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MULTICRITERIAL ANALYSIS IN SELECTING A WASTE MANAGEMENT SYSTEM IN REGION

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Introduction. The implementation of the European Union regulations into Polish law resulted in the establishment of such methods of dealing with waste in order to comply with the requirements of environmental protection and waste management plans. Each time the construction of another plant is a social and economic problem, therefore, the enhancement of the form and shape of such a system requires justification. The basic task of municipal waste management is to create technical conditions for the collection, transport, recovery, recycling and disposal of waste. The technical correctness of the system and the scope of the adverse impact resulting in lowering ecological, aesthetic and cultural values will decide about its capital expenditure and operating costs. The large number of imposed, overlapping, and often conflicting goals means that finding a favourable solution and decisively accepting it is a very difficult task, often requiring a compromise. The solution will be based on searching for the shape of a waste management system that, under existing restrictions, will ensure the best possible implementation of specific objectives under the specific conditions of the region.

Aim and tasks. The aim of the article is to present the multicriteria analysis method as a tool for analysis and selection of the waste management system in the region. In the multicriteria analysis for the selection of the most beneficial solution, it is necessary to find a function integrating individual objectives into one overall assessment. However, it is possible to choose only one solution - a compromise, and then a consistent implementation of the tasks of the chosen scenario. The presented analysis presents an example for a large city in Poland - Krakow.

Research results. The result of the presented calculations is the presentation of the assessment method for various waste management scenarios in the technical, socio-political and economic aspects. Such an assessment allows for an objective comparison between the presented waste management scenarios.

Conclusions. The result of the presented methodology of multi-criteria evaluation and analysis is the selection of the most advantageous solution of the waste management system. The presented system was assessed in a multi-aspect manner and the result allows to indicate the best solution in the presented assumptions and limitations. The method is universal and can be used for other waste management and environmental management systems.

Key words: multi-criteria analysis, solid waste, waste management, municipal waste.

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МУЛЬТИКРИТЕРІАЛЬНИЙ АНАЛІЗ У ВИБОРІ СИСТЕМИ УПРАВЛІННЯ ВІДХОДАМИ У РЕГІОНІ

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Проблема. Реалізація норм Європейського Союзу в польському законодавстві призвела до встановлення таких методів поводження з відходами, щоб відповідати вимогам природоохоронних та планів поводження з відходами. Кожного разу, коли будівництво іншого заводу є соціально-економічною проблемою, постає необхідність обґрунтування такої системи поводження з відходами. Основним завданням управління муніципальними відходами є створення технічних умов для збору, транспортування, відновлення, переробки та утилізації відходів. Технічна обґрунтованість системи та обсяг несприятливого впливу відходів, що призводить до зниження екологічних, естетичних та культурних цінностей, обумовлюють вибір варіантів щодо рівня капітальних та операційних витрат на функціонування системи управління відходами. Велика кількість пов'язаних і часто суперечливих цілей означає, що знайти сприятливе рішення та рішуче прийняти це є дуже складним завданням, часто вимагаючи компромісу. Рішення буде засноване на пошуку форми системи поводження з відходами, яка, за існуючими обмеженнями, забезпечить найкращу реалізацію конкретних цілей в конкретних умовах регіону.

Мета та завдання. Метою статті є представлення методу багатокритеріального аналізу як інструменту для аналізу та вибору системи управління відходами в регіоні. У багатокритеріальному аналізі для вибору найбільш вигідного рішення необхідно знайти одну функцію, що об'єднує окремі цілі, в одну загальну оцінку. Однак можна вибрати лише одне рішення - це компроміс, а потім послідовне виконання завдань обраного сценарію. Представлений аналіз є прикладом для великого міста Польщі - Кракова.

Результати. Результатом представлених розрахунків є презентація методу оцінки різних сценаріїв поводження з відходами в технічних, соціально-політичних та економічних аспектах. Така оцінка дозволяє провести об'єктивне порівняння між представленими сценаріями поводження з відходами.

Висновки. Результатом представленої методології багатокритеріальної оцінки та аналізу є вибір найбільш вигідного рішення системи управління відходами. Представлена система була оцінена у багатоаспектному стилі, і результат дозволяє обрати найкраще рішення у представлених припущеннях та обмеженнях. Метод є універсальним і може використовуватися для інших систем управління відходами та управління навколишнім середовищем.

Ключові слова: мультикритеріальний аналіз, тверді відходи, поводження з відходами, муніципальні відходи.

Introduction. The dynamic development of Polish waste management legislation in recent years has been connected with the necessity to adapt the legal provisions to accepted international obligations, in particular those resulting from the accession to the European Union. Directive 2008/98 / EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives (called the "Waste Framework Directive") [1] is one of the key EU directives for the management of all types of waste within the community. It establishes a legal framework, defines key concepts, establishes important requirements in the field of waste management, in particular the obligation to obtain a permit or registration and the obligation to draw up waste management plans. It also encourages the use of a hierarchy of waste management and the application of the "polluter pays" principle. The basic concept of waste framework directive is waste, defined in art. 3 point 1 as "any substance or object which the holder discards, intends to get rid of, or to which he has been required to get rid of".

The provisions of EU law are implemented into Polish law, which resulted in the creation of two basic laws in the field of municipal waste management [2-3]:

– The Act of 14 December 2012 on waste (Journal of law 2013, item. 21)

– The Act of 28 November 2013 about maintaining cleanliness and order in communes (Journal of law 2013, item. 1399).

The Act of 14 December 2012 on waste specifies that in accordance with the "polluter pays" principle, anyone who takes actions that cause or can cause waste, should conduct their activities in such a way as to prevent or reduce their quantity, reduce the negative impact of waste on the environment, ensure in accordance with environmental protection rules, recovery or disposal, if waste was not prevented from occurring.

Aim and tasks. The aim of the article is to present the multicriteria analysis method as a tool for analysis and selection of the waste management system in the region.

Results. The Waste Framework Directive in Art. 28 requires Member States to develop at least one waste management plan, which plans, either individually or collectively, must cover the entire geographical area of the country concerned. According to art. 34 par. 1 of the Waste Act, the plans are aimed at achieving the goals set in the environmental policy, separating the trends in the amount of waste generated and their impact on the environment from the country's economic growth trends, implementing the hierarchy of waste management practices and the principles of self-sufficiency and proximity, and setting up and maintaining an integrated country and a sufficient network of waste management installations that meet environmental protection requirements. Therefore, it is possible to specify that waste management plans are the basis for waste.

Cracow is a large city in south-eastern Poland on the Vistula. At present, there are about 1 million inhabitants, which collect on average over 300 kg a year each. In Krakow, waste management is implemented according to the provisions of the Waste Management Plan of the Malopolska Voivodship, which defines the objectives and directions of actions for 2016-2022 with a perspective up to 2030. The currently functioning waste management system is the effect of many years of work and analysis. One of its elements was, among others "Strategic Assessment of the Waste Management System of the City of Cracow along with the selection of variants of the location of the municipal waste thermal treatment plant", developed in 2007, which showed the most advantageous shape of the currently operating system. The assessment was an analysis of the existing waste management system, which after social consultations and experts' assessments finally proposed one model of the system to be implemented, functioning today.

Based on the analysis of the then binding waste management plan and reports on its implementation as well as legal requirements, four potential waste management scenarios in the city of Cracow were identified for the assessment [4].

S0 scenario - continuation of the existing state - the waste management model will be based on the infrastructure existing at that time [4]:

– Barycz landfill with a capacity of approximately 2 million m3;

– a composting plant processing green waste in the amount of 6,000 Mg/year,

– Barycz composting plant that processes green waste with a capacity of approx. 6,000 Mg/year;

– Barycz sorting of secondary raw materials, with a target recycling of raw materials at the level of approx. 8,000 Mg/year;

– recovery of construction waste in existing installations for sorting and recycling of construction waste at the level of 12,000 Mg/year;

– sets of containers for separate collection of waste - a target of 750 sets ensuring collection of 9,000 Mg/year.

As a result, the implementation of the S0 scenario will be accompanied by the expansion of the system for business trips to the colossal blindfolders of the most productive years in 2017-2018. The above scenario could not be implemented from 2013 due to legal reasons.

S1 scenario - extension of sorting lines and extension of further composting units - assumed the development of a separate waste collection system and operation of the following installations [4]:

– Barycz landfill with a capacity of approximately 2 million m3;

– a composting plant processing green waste in the amount of 6,000 Mg/year;

– Barycz composting plant that processes green waste with a capacity of approx. 6,000 Mg/year;

– composting plant for wet fraction collected selectively in a two-container system

– with a capacity of 45,000 Mg/year;

– Barycz sorting of secondary raw materials, with a maximum recovery of raw materials at the level of approx. 16,000 Mg/year;

– construction of another sorting plant for secondary raw materials, with recycling of raw materials at the level of approx. 20,000 Mg/year;

– construction of an installation for mechanical and biological treatment of municipal mixed waste (not sorted) with a capacity of 120,000 Mg/year;

– large disassembly waste facilities with a total capacity of approximately 12,000 Mg/year;

– recovery of construction waste in existing and planned installations for sorting and recycling of construction waste at the level of 30,000 Mg/year;

– sets of containers for separate collection of waste - a target of 750 sets ensuring collection of 9,000 Mg/year;

– Collective Waste Collection Points (9 in the city).

At the same time, it was assumed that implementation of the S1 scenario would require the extension of the waste management system with further waste sorting and composting installations, as well as the mechanical and biological transformation plant for unsorted (mixed) municipal waste and the construction of a landfill in 2017-2018. The scenario will also require the construction of another final disposal site.

S2 scenario - extension of sorting lines and addition of further composting modules - waste management model assumed the development of a separate waste collection system and operation of the following installations [4]:

– Barycz landfill with a capacity of approximately 2 million m3;

– a composting plant processing green waste in the amount of 6,000 Mg/year;

– Barycz composting plant that processes green waste with a capacity of approx. 6,000 Mg/year;

– composting plant for wet fraction collected selectively in a two-container system

– with a target capacity of 65,000 Mg/year (whereas from 2016 some of the waste will be directed to a composting plant located in the plant for the treatment of municipal waste in a biological and biological manner);

– Barycz sorting of secondary raw materials, with a maximum recovery of raw materials at the level of approx. 16,000 Mg/year;

– construction of another sorting plant for secondary raw materials, with recycling of raw materials at the level of approx. 25,000 Mg/;

– construction of an installation for mechanical and biological treatment of municipal mixed waste (not sorted) with a capacity of 120,000 Mg/year;

– large disassembly waste facilities with a total capacity of approximately 12,000 Mg/year;

– recovery of construction waste in existing and planned installations for sorting and recovery of construction waste at the level of 30,000 Mg/year;

– sets of containers for separate collection of waste (segregation sockets) - a target of 750 sets ensuring collection of 9,000 Mg/year;

– Collective Waste Collection Points (9 in the city);

– implementation of a two-container municipal waste collection system, and ultimately covering all residents of the city of Craków.

The implementation of this scenario variant S2 required the extension of the waste management system with further waste sorting and composting installations, as well as a mechanical-biological transformation plant for unsorted (mixed) municipal waste (and from 2016 also separately collected) and construction of a landfill in 2018- 2019.

Scenario S3 - considering the incineration plant of waste as an element of the system. The waste management model assumed the development of a separate waste collection system and operation of the following installations [4]:

– Barycz landfill, which mainly accepts slag after burning waste,

– composting plant processing green waste in the amount of 6,000 Mg/year;

– Barycz composting plant that processes green waste with a capacity of approx. 6,000 Mg/year;

– composting plant for wet fraction collected selectively in a two-container system with a capacity of 12,000 Mg/year;

– Barycz sorting of secondary raw materials, with a maximum recovery of raw materials at the level of approx. 16,000 Mg/year;

– a municipal incineration plant, with a processing capacity of approx. 240,000 Mg/year;

– large disassembly waste facilities with a total capacity of approximately 12,000 Mg/year;

– recovery of construction waste in existing and planned installations for sorting and recovery of construction waste at the level of 30,000 Mg/year;

– sets of containers for selective collection - ultimately 750 sets ensuring the collection of 9,000 Mg/year;

– Collective Waste Collection Points (9 in the city);

– implementation of a two-container municipal waste collection system, in selected areas of the city (covering approximately 12% of the inhabitants of the city of Kraków with the system).

The implementation of the S3 scenario required, first and foremost, financial outlays for the construction of a incineration plant.

The objective assessment of scenarios is the most difficult element of the analysis. Assessment of individual waste management strategies, comparison and selection of the best one is possible thanks to the numerical determination of indicators measuring the functioning of the entire system. They are a measure of the consequences of the operation of individual strategies and the degree of meeting the assumed goals. For the full description of the system, three groups of criteria were adopted, presented in Tables 1, 2, 3 [4-7].

Table 1. Criteria for waste minimization and recovery for identified waste management scenarios in Cracow, after 2007

	Criterion	Limit or the best value	S0	S1	S2	S3
1	Reduction of the amount of municipal waste deposited	44.000 Mg until the end of 2014 year	52.000 Mg (>100%)	95.300 Mg (>100%)	101.300 Mg (>100%)	243.500 Mg(>100%)
2	Reduction of the amount of municipal biodegradable waste stored (requirement of the EU directive)	until the end of 2010 year 65.600Mg until the end of 2013 year 97.500 Mg until the end of 2020 year 123 700 Mg	28.200Mg (43,1%) 29.300 Mg (30,0%) 29.300 Mg (23,7%)	33.300 Mg (50,8%) 102.600. Mg (>100%) 126.600 Mg (>100%)	52.000Mg (79,3%) 120.100 Mg (>100%) 131.900 Mg (>100%)	34.600 Mg (52,7%) 154.200 Mg (>100%) 162.900 Mg (>100%)
3	Raw materials recovery	89.100 Mg	38.400 Mg (43,1%)	72.900 Mg (81,8%)	89.100 Mg (100%)	51.600 Mg (57,9%)
4	Energy recovery	97,5 GWh	8 GWh (8,2%)	4 GWh (4,1%)	4 GWh (4,1%)	97,5 GWh (100%)
5	The lifetime of the landfill	calculated since 2005	12 years	13 years	15 years	38 years

Source: made by author.

Table 2 Socio-political criteria for identified waste management scenarios in Cracow, after 2007

	Criterion	Limit or the best value	S0	S1	S2	S3
K6	Compliance with the directions indicated by waste management plans	0/1	0	1	1	1
K7	Compliance with EU directives	0/1	0	1	1	1
K8	Regional and perspective of the solution	0/1	0	0	0	1
K9	Social acceptance	0,86	0,4	0,83	0,83	0,86

Criteria 6 - 8 were estimated using the expert method on a scale of 0 - 1, while criterion 9 was determined on the basis of a survey conducted among Cracow residents on a sample of approx. 1000 people.

Source: author's development based on [4].

Table 3. Economic criterion for waste management scenarios in Cracow, after 2007

	Criterion	S0	S1	S2	S3
K 10	Financial burden of 1 inhabitant [Polish zloty/ Inhabitant]	19,63	28,38	30,15	22,05
K 11	The cost of neutralization of 1 Mg of waste [Polish zloty / Mg of waste]	844	1221	1297	948

Source: author's development based on [4].

Multicriteria decision analysis (MCDA) is a mathematical method that can be used for selection of the best of the many considered options [8]. MCDA can be applied to assess value judgments of individual decision makers or multiple stakeholders [8]. There are usually various MCDM methods applied to the selection of the various treatment process of waste [46]. The common purpose of MCDA methods is to assess and choose among alternative scenarios based on multiple criteria using systematic analysis that overcomes the limitations of unstructured individual or group decision making [8-11].

The decision problem is formulated when criteria values are determined by expressing them in the form of a finite set of numbers, which constitute the assessment of individual scenarios (Table 4). In this calculation example, these values will be entered in accordance with Tables 1 - 3 and will constitute a formal record of a multi-criteria decision problem.

Table 4. Multi-criteria selection matrix

Criterion	**Individual scenarios / variants of action**			
	S1	**S2**	**...**	**SN**
K_1	r_{11}	r_{21}	...	r_{N1}
K_2	r_{12}	r_{22}	...	r_{N2}
...	...	...	...	...
K_M	r_{1M}	r_{2M}	...	r_{NM}

where: r_{NM} - measure of the degree of implementation of the M-th criterion in the N-th scenario.

Source: author's development based on [5-7].

The decision task was solved with compromise programming method [8]. It allows to organize the options from the worst to the best one using the concept of their arrangement, according to the distance from so called "ideal point" with the coordinates X'(x_1', x_2',...,x_m'). All coordinates of the ideal point are equal to a maximum value of the assumed normalization scale, i.e. the point is always in the most advantageous position. Mathematical depiction of the searched distance of the analysed option from an ideal point can be presented as follow (Eq. 1) [8, 9, 11, 13]:

$$L_\alpha(s_n) = \sum_{m=1}^{M} w_m^\alpha \cdot (x_m' - r_{NM}')^\alpha \quad (1)$$

The selection of the best option is done according to the following rule (Eq. 2):

$$s_j = \bar{s} \Leftrightarrow L_\alpha(s_j) = \min L_\alpha(s_n); n = 1,2,\ldots,N \quad (2)$$

where:

Lα(sn) - measure of divergence of a specific option sn from the ideal point

š - selected option,

wm - weight coefficient for the criterion "m",

xm' - „m" coordinate of the ideal point,

rNM' - normalized value of a criterion,

M - number of criteria,

α - exponent that measures the divergence of a criteria from the ideal point X'; in practice equal to 1, 2 and ∞.

To solve the decision-making task, a method of compromise programming was used, using the concept of organizing individual strategies according to their distance from a fixed ideal point. For the calculations it is necessary to adopt a hierarchy of importance of individual criteria, defining the priorities of the participants in the decision-making process. At present, the values of criteria weights adopted by the authors of the study were adopted for the calculations. For example, for case 1, weight 1 was assigned to each criterion.

In the second case, all the minimization and recovery criteria received a weight of 5, while the other criteria were weight 1, while the last line, the minimization and recovery criteria, and socio-political criteria were given a weight of 5, and economic criteria weight 1 [11-13, 14]. The results of the analysis are presented in Table 5.

Table 5. Results of multi-criteria analysis for identified waste management system scenarios for the city of Cracow after 2007

Hierarchy of criteria validity Minimization and recovery of waste: socio-political: economic	Sorting the strategy		
	alfa = 1	alfa = 2	alfa = ∞
1:1:1	**s3***→s2→s1→s0	**s3***→s1→s2→s0	**s3***→s2→s1→s0
5:1:1	**s3***→s1→s1→s0	**s3***→s2→s1→s0	**s3***
10:1:1	**s3***→s2→s1→s0	**s3***→s2→s1→s0	**s3***
1:5:1	**s3***→s2→s1→s0	**s3***→s1→s2→s0	**s3***
1:10:1	**s3***→s2→s1→s0	**s3***→s1→s2→s0	**s3***
1:15:1	**s3***→s2→s1→s0	**s3***→s1→s2→s0	**s3***
1:1:2	**s3***→s1→s2→s0	**s3***→s0→s1→s2	**s3***
1:1:5	**s3***→s0→s1→s2	**s3***→s0→s1→s2	**s3***→s1→s0→s2
1:1:6	**s3***→s0→s1→s2	**s3***→s0→s1→s2	**s3***→s1→s0→s2
1:1:10	**s3***→s0→s1→s2	**s0***→s3→s1→s2	**s3***→s1→s0→s2
5:1:5	**s3***→s0→s2→s1	**s3***→s0→s1→s2	**s3***
1:5:5	**s3***→s1→s2→s0	**s3***→s1→s2→s0	**s3***
5:5:1	**s3***→s2→s1→s0	**s3***→s2→s3→s0	**s3***

Sn* - acceptable strategy
Source: made by author.

The method gives the possibility of additional weighting of criteria by using the exponent in the formula [15-17]. This exponent allows additional weighting of each deviation from the ideal point in proportion to their size. The higher the α value is, the greater the deviations of the strategy from the ideal point. Individual calculation cases considering different values of the α coefficient are included in three different columns in Table 5.

Analyzing the results of a multi-criteria analysis, it can be concluded that:

– for 39 calculation cases, the strategy most often chosen is strategy s3 (thermal treatment of waste as part of a comprehensive waste management system) - 38 times;

– in the remaining one case, the strategy s0 assumes the implementation of the existing waste management system. It is chosen when, as the most important, we accept the economic criterion (10 times more important than the others);

– Strategies s1 and s2 ("deep waste segregation" and composting) were not selected as the best in a single calculation case

– The decision maker can accept certain restrictions in the choice of strategy. In these calculations, such limitations have been assumed as so-called acceptance threshold calculated as:

$$s_n^* = 0{,}1 * L_\alpha(s_n)_{\min} \qquad (3)$$

Acceptable strategies are marked in the table *) and are a solution to the decision-making task as choosing a strategy lying close to the ideal point.

For the purpose of this analysis, it was assumed that people interested in the structure and function of the waste management system in Cracow and willing to participate in decision-making can be divided into three groups:

Ecologist: it primarily weighs the rationale of protecting the natural environment, although the social environment may also be important to it.

A local self-government employee: what counts for him is the interest of the local community who chose him and which he represents.

Others: a group of people unrelated to any of the above presented, especially since everyone could participate in the public consultations. Preferences are difficult to predict in this group.

In selected groups, after conducting education, questionnaire surveys were carried out in which respondents were asked to divide the criteria belonging to individual groups as a percentage of significance. The results of the research are presented in Table 6.

Table 6 The main criteria for identified waste management scenarios for the city of Cracow adopted for the analysis of the weight, reflecting the preferences of social consultation participants

GROUPS OF CRITERIA	WEIGHT OF MAIN GROUPS OF CRITERIA [%]			
	Ecologist	**Local self-government**	**Others**	**Average**
Criteria for minimization and recovery	41,67	37,05	45,43	**41,38**
Socio-political criteria	38,33	42,15	34	**38,16**
Economic criteria	20	20,8	20,57	**20,46**
	100	100	100	**100**

Source: made by author.

Preferences in the main groups of criteria are used in the multi-criteria analysis to equalize the number of groups of criteria. There are 5 criteria in the decision process of waste minimization and recovery, while only 2 economic criteria. Economics would then weigh less in the decision-making process and even very high values of economic criteria would not favourably enough profitable options.

Therefore, the weight vectors are constructed in such a way that all criteria within the main group weigh as much in the decision-making process as their preference determined by the group interested in the proceeding.

In the further part of the decision-making process, it was necessary to examine the preferences of interested persons regarding individual evaluation criteria. The survey technique was also used here. Respondents, in order to express their preferences regarding each of the criteria, evaluated it on a scale of 1 ... 10 points.

The results are presented in Table 7, described as "raw weights". In the table on the right, transformed weights are presented, reflecting the exact preferences of the participants in the decision-making process expressed by means of the weights of the groups of main criteria and raw weights.

Transformation is based on the following formula (Eq. 4):

$$T_{i,j} = P_i W_{i,j} \Big/ \sum_{k=1}^{L_i} W_{i,k} \qquad (4)$$

where:

Ti, j - the weight transformed by the j-th criterion belonging to the i-th group,

Pi - weight assigned to the i-th group of criteria (0, 100),

Wi, j - raw weight of the j-th criterion belonging to the i-th group (1…10),

Li - number of criteria in the i-th group.

Table 7. The weightings of criteria used in multi-criteria analysis for identified waste management scenarios for the city of Cracow after 2007

	RAW WEIGHTS				TRANSFROMED WEIGHTS			
Criteria	Ecologist	Local self-government	Others	Average	Ecologist	Local self-government	Others	Average
K1. reduction of waste	9,33	8,5	8,98	8,94	11,06	8,95	10,22	10,06
K2. reduction of biodegradable waste	8,5	7,4	7,21	7,7	10,07	7,79	8,21	8,67
K3. Raw materials recovery	6	7,7	7,74	7,15	7,11	8,1	8,81	8,05
K4. Energy recovery	6	6,2	7,8	6,67	7,11	6,53	8,88	7,51
K5. lifetime of the landfill	5,33	5,4	8,19	6,31	6,32	5,68	9,32	7,1
K6. Compliance with waste management plans	6,67	5,6	6,03	6,1	9,19	7,82	7,15	8,05
K7. compliance with EU directives	7	7,7	7,97	7,56	9,64	10,75	9,45	9,98
K8. regional and perspective of the solution	6,33	8,4	6,97	7,23	8,72	11,72	8,27	9,55
K9. social acceptance	7,83	8,5	7,7	8,01	10,78	11,86	9,13	10,58
K10. the average financial burden on the inhabitant	3,17	7,1	6,14	5,47	10	10,78	10,62	10,52
K11. the cost of disposal of 1 Mg of waste	3,17	6,6	5,75	5,17	10	10,02	9,95	9,94

Source: made by author.

Finally, the multi-criteria analysis was carried out using the transposed weightings of the evaluation criteria. The calculations were carried out for particular social groups that expressed their preferences in the survey. In addition to the calculations for individual social groups, calculations were also made for the average transposed weight, considering all groups taking part in the decision-making process. The results of calculations are presented in Table 8.

During the public consultations, their participants had the opportunity to determine their priorities and hierarchy of validity of the criteria on the basis of which the final calculations and multi-criteria analysis of the choice of waste management system in Kraków were made. Among the participants in the consultations, questionnaire surveys were conducted in which the criteria were asked to determine the relevance of the group of criteria.

On the basis of the results obtained (multi-criteria analysis) it can be stated that using the tools of social consultations as the most advantageous for Krakow, the S3 scenario was chosen (with waste incineration as one of the elements of the waste management system).

Table 8. Results of the multi-criteria analysis for identified waste management system scenarios for the city of Cracow after 2007, after considering the weightings of the criteria set by the participants of public consultations

Social group	Sorting the strategy
ECOLOGISTS	
alfa = 1	**s3***→s2→s1→s0
alfa =2	**s3***→s1→s2→s0
alfa = ∞	**s3***
LOCAL SELF-GOVERMENTS	
alfa = 1	**s3***→s2→s1→s0
alfa =2	**s3***→s1→s2→s0
alfa = ∞	**s3***
OTHERS	
alfa = 1	**s3***→s2→s1→s0
alfa =2	**s3***→s1→s2→b0
alfa = ∞	**s3***
AVERAGE	
alfa = 1	**s3***→s2→s1→s0
alfa =2	**s3***→s1→s2→s0
alfa = ∞	**s3***

Source: made by author.

The current waste management system operates based on the model chosen in the multi-criteria analysis and includes [14]:

– Barycz landfill (stage III), on which only processed waste is stored, mechanical and biological processing installation operating since 2012 in a fully mechanized waste sorting plant, which is a mechanical part of the installation. It allows the separation of recyclable materials that can be recycled and recycled, and the production of alternative fuel from non-recyclable waste, used as a source of energy in cement plants. In addition to the biological stabilization, a wet fraction composting plant used in a mechanical-bionic processing plant is used;

– Barycz composting plant that processes green waste with a capacity of approx. 6,000 Mg/year; working since 2005, expanded in 2012 - 2015

– Barycz sorting of secondary raw materials, with a maximum recovery of raw materials at the level of approx. 20,000 Mg/year;

– a municipal waste incineration plant, with a processing capacity 240,000 Mg/year;

– large disassembly facility with an alternative fuel production plant;

– recovery of construction waste;

– sets of containers for selective collection - eventually 750 sets;

Collective Waste Collection Points (2 within the city).

Conclusion. The choice of waste management strategy in the region is a difficult decision-making task, which must consider various, often conflicting goals and tasks as well as social and political interests. Presented results of calculations made for a large city in Poland (Krakow) are a mathematical tool that allows the decision-maker to justify the choice.

The results of analyzes of individual strategies indicated the most favorable solution, which allowed for the implementation of a waste management system in a large city.

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