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Development of Energy Recovery from Waste in Slovakia Compared with the Worldwide Trend

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Abstract: With societal development and population increase, the amount of waste and energy consumption is also increasing. The use of waste for energy production is gradually establishing in the international and national legal norms and political programs of most developed countries around the world. Many experts are beginning to be inclined to hold the opinion that it will be necessary to include energy-recoverable waste as a renewable energy source. Slovakia is a country that understands the importance of producing energy from waste without harming the environment. The current paper focuses on the potential of Slovakia compared to other countries in the area of energy recovery from waste. With the use of regression analysis, the growth trend of municipal waste in Slovakia was defined. The results show that the Slovakian trend goes against the EU goals. On the one hand, this represents a very serious problem for the environment, but it also indicates the significant potential of secondary raw materials and energy in the case of energy recovery from waste.

Keywords: waste management; energy recovery from waste; regression analysis; Slovakia

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1. Introduction

Recently, various countries have been actively looking for energy sources that can provide an alternative to fossil fuels, especially in countries with highly developed energy sectors. Energy from waste can be an effective way of reducing the consumption of primary fossil energy sources. The main principle of waste management is waste reuse or the use of waste as a secondary material. For non-recyclable waste, other recovery processes also play a role. Waste-to-energy (WTE) processes, such as thermal technologies, can be used to recover energy from municipal solid waste (MSW), as well as to reduce the volume of landfilled material [1]. WTE operation must observe environmental legislation and standards [2].

Several authors have addressed the energetic use of waste in the literature in their individual areas. In the case of plastic waste, economically and ecologically justified processes of thermal transformation and catalytic depolymerization leading to the formation of fuel fractions destined for energetic use may be useful [3]. Waste-to-energy processes present a possibility for developing waste management technologies in the future. With this goal in mind, Chow et al. explored the possibility of producing energetic materials by converting inert plastic waste into energy [4]. In addition, material recovery by way of packaging waste is a goal of the municipal waste management system [5], meaning that any remaining waste can be used in energy recovery. In this way, energy recovery presents a competitor to material recovery, diminishing the energetic value of residual waste and contributing to economic efficiency [6].

In the case of organic materials, energy recovery is predominantly applied [7]. Energy recovery can require a lower energetic input by way of energy transformation using heat. Moldgy and Parameshwaran investigated the properties of organic materials for waste heat recovery applications and found a high heat capacity [8]. Montes and Rico evaluated the possibility of applying energetic valorization to solid wastes from alcoholic beverage production and found that the use of waste material as a power source was possible given its high heating value [9]. Onorevoli et al. presented a material with a high absorption potential which was acquired through energetic extraction from tobacco seeds, which is a material with high added value [10]. Moreover, kitchen waste can also serve as a type of waste with a considerable volume of energetic elements [11]. Through energy recycling and recovery, "bio-waste-to-energy storage" can be achieved [12]. In the case of materials recycled from construction, Porras-Amores et al. evaluated the energy efficiency potential of these materials, carrying out an energetic evaluation [13]. The study demonstrated the successful use of recycled materials in some building elements, which reduced the use of raw materials and energy [14]. According to Lee et al., various fractions of communal waste can be separated and recycled with consequent energy recovery [15]. Waste-to-energy systems can contribute to closing the loop in material flows and reducing environmental impacts (Vlachokotas, 2020) [16].

Ghazanfari (2023) constructed a structural and conceptual literature review which provides the most decisive determinants in the formation of circular strategies, outlines obstacles that hinder CE adoption, and formulates drivers and measures to overcome them [17]. WTE processes have been studied worldwide across the individual countries. For example, Bhalla focused on shifting from the use of conventional sources of energy to solid and industrial waste for energy generation and found that current waste-to-energy technologies being used in India have provided a solution to India's growing waste and energy problems [18]. In Australia, Dastjerdi et al. found that the country caused more than one third of total waste generation [19]. Economic waste treatment can be conducted using technologies to ensure the energetic use of waste and greater energy production. Such technologies could allow organic waste landfilling and emissions to be avoided, as well as increase the amount of production of renewable energy. In Palestine, a study conducted by Tayeh et al. showed that WTE plants represent the most acceptable solution [20]; however, on the other hand, they are impractical due to demand shortage. Similarly, Helou et al. found that in spite of all its advantages and environmental contributions, heat technology poses a number of challenges regarding its use for communal waste processing in California [2]. These include the negative opinions of the public, economic disadvantages, the local sale of the semi-products, and the possibility of liquidating the remaining material. In Europe, Perkoulidis et al. developed a database with equipment for the energetic use of waste and for the evaluation of the effectiveness of energetic recovery [21]. The main information included in the database comprise energetic use per inhabitant, supplier, placement of the equipment, investment and operation costs, and the different indicators of the boilers, which affect the effectiveness of a WTE operation.

In New Zealand, Munir et al. researched the state of the comparative advantages of communal waste production, as well as its energetic deficit, together with energetic waste recovery [22]. The study researched different technologies which allowed the transformation of waste into energy, described their potential in the country, and identified connected appeals with the goal of developing potential circular economy in the country. The results of the study prove that the successful use of WTE in New Zealand needs the technologies for energetic recovery of the waste would decrease the capital and operation costs and create additional revenues from fuel and semi-products.

In the case of Germany, Puttachai et al. studied the situation from the perspective of the relation between energy recovery of the waste and energy consumption from the side of producer and consumer. The study showed permanent sustainable waste treatment in German industrial sectors, finding confirmation of the relation between waste to energy and net import of energy [23].

Also, in other the developed and developing countries, the growth of the amount of municipal solid waste production (MSW) nowadays presents a big problem since developing countries have poor waste management and inadequate electricity generation [24]. In

Uruguay, where its main energy sources is hydroelectric and thermal power from fossil fuels, it is important to consider other energy sources such as Energy from Waste [25]. In Brazil, Luz et al. analyzed technical and economic realization for the situation in the country and considered costs and revenues to construct a WTE plant which proved to be influenced by interest rate and inflation, presently considerable [26]. Also, Fernández-González et al. analyzed the costs for WTE in south Spain [27], showing that from the view of the economy, WTE implementation decreases operation costs. From the environmental point of view, WTE presents considerable benefits for the living environment.

The necessity to search WTE development results from the fact that systems for the waste transmission to energy have become very necessary for the industry. In addition, scientists express a lot of interest in searching for WTE due to its better effectiveness and cost of solution meeting environmental requirements. The transition to biomass is also very important for the industry [28]. During the development, processing, and implementation of serious energetic policies, it is necessary to consider the relation between WTE and energy consumption when there is no consistent conclusion [29]. In general, it should be noted that this problem is multidimensional because there is a huge amount of waste, and each type of waste is different. Therefore, it is not possible to include everything in one work. In order to address the topic of methods of obtaining energy from waste, we try to cover Slovakia’s potential in using waste as a source of energy compared with the trends of worldwide development.

This research is a continuation of the previous study in which we evaluated the position of waste economy in Slovakia from the perspective of total circular economy. In the present research, we orientate to waste as a source of energetic raw material. One of the reasons is a long-term reactive approach of the government in Slovakia to the energetic use of waste. Only in the last period, due to the energetic crisis, did the governmental institutions become interested in the possibility of using waste for energetic recovery with minimization of the impacts on the living environment.

The goal of Envirostrategy 2030 is to increase the measure of communal waste recycling, including its preparation for repeated use to 60%, and to decrease the measure of waste stocking to less than 25% by 2035. In connection with the strategy, the presented contribution has a goal to evaluate the waste potential and use in Slovakia compared with the worldwide trend with a goal to find out the measure of the Envirostrategy goal achievement. Waste-to-energy in Slovakia is provided by a few studies such as those of Pavolova et al. (2020) and Fehér et al. (2002); however, the paper's goal is to provide more data about the situation in Slovakia [30,31].

2. Materials and Methods

The object of investigation is waste management in Slovakia and in the world. The research is based on the analysis of waste management procedures in individual countries over the years, a description of waste generation and the share of waste disposal and recovery, and a description of waste management. The data were obtained from the databases of World Bank, Eurostat, the Waste Management Program of the Slovak Republic, as well as the Waste portal. The potential of waste utilization was monitored on different levels, from the point of view of trends in waste production, comparison of waste production in EU countries, and waste management, comparing Slovakia and the world. To analyze the problem, it is necessary to understand the current trends in waste management in Slovakia. Data were taken from the “Waste Management Program of the Slovak Republic”.

The evaluation regarded waste treatment hierarchy according to the UN Environmental Program [29], as illustrated in Figure 1.

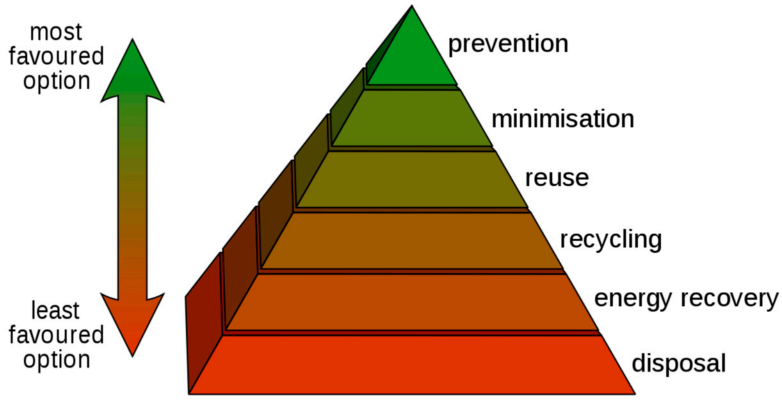

Figure 1. Illustration of waste treatment hierarchy [29].

Slovakian waste economy has a goal to minimize negative influences of the waste rising and to treat waste in an effective way considering human health and the living environment. To achieve the determined goal, it is necessary to assert and observe an obligatory waste economy hierarchy to increase waste recycling, mainly in the area of communal and construction waste, considering the legislation. In a waste economy, it is also necessary to apply the principle of proximity, independence, and responsibility. During the implementation of the waste economy hierarchy, it is necessary to apply the best technique to the environmental processes. Slovakian waste economy has a strategic goal to move considerably away from communal waste landfilling [32].

The analytical part of the contribution presents situation analysis in the beginning by which we follow up production of communal waste in the chosen countries. Division of the countries into three parts, according to the trend of produced communal waste development, is presented mainly as follows:

- Countries with decreasing communal waste production;
- Countries with stable production of communal waste;
- Countries with increasing production of communal waste.

The Slovak Republic belongs to the group of countries with stable production of communal waste; however, the problem is still a high proportion of municipal waste disposal by landfilling (40, 69% in 2021). Resulting from the aforementioned, it is necessary to minimize landfilling in the following period and start to actively support waste recovery. The contribution is aimed at the analysis of the energetic recovery of communal waste in Slovakia, and through the analysis performed in regard to concrete equipment for energetic recovery of communal waste, the paper points out the effects of waste recovery by the way of heat and electricity production.

During the research, it was not possible to include all data, information, and indexes if they have not been reported. Most of the evaluation is in percentage rather than absolute amounts of waste values. The reasons for the percentage expression are as follows:

- Absolute amounts are challenging to compare;
- Percentages can be better compared and used for trend assessment.

During the research, we performed the following:

- Evaluated waste production according to the individual;
- Estimated production of communal waste in Slovakia in kg/inhabitant;
- Described the trends of communal waste production in Slovakia in 2011–2020 when the average year-to-year change in municipal waste production was defined through simple regression analysis. A mathematical model defining the influence of the independent variable (time) on the dependent variable (municipal waste production) was created;
- Analyzed the rate of energy recovery of waste vs. total waste recovery;
- Compared the regions of Slovakia from the point of view of energy recovery of waste;

- Identified the most energetically recovered waste in Slovakia;
- Analyzed the energetically recovered communal waste in equipment ZEVO in Bratislava and Košice.

Data

The main information source is RISO. Since 1995, the analysis of waste treatment in Slovakia has been based on the national regional waste information system (RISO). RISO registers all reports of waste generators who every year report the data from a given registration of the correspondent municipality institution through the report "on waste generation and treatment." Data from the reports are then entered online by the district offices into the RISO information system. Statistics on municipal waste are provided by the Slovak Statistical Office, where the database of municipal waste is provided by municipalities. Statistical processing of data is carried out according to the decree of the Ministry of the Interior of the Slovak Republic no. 284/2001 Coll., which establishes the Waste Catalog as amended and which is fully in line with the European Waste Catalog [33].

The time frame for data processing is as follows:

- waste production development in 2004–2020 together with prognosis to 2050;
- waste production development is also expressed in percentage change in 2011–2020;
- recovered waste development is followed up in 2015–2021 with consequent percentage expression in individual Slovakian counties in 2019, 2020, 2021, helping to determine the most important counties to be followed up (KE, BA—in 2015–2021).

3. Results

3.1. Waste Treatment in the World

Humanity produces around 2 billion tons of waste every year (World Bank data) [34]. There is a threat that by 2050 this figure will rise to 3.4 billion tons, as each person produces up to 500 kg of waste per year. Figure 2 illustrates the expected generation of waste by individual regions of the world until 2050.

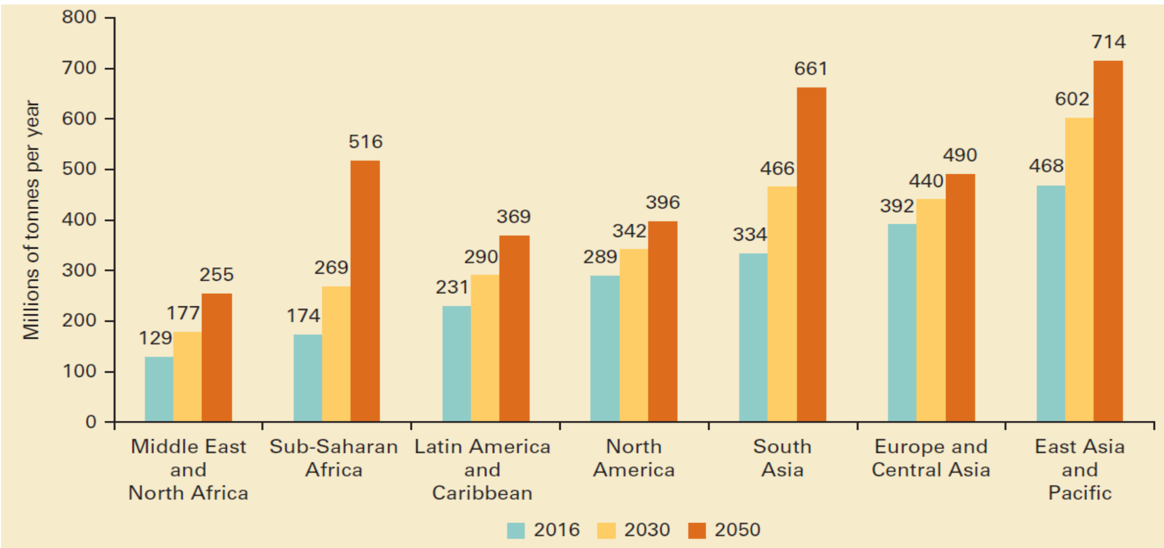

Figure 2. Assumed waste production according to the individual regions (mill. tons per year) [34].

The United States and other developed countries export most of their waste to China over the long term. China is the largest importer of waste. Since 1992, the country has imported 45% of the world's plastic waste. In 2018, Beijing restricted imports, and as a result, in 2019, the import of plastic waste from China decreased by 89% and that of waste paper decreased by 96%. compared to the beginning of 2017. The export of plastic waste decreased by 64% and that of waste paper by 42%. Countries started to send waste to India, Indonesia, and Malaysia. Soon, these countries also introduced their restrictions, and the world had a serious problem with waste recycling.

Figures 3–5 illustrate the situation in Europe in various EU countries, determining countries with decreasing, stable, and increasing communal waste production between 2004 and 2018.

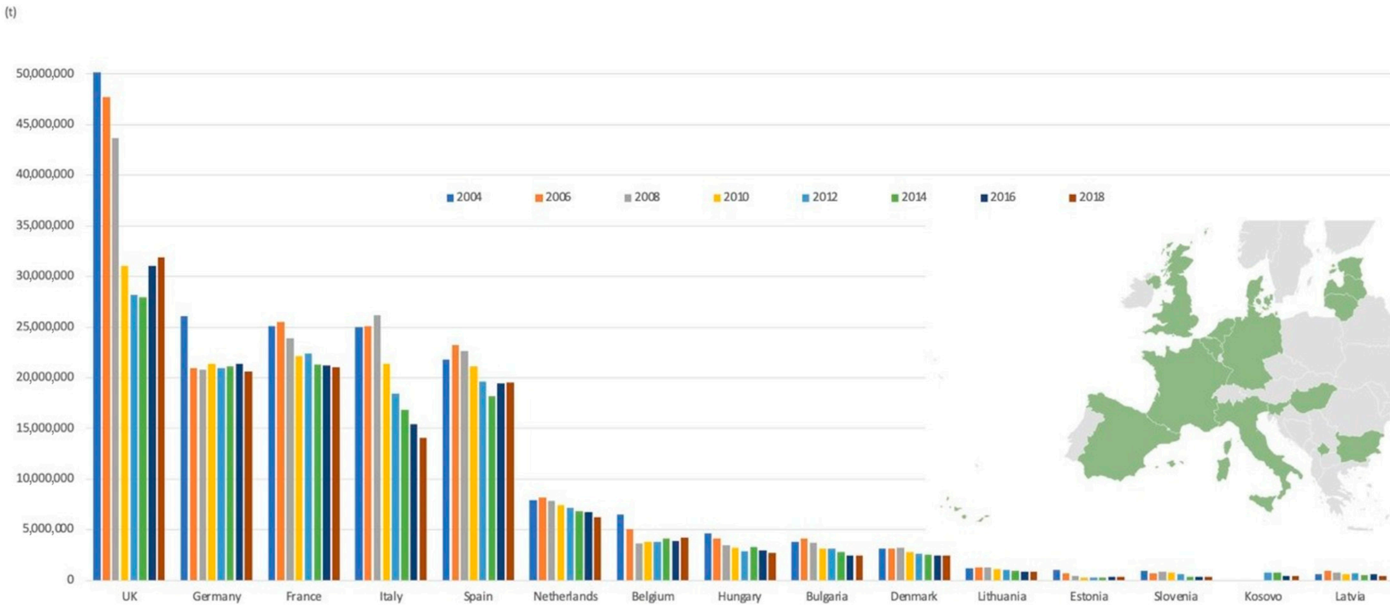

Figure 3. Countries with decreasing production of communal waste (t/year) [33,34].

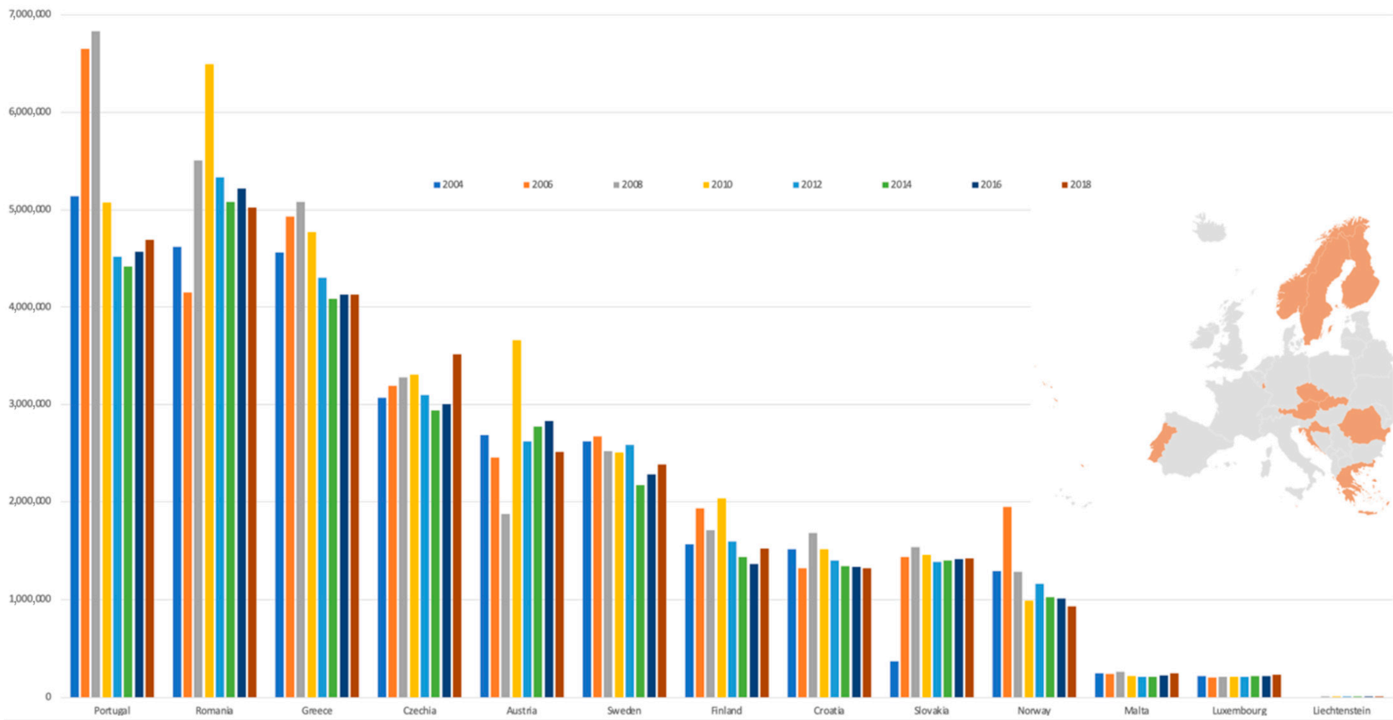

Figure 4. Countries with stable production of communal waste (t/year) [33,34].

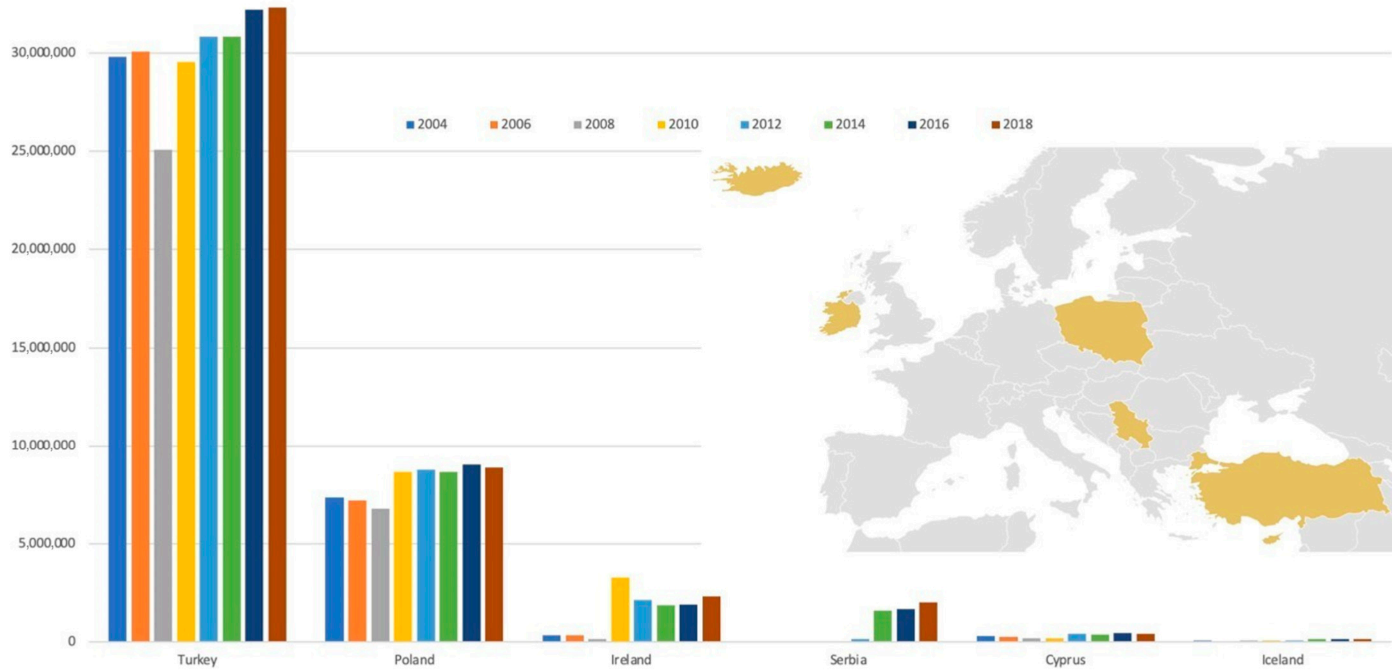

Figure 5. Countries with increasing production of communal waste (t/year) [33,34].

The state of the urban environment depends on not only the method of waste collection, but also the efficiency of its further disposal. Mixed waste requires additional costs for the separation and purification of the components to be recycled. The most primitive method is street storage. The costs of waste collection in such a case may exceed the benefits of recycling. In the absence of formal waste sorting and transportation programs, informal groups of citizens take over this function. In some cases, they form communities of many thousands, such as the Kartoneros in Buenos Aires or the Zabbalins in Cairo [35,36].

A more organized way is the individual house-to-house fee, usually paid by the residents. In Mexico City, all waste is collected in this way, and in Copenhagen it is only certain types of hazardous waste [37]. Residents themselves may be responsible for taking waste to the landfill. This principle is often used for the separate collection of certain categories of waste, which must be disposed of in specialized containers or handed over to recycling stations [38].

Collecting in containers is the usual method, but the types of containers in different countries may differ. They can be general or specialized for different materials. For aesthetic and sanitary reasons, they can be placed in metal boxes; containers can also be stored underground, leaving the trash can outside. This is achieved in different ways: for example, containers from the Italian company Ecopunto are installed on a lifting platform (www.environmental-expert.com), and special machines with a crane are needed to lift Canadian underground containers Ecoloxia or Finnish Moloks [39,40]. In Sweden, Singapore, and other countries, waste from containers is collected using underground pneumatic systems [38].

Sorting of waste can be carried out by separate collection. In the simplest case, waste is divided into “dry” and “wet”. The number of categories can be large: Australia has 5 categories and Denmark has 11: bulk waste, cardboard, electronics, garden waste, glass, food waste, plastic, hazardous waste, metal, paper, and non-recyclable waste. They use different containers or, like in Oslo, bags of different colors that can be sorted after collection. This is often performed manually, although, for example, in developed countries in Europe and Beijing, the process is automated.

Fees for waste collection are usually collected based on the “polluter pays” principle, which is set out mainly in the EU and US legislation [41]. The amount of payment can be fixed or, as in some regions of Spain and Germany, it depends on the amount of waste, in which case individual containers are used to determine who exactly uses them. Some municipalities in Sweden use a combined approach: residents pay for waste collection at a fixed rate and pay extra for each kilogram that exceeds a set limit. In addition, the payment may depend on the type of waste: for example, in Zurich and Taipei, waste from containers for separate collection is removed free of charge, but for unsorted waste, special bags must be purchased, the price of which includes the removal tariff.

In many countries, separate collection is supported through the so-called "container deposit". This is a certain amount that is included, for example, in the price of the drink and is returned to the buyer when they return an empty bottle or can. As world practice shows, waste can act as a generator of various, unusual ideas [42].

In Finland and Sweden, waste is transported underground, and there are containers on the ground to which vacuum pipes are connected. It is through them that waste is delivered to underground facilities. Thirty-two power plants in Sweden work with waste recycling. The Scandinavian countries of Sweden, Finland, and Norway are best able to sort and recycle waste.

However, in Japan, a whole industry of recycled waste has been established: for example, plastic bottles serve as the material for wear-resistant sportswear, machine or cooking oil becomes biofuel for vehicles, and construction waste is used for the production of finishing materials and even in the construction of artificial mass islands.

In Brazil, Muzzi (2018) developed bicycles with frames made from recycled plastic bottles, using around 200 bottles per frame. The production of such bicycles is much cheaper than conventional ways; in addition, their weight is significantly lower than that of traditional models [43].

In the USA, under the Rothy brand (www.rothys.com, accessed on 10 July 2023), recycled plastic bottles are used to make shoes, such as washable ballet flats in a variety of bright colors. Due to its technology, the company has already managed to recycle more than 25 million plastic bottles. Another American company, Nebia (www.nebia.com, accessed on 10 July 2023), with the help of engineers from NASA, Apple and Tesla developed and implemented a shower system that, due to the innovative principle of spraying water into the smallest droplets, can save 70% of water.

In Germany, most of the country's waste is incinerated. There are 551 waste incineration plants in Germany. Household waste recycling rates range from 16 percent (domestic waste) to 100 percent (glass and electrical appliances). Waste also contributes to energy supplies. The production of electricity in Germany from waste in 2018 amounted to roughly 5.8 billion kilowatt hours. In recent years, there has been an upward trend in sales in the waste management sector in this country, the area with the latest recycling turnover. However, most companies are in this area. Garbage collection counts. Germany's largest waste management company, Remondis (www.remondis-australia.com.au, accessed on 10 July 2023), is also one of the strongest in terms of turnover in its industry worldwide. Per capita, an average of 296.6 kWh of electricity and 741.4 kWh of heat per inhabitant is produced from waste in Germany [44].

3.2. Waste Treatment in Slovakia

Waste production in Slovakia is growing. Moreover, in the last years, its growth is rapid. In recent years, production of communal waste per inhabitant achieved the level of 427 kg, with a growth of 9%. During the last ten years, the total number increased to 30%. In other words, while in 2008 Slovakia produced waste in the amount of 327 kg per year per inhabitant, in the last year, it was 100 kg more of waste (Figure 6).

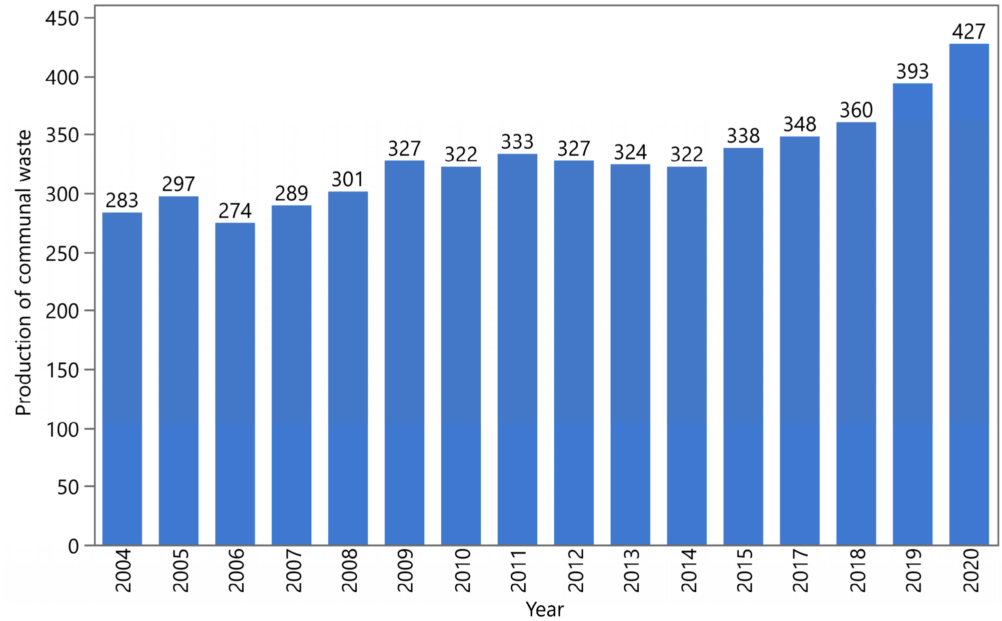

Figure 6. Production of communal waste in Slovakia in kg/inhabitant [45].

As a whole, Slovakia presents the production of communal waste in 2021 with a volume of 2,434,040 tons. By analyzing the data for the last ten years (Table 1), a growth trend at the level of 86,213 tons per year was defined through regression analysis. In percentage terms, this is an annual increase of approximately 0.6% (Figure 7). In recent years, there has been a certain slowdown in the growth of municipal waste production, but this situation still represents a very serious problem, not only in Slovakia.

Table 1. Total development of communal waste in Slovakia in 2011–2020.

Year	Communal Waste (t)	Annual Growth (t)	Change (%)
2011	1,766,991		
2012	1,750,775	−16,215	−0.92%
2013	1,744,429	−6347	−0.36%
2014	1,830,167	85,738	4.91%
2015	1,888,456	58,289	3.18%
2016	1,953,478	65,023	3.44%
2017	2,136,952	183,474	9.39%
2018	2,325,178	188,226	8.81%
2019	2,369,725	44,548	1.92%
2020	2,434,040	64,314	2.71%

Source: own processing according to https://ec.europa.eu/eurostat (accessed on 15 March 2023) [33].

According to the EC, air quality in Slovakia continues to be of concern. This follows from the Evaluation of the Implementation of the EU Environmental Policies. In the evaluation, the commission stated that the low rate of recycling and strong dependence on landfills caused Slovakia, together with Malta, to occupy the last place in the recycling of municipal waste in the EU. The EC has therefore identified the low level of waste management as one of the country's main environmental problems. According to the Commission, Slovakia should make better use of recycling and separate collection and use landfills less.

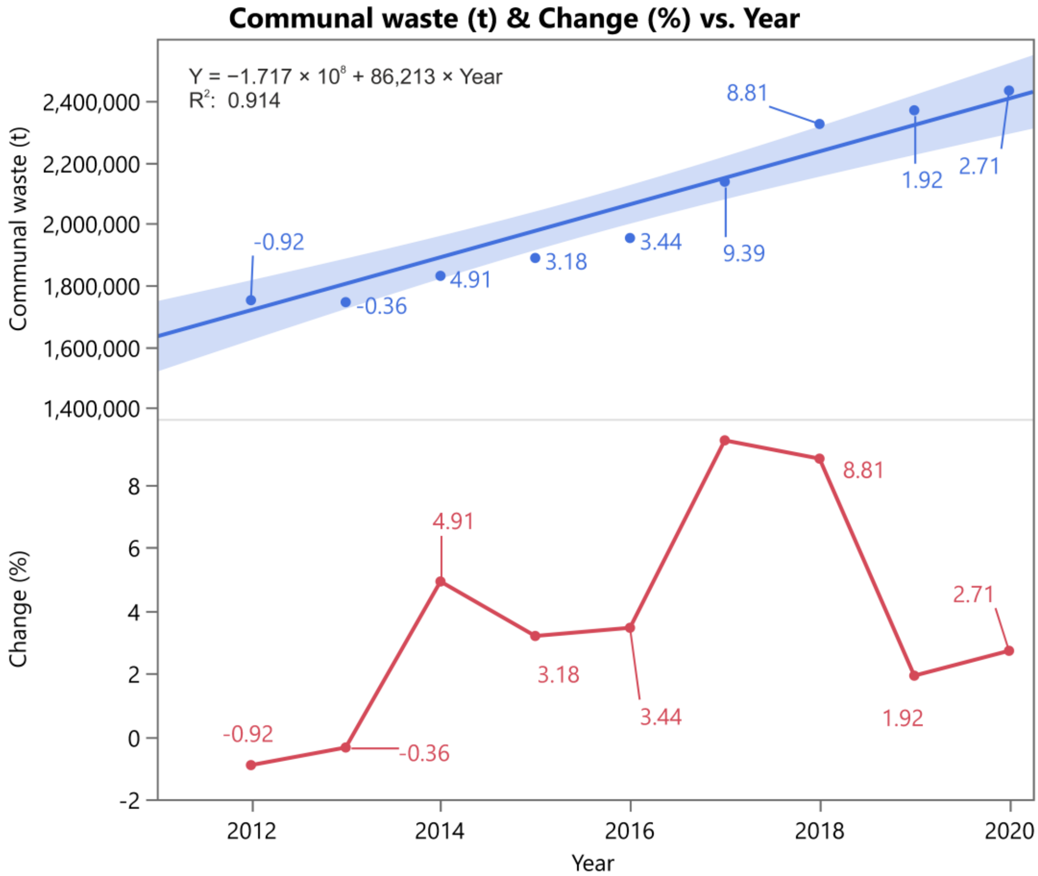

Figure 7. Growth trend of communal waste development in Slovakia in 2011–2020. Source: own processing according to (accessed on 15 March 2023) [33].

Separate collection and recycling of waste is actively supported. In the courtyards of residential buildings, in public places, in shopping centers, and grocery stores, there are a lot of containers for the separate collection of waste. Parents can be seen escorting their children to school carrying discarded newspapers and magazines. Every month, competitions are held in schools to determine which class brings more waste paper. Battery and bulb bins in grocery stores are within walking distance. Special containers are regularly organized for the collection of varnishes, paints, and other toxic waste, of which the residents of the house are informed in advance. The collection of bulky waste is organized in the same way. Separate containers are ordered for the removal of construction waste. Medicine is taken to the pharmacy. There are also separate containers for unwanted clothing and shoes in each yard, although they are separate from the container area. Large grocery stores have machines that accept glass and plastic bottles, together with cans. By handing in an empty bottle, an individual received a certain amount of money to spend at the grocery store.

Figure 7 is a follow-up of Table 1 where the goal was to define the trend of CW production development. The research is orientated only to observations for the last 10 years, but the data have a stable development, and therefore it was possible to define a regression model which the statistical software JMP evaluated as statistically significant.

As stated, communal waste production in Slovakia is annually growing. In spite of this negative fact, the volume of separated and recovered waste is increasing. An important task in problem solving in Slovakia can be the energy recovery of waste.

In Slovakia, there are two large incinerators (capacity over 2 tons per hour) of municipal waste in Bratislava (capacity 32.7 t/h) and in Košice (10 t/h) and two for incineration of industrial waste on the premises of Slovnaft and Duslo Šal'a. Smaller incinerators include nine hospital waste incinerators, four industrial waste incinerators and one rendering plant. There are also four waste co-incineration facilities that participate in the cement production process.

The following Table 2 illustrates the percentage of recovered communal waste from the total volume of communal waste together with the rate of the given energy recovery of communal waste.

Table 2. Percentage of total and recovered communal waste.

	2019		2020		2021	
	Communal Waste Recovery	**Energy Recovery of CO**	**Communal Waste Recovery**	**Energy Recovery of CO**	**Communal Waste Recovery**	**Energy Recovery of CO**
BA	46.36	22.42	73.45	40.41	75.06	33.37
TRN	45.02	0	47.25	0.02	53.87	0.02
TRE	43.08	9.69	42.65	-	50.64	0.08
NIT	42.05	0	44.71	0	50.62	0.21
ŽI	43.52	0.07	45.73	0.35	52.19	0.42
BB	41.23	0	43.46	0	49.86	0.18
PR	40.16	0.82	42.49	1.15	55.06	13.28
KE	64.26	45.25	66.76	41.04	68.15	41.68
SR	45.61	11.6	51.44	15	57.63	14.09

Source: own processing according to Statistical Office, SR [45].

The data show that the amount of waste that is recovered every year is increasing, and the amount of energy recovery from waste is increasing. Currently, 104 municipalities submit waste for energy recovery, i.e., 3.6% of the total number of municipalities in Slovakia.

The following Table 3 illustrates a detailed view of the waste types that were mostly energetically recovered in Slovakia in individual years. The development showed five types of most energetically recovered waste. In all years, a mixture of communal waste dominates, as does bulky waste.

Table 3. Types of energetically recovered waste in Slovakia (tons).

	2019	**2020**	**2021**
Mixture communal waste	103,499.1	159,055.8	177,390.6
Bulky waste	18,978.7	23,856.9	5501.2
Biologically degradable waste	2136.2		5845.9
Waste other than the specified			27,553.4
Waste from street pollution	569	3733.8	
Waste from marketplaces		254.9	
Wood	111	538.8	
Mix packages			1344.6
Other types of waste	89.5	355.1	1733.1
Slovakia—total	125,383.5	187,795,3	219,368.8

The highest rate of energetically recovered waste is observed in two regions, namely Bratislava (BA) and Košice (KE) (Figure 8). The reason is that it is precisely in these regions that the facilities for the energy recovery of waste are built.

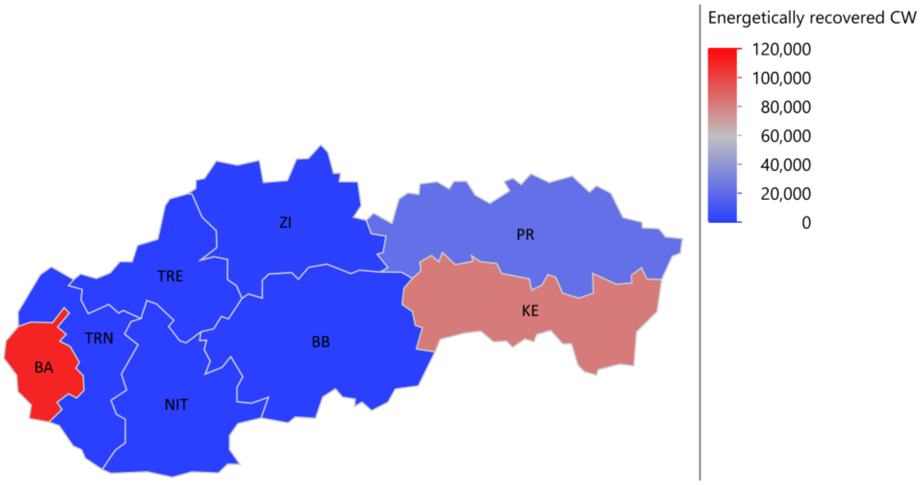

Figure 8. Cartographer—energy recovery in 2021 in individual Slovakian regions. Source: own processing according to Statistical Office, SR [45].

The following graph (see Figure 9) provides an overview of the development of the amount of energy recovery of waste for the whole of Slovakia and for the Bratislava and Košice regions. The decrease, which was recorded in 2018 and 2019, is related to the limited operation of the ZEVO organization in Bratislava.

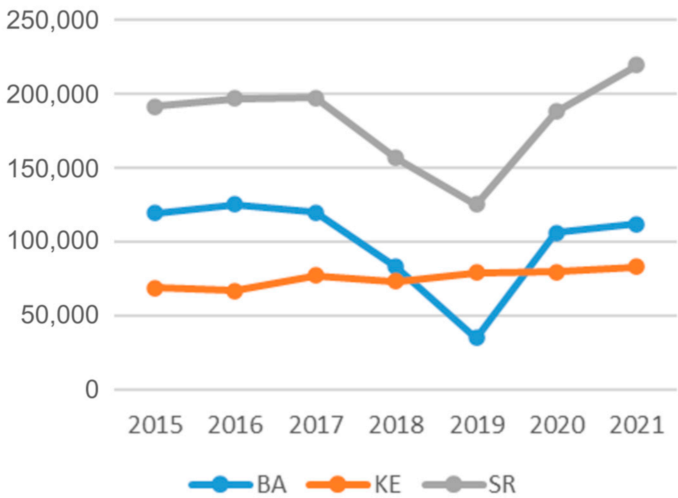

Figure 9. The volume of energy recovery of waste in tons. Source: own processing according to Statistical Office, SR [45].

In the following part, more attention is given to two facilities for the energy recovery of municipal waste—ZEVO Bratislava and ZEVO Košice. The data processed in Tables 4 and 5 based on the annual reports of the mentioned companies indicate the amount of waste accepted for energy recovery as well as the data on evaluated waste in the form of produced heat and electricity.

Table 4. ZEVO Bratislava.

	2015	2016	2017	2018	2019	2020	2021
Volume of energy recovery of waste	131,031	130,466	136,896	95,484	34,982	126,432	120,763
Sale of heat and electricity (thousand EUR)		217,019	264,755	365,692	555,915	830,060	1,067,198
Sale of heat and electricity (MWh)	36,617	34,921	36,131	24,873	8979	37,163	33,557

Source: Annual reports OLO [46].

Table 5. ZEVO Košice.

	2015	2016	2017	2018	2019	2020	2021
Waste transport to ZEVO (tons)	91,738	93,626	99,264	117,487	112,729	114,655	134,474
Sale of heat and electricity (thousand EUR)	417	1230	1523	1872	2346	2018	4226
Sale of heat and electricity (MWh)	10,921	47,251	52,412	62,632	67,787	68,288	73,611

Source: Annual reports KOSIT [47].

The Bratislava ZEVO is operated by the OLO company; it uses energy-enhanced waste to produce heat and electricity. Part of the heat produced during the incineration of waste is used for ZEVO's own needs and the rest is used for the production of electricity, which is supplied via an underground cable line to the city's distribution network. In 2018 and 2019, as already mentioned, a decrease in waste was recorded, which was affected by the technological shutdown of the equipment due to the overhaul of the turbine, gearbox, and generator.

Košice ZEVO annually evaluates approximately 66% of the total waste collected by Kosit, which also operates the facility. Energy-enhanced waste is used for the production of heat, which is supplied to the city's heating network, and the production of electricity, not only for its own consumption but also for the supply of energy to the distribution network.

From the point of view of the composition of municipal waste, it means that a larger amount of waste can produce a larger amount of energy. This does not mean that more and more waste should be produced. On the contrary, it means that a large amount of waste is still landfilled in Slovakia, and therefore it is advisable to intensify the energy use of waste by building ecological facilities for the energy recovery of waste at several locations. This will increase the amount of energy obtained from the larger amount of waste that is currently landfilled.

Due to constant investments in modernization, both facilities meet all requirements for waste incineration and flue gas cleaning, comply with emission limits, and can be ranked in terms of environmental impact with other comparable plants in Europe.

4. Discussion

As it is clear from the results of the above analysis, Slovakia is a country that increases the share of waste in landfills while maintaining energy recovery at a stable level. When comparing Slovakia with Germany as one of the leading countries in the area of energy recovery of waste, in Slovakia, it is necessary to continue to apply and expand waste separation and recycling technologies and simultaneously increase the share of waste intended for energy use, at least to the average level of European states. In Germany, 1038 kWh of energy (heat + electricity) per inhabitant is produced annually from waste. In Slovakia, it is only 16 kWh of energy from waste per inhabitant [44].

Rational and economic use of energy presents one of the main tasks in developed countries, especially in countries with complications regarding provision of fuels and energy due to high prices [48]. One of the effective ways is to obtain energy and fuel from solid waste [49] as well as from agriculture [50]. To obtain energy in facilities for the combined production of electricity and heat, it is convenient to use, for example, semi-liquid wastewater as an additive to fossil fuels.

Rational and economic use of raw materials and energy applies especially to countries like Slovakia, where a complex situation with raw materials and energy resources has developed. The need is to increase the share of renewable and alternative energy sources. In the long term, we can also include waste, which is there together with the existence and activities of humankind. The effective ways of obtaining energy while using solid waste as a fuel can contribute to the protection of the living environment [51]. An important factor is the local use of waste as a source of energy with technically and environmentally proven technologies. Renewable energy sources based on biodegradable waste provide a substitute for mineral fuels used as an energy carrier replacing natural gas.

In Slovakia, it is necessary to start thinking comprehensively in the field of environmental protection. It is not possible, on the one hand, to protect the environment with an artificial and scientifically unfounded negative approach to waste energy recovery facilities and, on the other hand, to allow waste to be dumped in huge areas and in huge volumes directly in the natural environment [52].

Also, based on the results of the performed analyses, it has been proven that increasing the share of energy recovery waste in countries increases the share of separation and recycling. It is a natural and technically justified process. Operators of waste-to-energy facilities cannot allow the material entering the process that does not allow them compliance with very strict emission and environmental standards [53]. In the field of energy recovery of waste, the results of research and development are already at a very high environmental level. What is important in this area is that these results have already been verified in practice, so their implementation is only a matter of effort and willingness of the responsible authorities.

This is precisely the reason why the competent authorities in the country should start implementing local facilities for the energy recovery of waste. This will allow, in addition to a significant reduction in the volume of landfilled waste, an increase in the diversification of the state's energy resources [54]. Energy will thus be produced directly at the point of consumption.

Without increasing the share of waste in energy production, it will be very difficult for Slovakia to meet the energy efficiency goals set by the European Union.

5. Conclusions

In relation to humanity, waste can be considered a renewable source of raw materials and energy. As long as humanity exists, waste will be produced. Due to its composition, the majority of municipal waste can be recycled into energy. Even with the preservation and strict adherence to the principles of the waste pyramid, a huge amount of waste is produced. More and more countries are realizing that it is not only a source of raw materials within the circular economy, but also a renewable source of energy. Current technologies recovering waste produce fewer emissions, such as coal-fired power plants or combined fuel-heating plants.

The advantage of household waste is that it does not have to be searched or mined, but in any case, it has to be destroyed, which requires a lot of money. A rational approach here enables not only the acquisition of cheap energy, but also the prevention of unnecessary costs. A significant increase in the effectiveness of the solid waste use as a fuel, production of electricity and the achievement of specific indicators close to commercially used thermal power plants can most likely be achieved by partial substitution of energy fuel for domestic waste.

The trend of increasing the share of waste in energy production with the simultaneous intensification of waste separation and recycling is inescapable within Europe. On the other hand, there are countries that ignore this fact. Despite the existing and proven environmentally suitable technologies for obtaining energy from waste, these countries prefer landfilling.

The results provided in the paper can serve as material for a significant increase in the efficiency of waste used as an energy source or for the process of development of energy production from waste. The research results could contribute to the rapid and more effective decision of the competent institutions in the WTE area. Except for the aforementioned, the facts of the potential and WTE impacts on the living environment could positively influence the opinions of non-governmental institutions that hinder the efforts of experts to introduce sustainable WTE technologies in Slovakia in the long term.

The significant economic effect of the results presents the reduction of investment into other sources of energy production and income from waste use, as well as environment protection. However, the research is limited to conditions in Slovakia, which can be extended in future research by comparison in the V4 region; it is recommended due to the sustainable development of regions.

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