The Potential of Energy Recovery of Waste in EU countries in Sustainable Waste Management

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Abstract
This paper provides an overview of waste management and its importance in waste management in the EU. High waste production has long been a global problem. Sustainability is currently a critical goal of human activity and development of countries. The increasing population and waste generation without the proper measures of waste mitigation lead to the major challenge of environmental sustainability. Energy sustainability is important for any plans that concern overall sustainability in the future. Any form of development can only be sustainable if the waste it generates does not accumulate, but is properly recovered. Strategies to achieve this goal have included attempts to obtain energy from waste. In the first part of paper we discuss the importance of sustainable waste management, issue of sustainable energy recovery from waste, the advantages and disadvantages of selected waste management operation. In the second part of the paper, we paid attention to the analysis of waste management as an energy source in selected countries of European Union and the potential of this method of waste management.

Keywords: energy recovery, sustainability, waste, waste management, rationality, consumer behaviour

JEL Classification: O13, M30, Q40

1. Introduction
Waste management has become the focus of European Union environmental policies since the 1970s. In terms of resource use, their goal is to become the most efficient economy in the world through the set strategic goals, which want to work towards more sustainable patterns of production and consumption with regard to those resources and waste production that have negative impacts on the environment (Báreková, 2014). The aim of the current European Union directives on waste management is to promote the prevention and generation of waste and the application of the waste hierarchy: preparation for re-use, recycling, other recovery (energy recovery), disposal (Pires & Martinho 2019).

The increasing production of waste can be considered as an opportunity for sustainable development in European Union countries (Zhou & Zhang, 2022). End users or consumers are the starting point where waste starts its journey into several paths within the circular economy, such as repair, reuse, remanufacturing, and recycling. It is also necessary to monitor consumer behavior, which can also be influenced in favor of sustainable waste management (Islam, et al. 2021). Food waste has a great significance in this context. Achieving food sustainability and reducing food waste are among the top challenges for achieving global sustainable development and waste management (Dinu, 2020).

The waste hierarchy is a key indicator of EU waste policy and legislation and a key to the transition to a circular economy. Its primary purpose is to prioritize that minimizes adverse environmental impacts and optimizes resource efficiency in waste prevention and management.
Waste generation has rapidly increased due to the worldwide population, urbanization, and industrialization. Waste management is a significant challenge for a society that arises local issues with global consequences (Khan, et al. 2022). The serious environmental impacts include environmental contamination, methane gas generation which leads to global warming and other labor issues (Amulen et al. 2022). In the hierarchy of sustainable waste management, the energy recovery as part of a holistic solution will lead to a zero waste scenario (Zero Waste Europe, 2019). Redirecting the non-recyclable part of waste from landfills to a higher hierarchical level, such as recovery, is an energy tool for building an integrated waste management system (TASR, 2022).

Figure 1 presents that once reduction, reuse, and recycling have been deployed, the remaining waste should be processed for energy recovery. The energy recovery from waste is consistent with the hierarchy and provides an opportunity for additional recovery of materials such as aluminum, iron, copper. Reduce, reuse and recycle are generally recognized by the public, however, there is less awareness and knowledge of recovery of waste (Castaldi, 2021).

1.1 Definition of Waste

An important feature of people's use of natural resources is the production of waste. Every production and consumer activity is always associated with the production of waste. Waste is often characterized by a substance that cannot be reused for economic reasons. Although waste is defined as a substance that can be further recovered (Pánik & Jantová, 2019). Countries that seek to minimize waste generation should also pay more attention to promoting sustainable consumption. In addition, only recycling behavior has had a significant impact on waste reduction efforts, while resource efficiency attitudes have insignificantly determined all ways of managing waste, revealing that people in the EU lack knowledge of the relationship between waste reduction and recovery and recovery as a source of energy. The level of waste production depends mainly on economic development (Minelgaitė & Liobikienė, 2019).

Waste is not a substance or movable property that is a by-product, specific waste that has reached the end-of-waste status, waste that has undergone a process for preparation for re-use and meets the requirements for a marketed product set out in a special regulation, or waste handed over for domestic use. The waste is divided into:

- Biodegradable waste
- Biodegradable municipal waste
- Dangerous waste (European commission, 2017)
1.2 Energy recovery from waste

The main effort and premise of modern waste management, in addition to preventing waste and reducing the amount of waste deposited in landfills, is the use of raw materials and energy from waste. In this context, it is important to specify the so-called energy potential of waste, in this case municipal waste (Bilik et al. 2010).

Energy recovery is one of the circular economy solutions that can have economic, social, and environmental co-benefits through efficient use of natural resources, reduced emissions, job creation, and fostering innovation. As such, the emergence of the circular economy has changed the way governments think about waste (European Commission, 2017). The utilisation of energy recovery has become an integral part of sustainable waste management (Hasan et al. 2021).

Waste recovery for energy is an important part of a strong and sustainable waste management chain. Fully complements recycling. This chosen method of waste management is an economically and ecologically reasonable way to secure a renewable energy source and at the same time divert waste from landfills. Energy recovery from waste is one of the most robust and efficient energy options for waste generation and emission reduction as an alternative to fossil fuels (Babcock & Wilcox, 2022).

Energy recovery from waste is not a new concept, as it is an important area that requires serious attention. Various waste-to-energy technologies are available. However, the choice is based on the physico-chemical properties of the waste, both on the type and amount of waste available, as well as on the form of energy required. The conversion of solid waste into energy can take place through three main process technologies: biochemical extraction, thermochemical extraction and mechanical extraction (Hamad et al. 2014).

Energy recovery has the potential to become an important component in Europe's renewable energy sector (Scarlat et al. 2017). Energy recovery is not just a way of disposing of waste. It's a way to get valuable resources back. Today, it is possible to reuse 90% of the metals contained in the bottom ash. And the remaining clinker can be reused as road material. This waste recovery method prevents methane emissions from landfills, compensates for greenhouse gas emissions from fossil fuel power generation, recovers / recycles valuable resources such as metals, produces clean, reliable base energy and steam, and is a sustainable and stable renewable fuel source (compared to wind and solar energy) (Babcock, 2022).

Advantages of energy recovery of waste:

- obtaining the so-called "Alternative energy", which saves primary energy sources,
- the possibility of excluding mixed household waste from landfills,
- options for disposal of residual municipal waste (waste after separation of secondary raw materials and bio-waste),
- minimization of the volume of waste at final disposal (10-15% of ash remains from the waste),
- perfect waste sanitation,
- detoxification of organic pollutants (Jandačka et al. 2014).

Disadvantages of energy recovery of waste:

- the waste must be treated according to the technology used,
- in energy recovery of mixed and municipal waste it is necessary to ensure continuous measurement of the composition of the waste,
• investment-intensive additional equipment must be used for the disposal of harmful components of emissions (Jandačka et al 2014).

2. Data and Methods

The main aim of this paper is to evaluate the potential of waste as an energy source and to compare trends / developments and see if there is a difference in selected EU countries. To meet this goal, we will use selected statistical methods such as Shapiro-Wilk test, Kruskall Wallis test and Pairwise comparison of selected countries with Bonferroni correction.

Selected data show energy recovery of waste in Slovakia, the Czechia, Hungary and Austria for the period from 2012 to 2020. The data in the following table 1 are expressed in tonnes / capita. In this part of the paper, we paid attention to waste management and the use of waste as an energy source in selected EU countries.

Table 1: Energy recovery of waste in selected EU countries

<table>
<thead>
<tr>
<th>TIME/COUNTRY</th>
<th>Czech R.</th>
<th>Hungary</th>
<th>Austria</th>
<th>Slovakia</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>0,078</td>
<td>0,085</td>
<td>0,253</td>
<td>0,044</td>
</tr>
<tr>
<td>2013</td>
<td>0,078</td>
<td>0,096</td>
<td>0,252</td>
<td>0,049</td>
</tr>
<tr>
<td>2014</td>
<td>0,077</td>
<td>0,107</td>
<td>0,25</td>
<td>0,054</td>
</tr>
<tr>
<td>2015</td>
<td>0,078</td>
<td>0,097</td>
<td>0,247</td>
<td>0,071</td>
</tr>
<tr>
<td>2016</td>
<td>0,079</td>
<td>0,087</td>
<td>0,244</td>
<td>0,088</td>
</tr>
<tr>
<td>2017</td>
<td>0,084</td>
<td>0,085</td>
<td>0,243</td>
<td>0,088</td>
</tr>
<tr>
<td>2018</td>
<td>0,09</td>
<td>0,084</td>
<td>0,241</td>
<td>0,088</td>
</tr>
<tr>
<td>2019</td>
<td>0,09</td>
<td>0,078</td>
<td>0,24</td>
<td>0,097</td>
</tr>
<tr>
<td>2020</td>
<td>0,093</td>
<td>0,073</td>
<td>0,239</td>
<td>0,103</td>
</tr>
</tbody>
</table>

Source: Eurostat (2021)

3. Result and discussion

Table 2: Average abs.difference and Average growth rate

<table>
<thead>
<tr>
<th></th>
<th>Czech R.</th>
<th>Hungary</th>
<th>Austria</th>
<th>Slovakia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average abs. difference t / capita</td>
<td>0,0019</td>
<td>-0,0015</td>
<td>-0,0018</td>
<td>0,0074</td>
</tr>
<tr>
<td>Average growth rate</td>
<td>1,0222</td>
<td>0,9812</td>
<td>0,9929</td>
<td>1,1122</td>
</tr>
</tbody>
</table>

Source: Author’s calculations

The table 2. represent that the best disposal of waste for energy is in Austria, where the usability of waste is in the range of 0.239-0.253 tons per capita. Despite the highest values, the recovery of waste to energy per capita has a declining trend, similar to that in Hungary. In the country, there was an average year-on-year decrease of 0.0018 tons, respectively. 0.71%. Even worse is Hungary, which among the V4 countries started in 2012 at 0.085 tonnes / capita, but despite growth in 2013 and 2014, since 2015 it has gradually reached a downward trend of 0.073 tonnes / capita. and since 2018 it is the worst of the countries monitored. The most significant decline is recorded in the last 2 years. The average relative change represents a decrease of 1.88%. Slovakia represents a different picture. The country was the worst of the 4 countries monitored in 2012 (0.044 t / inhabitant), but it recorded a significantly growing trend and already in 2016 it was better than Hungary or the Czech Republic with a value of 0.103 t / inhabitant. In Slovakia, the average year-on-year usability increased by 7.4 kg or 11.22%, which is the fastest growth of all countries monitored. The country
has increased its usability more than 2.3 times. The most significant increase is in 2015 and 2016, when the country used 17 kg of waste per capita more than in the previous year. Higher usability also occurs in the Czech Republic, but not to the same extent as in Slovakia. The highest increase occurred in 2018, when 6 kg more waste was used per capita. Utilization increased by an average of 1.9 kg / inhabitant - 2.22%.

In this part of paper we compare trends/development to found out the difference between selected countries. For this reason, we have decided not to work with the original values, which may be influenced mainly by higher (Austria) or lower (Slovakia) values at the beginning of the observed period and not to take into account the development itself but to compare the average absolute differences. As we want to compare 4 averages of independent groups, the most appropriate method seems to be the analysis of variance, but this method is one of the parametric tests and assumes normality in each group.

Table 3: Shapiro-Wilk normality test

<table>
<thead>
<tr>
<th>Country</th>
<th>Shapiro-Wilk test for normality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistic</td>
</tr>
<tr>
<td>Austria</td>
<td>0,782</td>
</tr>
<tr>
<td>Czech R.</td>
<td>0,896</td>
</tr>
<tr>
<td>Hungary</td>
<td>0,849</td>
</tr>
<tr>
<td>Slovakia</td>
<td>0,870</td>
</tr>
</tbody>
</table>

Source: Author’s calculations

Table 3 shows that Shapiro Wilk's test did not confirm normality in the case of Austria, so we will use a non-parametric analogy of the one-way analysis of variance, which is the Kruskal Wallis test. The test, unlike the anova, compares medians.

Table 4: Kruskall Wallis test

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test</th>
<th>Sig.</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The medians of absolute differences are the same in all countries.</td>
<td>Independent-Samples Kruskal-Wallis Test</td>
<td>0,0019</td>
<td>Reject the null hypothesis.</td>
</tr>
</tbody>
</table>

Asymptotic significances are displayed. The significance level is 0.05.

Source: Author’s calculations

Based on the p value (<0.05) of the Kruskall Wallis test, which is represented in table 4, we can state that there are differences between countries in the trend of energy waste valuation - changes in countries vary.

Table 5: Pairwise comparison with Bonferroni correction

<table>
<thead>
<tr>
<th>Sample1 - Sample2</th>
<th>Test Statistic</th>
<th>St. Error</th>
<th>Std. Test St.</th>
<th>Sig.</th>
<th>Adj. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria-Hungary</td>
<td>-1,562</td>
<td>4,665</td>
<td>-0,335</td>
<td>0,738</td>
<td>1</td>
</tr>
<tr>
<td>Austria-Czech R.</td>
<td>-10,5</td>
<td>4,665</td>
<td>-2,251</td>
<td>0,024</td>
<td>0,146</td>
</tr>
<tr>
<td>Austria-Slovakia</td>
<td>-15,438</td>
<td>4,665</td>
<td>-3,309</td>
<td>0,001</td>
<td>0,006</td>
</tr>
<tr>
<td>Hungary-Czech R.</td>
<td>8,938</td>
<td>4,665</td>
<td>1,916</td>
<td>0,055</td>
<td>0,332</td>
</tr>
<tr>
<td>Hungary-Slovakia</td>
<td>-13,875</td>
<td>4,665</td>
<td>-2,974</td>
<td>0,003</td>
<td>0,018</td>
</tr>
<tr>
<td>Czech R. - Slovakia</td>
<td>-4,938</td>
<td>4,665</td>
<td>-1,058</td>
<td>0,29</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Author’s calculations
The table 5 shows that there are statistically significant differences based on the Bonferroni correction between Austria and Slovakia and Slovakia and Hungary.

While in Slovakia the trend is positive and the country increased the amount of waste used for energy in the years 2012-2020 by an average of 7.4 kg in Austria and Hungary the opposite trend occurs and the amount of waste used for energy production is declining. In Hungary, an average of 1.5 kg / capita per year, in Austria even by 1.8 kg / inhabitant.

4. Conclusion

At present, we cannot separate the generation of waste from the existence of mankind. Its volume is mainly influenced by human activity such as production and consumer behaviour, maturity and lifestyle. It is important to monitor its development, structure, so that we can subsequently evaluate the waste, or even minimize its volume. Waste minimization is a new philosophy adopted by the European Commission along with the whole waste hierarchy.

The aim of this paper was to clarify the current issues of waste management and methods of waste recovery, namely the specific identification of waste as a source of energy. We also focused on waste management as an energy source in selected EU countries. Based on statistical methods, we found out what is the economic potential of waste as an energy source and the development of energy waste consumption in a selected period of time in the countries. Based on the results, we came to the conclusion that the largest energy recovery of waste is in Austria, although the trend is declining there, similar to Hungary, and the last place in energy recovery of waste is Slovakia. Although Slovakia is in last place among the selected countries, the growing trend is positive. In conclusion, it is clear that waste recovery is becoming increasingly popular in selected countries and is of importance. There is a need for EU citizens to be more informed and educated about waste management, waste management but also waste recovery in general.

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