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Evaluation of the Landfill Storage Capacity in Slovakia, Compared to the EU Situation

Zuzana Šimková, Marcela Taušová *, Katarína Čulková, Peter Tauš, Danylo Shyp, David Krasniči and Simona Novotná

Department of Earth Resources, FBERG, Technical University of Košice, Letná 9, 04200 Košice, Slovakia; zuzana.simkova@tuke.sk (Z.Š.); katarina.culkova@tuke.sk (K.Č.); peter.taus@tuke.sk (P.T.); danylo.shyp@tuke.sk (D.S.); david.krasnici@tuke.sk (D.K.); simona.novotna@tuke.sk (S.N.)

* Correspondence: marcela.tausova@tuke.sk (M.T.); Tel.: +421-6023116

Abstract: The circular economy and efficient use of resources gained importance in the context of sustainable development. The paper aims to evaluate the development of landfilling in Slovakia. The next goal is to assess the trend in compared with the EU's situation. The presented research presents a continuation of previous research in the area of waste recycling in Slovakia, pointing to the waste and landfilling, which is deserving of analysis from a long-term perspective. The research is carried out via data collection at the EU level by recording continuously published values. The paper's results are processed in statistical software. Considering regional development, landfilling in Slovakia is followed up according to the geographical units of the entire country. The results shown here show that a higher recycling capacity is required and Slovakia should decrease its level of landfill. Such results can be used in the waste treatment area, protection of the living environment and sustainable development of regions.

Keywords: waste treatment; circular economy; landfilling; sustainability; regional development

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1. Introduction

The circular economy and efficient use of resources, pollution reduction and waste minimization have become important global political goals. They represent challenges for the political community in formulating credible and ambitious targets in resource use, greenhouse gas emissions and waste use. Currently, the EU increasingly regulates and evaluates waste management. The EU's goals in waste management are strict. This paper aims to monitor indicators in specific areas of municipal waste production, consumption or secondary raw materials that accurately reflect the current situation in the EU. Likewise, the production of waste per capita, which increases yearly in many EU countries, presents an opportunity for a greater return of raw materials and energy to industry. The circular economy, as one of the youngest interdisciplinary industries, is gaining nowadays gaining increasing importance in several aspects, not only from an economic or ecological point of view, because recycling materials is many times cheaper than extracting them from the depths of the Earth with extraordinary energy demands. Among the key aspects, we can include economic and ecological ones. These two aspects are interlinked. On the other hand, using waste as a source of raw materials reduces the financial costs of extracting materials. It reduces the environmental impacts of mining as well, whether by reducing surface degradation by surface mining or tailings heaps from underground mining, or by eliminating the energy intensity of mining processes. In addition, waste as a "domestic" source of materials, can increase the security of a country's supply of raw materials. Waste is the raw material of the future, and the transformation of Slovakia's waste management is only the beginning of this critical and overall transition to a circular economy. A set of current and available information, knowledge of technologies stemming from experience with the application of circular economy principles, a sufficient number of examples from practice, as well as legislation and data on the current state of waste management, were the basis for the creation of the presented analysis. Given the above, Slovak waste management, after more than 30 years of independent operation, is still characterized by a dominant model of waste landfilling, which is gradually ending its chapter of existence.

Western Europe has been struggling for years for waste management services for citizens. Therefore, the citizens of the Slovak Republic will urgently need a suitable waste management system in the coming years. There should be no unnecessary attempts or stumbles, as has happened many times in the West. Still, eventually, these countries ended up with the same thing—separation, recycling, energy recovery, and ecological design. Currently, an enormous volume of waste is not used, which ends up in landfills throughout Slovakia and, besides the environmental burden for future generations, creates greenhouse gases with a far-reaching impact on the atmosphere. In 2020, the share of landfilling in the Slovak Republic was at the level of 48%, the share of recycling was 44%, and the energy use of waste was 8%.

Because of European legislation, this trend must change by 2035, while landfilling should be at a maximum level of 10%, and recycling at least 65%. Before then, the share of recycling should be 55% by 2025 with a gradual reduction in landfilling. The rest can be energetically recovered, while the expected composition copies and fulfills the principles of the hierarchy of waste management and the principles of the circular economy. The results mention the acquisition of electricity and heat, but also the return of materials back to industry as secondary raw materials, where primary raw material and energy resources are saved, especially if we are talking about the ongoing fourth industrial revolution essentially dependent on the import of non-renewable and exhaustible raw materials. Because of the mentioned facts, the academic community dealing with mineral raw materials, recycling and renewable energy sources aims to popularize the topic of municipal waste management and to define the development and the needs of waste management in the horizon of 15 years, resulting in recommendations, the fulfillment of which is needed to start working today. The permitting process of waste management activities takes years. Therefore, it is necessary to define clearly achievable goals, cost-effective and socially acceptable solutions, as well as existing technologies [1].

"Landfilling" represents the worst and most unsuitable alternative for waste management, because in this case none of its potential, material or energy is recovered. Waste is only stored in managed waste dumps. There are currently 111 active landfills of all types of waste in the Slovak Republic, with the aim of gradually closing them down. The paper aims to evaluate landfilling in Slovakia in terms of the capacity possibilities of individual landfills and annual requirements for landfilling. Many analysis points to the impossibility of meeting the goals by 2035 (in the area of landfilling). In this paper, we critically evaluate the sustainability of landfilling according to the current setup in the country, and we outline the turning point.

Rational use of landfills significantly increases storage capacity [2]. Moreover, the settlement of municipal solid waste (MSW) in the landfilling process affects the structure and capacity of the landfill [3]. From this view Gao et al. proposes a calculation of the settlement and capacity of landfills [4]. Landfilled solid wastes should also be solved due to the problem of acids and their effects [5].

The maximization of secondary raw material recovery is necessary to increase the economic and environmental sustainability of landfills and their capacity for economic effectiveness [6]. In the frame of rapid population growth, rapid urbanization creates a need to select appropriate landfill sites. Therefore, Arkoc presented a new solid waste site selection tool to assess and choose areas for municipal solid waste (MSW) landfill use, saving time and money [7].

Landfill capacity belongs to the significant task of municipal solid waste management [8]. According to Gao et al., landfill stability is also important [9]. Belciu et al. (2016) calculated the production capacity of landfill situated in Romania related to the total amount of waste disposed of in landfill [10]. According to Ionescu et al., MSW sorting and material recovery from landfill waste should consider other parameters [11]. According to Mahanta et al., the slope of landfill is important for the evaluation of landfill capacity as well [12].

The evaluation of landfill capacity demands considering the lifecycle [13]. Engineering measures must be proposed to increase the slope stabilization and landfill capacity [14]. According to Li et al., landfill capacity can be increased by intensive initial compaction, decomposition condition adjustment and the lowering of leachate levels [15]. Goli et al. improved the methodology employed for determining the capacity since the utilization of landfill mining activity lacks an understanding of its characteristics [16]. As Davoli et al. stated, integrated risk assessment studies help to solve landfill capacities [17]. On the other hand, exceeding landfill capacity faces significant environmental and sustainability challenges, indicating it is important to find an environmentally friendly operation of landfills [1]. The problem with the landfill capacity stems from unplanned future landfill locations, when the controlled landfill is a more appropriate solution [18]. Therefore, Amritha and Anilkumar suggested an approach of knowing the quality and quantity of the waste and the background environmental conditions of a particular region to plan landfills for urban conditions [19].

Landfill capacity is studied across the different regions. For example, Yamawaki et al. in Japan and three other countries [20] also study the bearing capacity of the landfills. Roofed landfills have gained popularity in Japan, contributing to solving the problem of exceeded capacities of landfills' urban dimensions [21]. Johansson et al. investigated the capacity of Sweden to manage the environmental, resource and economic conditions of landfill mining [22]. Moreover, in Sweden, landfills are excavated on a relatively modest scale to increase landfill capacity proposing a potential increase in the demand for recycled materials [23]. Wee et al. made a study of landfills in Indonesia, and found that controlled landfills support sustainable development at the local and national levels [24]. Aleluia and Ferrao completed a study of relations between urban indicators and landfill capacities in developing countries in Asia, finding differences between low-income and high-income countries [25]. In China, landfills are the most widely used method for the disposal of municipal solid waste (MSW). Han et al. indicated that the groundwater contamination near MSW landfills should be a concern, but also valuable to prevent the MSW landfill from secondary pollutants [26]. Owusu-Nimo et al. contributed to the limited information on the landfill waste capacity in Ghana [27].

The study of landfill capacity can contribute to solving landfill gas use. Arkharov et al. showed how to use such technologies to provide the economic benefits of landfill gas [28]. The next landfilling area for solid waste use is in municipality waste management. In this area, Ding et al., provide an improved framework for selecting a landfill site, for urban planning [29]. Landfill sites act as ecological reactors and are critical factors for sustainable landfilling [30]. Current landfill waste should eliminate the negative environmental impacts associated with waste disposal on land, controlling the emissions [31]. However, according to Jo and Jang, landfill settlement and capacity must be studied from the long-term view [32].

Waste is nowadays considered as a sustainable energy source [33,34]. Individual countries have their percentage rate of municipal waste generation. Great importance is given to landfilling and waste-to-energy [35], together with economic development and environmental practices [36]. Waste-to-energy is important to implement in developed and developing countries to manage waste and reduce landfilling. Socioeconomic factors have great importance in terms of of public preference and acceptance [37]. In this context, Beloborodko et al. studied the implementation of waste-to-energy technologies in Latvia, considering non-technical aspects to increase public acceptance [38]. Researchers showed there are obstacles, but also the potential for waste-to-energy projects, mostly in developing countries [39]. Such projects can improve the quality of the entire waste management system [40]. The main global goals include a reduction in emissions and waste minimization. The paper is not primarily orientated to the effects of landfilling but to the use of waste as a raw material. Another issue is leakage from landfills, but this mainly comes from old landfills; the new ones are created according to modern standards. We determined to study according to the geographical view, since sustainable development of waste management presents part of the regional planning and prediction of waste management [41].

2. Results

Here, we provide an analysis of the state of landfill capacities in Slovakia. Due to the lack of publicly available data for the analysis and evaluation of measures in waste management and the implementation of the circular economy approach, it was necessary to analyze the current state of landfill capacities of individual waste disposal facilities in Slovakia. For this, the method of obtaining data from state institutions, which catalogs the relevant information to monitor and control environmental pollution, was chosen. Based on Act 211/2000 Coll. on free access to information, in 2021, the Slovak Environmental Inspectorate was asked for information related to the amount of imported waste in recent years, but also for information that is more substantial—the remaining landfill capacities in the Slovak Republic, in individual regions. Based on the data that were made available for the purposes of this study, we can state that almost 70–80% of the data on individual active landfills in the Slovak Republic was provided. For the correctness of handling the data of the operators and for their acquisition for academics, regions will be evaluated in the summary, and individual landfills will only be based on their occurrence in a given municipality or city based on the currently available landfill capacities. At the same time, capacities permitted in the EIA process or permitted in the last 2–3 years will be taken into account; these data are available from publicly available sources on the state portal www.enviroportal.sk, accessed on 1 December 2023. A conservative outlook for generating waste volume was prepared to better understand today's volume of municipal waste produced in the Slovak Republic. If we were to landfill all the waste produced in Slovakia today and until 2035, the capacity requirements would be as follows with a compaction coefficient of 1.4 in individual regions (see Table 1). In the row where the current production is, the amount of waste is in tons per year, in relation to the production in individual regions. Below is the value converted to potential capacities in $m^3 \cdot year^{-1}$.

Table 1. Prediction of the landfill capacity need in Slovakia.

Region	Western Slovakia	Central Slovakia	Eastern Slovakia	SUM
CW production/year	1,290,250.50	564,712.60	579,076.40	2,434,039.50
Prediction m^3/year				
2021	930,823.58	407,399.80	417,762.26	1,755,985.64
2022	940,131.81	411,473.80	421,939.88	1,773,545.50
2023	949,533.13	415,588.54	426,159.28	1,791,280.95
2024	959,028.46	419,744.43	430,420.87	1,809,193.76
2025	968,618.74	423,941.87	434,725.08	1,827,285.70
2026	978,304.93	428,181.29	439,072.33	1,845,558.55
2027	988,087.98	432,463.10	443,463.06	1,864,014.14
2028	997,968.86	436,787.73	447,897.69	1,882,654.28
2029	1,007,948.55	441,155.61	452,376.66	1,901,480.82
2030	1,018,028.04	445,567.17	456,900.43	1,920,495.63
2031	1,028,208.32	450,022.84	461,469.44	1,939,700.59
2032	1,038,490.40	454,523.07	466,084.13	1,959,097.59
2033	1,048,875.30	459,068.30	470,744.97	1,978,688.57
2034	1,059,364.06	463,658.98	475,452.42	1,998,475.46
2035	1,069,957.70	468,295.57	480,206.95	2,018,460.21
SUM	14,983,369.85	6,557,872.09	6,724,675.46	28,265,917.40

Table 2 gives a prediction in comparison with the EU-determined goals. From Table 2, the volume of landfilling in Slovakia and the goal of achieving a maximally determined recycling and potential for energetic recovery (ER) of 10% are obvious. As we can see from Table 2, if in 2035 we want to reach the goal set by the EU and landfill a maximum of 10%, it is clear from the prediction that we will produce 282,584.43 of waste per year. If we were to recycle up to 65% of waste simultaneously, we would still have 25% of waste that we cannot deal with further. Therefore, in our prediction, we arrive at a value of 989,045.50 tons of waste (the amount of landfilled waste in 2035 plus waste that is no longer recyclable), which will have to be considered further, while only energy recovery is considered.

Table 2. Prediction of landfilling in Slovakia compared with EU goals.

Year	Sum	Landfilling Rate	Ton/Year	Recycling Rate	Ton/Year	Not Recycled	Ton/Year	Energetic Recovery Potential
2020	2,434,039.50	45%	1,106,270.95	46%	1,130,854.75	8%	196,913.80	1,303,184.75
				Prediction				
2021	2,458,379.90	45%	1,106,270.95	46%	1,130,854.75	9%	221,254.19	1,327,525.14
2022	2,482,963.69	42%	1,042,844.75	48%	1,191,822.57	10%	248,296.37	1,291,141.12
2023	2,507,793.33	39%	978,039.40	51%	1,278,974.60	10%	250,779.33	1,228,818.73
2024	2,532,871.26	36%	911,833.66	53%	1,342,421.77	11%	278,615.84	1,190,449.49
2025	2,558,199.98	30%	767,459.99	55%	1,407,009.99	15%	383,730.00	1,151,189.99
2026	2,583,781.98	28%	723,458.95	56%	1,446,917.91	16%	413,405.12	1,136,864.07
2027	2,609,619.80	26%	678,501.15	57%	1,487,483.28	17%	443,635.37	1,122,136.51
2028	2,635,715.99	24%	632,571.84	58%	1,528,715.28	18%	474,428.88	1,107,000.72
2029	2,662,073.15	22%	585,656.09	59%	1,570,623.16	19%	505,793.90	1,091,449.99
2030	2,688,693.89	20%	537,738.78	60%	1,613,216.33	20%	537,738.78	1,075,477.55
2031	2,715,580.82	28%	760,362.63	61%	1,656,504.30	11%	298,713.89	1,059,076.52
2032	2,742,736.63	16%	438,837.86	62%	1,700,496.71	22%	603,402.06	1,042,239.92
2033	2,770,164.00	14%	387,822.96	63%	1,745,203.32	23%	637,137.72	1,024,960.68
2034	2,797,865.64	12%	335,743.88	64%	1,790,634.01	24%	671,487.75	1,007,231.63
2035	2,825,844.30	10%	282,584.43	65%	1,836,798.79	25%	706,461.07	989,045.50
Sum	39,572,284.36	0%	10,169,727.32	0%	22,727,676.78	0%	6,674,880.26	16,844,607.58

Source: own processing according to Statistical Office, SR and prediction.

The prediction was based on statistical data (www.enviroportal.sk; accessed on 1 December 2023), which show that the annual increase in landfilled waste in Slovakia is 1%. Presently free capacities in the individually open landfills in Slovakia are as follows (see Figure 1).

Figure 2 illustrates the actual free capacity and filling of landfills in Slovakian counties. The horizontal axis illustrates the volume of the waste, deposited at landfills in 2021. The vertical axis illustrates free landfill capacity in a given county, and the volume of the bubble corresponds with the waste storage volume. The color scale presents a measure of material recovery of communal waste in the counties.

From Figure 2, it is obvious that Kosice and Bratislava counties have the highest rates of communal waste recovery (datacube.statistics.sk/, accessed on 1 December 2023). Kosice county conducts landfilling at a low rate, and it uses a low amount of its allowed capacity of landfills. The highest capacities are in Banska Bystrica and Trnava counties; Presov and Trencin counties are relatively in the middle. The largest volume of stored waste is in Trnava county, which reflects the presence of the highest measure of waste production and the high concentration of industry in the western part of Slovakia. There is probably a confirmed dependence between equipment for energetic waste recovery and the lowest weight of the waste which ended up at the landfills. Kosice and Bratislava counties have the highest material recovery of waste. It is necessary to mention that this does not mean only landfilling of communal waste, since according to the data available, it was not possible to separate communal and industrial waste. In addition, structuring according to the individual region would be even more difficult, since the waste, starting in one county, can end at a landfill in another county, either via industry or the communal sphere.

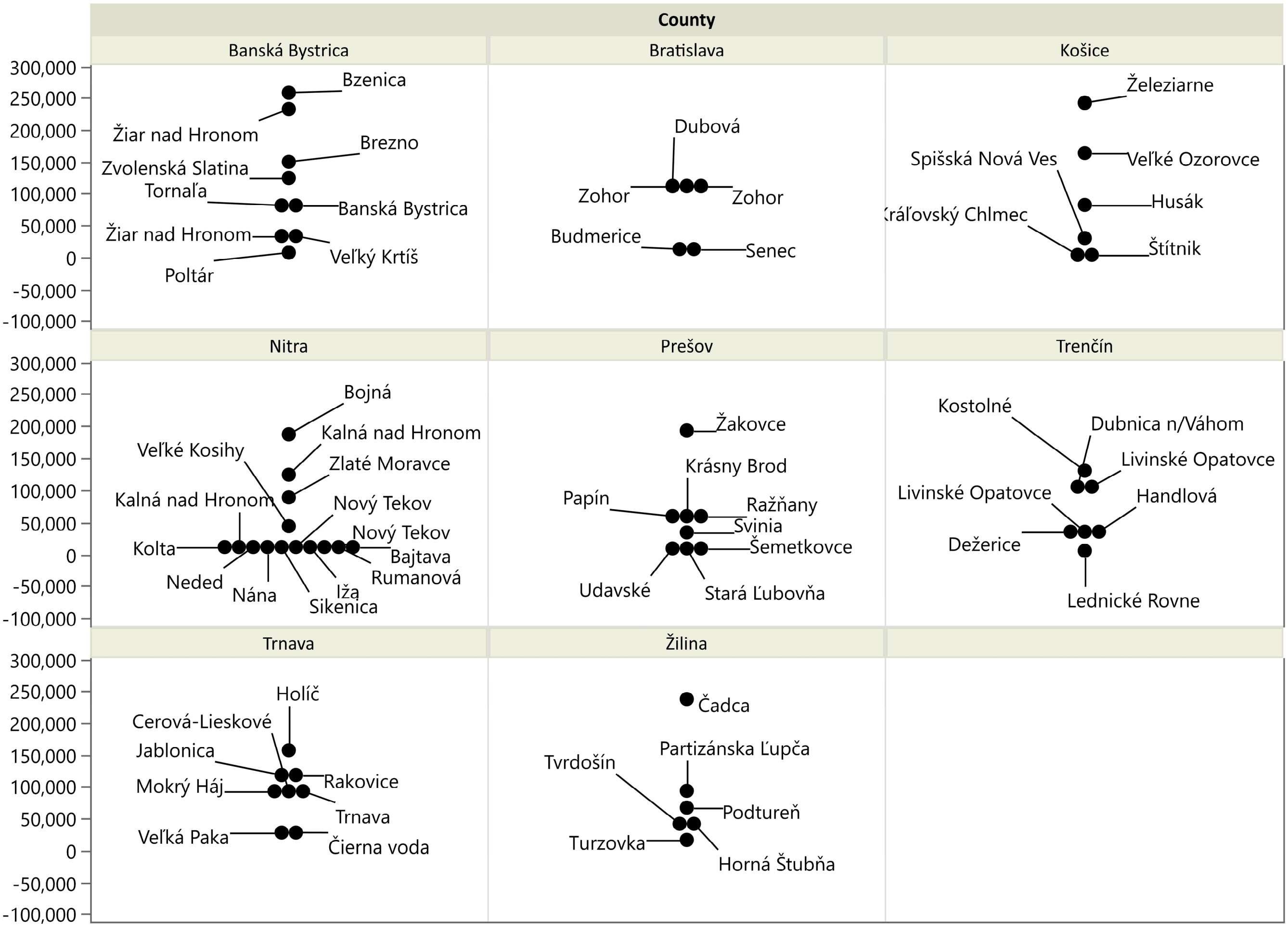

Figure 1. Free capacity in the individually open landfills in Slovakia. Source: own processing according to available data.

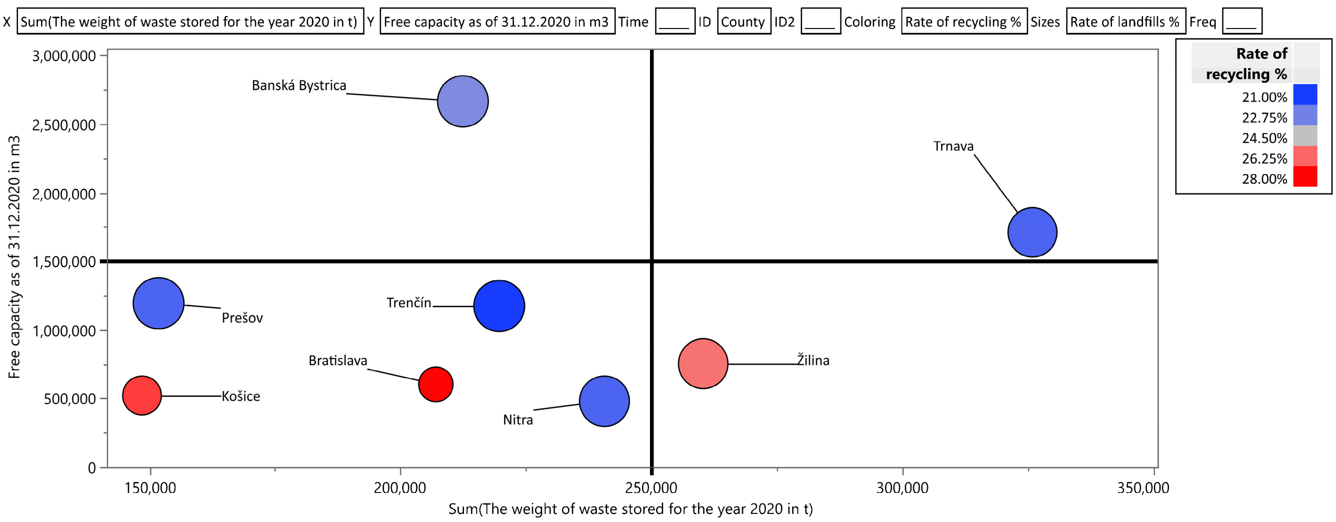

Figure 2. Present state of landfills capacity in Slovakia. Source: own processing in (http://datacube.statistics.sk; accessed on 1 December 2023).

3. Discussions

After entering the EU, Slovakia had landfilled 46% of produced waste (in 2007), during the crisis and after the crisis the percentage decreased significantly to 39% and 31%. In

2018, in Slovakia, it reached 21%, and in 2019, it reached 17%. This means that from 2005 to 2008, Slovakia stored approximately four million tons per year; during the crisis, the absolute volume decreased to 2.6 mil tons per year. Between 2011 and 2016, Slovakia stored approximately 2.9 mil tons per year, and in the last three years, the volume was 4262 mil tons. In 2019, Slovakia's industrial waste production was a little higher—10,038 mil tons and 1667 mil tons. These are excellent results, showing that the majority of industrial organizations transitioned from waste disposal to waste recovery and recycling.

In spite of the production of industrial waste during the economic growth smoothly increasing, which shows the natural cycle, environmental principles of the waste economy are successfully implemented, and still, increasing amounts of industrial waste are recovered and recycled. The decrease in stored industrial waste from 46% to 17% underlines the situation (www.odpady-portal.sk; accessed on 1 December 2023). When considering waste volume and storage in Slovakia, in the communal sphere, it represents 48%, and in the industrial sphere, it represents 17%—approximately 2.8 mil tons per year. By 2035, with a 1% growth in communal waste and a decrease in weight to 10% of production, Slovakia could store only 280 thousand tons per year. This means the present volume of waste storage – 42%—could be only 15% in 2035.

This is because the storage of waste (present 17%) from industry presents the least likely possibility due to the previous trends and recovery capacity. Probably, only the waste, which is not economically available, will be stored, or there will be no recovery capacity.

Data available from the information system and data from the Ministry of Living Environment show that in 2020, in the whole of Slovakia, there was an approximate landfill capacity of 18 mil m^3 in the landfills with non-dangerous and inert waste.

Similarly, certain landfills in past years demanded an extension of their capacities through the EIA process, which presents a possible increase in the whole of Slovakia's capacity of approximately 3.7 mil m^3 in summer 2021, consisting of evaluated capacities or landfills with finished evaluation. The summary of the data gives a capacity of approximately 22 mil m^3. The free capacity for communal waste for SKNNO will be approximately 9 mil m^3, and an approximately 3 mil m^3 capacity will be allowed due to the following rapidly decreasing trend of landfilling, since in 2035, the total need will be approximately 10 mil tons. This can be presented with the coefficient of the waste density (approximately 1.4 consumed capacity) of 7–8 mil m^3.

The need to predict production capacities and develop the landfill capacities in time results in there not being enough recycling capacity at the level of bio-waste [42]. Therefore, it will be necessary to accept action plans for the recovery capacities at the level of autonomies as soon as possible. The task is also to find a way to solve non-recycled communal waste in the sense of the waste economy hierarchy [43].

It is not possible to consider only communal waste since CW depends on the creation of waste by inhabitants, but similarly, industrial waste is connected to the economy and GDP [44]. Therefore, it is necessary to catch the capacities according to the regions and from the view of proper logistics in order to avoid the situation where the waste from the middle of Slovakia must be due to a lack of capacity in other parts of Slovakia, which would be not an economical solution. A circular economy is presently a tool for sustainable development in areas with raw materials, energy and waste treatment; therefore, its potential should be fully utilized.

Observing the principles of the waste economy hierarchy is necessary since it is a way to increase recycling and minimize landfilling [45]. This goal uses the support of the regional capacities of mechanical and biological waste treatment to maximize waste recycling and recovery.

It is necessary, for example, at the county level, to solve waste treatment as the strategic task of control over public finances for a consequent period [46].

Control organizations must continue to control the reporting of autonomies with the aim of tracking the actual sorting measurement and verifying the fees for landfilling with the goal that autonomies and inhabitants would be motivated to sort their waste [47].

It is also necessary to use bio compost as a standard fertilizer and to use it for soil regeneration as a bio cultivation fertilizer. The reason is that when the compost ends up at a landfill and covers the waste, it does not meet the principles of the circular economy [48].

Lastly, but very importantly in the waste economy and area of science and research of raw materials, is the approach "landfill mining", where from the existing and full landfills, it would be possible to extract materials as a potential source of secondary raw materials for industrial use in the future [49].

It is very important to consider a fact and a trend: when speaking of energetic recovery, it is important to make appropriate strategic decisions for the complex system of a waste economy and circular economy in Slovakia [50,51].

4. Materials and Methods

Landfilling is still the most common method of waste management in Slovakia. The aim of the present contribution is a description of the dominant waste management end devices, current and future capacities, prediction of the likely consumption of landfill capacities, and evaluation of the potential end devices in the context of Slovakia's obligations and under the proposal of the Program of Waste Economy, Slovakia, the hierarchy of waste management and the transition to the principle of a circular economy.

In Slovakia, 111 landfills are legally operated in 101 landfill areas with a total amount of municipal waste of 1.2 million tons annually. The number of landfills and the rate of landfilling are gradually decreasing. While in 2010, 81% of municipal waste was landfilled in Slovakia, in 2018, this value dropped to 55% and in 2020 to 48%. In Slovakia, approximately 10,700 people live within 500 m of legal landfills. The number of inhabitants near landfills varies significantly from less than 10 people to landfills with a local population of 1300 or 3700 inhabitants. More than 40% of sites do not meet the technical distance standards, of which 16 were created after the publication of the standard in 2004. Out of 42 risky sites, 38 sites do not meet the standard regarding dwellings within 500 m, there is a medical facility near one landfill, and 12 landfills are less than 1000 m from the nearest schools (www.minzp.sk, IEP; accessed on 1 December 2023) (www.enviroportal.sk; accessed on 1 December 2023).

As already mentioned, the biggest problem continues to be the high proportion of waste landfilling, which represents up to 24.8% of the total amount of generated waste (see Table 3). In 2018, 111 waste landfills and 9 incinerators were operating in Slovakia, including two waste energy recovery facilities and waste co-incineration facilities (https://envipak.sk; accessed on 1 December 2023, POH SR 2021–2025).

Table 3. Waste treatment, including communal waste in Slovakia.

The Way of Waste Treatment (t)	
Landfilling	3,344,077
Burning without energetic use	40,857
Other disposal	321,294
Burning with energetic use	569,321
Recycling	3,721,477
Other evaluation	1,526,576
Other treatment	3,954,434
SUM	13,478,036

Source: own processing according to the Ministry of Living Environment, SR.

The Eurostat data document the unevenness of waste management in EU countries, showing significant differences in waste policies of the individual countries (www.ec.europa.eu, accessed on 1 December 2023). A positive finding is that the share of waste incineration without energy use, and the share of landfilling in most countries, has significantly decreased. In addition, from the point of view of environmental impact, the increase in waste recycling, composting and use in digestion processes, as well as the increase in the energy use of waste, is positive. EU countries are gradually trying to reduce the share of waste placed in landfills, eliminate the incineration of waste without energy use and increase the share of energy recovery from waste (related to the increase in the share of waste sorting) with an almost unchanged share of material recycling of waste. This indicates the dependence of reducing waste landfilling on increasing waste sorting related to energy recovery. The stable share of recycling indicates that the increased amount of waste sorted does not result in an enormous increase in recycling. Waste that is technically and technologically no longer possible, or economically not advantageous to recycle, means that mixed municipal waste that is treated and no longer recyclable has energy recovery as its last treatment.

By analyzing the data published by Eurostat, it was possible to compile a ranking of the most prosperous countries that achieve the highest rate of waste recycling, the highest rate of energy recovery and the lowest rate of landfilling (Table 4).

Table 4. Top 10 EU countries in 2018 according to the waste economy hierarchy.

Rank	Highest Rate of Energetic Recovery	Rank	Highest Rate of Recycling	Rank	Lowest Rate of Landfilling
1.	Finland	1.	Slovenia	1.	Switzerland
2.	Norway	2.	Germany	2.	Sweden
3.	Sweden	3.	Belgium	3.	Finland
4.	Denmark	4.	Norway	4.	Germany
5.	Switzerland	5.	Denmark	5.	Belgium
6.	Luxemburg	6.	Italy	6.	Denmark
7.	Estonia	7.	Switzerland	7.	Netherland
8.	Ireland	8.	Ireland	8.	Austria
9.	Belgium	9.	Sweden	9.	Norway
10.	Netherland	10.	Luxemburg	10.	Luxemburg

Source: own processing according to Eurostat.

The Nordic countries are leaders not only in reducing the share of landfilling and increasing the share of energy recovery of waste but also in recycling and material recovery from waste. From the point of view of the connection between reducing the share of landfilling and increasing energy recovery capacities, it is interesting that the number of countries introducing this method of waste recovery is also increasing. As illustrated, Slovakia does not belong among the top 10 EU countries in terms of landfilling. The present method of solving this problem is also supported by previous research on communal waste recycling in self-governing regions of Slovakia through chosen economic indicators, specifically the results of Jo and Jang. Waste and landfilling deserves analysis from a long-term perspective [42,52–54].

The data of the research are from the EU, recording continuously published values of selected indicators from the portal https://ec.europa.eu/eurostat/data/database (accessed on 1 December 2023) for all available years and all available member states. Slovak data were continuously collected within the framework of the Slovak statistical portal http://datacube.statistics.sk/ (accessed on 1 December 2023). We recorded, sorted and edited the collected data in a database created in the spreadsheet editor MS Excel according to the requirements of the statistical software, into which the edited data were transferred and subsequently analyzed. The range of published data differs significantly for individual indicators, while the volume of data is related to the incompleteness of entry by countries, or the publication of data for some indicators every other year, as is the case with data at the level of regions of the Slovak Republic. We adapted the choice of analysis and the formulation of conclusions to the scope and structure of the obtained data. All presented data, generated analyses, conclusions and recommendations are based on the available database Eurostat, the Statistical Office of the Slovak Republic, the database of environmental data on the Enviro-portal, and websites of operators of waste management services. Much data are not publicly available, and the information was obtained by Act No. 211/2000, about free access to information.

As part of the research, we compared the regions with each other. The graphic analysis was carried out using cartographers, in which we compared the results, while we examined whether there was a change in the analyzed regions. In a point graph, color distinguishes the compared results for individual regions. In individual analyses of each indicator, the interrelationship between several indicators was investigated at the same time, which is graphically displayed using bubble charts. This made it possible to take a comprehensive look at the interrelationship between four indicators—the free capacity of landfills, the weight of stored waste, the rate of recycling and the rate of landfilling in a specific year. The horizontal axis shows the amount of waste stored in landfills for the year 2020, the vertical axis shows the free capacity of landfills in a given region, the size of the bubble corresponds to the share of landfilling and the color scale represents the rate of material recovery in the regions.

In the research, we considered the EU action plan for the circular economy, the Europea Circular Economy Package and its relevant directives (https://www.europarl.europa.eu; accessed on 1 December 2023), the Framework Directive on Waste (2008/98/EC), the Directive on Landfills (1999/31/EC), the Directive on Packaging Waste (94/62/EC), and the Directives on End-Of-Life Vehicles (2000/53/EC), on Batteries, Accumulators, Used Batteries, and Accumulators (2006/66/EC) and on Waste from Electrical and Electronic Equipment (2012/19/EU). The other directives considered are the Common EU Target tp recycle 65% of municipal waste by 2035, the Common EU Target to recycle 70% of packaging waste by 2030, the Binding Goal to limit landfilling to a maximum of 10% of municipal waste by 2035 (with exceptions to postpone the deadline for achieving this goal by five years), the European Green Deal and New Circular Economy Action Plan.

During the research, we utilized the hierarchy of waste economy (§ 6 Law No. 79/2015 Codex—Hierarchy of waste economy, goals and obligatory limits for waste economy). The most inconvenient methods of waste disposal are landfilling, incineration, recovery by energy production, and material recovery, which means recycling.

We studied the situation of landfilling in Slovakia according to the geographic division of the entire country. Slovakia is divided into Bratislava (NUTS SK01), western Slovakia (SK02), middle Slovakia (SK03) and eastern Slovakia (SK04). The Bratislava region is due to the counties' division from western Slovakia (www.sodbtn.sk, accessed on 1 December 2023). The division of the Slovak Republic is into the territorial units (regions), which are western Slovakia (regions Bratislava, Trnava, Trenčín, Nitra), central Slovakia (regions Banska Bystrica, Zilina) and eastern Slovakia (regions Kosice, Presov).

5. Conclusions

Consumption of the landfill capacity can be modeled with specific measures over time because of the present state of the waste economy in the industrial sector. Since non-dangerous waste landfills also obtain waste from industry, we cannot consider the landfills to be only filled with communal waste. A definite, immediate, economical and rapid tool for solving the waste economy does not exist. Such approaches must reflect legislative needs and claims, but also financially acceptable measurements in the area of public finances by ensuring that inhabitants do not pay hundreds of EUR for their waste annually. They should treat the waste in a sustainable, motivational and environmental way and not burden the waste treatment system with non-recyclable waste.

Regarding the Program for Waste Economy in Slovakia for 2021–2025, it is necessary to mention that from the view of the action plan and in accordance with the analysis results that define where there are ZEVO, there are waste landfills that are more environmentally acceptable. Therefore, it is necessary as soon as possible to extend the present processing capacities for the energetic recovery in Bratislava and Kosice, since the potential of those regions of Slovakia in the communal and industrial spheres is significant. Concerning the previous development, it is also very important to build recycling capacities in the mentioned regions, since the results of the waste treatment according to the material recovery rate solidly prove the trend.

The following two factors can be a problem: a shortage of capacity for the recovery of communal waste, which would not end up in landfill in the future, and a shortage of capacity for industrial waste. By around 2030, the recovery capacities will no longer be increasing; there will be a big problem with non-recycled communal waste and a problem with industrial waste that is presently stored and heavily placed in the present recovery capacities.

The basis for the first factor is the energetic recovery of the waste; in the second case, the solution can be heavily solved, since a volume of the industrial waste can have an energetic use instead of the present landfilling. Waste landfilling in upcoming years is not possible to predict. Still, we can build recovery capacities in order to not landfill the industrial waste, but use it for economic or energetic use instead. Therefore, it is necessary to consider all traps and risks associated with waste treatment. From the mentioned data and the assumed waste creation and consumption, which show that landfill capacities are presently at a sufficient volume until 2035, the landfill capacities will remain sufficient; it is therefore not necessary to increase the capacity. However, landfills are regionally unevenly distributed. In Slovakia, there are no capacities for waste recycling, and the country should decrease the landfill and increase the principle of a circular economy.

There is significant potential for the energetic recovery of waste in Slovakia in individual counties, not only hypothetical but also actual, and therefore, it is necessary to discuss the economic and logical situations of the capacities for energetic recovery and heat production to suggest real possibilities for individual regions of Slovakia.

Finally, yet importantly, a significant European factor during the transition to the circular economy is to educate all generations in the area of the circular economy by possible replacement of the raw materials with waste, which have to be first properly sorted and consequently selected by consumers and, in this way, economically recycled again. Nowadays, we need to present the potential of full raw material supplementation with waste and recycling; however, it is very important to substitute a considerable part with waste that would otherwise end up not being used as a source of raw materials and energy, but as waste in landfill.

The primary use of our results is for waste management in the area of waste reduction via ensuring effective landfill capacity and income from waste use, as well as contribution to the protection of the living environment and sustainable development of regions. However, the research is limited to Slovakia, and the task is how Slovakia could decrease the landfill. In summary, there is not enough recycling capacity at the waste level.

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