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Original Research

Multi-Criteria Analysis of Waste Management in Szczecin

Agnieszka Generowicz*

Faculty of Environmental Engineering, Institute of Water Supply and Environmental Protection, Kraków University of Technology, Kraków, Poland

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Abstract

The article tries to find the best solution of the system, which aims to dispose of the waste stream, being at the same time an economically justified and socially acceptable system. In order to find the best possible system three strategies for dealing with waste were considered, evaluated by 11 criteria in line with sustainable development, included in the following groups: environmental, social, and economic. The evaluation criteria are used in the multi-criteria analysis, which is the final step in the decision-making analysis. The most effective solution selected is additionally dependent on the importance of specific criteria adopted for the calculations. The proposed methodology was used and verified in the selection of a waste management system for the city of Szczecin.

Keywords: municipal waste, multi-criteria analysis, waste-management system

Introduction

The concept of "Sustainable Development," as defined in the report "Our Common Future" (1987), developed by the World Commission on Environment and Development of the United Nations, defines the process aimed at meeting the development aspirations of the present generation in a manner enabling the same aspirations for the next generation [1-9]. Due to the multiplicity and diversity of factors influencing this phenomenon, three main areas were identified on which to focus when planning an effective strategy to achieve sustainable development. These are: environmental protection and rational management of natural resources, economic growth and equitable sharing of benefits arising from it, and social development. The system that should meet these assumptions is the system of waste management. The possibilities for the solution as far as its technology is concerned are very complex. An additional difficulty is the incorporation of the technical system in the natural conditions of the region and the inclusion of locally existing economic and social conditions. Considering all these factors, it can be concluded that the solution for the system of waste management in the region is a choice that will reconcile the conflict between human activities and the natural and social environments. The practical implementation and application of principles of sustainable development in the waste management system requires finding measurements, criteria, or indicators evaluating the proposed solution – measurements that in a practical way will check its operation [1, 2, 10, 11]. This measurements will allow the selection of a waste management system in a region, which is the most advantageous system in light of the principles of sustainable development.

*e-mail: agnieszka@generowicz.org

Methods

Multi-Criteria Analysis as a Tool for Decision Making

An attempt to measure the functioning of the waste management system and selection of the most advanta-

geous system has already been taken several times. The results of these analyses have been published. These were mainly analyses conducted on the basis of data for the city of Kraków [12-15].

The solution of problems related to the planning and selection of the technical structure of the waste management system is a multistep process consisting in identifying the differences and elements of common variant solutions, in selecting the most beneficial solutions, and in assessing the results of actions [2, 3, 5, 7, 10, 16-18]. Next steps in this process are shown in Fig. 1.

The most difficult task of the whole analysis is finding the evaluation criteria, such that in a uniform, measurable and most objective way will evaluate different options. The aim of the analysis carried out is to find the best solution of the waste management system in the city of Szczecin. This analysis was part of the "Strategic Evaluation of the Final Waste Management System for the City of Szczecin, Including the Choice of Location Options For Waste Incineration Plant" [19] conducted in 2008.

The Description of the Analyzed Waste Management Options in Szczecin

Szczecin is a city in northwestern Poland, the capital and the largest city of Zachodniopomorskie Voivodeship, with more than 400,000 inhabitants. It is one of the oldest and largest cities in Poland. The city is the center of the agglomeration of Szczecin, comprising surrounding communities and cities. An enhanced economy with a variety of industries makes Szczecin a major economic center in the region. Typical of the town is the maritime industry, e.g. there is a large seaport and a shipyard. The seagoing port supports ship owners from around the world. The city is a tourist center with a large number of monuments. It is a cultural hub with numerous theaters, museums, and cultural centers [19].

At the time when the calculations were performed in the city there was organized waste management based on the Waste Management Plan [19]. A selective collection was carried out in containers for collection of recyclable materials, which are placed as the residents need them. The amount of recyclables collected showed an upward trend. In Szczecin there was a sorting plant for recyclable materials from a separate collection with a capacity for 20,000 t/year. All municipal waste from the area of Szczecin was disposed of in landfills located outside the city boundaries. Due to the large distance to the landfill, there was a transfer station in the city. The planning waste accumulation rate was 342.92 kg/t per year. It is possible to develop any number of variant-evaluated systems. These are developed based on the balance of the municipal waste stream, described by its quantity and quality. A limitation in the development and evaluation of alternatives are the technological possibilities of processing the waste stream. Another important limitation in creating variants of the system are economic conditions in the region. In this case, the constraint was the quality and quantity of waste processed per unit of settlement.

For the purposes of calculation three scenarios involving the development of the existing waste management system were adopted:

Scenario No. 1 – the continuation of the current method of waste disposal with the addition of facilities for recycled waste collected selectively. The basic method of disposal is placing the waste in the landfill after the separation of commercial fractions by method of selective collection at source. Landfilling will be done at modern landfills located outside town. This will require middle-distance transportation (approximately 100 km), which is why the waste will be reloaded at the transfer station (an existing facility) to large-size containers and compressed. Separate collection at source is carried out for three waste fractions (paper and cardboard, glass and plastics). These wastes are sorted in

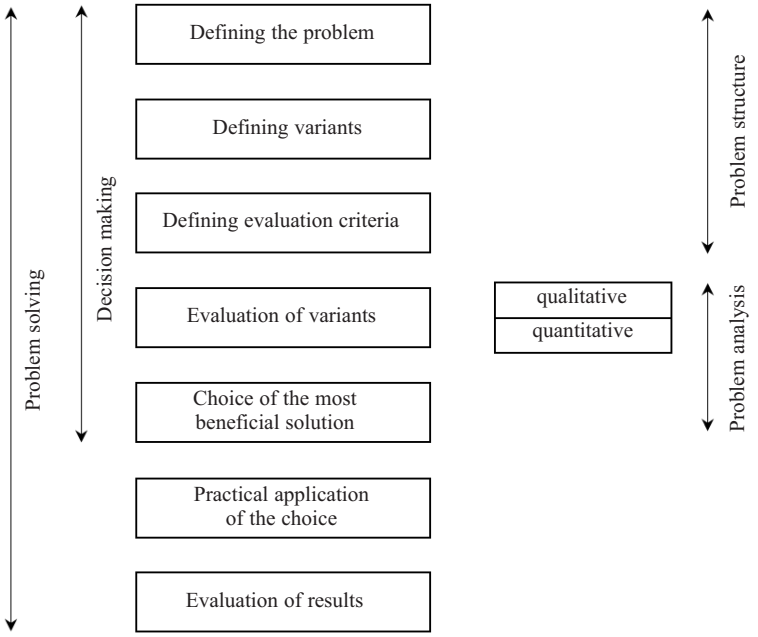

Fig. 1. Diagram of the problem-solving process [1].

the existing sorting plant of recyclables. In certain areas of the city and in select facilities (catering, markets) a separate collection of biodegradable waste is organized. For the selectively collected biodegradable waste a composting plant must be built. In the city, periodically or as a custom collection, bulky waste and construction waste collection is carried out. These wastes are processed in commercial recovery plants: bulky waste dismantling plant, construction waste sorting plant. The system is complemented by a collection of hazardous waste and problem waste.

Scenario No. 2 – Scenario 2 differs from Scenario 1 by the method of disposal used. The collected mixed waste rather than to the transshipment point (described in Scenario 1), goes to a mechanical and biological treatment line. At the sorting line the following are separated: subscreen mineral fraction and ballast, organic fraction made of kitchen waste and fine elements of other fractions, and light raw fraction. The separated organic fraction is subjected to stabilization by composting. Oversized waste is subjected to sorting, through which part of the recyclable raw material is separated. The sorting line can also be used to sort recyclable materials collected selectively, while the modular installation for composting can also compost green waste. The subscreen fraction, the remnants of the sorting, and the sifting of compost are deposited in a landfill outside the city.

Scenario No. 3 – in which the target site of disposal is the incineration plant. To the incineration plant goes mixed waste, excluding fractions collected separately as in Scenario No. 1. For these fractions the recovery facilities operating as in Scenario No. 1 are implemented. The thermal plant is expected to accept mixed waste collected in Szczecin and part of the waste collected in municipalities belonging to the so-called Szczecin Metropolitan Area. This area includes, apart from Szczecin, the entire area of Police district and the city of Gryfino, Stargard Szczeciński and Goleniów, as well as municipalities of Stargard Szczeciński and Kobylanka (belonging to the Stargard county). According to the agreement on the establishment of the Szczecin Metropolitan Area (of 30 October, 2006) the population in the area is about 630,000 residents (including about 400,000 from the area of the city of Szczecin). Residues from combustion (slags) will undergo a process of ferrous fraction separation, fractionation, seasoning, and use in whole or in part for construction purposes. Unused slag and ash after extraction are sent to landfills outside the city.

Description and Calculation of the Value of Criteria Adopted for Analysis

In such a developed system as is the waste management system, additionally taking into account the specificities of the region in which it will operate, defining the evaluation criteria for individual solutions is a very difficult task. For all three scenarios the calculations were made on the basis of the same assumptions, and assuming the balance of quality and quantity of waste entering the system. In order to obtain a full description of the operation of the waste management system and to meet the objectives of sustainable development, the criteria for defining the operation of the comprehensive system were adopted and summarized in three groups: environmental, social, and economic criteria. Different criteria have been carefully defined and calculated as measurable indicators of the functioning of all scenarios for the waste management system in Szczecin [17, 18, 20-22]. In the environmental criteria group the following were distinguished:

Criterion 1 – the reduction of the amount of waste disposed, it was calculated in terms of value as the amount of waste ultimately sent to the landfill as the result of the operation of the various waste management scenarios in Szczecin in 2020.

Criterion 2 – the reduction of the amount of biodegradable waste placed into the landfill, calculated as the amount of processed and used (not intended for storage) organic waste in the operation of the various scenarios in 2020.

Criterion 3 – the recovery of secondary raw materials – the value of the criterion was calculated as the amount of recovered materials from the waste stream and high-quality compost, which should be used in the operation of the various waste management scenarios in Szczecin. In Scenario No. 1 this variable was calculated as the total weight of raw materials recovered in the sorting plant, in the bulk waste dismantling plant and the compost waste, which can be used for agricultural purposes, or at least for the purpose of rehabilitation. In Scenario No. 2 this variable was calculated as the total weight of raw materials recovered in the sorting plant, in the bulky waste dismantling plant and high-quality compost mass from green waste composting, and an additional amount of raw materials recovered in the operation of the mechanical-biological treatment plant. The compost produced from composting the biofraction of mixed waste was not included because of uncertainty as to possible use. In Scenario No. 3 this variable was calculated as the amount of raw materials recovered in the sorting plant, the amount of raw materials from bulk waste dismantling plant, high-quality compost from green waste composting, and the amount of ferrous material recovered from the slag in the operation of waste incineration plant. However, the recovery of slag for aggregates was not included due to uncertainty as to its use.

Criterion 4 – the recovery of energy, calculated as the amount of energy recovered by incineration of waste in the scenario providing for building an incineration plant as an element in a comprehensive waste management system. In other scenarios, the recovery of energy from the landfill is not included, because the landfill is not located in Szczecin, and even if energy is recovered, the city of Szczecin will not use it.

Criterion 5 – the impact of different waste management systems on the environment – taking into account on a point scale: impact on ambient air (including: greenhouse gas emissions, emissions of pollution associated with combustion processes, emissions of falling dust, emissions of odors); the impact on surface water and underground water (including: emissions of biogenic pollution, chemical pollution); the noise effect of individual recovery facilities and waste disposal systems; energy consumption; and the use of the earth's surface.

Table 1. The environmental criteria for the identified waste management scenarios in Szczecin.

	Criterion	Scenario S1	Scenario S2	Scenario S3
k1	Reduction of landfilled municipal solid waste [thousand of tons]	32,000 tons/year (17%)	62,500 tons/year (34%)	130,100 tons/year (70%)
k2	Reduction of landfilled biodegradable municipal solid waste [thousand of tons]	5,800 tons/year (5.9%)	34,100 tons/year (34.6%)	98,700 tons/year (100%)
k3	Recovery of raw materials [thousand of tons]	11,100 tons of raw materials/year +4,800 tons of compost/year	16,200 tons of raw materials/year +20 tons of compost/year	13,500 tons of raw materials/year +4.8 tons of compost/year
k4	Recovery of energy	0	0	Gross 1,084,000 GJ For sale: 638,000 GJ
k5	The impact of the system on the environment	21	21	11

Table 2. The social criteria for the identified waste management scenarios in Szczecin.

	Criterion	Scenario S1	Scenario S2	Scenario S3
k6	The compliance with the directions indicated by the NWMP and VPMP and EU Directives and Polish law [0/1]	0	0	1
k7	Regionality and forward-looking solutions [0/1]	0	0	1
k8	Social acceptance [%]	15	78	80

Table 3. The economic criteria for the identified waste management scenarios in Szczecin.

	Criterion	Scenario S1	Scenario S2	Scenario S3
k9	The full average monthly financial burden per one inhabitant [PLN/residents]	14.95	20.3	17.32
k10	The cost of disposing one ton of waste [PLN/ton]	369	500	427
k11	Profits from the sale of compost and raw materials [PLN/year]	3,221,765	6,126,571	3,221,765

In the social criteria group the following were distinguished:

Criterion 6 – compliance with the directions indicated by the National Waste Management Plan 2010 and the Voivodeship Waste Management Plan and with the provisions of Polish law and EU directives - in this study this criterion was assessed by an expert method on a scale of 0/1.

Criterion 7 – regionality and forward-looking solutions – also rated by an expert method on a scale of 0/1.

Criterion 8 – social acceptance – the value of this criterion was based on the results of social research for the acceptance of individual scenarios.

In the economic criteria group the following were distinguished:

Criterion 9 – a full monthly average financial burden per one inhabitant - calculated as the fee that will be paid by every resident of Szczecin in the case of implementation of various waste management scenarios.

Criterion 10 – a fee for the disposal of 1 ton of waste, including penalties for failure to meet the standards – calculated as the fee for one ton of waste disposed of in the various scenarios of the system, together with penalties accrued for EU Member States that have not met the standards for the reduction of biodegradable waste.

Criterion 11 – profits from the sale of raw materials and compost – calculated as the profit of the individual scenarios for the waste management system in Szczecin, e.g. from the sale of recyclable materials, compost, etc. The values of the various criteria are presented in Tables 1, 2, and 3.

Disscussion of Result

Multi-Criteria Analysis and the Selection of the Best Strategy

The assessment of the individual waste management strategies, comparing and selecting the best of them is possible due to determining numerical indicators measuring the work of the whole system.

They show the consequences of the activity of various options and the degree of fulfillment of its objectives, formulated in a general way [7, 11, 17, 23]. This task is performed by the evaluation criteria of the performance of variants of a comprehensive system of waste management. It can be said that the decision problem is formulated at a time when numerical values of each criterion are determined by expressing them in the form of a finite set of numbers, which are the result of evaluation of particular waste management scenarios in the region in relation to the selected criteria. These figures, recorded in the so-called decision matrix, constitute the formal record of a discrete multi-criteria decision problem, in this article are stored in Tables 1, 2, and 3. Matrix elements are expressed in many different units. Due to the fact of facilitating the calculations and analysis results, a standardization and unification scale for all criteria is used. To solve the decision task, the method of compromise programming was applied, using the concept of organizing various strategies according to their distance from an ideal fixed point X' (x_1', x_2',...,x_M'), of which all the coordinates x_M' are equal to the maximum value of the adopted standardization scale. The criterion aggregating the measure of the distance of a tested strategy from the ideal point is:

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

However, the choice of the best strategy takes place according to the rule:

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

...where:

$L_\alpha(s_n)$ – measure of the distance of the tested strategy sn from the ideal point

$\bar{s}$ – the chosen strategy

w_m – weight ratio of the criterion m

x_m' – mth coordinate of the utopian point

r'_{NM} – normalized value of the criterion

M – number of criteria

α – an exponent measuring the deviation of a strategy from the ideal point x', assumed in practice as 1, 2, and ∞.

The method, in addition to the calculated, rational values of the criteria, also gives the possibility of weighing them. The adoption of a hierarchy of importance of various criteria allows the participants to identify priorities for the decision-making process. The authors adopted the values of the criteria weights for the calculation. For example, in the first case each criterion was assigned weight 1. In the second case, the group of environmental criteria received weight 5, while the other criteria weight 1, whereas in the last row the environmental criteria and social criteria were given weight 5, and the economic criteria weight 1. The results of the analysis, as an ordered sequence of individual scenarios, are presented in Table 4.

Table 4. The results of multi-criteria analysis for the identified waste management system scenarios for the city of Szczecin [own elaboration].

Order of precedence of environmental: social:economic criteria	Strategy ranking		
	α = 1	α = 2	α = infinity
1:1:1	s3*→s2→s1	s3*→s2→s1	s3*→s2→s1
5:1:1	s3*→s2→s1	s3*→s2→s1	s3*→s1↔s2
10:1:1	s3*→s2→s1	s3*→s2→s1	s3*→s1↔s2
1:5:1	s3*→s2→s1	s3*→s2→s1	s3*→s1↔s2
1:10:1	s3*→s2→s1	s3*→s2→s1	s3*→s1↔s2
1:15:1	s3*→s2→s1	s3*→s2→s1	s3*→s1↔s2
1:1:2	s3*→s2→s1	s3*→s1→s2	s3*→s1↔s2
1:1:5	s3*→s1→s2	s1*→s3*→s2	Lack of solution
1:1:8	s3*→s1*→s 2	s1*→s3→s2	Lack of solution
1:1:9	s1*→s3*→s 2	s1*→s3→s2	Lack of solution
5:1:5	s3*→s2→s1	s3*→s2→s1	Lack of solution
1:5:5	s3*→s2→s1	s3*→s2→s1	Lack of solution
5:5:1	s3*→s2→s1	s3*→s2→s1	s3*→s1↔s2

Sn* – acceptable scenario

This method gives the possibility of additional weighting of criteria by using in the formula an exponent α. This exponent allows for additional weighting of each deviation from the ideal point in proportion to their size. The greater the value of α, the more significant the big deviations of the scenario from the ideal point. Individual cases of calculation taking into account different values of the α coefficient are presented in three different columns in Table 4.

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

- In 39 calculation cases the most often selected scenario is S3 (thermal treatment of waste as part of a comprehensive waste management system in Szczecin) – 30 times; it should be noted that in 5 cases the task with the assumptions in the mathematical model did not have a solution.
- In the remaining four calculation cases, scenario S1 is chosen assumming the continuation of the existing waste management system. It is chosen in cases where we accept the economic criterion as the most important. However, it should be remembered that this scenario was taken into account in the calculations only for reasons of comparison (as reference), as from 2012 it will not be able to be implemented for legal reasons.

- Scenario S2 (assuming segregation and utility waste) has not been selected as the most favorable even in one computational case.
- The decision maker can adopt some restrictions in the choice of a scenario. In these calculations these limitations were assumed as the so-called acceptability threshold, calculated as:

$$S_n^{*)} = 0.1 * L_\alpha(s_n)_{\min} \quad (3)$$

...where:

Sn* – is the acceptable scenario

Acceptable scenarios are marked in a table with an asterisk (*) and constitute a solution of the decision-making task as a choice of a scenario lying acceptably close to the ideal point.

Conclusions

- The evaluation of such a complex object, which is the system of waste management, should be carried out taking into account environmental, social, and economic aspects. Such an evaluation is a measurable effect of the operation of a comprehensive waste management system in light of the principles of sustainable development.
- It is possible to carry out on this basis the multi-criteria analysis to thoroughly assess the impact of the operation of the system and to carry out the choice of the most suitable solution for the waste management system in the region.
- The proposed methodology has been fully tested, and detailed calculations were performed on the example of Szczecin, and earlier in Kraków. The results of calculations fully confirm the thesis that the proposed methodology is correct and the results obtained are a sufficient basis for carrying out a comprehensive, multi-criteria evaluation of the waste management system in the region.
- Detailed calculations and analyses of the results carried out for variants of the waste management system adopted for Szczecin raise the conclusion that in the various conditions of the region, the most preferred embodiment of the waste management system is the option of the largest range of waste processing in terms of both quantity and quality. The option restricting the system only to the waste landfill functioning at minimal recovery of recyclable materials in multi-criteria analysis usually is regarded as the least beneficial for the region.
- The analysis carried out has been used in the actual choice of the shape of the waste management system in Szczecin and the currently selected system is implemented.

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