

# Efficiency assessment of solid waste management in municipalities of Slovakia incorporating waste targets information - a DEA AR-I approach

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**Introduction:** Efficient solid waste management is one of the main objectives of municipalities across the world. All developed states prepare their fundamental visions of the environmental policy strategies which emphasize achieving better environmental quality and sustainable circular economies in harmony with both UN and EU strategies. Slovakia constantly assesses its own strategies goals fulfilment, releases new strategies for the future and implements the new EU waste legislation into the Slovak legislation and strategies.

In this paper we present an analysis of the current state of the municipal solid waste management (MSWM) efficiency in Slovakia employing composite indicators and using innovative methodology enabling to incorporate EU and Slovakia's waste targets directly into efficiency assessment model. Furthermore, our objective was also to identify factors that may influence performance of MSWM at the level of municipalities.

**Methodology:** In our study, we conceptualize the MSWM system as a dynamic process that involves the conversion of the total municipal solid waste (MSW) generated by the residents of a municipality into four primary waste streams (see Figure 1). This transformation is a result of waste sorting activities conducted both at the household level and within the municipal infrastructure. Adhering to the waste hierarchy and strategic goals outlined by the European Union (EU) and Slovakia strategic documents [1, 2], we categorize waste treatment processes into desirable (all types of recycling, incineration with energy recovery) and undesirable (landfilling). Subsequently, we postulate that every municipality incurs operational costs associated with running its MSWM system. We posit that the efficiency of MSWM system is determined by the waste sorting rates and influenced by external factors.

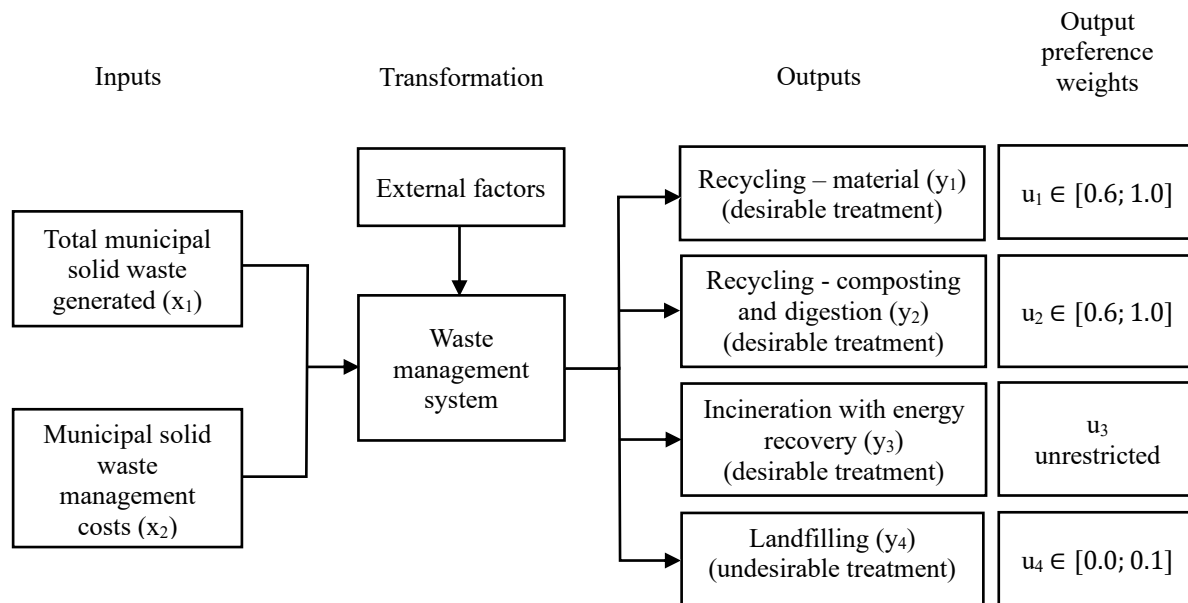
As a primary measure for evaluating the efficiency of MSWM, we utilize the composite indicator of technical efficiency, employing Data Envelopment Analysis (DEA). In our DEA analysis, depicted in Figure 1, we presume two inputs and four outputs. The first input encompasses the total MSW processed within the municipality's waste management system, which yields several outputs representing various waste treatment flows. In our investigation, we focus on the four most significant waste treatments, collectively constituting over 97% of total MSW in Slovakia. The waste transformation incurs associated costs, which we incorporate as a second input. We assume that the total municipal waste generation is a non-controllable variable, meaning municipality managers lack direct control over it. Conversely, we define recycling (material), recycling (composting and digestion), incineration with energy recovery, and landfilling as output variables, all of which are deemed controllable. Municipality management possesses tools to regulate the distribution of municipality solid waste into these respective treatment streams. This controllability of outputs is a rationale for employing an output-oriented DEA model. Character of output variables led to a selection of the DEA model with combination of desirable and undesirable outputs. Since a decrease in undesirable output (landfilling) does not lead to a decrease of desirable outputs (recycling and incineration with energy recovery), we assume strong disposability of the undesirable output. A linear monotone decreasing transformation proposed by Seiford and Zhu (2002) is applied for the undesirable output of landfilling.

To assess MSWM efficiency of municipalities from the prospect of EU/Slovakia waste targets we introduced an innovative approach translating waste hierarchy preference information into the DEA output variable weights. For that purpose, we use the Assurance Region DEA model. It consists of the original multiplier CCR DEA model proposed by Charnes, Cooper, Rhodes (1978) and the constraints for the weight restrictions. Expressed in an absolute form, the weight restrictions based on the waste target rates for specific waste treatment methods are illustrated in Figure 1. Within the DEA model, we implemented weight restrictions in the form of weight relations, known as Assurance Regions Type I, as proposed by Thompson et al. (1990).

In the second stage, nonparametric statistical tests and regression analysis were employed to examine the impact of four external factors on MSWM efficiency. These factors include: (1) the pricing method for residual waste (unit-based pricing vs. flat annual fee vs. combined), (2) the education level of the municipality population, (3) the type of municipality (urban vs. rural), and (4) the region (8 regions).

**Data:** In this study, we analyzed data from 2,887 municipalities out of a total of 2,890 municipalities of Slovakia (excluding the municipalities of 3 military districts). We utilized two primary sources of data. The first source was the "Annual report on municipality waste ŽP 6-01" as of the year 2021, obtained upon request from the Statistical

Office of the Slovak Republic (SOSR). The second source comprises open data of the Slovakia 2021 Population and Housing Census, accessible on the website of the SOSR.



**Figure 1. Model of the municipal solid waste management efficiency assessment**

**Findings and discussion:** First, we present the results obtained in the initial stage of analysis. Table 1 provides descriptive statistics of the technical efficiency scores of the 2,887 municipalities under examination. The mean technical efficiency score is relatively low (0.473), suggesting that municipalities, on average, have over 52% potential for improvement. Within our sample of municipalities, 35 are identified as efficient, all of which have access to the technology of incineration with energy recovery. This underscores the significance of incineration in waste management. A comparison of efficiency scores between municipalities with and without access to incineration technology revealed statistically significant differences in favor of municipalities with access.

**Table 1.** Descriptive statistics of the technical efficiency scores of the municipalities (2021)

Municipalities	Mean	Median	Min	Max	SD	TE=1	TE<1	N
All	0.473	0.466	0.024	1.000	0.176	35	2852	2887
With access to incineration	0.822	0.953	0.301	1.000	0.224	32	72	104
Without access to incineration	0.460	0.461	0.024	1.000	0.160	3	2780	2783

The results from the second stage analysis indicate that the pricing method for residual waste plays a significant role in waste management efficiency. Municipalities employing the unit-based pricing method demonstrate higher efficiency compared to those utilizing flat annual fees or combined pricing (see Table 2), with the differences being statistically significant.

**Table 2.** Descriptive statistics of the technical efficiency scores with respect to the pricing method (2021)

Pricing	Mean	Median	Min	Max	SD
Flat annual fee	0.464	0.457	0.024	1.000	0.176
Unit-based pricing	0.538	0.549	0.108	1.000	0.170
Combined pricing	0.500	0.488	0.132	1.000	0.156

Notably, no statistically significant difference in efficiency was observed between urban and rural municipalities. However, significant differences in efficiency exist among some of the eight regions in Slovakia, suggesting diverse strategies and technologies implemented within their respective territories. The regression analysis revealed a weak ( $r^2=5.5\%$ ) but statistically significant impact of the population's education level, measured by mean years of schooling, on waste management efficiency.

**Conclusions:** This study represents the inaugural analysis of Municipal Solid Waste Management (MSWM) efficiency conducted across the entire population of municipalities in the Slovak Republic. It introduces an innovative methodological approach that employs the DEA AR-I model to assess efficiency measures, with output weights directly derived from EU/Slovakia waste targets. The findings reveal a substantial gap between the average municipality and the top-performing municipalities, and a significant difference between municipalities employing unit-based pricing and flat annual fee. Furthermore, it is evident that municipalities with access to incineration-with-energy-recovery technology derive benefits from this advantage, thanks to fewer restrictions, despite

potential greenhouse gas emissions. Hence, future research could delve into refining the targets on incineration with energy recovery for improved waste management practices.

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