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SELECTION OF THE OPTIMAL SYSTEM FOR MUNICIPAL SOLID WASTE MANAGEMENT BY INTEGRATED APPLICATION OF LCA AND MCDM METHODS

Abstract: *Defining the optimal and sustainable system for municipal solid waste management at the local level is a very complex task that involves encountering challenges and overcoming a number of contradictories. The greatest efforts are directed towards designing a cost-effective system that will minimize negative impact on the environment and enhance energy efficiency. This paper presents a procedure for selection of the optimal local system for municipal solid waste management though integrated application of LCA and MCDM methods for the city of Kragujevac (the Republic of Serbia). Six different strategies for municipal solid waste management have been made and modelled using the software packet IWM2. For each strategy, a comparative analysis of the values for eight different parameters has been made. Based on the relevant indicators for each of the strategies and applying the Simple Additive Weighting (SAW) Method and multicriteria decision-making, the optimal management system has been chosen. In order to further verify the choice, an additional analysis of the sensibility of the results to the change of the criteria coefficients has been made. The applied procedure can be successfully used for defining the optimal system for municipal solid waste management for various municipalities.*

Keywords: *Municipal Solid Waste, Waste Management System, LCA Method, MCDM Method*

1. INTRODUCTION

One of the biggest challenges of modern society *is* disposal of solid waste. Inadequate waste management is a huge environmental problem of the modern world. On the other hand, enormous amount of waste remains unused, which is a huge economic and energy loss.

Modelling and estimate of ecological, energy and economic (EEE) performance of the municipal solid waste management system is a research area of interest for many scientific workers and engineers.

The first generation of engineering model systems for solid waste management based on linear programming appeared in the late 1960s [1]. These models utilized the cost-effectiveness principle [2]. In the years following 1980, authors of numerous studies started to take into account both direct and indirect economic and ecological benefits while analysing solid waste management processes. During 1990s, optimization analysis developed. It involved both short and long term waste management decisions, including various social economic and ecological objectives and limitations, like minimal sustainability standards. The studies carried out in this period comprise the second generation of optimization analysis of municipal waste management [3].

Development of the Life Cycle Assessment (LCA) method had a great impact on selection and use of suitable waste management techniques. A lot of studies used the LCA method as a comparison tool for different options in waste management [4]. Integrated solid waste management involves waste disposal in an ecologically, technically and economically sustainable way [5].

Multicriteria Decision Making Method (MCDM) has been increasingly used in the field of environmental engineering and environmental protection in the municipal waste management sector [6]. Decision support tools are most commonly used for municipal waste management [7]. Integrated use of multicriteria decision making methods and the LCA method has been analysed in various scientific papers [8,9]. The life cycle assessment method (LCA) can be described as a decision-making tool [10] or as a multicriteria decision making method [11]. The SAW method (Simple Additive Weighting) is one of the simplest multicriteria evaluation methods used in assessment of the total impact of the life cycle on the environment [12].

The primary benefit of using multicriteria analysis lies in adding weighting factors to certain parameters obtained by the LCA analysis. Once the parameters have been classified and the results characterized and normalized, the overall impact of the life cycle can be summed. The possibility to add variable weighting impact factors represents the main advantage gained by synthesis of these two methods. In general, the multicriteria and LCA methods can be directed towards adding weighting factors to impact categories in LCIA (Life Cycle Impact Assessment) or towards direct application to the LCIA results.

The primary objective of this paper is to choose an optimal waste management system for the city of Kragujevac through an integrated application of the LCA and MCDM methods. Based on the input data on the quantity of generated waste and its composition, the values of eight chosen parameters will be defined and then the optimal strategy for waste management will be chosen using the MCDM method. The analysis of the sensitivity of the obtained results will be performed by varying weighting coefficients of the chosen parameters.

The software package IWM2 [5], used in this paper, belongs to programming tools suitable for the LCA method.

2. INPUT DATA – AMOUNT AND COMPOSITION OF MUNICIPAL SOLID WASTE

Quantity and composition of the municipal waste are the main input data for the analysis of the proposed options for future solid waste management system in the area of the city of Kragujevac. Experimental results on the quantity and composition of the generated municipal waste in Kragujevac were obtained as part of cooperation between the Faculty of Engineering in Kragujevac and the Faculty of Technical Sciences in Novi Sad [13].

The landfill in Kragujevac is equipped to weigh the collected municipal waste on a daily basis. The weighbridge is connected to the computer that has special software to register the weighed waste mass. The diagram in Figure 1 shows quantities of the collected municipal waste at the Landfill in Jovanovac (the city landfill) per months for the period January 2009 – December 2013.

The diagram in Figure 1 shows five distinct local minimums of the disposed municipal waste, which, as a rule, occur in wintertime. This particularly refers to the two coldest months in the year – January and February. In contrast, local maximums of the collected waste are registered in spring and autumn.

Morphological composition of the municipal waste was also analysed for the five-year period (2009-2013), and the results are shown in Figure 2. Waste samples of approximately 500 kg were analysed. They were taken from different parts of the municipality, classified into the following zones:

- the city zone – individual residential area,
- the city zone – collective residential area and commercial zone
- the village zone.

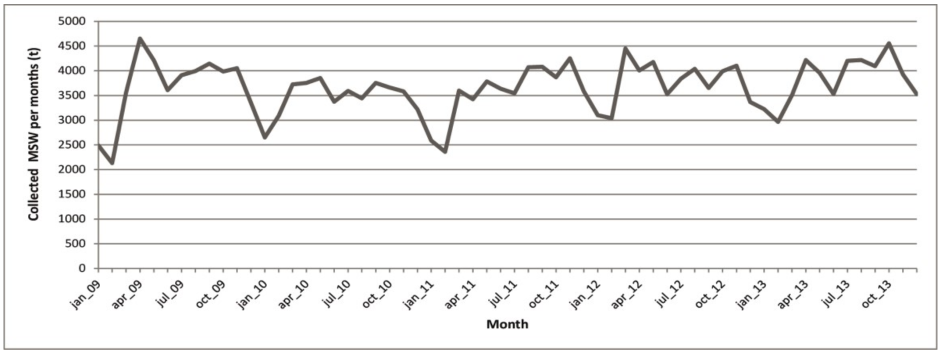

Figure 1. *Collected municipal waste per months for the city of Kragujevac, in tons*

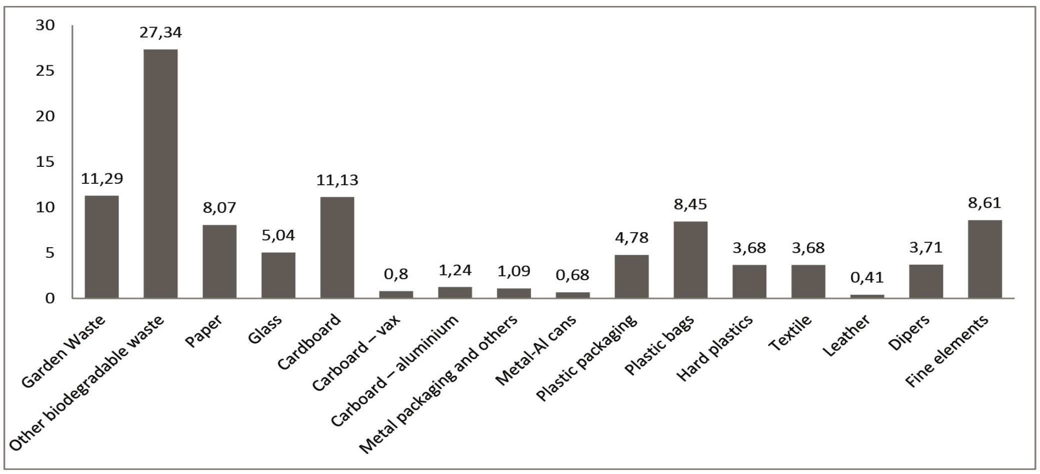

Figure 2. *Morphological composition of the generated municipal waste for the city of Kragujevac, in percentages*

Based on the Figure 2, it can be concluded that organic waste accounts for the greatest part of the municipal waste collected in the territory of the city of Kragujevac. Composition of the collected waste should directly impact the ranking of the suggested strategies.

3. RESULTS AND DISCUSSION

As part of this paper, six strategies of solid municipal waste management in the territory of the city of Kragujevac were created. They were all modelled using the software package IWM2.

Table 1 - Waste treatment methods and waste quantities

Strategy	*Waste treatment*								*Landfill gas collection system*
	Recycling		*Biological treatment*		*Incineration*		*Disposal*		
	(%)	(t)	(%)	(t)	(%)	(t)	(%)	(t)	
1KG	0	0	0	0	0	0	100	56.158	Absent
2KG	9,9	5.544	0	0	0	0	90,1	50.614	Present
3KG	21,66	12.162	0	0	0	0	78,34	43.996	Present
4KG	29,23	16.413	16,35	9.180	7,57	4.251	63,2	35.494	Present
5KG	29,28	16.441	16,35	9.180	31,79	17.850	38,94	21.867	Present
6KG	27,39	15.381	15,39	8.640	55,61	31.228	17,00	9.550	Present

Table 1 shows waste treatment methods and waste quantities for all the six strategies. In Table 1, the sum of all the percentage amounts for certain waste treatment types exceeds 100% for the strategies 4KG, 5KG and 6KG due to the fact that the waste residues that have already been treated are sometimes redirected to other treatment options, usually incineration or disposal. This way certain amounts of waste are registered twice during the treatment process.

For each of the chosen strategies, comparative analysis of the values of following eight parameters was performed:

- CH_4 emission,
- CO_2 emission,
- GWP factor,
- N_2O emission,
- Small particle emissions,
- -Fuel consumption for the system operation,
- Overall costs for the system operation,
- Volume of the remaining disposed solid waste.

It should be pointed out that the 1KG strategy almost entirely corresponds to the existing system of the municipal waste management in the territory of the city of Kragujevac. Hence, the proposed measures might have positive or negative impact on the existing waste management system.

The proposed multicriteria decision making SAW method was used to rank the six proposed strategies. It was not easy to choose the best waste management strategy and do the ranking based on the values of eight parameters. Therefore, the SAW method was applied as a multicriteria decision making method. First, the basic matrix table (Table 2) was defined. The proposed strategies represent the alternatives, (A_i, i=1,…,6), while the analysed parameters (C_j, j=1,…,8) comprise the criteria.

Table 2 - Tabular representation of the matrix for 6 strategies and 8 criteria

		Criteria							
		C_1 (CH_4)	C_2 (CO_2)	C_3 (GWP)	C_4 (N_2O)	C_5 (PM)	C_6 (FC)	C_7 (TOC)	C_8 (VW)
Alternatives (strategies)	A_1(1KG)	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}
	A_2(2KG)	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}	X_{28}
	A_3(3KG)	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	X_{36}	X_{37}	X_{38}
	A_4(4KG)	X_{41}	X_{42}	X_{43}	X_{44}	X_{45}	X_{46}	X_{47}	X_{48}
	A_5(5KG)	X_{51}	X_{52}	X_{53}	X_{54}	X_{55}	X_{56}	X_{57}	X_{58}
	A_6(6KG)	X_{61}	X_{62}	X_{63}	X_{64}	X_{65}	X_{66}	X_{67}	X_{68}
	max/min	min	min	min	min	min	min	min	min
	W_j	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8

The SAW method [12] is one the best known, relatively simple and most widely used procedures, which gives results similar to the ones obtained using more complex multicriteria decision making methods.

Table 3 gives the values of the parameter X_{ij} for each of the six proposed strategies. Once the maximum and minimum values have been chosen in each column (for each j^{th} criterion), normalized values are calculated (Table 4).

The further procedure of assessment and ranking through application of the SAW method requires determination of weighted normalized values per all the criteria (Eq. 1):

$$W'_j = \frac{W_j}{\sum_{j=1}^{8} W_j}. \quad (1)$$

Thus calculated values are used to rank alternatives by comparing the results obtained using the following expression:

$$A^* = \left\{ A_i \middle| \max_i \sum_{j=1}^{8} W'_j r_{ij} \right\}. \quad (2)$$

At this point, five variations of the weighting criteria coefficients were performed, and consequently five ranking of the proposed strategies were obtained. Values of eight criteria were varied and they are shown in Table 5. Based on the proposed weighting coefficients W_j, using the expression (1), the following normalized weights W'_j for five variants are calculated and also showed in Table 5. The strategies are ranked by comparing the sums of products of the normalized values of the parameters r_{ij} and normalized weighting coefficients W'_j (expression 2). The ranking was performed for each of the five variants of the weights added to certain criteria (Table 6). Taking into account the data presented in Table 6, Figure 3 shows diagrams of sum characteristics of the strategies obtained using the SAW method. It is obvious that the 4KG strategy, in all five variants of weighting coefficients distribution, has the best sum characteristics, therefore this strategy is the optimal solution. On the other hand, the 1KG waste management strategy has the worst sum characteristics in all the cases. It should be pointed out that the ranking of the six strategies remains the same for all the variations.

Table 3 - Parametric values (x_{ij}) for different strategies

	CH_4	CO_2	GWP	N_2O	PM	FC	TOC	VW
1KG	3660886419	9702095390	86580721178	35	0	24479	7549600	62330
2KG	322379185	8195270649	14951191400	-45297	-160	-349143	6708008	53579
3KG	275549875	7204401627	13006978099	51707	-109	-399987	7760535	41147
4KG	195373325	4645014256	8677579260	-226693	-71	-366249	7190784	32058
5KG	89847396	17931207137	19751628200	-214110	581	-488276	6934515	12968
6KG	-8941934	28161489424	27918594552	-177788	1026	-697531	9902157	-2557

Table 4 - Normalized parametric values (r_{ij}) for different strategies (SAW)

	CH_4	CO_2	GWP	N_2O	PM	FC	TOC	VW
1KG	0	0,784956	0	0,185603	0,865093	0	0,736521	0
2KG	0,909718	0,849031	0,919469	0,348434	1	0,517475	1	0,134865
3KG	0,922478	0,891166	0,944426	0	0,956998	0,587895	0,670483	0,326460
4KG	0,944326	1	1	1	0,924958	0,541167	0,848856	0,466534
5KG	0,973081	0,435026	0,857848	0,954802	0,375211	0,710177	0,929087	0,760738
6KG	1	0	0,753014	0,824335	0	1	0	1

Table 5 - Weighting and normalized weighting coefficients (five variations)

		CH_4	CO_2	GWP	N_2O	PM	FC	TOC	VW
I	W_j	80	80	100	80	50	80	100	50
	W_j'	0,12903	0,12903	0,16129	0,12903	0,08064	0,12903	0,16129	0,08065
II	W_j	100	100	100	100	100	100	100	100
	W_j'	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,125
III	W_j	80	50	80	50	50	100	100	100
	W_j'	0,13115	0,08197	0,13115	0,08197	0,08197	0,16393	0,16393	0,16393
IV	W_j	50	50	100	50	50	100	100	50
	W_j'	0,09091	0,09091	0,18182	0,09091	0,09091	0,18182	0,18182	0,09091
V	W_j	100	100	100	100	100	50	50	50
	W_j'	0,15385	0,15385	0,15385	0,15385	0,15385	0,07692	0,07692	0,07692

Table 6 - Sum characteristics of strategies for different values of the weighting coefficients

Strategy	*Weighting coefficients variants*				
	I	*II*	*III*	*IV*	*V*
1KG	0,313793	0,321522	0,271204	0,30079	0,339063
2KG	0,739779	0,709874	0,690889	0,737812	0,746588
3KG	0,67385	0,662488	0,656138	0,682065	0,69346
4KG	0,860161	0,84073	0,799098	0,828715	0,891933
5KG	0,776351	0,749496	0,77824	0,772098	0,737841
6KG	0,566529	0,572169	0,625341	0,575488	0,550361

The sum characteristics of the proposed alternatives (A_i) are not significantly sensitive to the change in normalized weighting coefficients. Table 7 shows the mean (average) values of the sum characteristics of all the proposed strategies in five simulation variants.

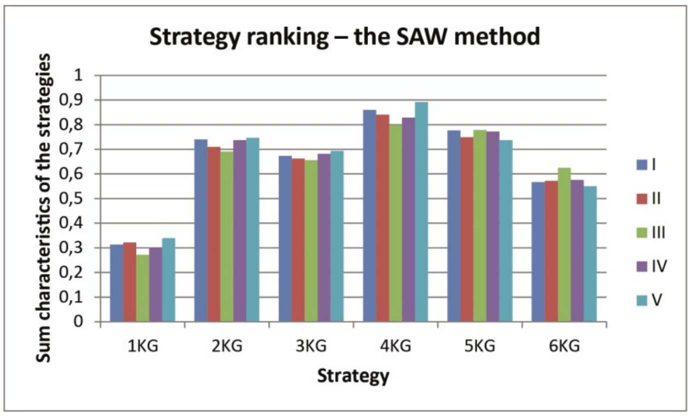

Figure 3. *Strategy ranking for different weighting coefficients variants (SAW method)*

Table 7 - Mean sum characteristics and strategy ranking (SAW method)

	1KG	*2KG*	*3KG*	*4KG*	*5KG*	*6KG*
A_i	0,309274	0,724988	0,6736	0,844127	0,762805	0,577978
Ranking	6	3	4	1	2	5

4. CONCLUSION

Waste management is one of crucial environmental issues largely due to the fact that waste may pose a hazard to the human health.

One of the ways to select the optimal waste management system is through the integrated application of the LCA and MCDM methods.

The first phase of the procedure involves calculation of the values of the chosen parameters – indicators for each of the waste management strategies, i.e. LCA analysis. Six different waste management strategies for the territory of the city of Kragujevac were formulated and eight parameters were selected. The second phase involved the MCDM procedure, when the parameters get the role of criteria, and when the best waste management option is selected using the SAW method.

SAW method indicated the 4KG strategy as the best alternative solution for the alternative waste management system in the city of Kragujevac.

This choice has been additionally proven through analysis of the results sensitivity to the weighting coefficients variation. This strategy is characterized with relatively large amounts of recycled waste (about 30%). One sixth of the waste undergoes biological treatment. A relatively small amount of waste (10%) is incinerated, while the amount of disposed waste is still significant – over 60%. In that sense, it is vital to install a landfill gas collection system.

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