzak and Pietrzak [2] used TOPSIS to examine the progress made by European countries in implementing the concept of sustainable development. Dias [3] used TOPSIS to benchmark countries around the world. On the other hand, Ding [4] used this method to assess the sustainability of 287 cities in China.

All of the studies mentioned above used the TOPSIS algorithm to compare countries, regions or cities among themselves in terms of sustainable development. Assessment process of urban sustainability can be viewed as a Multi-Criteria Decision Analysis (MCDA) problem. Multi-criteria analysis methods provide a tool for solving a problem in which there are simultaneously many criteria subject to optimisation [5, 9]. As Wątróbski underlines [11] the crucial task is the correct selection of the adequate MCDA method, which would allow to build a multi-layered model for sustainable development decision-making. Therefore in this paper the TOPSIS method is selected and applied to calculate a new proposed aggregated index that evaluates the progress of a single city towards the concept of sustainable development observed over a longer period of time.

3. Proposed selection of urban development indicators for Warsaw

Multidimensional assessment of sustainable development of Warsaw was carried out for the years 2008-2017. A total of 48 proposed indicators were thoroughly selected by us to construct the index system based on the understanding of urban sustainable development, data integrity and availability. These indicators represented three dimensions of urban sustainable development:

- 16 indicators selected from the economic dimension,
- 18 indicators selected from the social dimension,
- 14 indicators selected from the environmental dimension.

In order to verify whether Warsaw has been developed in a sustainable way, we based the analysis of changes on three synthetic indicators: Economic Index (EconI), Social Index (SocI) and Environmental Index (EnvI), that assess the direction of changes occurring in the city in the economic, social and environmental areas.

Then, on the basis of the three sub-indices, a new proposed aggregated index was calculated that we named Sustainable Urban Development Index (SUDI), constituting a summary of the capital city's progress in implementing the concept of sustainable development.

The set of proposed indicators describing the economic dimension includes issues related to the labour market, income of the city and its inhabitants, entrepreneurship, investments, tourism, land use, obtaining funds from EU programmes as well as road infrastructure and housing. The proposed social indicators included in the study take into account important areas of the city's development, such as demographic change, health care, education, culture, poverty and living conditions, inclusiveness, public and road safety, and social participation. In the area of the environment, the set of proposed indicators includes issues related to air quality, environmental protection, availability of green space, waste management, transport and resource use. All proposed 48 indicators are presented in Table 1.

Table 1. Proposed selection of urban development indicators for Warsaw.

Sub-indices	Indicators	Unit	s/d[1]
Economic Index (EconI)	E1. Average monthly gross salary	PLN	s
	E2. Investment spending in enterprises per person of working age	PLN	s
	E3. Individuals running a business per 100 persons of working age	pers.	s
	E4. National economy entities newly registered in REGON per 10,000 people of working age		s

	E5. Municipality's own-source revenue per capita	PLN	s
	E6. Share of the area covered by the local spatial development plans in the total area	%	s
	E7. Investment spending as a percentage of total expenditures	%	s
	E8. Public debt service expenditure per 1000 PLN of municipality's own-source revenue	PLN	d
	E9. Length of local public roadways per 100 km2	km	s
	E10. Public roads spending as a percentage of total expenditures	%	s
	E11. Tourists (overnight visitors) per 1000 population	pers.	s
	E12. Unemployment rate	%	d
	E13. Share of the long-term unemployed in the total number of registered unemployed	%	d
	E14. Average floor area of a dwelling per capita	m^2	s
	E15. Number of dwellings per 1000 population		s
	E16. Funds acquired from the EU to finance programmes and projects per capita	PLN	s
Social Index (SocI)	S1. Population growth rate per 1000 people	permil	s
	S2. The demographic dependency ratio	%	d
	S3. Population density	pers./km^2	d
	S4. Infant deaths per 1000 live births	permil	d
	S5. Number of physicians per 10,000 population		s
	S6. Number of in-patient hospital beds per 10,000 population		s
	S7. Percentage of children cared for in nurseries	%	s
	S8. Children aged 3-5 per one place in pre-school educational institution		d
	S9. Matriculation exam pass rate (secondary schools)	%	s
	S10. Population per 1 library	pers.	d
	S11. Population per 1 seat in theaters	pers.	d
	S12. Visitors to museums per 10,000 inhabitants	pers.	s
	S13. Number of foundations, associations and social organisations per 10,000 inhabitants		s
	S14. The range of benefiting from social assistance	%	d
	S15. Unemployed aged 55-64, unemployed for more than 1 year in total unemployed aged 55-64	%	d
	S16. Job offers for disabled persons per 1000 unemployed disabled persons		s
	S17. Total recorded crimes per 1000 inhabitants		d
	S18. Number of injured in road accidents per 100,000 vehicles	pers.	d
Environ-mental Index (EnvI)	N1. Carbon dioxide emissions from particularly onerous establishments per 1 km2 of city area	t/year	d
	N2. Emission of dust pollution from particularly burdensome facilities per 1 km2 of area	t/year	d
	N3. Share of pollutants retained or neutralised in pollution abatement equipment particularly burdensome facilities to pollutants generated - gaseous without CO2	%	s
	N4. Legally protected areas as percentage of total city area	%	s
	N5. Green area as percentage of total city area	%	s
	N6. Forest area as percentage of total city area	%	s
	N7. Total collected municipal solid waste per capita per year	kg	d
	N8. Share of city population served by wastewater collection	%	s
	N9. Total residential electrical energy use per capita	kWh	d
	N10. Total residential water use per capita	m^3	d
	N11. Total industrial water use per capita	m^3	d

N12. Number of personal automobiles per 1000 population		d
N13. Km of bicycle paths per 10,000 population	km	s
N14. Km of bus lanes per 100,000 population	km	s

[1] - s: stimulant; d: destimulant;

Source: Authors own elaboration.

4. Data preprocessing model for TOPSIS algorithm

The TOPSIS algorithm examines an m-element set of variants on the basis of values achieved by n criteria, which together form a decision matrix. In the study of sustainable development of Warsaw ten variants are compared, which are subsequent years of observation. The criteria on the basis of which the variants are compared are detailed economic, social or environmental indicators, i.e. respectively 16, 18 or 14 indicators depending on the dimension under consideration.

First, from the values of indicators (for each dimension separately) a data matrix was created, in which x_{ij} means the evaluation of the i-th variant in terms of j-th criterion:

$X = [x_{ij}]$, for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

Then, to provide a common set of values for all criteria, which is necessary for comparison, a normalisation process was performed using an arbitrary function. TOPSIS assumes that each attribute in the decision matrix has monotonically increasing or monotonically decreasing utility. In other words, the higher the values of the variables, the greater the preference for stimulants and the less for destimulants.

The indicators used in the study are numerical data of different scale and nature, which makes direct comparison impossible. Therefore, one of the most frequently used methods of unifying input data, i.e. min-max normalisation, was applied. Additionally, depending on the type of indicator (stimulant or destimulant), an appropriate normalisation function was applied so that in further proceedings all criteria were maximised, i.e. for maximised indicators (stimulants):

$z_{ij} = (x_{ij} - min_i x_{ij}) / (max_i x_{ij} - min_i x_{ij})$, for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

and for minimised indicators (destimulants):

$z_{ij} = 1 - [(x_{ij} - min_i x_{ij}) / (max_i x_{ij} - min_i x_{ij})]$, for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

By $max_i x_{ij}$ is meant the maximum and by $min_i x_{ij}$ the minimum value of the level of realisation of the j-th criterion determined after all decision alternatives. The variables normalised in this way will belong to the interval <0, 1>.

The TOPSIS algorithm then determines a vector of weights that should add up to 1. The weights correspond to the importance assigned to each criterion and are one method of incorporating the decision maker's preferences into the multi-criteria approach:

$w = [w_1, w_2, \ldots, w_n]$

In the next step, the values for each criterion are multiplied by the corresponding weight and thus a decision matrix was obtained:

$Y = [v_{ij}] = [w_j z_{ij}]$, for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

TOPSIS method refers to comparing the vector of values of decision criteria for a given object with the vectors of positive ideal solution (PIS) and negative ideal solution (NIS). The positive ideal solution is composed of all best values attainable of criteria, and the negative ideal solution consists of all the worst values attainable of criteria. In order to evaluate each variant and compare it with the others, the distance in Euclidean space between the vector of values determined for the object and the positive ideal and negative ideal vectors was measured. The best variant should have the smallest possible distance from the ideal solution and the largest possible distance from the negative ideal solution. Then, based on the value of the synthetic measure, the so-called ranking coefficient, which is a combination of these two distance measures, a final linear ranking of the objects was made [5].

Therefore, the next task was to find the positive ideal and negative ideal vectors. The positive ideal vector contains the highest values of the variables from the decision matrix Y, and the negative ideal contains the lowest values:

$v^+ = \{v_1^+, v_2^+, ..., v_n^+\}$, where
$v_j^+ = max_i v_{ij}$ for $i = 1, 2, …, m$ and $j = 1, 2, …, n$
$v^- = \{v_1^-, v_2^-, ..., v_n^-\}$, where
$v_j^- = min_i v_{ij}$ for $i = 1, 2, …, m$ and $j = 1, 2, …, n$

The next step was to calculate the Euclidean distance of the considered variants from the positive ideal and negative ideal vectors:

$d_i^+ = \sqrt{[\sum_{(j=1)}^n (v_{ij} - v_j^+)^2]}$ for $i = 1, 2, …, m$
$d_i^- = \sqrt{[\sum_{(j=1)}^n (v_{ij} - v_j^-)^2]}$ for $i = 1, 2, …, m$

On this basis, it was possible to calculate the value of the ranking coefficient R, which determines the similarity of a given variant to the ideal solution:

$R_i = d_i^- / (d_i^- + d_i^+)$ for $i = 1, 2, …, m$

The ranking coefficient R is in the range of <0;1>, and the higher its value, the more preferred the particular option. In each of the dimensions of sustainable development of the city, the values of the R coefficient were taken as the values of the Economic, Social and Environmental Index, respectively. The value of the synthetic measure allowed to create a final ordering of the variants and to assess the changes occurring from year to year in each area.

A parameter found in most multi-criteria analysis methods, including the TOPSIS algorithm, is a vector of weights. The weights undoubtedly affect the results obtained in the research, but the exact determination of their values is quite a difficult issue, and in many problems the importance of the criteria can be expressed at most on an ordinal scale. Weights can be selected based on statistical methods that are used to group indicators according to their degree of correlation. Weights can also reflect the statistical quality of the data by assigning higher weights to reliable data with broad coverage. However, this method may favor easily accessible indicators, downplaying information that is statistically more problematic to identify and measure, despite its high value to the problem under consideration.

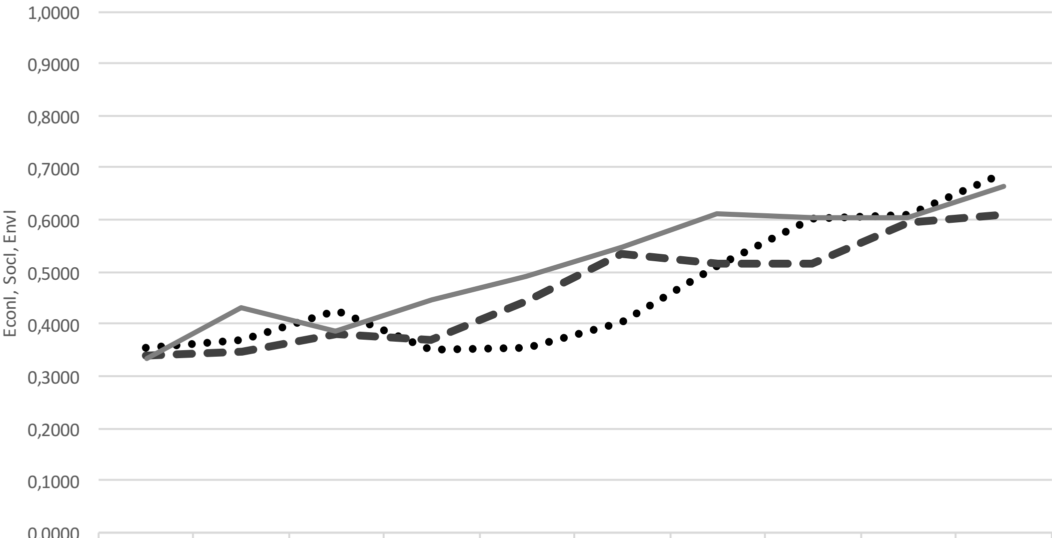
Alternatively, features that are considered more important based on the opinions of different stakeholders - experts, citizens or politicians - can be preferred to better reflect development policy priorities or theoretical factors. For international rankings, stakeholders preference surveys are difficult to implement and can provide conflicting results. Public opinion surveys are easier to conduct, but if many indicators are considered, assigning weights can be very difficult for survey participants [7]. Munda and Nardo note [6] that the estimation of weights is equivalent to the determination of the rate of substitution, which suggests a compensatory logic, that is, the existence of the possibility of compensating the disadvantage of some variables by a sufficiently large advantage of another variable. In the most commonly used linear and geometric aggregations, weights express the degree of compensation between indicators. In addition, linear aggregations reward criteria in proportion to the weights, while geometric aggregations promote options with higher scores.

When many different objectives are equally justified and important, and when various dimensions are aggregated, non-compensatory logic seems more appropriate. Therefore, many synthetic indicators used around the world are based on equal weights, meaning that they assign all specific indicators or thematic sub-indexes the same share [7]. Examples of internationally recognised synthetic measures in which individual indicators have been assigned equal shares in the creation of an index (or sub-indexes) are: Human Development Index (HDI), Environmental Sustainability Index (ESI), City Prosperity Index (CPI), Living Planet Index (LPI), Ecological Footprint (EF), Index of Sustainable Economic Prosperity (ISEW), and Green GDP.

The use of equal weights in the construction of a synthetic measure of urban sustainability essentially implies that all selected indicators have equal weight in determining urban well-being. In any case, the use of equal weights does not imply "no weighting" but that the weights of the detailed indicators are equal. In the study conducted, all the indicators were assigned the same weight, and therefore the same share in the value of the indices. The weighting step could therefore be omitted from the calculations, which would not affect the final results. However, the adopted methodology leaves the possibility of modification open at this stage if there is a need to differentiate the indicators among themselves because of their importance.

5. Application of TOPSIS algorithm and proposed Sustainable Urban Development Index

According to the TOPSIS algorithm, all indicators included in the study were first normalised using the min-max method with appropriate functions for stimulants and destimulants. As a result, all criteria were maximised in further calculations. The normalised variables were then weighted with each indicator arbitrarily assigned the same weight equal to 1/16, 1/18 and 1/14 depending on the dimension they represent. The Euclidean distance of the considered variants from the positive ideal solution vector and the negative ideal solution vector were calculated and, based on them, the value of the Economic, Social and Environmental Index was determined for each year covered by the analysis. Aggregating the detailed urban development indicators into single synthetic measures makes it possible to take a comprehensive look at the changes occurring from year to year, and to assess the city's progress in every area, as presented further in Figure 1.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EconI	0,3538	0,3695	0,4267	0,3497	0,3558	0,4026	0,5103	0,6035	0,6087	0,6870
SocI	0,3397	0,3480	0,3794	0,3699	0,4434	0,5331	0,5151	0,5150	0,5937	0,6083
EnvI	0,3337	0,4321	0,3873	0,4460	0,4926	0,5471	0,6109	0,6044	0,6050	0,6625

EconI SocI EnvI

Figure 1. Economic, Social and Environmental Indexes for Warsaw in years 2008-2017.
Source: Authors own elaboration.

The analysis of Economic Index changes over time allows us to determine the direction of changes occurring in the city in the economic area, taking into account a total of sixteen indicators. The EconI increased slightly between 2008 and 2010, before falling in 2011 to its lowest level in the whole period under review. Then between 2011 and 2017 the value of EconI steadily increased, although it was only in 2014 that the Index was higher than in 2010. The constant improvement in Warsaw's economic situation from 2011 to the end of the analysed period should be assessed positively, which proves the city's well pursued development policy in this dimension.

The analysis of the change in the value of the Social Index for Warsaw over time allows us to assess the changes occurring in the city in the social dimension, taking into account a total of eighteen indicators. Over the entire period under analysis, the SocI increased from 0.3397 to 0.6083 between 2008 and 2017, signifying an improvement in the social dimension of sustainable development in Warsaw. The upward trend continued throughout the period, with the exception of 2014 and 2015, when there were declines in the SocI.

The analysis of the Environmental Index changes over time made it possible to assess the development of Warsaw in the environmental dimension based on a total of fourteen indicators. Throughout the analysed period, the EnvI showed an upward trend, rising from 0.3337 in 2008 to 0.6625 in 2017. The greatest improvement in the environmental area occurred between 2010 and 2014, when the EnvI rose from 0.3873 to 0.6109. Then, after a slight decrease in the index in 2015, it rose again at the end of the period reaching its maximum in the last year of analysis. The results of the EnvI confirm a steady improvement in the environmental dimension of Warsaw's sustainable development.

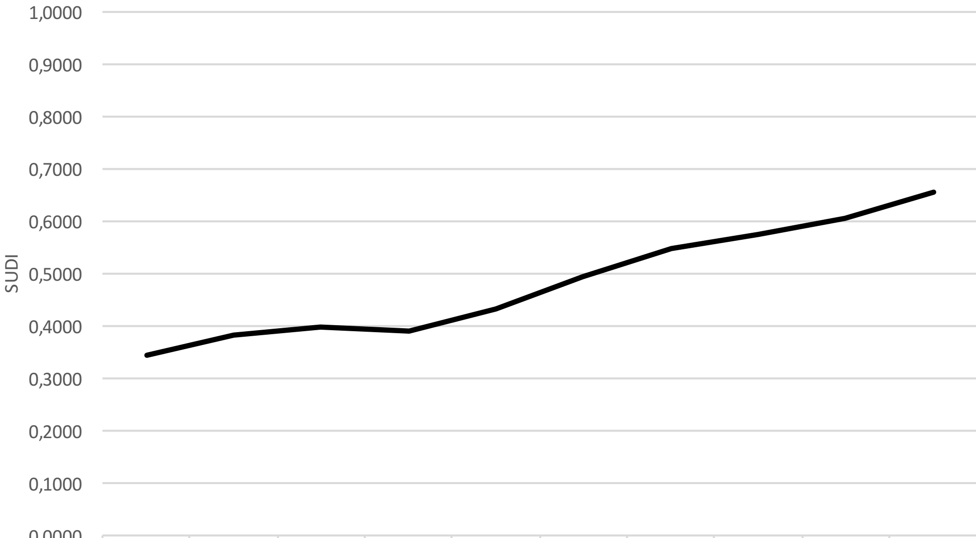
The analysis of the Economic, Social and Environmental Indices for Warsaw allows us to conclude that all three dimensions of sustainable development have improved between 2008 and 2017. In the period under review, the value of the index in the economic dimension rose from EconI = 0.3538 to EconI = 0.6870, in the social area from SocI = 0.3397 to SocI = 0.6083, and in the environmental dimension from EnvI = 0.3337 to EnvI = 0.6625. The values of three sub-indices and proposed Sustainable Urban Development Index for Warsaw between 2007 and 2018 are presented further in Table 2.

Table 2. Sub-indices and Sustainable Urban Development Index for Warsaw 2008-2017.

Year	EconI	SocI	EnvI	SUDI
2008	0.3538	0.3397	0.3337	0.3424
2009	0.3695	0.3480	0.4321	0.3832
2010	0.4267	0.3794	0.3873	0.3978
2011	0.3497	0.3699	0.4460	0.3885
2012	0.3558	0.4434	0.4926	0.4306
2013	0.4026	0.5331	0.5471	0.4942
2014	0.5103	0.5151	0.6109	0.5454
2015	0.6035	0.5150	0.6044	0.5743
2016	0.6087	0.5937	0.6050	0.6025
2017	0.6870	0.6083	0.6625	0.6526

Source: Authors own elaboration.

The overall assessment of Warsaw's sustainable development in the period 2008-2017 was carried out on the basis of a synthetic measure covering economic, social and environmental dimensions together. The Sustainable Urban Development Index (SUDI) for Warsaw was calculated as an arithmetic mean of the EconI, SocI and EnvI, i.e. all dimensions were assigned the same 1/3 share in the final index creation. The Figure 2 presents the values of the SUDI for Warsaw in years 2008-2017.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
SUDI	0,3424	0,3832	0,3978	0,3885	0,4306	0,4942	0,5454	0,5743	0,6025	0,6526

Figure 2. Sustainable Urban Development Index for Warsaw 2008-2017.
Source: Authors own elaboration.

All three sub-indices that make up the SUDI, i.e. the EconI, SocI and EnvI, were at very similar levels in 2008, recorded declines in 2010-2011, and then remained in an upward trend until 2014, while the increases slowed down between 2014 and 2016, with the strongest one in case of the Environmental Index. Such changes in the three sub-indices are expressed in a very analogous behavior of the SUDI, which remained in an upward trend throughout the period, with only a small decline in value in 2011. Then, until 2017, the SUDI grew steadily, with smaller increases between 2014 and 2016.

The SUDI for Warsaw increased in the examined period from the level of 0.3424 to 0.6526. The sustained upward trend of the index indicates positive changes that took place in the city. Based on the results obtained, it is possible to confirm that in the period 2008-2017 Warsaw has been developed in a sustainable manner.

6. Discussion

Numerous attempts are being made worldwide to develop multidimensional systems of urban development indicators covering economic, social and environmental issues. The study of sustainable urban development and the construction of evaluation systems are carried out (independently or in cooperation) by scientists and academic centers, urban and environmental organisations, local authorities and international organisations.

Multidimensional sets of standardised indicators constitute a very functional tool to assess a city performance, capture progressive trends and support cities in their development plans. The purpose of multi-criteria analysis is to identify quantitative relationships between the values of the criterion functions of competing objectives. The task is to determine such a decision variant from a finite set of variants that will ensure the best possible achievement of all objectives considered by the decision maker while the selected objectives create a conflict of interest (there is no solution that simultaneously optimises all the criterion functions).

So far there is no decision-making consensus achieved on the pros and cons of a particular evaluation system of urban development. In the scientific literature on the sustainable development subject the TOPSIS algorithm, made on the basis of a selected set of indicators, is dominant as a comparative analysis of various cities (regions, countries) progress in various years. Our proposed approach is to evaluate the development of a single city, although observed over a longer period of time (here: ten years). Assessing sustainability by a measure dedicated to a particular city seems to be well-founded. It takes into account the city's specific development problems and challenges, as well as the availability of data and local political, geographical and climatic conditions. Such an approach has great advantages as it responds to the needs and conditions of a particular city in a given region. However, cities vary considerably in terms of available resources, population size and urban metabolic processes, therefore a variety of tools constantly proves to be useful.

7. Conclusion

In this paper, the application of TOPSIS algorithm on the basis of our proposed selection of urban development indicators made it possible to evaluate long-run progress occurring in a single city in all dimensions of sustainable development. The new aggregated index, that we named Sustainable Urban Development Index (SUDI), for evaluating urban policy on the example of Warsaw was established. The obtained results show that it is possible to build a synthetic evaluation indicator in order to assess the development of a single city in a longer period of time using more than a dozen heterogeneous features in particular dimensions.

Assessment of a sustainable development of Warsaw in 2008-2017 in economic, social and environmental dimensions was carried out as multidimensional analysis on the basis of selected urban indicators, that are publicly accessible. All three sub-indices of Warsaw's development, i.e. the Economic Index, the Social Index and the Environmental Index, have increased between 2008 and 2017. Despite the short-term decreases in the indices observed during the studied period, an upward trend was maintained in the long-run. The new proposed index SUDI for Warsaw increased from 0.3424 to 0.6526 during the examined period, exhibiting only one temporary decrease in value in 2011. This demonstrates constant positive changes observed in the capital city and proves the city's progress in implementing the concept of sustainable development.

The proposed methodology, based on our selection of urban development indicators as an input for TOPSIS algorithm and resulting in calculation of a new proposed SUDI index, uses straightforward multi-criteria analysis and transparent statistical methods, which proves its undeniable advantage. At the same time, the proposed methodology remains flexible enough to easily implement changes. The data used in the study is publicly provided by the Central Statistical Office of Poland. Credibility and reliability of the data gathered by a public institution increases the quality of results and enables their update in the future.

The main conclusion of the study is the need to establish a well-defined set of indicators that will allow ongoing monitoring and evaluation of the effects of strategies and development programs implemented in cities by both the urban authorities and observers. More and more cities are giving priority to assessing the sustainability of their development, and many of them are making efforts to develop detailed measurement and evaluation programs that take into account environmental, social and economic aspects. The SUDI indicator proposed by us constitutes an easy-to-implement tool that can be successfully used by cities' authorities in Poland.

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