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THE APPLICATION OF THE PROMETHEE METHOD IN EVALUATION OF SUSTAINABLE DEVELOPMENT OF THE SELECTED CITIES IN POLAND

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ABSTRACT: The priority objective of the article is the valuation of the selected Polish cities in the light of the sustainable development indicators, which have been developed by Central Statistical Office of Poland. Several dozens of indicators have been included in the study, which are grouped according to the four domains: social, economic, environmental, and institutional-political. It is worth mentioning, that the selected multicriteria decision aid method was used (the PROMETHEE method). The multicriteria analysis enabled to indicate the strengths and weaknesses of cities in the light of the idea of sustainable development. Moreover, the research has shown that the selected method is useful in solving the issues of contemporary urbanism.

KEY WORDS: the sustainable development, ranking, the PROMETHEE method

JEL: C49, C88, Q01

Introduction

In the age of contemporary problems and urban trends the principle of sustainable development plays more and more important role. The principle of sustainable development assumes "such a socio-economic development in which occurs the process of integration of political, economic and social activities with the preservation of the natural balance and the sustainability of basic natural processes in order to guarantee. In order to ensure the possibility to meet the basic needs of individual communities or citizens of both the present and future generations" (Prawo ochrony środowiska).

The implementation of the concept of sustainable urban development is often seen as an opportunity to improve living conditions and the urban environment (Barełkowski, 2012, p. 760). Furthermore, as A. Rzeńca notes: "In the face the process of globalization, metropolization and unification processes, cities are looking for their individual development paths which can meet the contemporary demands and expectations. In this context, the implementation of the concept of sustainable development and ecosystem approach to the city management could be a factor in building a competitive advantage and creating a positive image" (Rzeńca, 2016, p. 53).

Therefore, it is important to assess the city's current level of sustainable development. Firstly, this evaluation provides the multifaceted diagnosis of cities (in terms of social, economic, environmental, and institutional-political domains). Secondly, it is easier to identify potential problems of cities, as well as, it will be a starting point for defining strategies to facilitate the development of a sustainable city.

The important source of information is a publicly accessible application called sustainable Development Indicators, which contains a database of indicators to monitor the sustainable development at the national level (including the European Union and EU Member States), regional level (concerns both regions and voivodships) and powiat levels (Sustainable Development Indicators).

In this article evaluation four selected Polish cities: Bialystok, Lublin, Chorzow and Czestochowa were evaluated in terms of available indicators of the sustainable development[1]. The ranking was drawn up using the selected multicriteria method – PROMETHEE (*Preference Organization METHod Ranking for Enrichment Evaluations*). The main part of the research had been preceded by literature review of theory and the implementation of the PROMETHEE method.

[1] The selected cities were a case studies in the Author's PhD thesis, in which the evaluation these cities were made in the light of the idea of a compact city.

The literature reviews

The PROMETHEE method was developed in 1982 by Professor J. P. Brans. Then Professor B. Mareschal joined the study (Mareschal, 2017, p. 1).

Nowadays the PROMETHEE method is used worldwide to solve complex decision-making problems in various areas of life. Already in 2010 a group of scientists reviewed works on the theory and applications of the PROMETHEE method. Among the main areas of application, there were such areas as: environment management, hydrology and water management, business and financial management, chemistry, logistics and transportation (Behzadian et al. 2010, p. 208).

Moreover, a comprehensive review of the PROMETHEE method is regularly published on the Visual PROMETHEE website. The current database includes as many as 1570 various positions (situation on 11 June 2017), showing the popularity and the versatility of the PROMETHEE method (PROMETHEE-GAIA).

Based on the literature review, it can be noted, that multicriteria decision aid methods, including the PROMETHEE method, are becoming increasingly popular in analyses and the decision-making problems concerning the sustainable development. So far, the PROMETHEE method has been applied, inter alia, to issues such as:

- the management of natural resources:
  - water (Raju, Duckstein, Arondel, 2000; Mutikanga, Sharma, Vairavamoorthy, 2011),
  - energy (Doukas, Patlitzianas, Psarras, 2006; Tsoutsos et al., 2009; Bagheri Moghaddam, Nasiri, Mousavi, 2011),
  - air (Lim, Ayoko, Morawska, 2005; Nikolić et al., 2010);
- transport systems:
  - intelligent transport systems (Brucker, Verbeke, Macharis, 2004),
  - the management of urban road infrastructure (Jajac, Knezic, Babic, 2012),
  - the implementation of sustainable parking development projects (Jajac, Marovic, Mladineo, 2014);
- waste management, for instance:
  - municipal solid waste management (Vego, Kucar-Dragicevic, Koprivanac, 2008),
  - solid waste disposal (Arikan, Simsit, Vayvay, 2017);
- spatial and urban planning:
  - the implementation of development strategy (Ergazakis et al., 2007),
  - the selection of an investment site (Sriniketha, Diwakar Reddy, Naga Phaneendra, 2014; Simic et al., 2015).

However, above mentioned issues and works do not cover the topic, but they show point to current research problems that can be solved by the PROMETHEE method. It is worth adding that multicriteria methods are commonly used for spatial planning issues, including urban planning. A very popular research area is a multicriteria location analysis. In this article, the new problem of urban planning has been proposed, that is, the application of the PROMETHEE method in the evaluation of the sustainable development of cities.

To conclude, it might also be useful to refer to the sustainable urban development and the sustainable development indicators. In Poland, the work on the sustainable development indicators started in the 1990s, then research team was established, which was headed by Professor Borys (Borys, 2005, p. 10). It is important to note, that developed indicators are the basis of the previously mentioned the application called Sustainable Development Indicators available by the Central Statistical Office of Poland.

In view of the development of various databases, recently an attempt of the evaluation of the sustainable development of Polish cities has been made. The results were published in the report "Sustainable Urban Development" which was prepared for the Polish Robert Schuman Foundation and the Konrad Adenauer Foundation by the INSIGHT Policy (www.europolis.schuman.pl). Authors of the report applied 71 indicators from various databases (for example databases of the Central Statistical Office of Poland, databases of the Ministry of Finance, databases of the Ministry of Digitalization and others). The zero unitarization method was used to determinate the value of group of indicators (relating to 4 dimensions of the sustainable development: environment, economy, society and politics). The final indicator of the sustainable urban development was calculated as the average of each group of indicators (Arak, Kusterka-Jefmańska, 2016, p. 38). The first place in the ranking was taken by Warszawa. Sopot came second. The third place was taken by Bielsko-Biala. It is worth noting that Bialystok was ranked 17th on the list. Lublin and Czestochowa were in the first thirty and Czestochowa was in the first fifty (Arak, Kusterka-Jefmańska, 2016, p. 16).

In this work, the 66 sustainable development indicators, available on the website of Central Statistical Office of Poland were used to assess the sustainability development of the selected cities. The calculations were made in Visual PROMETHEE software, based on algorithm of the PROMETHEE method.

Algorithm of the multicriteria analysis

Below are presented the stages of the multicriteria analysis and the main assumptions of the PROMETHEE method:

- Step 1. Define alternatives and criteria. This multicriteria analysis includes 4 alternatives (Bialystok, Lublin, Chorzow, Czestochowa) and 66 criteria, that is the sustainable development indicators available on the website of the Central Statistical Office of Poland.
- Step 2. Define the evaluation of the alternatives in the light of the criteria. Tables from 1 to 4 present general data.
- Step 3. Define the properties of criteria. First, the following information should be defined:
  - character (stimulant/destimulant),
  - weight (in the analysis criteria have the same weight, but in the software sensitivity analysis is available),
  - preference function (in the PROMETHEE method considers the differences between the evaluations of the decision options in the light of each criterion. What is important, the characteristic feature of the selected method is the preference function, which is used to measure a power of preference and takes values from the interval from 0 to 1, where 0 means no preference and 1 means a full preference. There are six types of preference functions: usual, U-shape, V-shape, level, linear and Gaussian preference function. The choice of the preference function depends on the decision-maker, although the authors of the method have developed some instructions. For example, both usual and level preference functions are recommended for qualitative criteria. The linear preference function and V-shape, which is one of linear preference functions, are used for quantitative criteria (Trzaskalik, 2014, p. 245; Instruction of PROMETHEE method, 2013, p. 145-146].
- Step 4. The final ranking. In the selected method, there are two rankings: partial and complete. The rankings are based on the preference flows, which "*are computed to consolidate the results of the pairwise comparisons of the actions and to rank all the actions from the best to the worst one*" (Instruction of the PROMETHEE method, 2013, p. 149). There are: the positive preference flow (Phi+), the negative preference flow (Phi-) and the net preference flow (Phi). The positive preference flow illustrates the power of exceeding one action over another. On the other hand, the negative preference flow shows to what extent the variant is overridden by other actions. The basis for the final ranking is the value of the net preference flow. The higher is the indicator, the better the action. (Trzas-

kalik, 2014, p. 245-246; Instruction of the PROMETHEE method, 2013, p. 149-150).

- Step 5. The additional analyses. The available software (for example Visual PROMETHEE) both makes calculations easier and allows for a variety analysis (for instance sensitivity analysis) which allows better understanding and helps to solve a given decision problem.

It should be emphasized, that the main steps of multicriteria analysis using the PROMETHEE method are outlined above. The complete description of this method can be found, for example, in the following publications (especially Brans and Mareschal, 2005, p. 163-195; Instruction of the PROMETHEE method, 2013, p. 143-151).

In the next part of the article, both the necessary data (the value of the sustainable development indicators of the four cities which were the case studies) and the results of the multicriteria analysis are presented.

Multicriteria analysis of the selected Polish cities in the light of the sustainable development

The tables below show the evaluation of the selected cities (Bialystok, Lublin, Chorzow and Czestochowa) in the light of 66 indicators of the sustainable development broken down into domains. Table 1 applies to social domain, table 2 refers to economic domain, table 3 environmental domain and table 4 refers to institutional-political domain. Moreover, the category of indicators has been included within the domains. Next to the name and the value of the indicators, the number, unit and the quality of each indicators are given in the tables. All data come from the Sustainable Development Indicators available by the Central Statistical Office of Poland (Sustainable Development Indicators).

Table 1. Social domain

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
Demographic changes							
1	Natural increase per 1000 population	-	↑	1,60	0,40	-3,70	-4,10
2	Ratio of balance of permanent migration person at working age	[person]	↑	7,10	-22,50	-7,80	-42,20
3	Demographic dependency ratio: post-working age population per 100 persons of working age	[person]	↓	29,00	34,00	35,40	36,50
4	Demographic dependency ratio: non-working age population per 100 persons of working age	[person]	↓	55,30	60,20	63,00	60,80
5	Demographic dependency ratio: post-working age population per 100 persons of pre-working age	[person]	↓	110,40	129,70	128,50	149,80
Public health							
6	Infant deaths per 1000 live births	[per mil]	↓	3,50	2,70	7,60	5,60
7	Deaths by selected causes of death in percentage of total: diseases of the circulatory system	[%]	↓	42,70	44,70	43,50	47,60
8	Deaths by selected causes of death in percentage of total: tumors	[%]	↓	24,60	26,70	27,70	26,30
9	Deaths by selected causes of death in percentage of total: diseases of the respiratory system	[%]	↓	6,60	6,20	2,80	3,80
10	Deaths of people aged up to 65 years per 1000 population at this age	-	↓	2,40	2,90	4,90	4,10
Poverty and living conditions							
11	People in households benefiting from the social assistance at their households in percentage of the total population	[%]	↓	5,90	5,40	8,00	5,00
12	Average monthly gross wages and salaries (economic entities which employ more than 9 persons)	[PLN]	↑	3706,73	3955,65	3638,84	3526,81
13	Average useful floor area of dwelling per capita	[m^2]	↑	25,60	25,50	24,80	26,30
Education							
14	Children covered by pre-school education in percentage of the total number of children at the age 3-5 (total)	[%]	↑	94,80	96,80	79,10	87,90

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
15	Ratios the quality of education and the level of students' knowledge: passing the exam maturity examination in the vocational upper secondary schools	[%]	↑	74,30	78,50	64,70	68,20
16	Ratios the quality of education and the level of students' knowledge: passing the final examinations in upper secondary vocational schools	[%]	↑	89,30	89,30	87,40	89,40
Access to labour market							
17	Long-term unemployed persons in registered unemployed persons total	[%]	↓	48,50	51,30	38,20	45,20
18	Registered unemployed persons in relation to persons of working age: unemployed persons, females	[%]	↓	7,20	6,80	6,80	8,80
19	Registered unemployed persons in relation to persons of working age: unemployed persons with tertiary education, total	[%]	↓	1,70	1,60	0,40	1,60
20	Job offers for disabled people in 1000 disabled unemployed	-	↑	39,00	74,00	28,00	2,00
21	Graduates – registered unemployed people (yet not working) in percentage of the total registered unemployed people	[%]	↓	4,50	4,00	2,10	3,10
22	Graduates – registered unemployed people (yet not working) in percentage of the total registered unemployed people: graduates – females	[%]	↓	5,80	5,00	2,20	3,90
23	Registered unemployment rate	[%]	↓	11,90	8,60	10,10	11,20
Sustainable consumption patterns							
24	The number of cars per 1000 people	[pcs]	↓	377,30	463,40	399,20	478,90
25	The consumption of water, electricity and gas in households during a year per capita: electricity	[kWh]	↓	609,70	695,40	780,20	704,80
26	The consumption of water, electricity and gas in households during a year per capita: gas	[m^3]	↓	103,60	143,20	111,10	124,40
27	Consumption of water, electricity and gas in households during the year per capita: water	[m^3]	↓	32,70	35,00	29,20	37,00
Old-age income adequacy							
28	Long-term unemployed people aged 55-64 in relation to registered unemployed people aged 55-64 total	[%]	↓	64,90	61,80	52,70	56,90

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
29	Persons at post-working age in households benefiting from social assistance at their households in percentage of the total number of people at this age	[%]	↓	2,00	3,30	3,00	1,50
Determinants of health							
30	People injured in accidents at work per 1000 employed persons	[person]	↓	6,86	8,25	8,17	4,89
31	Health clinics per 10 000 people	[facilities]	↑	10,00	9,00	6,00	7,00
Criminality							
32	Rate of detectability of the delinquents of identified crimes	[%]	↑	56,00	59,00	67,00	71,00
33	Identified crimes total per 1000 population	-	↓	17,76	28,34	42,09	24,61
Road accidents							
34	Victims of road accidents per 100 000 registered motor vehicles: injured	[person]	↓	111,93	128,25	114,47	432,49
35	The victims of road accidents per 100 000 registered motor vehivles: fatal accidents	[person]	↓	5,60	7,89	1,94	2,89

Source: author's own work based on www.wskaznikizrp.stat.gov.pl [30-06-2017].

Table 2. Economic domain

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
Economic development							
36	New-registered entities of the national economy recorded in the REGON register per 10 000 population at the working age	-	↑	164,00	170,00	136,0	165,00
37	Value of share capital of companies per 1 person on at the working age	[PLN]	↑	546,00	2145,00	25 817,00	3 772,00
38	Expenditure on innovation activities in enterprises by group of sections in percentage of the total expenditure on innovation activities in enterprises (up to 9 employees): industry and construction	[%]	↑	63,90	43,70	26,30	51,80

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
39	Expenditure on innovation activities in enterprises by group of sections in percentage of the total expenditure on innovation activities in enterprises (up to 9 employees): trade; repair of motor vehicles; transportation and storage; accommodation and catering; information and communication	[%]	↑	17,30	33,30	64,80	43,70
40	Expenditure on innovation activities in enterprises by group of sections in percentage of the total expenditure on innovation activities in enterprises (up to 9 employees): financial and insurance activities; real estate activities	[%]	↑	3,90	3,80	0,80	1,40
41	Expenditure on innovation activities in enterprises by group of sections in percentage of the total expenditure on innovation activities in enterprises (up to 9 employees): other services	[%]	↑	14,90	19,10	8,10	3,10
Employment							
42	Natural persons conducting economic activity per 100 persons of working age	-	↑	13,30	14,30	11,80	13,80
43	Entities by size classes per 10 000 population at the working age	-	↑	1773,50	2037,00	1657,10	1863,80
Transport							
44	The length of bicycle lane: per 10 000 km^2	[km]	↑	10 378,90	7432,00	4994,00	3 193,30
45	The length of bicycle lane: per 10 000 population	[km]	↑	3,60	3,20	1,50	2,20
46	The length of local public roads per 100 km^2: surfaced	[km]	↑	319,70	279,20	390,80	246,50
47	The length of local public roads per 100 km^2: unsurfaced	[km]	↑	52,10	52,80	5,40	118,60
48	The expenditures of gminas on public roads in percentage of their total expenditure	[%]	↑	12,20	13,60	6,10	14,60

Source: author's own work based on www.wskaznikizrp.stat.gov.pl [30-06-2017].

Table 3. Environmental domain

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
Climate change							
49	Emissions of carbon dioxide from plants especially noxious to air purity	[t/y]	↓	906 416,00	591 829,00	1 447 572,00	824 415,00
Energy							
50	Electricity consumption per capita: total	[kWh]	↓	609,70	695,40	780,20	704,80
Air protection							
51	The emissions of air pollutants from plants especially noxious to air purity: gases	[t/y]	↓	909 274,00	595 194,00	1 452 059,00	829 145,00
52	The emissions of air pollutants from plants especially noxious to air purity: particulates	[t/y]	↓	113,00	236,00	96,00	255,00
53	Pollutants retained or neutralized in pollutant reduction systems in polluting plants especially noxious to air purity in percentage of the generated: gases (excluding carbon dioxide)	[%]	↑	16,40	1,00	74,30	0,80
54	Pollutants retained or neutralized in pollutant reduction systems in polluting plants especially noxious to air purity in percentage of the generated: of dust	[%]	↑	99,60	98,70	99,90	99,10
Land use							
55	Forest cover	[%]	↑	17,90	11,10	6,90	4,00
Biodiversity							
56	Legal protected area in percentage of the total area	[%]	↑	1,02	17,16	8,51	6,34
57	Green belts in percentage of the total area	[%]	↑	5,00	5,70	22,20	3,10
Waste management							
58	Mixed municipal waste from household collected during a year per capita	[kg]	↓	186,20	173,00	216,80	192,50
59	Treated industrial and municipal wastewater in percentage of the total value of the industrial and municipal wastewater requiring treatment	[%]	↑	100,00	100,00	100,00	99,29

Source: author's own work based on www.wskaznikizrp.stat.gov.pl [30-06-2017].

Table 4. Institutional-political domain

No	The name of indicator	Unit	Quality	Białystok	Lublin	Chorzów	Częstochowa
Openness and participation							
60	Foundations, associations and social organizations per 10 000 population	-	↑	40,00	50,00	22,00	36,00
61	The structure of councilors in the authorities (legislative bodies) in gminas and poviats: females	[%]	↑	17,90	19,40	32,00	25,00
62	The structure of councilors in the authorities (legislative bodies) in gminas and poviats: people with higher education	[%]	↑	96,40	93,50	72,00	85,70
Economic instruments							
63	European Union funds for the financing of EU programs and projects acquired by the gminas and poviats in per capita	[PLN]	↑	4,30	11,00	12,90	6,60
64	Expenditure from the budgets of gminas and poviats on public debt in 1000 PLN per total revenue budgets of gminas and poviats	[PLN]	↓	17,80	15,00	5,80	11,10
65	The investment expenditures of gminas and poviats in percentage of their total expenditure	[%]	↑	20,00	30,80	13,60	14,70
66	The area covered by the local spatial development plans in percentage of the total area	[%]	↑	45,00	47,00	101,10	17,50

Source: author's own work based on www.wskaznikizrp.stat.gov.pl [30-06-2017].

The calculations were performed using the Visual PROMETHEE software. Both, the preference flows and the final ranking and are presented in table 5. In addition, the partial rankings were prepared in the light of individual domains, see table 6.

Table 5. The preference flows and the final ranking of cities

City	Phi	Phi+	Phi-	The place in the final ranking
Bialystok	0,1506	0,3619	0,2112	1
Lublin	0,0877	0,3204	0,2327	2
Chorzow	-0,0973	0,3043	0,4016	3
Czestochowa	-0,1410	0,2153	0,3563	4

Sour: author's own work.

Table 6. The partial rankings of the cities in the light of each domain

City	SOCIAL DOMAIN		ECONOMIC DOMAIN		ENVIRONMENTAL DOMAIN		INSTITUTIONAL-POLITICAL DOMAIN	
	Phi	The place in the ranking	Phi	The place in the ranking	Phi	The place in the ranking	Phi	The place in the ranking
Bialystok	0,2125	1	0,1648	2	0,1568	1	-0,1943	4
Lublin	-0,0031	2	0,2326	1	0,1234	2	0,2165	1
Chorzow	-0,0675	3	-0,3464	4	-0,0559	3	0,1513	2
Czestochowa	-0,1418	4	-0,0509	3	-0,2243	4	-0,1735	3

Source: author's own work.

Bialystok is characterized by positive demographic trends (for example natural increase or relatively low demographic dependency ratio). Also noteworthy are sustainable consumption patterns, expressed by relatively small number of private cars per 1000 people or low consumption of water, electricity and gas in households during a year per capita. Another distinctive feature of the capital of Podlasie is the transport system, especially the highly developed network of bicycle lanes. The weak points of the city are related to the socio-economic sphere, including situation on the local labor market, as well as, the selected economic instruments in the institutional-political domain.

In Lublin, high values of indicators from the categories: "poverty and living conditions" and "education" were recorded. Lublin is the city with the best situation in terms of the economic domain and the institutional-political domain (see table 6). Among the indicators which need improvement, the sustainable consumption patterns and some indicators of the environment domain should be indicated first.

Both Chorzow and Czestochowa to a lesser extent meet the principle of the sustainable development. The main weak point of Chorzow is level of education, the level of entrepreneurship of the inhabitants, as well as, the selected indicators of the environmental domain. The indicators relating to the labor market in Chorzow and economic instruments fared much better.

In Czestochowa, there are mainly adverse demographic trends, improper sustainable consumption patterns, and some disturbances of the environmental domain and the institutional-political domain. Among the indicators that received positive evaluations, should be mentioned, for example indicators that refer to old-age income adequacy or the selected indicators concerning the system of transport.

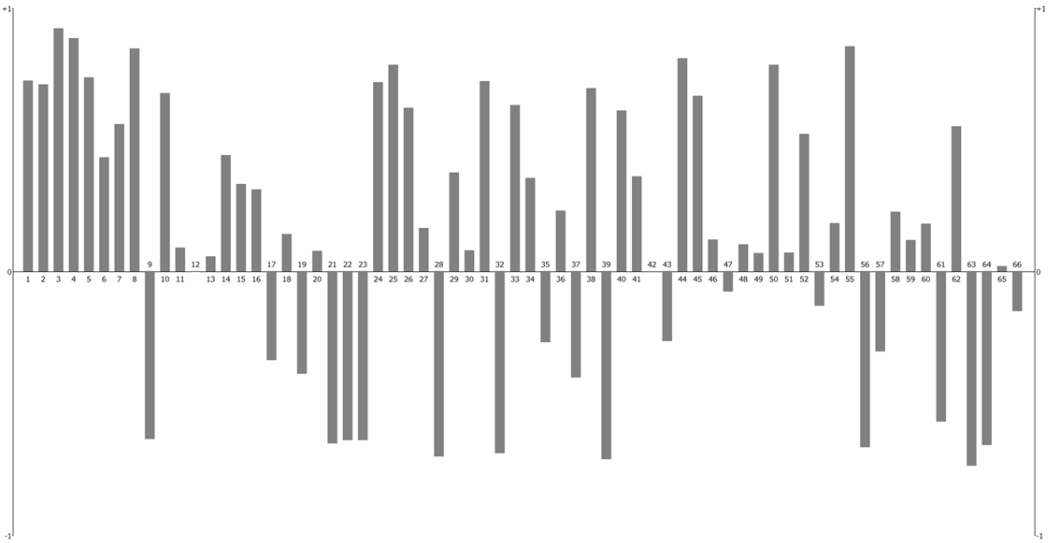

Figure 1. Profile of Bialystok

Source: author's own work based on Visual PROMETHEE software.

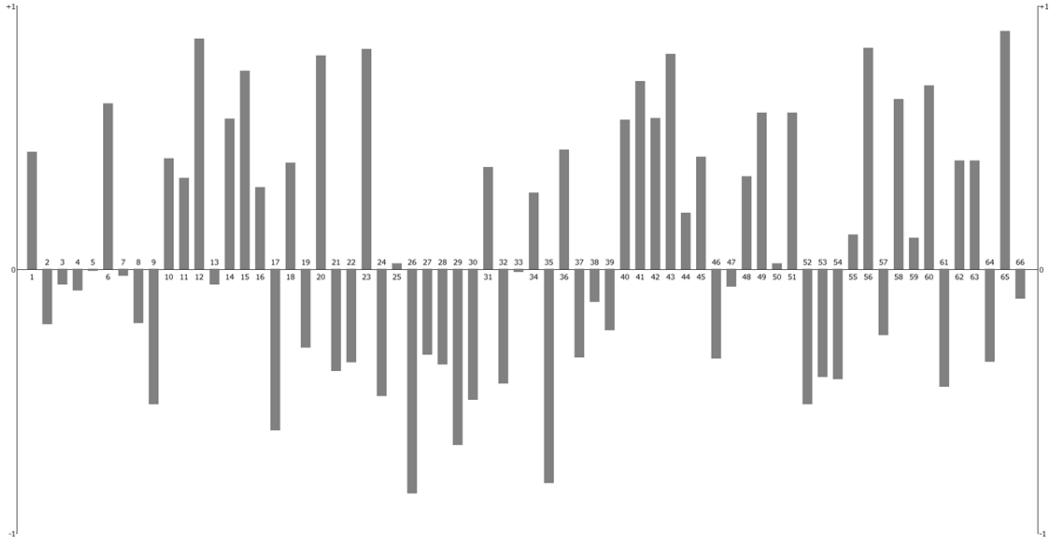

Figure 2. Profile of Lublin

Source: author's own work based on Visual PROMETHEE software.

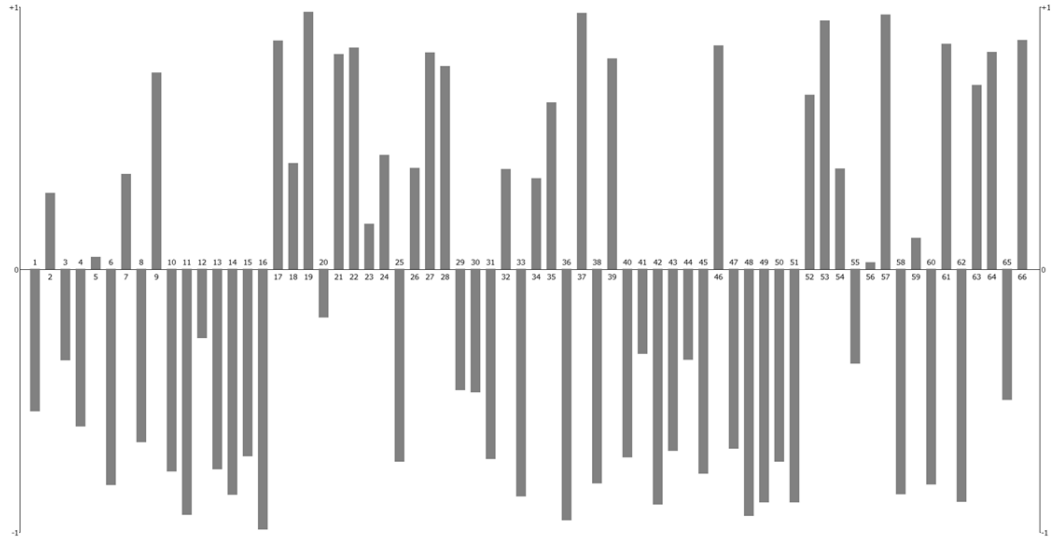

Figure 3. Profile of Chorzow

Source: author's own work based on Visual PROMETHEE software.

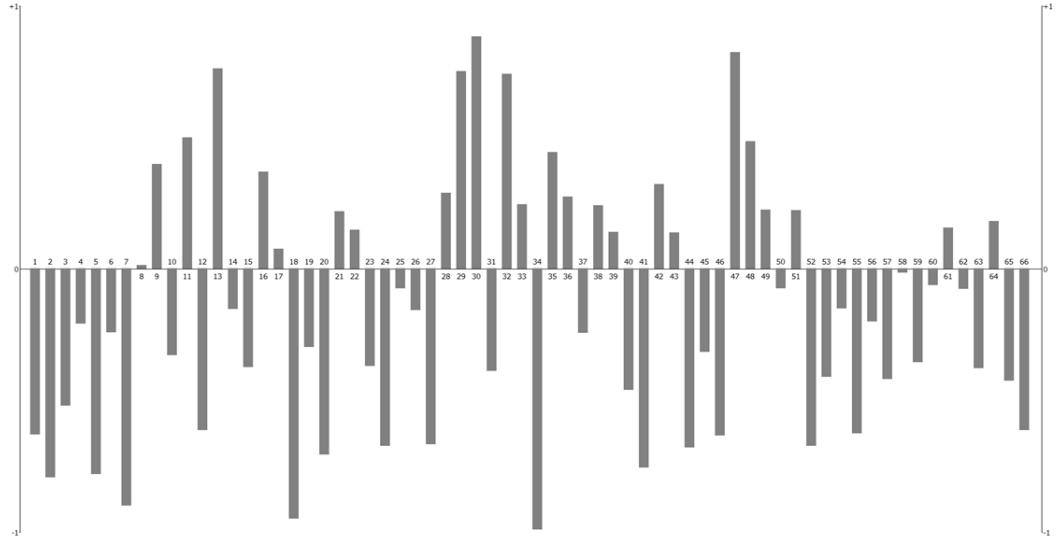

Figure 4. Profile of Czestochowa

Source: author's own work based on Visual PROMETHEE software.

Figures 1-4 show "profile of actions" then profile of the selected cities. It shows strengths and weaknesses in the light of the sustainable development. The function "*Action Profiles*" which is available in Visual PROMETHEE software was used. What is important, the bars show the net flows of each criterion. The upper bars indicate advantages, while the lower ones indicate the criteria which require corrective action to ensure that the city's development is sustainable (Instruction of PROMETHEE method, 2013, p. 119).

Conclusions

Based on the literature review and the results of multicriteria analysis the following conclusions were drawn:

- the principle of the sustainable development plays a significant role in the context of contemporary problems and urban trends, focusing primarily on the phenomenon of urban sprawl, the unfavorable demographic trends and problems of urban management;
- for years multicriteria decision aid methods have been used in many fields around the world, including the topic of the sustainable development;
- the selected multicriteria decision aid method might be a useful instrument for evaluation the sustainability development of cities, as well as, in the light of other, well known concepts (for instance: smart cities, compact cities, etc.);
- multicriteria analysis makes it possible to identify the elements which need corrective action plans, this is particularly important at the stage of creating and updating urban development strategies and plans.

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