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MULTICRITERIA EVALUATION OF MUNICIPAL SOLID WASTE MANAGEMENT SCENARIOS: CASE STUDY IASI, ROMANIA

***Cristina GHINEA[1,2], Hans Th. A. BRESSERS[3], Maria GAVRILESCU[1,4]**

[1] *"Gheorghe Asachi" Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, Department of Environmental Engineering and Management, 73 Prof. dr. doc. Dimitrie Mangeron Street, 700050 Iasi, Romania; cbghinea@yahoo.com*
[2] *Stefan cel Mare University of Suceava, Faculty of Food Engineering, 13 Universitatii Street, 720229 Suceava, Romania, cbghinea@yahoo.com*
[3] *University of Twente, Faculty of Management and Governance, Twente Centre for Studies in Technology and Sustainable Development, P.O. Box 217, 7500 AE Enschede, The Netherlands*
[4] *Academy of Romanian Scientists, 54 Splaiul Independentei, RO-050094 Bucharest, Romania*
*Corresponding author
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Abstract: *Solid waste management is of great interest as a topical issue discussed and reviewed internationally. Interdisciplinary studies have been conducted worldwide to assess sustainable solid waste management. The main objectives of a sustainable waste management should be: preservation of natural resources and energy, minimizing pollution and environmental impacts, establishing a high quality performance of the environment. Due to its complexity and the uniqueness, each waste management system is designed to satisfy particular objectives, such as waste policies and specific environmental targets (restricted to site specific constraints such as: waste composition, generation rates, geographical origin, installed treatment capacity, waste management technologies, stakeholders preferences). Sustainable management of waste can be accomplished using different types of models, which are in fact decision support models such as multicriteria evaluation models. The multicriteria evaluation can rank different waste management systems considering various evaluation criteria in order to choose the most suitable system. In this purpose we have proposed different scenarios as alternatives to the municipal solid waste management system existent in Iasi in 2009. Multicriteria decision making approach was emphasized and applied for the evaluation of waste management scenarios, since it enables a complex, integrated and logical framework. This way we are able to identify and characterize the interactions and interdependence among factors, structured hierarchically or like a network to deal with dependence and feedback.*

Keywords: *AHP, models, solid waste, sustainability*

1. Introduction

Waste management is a major problem for all communities in the world and in particular for the EU countries, since different actors involved (policymakers, industry, and municipalities) are facing a lack of methodology and software for defining, evaluating, optimizing or adapting their waste treatment decision and for meeting the progress targets set at the EU level [1].

One of the most relevant objectives is to reduce the amount of waste generated. However, these efforts are still very limited, especially in some South-Eastern European countries, like Romania, with a mix of results and relatively few efforts that have been made to regulate the management of various categories of waste (for example, organic materials that usually comprise over 50% of the total waste generation in the cities) [1]. Although Romania is an EU Member State, and the European policy in the area of solid waste management should be implemented as soon as possible, these changes are still difficult to be made [1].

The solid waste management (SWM) is a complex multidisciplinary issue since a waste management system must cover all activities: collection, transport, and waste treatment processes [1-5].

Municipal and industrial wastes should be managed according to the solid waste management hierarchy for a healthy environment (Fig. 1) [1, 2]. Waste hierarchy does not attempt to assess environmental impacts for a waste management system and does not take into account any local conditions which may significantly change the environmental consequences [6].

Economic, environmental, technical, social and legal issues must be considered in planning, selection, design and implementation of solid waste management systems [1, 7, 8]. Over the years different methods have been developed to assist the decision factors in the selection of the appropriate municipal solid waste management (MSWM) systems in such a way to ensure sustainable development and solve *environmental problems* associated to waste generation [1, 7, 9, 10].

One of the very fast growing areas is considered multicriteria decision analysis (MCDA) developed for supporting decision makers to make suitable choice in different situations [1], [11-12]. It is considered that MCDA methods can help in selecting the best compromise alternatives [11]. This method has an important applicability in the waste management area and can be considered a valuable tool for decision makers [1], [13-15].

There are several methods available to solve multicriteria decision making problems: Analytic Network Process (AHP) developed by Saaty [16], Preference Ranking Organisation MeTHod for Enrichment Evaluations (PROMETHEE) developed by Brans [17], ELECTRE (Elimination Et Choix Traduisant la REalité/The Elimination and Choice Translating Reality) developed by Bernard Roy [18], Technique for Preference by Similarity to the Ideal Solution (TOPSIS), Multicriteria Decision Aiding Hybrid Algorithm (THOR) developed by Gomes [19] etc. These methods were used in several disciplines as well as in environmental engineering.

In this paper we have applied a multicriteria evaluation method (AHP), considering three criteria (environmental, economic and technical criteria) to evaluate the municipal solid waste management system existent in Iasi, Romania (in 2009) and alternatives that we have proposed.

2. Experimental

Waste management in Iasi, Romania

The waste composition consists in **organic waste** (**biowaste: Food waste** and **Garden waste,** generated in gardens and streets from plants and grass) which represents the fraction with the major percentage (approximately 50%) followed by **paper and cardboard, plastic, glass, metals** (Table 1)[20].

Until 2009 the mixed waste collected in Iasi was landfilled at the nonconform Tomesti landfill which was closed in 2009. Landfill from Tomesti continues to be an important source of pollution for soil and groundwater, because the leachate collection is improper.

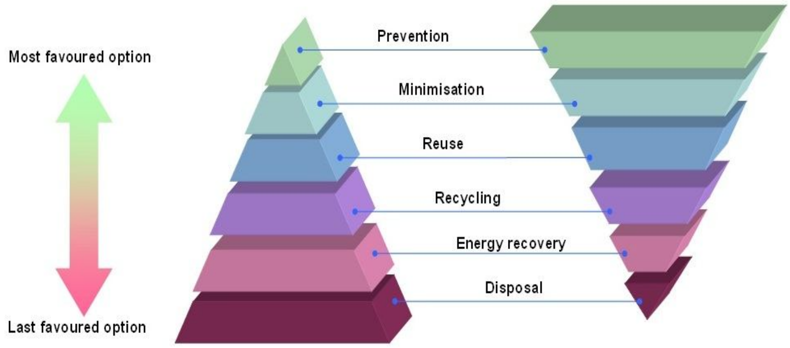


Figure 1. Classic and reversed management hierarchy with the most and the least favourable option [1].

Table 1

Waste composition in Iasi in 2008 under the Long Term Investment Plan [20]

Waste fraction (%)	Urban	Rural
Paper and cardboard	7.68	6
Glass	4.35	3.5
Metals	1.78	2.5
Plastic	6.17	5.5
Textiles	3.16	2.5
Biodegradable waste	47.15	64
Wood	1	0.5
Others	28.71	15.5

Leachate may migrate into soil and groundwater and can generate risks for the environment and human health [21]. From 2009 a new landfill was built according with the legislation and put into operation namely Tutora landfill. In Tutora landfill the collection and treatment of leachate is carried out according to the law.

Also the collection of landfill gas is going to be set up. In 2009 a sorting station at Tutora was put into operation with a capacity of 29,000 t/y and a composting station was at that time under construction [1, 20, 21, 22]. In March 2012 was started composting process also at this point return manually by operators windrows with pyramidal shape, a length of 30 m, height 2 m and width 3 m, wetting is made by the operator (waste of the windrow are 100% vegetable) in October 2012 was made windrows with green waste and household waste (25-30%) [1].

In the municipal waste stream the organic waste consists mainly of organic household waste and garden waste [23]. Both biowaste from households and garden waste are suitable for composting. Another biological process used for treatment of organic waste is anaerobic digestion in which the organic wastes are decomposed by microorganisms in anaerobic conditions. The main products of the anaerobic digestion are: biogas which can be used to produce electricity and compost.

3. Results and discussion

Application of Analytic Network Process for evaluation of waste management scenarios

In the AHP method the most important components of a problem are arranged into a hierarchical structure similar to a family tree [13]. AHP is based on the utility function that aggregates different criteria into one global criterion [8]. The AHP method was applied for: the evaluation and choice of the best solid waste management alternative (system) [13, 15], evaluation of the implementation of WEEE management systems [24], for assessing the collection of municipal solid wastes and comparing different cases [14], assessment of scenarios on thermal processing of infectious hospital wastes [25], for landfill site selection [26], for supplier evaluation and selection in a steel manufacturing company [27] etc.

Analytic Hierarchy Process is a support for decision making with regard to complex sustainability issues and can help to recognize and define a problem in detail. It can be used to compare the impacts of alternative policies generated by other tools like: physical assessment tools, modelling tools and environmental appraisal tools [28, 29]. Analytic Hierarchy Process (AHP) was developed and introduced by Saaty (1980) and is one of the widely methods used in Multi-Criteria Decision Making (MCDM) problems [29, 30].

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making method, which helps the decision-maker to solve problems based on the evaluation of a set of criteria [24, 31, 32]. The AHP methodology compares criteria or alternatives with respect to a criterion, in a natural, pairwise mode allowing structuring, measuring and/or synthesis [33].

AHP is based on: decomposition, comparative judgement and hierarchic composition or synthesis of priorities [33, 34]. It is a method that decomposes a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives [35] (Fig. 2).

Basically, the AHP method consists of four main steps [30]:

- structuring the hierarchy of criteria and alternatives for evaluation;
- establishing a pair-wise comparison to assess the decision makers evaluation;
- prioritising of criteria and alternatives using eigenvector method;
- synthesizing the priorities of alternatives according to the criteria to rate the alternatives for performance score calculation.

3.1. Goal of the study

The aim of this study is to analyze and evaluate different scenarios of municipal solid waste management and alternatives that could be implemented by considering economic, environmental and technical criteria in an integrated manner. In this purpose **we have applied** the *Analytic Hierarchy Process (AHP)* methodology which include different types of methods (*rating and raking methods, Pairwise Comparisons*) **to evaluate** the four proposed MSWM scenarios

3.2. Establishing of criteria and sub-criteria indicators

For the evaluation of the waste management system, the three criteria selected include different indicators [1] (Fig. 3):

- economical criteria (C1): economical indicators (costs (C.1.1), benefits (C1.2), market prospect of products (C1.3), land requirement (C1.4)),
- environmental criteria (C2): environmental indicators (acidification (C2.1), eutrophication (C2.2), climate change (C2.3), human toxicity (C2.4), photochemical ozone formation (C2.5), wastewater (C2.6), water consumption (C2.7), noise pollution (C2.8)),
- technical criteria (C3): technical indicators (existing experience reliability (C3.1), adaptability to local conditions

(C3.2), energy consumption (C3.3), energy production (C3.4)).

The investment costs, operating and maintenance costs, administrative and other costs of municipal solid waste management scenarios were calculated and are expressed in euro per tone of waste treated (€/t). Investments costs are for: sorting 122 €/t, composting 159 €/t, anaerobic digestion 370 €/t and the operating and maintenance costs: sorting 30.72 €/t, composting 30.3 €/t, anaerobic digestion 70.1 €/t [1]. The benefits were calculated considering considering three types of benefits: economic benefits, environmental and social benefits [1]. The environmental criteria such as acidification potential (expressed in kg SO_2 eq.), eutrophication potential (expressed in kg PO_4^{3-} eq.), global warming potential (expressed in kg CO_2 eq.), human toxicity potential (kg DCB eq., Dichlorbenzol), and photochemical ozone creation potential (expressed in kg ethene eq.) were calculated using *Life Cycle Assessment* methodology [1]. The indicators indicator *existing experience – reliability* and *adaptability to local conditions* were estimated using a qualitative scale from 0-100, where 100 is the score where a facility is fully accepted, while 0 is the lowest social acceptance degree for a certain facility in the case of first indicator and for the second indicator 100 is the score when a facility is fully adaptable, while 0 denotes the lowest adaptability to local conditions.

3.3. Setting of alternatives: Municipal Solid Waste Management Scenarios for Iasi

The first scenario *includes mixed waste collection, landfilling with collection of biogas and treatment of leachate* new landfill was established in 2009, according to landfill Directive provisions [36]. Scenarios 2-4 are alternatives to the waste management system including various methods for treatment/elimination of waste (Fig. 3):

- **scenario 2:** composting of biodegradable waste and landfilling;
- **scenario 3:** sorting of recyclable waste, composting of biodegradable waste and landfilling;
- **scenario 4:** sorting of recyclable waste, composting and anaerobic digestion of biodegradable waste, and landfilling.

3.4. Application of rating and raking methods and Pairwise Comparisons for evaluation of scenarios –Results

Rating and raking methods and Pairwise Comparisons were applied for evaluation of municipal solid waste management scenarios. The steps that we performed applying **ranking method** are:

- setting of the decision elements (indicators) list;
- each expert involved in the evaluation was asked to put the list of decision elements in order of importance using Saaty scale (Table 2);
- calculation of ranking votes sum for every economic, environmental and technical criteria for each scenario evaluated according to Table 3;
- the relative weight of each criterion calculated according with Table 4.

Also was performed the following phases of the **rating method**:

-to each decision element was given a rating or a percentage score between 0 and 100;
- the sum of rating votes for every economic, environmental and technical criteria for each scenario evaluated were calculated according to Table 3;
- also the relative weights of each criterion were calculated according with Table 4.

Results obtained from both calculation methods were combined (according with Table 5) in order to obtain the *combined weight*. Combined weights for each criterion were calculated by averaging the relative weights determined for both the ranking and rating techniques.

The next step is represented by scoring. A score is given for each criteria or indicator, which reflects the performance. Combined weights were multiplied by the score in order to establish the final score for each indicator. Final score of the analysis is calculated by taking the sum of the final scores obtained for each criteria and dividing it by 100.

The score obtained for each scenario were:

- S1 - 2.02
- S2 - 2.99
- S3 - 3.53
- S4 - 3.17

A score of three or better is acceptable: at or above the norm for good operations in the region (Table 6).

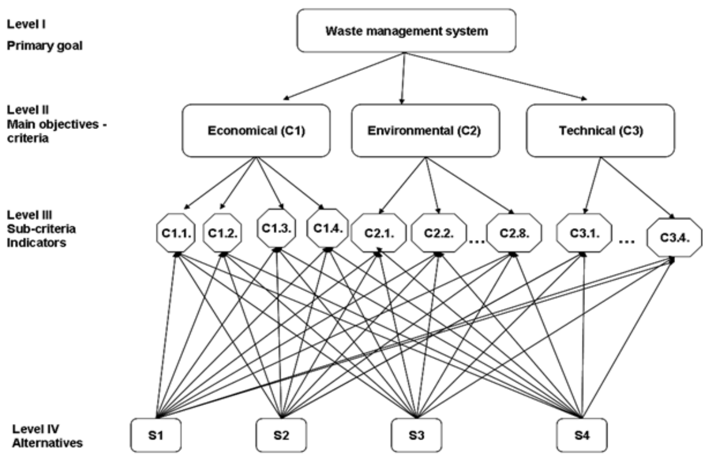
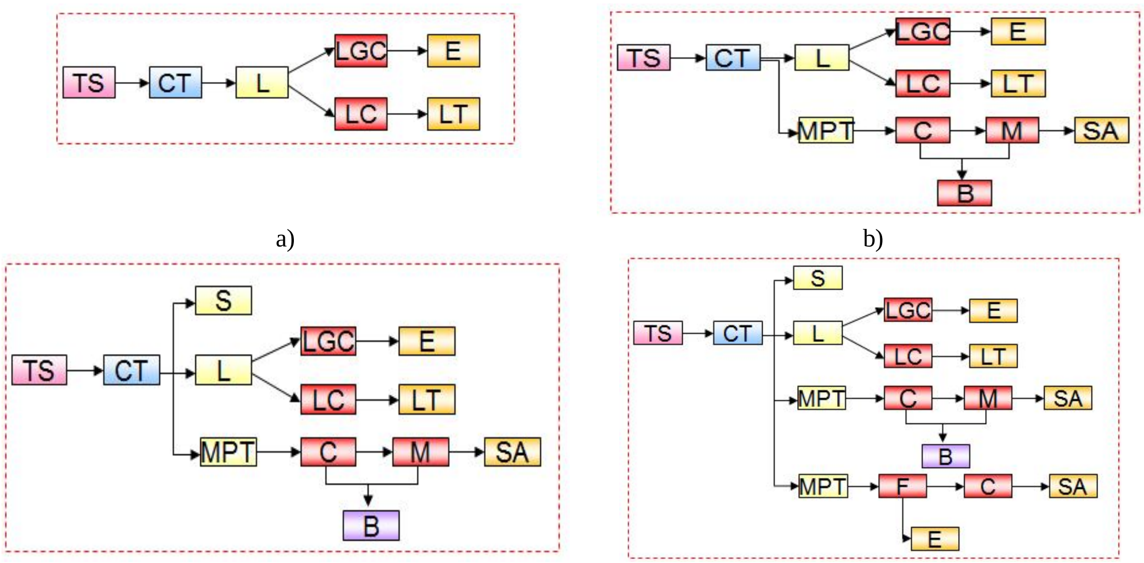


Figure 2. Proposed hierarchy for municipal solid waste management system [1]



a) b) c) d)

Figure 3. Scenarios proposed for the analysis of MSW management in Iasi, Romania: a) scenario 1, b) scenario 2, c) scenario 3, d) scenario 4, TS – temporary storage; CT - collection and transport; L - landfilling; LGC - landfill gas collection; LC - leachate collection; E - engine; LT -leachate treatment; MT - mechanical treatment; C - composting; M - maturing; SA - soil application; B - bio-filter; S – sorting; F – fermentation.

Table 2

Scale of relative importances [16, 29, 37]

Intensity of importance	Definition/Judgment	Explanation/Significance
1	Equal importance	Two actions contribute equally to the objective
3	Weak importance of one over other	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgment	When compromise is need

Table 3

Calculation of the sum of experts votes [1]

Criteria	Rank	Rating
C1	n_1	$\mathbf{m_1}$
C2	n_2	$\mathbf{m_2}$
	.	.
	.	.
	.	.
	n_k	$\mathbf{m_k}$
	$\sum n_i$ **, i=1,…, k**	$\sum m_i$ **, i=1,…,k**

Table 4
Calculation of relative weights [1]

Criteria	Relative weight	Relative weight
C1	$n_1 / \sum n_i * 100 = a_1$	$m_1 / \sum m_i * 100 = b_1$
C2	$n_2 / \sum n_i * 100 = a_2$	$m_2 / \sum m_i * 100 = b_2$
	.	.
	.	.
	.	.
	$n_k / \sum n_i * 100 = a_k$	$m_p / \sum m_i * 100 = b_k$
	$\sum a_i = 100$ **, i=1,…,k**	$\sum b_i = 100$ **, i=1,…,k**

Table 5
Calculation of combined weight [1]

Criteria	Combined weight
C1	$(a_1 + b_1)/2 = r_1$
C2	$(a_2 + b_2)/2 = r_2$
	.
	.
	.
	$(a_k + b_k)/2 = r_k$
	$\sum r_i = 100$ **, i=1,…,k**

Table 6

The score scale [1]

Score	*Description*
0	not an applicable criteria or indicator
1	extremely weak performance; strongly unfavourable
2	poor performance; unfavourable; may be the norm for the region, but major improvement needed
3	acceptable; at or above the norm for good operations in the region
4	very favourable performance; well above the norm for the region, but still needing improvement to be state of the art
5	'State of the art' in region; clearly outstanding performance which is way above the norm for the region

Scenarios S4, S3, had a good score while S1 and S2 performing a little below what is considered good operational regional standard (poor performance).

The pairwise comparison method involves one-on-one comparisons between each of the indicator [39].

Pairwise Comparisons was performed following these steps:

- comparative judgements on the relative importance of each pair of indicators in terms of the measured criterion were made;
- comparative matrixes of the criteria for each scenario were determined;
- relative weights of the indicators in each matrix were determined in three steps according to Pairwise Comparisons methodology;
- the vector of priorities (VP) for each matrix was obtained after determining the matrices by multiplying the *n* elements in each row and taking the n-th root resulting in a column vector which was normalized;
- The consistency of the results can be determined by the calculation of the eigenvalue $\lambda_{\max}$, when each matrix is multiplied by its vector of priorities VP [38];
- The final $\lambda_{\max}$ was determined by summing the components in the resulting vector and dividing the results by *n*.

In this case final eigenvalue is almost equivalent to the *n* number of alternatives $n = 4$. This indicates that the results have a very high consistency since the closer the $\lambda_{\max}$ is to *n*, the more consistent are the results of the pairwise comparison for the criteria.

- final criteria for each scenario using the Pairwise comparison were determined by multiplying the calculated weights with the score given to each indicator.

The final score obtained for each scenario was:

- S1 - 1.93
-S2- 2.61
- S3 - 3
- S4 - 3.23
- Consistency index (CI) was also calculated for each matrix: the CI values were below the tolerance consistency index of 0.10 which means tolerable limits of inconsistency ($CI_{S1} = 0.045$; $CI_{S2} = 0.0045$; $CI_{S_3} = 0.001$).

Scenario S4 is the most suitable alternative to the municipal solid waste management system, followed by scenarios S2, S3. In rank order of the alternatives, the weight of criteria has a big influence. In order to be able to make the final decision the decision makers must know the degree of reliability of the results [39].

4. Conclusions

The evaluation was performed by applying the rating, ranking and the Pairwise Comparisons methods using the software media offered by Excel and Matlab. Results highlighted that scenario 4 is the most suitable alternative to the municipal solid waste management system in terms

of environmental, economic and technical aspects followed by scenarios 2 and 3.
Future studies will be performed since other alternatives can be also proposed and evaluated and can be chosen other criteria such social criteria in order to be much closer to the real situation.

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