Acta Polytechnica CTU Proceedings **46**:65–84, 2024
https://doi.org/10.14311/APP.2024.46.0065

MUNICIPAL WASTE MANAGEMENT PERFORMANCE: A FOCUS ON SLOVAKIA AND ITS LAU-1 DISTRICTS

Eleonóra Marišová*, Peter Fandel

Slovak University of Agriculture in Nitra, Faculty of European Studies and Regional Development, Institute of Law, Trieda A. Hlinku 2, 949 76 Nitra, Slovakia

* corresponding author: eleonora.marisova@uniag.sk

Abstract. In this paper, we analyse the changes made to the basic EU directive on waste and assess its impact on the waste legislation of EU members. We then examine the Slovak waste strategies/programs that have implemented the EU directive on waste, namely the Waste Prevention Program, the Waste Management Program, and the Envirostrategy 2030. Based on EU waste legislation, the Environmental Strategy 2030 sets the waste treatment aims for Slovakia until 2030. However, it is questionable whether Slovakia will achieve the set goals. Our research indicates that as of 2021, Slovakia's rate of waste incineration with energy recovery and landfilling rate of municipal waste are below the EU average, while the recycling rate, both for materials and composting and digestion, is higher. In our quantitative analysis, we examine the progress of waste management performance in Slovakia from 2017 to 2021, focusing on the LAU-1 districts. We estimate composite efficiency indicators using the techniques of Data Envelopment Analysis and Malmquist Indices. In accordance with the hierarchy of waste treatment methods, the applied models consider desirable waste operations variables (recycling and incineration with energy recovery) and undesirable waste operation variables (landfilling). Our results reveal significant variations in efficiency across the LAU-1 districts. The average technical efficiency of the 72 districts has improved from 0.714 in 2017 to 0.852 in 2021, indicating that the performance of districts is generally improving and catching up with the best-performing districts. The total performance, as measured by the Malmquist index, has improved by 45.5 %. Districts with access to waste incineration facilities with energy recovery have exhibited higher efficiency scores, benefitting from this advantage.

Keywords: Waste legislation, strategies, municipal waste management, LAU-1 districts, performance, composite indicators, Data Envelopment Analysis, Malmquist Index.

1. Introduction

Sustainability issues are closely connected to economic growth of all countries in the world and waste generated by developed and less developed countries. Slovakia, similarly, to other countries worldwide committed to the fulfilment of 17 sustainable development goals (SDGs) [1]. The philosophy includes environmental, economic, and social pillars of sustainability. We focus mainly on the Goal 12 of SDGs: Ensure sustainable consumption and production patterns. This goal should be fulfilled by 2030 as it is formulated: substantially reduce waste generation through prevention, reduction, recycling, and reuse.

Our paper examines how Slovak and European waste legislation and waste programs boost municipal waste recycling and advance the circular economy that affect each other. If we talk about municipal waste in connection with circular economy, each European produces about 500 kg of waste per year. Less than half of it is 46 % recycled, 27 % is incinerated and 24 % is landfilled [2].

The paper is aimed at analysis of the fundamental EU legislation and programs relating to minimizing the waste in the EU member states and their impact on waste management performance in Slovakia. First partial objective is to analyse the changes of the basic EU directive on waste – Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 [3] on waste that was amended by Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 [3] (hereafter Waste Framework Directive). This revised Directive brought many stipulations that had to be implemented into the waste legislation of the EU member states to increase waste incineration with energy recovery, use good techniques for its recycling and minimize landfilling. EU member states are to take among others, measures to support the design, production and use of products that use resources efficiently, are durable, repairable, reusable, and updatable. Except of this, the measures have to set aims how to reduce food waste as a contribution to the United Nations Sustainable Development Goal [4] of reducing global food waste per capita by 50 % by 2030 at retail and consumer level. Member States must by January 1, 2025, establish a sorted collection for textiles and hazardous waste from households and ensure that by December 31, 2023, biological waste is either sorted or recycled at the source (e.g., by composting). Since the Waste Framework Directive establishes the legal basis in the field of waste management in the European Union, we deal with the Slovak waste legislation and strategies/programs that implemented this EU directive. We analyse the implementation of EU waste legislation into Slovak Waste Prevention Program 2018 [5], Slovak Waste Management Program, 2021 [6] and Environmental strategy 2030 [7].

The second objective of this paper is to analyse how Slovak legislation and adopted strategies influence the municipal waste management performance. The analysis is conducted at the level of LAU-1 districts. The aim is to assess the trends in waste management performance using waste treatment-specific indicators, as well as composite indicators based on Data Envelopment Analysis and Malmquist index methodology.

This paper aims to bridge a gap in the current literature by providing a comprehensive analysis of municipal waste management performance at subregional level of LAU-1 districts in Slovakia, in relation to the environmental goals of EU and Slovakia, employing both partial waste treatment-specific indicators and composite indicators The findings will be relevant to waste management practitioners, policymakers, and researchers who are interested in enhancing the efficiency and sustainability of waste management practices and achieving the environmental objectives set by the EU.

The paper is structured as follows: Section 2 provides the theoretical background of the topic, Section 3 describes the data and methodology used, Section 4 presents and discusses the results, and Section 5 concludes the paper.

2. Theoretical background

The theoretical background is processed mainly through the interpretation of the basic EU legislation on waste – Directive (EU) 2018/851 [3] of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste [3], which has undergone several serious changes. In July 2018, the EU Circular Economy Package was introduced by the EU Commission with particular relevance for management of municipal waste. It is intended to serve the objectives of growth and employment while at the same time ensuring and strengthening environmental protection [8]. Rogge et al. [9] state that focus of EU municipal solid waste policy shifted from basic waste handling standards to promoting, recycling, re-use, and energy recovery. An important guiding principle in the designs of EU waste legislation and policy is the so called "waste management hierarchy".

The Slovak legislation on waste is represented by waste legislation Act No. 79/2015 Coll. as amended [10] and Slovak programs: Waste Prevention Programme [5] for years 2019-2025, Environmental strategy 2030 [7] and Waste Management Programme [6] for years 2021–2025, responding to the EU legislation in the field of waste.

We deal in the theory also by amended legislation on waste in the Slovak Republic – Act on Waste No. 79/2015 Coll. [1] in the valid wording and opinions of foreign and domestic authors who make research in the field of waste.

Environmental strategy 2030 [7] set the Slovakian aims till 2030, that the municipal waste recycling rate, including the preparation for re-use, will be increased to 60 %, and the land-filling rate will be reduced to less than 25 % by 2035. A green procurement will cover at least 70 % of the total number of all public procurements, and the support for green innovation, science and research will be at a comparable level to the EU average. The energy intensity of the Slovak industry will be closer to the EU average, and by 2020, the sustainability criteria for all renewable energy production sources will be developed and accepted. The production of electricity and heat from coal will be gradually reduced [7].

Cleaning and wasting are quite familiar to us, and once discarded their products have to be dealt with somehow or managed. Yet in many ways research on what becomes of all that we discard has only just begun [11].

In charge of the waste management in Slovakia are both state and self-government. Today, adequate waste services are considered vital to the governance of cities, industries, and refugee camps: a basic human right, an economic opportunity and an ecological imperative [11]. Municipal waste is the total amount of used materials coming from households and smaller local businesses, where the collection is ensured by the local government [12].

Mura [13] states that municipalities and regions are part of the public administration system, which are most closely connected with the everyday life of citizens. The waste management system consists of the whole set of activities related to handling, treating, disposing or recycling the waste materials [14].

We agree with Kahle et al. [15] who states that sustainability is the ability to remain productive indefinitely. But knowledge is still lacking on local waste prevention, especially regarding the methods for monitoring and how local waste management systems can be designed to encourage waste reduction in the households [16].

Waste management is one of the major environmental concerns in the world. Human activities and changes in lifestyles and consumption patterns have resulted in an increase in solid waste generation rates [14].

The differences in terms of waste handling among the EU members states are immense. Slovakia belongs to the lowest quartile of EU states in terms of waste volumes disposed of by landfilling [17].

The current EU legislation increases the requirements on knowledge of food producers, in particular on the packaging of the product, which must fit even more information in a reasonably large font, and on the environment, as the amount of waste produced increases with increasing packaging area [18].

We appreciate that beside the EU member states, the Republic of Serbia as part of the negotiations for EU accession, has begun the process of establishing a waste management system and adapting it to the goals and acquis Communautaire. The key document in Serbia that aims for environmental awareness is called the Waste Management Program [6] of the Republic of Serbia and it harmonizes the waste management in the candidate state with EU regulations [19].

There has been a significant body of literature addressing municipal waste management performance. Simões and Marques [20] conducted a literature review of 107 studies published from 1965 to 2011, providing a comprehensive overview of the topic. In the past decade, numerous studies have been published, focusing on various aspects of waste management performance.

The first aspect examined in the literature is the waste management performance of different geopolitical entities, with a particular focus on EU countries or EU NUTS2 regions. Examples of such studies include Chiaotto [21, 22], Khan et al. [23], Rios [24], and Rogge et al. [9, 25], which commonly utilize Eurostat datasets. While these studies offer valuable insights, less frequent are subregional analyses that specifically analyse district or municipal-level data. Some notable examples of these subregional studies include Rogge-Jaeger [25], Peréz-López [26], and Struk and Boďa [27].

The second aspect explored in the literature pertains to the different methods employed to estimate performance indicators in waste management. While partial waste treatment-specific indicators are frequently used, their ranking ambiguity has led to the adoption of more sophisticated methods that enable the estimation of composite indicators. A mathematical programming approach to model composite indicators can be found in Zhou et al. [28]. Other approaches such as multi-criteria decision-making methods, employed in Castillo [29], have found wide applicability in this field. Another commonly used method is Data Envelopment Analysis (DEA), utilized in studies by Castillo [29, 30], Delgado-Antequera [31], Peréz-López [26], Rios [24], and Struk and Boďa [27]. Other DEA derivatives, such as the Benefit-of-Doubt (BoD) method used in Chiaotto [22] and Rogge [9], Directional Distance Functions applied in Villavicencio [32] and Ye [33], and the Free Disposal Hull (FDH) employed by Rios [24], have also been applied.

The third topic thoroughly analysed in literature is the selection and classification of variables in waste management performance models. Key discussions revolve around the hierarchy and weighting of variables [34], as well as the identification of desirable and non-desirable variables and their controllability [31].

By considering the insights provided by these different strands of literature, a comprehensive understanding of municipal waste management performance can be achieved, resulting in the design of a reliable model, what is the aim of this study.

3. Material and methods

The theoretical background of the paper is processed mainly through the interpretation of the Waste Framework Direction and above-mentioned strategies of the Slovak Republic, the amended legislation on waste in the Slovak Republic – Act on Waste No. 79/2015 Coll. [10] in the valid wording and opinions of foreign and domestic authors who deal with the issue of waste.

Method of analysis is used to evaluate the Slovak strategies in accordance with EU legislation. We examine to what extent the goals set by the Slovak government in the above-mentioned strategies have been met in the field of waste in the Slovak Republic.

In the quantitative analysis of the municipal waste management performance at the subregional level of LAU-1 districts, we used data of the Statistical Office of the Slovak Republic. We have analysed data of 72 districts of the Slovak republic, using the database coded zp3802rr [35] and named as "Municipal waste and small construction waste from municipalities according to the waste treatment categories per district (in Tonnes)", 2021–2017 period.

The data were used to calculate both partial waste treatment-specific indicators and composite performance indicators.

Following treatment specific indicators were calculated:

- total municipal waste [kg per capita],
- recycling [kg per capita], Recycling rate [%],
- landfilling [kg per capita], Rate of landfilling [%].

As composite indicators, we used the technical efficiency, technical super-efficiency, and Malmquist indices to consider simultaneously multiple metrics of the municipal waste management efficiency, employing the Data Envelopment Analysis (DEA) methodology in this study.

Technical efficiency (TE) is used to measure performance (productivity, efficiency) of the waste management of analysed districts in comparison to the best performing districts. In economic terminology, it is defined as the total factor productivity (TFP) of an evaluated district expressed relative to the highest TFP in the sample of districts. Formally, technical efficiency can be expressed by the following equations Eq. (1) and Eq. (2):

$$TFP = \frac{\text{agregate output of the district under evaluation}}{\text{agregate input of the district under evaluation}}, \tag{1}$$

$$TE = \frac{TFP \text{ of the district under evaluation}}{\text{maximum } TFP \text{ in the sample of districts}}. \tag{2}$$

We estimate technical efficiency using the CCR DEA (Charnes, Cooper, Rhodes, [36]). To determine the ranking of districts based on their efficiency in waste management, we used an adjusted CCR DEA model for calculating super-efficiency, as proposed by Andersen and Petersen [37].

The formal notation of the DEA models used to estimate the technical efficiency is presented in the Scheme (3):

CCR DEA model

$$\begin{aligned}
&\max \varphi \\
&\text{subject to} \\
&\sum_{j=1}^{n} y_{ij}\lambda_j \geq \varphi y_{ro}, \quad r = 1, 2, \ldots, s \\
&\sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{io}, \quad i = 1, 2, \ldots, m \\
&\lambda_j \geq 0, \quad j = 1, 2, \ldots, n \\
&\varphi \text{ – free}
\end{aligned} \tag{3a}$$

Super-efficiency CCR DEA model

$$\begin{aligned}
&\max \varphi \\
&\text{subject to} \\
&\sum_{j=1}^{n} y_{ij}\lambda_j \geq \varphi y_{ro}, \quad r = 1, 2, \ldots, s \\
&\sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{io}, \quad i = 1, 2, \ldots, m \\
&\lambda_j \geq 0, \quad j = 1, 2, \ldots, n;\ j \neq o \\
&\lambda_o = 0 \\
&\varphi \text{ – free}
\end{aligned} \tag{3b}$$

where

x_{ij} i^{th} input of the district j,

y_{rj} r^{th} output of the district j,

x_{io} i^{th} input of the district under observation o,

y_{ro} r^{th} output of the district under observation o,

λ_j intensity variable of the j^{th} district,

φ technical efficiency (TE) measure. The measure is from the interval [1; ∞). However, for the convenience, in the following sections, we report and interpret the inverse value $1/\varphi$, which is from the interval [0; 1].

- If $TE = 1$, then the evaluated district is efficient, that is, it achieves the maximum performance (TFP) in the sample of evaluated districts and serves as a benchmark for other districts in the sample.
- If $TE < 1$, then the evaluated district is inefficient and achieves only (TE∗100) % of the performance of the best districts. The level of the best districts can be achieved either by generating $[(1 - TE) * 100]$ % higher outputs from the inputs used, or by using only $(TE * 100)$ % of the inputs to generate their outputs.
- When determining the ranking of districts according to TE, efficient districts with $TE = 1$ are ranked at the top and districts with the lowest TE value are ranked at the bottom. In a situation where several districts achieve $TE = 1$, it is not possible to unambiguously determine the ranking of efficient units, and in such cases, super-efficiency measures are calculated for efficient districts. Super-TE measures are from the interval [1; ∞), and the best district is the one with the maximum value of the super-TE.

The Malmquist index (MI) proposed by Färe et al. [38] expresses changes in total productivity over time. It is based on estimating Shepard distance functions. In our study, we comprehensively evaluate the development of district performance in waste management over time using the output-oriented Malmquist index and its components, simultaneously considering several performance indicators. The Malmquist index of total productivity can be expressed as follows:

$$\begin{aligned}
MI &= (y_{t+1}, x_{t+1}; y_t, x_t) \\
&= \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \times \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)} \right]^{\frac{1}{2}},
\end{aligned} \tag{4}$$

- if $MI > 1$, then the TFP of the evaluated district has improved,
- if $MI = 1$, then the TFP of the evaluated district has not changed,
- if $MI < 1$, then the TFP of the evaluated district has worsened.

Malmquist index can be decomposed into the index of technical efficiency change (TEC) and the index of technological change (TC): $MI = TEC \times TC$, where

$$TEC = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)}, \tag{5}$$

- if $TEC > 1$, then the evaluated district improved its TE (catching up with the best districts),
- if $TEC = 1$, then the evaluated district did not change its TE,
- if $TEC < 1$, then the evaluated district worsened its TE (lagging behind the best districts).

$$TC = \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \times \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)} \right]^{\frac{1}{2}} \tag{6}$$

- if $TC > 1$, then we observe progress in technology (innovation in technology) in the evaluated district,
- if $TC = 1$, then there has been no change in technology in the evaluated district,
- if $TC < 1$, then we observe regression in technology in the evaluated district.

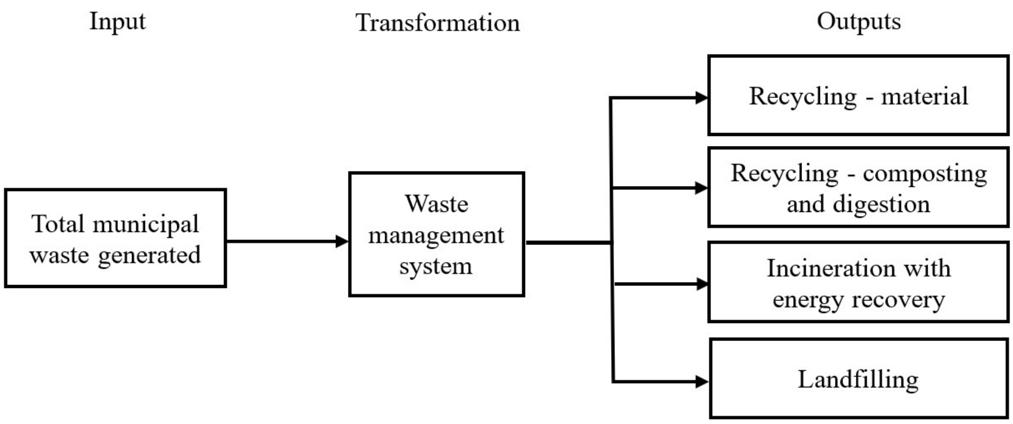

Figure 1. The scheme of the transformation process in waste management system.

We estimated the Shepard distance functions using following output-oriented CCR DEA models:

$$\begin{aligned} \left[d_o^t(y_t, x_t)\right]^{-1} &= \max_{\varphi,\lambda} \varphi \\ \text{subject to} & \\ \varphi y_{ot} - Y_t\lambda &\leq 0 \\ X_t\lambda &\leq x_{ot} \\ \lambda &\geq 0 \end{aligned} \tag{7}$$

$$\begin{aligned} \left[d_o^{t+1}(y_{t+1}, x_{t+1})\right]^{-1} &= \max_{\varphi,\lambda} \varphi \\ \text{subject to} & \\ \varphi y_{ot+1} - Y_{t+1}\lambda &\leq 0 \\ X_{t+1}\lambda &\leq x_{ot+1} \\ \lambda &\geq 0 \end{aligned} \tag{8}$$

$$\begin{aligned} \left[d_o^t(y_{t+1}, x_{t+1})\right]^{-1} &= \max_{\varphi,\lambda} \varphi \\ \text{subject to} & \\ \varphi y_{ot+1} - Y_t\lambda &\leq 0 \\ X_t\lambda &\leq x_{ot+1} \\ \lambda &\geq 0 \end{aligned} \tag{9}$$

$$\begin{aligned} \left[d_o^{t+1}(y_t, x_t)\right]^{-1} &= \max_{\varphi,\lambda} \varphi \\ \text{subject to} & \\ \varphi y_{ot} - Y_{t+1}\lambda &\leq 0 \\ X_{t+1}\lambda &\leq x_{ot} \\ \lambda &\geq 0 \end{aligned} \tag{10}$$

In modelling the waste management performance of districts, we assume that the waste management system corresponds to the process of transforming inputs into outputs. In our analysis, the total quantity of municipal waste generated in districts serves as the input, which enters the waste management system. The quantities of municipal waste processed by the alternative treatment methods are regarded as the outputs of the system. The scheme of the transformation process is depicted in Figure 1.

The inputs and outputs in our analysis are defined in accordance with the above assumption as follows:

- Input (input variable)
  (1.) Total municipal waste generated in a district per capita per year. We work with the only input variable, which we consider to be a short-term uncontrollable variable.
- Outputs (output variables)
  (1.) Recycling – material (R02-R13, except R03)
  (2.) Recycling – composting and digestion (R03)
  (3.) Incineration with energy recovery (R01, D10)
  (4.) Landfilling (D01)

The four selected outputs variables represent the prevailing quantities of municipal waste in Slovakia. To account for population density, all outputs, as well as the input, are expressed in per capita values. Consistent with the waste management strategies adopted by the EU and Slovakia, the objective is to minimize the disposal of municipal waste in landfills and encourage recycling and environmentally friendly incineration with energy recovery. For this reason, the selected output variables are hierarchically defined into two groups:

(a) Good outputs: These represent desirable treatment methods of waste, including material recycling, organic recycling, and incineration with energy recovery. For these outputs, we adopt the preference of "the more – the better".

(b) Bad outputs: These represent undesirable waste treatment methods, specifically landfilling, with the preference of "the less – the better". Since outputs are generally modelled in DEA models as maximization variables, the maximization preference for bad outputs needs to be transformed into minimization. In our study, we adopt the transformation approach proposed by Seiford and Zhu [39]: firstly, each undesirable (bad) output is multiplied by a coefficient of −1, and then a suitable transformation vector, denoted as w, is determined to convert all negative outputs into positive ones:

$$\begin{aligned} \overline{y_j}^b &= -y_j^b + w > 0 \\ \overline{y_j}^b &= -y_j^b + \max(y_j^b) + 1 \end{aligned} \tag{11}$$

where y_j^b is the bad output and $\overline{y_j}^b$ is the transformed bad output.

The CCR DEA model with bad outputs then has the following form:

$$\begin{aligned} &\max f = \varphi \\ &\text{output constraints for good outputs} \\ &\sum_{j=1}^{n} y_{ij}^g \lambda_j \geq \varphi y_{ro}^g, \quad r = 1, 2, \ldots, s \\ &\text{output constraints for bad outputs} \\ &\sum_{j=1}^{n} \overline{y_{ij}}^b \lambda_j \geq \varphi \overline{y_{ro}}^b, \quad r = 1, 2, \ldots, s \\ &\text{standard input constraints} \\ &\sum_{j=1}^{n} x_{ij} \lambda_j \leq x_{io}, \quad i = 1, 2, \ldots, m \\ &\lambda_j \geq 0, \quad j = 1, 2, \ldots, m \\ &\varphi - \text{free}, \ y_j^g \text{ are good outputs.} \end{aligned} \tag{12}$$

We applied the same adjustment in models for calculating the super-efficiency and the Malmquist indices.

4. Results

4.1. Municipal Waste – EU legislation

The Waste Framework Directive lays down measures to protect the environment and human health by preventing or reducing the generation of waste, the adverse impacts of the generation and management of waste by reducing overall impacts of resource use and improving the efficiency of such use, which are crucial for the transition to a circular economy and for guaranteeing the Union's long-term competitiveness [3].

This directive stresses the transition to a circular economy in all EU member states and changes of the former waste directive 2008/98/EC by new definition the municipal waste [3]:

(a) mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, and bulky waste, including mattresses and furniture;

(b) mixed waste and separately collected waste from other sources, where such waste is similar in nature and composition to waste from households.

Municipal waste does not include waste from production, agriculture, forestry, fishing, septic tanks and sewage network and treatment, including sewage sludge, end-of-life vehicles or construction and demolition waste.

We can see that the new stipulation of the Waste Framework Directive includes separately collected waste that is more and more important for the EU. As for the municipal waste, it excludes mainly waste from production, agriculture, forestry, fishing. Newly is defined also construction and demolition waste like waste generated by construction and demolition activities, as well as bio-waste that means biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants.

The original characteristics of the waste in article 4 Waste Framework Directive [3] was much simpler: any substance or object which the holder discards or intends or is required to discard.

As for the waste management, the new directive states that it is not only collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, but includes into management also the waste sorting. Except of waste sorting, the new directive also stipulates a new tool for producers' responsibility by adding so called extended producer responsibility scheme that means a set of measures taken by member states to ensure that producers of products bear financial responsibility or financial and organisational responsibility for the management of the waste stage of a product's life cycle [3].

4.2. Implementation of EU waste legislation into Slovak one

This amendment was transposed into Slovak waste legislation by amending the act on waste No. 79/2015 Coll. Waste Act [10]. As part of the extended responsibility, producers of reserved products basically bear all the costs of dealing with the reserved waste stream, from its sorted collection to the recovery and eventual disposal of unrecoverable residues. Exceptions to this rule are cases where the obligation of the producer of a reserved product, which is not registered in the Register of Producers, is transferred from the Waste Act to the distributor of this product. Pursuant to § 81 par. 4 of the Waste Act, the manufacturer is obliged to bear the costs of providing the necessary collection containers (e.g., containers or bags).

The transfer of costs for separate collection from citizens to producers also creates financial motivation for the improvement of sorting. Although the principles supporting extended producer responsibility create room for an increase in the rate of sorting of municipal waste, extended producer responsibility cannot be considered a direct tool for its increase. It is only a means for shifting the costs of separate collection and recycling from local governments and taxpayers directly to producers, which stimulates waste prevention on the part of producers and, on the other hand, creates room for citizens to manage waste more responsibly [40].

OECD [41] defines the extended producer responsibility as an environmental policy tool that extends the producer's responsibility for the product to the post-consumer phase of its life cycle. In other words: the manufacturer is responsible for handling the product even after the product has become waste.

"Not the consumer, but the producer of the product is the one who creates the demand for packaging and determines the requirements for its composition. Therefore, if the customer makes the effort and sorts the packaging, the subsequent costs associated with the waste are transferred to the manufacturer. In the extended responsibility of producers, producers are responsible for sorted waste from packaging", the analysts of the Slovak Institute of Environmental Policy explain in their latest study How to sort out sorted collection [40].

In the legislation of the European Community, the idea of extended producer responsibility appeared for the first time when the Directive [42] on packaging and packaging waste set Member States targets for waste sorting and recycling, as well as requirements for packaging design. However, this directive did not oblige producers to finance the collection and recycling of waste – this resulted only from the legislation of individual states.

4.3. EU Prevention of waste

According to Article 9 of the Waste Framework Directive [3], the member states shall take measures to prevent waste generation. Those measures shall, at least:

- reduce the generation of waste, in particular waste that is not suitable for preparing for re-use or recycling,
- develop and support information campaigns to raise awareness about waste prevention and littering,
- target products containing critical raw materials to prevent that those materials become waste,
- encourage the re-use of products and the setting up of systems promoting repair and re-use activities, including in particular for electrical and electronic equipment, textiles and furniture, as well as packaging and construction materials and products,
- reduce waste generation in processes related to industrial production, extraction of minerals, manufacturing, construction and demolition, taking into account best available techniques,
- reduce the generation of food waste in primary production, in processing and manufacturing, in retail and other distribution of food, in restaurants and food services as well as in households as a contribution to the United Nations Sustainable Development Goal [4] to reduce by 50 % the per capita global food waste at the retail and consumer levels and to reduce food losses along production and supply chains by 2030;
- encourage food donation and other redistribution for human consumption, prioritising human use over animal feed and the reprocessing into non-food products.

4.4. Main aims of waste prevention in Slovak Waste Prevention program

Slovak Republic implemented these goals into its Waste Prevention Programme (WPP), 2018 for years 2019–2025 [5]. The main aim is to break the link between economic growth and environmental impacts related to the generation of waste. WPP [5] states that the capacity of the currently operating waste dumps is sufficient, therefore it is not necessary to build new waste dumps.

Unlike common dumps, however, landfills are more carefully designed to cordon off waste from both society and nature, maintaining their contents in a state of suspended animation. This makes it possible for landfills to one day be recovered as an invented common, a source of new land upon which to build or reclaim for other purposes [43].

The Slovak Republic is a rural country which is also reflected in the method of sorted collection of biodegradable waste with predominant domestic composting. We analyze the main goals, financing and measures taken in the Slovak WPP [5] relating to mixed and biodegradable municipal waste.

The main goal of WPP [5] as for Mixed municipal waste is to reduce the amount of mixed municipal waste by 50 % by 2025 compared to 2016 mostly by introduction of mandatory mass collection of municipal waste and activities to prevent the creation of mixed municipal waste should be financed from the Environmental Fund. As for the biodegradable municipal waste, the main goal of WPP [5] is to reduce the amount of biodegradable waste in mixed municipal waste by 60 % by 2025 compared to the situation in 2016.

Stipulated measures in WPP [5]:

- legislative, financial, and informational support for home and community composting,
- creation of a unified methodology for monitoring the amount and types of biodegradable waste in mixed municipal waste.

Illegal handling of biodegradable municipal waste is also a serious problem in Slovakia. A large part of it is dumped in illegal landfills or burned in the spring and autumn months on public and private lands.

4.5. Waste management Program and Slovak LAU-1 districts competencies

Another important strategy that implemented the EU legislation, is the Slovak Waste Management Programme [6] for years 2021–2025.

The new version of the Waste Framework Directive 2008/98/EC established new definitions (municipal waste) [3] related to the concept of waste, as well as improving existing ones (waste management). It should be noted that the basic definition of waste remains unchanged [44].

Slovakia needs to focus strongly on separate collection at source. A low level of separate collection would result in a low recycling rate of municipal waste. The separate collection of municipal waste has increased in the past period, especially for metals, paper, plastics, glass and biodegradable green waste, but there is also a need to focus on the separate collection of other components and types of waste that are currently underestimated (e.g., hazardous waste, textiles).

WMP [6] states the tools to improve the separate collection of municipal waste that were included into Slovak waste legislation:

- Act No. 329/2018 Coll. on fees for waste disposal – to make landfilling, which is the last in the waste management hierarchy, handicapped and to create an incentive for the sorted collection of municipal waste and to increase the recycling of municipal waste [3],
- Regulation No. 330/2018 Coll. – the new rate for the disposal of mixed municipal and bulky waste, depends on the level of municipal waste sorting in the municipality,
- new law on fees is the result of a number of activities at the Slovak level and the EU one.

As for Slovakia, a member state of the EU since 2004, all district offices in the seat of the regions (8) shall be obliged to work out plans of regions based on the objectives and measures set in the Slovak Waste Management Program. This way there are together eight regional Waste Management Programs for years set by the Slovak program that determines the direction of waste management for a set period and are binding for respective region, based on its particularities with specific goals and measures to support waste prevention. The new Act on Wastes imposes the duty on the producers that fulfils their duties individually to perform promotional and educational activities in the district, in which they provide for the waste collection, focusing on end users, about management of selected waste streams, separate collection of municipal wastes and waste prevention [6].

4.6. The Strategy of the Environmental Policy of the Slovak Republic until 2030

Envirostrategy (2030) that was prepared under leadership of Slovak Ministry of environment in 2019, defines a vision until 2030, which takes into account a possible, probable, and the desired future development, identifies the fundamental systemic problems, sets the objectives until 2030 and proposes a framework for measures to improve the current situation, and it also contains basic result indicators that will enable a verification of achieved results. The basic vision of Envirostrategy 2030 is to achieve better environmental quality and sustainable circulation of the economy, which is based on rigorous protection of environmental compartments and using as little non-renewable natural resources and hazardous substances as possible, which will lead to an improvement in health of the population. Environmental protection and sustainable consumption will be part of the general awareness of citizens and policy makers [7].

The main aims of Envirostrategy 2030 are as follows:

- to achieve better environmental quality and sustainable circulation of the economy,
- environmental protection and sustainable consumption will be part of the general awareness of citizens and policy makers,
- the prevention and adaptation to climate change.

The tools to fulfil the main objectives of Envirostrategy 2030:

- incentive-based municipal waste collection for municipalities,
- increase prevention of black dumping and enforcement of the polluter pays,
- restaurants and supermarkets will be obliged to make use of the food (charity donation of the food that fulfils food safety requirements),
- if they are no longer suitable for consumption, they will be able to compost them or energetically utilize,
- renewable energy production will be preferred, which by its nature does not burden the environment and contributes to the long-term sustainable development of the Slovak Republic.

4.7. Results of the quantitative analysis

In the opening part of this section, we focus on presenting selected partial indicators that reflect the performance of waste management. Through these indicators, we aim to document the progress of municipal waste management in Slovakia between 2017 and 2021, while also comparing it to the average performance of the EU-27 countries, Slovakia, and the target values set specifically for Slovakia.

In Table 1 we present a comparison of total municipal waste generated. It is evident that Slovakia remains below the EU-27 average. However, economically developed districts of western Slovakia, such as Trnava and Galanta, significantly surpass the EU-27 average in waste generation per capita. Waste growth index indicates a higher growth rate in Slovakia compared to EU-27.

The assessment of a waste management system's performance is primarily contingent on the extent to which recycling methods are utilized. In this regard, there have been significant and positive developments. Table 2 illustrates the advancement in recycling, encompassing both material recycling and recycling through composting and digestion. Over the

Geopolitical entity	2017	2021	Index 2021/2017
EU-27	499	530	106 %
Slovakia	378	496	131 %
Best districts	Sobrance: 126	Sobrance: 220	175 %
Worst districts	Trnava: 563	Galanta: 830	147 %

Table 1. Total municipal waste generated [kg per capita].

Geopolitical entity	2017	2021	Index 2021/2017
EU-27	231	257	111.3 %
Slovakia	113	242	214.2 %
Best districts	Nitra: 225	Galanta: 514	xxx
Worst districts	Sobrance: 12	Sobrance: 88	xxx

Table 2. Recycling [kg per capita].

Geopolitical entity	2017	2021	Index 2021/2017
EU-27	46.3 %	48.5 %	104.7 %
Slovakia	29.9 %	48.8 %	163.2 %
Best districts	Žiar nad Hronom: 49.6 %	Žiar nad Hronom: 65.3 %	130.0 %
Worst districts	Medzilaborce: 6.7 %	Medzilaborce: 29.8 %	428.6 %
Slovakia target 2030		min 60 %	

Table 3. Recycling rate [%].

Geopolitical entity	2017	2021	Index 2021/2017
EU-27	127	121	95 %
Slovakia	229	202	88 %
Best districts	Košice I-IV: 16	Košice I-IV: 7	44 %
Worst districts	Galanta: 429	Malacky: 360	xxx

Table 4. Landfilling [kg per capita].

span of five years analyzed, recycling in Slovakia has doubled. However, as of 2021, it still falls below the average recycling rate of the EU-27 countries.

Table 3 provides an overview of the share of recycling in relation to the total municipal waste generated. Slovakia has witnessed significant progress in its recycling rate, which has increased from 29.9 % to 48.8 %, surpassing the average rate of the EU-27. This positive trend is also evident within the districts of Slovakia. The district with the lowest recycling rate has tripled its rate, showing a remarkable improvement, while the district with the highest rate has seen a 30 % enhancement. Although Slovakia as a whole has not yet met the recycling rate target set for year 2030, some of the best districts have already achieved this milestone.

Waste landfilling is considered as a least desirable treatment method. In line with EU Landfill Directive, member states are required to reduce the amount of municipal waste sent to landfill to 10 % or less of the total amount of municipal waste generated by 2035. In Table 4 we provide per capita statistics of Slovakia and its districts.

Landfilling in Slovakia remains significantly high, nearly double the average of the EU-27. Moreover, the worst-performing districts exhibit even higher values, almost triple the EU-27 average. Over the five-year period under analysis, Slovakia has managed to decrease its landfill usage by approximately 12 %. The best practicing districts show 56 % decrease.

The target rate of landfilling set in Slovakia for 2035 is 25 %. However, as of 2021, the current rate of landfilling stands at 40.7 % (Table 5). This indicates that there is still a significant gap between the current rate and the desired target, highlighting the need for further efforts and strategies to reduce landfilling and promote more sustainable waste management practices. The district of Košice I-IV stands out as the best performer, with a remarkably low landfilling rate of only 1.5 %. This achievement can be attributed to its significant reliance on incineration with energy recovery, a method that effectively reduces the amount of waste sent to landfills. Conversely, the worst-performing districts are characterized by low rates of recycling, indicating a need for improvement in their waste management practices. Encouraging higher recycling rates

Geopolitical entity	2017	2021	Index 2021/2017
EU-27	25.5 %	22.8 %	89.7 %
Slovakia	60.6 %	40.7 %	67.3 %
Best districts	Košice I-IV: 3.8 %	Košice I-IV: 1.5 %	39.5 %
Worst districts	Medzilaborce: 93.3 %	Medzilaborce: 69.7 %	74.7 %
Slovakia target 2035		max 25 %	

Table 5. Rate of landfilling [%].

Rank	Total municipal waste$^{(D)}$	Recycling – material$^{(I)}$	Recycling – composting and digestion$^{(I)}$	Incineration with energy recovery$^{(I)}$	Landfilling$^{(D)}$
1	Sobrance (220)	Kysucké N. Mesto (234)	Galanta (369)	Košice I-IV (290)	Košice I-IV (7)
2	Trebišov (229)	Bytča (207)	Senec (324)	Bratislava I-V (234)	Bratislava I-V (47)
3	Medzilaborce (309)	Žiar nad Hronom (192)	Dunajská Streda (261)	Prešov (133)	Prešov (72)
4	Vranov n/Topľou (317)	Zlaté Moravce (190)	Malacky (257)	Košice – okolie (97)	Košice – okolie (91)
5	Stará Ľubovňa (322)	Senec (174)	Nitra (233)	Rožňava (63)	Sobrance (128)
...	...	...	...	...	...
68	Nitra (613)	Zvolen (60)	Detva (54)	26 districts with zero values	Nitra (285)
69	Malacky (763)	Stará Ľubovňa (60)	Rožňava (49)		Galanta (293)
70	Senec (770)	Poprad (59)	Gelnica (48)		Komárno (309)
71	Dunajská Streda (771)	Banská Štiavnica (51)	Košice – okolie (36)		Dunajská Streda (338)
72	Galanta (830)	Medzilaborce (37)	Sobrance (21)		Malacky (360)

$^{(D)}$ decreasing preference, $^{(I)}$ increasing preference.

Table 6. Top 5 and bottom 5 districts in waste management performance by treatment-specific indicators, 2021 (districts sorted by waste in kg per capita).

in these districts would contribute to reducing the reliance on landfilling and promoting a more sustainable approach to waste management.

The top 5 and bottom 5 ranks of districts based on waste management performance using treatment-specific indicators in kg per capita are presented in Table 6.

The corresponding rankings based on the percentage share of quantities treated by selected methods in the total quantity of municipal waste is shown in Table 7.

As evident from the previous section, partial waste treatment-specific indicators lead to different rankings of the districts, and in some cases, these rankings can be contradictory. To avoid this discrepancy, the next part of this section presents the results of the waste management performance analysis assessed using composite indicators. In the analysis, a dataset comprising 72 districts was utilized, and waste management performance was evaluated by considering one input variable and four output variables simultaneously, employing the DEA model (3a). Descriptive statistics of the variables used in the analysis are provided in Table 8.

The technical efficiency composite indicator of the municipal waste performance of the 72 districts of Slovakia for the period 2017–2021 is presented in Table 9.

As evident from Table 9, the average technical efficiency of districts in the evaluated period increased from 0.714 in 2017 to 0.852 in 2021. If in 2017 districts, on average, achieved 71.4 % of the performance of the best-performing districts, by 2021, it had already increased to 85.2 %, while simultaneously reducing the variability in district efficiency. This indicates that districts are converging towards the desired state outlined by waste management strategies. Unfortunately, it is showing that the pace of convergence is slowing down, as demonstrated in Table 10.

While in 2018, the average technical efficiency of districts increased by 15 % compared to the previous year, in 2019 it was a growth of 7.2 %. In 2020, there was a decline of 0.1 %, but in 2021, there was an increase of 2.4 %. The average annual growth of

Rank	Recycling – material rate(I)	Recycling – composting and digestion rate(I)	Incineration with energy recovery rate(I)	Landfilling rate(D)
1	Kysucké Nové Mesto (42)	Galanta (44)	Košice I-IV (65)	Košice I-IV (1)
2	Košice – okolie (38)	Senec (42)	Bratislava I-V (41)	Bratislava I-V (8)
3	Bytča (38)	Topoľčany (40)	Prešov (30)	Prešov (16)
4	Žiar nad Hronom (37)	Nitra (38)	Košice – okolie (27)	Košice – okolie (25)
5	Gelnica (34)	Banská Štiavnica (38)	Rožňava (18)	Senec (31)
...	...	...	...	...
68	Zvolen (14)	Rožňava (14)	26 districts with zero values	Sabinov (58)
69	Bratislava I-V (13)	Detva (14)		Rimavská Sobota (59)
70	Poprad (13)	Revúca (12)		Kežmarok (61)
71	Medzilaborce (12)	Košice – okolie (10)		Revúca (62)
72	Banská Štiavnica (11)	Sobrance (9)		Medzilaborce (70)

(D) decreasing preference, (I) increasing preference.

Table 7. Top 5 and bottom 5 districts in waste management performance by treatment-specific indicators, 2021 (districts sorted by % rate).

Statistics	2017	2018	2019	2020	2021
I – Total municipal waste					
Mean	364.2	405.6	414.2	444.1	472.4
Minimum	126.3	133.4	156.5	159.4	220.2
Maximum	563.2	654.2	690.1	1017.9	830.2
Standard deviation	99.2	103.7	101.8	132.3	117.2
O1 Recycling – material (desirable treatment)					
Mean	52.2	89.5	91.9	85.9	108.9
Minimum	4.8	7.1	9.9	10.7	37.3
Maximum	151.5	221.4	234.1	168.6	233.7
Standard deviation	32.6	42.6	39.5	31.8	38.7
O2 Recycling – composting and digestion (desirable treatment)					
Mean	52.2	64.7	77.5	112.4	127.3
Minimum	5.0	5.8	11.3	22.3	20.9
Maximum	177.5	169.8	174.7	361.1	368.8
Standard deviation	31.5	34.0	35.7	62.5	63.7
O3 Incineration with energy recovery (desirable treatment)					
Mean	9.4	7.8	7.8	9.3	11.7
Minimum	0.0	0.0	0.0	0.0	0.0
Maximum	275.0	238.5	258.0	274.2	290.0
Standard deviation	46.2	38.2	35.8	44.6	47.2
O4 Landfilling (undesirable treatment)					
Mean	250.4	242.4	234.1	229.4	217.1
Minimum	15.6	23.4	17.3	6.2	6.6
Maximum	429.2	369.3	363.6	371.3	359.7
Standard deviation	69.3	65.6	63.1	60.4	58.4

Table 8. Descriptive statistics of input (I) and output (O) variables, 2017–2021, $n = 72$ districts [kg per capita].

Descriptive statistics	2017	2018	2019	2020	2021
Mean	0.714	0.799	0.842	0.839	0.852
Minimum	0.443	0.467	0.499	0.533	0.612
Maximum	1.000	1.000	1.000	1.000	1.000
Standard deviation	0.159	0.151	0.118	0.118	0.099
No. of inefficient districts ($TE < 1$)	64	61	62	64	62
No. of efficient districts ($TE = 1$)	8	11	10	8	10

Table 9. Descriptive statistics of technical efficiency of districts of Slovakia, 2017–2021, $n = 72$.

Descriptive statistics	TEC index 2018/17	TEC index 2019/18	TEC index 2020/19	TEC index 2021/20	Mean annual TEC index	Cumul. TEC index
Mean	1.150	1.072	0.999	1.024	1.051	1.242
Minimum	0.710	0.899	0.694	0.751	0.957	0.838
Maximum	2.044	1.920	1.169	1.299	1.220	2.220
Standard deviation	0.255	0.155	0.077	0.096	0.054	0.270
No. of districts with $TEC < 1$ (regress)	15	21	34	20	11	11
No. of districts with $TEC = 1$ (stagnation)	5	9	5	7	4	3
No. of districts with $TEC > 1$ (progress)	52	42	33	45	57	58

TEC – technical efficiency change

Table 10. Descriptive statistics of technical efficiency change indices of districts of Slovakia, 2017–2021, $n = 72$.

technical efficiency over the entire period was 5.1 %. Overall, the average technical efficiency of districts increased by 24.2 % throughout the evaluated period. Complete results on technical efficiency change are presented in Appendix B.

Table 11 shows the 5 best and the 5 worst districts. The most efficient district in Slovakia from 2017 to 2020 was district of Sobrance, while in 2021 it was Košice I-IV, which held the second position in the previous period. While Sobrance are so efficient probably thanks to low waste generation, district of Košice I-IV exhibits so high efficiency score due to a high proportion of incineration with energy recovery. The least efficient districts in respective years of the examined period were Partizánske, Komárno, and Revúca. The detailed ranking of districts according to technical efficiency in each year is provided in Appendix A.

Technical efficiency is a relative measure of performance (productivity) of districts, indicating how far the evaluated districts are from the best-performing districts that utilize the most productive waste treatment methods and technologies for municipal waste management. The Malmquist index allows for assessing changes in the overall productivity of districts in terms of the transformation of total generated municipal waste into individual components based on waste treatment methods. In Table 12 we present Malmquist indices for the period 2017–2021. Average Malmquist index, as a composite indicator of total factor productivity change of districts increased by 16.75 % in 2018 compared to the previous year, in 2019 it was a growth of 6.6 %, in 2020 there was an increase 9.6 % and in 2021 there was an increase of 2.4 %. The average annual growth of TFP measured over the entire period was 9.2 %. Overall, the average Malmquist index of districts increased by 45.5 % throughout the evaluated period.

The district of Dunajská Streda achieved the highest average annual TFP change index of 1.3, indicating a 30 % improvement in total performance every year during the analyzed period. Furthermore, this district has the best cumulative Malmquist index of 2.852, suggesting that an initially inefficient district significantly improved its performance at a high pace, resulting in an overall TFP increase of 185.2 %.

On the other hand, the district of Sobrance exhibited the lowest annual change index of 0.901 and cumulative MI index of 0.657. These values represent a regress of 9.9 % and 34.3 % respectively, likely due to uncompetitive waste management technology. The complete list of districts with Malmquist indices of TFP change can be found in Appendix C.

5. Conclusions

The goal of waste strategies in the Slovak Republic is to reduce the volume of landfill waste by separating its components to be used in the recycling process. By analysing the legislation and strategies of

Rank	2017	2018	2019	2020	2021
1	Sobrance	Sobrance	Sobrance	Sobrance	Košice I-IV
2	Košice I-IV	Košice I-IV	Košice I-IV	Košice I-IV	Sobrance
3	Tvrdošín	Kysucké Nové Mesto	Žiar nad Hronom	Košice – okolie	Košice – okolie
4	Žiar nad Hronom	Žiar nad Hronom	Kysucké Nové Mesto	Galanta	Kysucké Nové Mesto
5	Nitra	Košice – okolie	Myjava	Žiar nad Hronom	Prešov
...	...	...	...	...	...
68	Komárno	Bánovce nad Bebravou	Kežmarok	Medzilaborce	Hlohovec
69	Bánovce nad Bebravou	Považská Bystrica	Považská Bystrica	Považská Bystrica	Považská Bystrica
70	Galanta	Rožňava	Žarnovica	Rožňava	Kežmarok
71	Dunajská Streda	Medzilaborce	Rožňava	Revúca	Komárno
72	Partizánske	Komárno	Komárno	Komárno	Revúca

TABLE 11. Top 5 and bottom 5 districts in waste management performance measured by the composite indicator of technical super-efficiency, 2017–2021.

Descriptive statistics	MI 2018/17	MI 2019/18	MI 2020/19	MI 2021/20	Mean annual MI	Cumulative MI
Mean	1.167	1.066	1.078	1.096	1.092	1.455
Minimum	0.673	0.851	0.827	0.774	0.901	0.657
Maximum	2.208	1.735	1.413	1.421	1.300	2.852
Standard deviation	0.266	0.146	0.113	0.116	0.069	0.388
No. of districts with $MI < 1$ (regress)	17	26	15	11	6	6
No. of districts with $MI = 1$ (stagnation)	0	1	0	0	0	0
No. of districts with $MI > 1$ (progress)	55	45	57	61	66	66

MI – Malmquist index of total factor productivity change

TABLE 12. Descriptive statistics of Malmquist indices in districts of Slovakia, 2017–2021, $n = 72$.

the Slovak Republic, as well as the EU legislation, we can formulate the conclusion that a system for waste generators should contribute to the objective of significantly reducing the overall waste generation, in particular as regards halving the amount of residual, non-recycled municipal waste by 2030 and the land-filling rate should be reduced to less than 25 % by 2035. At the same time, the functionality of the extended liability system will be improved.

Municipal waste management should contribute to the SDGs' fulfilment, and we need to consider not just environmental and economic but also social factors influencing the waste generation, waste treatment and processing.

The quantitative analysis of waste management performance reveals a positive trend in the average technical efficiency of the LAU-1 districts in Slovakia, increasing from 0.714 in 2017 to 0.852 in 2021, indicating a significant improvement of 19.3 %. This indicates a positive convergence of district productivity towards the performance of the best-performing districts, highlighting progress in waste management practices. We found out that among the best-performing districts belong the ones with access to waste incineration facilities with energy recovery.

However, it is important to note that there has been a slight deceleration in the pace of convergence. The initial improvement observed between 2017 and 2018, which amounted to a 15 % increase, decreased to a 2.4 % change between 2020 and 2021. While there is still progress, the rate of improvement has slowed down compared to the earlier period.

Over the period from 2017 to 2021, the average cumulative municipal waste management performance, measured by Malmquist index of Total Factor Productivity change, improved by a significant 45.5 %. This improvement indicates an equiproportional growth in the quantities of municipal waste treated using desirable treatment methods, accompanied by a decrease in quantities of waste treated using undesirable treatment methods.

On average, there was an annual improvement of 9.2 % in the performance of municipal waste management in the LAU-1 districts measured by Malmquist index of TFP change.

If the observed trend from 2017 to 2021 persists, it can be reasonably expected that the targets set for the recycling rate and landfilling rate for the years 2030 and 2035 will be met. However, this expectation is not statistically analysed in this paper. Examples of some districts show that the set goals in recycling and landfilling are already being met or even exceeded. On the other hand, there are districts that are far from meeting the goals, and it is not expected that they will achieve them by the specified target years.

Positive advancements in waste management practices demonstrate the potential for continued progress in achieving sustainable waste treatment goals.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under the Contract No. APVV-20-0076 entitled “Waste and Construction – Modelling the Effectiveness of Alternative Options for Cooperation between Administrative Authorities”.

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Appendix A. Rank of districts of Slovakia according to waste management performance measured by the composite indicator of technical super-efficiency, 2017–2021

Rank	2017	2018	2019	2020	2021
1	Sobrance	Sobrance	Sobrance	Sobrance	Košice I-IV
2	Košice I-IV	Košice I-IV	Košice I-IV	Košice I-IV	Sobrance
3	Tvrdošín	Kysucké Nové Mesto	Žiar nad Hronom	Košice – okolie	Košice – okolie
4	Žiar nad Hronom	Žiar nad Hronom	Kysucké Nové Mesto	Galanta	Kysucké Nové Mesto
5	Nitra	Košice – okolie	Myjava	Žiar nad Hronom	Prešov
6	Stará Ľubovňa	Gelnica	Košice – okolie	Stropkov	Žiar nad Hronom
7	Myjava	Nitra	Nitra	Bratislava I-V	Galanta
8	Brezno	Myjava	Svidník	Zlaté Moravce	Senec
9	Bratislava I-V	Šaľa	Galanta	Žilina	Bratislava I-V
10	Ilava	Banská Bystrica	Gelnica	Ilava	Myjava
11	Banská Bystrica	Trebišov	Veľký Krtíš	Tvrdošín	Tvrdošín
12	Šaľa	Ilava	Ilava	Prešov	Svidník
13	Detva	Tvrdošín	Šaľa	Svidník	Banská Štiavnica
14	Košice – okolie	Stará Ľubovňa	Zlaté Moravce	Kysucké Nové Mesto	Bytča
15	Spišská Nová Ves	Skalica	Bardejov	Myjava	Topoľčany
16	Zvolen	Bratislava I-V	Liptovský Mikuláš	Bardejov	Stará Ľubovňa
17	Žilina	Nové Zámky	Stropkov	Nové Zámky	Ilava
18	Pezinok	Hlohovec	Levoča	Trenčín	Dolný Kubín
19	Prešov	Galanta	Banská Bystrica	Banská Bystrica	Bardejov
20	Snina	Veľký Krtíš	Trebišov	Stará Ľubovňa	Humenné
21	Zlaté Moravce	Lučenec	Tvrdošín	Veľký Krtíš	Krupina
22	Bardejov	Bardejov	Pezinok	Senec	Levoča
23	Liptovský Mikuláš	Stropkov	Senec	Banská Štiavnica	Skalica
24	Turčianske Teplice	Snina	Bratislava I-V	Šaľa	Veľký Krtíš
25	Bytča	Prešov	Stará Ľubovňa	Púchov	Gelnica
26	Veľký Krtíš	Námestovo	Medzilaborce	Nitra	Piešťany
27	Gelnica	Ružomberok	Hlohovec	Pezinok	Nitra
28	Skalica	Senec	Spišská Nová Ves	Gelnica	Vranov nad Topľou
29	Lučenec	Humenné	Snina	Dolný Kubín	Snina
30	Dolný Kubín	Spišská Nová Ves	Ružomberok	Snina	Šaľa
31	Trenčín	Vranov nad Topľou	Prešov	Skalica	Námestovo
32	Humenné	Liptovský Mikuláš	Žilina	Námestovo	Trebišov
33	Martin	Michalovce	Dolný Kubín	Michalovce	Lučenec
34	Púchov	Žilina	Skalica	Ružomberok	Trenčín
35	Senica	Pezinok	Nové Zámky	Lučenec	Pezinok
36	Vranov nad Topľou	Piešťany	Humenné	Vranov nad Topľou	Ružomberok
37	Ružomberok	Bytča	Púchov	Dunajská Streda	Dunajská Streda
38	Svidník	Krupina	Topoľčany	Hlohovec	Turčianske Teplice
39	Topoľčany	Topoľčany	Dunajská Streda	Liptovský Mikuláš	Zlaté Moravce
40	Banská Štiavnica	Dolný Kubín	Krupina	Trebišov	Brezno
41	Rimavská Sobota	Trnava	Levice	Piešťany	Bánovce nad Bebravou
42	Piešťany	Trenčín	Michalovce	Humenné	Liptovský Mikuláš
43	Michalovce	Martin	Trenčín	Krupina	Stropkov
44	Nové Mesto nad Váhom	Zvolen	Námestovo	Levice	Banská Bystrica
45	Revúca	Púchov	Lučenec	Levoča	Zvolen
46	Poltár	Poltár	Senica	Turčianske Teplice	Nové Mesto nad Váhom
47	Levice	Levoča	Poprad	Spišská Nová Ves	Sabinov
48	Nové Zámky	Senica	Vranov nad Topľou	Topoľčany	Detva
49	Levoča	Brezno	Prievidza	Bánovce nad Bebravou	Poltár
50	Námestovo	Rimavská Sobota	Piešťany	Malacky	Michalovce
51	Trnava	Svidník	Trnava	Senica	Malacky
52	Žarnovica	Poprad	Martin	Brezno	Nové Zámky
53	Poprad	Malacky	Turčianske Teplice	Bytča	Martin
54	Krupina	Levice	Poltár	Martin	Žarnovica
55	Medzilaborce	Kežmarok	Bánovce nad Bebravou	Zvolen	Levice
56	Hlohovec	Zlaté Moravce	Banská Štiavnica	Trnava	Spišská Nová Ves
57	Senec	Dunajská Streda	Bytča	Nové Mesto nad Váhom	Púchov
58	Sabinov	Prievidza	Brezno	Poltár	Prievidza
59	Kysucké Nové Mesto	Nové Mesto nad Váhom	Zvolen	Čadca	Čadca
60	Prievidza	Banská Štiavnica	Malacky	Detva	Trnava
61	Kežmarok	Partizánske	Nové Mesto nad Váhom	Prievidza	Poprad
62	Čadca	Revúca	Detva	Sabinov	Partizánske
63	Považská Bystrica	Detva	Sabinov	Rimavská Sobota	Žilina
64	Malacky	Sabinov	Rimavská Sobota	Poprad	Rimavská Sobota
65	Stropkov	Turčianske Teplice	Čadca	Partizánske	Rožňava
66	Trebišov	Žarnovica	Revúca	Kežmarok	Senica
67	Rožňava	Čadca	Partizánske	Žarnovica	Medzilaborce
68	Komárno	Bánovce nad Bebravou	Kežmarok	Medzilaborce	Hlohovec
69	Bánovce nad Bebravou	Považská Bystrica	Považská Bystrica	Považská Bystrica	Považská Bystrica
70	Galanta	Rožňava	Žarnovica	Rožňava	Kežmarok
71	Dunajská Streda	Medzilaborce	Rožňava	Revúca	Komárno
72	Partizánske	Komárno	Komárno	Komárno	Revúca

Appendix B. Technical efficiency change index, 2017–2021

District	2018/ 2017	2019/ 2018	2020/ 2019	2021/ 2020	Mean *TEC*	Cumulative *TEC*
Bratislava I-V	1.028	0.949	1.108	1.000	1.020	1.081
Malacky	1.383	1.056	1.079	0.997	1.120	1.571
Pezinok	0.986	1.128	0.964	0.971	1.010	1.041
Senec	1.489	1.057	0.973	1.127	1.146	1.726
Dunajská Streda	1.466	1.283	1.008	0.994	1.172	1.885
Galanta	2.044	1.086	1.000	1.000	1.220	2.220
Hlohovec	1.589	0.967	0.944	0.816	1.043	1.184
Piešťany	1.196	0.976	1.063	1.060	1.071	1.315
Senica	1.004	1.127	0.986	0.916	1.006	1.022
Skalica	1.274	0.914	0.986	1.031	1.043	1.184
Trnava	1.256	0.986	0.987	1.000	1.052	1.222
Bánovce nad Bebravou	1.191	1.392	1.069	1.032	1.163	1.829
Ilava	1.071	0.965	1.043	0.932	1.001	1.005
Myjava	1.000	1.000	0.957	1.045	1.000	1.000
Nové Mesto nad Váhom	0.989	1.115	1.054	1.062	1.054	1.234
Partizánske	1.463	0.999	1.014	1.150	1.143	1.704
Považská Bystrica	1.015	1.132	1.031	1.110	1.071	1.315
Prievidza	1.183	1.208	0.907	1.081	1.088	1.401
Púchov	1.048	1.111	1.029	0.880	1.013	1.054
Trenčín	1.070	1.049	1.112	0.928	1.037	1.158
Komárno	1.006	1.069	1.068	1.197	1.083	1.375
Levice	1.064	1.202	0.995	0.938	1.045	1.194
Nitra	1.000	1.000	0.880	1.006	0.970	0.885
Nové Zámky	1.453	0.944	1.077	0.841	1.056	1.242
Šaľa	1.130	0.952	0.929	0.993	0.998	0.992
Topoľčany	1.136	1.064	0.959	1.185	1.083	1.374
Zlaté Moravce	0.858	1.405	1.054	0.839	1.016	1.066
Bytča	1.045	0.947	1.050	1.223	1.062	1.271
Čadca	1.040	1.244	1.100	1.018	1.097	1.449
Dolný Kubín	1.069	1.109	0.997	1.056	1.057	1.248
Kysucké Nové Mesto	1.795	1.000	0.964	1.037	1.157	1.794
Liptovský Mikuláš	1.070	1.137	0.896	0.988	1.019	1.077
Martin	1.069	0.985	1.003	1.012	1.017	1.069
Námestovo	1.396	0.939	1.037	1.009	1.082	1.372
Ružomberok	1.229	1.023	0.960	0.994	1.047	1.200
Turčianske Teplice	0.816	1.212	1.075	1.033	1.024	1.098
Tvrdošín	0.988	0.932	1.065	1.006	0.997	0.987
Žilina	0.973	1.092	1.130	0.751	0.975	0.902
Banská Bystrica	1.109	0.930	0.986	0.898	0.978	0.913
Banská Štiavnica	0.947	1.163	1.169	1.111	1.094	1.430
Brezno	0.710	1.059	1.056	1.055	0.957	0.838
Detva	0.743	1.134	1.041	1.075	0.985	0.943
Krupina	1.323	1.053	0.994	1.076	1.105	1.490
Lučenec	1.218	0.899	1.040	1.011	1.036	1.151
Poltár	1.130	1.025	1.010	1.051	1.053	1.229
Revúca	0.972	1.035	0.846	1.089	0.981	0.927
Rimavská Sobota	1.040	0.991	0.997	1.064	1.023	1.093
Veľký Krtíš	1.197	1.084	0.899	1.001	1.039	1.168
Zvolen	0.932	0.949	1.036	1.057	0.992	0.969
Žarnovica	0.906	1.048	1.071	1.225	1.056	1.246
Žiar nad Hronom	1.000	1.000	1.000	1.000	1.000	1.000
Bardejov	1.156	1.051	0.996	0.973	1.042	1.177
Humenné	1.156	1.012	0.969	1.078	1.051	1.222

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District	**2018/ 2017**	**2019/ 2018**	**2020/ 2019**	**2021/ 2020**	**Mean *TEC***	**Cumulative *TEC***
Kežmarok	1.262	0.918	1.020	1.034	1.051	1.222
Levoča	1.129	1.295	0.885	1.087	1.089	1.406
Medzilaborce	0.796	1.920	0.694	1.114	1.042	1.182
Poprad	1.139	1.140	0.838	1.139	1.055	1.239
Prešov	1.100	1.003	1.107	1.020	1.056	1.246
Sabinov	1.120	1.136	0.981	1.156	1.096	1.443
Snina	1.120	1.000	0.983	1.006	1.026	1.108
Stará Ľubovňa	0.976	0.924	0.990	1.059	0.986	0.945
Stropkov	1.795	1.040	1.066	0.825	1.132	1.642
Svidník	1.001	1.421	0.965	1.022	1.088	1.403
Vranov nad Topľou	1.194	0.950	1.059	1.041	1.058	1.250
Gelnica	1.320	1.000	0.878	1.013	1.041	1.174
Košice I-IV	1.000	1.000	1.000	1.000	1.000	1.000
Košice – okolie	1.168	1.000	1.000	1.000	1.040	1.168
Michalovce	1.238	1.010	1.021	0.936	1.046	1.195
Rožňava	1.019	1.242	0.960	1.299	1.121	1.578
Sobrance	1.000	1.000	1.000	1.000	1.000	1.000
Spišská Nová Ves	0.996	1.048	0.912	0.954	0.976	0.908
Trebišov	2.036	0.926	0.905	1.033	1.152	1.763

Appendix C. Malmquist index of *TFP* change, 2017–2021

District	2018/ 2017	2019/ 2018	2020/ 2019	2021/ 2020	Mean *MI*	Cumulative *MI*
Bratislava I-V	0.973	0.915	1.323	1.037	1.051	1.221
Malacky	1.491	1.034	1.152	1.119	1.187	1.987
Pezinok	1.027	1.172	1.096	1.088	1.094	1.435
Senec	1.539	1.067	1.198	1.247	1.252	2.453
Dunajská Streda	1.602	1.337	1.204	1.106	1.300	2.852
Galanta	2.208	1.075	1.079	1.079	1.289	2.763
Hlohovec	1.726	0.957	1.004	0.886	1.101	1.469
Piešťany	1.302	0.984	1.174	1.172	1.152	1.763
Senica	1.051	1.139	1.057	1.016	1.065	1.286
Skalica	1.303	0.957	1.168	1.055	1.113	1.537
Trnava	1.376	1.005	1.072	1.12	1.135	1.660
Bánovce nad Bebravou	1.223	1.394	1.269	1.035	1.223	2.239
Ilava	1.11	0.942	1.09	0.988	1.030	1.126
Myjava	0.993	1.03	1.133	1.02	1.043	1.182
Nové Mesto nad Váhom	0.982	1.154	1.128	1.182	1.109	1.511
Partizánske	1.528	0.985	1.068	1.218	1.183	1.958
Považská Bystrica	1.063	1.125	1.068	1.184	1.109	1.512
Prievidza	1.249	1.195	1.026	1.138	1.149	1.743
Púchov	1.086	1.093	0.923	1.09	1.045	1.194
Trenčín	1.12	1.1	1.287	1.004	1.123	1.592
Komárno	1.049	1.077	1.225	1.312	1.161	1.816
Levice	1.166	1.18	0.937	1.151	1.104	1.484
Nitra	0.996	1.035	1.099	1.067	1.049	1.209
Nové Zámky	1.539	0.932	0.993	1.03	1.101	1.467
Šaľa	1.083	0.973	1.178	1.046	1.068	1.298
Topoľčany	1.182	1.104	1.161	1.226	1.167	1.857
Zlaté Moravce	0.933	1.386	0.934	1.103	1.074	1.332
Bytča	1.098	0.975	1.11	1.421	1.140	1.689
Čadca	0.999	1.223	1.111	1.064	1.096	1.444
Dolný Kubín	1.102	1.15	1.086	1.078	1.104	1.484
Kysucké Nové Mesto	1.795	0.992	0.827	1.399	1.198	2.060
Liptovský Mikuláš	1.163	1.157	0.979	1.086	1.093	1.431
Martin	1.148	1.026	1.126	1.096	1.098	1.454
Námestovo	1.37	0.913	1.024	1.086	1.086	1.391
Ružomberok	1.282	1.066	1.11	1.092	1.134	1.656
Turčianske Teplice	0.869	1.25	1.227	1.084	1.096	1.445
Tvrdošín	1.024	0.945	1.132	1.066	1.039	1.168
Žilina	1.033	1.082	0.971	0.996	1.020	1.081
Banská Bystrica	1.188	0.969	1.089	0.986	1.054	1.236
Banská Štiavnica	0.933	1.156	1.413	1.105	1.139	1.684
Brezno	0.712	1.098	1.196	1.037	0.992	0.970
Detva	0.744	1.096	1.048	1.329	1.032	1.136
Krupina	1.334	1.036	1.054	1.204	1.151	1.754
Lučenec	1.253	0.879	1.027	1.188	1.077	1.344
Poltár	1.086	0.983	1.06	1.142	1.066	1.292
Revúca	0.956	1.023	0.844	1.332	1.024	1.099
Rimavská Sobota	1.015	0.964	1.129	1.042	1.036	1.151
Veľký Krtíš	1.154	1.045	0.933	1.034	1.038	1.163
Zvolen	0.984	1.006	1.174	1.054	1.052	1.225
Žarnovica	0.95	1.026	1.097	1.312	1.088	1.403
Žiar nad Hronom	1.053	1.012	1.044	1.123	1.057	1.249
Bardejov	1.099	1.001	1.052	1.053	1.051	1.219
Humenné	1.122	1.03	1.027	1.079	1.064	1.281

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District	**2018/ 2017**	**2019/ 2018**	**2020/ 2019**	**2021/ 2020**	**Mean** MI	**Cumulative** MI
Kežmarok	1.278	0.902	1.042	1.066	1.064	1.280
Levoča	1.088	1.272	1.085	1.009	1.109	1.515
Medzilaborce	0.673	1.735	0.843	0.929	0.978	0.914
Poprad	1.167	1.195	0.985	1.158	1.123	1.591
Prešov	1.105	0.977	1.175	1.103	1.088	1.399
Sabinov	1.065	1.105	1.05	1.131	1.087	1.398
Snina	1.11	0.971	1.07	1.005	1.038	1.159
Stará Ľubovňa	0.952	0.915	1.084	1.013	0.989	0.957
Stropkov	1.648	1.006	1.318	0.774	1.140	1.691
Svidník	1.037	1.402	0.965	1.061	1.105	1.489
Vranov nad Topľou	1.109	0.905	1.111	1.107	1.054	1.234
Gelnica	1.235	0.952	0.874	1.167	1.046	1.199
Košice I-IV	0.978	1	1.004	0.999	0.995	0.981
Košice – okolie	1.131	0.99	1.023	1.065	1.051	1.220
Michalovce	1.248	0.977	1.044	0.995	1.061	1.267
Rožňava	1.032	1.21	1.03	1.32	1.141	1.698
Sobrance	0.865	0.851	1.053	0.848	0.901	0.657
Spišská Nová Ves	1.045	1.029	0.908	0.992	0.992	0.969
Trebišov	1.919	0.894	0.98	0.988	1.135	1.661