Waste Management in European Countries: Indicators, Clustering, and Socioeconomic Implications

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Abstract. The work is aimed at analyzing approaches to waste management and dividing them into clusters. The objectives of the study were to determine indicators related to waste management and to investigate their relationship; analyze the main groups of waste management solutions used by European countries and identify waste management clusters according to the most important parameters. The work hypothesized that there are several common groups of decisions regarding waste management (recycling, incineration or disposal is preferred). Correlation, dispersion and cluster analysis (hierarchical and k-means) were performed. It was proved that there are a strong direct link between incineration and current health expenditure per capita, waste thermally treated in WtE plants and WtE plants, waste thermally treated in WtE plants and GDP, WtE plants amount and GDP. There is a strong inverse link between recycling and landfilling, incineration and landfilling, landfilling and current health expenditure per capita. At the same time, there are weak direct links between research indicators and life expectancy at birth, government expenditure on education. Three clusters were identified regarding waste management. Cluster 1 (Czech Republic, Hungary, Lithuania, Poland, Portugal, Slovakia, Spain, Estonia): recycling and landfilling are the main methods of waste management, with their help, about 80% is destroyed, an average of four WtE plants operate, and up to one t of waste is processed. Current health expenditure per capita exceeds GDP by 4.5 times. Cluster 2 (France, Germany, Italy, UK): they recycle about half of the waste, and the rest are incinerated or landfilled in certain proportions. On average, 76 WtE plants work in the countries and about 15 tons of waste are processed. Current health expenditure per capita exceeds GDP by 1.5 times. Cluster 3 (Austria, Belgium, Denmark, Finland, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland): with the help of recycling and incineration, almost all waste is removed, and up to 2% remains for landfill (except Ireland - 23%). On average, 16 WtE plants work in the countries and 3 tons of waste are processed. Current health expenditure per capita is the largest and exceeds GDP by 13.5 times. The results of this study can be used by government officials to develop recommendations for improving the waste management system in their country and by scientists for further research.

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1 Introduction

All over the world, the study of waste manegement is interesting for various scientific schools, economics, and especially stakeholders, who can benefit from the use of waste processing technologies.

The number of scientific publications devoted to waste management is increasing every year [1-3]. They are focused on waste management system [4], waste recycling [5-6], waste incineration [7-8], landfilling [9], Waste-to-Energy (WTE) plants [10-12], municipal solid waste [13], life cycle assessment and models [14-15], optimization and performance [16]. In recent years, more research has been done on sustainable development [17], economic recovery projects [18], influence of COVID-19 [19-21]. There are a large number of studies on carbon neutrality and renewable energy [22-25], energy consumption [26-27], economic security [28], energy efficiency management [29-30], household expenditure on electricity consumption [31].

Research is related to various fields: energy [32-33], production [16], medicine [1, 34-35], marketing [5], ecology [36-91]. Scientists separately consider the implementation of the researched topic in business, entrepreneurship and their impact on the global market [97-111] and the possibility of their implementation via establishing digital technologies [112-128]. The impact of the obtained results on the financial and economic indicators of individuals and legal entities, as well as changes in macro- and micro-markets, are assessed by scientists as urgent and important issues [129-155]. Research on the construction of an effective management system remains undeniably relevant [156-177].

However, issues related to the clustering of the waste management system have not been sufficiently investigated. There are only publications on clustering of research on solid waste management [178], nuclear waste management [179], and field of waste management [180-181].

In Ukraine more than 400 million tons of waste is generated annually, which is a significant problem for ecology [1]. And in connection with a full-scale invasion, the volume of waste will increase even more. Of these, only 100 million tons are disposed of and 1 million tons are incinerated. About 95% of all generated waste are landfilled, and only a small part is recycled.

At the same time, in many European countries, it is the other way around - most of it is recycled and only a small amount are landfilled. And some countries not only process their own waste, but also those of neighboring countries.

The relevance of the work related with the signing of the Association Agreement between Ukraine and the EU, new requirements regarding waste management are being put forward to the country. The National Waste Management Strategy was developed, the implementation of which also became a priority task of Ukraine, based on the EU Directive 2008/98/EC on waste management.

Therefore, there is a need to analyze the experience of countries that have successfully organized work on waste management and develop recommendations for adapting waste management systems in Ukraine to EU requirements based on their experience.

The formed system of waste management will allow to maximally reduce the volume of waste in Ukraine, which ends up in landfills and harms the environment.

EU Directive 2008/98/EU defines important points [182]: waste prevention, sorting or preparation for reuse, reuse, recycling or recycling, utilization for energy recovery, disposal, including landfilling. That is, the main ways of handling waste: recycling (including composting), incineration, and landfilling.

The waste that remains after recycling is incinarated to generate energy (electrical, thermal), and the rest is landfilled. At the same time, only some types of waste can be processed. Combustion is accompanied by emissions of pollutants into the environment. And burial carries the danger of contamination of underground water, subsoil, including mineral deposits. Given that each of the options has both advantages and disadvantages, each country independently chooses its own combination of these aproaches, which is different from the others. For example, in 2020, Switzerland recycled 53% and incinerated 47%.

In order to ensure the operation of the waste management system in accordance with European legislation, appropriate enterprises must function.

The article is aimed at finding clusters (groups) of such solutions and identifying those that can be adapted to Ukrainian realities.

Therefore, our research focuses on indicators related to waste management and their interrelationships.

The main area of work is correlation, dispersion and cluster analysis of waste management indicators. This makes it possible to develop recommendations for the adaptation of the waste management system in Ukraine, taking into account the directives and EU countries experience.

Research goals:

- determine indicators related to waste management and investigate their relationship;
- analyze the main groups of waste management solutions used by European countries;
- to highlight clusters regarding waste management according to the most important parameters.

The object of the study is 22 European countries. The subject of the study is indicators related to waste management (the share of recycling, incineration and landfilling), the number of Waste-to-Energy plants, waste thermally treated in Waste-to-Energy plants, as well as GDP, health expenditure per capita, life expectancy at birth, and government expenditure on education.

It is hypothesized that there are common groups of waste management decisions (recycling, incineration, or landfill are preferred). And this method affects the level of income, health, life expectancy of the population and it is related to the education level.

2 Materials and Methods

Methods were used in the work: statistical, correlational, variance and cluster analyzes [5,38-40].The statistical method involved the collection and analysis of statistical data on waste management (recycling, incineration and landfilling, the number of Waste-to-Energy plants, waste thermally treated in Waste-to-Energy plants) and the life of society in the country (GDP, health expenditure per capita, life expectancy at birth, and government expenditure on education).

Next, correlation analysis was used to test the relationship between waste management indicators and other indicators. Pearson's correlation criteria were used to measure the degree of linear relationship between indicators.

To conduct a correlation analysis it was used indicators, presented in table 1.

Different types of weights are used for different measurements, so the data has been standardized.

First, a hierarchical cluster analysis was performed to visualize existing relationships between objects in the STATISTICA 10 program. Then, a k-means cluster analysis was performed to select segments. The initial centers of the clusters were sorted by distance; observations were established at regular intervals. The analysis included only 7 indicators from 22 countries for 2016-2020.

To determine the most important parameters, variance analysis was carried out. The data were analyzed for the number of clusters from 2 to 10. Only those parameters were used in which the p-value was significantly less than 0.05, the intergroup variance was large, and the actual F was greater than the critical value. Average values by clusters were studied. All clusters are described.

Table 1. Description of the source data

Indicator	Measurement units	Resource
Recycling (including composting)	%	CEWEP
Incineration	%	CEWEP
Landfilling	%	CEWEP
Waste thermally treated in WtE plants	mln t	CEWEP
Waste-to-Energy Plants (WtE plants)	items	CEWEP
GDP	mln US$	World Bank
Health expenditure per capita	US$	World Bank
Life expectancy at birth	years	World Bank
Government expenditure on education	% of GDP	World Bank

3 Results and discussions

The study includes data from 22 countries for 2016-2020 (a total of 110 objects).

First, data on waste management was collected, including the share of recycling, incineration, landfilling, the number of WtE plants, and waste thermally treated in WtE plants. The sample also includes indicators that may be related to the waste management system, such as GDP, current health expenditure per capita, life expectancy at birth, government expenditure on education. To determine whether there is a significant relationship between the variables, a correlation analysis was performed. It made it possible to establish relation between all indicators. The results of the correlation analysis are presented on fig. 1.

	Recycling (including compos-ting)	Incine-ration	Land-filling	Waste thermally treated in WtE plants	WtE plants	GDP	Current health expenditure per capita	Life expec-tancy at birth	Government expenditure on education
Recycling (including composting)	1								
Incineration	0,3391	1							
Landfilling	**-0,7062**	**-0,8862**	1						
Waste thermally treated in WtE plants	0,5703	0,1140	-0,3292	1					
WtE plants	0,4160	0,1427	-0,2753	**0,8764**	1				
GDP	0,4357	-0,0435	-0,1598	**0,9259**	**0,8551**	1			
Current health expenditure per capita	0,5628	**0,7262**	**-0,7729**	0,2621	0,2912	0,1558	1		
Life expectancy at birth	0,2082	0,2876	-0,3575	0,2738	0,2224	0,2410	0,0267	1	
Government expenditure on education	0,3787	-0,0924	-0,0956	0,3154	0,2362	0,2280	0,0170	0,2624	1

Fig. 1. The correlation analysis results (source: developed by the authors)

As can be seen from fig. 1, there are a strong direct link between incineration and current health expenditure per capita, WtE plants and waste thermally treated in WtE plants, WtE plants and GDP, waste thermally treated in WtE plants and GDP.

There is a strong inverse link between recycling and landfilling, incineration and landfilling, landfilling and current health expenditure per capita.

At the same time, there are a weak direct link between research indicators and life expectancy at birth, and government expenditure on education. Therefore, they are excluded from further research and do not participate in the cluster analysis.

Because different measures used different types of scales, the data were standardized.

First, hierarchical clustering was performed in Statistica 10 to visualize relationships and estimate the number of clusters. The objects are strings, the join rule is the full join method, and the proximity measures are Euclidean distances. The vertical dendrogram is presented in fig. 2.

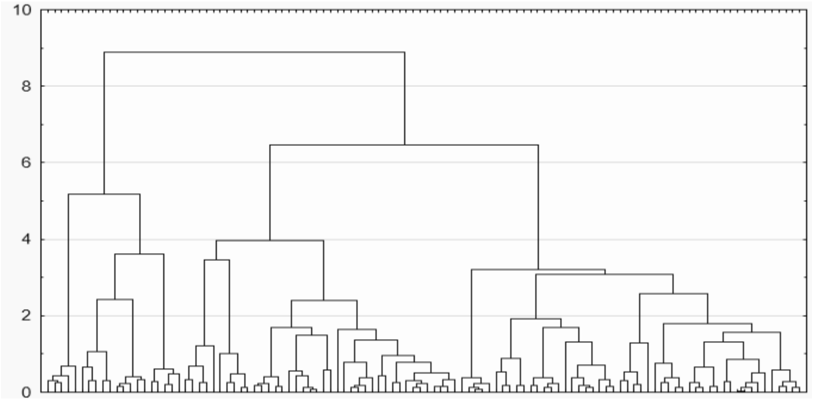

Fig. 2. The vertical dendrogram (source: developed by the authors using STATISTICA 10)

According to the vertical dendrogram, there can be at least 3 clusters.

After that, the data were collected and processed for the needs of K-means cluster analysis in Statistica 10. The number of clusters was checked from 2 to 10. The optimal result was obtained with the number of indicators 7, the number of observations 110, the number of clusters 3, obtaining the result in 3 iterations. It was stopped at 3 clusters because three clusters are clearly visible on the vertical dendrogram and as the number of clusters increases, small clusters with a small number of objects begin to appear. The results of variance analysis for three clusters are presented in Table 2.

Table 2. Analysis of variance for seven parameters (source: developed by the authors using STATISTICA 10)

Indicators	Between SS	df	Within SS	df	F	p-value
Recycling (including composting)	48,68	2	60,32	107	43,17	0,00
Incineration	77,38	2	31,62	107	130,94	0,00
Landfilling	84,31	2	24,69	107	182,73	0,00
Waste thermally treated in WtE plants	71,71	2	37,29	107	102,89	0,00
WtE plants	75,28	2	33,72	107	119,45	0,00
GDP	91,66	2	17,34	107	282,75	0,00
Current health expenditure per capita	78,39	2	30,61	107	137,03	0,00

As can be seen from the table 3, for all indicators the value of p reaches 0. F is greater than the critical value. Between SS is big. Therefore, all these indicators are important for study. Based on the average distances, it was determined characteristics for each clusters.

Cluster 1 is represented by 39 objects or 8 countries: the Czech Republic, Hungary, Lithuania, Poland, Portugal, Slovakia, Spain, and Estonia (2017-2020 only). This is 35.5% of the sample. On average, 35% of waste is recycled, 18.5% is incinerated, and 43.5% is landfilled. A small number of waste-to-energy enterprises operate in the countries - on average four, and up to 1 ton of waste is processed in this way. The average GDP of these countries is the smallest of the sample - about $342, current health expenditure per capita is only $1,556.7 on average. This exceeds GDP by 4.5 times. The structure of cost management by country in 2020 is presented in fig. 3.

Table 3. Middle clusters (source: developed by the authors)

Indicators	Cluster 1	Cluster 2	Cluster 3
Recycling (including composting)	35,38	51,20	48,33
Incineration	18,54	31,00	46,43
Landfilling	43,54	15,60	3,95
Waste thermally treated in WtE plants	0,86	14,74	3,07
WtE plants	4,05	75,75	15,76
GDP	342,16	2790,00	442,38
Current health expenditure per capita	1556,69	4260,38	5980,58

Cluster 1 is represented by 39 objects or 8 countries: the Czech Republic, Hungary, Lithuania, Poland, Portugal, Slovakia, Spain, and Estonia (2017-2020 only). This is 35.5% of the sample. On average, 35% of waste is recycled, 18.5% is incinerated, and 43.5% is landfilled. A small number of waste-to-energy enterprises operate in the countries - on average four, and up to 1 ton of waste is processed in this way. The average GDP of these countries is the smallest of the sample - about $342, current health expenditure per capita is only $1,556.7 on average. This exceeds GDP by 4.5 times. The structure of cost management by country in 2020 is presented in fig. 3.

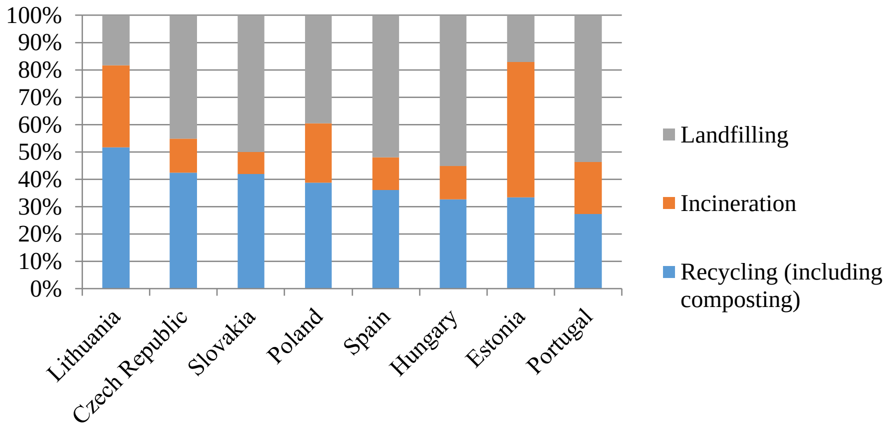

Fig. 3. Structure of cost management in cluster 1 countries (source: developed by the authors)

Cluster 2 is represented by 20 objects or 4 countries: France, Germany, Italy, UK. Half of the waste (51% on average) is recycled, one third (31% on average) is incinerated and 15% is landfilled. On average, there are 76 waste-to-energy enterprises operating in the country, and up to 15 tons of waste are processed in this way. The average GDP of these countries is the highest and is $2,790 on average, the state spends the most on health care - about $4,260.4. In this group of countries, medical expenses exceed GDP by 1.5 times.

The structure of cost management by country in 2020 is presented in fig. 4.

As can be seen from fig. 4, in 2020 the most waste was recycled in Germany (almost 70%), the least in France (about 40%). The most waste was incinerated in the UK (about 40%), the least - in Italy (up to 20%). The most waste was landfilled in France (26%), and the least in Germany (only 1%). That is, in the cluster 2 countries, almost half of the waste is recycled, and the rest is incinerated / landfilled in some proportions.

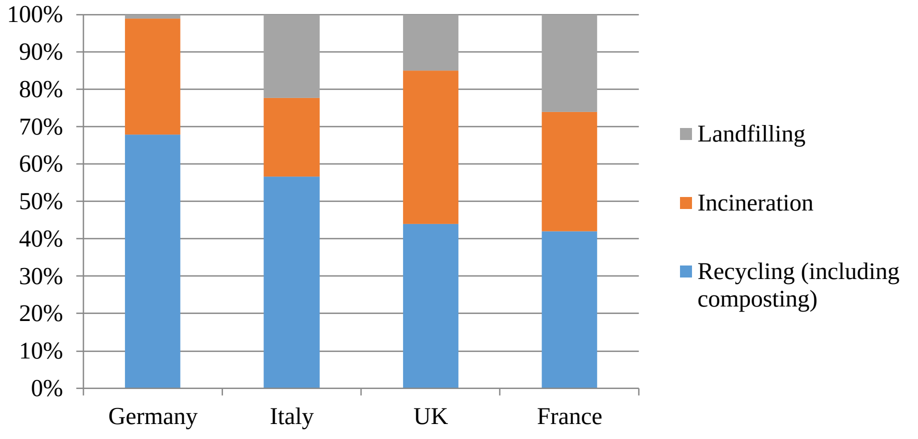

Fig. 4. Structure of cost management in cluster 2 countries (source: developed by the authors)

Cluster 3 is represented by 51 objects or 10 countries (Austria, Belgium, Denmark, Finland, Ireland, Luxembourg, the Netherlands, Norway, Sweden, Switzerland, and Estonia (2016 only). Half of the waste (48.3% on average) is recycled, almost half is incinerated (46.4%) and only 4% is landfilled. On average, 16 waste-to-energy enterprises operate in the country and 3 tons of waste are processed in this way. The average GDP of these countries is $442.4, for health care the state spends the most - about $5,980.6.

The structure of cost management by country in 2020 is presented in fig. 5.

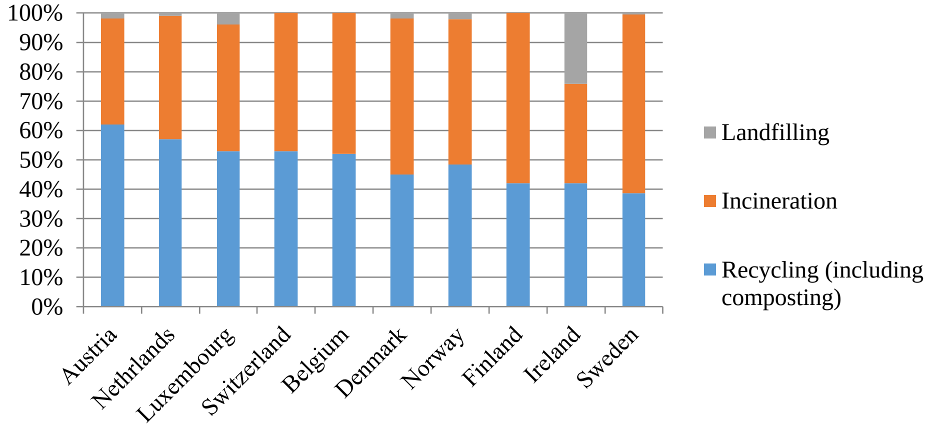

Fig. 5. Structure of cost management in cluster 3 countries (source: developed by the authors)

As can be seen from fig. 5, in 2020 the most waste was recycled in Austria (more than 60%), the least in Sweden (less than 40%). The most waste was incinerated in Sweden and Finland (about 60%), the least - in Ireland (about 30%). Most waste was landfilled in Ireland (more than 20%) and Luxembourg (4%), in other countries less than 2%. That is, in these countries, with the help of recycling and incineration, almost all waste is removed, and up to 2% remains for landfill (except for Ireland - 23%).

If the data is averaged, then these clusters can be schematically presented in fig. 6.

Adequacy of the model was checked by multiple clustering using other methods: squared Euclidean distances, Manhattan distance, Chebyshev and 1-r Pearson distances. Vertical dendrograms have almost the same appearance as shown in Fig. 1. A conclusion was made about the adequacy of the model.

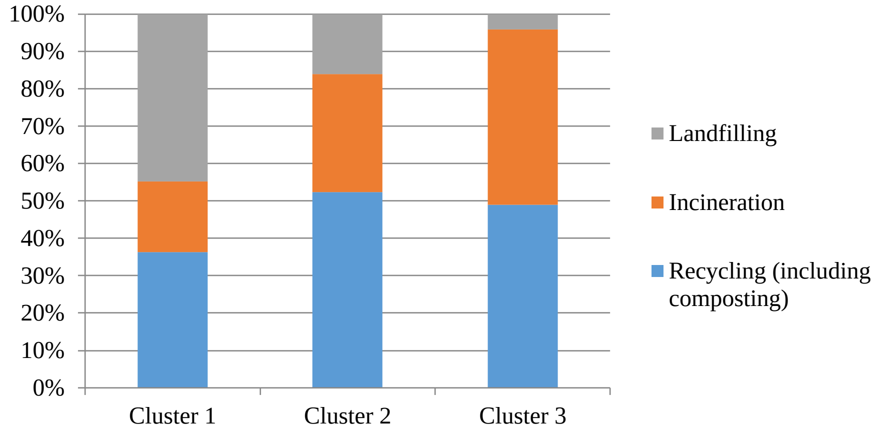

Fig. 6. Clusters by type of waste management (source: developed by the authors)

4 Discussion and conclusion

The work hypothesized that there are several common groups of decisions regarding waste management (recycling, incineration or landfilling is preferred). And this aproach affects the level of income, health, life expectancy of the population and is related to the education.

In this study, it was proved that the method of waste management is correlated with the number of WtE plants and capacity of waste thermally treated in WtE plants, GDP, current health expenditure per capita.

It was proved that there are a strong direct link between incineration and current health expenditure per capita, waste thermally treated in WtE plants and WtE plants, waste thermally treated in WtE plants and GDP, WtE plants and GDP. That is, the more waste is burned, the greater the current health expenditure per capita. With the increase in the number of WtE plants and waste thermally treated in WtE plants, the country's GDP also increases.

There is a strong inverse link between recycling and landfilling, incineration and landfilling, landfilling and current health expenditure per capita. That is, the more waste is recycled and incinerated, the less it is landfilled; the more it is landfilled, the lower the current health expenditure per capita.

At the same time, there are weak direct links between research indicators and life expectancy at birth, government expenditure on education. Therefore, they were removed and did not participate in further analysis.

Three clusters were identified regarding waste management.

Cluster 1 includes Czech Republic, Hungary, Lithuania, Poland, Portugal, Slovakia, Spain, and Estonia (2017-2020 only). Recycling and landfilling are the main methods of waste management, with their help about 80% is disposed. On average, 35% of waste is recycled, 18.5% is incinerated, and 43.5% is landfilled. A small number of waste-to-energy enterprises operate in the countries - on average four, and up to 1 ton of waste is processed in this way. The average GDP of these countries is about $342, current health expenditure per capita is $1,556.7 on average, which is 4.5 times more than GDP.

Cluster 2 includes France, Germany, Italy, UK. They recycle about half of the waste, and the rest are incinerated or landfilled in certain proportions. On average, in the cluster, half of the waste (51%) is recycled, almost a third (31%) is incinerated, and 15% is landfilled. On average, 76 WtE plants work in the countries and recycle up to 15 tons of waste in this way. The average GDP of these countries is the highest and is $2,790 on average, the state spends the most on current health expenditure per capita - about $4,260.4, which is 1.5 times more than GDP.

Cluster 3 includes Austria, Belgium, Denmark, Finland, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland. With the help of recycling and incineration, almost all waste is removed, and up to 2% remains for landfill (except Ireland - 23%). On average, for the cluster, almost half of the waste (48.3%) is recycled, almost half is incinerated (46.4%), and only 4% is landfilled. On average, 16 WtE plants work in the countries and 3 tons of waste is recycled with them. The average GDP in the countries is $442.4, current health expenditure per capita is the most - $5,980.6, which is 13.5 times more than GDP.

Ukraine can follow any of these aproaches, but it is necessary to understand that the possibilities of disposal through energy recovery depend significantly on the number of WtE plants. At the same time, waste thermally treated in WtE plants will contribute to increasing the level of GDP.

Unfortunately, the study involve the data of only 22 European countries, and the countries of Africa, America and Asia were not included at all. This can be the topic of further scientific research. Also, not all indicators that could be related to the waste management system were analyzed.

The results of this study can be used by government officials to develop recommendations for improving the waste management system in their country and by scientists for further research.

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