Karolina OGRODNIK

APPLICATION OF MCDM/MCDA METHODS IN CITY RANKINGS – REVIEW AND COMPARATIVE ANALYSIS

Karolina **Ogrodnik** (ORCID: 0000-0002-6357-6870) – *Bialystok University of Technology*

Correspondence address:
Wiejska Street 45E, 15-351 Bialystok, Poland
e-mail: k.ogrodnik@pb.edu.pl

ABSTRACT: The priority objective of this study is to identify the most popular MCDM/MCDA methods typically used to create city rankings and to conduct a comparative analysis of the selected methods. In the first part, a literature review was prepared, on the basis of which it was established that the following methods were most commonly used to assess cities: TOPSIS, AHP and PROMETHEE. In addition, the above city rankings usually pertained to the subject of sustainable development and the concept of smart city. In the subsequent empirical part, a ranking of Polish cities was created using PROMETHEE and TOPSIS methods, which enabled a comparative analysis of these methods; especially in terms of the algorithm, data selection, as well as the possibility of integration with other methods.

KEYWORDS: MCDM/MCDA methods, TOPSIS, PROMETHEE, city ranking, comparative analysis

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Introduction

Today, more than 50% of the world's population lives in urban areas. Moreover, by 2050, two out of every three people are likely to live in cities. Contemporary cities perform important economic, social and cultural functions. They also play a key role in environmental contexts, for example in combating climate change. They are also on the front line in the fight against epidemics (The World Bank, 2023; United Nations, 2023; Zhang, 2011). Due to these factors, the evaluation of cities is an important assignment. For years, various rankings of cities have been created, evaluating for example the quality of life (The Global Liveability Index (Economist Intelligence, 2023)), the overall attractiveness of cities; both for residents, tourists, and people of business (World's Best Cities (Best Cities powered by Resonance, 2023)), or their level of "smartness" (Smart Cities Index Raport (Smart City Index Report, 2023)).

City rankings make it possible to compare cities against selected criteria, enable the exchange of experiences, and facilitate the assessment of individual centers, which is necessary when formulating or updating development strategies (more about the role of city rankings: Giffinger et al., 2010).

This paper focuses on the analysis and evaluation of the application of MCDM/MCDA methods in creating urban rankings. The conducted literature studies and the author's multi-criteria analysis made it possible to answer the following research questions:

1. What MCDM/MCDA methods have been the most popular in recent years in the context of creating city rankings?
2. Which hybrid models dominate?
3. Against which criteria were cities most often assessed through the selected MCDM/MCDA methods and, therefore, which urban development concepts are most popular?
4. What are the advantages and disadvantages of the most popular MCDM/MCDA methods currently used to build city rankings?

In the subsequent section, a literature review is conducted, the criteria for its development are indicated, and a detailed analysis of the selected scientific papers is performed. The "Materials and Methods" section primarily discusses the data necessary to develop the author's own ranking of cities, as well as the algorithm of the applied MCDM/MCDA methods. In the following case study section, 2 rankings of Polish cities were developed using the TOPSIS and PROMETHEE methods. A total of 18 Polish voivodeship cities were assessed against 43 smart city indicators available in public statistics. In the last part of the work, the results are summarized, a comparative analysis of the MCDM/MCDA methods used is made, and future directions of action are indicated.

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An overview of the literature

MCDM/MCDA methods have been popular for many years and are being used in many areas of life and science, as confirmed by numerous review articles (Toloie-Eshlaghy & Homayonfar, 2011; Zavadsakas et al., 2014; Stojcic et al., 2019). As part of this research effort, the literature on the use of MCDM/MCDA methods in creating urban rankings was reviewed. MCDM/MCDA methods are increasingly used in the field of architecture and urban planning (Ogrodnik, 2019). This paper narrows the analysis to urban rankings, which may fill the research gap. The literature review was prepared on the basis of scientific papers indexed in the Web of Science and Scopus databases. “MCDM city ranking” and “MCDA city ranking” were used as keywords. Papers written in English, the full text of which was made public, were selected for thorough analysis and the main purpose of the research was assessing cities through MCDM/MCDA methods. Finally, 30 scientific articles that met the above-mentioned criteria were selected for analysis. Detailed information on these works is presented in Table 1. The literature review made it possible to answer questions about which MCDM/MCDA methods are used to build city rankings and – most importantly – which methods are most popular. In addition, the analysis of scientific papers made it possible to determine the most popular concepts and the criteria for evaluating modern cities.

Table 1. The use of MCDM/MCDA methods in city rankings – a review of scientific papers

Author/authors (year of publishing)	MCDM/MCDA methods used	Main ranking criteria	Cities
Badi I., Pamučar D., Stević Z., Muhammad L.J. (2023)	BWM, AHP, MARCOS	wind farm site selection	5 cities in Libya
Hajduk S. (2022)	TOPSIS	smart cities in terms of urban transport	44 cities around the world
Jahangiri M., Rezaei M., Mostafaeipour A., Goojani A.R., Saghaei H., Hosseini Dehshiri S.J., Hosseini Dehshiri S.S. (2022)	TOPSIS	hydrogen production	31 cities in Iran
Raheja S., Obaidat M.S., Kumar M., Sadoun B., Bhushan S. (2022)	AHP, CODAS, TOPSIS	air quality	7 cities in India
Silva C.M., Granemann S.R., Guarnieri P., Da Silva G.L. (2022)	MACBETH	attractiveness of cities to receive investments in regional airport infrastructure	47 cities in Brazil
Sotirelis P., Nakopoulos P., Valvi T., Grigoroudis E., Carayannis E. (2022)	PROMETHEE II	smart city	17 cities around the world

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Author/authors (year of publishing)	MCDM/MCDA methods used	Main ranking criteria	Cities
Zapolskytė S., Trépanier M., Burinskienė M., Survilė O. (2022)	AHP, SAW, COPRAS, TOPSIS	smart urban mobility system	3 cities: Vilnius (Lithuania), Montreal (Canada), Weimar (Germany)
Corrente S., Greco S., Leonardi F., Słowiński R. (2021)	SMAA-PROMETHEE	sustainable development	20 European cities
Hajduk S. (2021)	TOPSIS	smart city	66 poviat-level Polish cities
Hajduk S., Jelonek D. (2021)	TOPSIS	smart cities in the context of urban energy	21 cities around the world
Mokarrari K.R., Torabi S.A. (2021)	SECA, TOPSIS, PROMETHEE II, WASPAS, CoCoSo, MULTI-MOORA	smart city	5 cities in Iran
Mukul E., Güler M., Büyüközkan G. (2021)	HFL SAW, HFL MABAC	sustainable city	Turkey
Saeed U., Ahmad S.R. (2021)	AHP	urban environmental sustainability	10 main cities in Punjab, Pakistan
Yang Y., Lu R.X., Xue M., Shou Z.Q., Yang J.B., Fu L. (2021)	DDER	evaluating e-government performance	16 cities of Anhui province in China
Boyaci A.C. (2020)	HFLTS, ARAS	eco-friendly cities	81 cities in Tukey
Chen Z.B. (2020)	TOPSIS, PCA, Gini coefficient, Bord fuzzy method, fuzzy neural network T-S	sustainable, livable city	13 big cities in China
Feizi A., Joo S., Kwigizile V., Oh J.S. (2020)	TOPSIS	transportation performance measures and smart growth of cities	46 cities in the USA
Ogrodnik K. (2020)	PROMETHEE	smart city	18 cities in Poland
Ozkaya G., Erdin C. (2020)	ANP, TOPSIS	smart and sustainable city	44 cities around the world
Yücenur G.N., Çaylak S., Gönül G., Postalcıoğlu M. (2020)	SWARA, COPRAS	biogas plant location	3 cities in Turkey
Borissova D., Korsemov D., Mustakerov I. (2019)	Individual Decision Making Model, Group Decision Making Model	the most preferable city to invest	22 cities in Bulgaria, Romania and Hungary
Hu S.K., Tzeng G.H. (2019)	DEMATEL, DANP, modified PROMETHEE	sustainable development of a better life	6 cities in Taiwan
Özkan B., Özceylan E., Korkmaz I.H., Çetinkaya C. (2019)	DANP, VIKOR	R&D performance	81 cities in Turkey
Zhu S., Li D., Feng H. (2019)	AHP, TOPSIS	resilience of smart cities	187 cities in China
Yi P., Li W., Li L. (2018)	the equal weighting method, SAW	sustainable development	14 cities in the Liaoning province in China

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Author/authors (year of publishing)	MCDM/MCDA methods used	Main ranking criteria	Cities
Mostafaeipour A., Sarikhani S., Sedaghat A., Arabnia H.R. (2017)	DEA	the most suitable locations for bioethanol production	26 cities in Iran
Shmelev S. (2017)	ELECTRE III, NAIADE, APIS	sustainable develop-ment	12 big cities around the world
Banar M., Tulger G., Özkan A. (2014)	AHP, ANP, ELECTRE, PRO-METHEE	waste recycling plants site selection	16 cities in Turkey
Vafaeipour M., Hashemkhani Z.S., Varzandeh M.H.M., Derakhti A., Eshka-lag M.K. (2014)	SWARA, WASPAS	solar projects	25 cities in Iran
Cinar N., Ahiska S. S (2010)	FAHP, TOPSIS	the bank branch loca-tion selection	6 cities in Turkey

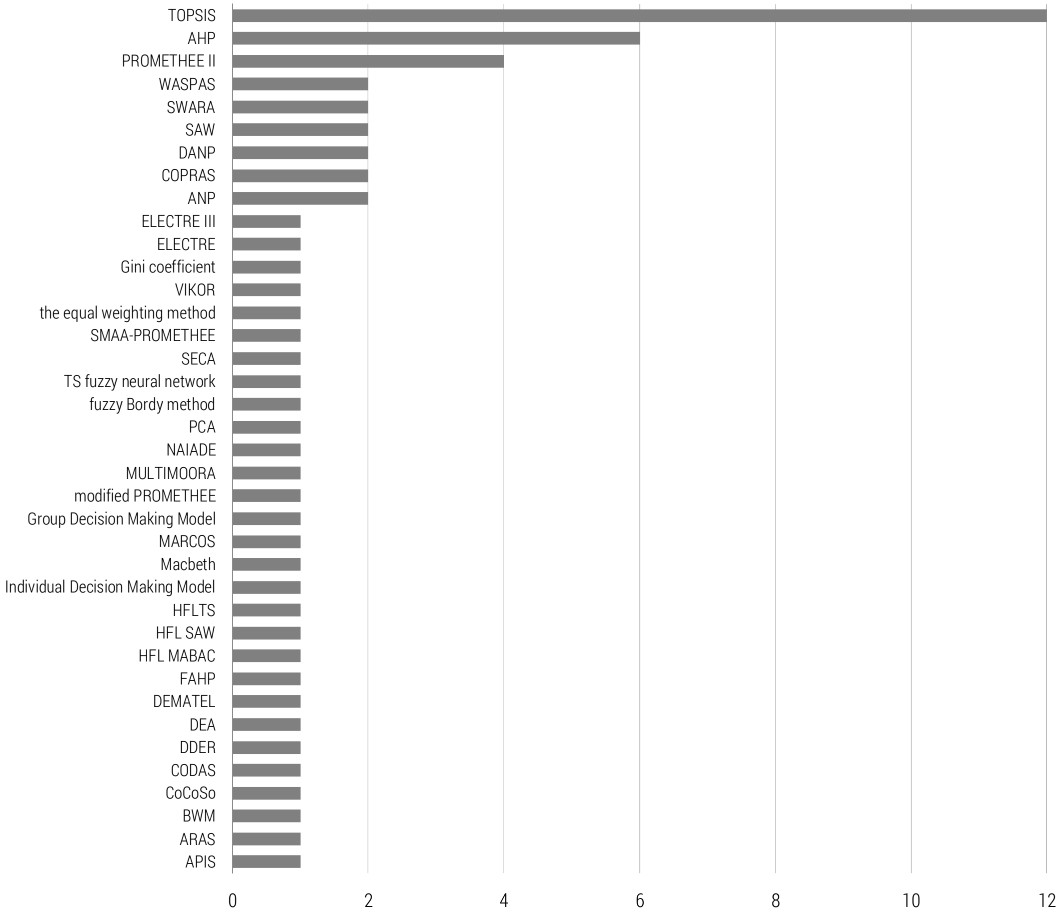

Figure 1. MCDM/MCDA methods used in city rankings

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On the basis of literature studies, it can be concluded that the MCDM/MCDA methods have been used for many years to create various city rankings and, according to the analysis, the most popular methods are: TOPSIS, AHP and PROMETHEE (Figure 1). It is worth noting that the TOPSIS method is used to rank cities against the selected criteria. On the other hand, the AHP method is most often used to evaluate the criteria themselves and to weigh them. The PROMETHEE method, representing the so-called European trend of multi-criteria decision support, is ranked as the next most popular methodology.

The above list also confirmed the known trends in the field of multi-criteria decision support, i.e. the use of hybrid models that combine several MCDM/MCDA methods (simultaneous use of different methods for ranking cities and combining methods for weighing criteria with ranking methods), as well as the use of fuzzy sets which allow for the inclusion of uncertain and imprecise decision information (e.g. FAHP).

It should be noted that, apart from the traditional MCDM/MCDA methods, new methods also appear, which shows the dynamic development of this branch of operations research. For example, in the work of Mokarrari and Torabi (2021), apart from the known methods: TOPSIS and PROMETHEE II, new methods such as CoCoSo and SECA were used. Similarly, in the work of Badi et al. (2023), next to the popular AHP, the little-known MARCOS method was used.

Moving on to the criteria for creating rankings, among the main contemporary concepts of urban development, sustainable development and smart city should be mentioned first. They were assessed both holistically, within their respective contexts, but there were also rankings focusing on the selected assumption of a given concept, e.g. smart urban mobility system (Zapolskyte et al., 2022). It is worth noting that the MCDM/MCDA methods have been known for years in the field of spatial planning, as a supporting tool for the selection of locations for various investments. This review includes only works that analyzed cities holistically as alternatives.

In the case of the studies' territorial delimitation included in Table 1, it can be stated that the rankings were created at the international level, including various cities around the world (Sotirelis et al., 2022; Ozkaya & Erdin, 2020). MCDM/MCDA methods were also used for national rankings, with most of the work concerned Turkey, China and Iran.

In the next part of the work, the 2 most popular ranking methods: TOPSIS and PROMETHEE were used to assess Polish cities against the selected smart city indicators. It should be emphasized that the purpose of the case study is delivering a comparative analysis of the selected MCDM/MCDA methods as tools for building urban rankings, and not the ranking itself.

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Materials and Methods

The study used quantitative data provided by the Central Statistical Office, Local Data Bank (2023). The latest available statistical data (mainly from 2021) on selected smart city measures (broken down into the main pillars of the concept: smart economy, smart people, smart governance, smart mobility, smart environment and smart living) were taken into account. Figure 2 shows the subsequent stages of the research, as well as the algorithm of the MCDM/MCDA methods selected for the analysis. Calculations were made using Visual PROMETHEE and OnlineOutput MCDM Software. Due to the popularity of the methods used, the main calculation stages are described in Figure 2.

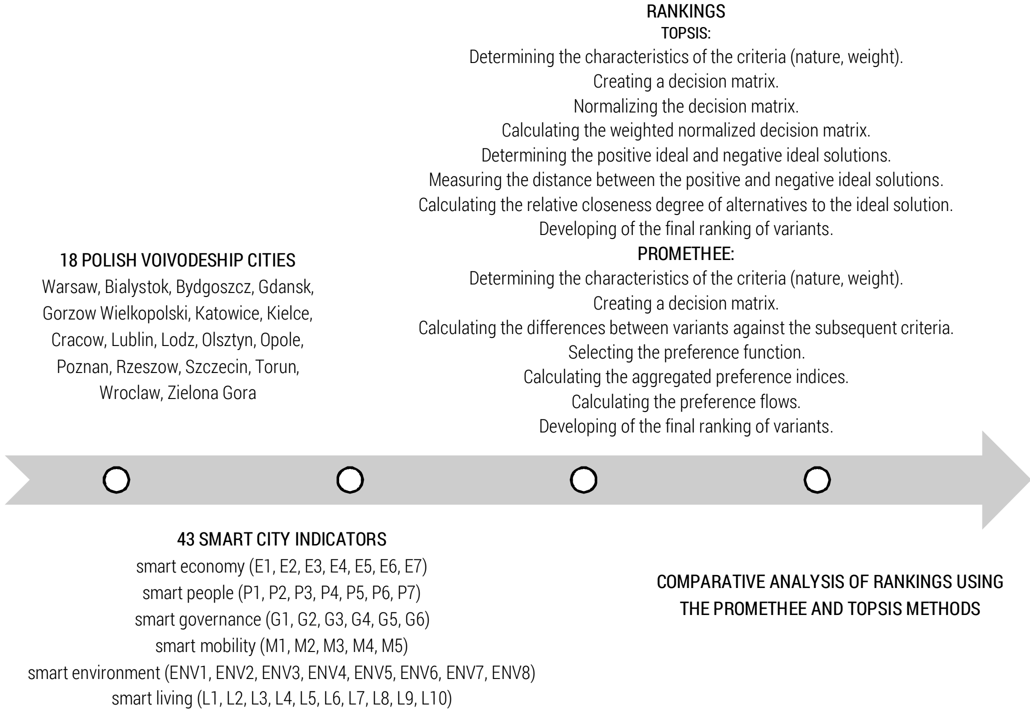

Figure 2. Subsequent research stages

Source: author's work based on OnlineOutput MCDM Software; Brans & Marschal, 2005; Kobryń, 2014.

The case study

The case study relies on developing 2 smart city rankings using the PROMETHEE and TOPSIS methods. This chapter presents the basic assumptions of the case study, the statistical analysis, two alternative smart city rankings and the interpretation of the results obtained.

Basic case study assumptions

As part of the case study, 2 comparative rankings were developed using smart city indicators and applying the PROMETHEE and TOPSIS methods. Importantly, the assumptions adopted in the work (Ogrodnik, 2020) were retained, with the main changes concerning updating the data and the inclusion of the PROMETHEE method. The main assumptions of this case study are presented below:

- 18 Polish cities were included (alternative level),
- 43 smart city indicators were taken into account, referring to the 6 pillars of the concept: smart economy, smart people, smart governance, smart mobility, smart environment, smart living (criteria level),
- 2 MCDM/MCDA methods were used: TOPSIS and PROMETHHE, (the most popular methods as demonstrated by the literature review, see Figure 1),
- equivalence of the criteria was adopted.

List of indicators

In Tables 2-7 there is a list of all indicators with basic information (abbreviation, unit, quality, preference function, necessary for the PROMETHEE method). In addition, a statistical analysis of the output data is presented.

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Table 2. Smart economy indicators – characteristics and basic statistical analysis

No.	The name of indicator (year)	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
E1	Average gross monthly salary (2021)	PLN	↑	7687.58	5242.27	6239.62	635.93	Linear
E2	Entities registered in the REGON register per 10 000 inhabitants (2021)	number	↑	2679.00	1323.00	1736.33	330.07	Linear
E3	Units newly registered in the REGON register per 10 000 inhabit-ants (2021)	number	↑	208.00	103.00	132.39	28.62	Linear
E4	Natural persons running a business per 1 000 inhabitants (2021)	number	↑	147.00	90.00	111.72	15.03	Linear
E5	The share of newly registered creative sector entities in the total number of newly registered entities (2021)	%	↑	11.05	5.28	8.46	1.29	Linear
E6	Registered unemployment rate (2021)	%	↓	1.60	6.10	3.40	1.43	Linear
E7	Foreign capital per capita of work-ing age (2020)	PLN	↑	83073.00	0.00	12747.06	18561.25	Linear

Source: author's work based on Central Statistical Office, Local Data Bank, 2023.

Table 3. Smart people indicators – characteristics and basic statistical analysis

No.	The name of indicator (year)	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
P1	Net enrollment rate (primary schools) (2021)	%	↑	113.27	100.64	106.25	3.46	Linear
P2	Passability of the final school exams (vocational schools) (2018)	%	↑	88.80	67.50	82.26	5.40	Linear
P3	Passability of the final school exams (general high schools) (2018)	%	↑	94.70	83.30	89.89	3.34	Linear
P4	Higher education institutions in general per 1 000 inhabitants (2021)	facility	↑	0.04	0.01	0.03	0.01	Linear
P5	Users of public libraries per 1 000 inhabitants (2021)	person	↑	229.00	82.00	147.06	40.18	Linear
P6	Foundations, associations and social organizations per 1 000 inhabitants (2021)	unit	↑	8.06	4.09	5.75	1.02	Linear

DOI: 10.34659/eis.2023.86.3.689

No.	The name of indicator (year)	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
P7	The balance of foreign migration (2021)	person	↑	1247.00	19.00	196.39	297.75	Linear

Source: author's work based on Central Statistical Office, Local Data Bank, 2023.

Table 4. Smart governance indicators – characteristics and basic statistical analysis

No.	The name of the indicator	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
G1	City income per capita (2021)	PLN	↑	11608.82	7557.06	8681.04	895.02	Linear
G2	European Union city resources to finance EU programs and projects per capita (2021)	PLN	↑	7.50	0.60	3.72	2.26	Linear
G3	The participation of women in the city council (2021)	%	↑	45.00	8.00	31.69	9.43	Linear
G4	The share of people with higher education in the city council (2021)	%	↑	100.00	62.16	88.51	8.31	Linear
G5	Turnout in local government elections in 2018 (2018)	%	↑	66.57	50.94	55.72	3.59	Linear
G6	Planning support (2021)	%	↑	71.40	16.30	45.73	16.89	Linear

Source: author's work based on Central Statistical Office, Local Data Bank, 2023.

Table 5. Smart mobility indicators – characteristics and basic statistical analysis

No.	The name of the indicator	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
M1	Length of bus lanes per 10 000 km^2 (2021)	km	↑	2078.43	7.22	823.25	628.64	V-shaped
M2	The number of Park&Ride parking lots (2021)	number	↑	34.00	0.00	4.83	8.15	V-shaped
M3	The number of passenger cars per 1 000 inhabitants (2021)	number	↓	516.50	810.80	674.64	76.46	Linear
M4	Cycle paths per 10 000 km^2 (2021)	km	↑	15940.50	3029.50	9586.76	3287.83	V-shaped
M5	Road accidents per 100 000 inhabitants (2021)	person	↓	21.20	136.80	66.81	31.34	V-shaped

Source: author's work based on Central Statistical Office, Local Data Bank, 2023.

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Table 6. Smart environment indicators – characteristics and basic statistical analysis

No.	The name of indicator (year)	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
ENV1	The share of parks, lawns and green areas in the total area (2021)	%	↑	13.30	0.80	4.58	2.57	Linear
ENV2	The share of legally protected areas in the total area (2021)	%	↑	62.00	0.10	12.72	14.69	V-shaped
ENV3	Particulate matter retained or neutralized in pollution abatement equipment in % of pollution generated (2021)	%	↑	100.00	87.30	98.48	3.10	Linear
ENV4	Municipal waste collected selectively in relation to the total municipal waste collected during the year (2021)	%	↑	48.20	22.00	38.52	7.21	Linear
ENV5	Industrial and municipal sewage treated in % of sewage requiring treatment (2021)	%	↑	100.00	83.74	98.08	4.26	Linear
ENV6	Water consumption per capita (2021)	m^3	↓	33.30	44.40	38.11	3.54	Linear
ENV7	Electricity consumption per capita (2021)	kWh	↓	666.40	1062.30	824.34	113.57	Linear
ENV8	Gas from its network consumption per capita (2021)	kWh	↓	1199.60	2430.70	1782.37	329.87	Linear

Source: author's work based on Central Statistical Office, Local Data Bank, 2023.

Table 7. Smart living indicators – characteristics and basic statistical analysis

No.	The name of the indicator	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
L1	The average usable floor area of a flat per person (2021)	m^2	↑	33.90	27.20	30.63	1.88	Linear
L2	Dwellings with water supply in relation to total dwellings (2020)	%	↑	99.80	94.20	98.06	1.46	Linear
L3	Dwellings with bathrooms in total dwellings (2020)	%	↑	98.70	90.10	95.59	2.07	Linear
L4	Dwellings with central heating in total dwellings (2020)	%	↑	96.30	80.10	89.69	4.71	Linear

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No.	The name of the indicator	Unit	Quality	The best value	The worst value	The avarage value	Standard deviation	Preference function
L5	Doctors (total staff working) per 10 000 people (2021)	person	↑	158.10	41.60	99.23	29.32	Linear
L6	Crimes found by the police in total per 1 000 inhabitants (2021)	number	↓	18.63	69.86	30.46	11.64	Linear
L7	Beneficiaries of local social welfere per 10 000 inhabit-ants (2021)	person	↓	123.00	390.00	254.00	67.34	Linear
L8	The number of people per seat in permanent cinemas (2021)	person	↓	31.00	107.00	59.56	20.31	Linear
L9	Visitors of museums and their branches per 10 000 inhabitants (2021)	person	↑	50333.90	1226.20	9778.78	12865.72	V-shaped
L10	Accommodation occupancy rate (2021)	%	↑	39.00	21.70	30.04	4.16	Linear

Source: author's work based on Central Statistical Office, Local Data Bank, 2023.

Results of the analysis

Table 8 presents the final rankings of 18 Polish cities compiled against 43 smart city indicators developed using the PROMETHEE and TOPSIS methods. In the case of PROMETHEE, the final ranking of cities was developed on the basis of the *Phi* coefficient, the value of net flow. When it comes to the TOPSIS method (based on the value of the *CI* coefficient) it was based on defining the degree of relative closeness of each alternative to the ideal solution.

Warsaw was ranked first in both rankings. The significant advantage of the capital of Poland over other voivodship cities stems primarily from high economic indicators. In the prepared ranking, Warsaw obtained the highest values of E1-E5 and E7 indicators. In addition, the capital of Poland is characterized by a high level of smart governance. The last place, both in the ranking prepared using the TOPSIS and the PROMTHEE method, was taken by Zielona Gora. The last position of this city in the prepared ranking stems from its relatively weaker indicators in the field of smart mobility and smart environment.

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Table 8. Final smart city rankings in Poland with the values of base indicators

TOPSIS			PROMETHEE		
No	City	CI	No	City	Phi
1	Warsaw	0.6740	1	Warsaw	0.2991
2	Wroclaw	0.4450	2	Gdansk	0.1154
3	Cracow	0.4390	3	Bialystok	0.0853
4	Kielce	0.3910	4	Cracow	0.0687
5	Gdansk	0.3650	5	Lublin	0.0598
6	Lublin	0.3500	6	Olsztyn	0.0518
7	Rzeszow	0.3390	7	Poznan	0.0380
8	Poznan	0.3350	8	Rzeszow	0.0358
9	Bialystok	0.3330	9	Opole	0.0268
10	Olsztyn	0.3150	10	Wroclaw	0.0107
11	Bydgoszcz	0.3110	11	Kielce	-0.0164
12	Torun	0.3050	12	Szczecin	-0.0286
13	Katowice	0.2780	13	Bydgoszcz	-0.0969
13	Opole	0.2780	14	Gorzow Wielkopolski	-0.0990
14	Lodz	0.2560	15	Torun	-0.1066
14	Szczecin	0.2560	16	Katowice	-0.1216
15	Gorzow Wielkopolski	0.2550	17	Lodz	-0.1379
16	Zielona Gora	0.2180	18	Zielona Góra	-0.1841

Differences in the developed rankings stem quite clearly from the different algorithms of the selected methods. Those differences appear already at the initial stage of the multi-criteria analysis, i.e. when determining the properties of the criteria. In both methods, the weights of the criteria and their nature (stimulant/destimulant) are determined. In the PROMETHEE method, the preference function should also be selected. Research, see e.g. Sałabun et al., 2020 shows that the final ranking is influenced by both the selection of the preference function, as well as the determination of the value of any thresholds required, for example, in the case of a linear or V-shaped function. The selection of functions is made on the basis of differences between decision alternatives against a given criterion. In addition, Visual PROMETHEE is equipped with a "Preference Function Selection Assistant", which supports

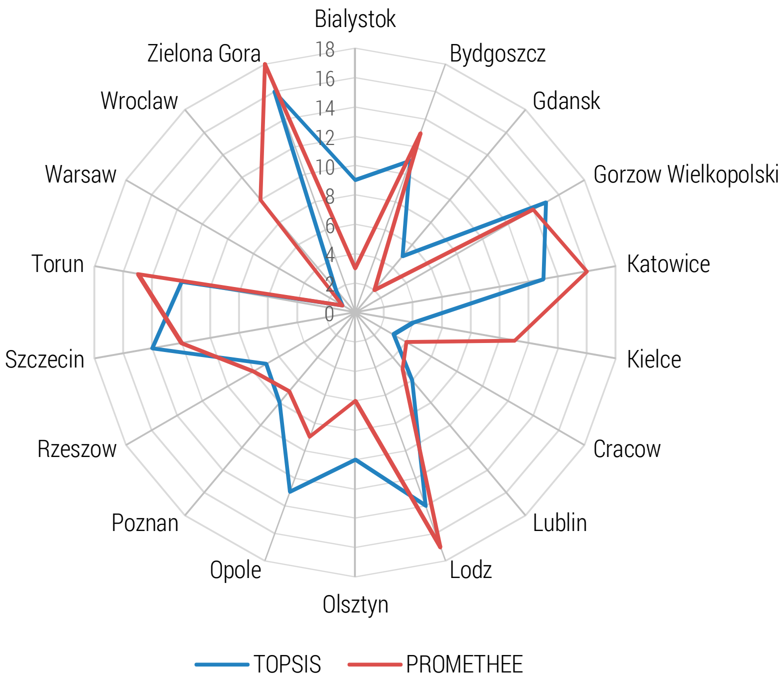

Figure 3. Final smart city rankings in Poland

this step of multi-criteria analysis. However, this does not change the fact that the final choice of the preference function depends on the decision maker's knowledge and experience.

Another difference lies in the normalization, which is carried out only in the TOPSIS method. It is worth noting that there exist different methods of normalizing the output data and the choice of method may also affect the final results.

It is also worth adding that in non-compensatory methods, which include PROMETHEE, there is no compromise between the criteria, which means that good results of the alternative against the selected criteria cannot compensate for its poor results in others. However, in the case of compensation methods (such as TOPSIS), compromises between the criteria are possible (Mokarrari & Torabi, 2021).

In literature studies, only one case compared TOPSIS and PROMETHEE rankings (in general, the study included 6 different methods). This study was primarily focused on proposing a reliable smart city assessment/ranking framework, rather than comparing the MADM methods used (Mokarrari & Torabi, 2021).

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Discussion and Conclusions

The following section focuses primarily on assessing the usefulness of MCDM/MCDA methods in creating urban rankings. Based on the literature review and through the developed case study, general advantages and disadvantages of MCDM/MCDA methods in the context of city rankings are presented below:

- The possibility of including many alternatives and criteria (the list of works in Table 1 shows examples of both short rankings, covering only a few cities, and examples of global rankings).
- The possibility of taking into account the criteria's weights.
- The possibility of taking into account the opinions of many decision-makers at the stage of weighing the criteria. Using the MCDM/MCDA methods – for example the AHP method for estimating the weights of the criteria – it is finally possible to take into account the preferences of various groups of urban space users (e.g. residents, authorities, investors) within one analysis, by using different weights and obtaining several rankings.
- The ability to carry out sensitivity analyses, which may facilitate the selection of decision criteria.
- The ability to include criteria with different measures.
- The ability to create, apart from multi-criteria analyses, also statistical analyses.
- Relatively convenient integration of methods.

This section also includes a comparative analysis of the applied TOPSIS and PROMETHEE methods. The comparative analysis concerned the following issues: alternatives, criteria, algorithm, software, integration with other methods.

The undertaken literature review pertaining to the selected applications of MCDM/MCDA methods and the subsequent case study made it possible to formulate the following conclusions and recommendations:

Among the most popular MCDM/MCDA methods used so far in city rankings, the following methods should be mentioned: TOPSIS, AHP and PROMETHHE.

The TOPSIS method allows one to develop a ranking of alternatives taking into account the distances from the best and worst solutions, while the PROMETHEE method allows one to take into account preferences by assigning at the level of criteria: the so-called preference function. The AHP method, on the other hand, works well at the stage of weighing decision criteria.

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Table 9. Comparative analysis of PROMETHEE and TOPSIS

Category	Similarities	Differences
Alternatives	• no limit to the number of alternatives	–
Criteria	• no restrictions as to the number of criteria • the possibility of including a ready-made set of criteria weights • the need to define the nature of the criteria (stimulant/destimulant)	• the possibility of including qualitative criteria in the PROMETHEE method (however, they are ultimately reduced to quantitative values)
Algorithm	• the starting point is the development of a decision matrix containing the assessment of variants against the criteria • the final ranking is created on the basis of the index value	• PROMETHEE requires the selection of a preference function, which is made by the decision maker, based on the differences between the alternatives against the subsequent criteria • in some preferences functions, the so-called thresholds need to be defined • in the TOPSIS method, an ideal and anti-ideal solution, constituting points of reference, should be defined
Possibilities for technical support	• specialized computer programs supporting multi-criteria analyses available	• the implementation of the algorithm into an ordinary spreadsheet is easier in the case of the TOPSIS method
Integration with other methods	• the possibility of linking it with other methods, especially at the stage of weighing decision criteria	–

Various methods of multi-criteria decision support have been developed over the years, each of which has individual characteristics, the level of computational complexity, as well as the scope of application. The number and nature of decision criteria, the availability of data, the possibility of technical support, as well as the number of decision makers should all be taken into account when selecting the right method for the creation of a city ranking.

It is recommended to use a hybrid approach, assuming the use of several methods, not only a combination of methods for weighting and creating a ranking vector, but also the use of several ranking methods, which will strengthen the credibility of the developed ranking.

Future research directions include the implementation and possible comparison of MCDM/MCDA methods at the stage of criteria weighting, as well as sensitivity analysis.

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Appendix 1

Abbreviations:

AHP – Analytical Hierarchical Process
ANP – Analytic Network Process
APIS – Aggregated Preference Indices System
ARAS – Additive Ratio Assessment
BWM – Best-Worst Method
CoCoSo – A Combined Compromise Solution
CODAS – Combinative Distance-Based Assessment
COPRAS – Complex Proportional Assessment
DANP – DEMATEL-based Analytic Network Process
DDER – Data-Driven Evidential Reasoning
DEA – Data Envelopment Analysis
DEMATEL – Decision Making Trial and Evaluation Laboratory
ELECTRE – ELimination Et Choix Traduisant la REalité
FAHP – Fuzzy Analytical Hierarchical Process
HFL MABAC – Hesitant Fuzzy Linguistic Multi-Attributive Border Approximation Area Comparison
HFL SAW – Hesitant Fuzzy Linguistic Simple Additive Weighting
HFLTS – Hesitant Fuzzy Linguistic Term Set
MACBETH – Measuring Attractiveness by a Categorical Based Evaluation Technique
MARCOS – Measurement of Alternatives and Ranking According to Compromise Solution
MULTIMOORA – Multi-Objective Optimization by Ratio Analysis plus the Full Multiplicative From
NAIADE – Novel Approach to Imprecise Assessment and Decision Environment
PCA – Principle Component Analysis
PROMETHEE – Preference Ranking Organization Method For Enrichment Evaluation
SAW – Simple Additive Weighting
SECA – Simultaneous Evaluation of Criteria and Alternatives
SMAA-PROMETHEE – Stochastic Multicriteria Acceptability Analysis – Preference Ranking Organization Method For Enrichment Evaluation
SWARA – Stepwise Weight Assessment Ratio Analysis
TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution
VIKOR – VIsekrzterijumska Optimizacija i Kompromisno Resenje
WASPAS – The weighted aggregated Sum Product Assessment

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