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# Recycling of Communal Waste: Current State and Future Potential for Sustainable Development in the EU

**Marcela Taušová [1,†], Eva Mihaliková [2,†], Katarína Čulková [1,†], Beáta Stehlíková [3,†], Peter Tauš [1,†], Dušan Kudelas [1,†] and Ľubomír Štrba [1,*,†]**

1 Institute of Earth Resources, Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Košice, Letná 9, 042 00 Košice, Slovakia; marcela.tausova@tuke.sk (M.T.); katarina.culkova@tuke.sk (K.Č.); peter.taus@tuke.sk (P.T.); dusan.kudelas@tuke.sk (D.K.)

2 Department of Economics and Management of Public Administration, Faculty of Public Administration, Pavol Jozef Šafárik University in Košice, Popradská 66, 041 32 Košice, Slovakia; eva.mihalikova@upjs.sk

3 BERG Faculty, Technical University of Košice, B. Nemcovej 3, 042 00 Košice, Slovakia; beata.stehlikova@tuke.sk

* Correspondence: lubomir.strba@tuke.sk; Tel.: +421-55-602-2442

† These authors contributed equally to this work.

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**Abstract:** The constant consumption of resources exerts pressure on the environment. In this sense, waste management has obtained increasing attention from the view of a circular economy. The European Union deals with these mentioned aspects, trying maintain long-term competitiveness and to provide sustainable development in accordance with all related environmental aspects. This paper focuses on the evaluation of the production of communal waste in 36 EU countries. The main aim is to evaluate the success of countries' efforts to decrease waste production and increase recycling rates. The methodology used for the evaluation included data collected from the publicly available database Eurostat, consequent analyses and evaluation in the statistical software JMP 13 through regression, distribution, and cluster analysis, and the interpretation of the results. The results of the cluster analysis showed that despite clear EU waste management legislation, EU member states have significantly different waste management systems at the national level. However, generally, we could see positive correlation between the generation of waste and recycling rates. Although, Malta, Austria, Greece, and Norway recorded a decreasing level of waste recycling over the last several years, some countries (Slovakia, Poland, Czech Republic, Latvia, Lithuania) had significantly lower recycling rates accompanied by low landfill taxes. The evaluation of waste production and recycling can be used for government policy in the area of waste management, as well as for individual communities dealing with communal waste.

**Keywords:** circular economy; living environment; waste production; waste recycling; sustainable development

## 1. Introduction

The present worldwide growth of the population and increasing economic growth has influenced considerably the living environment. Constant consumption of resources exerts pressure on the environment, not only due to their exploitation, but also because, once processed, resources produce waste, emissions or effluents. To provide worldwide long-term sustainable development, resources must be used in an intelligent way. To solve such situations regards the use of circular economy and waste management. Waste management is orientated to the avoidance and limitation of waste volume and to decreasing the negative impacts of individual waste types to the living environment. This policy of waste management is orientated to waste prevention and recycling, and conversely, reducing waste landfill. The goal of a circular economy is to observe the value of products and materials in the long-term, which means after the termination of their life cycle not to reject resources from the economy, but to use them repeatedly for creation of new value. In this way, waste creation can be minimized.

In addition, the European Union deals with these mentioned aspects, trying to hold long-term competitiveness and to provide sustainable development in accordance with all environmental aspects resulting from sustainable development [1]. It presents clear orientated conceptions, dealing not only with the single concept of sustainability in relation to the living environment and economy, but it also presents some tools for further development. Its goal is to solve the relationship between economic development and the living environment, which threatens the quality of natural resources [2]. The aim is to provide for present and future generations the possibility to satisfy their basic living needs, and at the same time, to ensure that natural diversity does not decrease. In the European Union, it is extremely important to develop an adequate system of waste management together with the development of society and the economy as a whole. The economy can be supported by the waste-to-energy process that is environmentally, economically, and socially sustainable and has the potential to produce energy from communal and industrial waste. Due to the desire to achieve these goals, a program to avoid increasing waste must be defined by certain specific measurements. At the same time, it is necessary to increase society's awareness of environmental issues and the types of material that can be produced from recycled wastes [3].

The basic strategic EU document (agenda) in this area is the "Europe 2020 strategy" [4]. It presents a strategy for providing intelligent, sustainable, and inclusive growth when the prior demand was "Sustainable growth: support of a more ecologic and competitive economy that uses sources more effectively". The mentioned strategy is connected to the 7th Environmental Action Program "Living well, within the limits of our planet" [5], which is a part of a long-term vision and strategy for the EU in the area of living environment protection until 2050 [6]. The EU goal is to live until 2050 in accordance with the ecological limits of the planet. The 7th Environmental Action Program covers the period to 2020 and the key characteristic is to "protect, preserve and reclaim natural capital in EU, to protect its inhabitants against environmental threats and risks, threating the health and wealth, to perfect knowledge base for environmental policy and to strengthen sustainability of EU cities" [5]. From these documents, it can be assumed that protection of the living environment obtains still more and more attention not only in the frame of the EU but worldwide too. The "OECD Green Growth Strategy" also refers to the quality of the living environment and optimal use of natural resources from the view of future generations. This strategy supports economic development with the present, provided that natural resources can still serve as an ecosystem through which human needs and wealth are provided [7]. The mentioned strategies connect economic and environmental context and they influence individual action plans.

In spite of the waste economy having improved in the EU recently, more than a quarter of the waste is still stocking and less than half is recycled, while there are some differences among EU member states. The present paper points out the need to give attention to the waste economy with an emphasis on open economy. This paper is oriented to the analysis of the production and recycling of communal waste in individual European countries. Its goal is to evaluate the success of efforts by countries to reduce waste production and increase measures to recycle waste, as well as to find out by which factors the situation was influenced.

Long-term efforts in the EU are aimed toward changing Europe into a recycling society that avoids increasing the production of waste, and which instead uses waste in accordancde with its possibilities as an energy source [8]. The mentioned approach is a key element for effective energy use and the sustainable development of European economies.

A healthy living environment should result from a circulating economy, where there is no waste and natural resources are used permanently, the biodiversity of the environment is protected, and society produces a minimum of greenhouse gases. Accordingly, the European Commission presented legislative suggestions to make the transition from the linear model of production and consumption to a new model, oriented to the closed flow of materials [9]. The suggestions introduce new goals in the area of waste economy from the view of repeated uses, recycling, stocking, strengthening of waste avoidance, and the increased responsibility of a producer. Additional measurements to decrease waste creation and resource use have also been introduced [10]. The mentioned goals were determined in accordance with (1) demands resulting from the environmental acquis and (2) the waste economy hierarchy. The hierarchy of waste economy is a basis of the European policy and legislation in the area of wastes [11], with the main aim to minimize the negative influences of waste on the living environment and to increase and optimize the effectiveness of waste resources use. The hierarchy of waste economy allows stocking only in cases where there is no possibility to avoid an increase in waste or its assessment. The avoidance of an increase in waste should be a priority of the waste economy in the EU, as well as the repeated use and recycling of materials, which should be conducted before evaluation of its energetic value, if possible, and done properly from an environmental, economic, and technical point of view. Saita and Franceschelli [12] mention that one of the main sectors of the ecologic economy is searching for and recycling of waste. Recycling in developing countries as one form of sustainable waste management has been studied by various authors. Troschinetz and Mihelcic [13] studied three dimensions of sustainability, environment, society, and economy. The only factors driven by all three dimensions (i.e., waste collection and segregation, a MSWM plan, and a local recycled material market) were those requiring the greatest collaboration with other factors.

Legislation of the waste economy in the EU is still improving and accepting concrete measurements to increase the quality of processes in waste management and stocking. The report on the communal waste economy in the EU (conducted by German consultation company BiPRO for the European Committee) showed that in spite of better alternatives given by the European regulatory framework and in spite of disposal structural funds for financing of better possibilities, a number of EU member states were still disposing communal waste in landfills, which is the worst possibility for a waste economy [14].

However, Wilts et al. [15] point out that the implementation of current EU legislation into national law is diverse and not sufficient. The authors argue that "most policy approaches do not sufficiently consider the steps of the waste hierarchy and thus do not systematically take into account aspects of resource efficiency and life-cycle thinking". Price and Joseph [16] discuss limitations to the waste hierarchy in terms of sustainable development. Additionally, van Ewijk and Stegemann [17] conclude that EU waste hierarchy is unable to reduce the consumption of natural resources and the impact on the environment. Identifying such gaps in the waste hierarchy, Gharfalkar et al. [18] have proposed an alternative to the hierarchy that improves clarity and provides the basis for improvement in the wastes that could be transformed into resources.

An important element in waste management is the application of logistics models for a waste economy that, according to Šebo [19], has a goal to optimize waste treatment, to decrease pollution of the living environment, to treat sources effectively, and to minimize financial means in relation to the concrete locality of the waste source. Also, Zhuonan [20] mentions that a useful tool for waste management is recycling logistics, having obvious advantages in such aspects as the economy and environmental protection.

In connection with waste, it is necessary to underline what environmental risks can arise in the case of improper waste treatment. Iacoboae et al. [21] show by analysis the negative impacts of improper waste treatment on contamination of soil, air, and water, which could also be dangerous for human health.

## 2. Literature Review

Development of waste and its use have been studied by a number of authors from various points of view [22–41], discussing various aspects of the waste hierarchy [11].

Waste disposal and landfill issues have been the subject of interest among authors for several decades, studying it from various perspectives, from environmental and health issues to suitable landfill site selection e.g., [22–25]. As summarized by, for example, Magrinho et al. [22], waste disposal is one of the most important environmental problems. Powel et al. [23] pointed out that municipal waste in landfills is one of the largest sources of global anthropogenic methane emissions. Shaddick et al. [24] have proposed a methodology for health impact assessment of environmental stressors due to the presence of landfills, pointing out that the presence of landfills affects human health.

Solid waste production and storage must be managed in any municipality, in any part of the world, since waste can have serious negative impacts on the living environment [26]. Therefore, solid waste treatment management should forecast waste production, storage and collection, transportation, and waste disposal. The present state of solid waste management was studied also in India [27], since India produces more than three thousand tons of solid waste every day. An increase in waste can be caused by a lack of suitable facilities and inadequate management, improper collection, and planning of further waste using. A lack of suitable facilities (i.e., equipment and infrastructure) and underestimation of waste generation rates, inadequate management and technical skills, and improper bin collection and route planning are responsible for poor collection and transportation of municipal solid wastes.

Systems for solid waste management should be optimized and integrated [28]. Such optimizing of waste management could save costs for waste treatment. Proper waste management is not yet applied in some countries. Badran and El-Haggar [29] show applied principles of waste management for Egypt with the use of waste collection principles. There is a significant increase in the volume of municipal solid waste (MSW) that is being generated across the world. In China, MSW management and MSW separation of waste were launched over the last 10 years [30] with the aim to convert new waste into energy.

The energy potential of waste, which can ensure sustainable development as well as energy security, has been studied by Bajić et al. [31]. Due to the use of global resources, there is a need for decoupling of economic growth and resource consumption by application of circular economy approaches [32]. Aguilar-Hernandez et al. [33] applied circularity to waste management, closing supply chains, product lifetime extension, and resource efficiency, showing that residual waste management can be modeled by increasing the amount of waste flows absorbed by the waste treatment sector. The concept of a circular economy, introduced by David Pearce in 1990 [34], addresses the interlinkages of the economic functions of the environment. The environment not only provides amenity values, in addition to being a resource base and a sink for economic activities, it is also a fundamental life-support system.

Abreu and Ceglia [35] identified the forces that are driving the shift from the current and traditional linear material and energy flows to a circular economy. Their study indicates that the government is playing a vital role in building and maintaining a cyclical flow of materials and energy. Horvath et al. [36] mentioned that the consumption increase in Western European countries has led to the transfer of used products to Central and Eastern Europe for further utilization. This process resulted in lower circular priorities (e.g., repair, remanufacture, repurpose) in such destination countries. Additionally, this model enabled the expansion of the lifespan via extenstion of the territorial perspecitve [36]. In the context of waste management, Rudolph et al. [37] provided an outlook on waste handling and recycling in the global market. However, business with waste demands circular business models, promising significant cost savings as well as radical reductions of environmental impact [38]. The topics of circular economy and resource efficiency, pollution reduction, and waste minimization have become important global policy goals and have gained prominence in developing countries in the context of the new sustainable development goals [39]. These pose challenges to the policy community in the formulation of plausible and ambitious targets for resource use, greenhouse gas emissions, and waste.

Society has altered the biophysical environment upon which it depends through the overexploitation of resources and growing waste generation. In this regard, action is urgently needed to reform the resource economy into a sustainable circular economy. Velenturf and Jopson [40] argues that resource recovery should support multi-dimensional growth to partly redistribute economic benefits to social and environmental values through the preservation of the technical and functional value of materials and products.

Also, individual businesses and industries should improve their economic and environmental performance through waste management with the aim to decrease their costs. Therefore, waste management issues should be solved from the perspective of supra-national to sub-national levels of government [41].

## 3. Methodology

Results presented in this paper are based on the data that were collected from the publicly available database Eurostat [42] and consequently analyzed and evaluated in statistic software JMP 13 (SAS Institute Inc, Cary, NC, USA). The analysis was conducted according to the following steps:

1. Graphical analysis of communal waste production in EU countries and number of inhabitants: cartographer;
2. Regression analysis of communal waste production in EU countries and the number of inhabitants;
3. Graphical analysis of communal waste production in EU countries per inhabitant: cartographer;
4. Distribution analysis of communal waste recycling;
5. Analysis of variability of communal waste recycling according to countries: Kruskal–Wallis test;
6. Summary analysis of production and recycling of the communal waste with regard to trends of development: basic index;
7. Cluster analysis.

### 3.1. Correlation

While monitoring socioeconomic phenomena we often see whether a change of one or more variables affects another variable, and if, then how. Defining the relationship between two or more variables allows regression and correlation analysis. The aim of regression analysis is to explain the biggest part of the variability of the primary variable through its relationship with other variables. Correlation analysis through statistical methods and approaches valuates the intensity of statistical dependence between quantity variables. Existence of the linear relationship between two variables is classified due to the covariance *cov xy*.

$$cov\ xy = \frac{1}{n}\sum\nolimits_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y}) \tag{1}$$

or

$$cov\ xy = \frac{n}{n-1}(\overline{xy} - \overline{x}\cdot\overline{y}) \tag{2}$$

Covariance acquire values from the interval $<-\infty; +\infty>$.

The calculated values indicate the direction of linear dependence between the two variables.

- $cov\ xy > 0$: between X and Y exists positive linear dependence;
- $cov\ xy < 0$: between X and Y exists negative linear dependence;
- $cov\ xy = 0$: between X and Y exists no linear dependence.

By studying the strength of the linear relationship of two variables we use the coefficient of correlation $r$. The correlation coefficient is defined by the equation:

$$r_{xy} = \frac{cov\ xy}{S_x \cdot S_y} = \frac{\widetilde{cov}\ xy}{\widetilde{S}_x \cdot \widetilde{S}_y} \tag{3}$$

Standard deviations, $s_x$, $s_y$, measure the spread of distribution around the mean. It is often denoted as $s$ and is the square root of the sample variance, denoted $s^2$.

$$s_x = \sqrt[2]{s_x^2} = \sqrt{\frac{1}{n}\sum\nolimits_{i=1}^{n}(x_i - \overline{x})^2} \text{ and } s_y = \sqrt[2]{s_y^2} = \sqrt{\frac{1}{n}\sum\nolimits_{i=1}^{n}(y_i - \overline{y})^2} \tag{4}$$

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \quad (5)$$

where:

$x_i$ is variable $x$ observed in time $i$,
$\overline{x}$ is athe rithmetic mean of variables $x$ in time series,
$y_i$ is variable $y$ observed in time $i$,
$\overline{y}$ is the rithmetic mean of variables $y$ in time series,
$n$ is sample size (number of time series examined).

The coefficient of correlation measures two-sided linear dependence and gains value form the interval <−1,1>, while the closer value is to |1|, the stronger dependence. In the case of coefficient $r$ = 1, there is a positive linear dependence. In the case of $r$ = −1, it means negative dependence. If the correlation coefficient equals 0, there is no relationship between variables X and Y. The correlation coefficient also has other values, which can be classified as follows:

| | |
|---|---|
| $0 < \lvert r\rvert < 0.3$ | low level of dependence among variables, |
| $0.3 \leq \lvert r\rvert < 0.5$ | moderate level of dependence among variables, |
| $0.5 \leq \lvert r\rvert < 0.7$ | medium level of dependence among variables, |
| $0.7 \leq \lvert r\rvert < 1$ | strong level of dependence among variables. |

Regression analysis
The next method for evaluation was regression analysis, according to the formula:

$$y = \beta_0 + \beta_1 x + e \quad (6)$$

where:

$y$ is the dependent variable,
$x$ is the independent variable,
$\beta_0$ is the model parameter, so-called localization constant, expressing what value will have Y in case X will equal zero,
$\beta_1$ is the model parameter, the so-called regression coefficient, expressing the slope of the regression line. The parameter informs by how many units $y$ will change averagely if $x$ will change by one unit.
$\beta_1 > 0$: positive dependence
$\beta_1 < 0$: negative dependence

### 3.2. Distribution Analysis

The distribution analysis allowed us to fit one or more distributions to the input data. Based on the statistical significance ($p$-values) of the results of these tests, we could determine which distribution best represents the data [43]. The distribution analysis helps to understand the overall nature of analyzed data and to make decisions about analysis. Data that fits a normal distribution would likely be well suited to linear regression, while data that are gamma distributed be better suited to analysis via the gamma regression tool.

### 3.3. Kruskal–Wallis Test

The Kruskal–Wallis test, as a non-parametric test (without distribution), is used when assumptions of one-way analysis of variance (ANOVA) are not met. The Kruskal–Wallis test and one-way ANOVA evaluates significant differences to the permanently dependent index by the categorical independent index (with two or more groups). In ANOVA, there is an assumption that the dependent index is normally distributed and there is approximately the same deviation between individual groups. The application of the Kruskal–Wallis test does not require making any of these assumptions. Therefore, the Kruskal–Wallis test can be used for the constant, as well as for the ordinal level of dependent indexes [44].

### 3.4. Cluster Analysis

Clustering clumps together points that are close to each other (points that have similar values). In Ward's minimum variance method, the distance between two clusters is the ANOVA sum of squares between the two clusters added up over all the variables. At each generation, the within-cluster sum of squares is minimized over all partitions obtainable by merging two clusters from the previous generation.

Ward's method joins clusters to maximize the likelihood at each level of the hierarchy under the assumptions of multivariate normal mixtures, spherical covariance matrices, and equal sampling probabilities [45].

Ward's method tends to join clusters with a small number of observations and is strongly biased toward producing clusters with roughly the same number of observations.

The clusters are formed in such a way that the increase in the variability of the intragranular component $W$ is small and the increase of the inter-noise variability $B$ is large [46].

$$W = \sum_{j=1}^{k} W_j = \sum_{s=1}^{m} \sum_{i=1}^{k} (x_{si} - \overline{x}_s)^2 \tag{7}$$

$$B = \sum_{s=1}^{m} \sum_{j=1}^{k} k\left(\overline{x}_{sj} - \overline{x}_s\right)^2 \tag{8}$$

where

$\overline{x}_s$ is the total diameter of the $s^{th}$ cluster,
$x_{si}$ is the value of the $s^{th}$ cluster for the $i^{th}$ variable.
Partial analysis of data was realized by the statistical software JMP.

## 4. Results and Discussion

The European Union gives increased attention to the protection of the living environment and points to the need to support ecologic activities and to stimulate the development of the ecological economy. Its long term goal is to change Europe into a recycling society that minimizes the increase in waste and increases levels of waste recycling. The research aspects mentioned above were analyzed in individual EU countries.

By comparing EU countries in the area of communal waste production over the last several years, it was obvious that the biggest producers were the following countries—Germany, Italy, France, and England (Figure 1). According to the graphical analysis of population numbers in the EU (Figure 1), the mentioned countries can be identified as countries with the highest numbers of inhabitants.

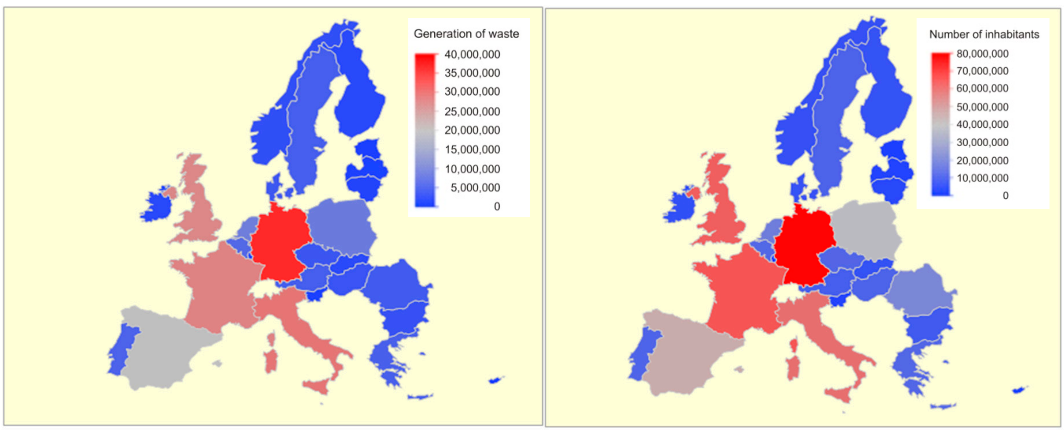



**Figure 1.** Production of communal waste (left) versus the number of inhabitants (right).

By consequent analysis of the number of inhabitants and the index of communal waste production, considerable correlation was confirmed according to expectations. Through regression analysis, the linear regression model was calculated, which describes 96% unknown (Figure 2). Such results did not give a sufficient description and characterization of communal waste production. Therefore, a more detailed analysis was required, e.g., production of communal waste per inhabitant (Figure 3).

Analysis through an index of communal waste production per inhabitant showed countries with the highest production of communal waste. The highest producer was Iceland with a production of 0.91 tons per inhabitant annually, which in graphical analysis significantly overshadows values of other countries (Figure 3, left). Therefore, Iceland was excluded from the analysis. Other countries, e.g., Denmark, Italy, Netherlands, Belgium, and Austria, had a production to 0.61 tons per inhabitant (Figure 3, right).

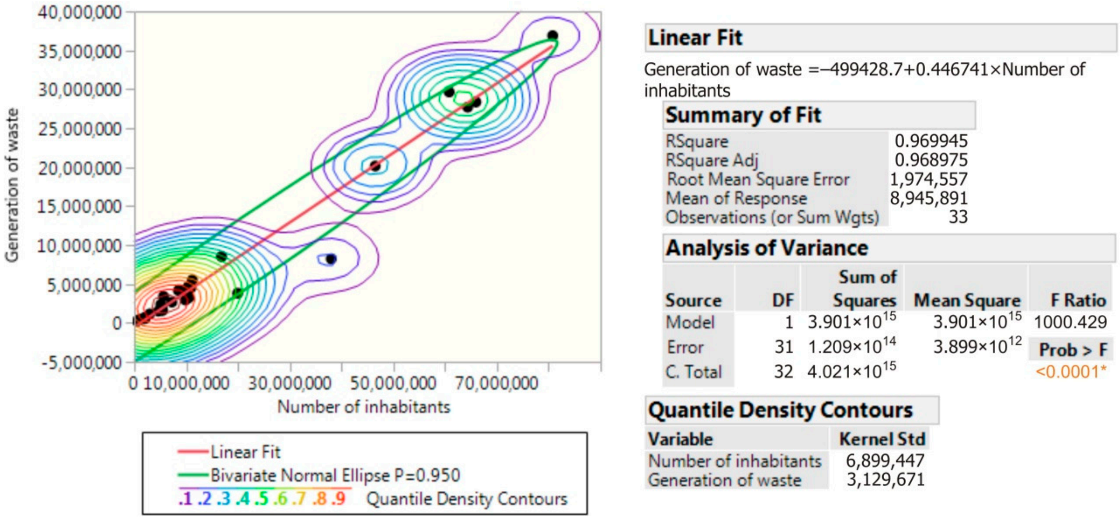



**Figure 2.** Regression analyses of communal waste production and the number of inhabitants in EU countries.

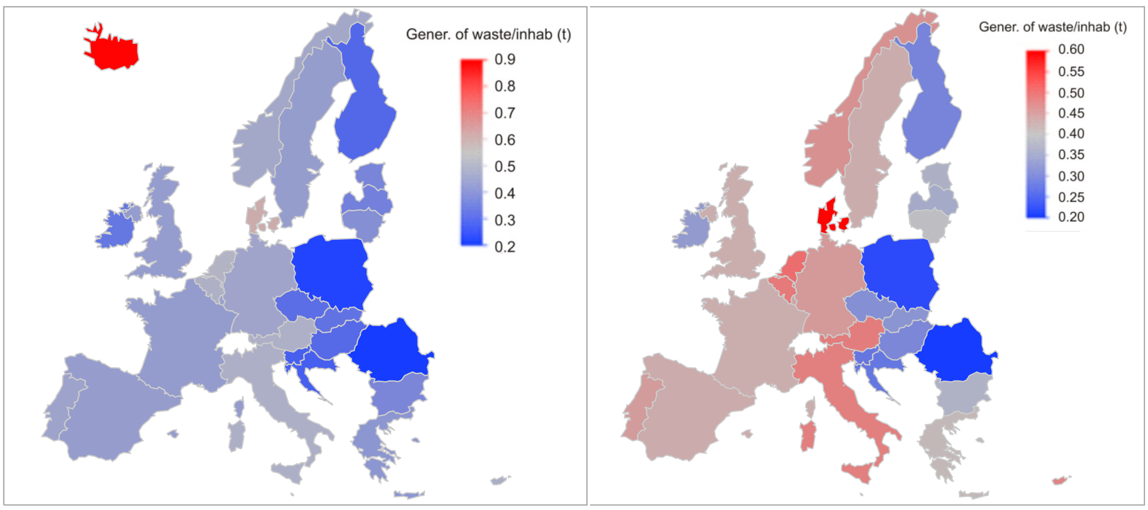
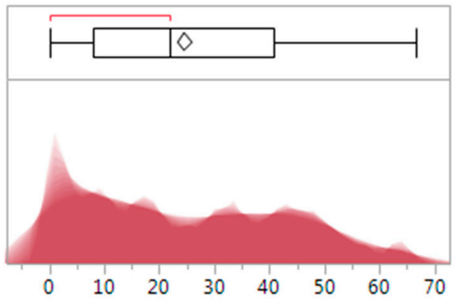



**Figure 3.** Production of communal waste per inhabitant in EU countries in 2016 with Iceland (left) and without Iceland (right).

The intensity of communal waste recycling was calculated by the index of recycling measure expressing the percentage of the repeated use of communal waste elements. From the available Eurostat database [47], data from EU countries were collected between 1995–2016. The average measure of recycling was approximately 25%, but the dispersion value was very significant, with a standard deviation of 18.6 (Figure 4).

**Recycling rate of municipal waste**




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 66.7 |
| 99.5% | | 65.44 |
| 97.5% | | 62.5 |
| 90.0% | | 50.1 |
| 75.0% | quartile | 40.9 |
| 50.0% | median | 21.8 |
| 25.0% | quartile | 7.8 |
| 10.0% | | 1 |
| 2.5% | | 0 |
| 0.5% | | 0 |
| 0.0% | minimum | 0 |

**Summary Statistics**

| | |
|---|---|
| Mean | 24.622533 |
| Std Dev | 18.608821 |
| Std Err Mean | 0.714141 |
| Upper 95% Mean | 26.024727 |
| Lower 95% Mean | 23.220339 |
| N | 679 |

**Figure 4.** Distribution analysis of communal waste recycling.

Analysis of recycling measures through the Kruskal–Wallis test evaluated the variability of the index from 1995–2016 in EU countries. The test proved the statistically important variability of the measured values in compared countries (Figure 5), meaning that the measure of recycling was significantly different in regard to the country.

**1-Way Test, ChiSquare Approximation**

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 519.0259 | 35 | <0.0001* |

**Figure 5.** The output of the Kruskal–Wallis test.

Looking at the development over time, we can state that, generally, recycling of communal waste has had an increasing trend in EU countries, which can be evaluated positively. However, there are also countries with a decreasing trend over the last several years (Figure 6).

The dominating country, as for the recycling measure, was Germany followed by Austria. The more detailed overview of environmental indicators oriented to the production of communal waste per inhabitant, waste recycling per inhabitant, as well as a total measure of recycling in the year 2016 (as the most actual year at the time writing) is given in Figure 6. From this picture, it is obvious that, in 2016, Denmark had the biggest waste production per inhabitant and Germany had the highest measure of recycling per inhabitant. Several EU countries, Romania, Poland, Czech Republic, Latvia, Lithuania, Cyprus, Italy, Hungary, and Portugal, based on the base index in 1995–2016, had positively changed their waste management towards waste recycling.

Recycling of wastes fills the United Nations Sustainable Development Goals (SDGs) and related targets, as it achieves the sustainable management and efficient use of natural resources and substantially reduces waste generation through prevention, reduction, recycling, and reuse by 2030 [48]. Recycling, as a part of waste management for sustainable development, is the base for sustainable development in the EU.

In the waste infrastructure sector, academic and practical progress has been made with respect to waste management and sustainable development. However, most conventional approaches to investment evaluation fail to consider infrastructure at a national scale and are not suited to consider future uncertainties or the complex relations between the social, technical, economic, and environmental dimensions of sustainability [49].

According to the two homogeneity indexes, a measure of recycling and production of communal waste in EU countries in 2016, clusters of states were constructed by the hierarchic cluster method (Ward's method). The following four clusters (Figure 7) were constructed:

1. the red cluster presents countries with a medium creation of communal waste and with a high measure of recycling,

2. the green cluster presents countries with a low creation of communal waste and medium measure of recycling,
3. the blue cluster presents countries with a low creation of communal waste and low measure of recycling,
4. the brown cluster presents countries with a high creation of communal waste and average or high measure of recycling.

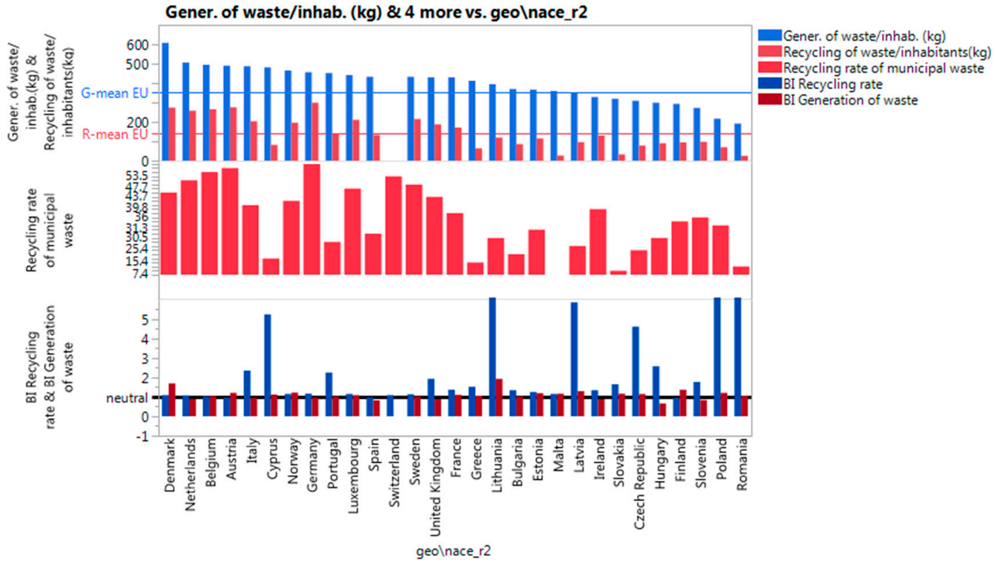



**Figure 6.** Waste production and recycling per inhabitant in EU countries in 2016.

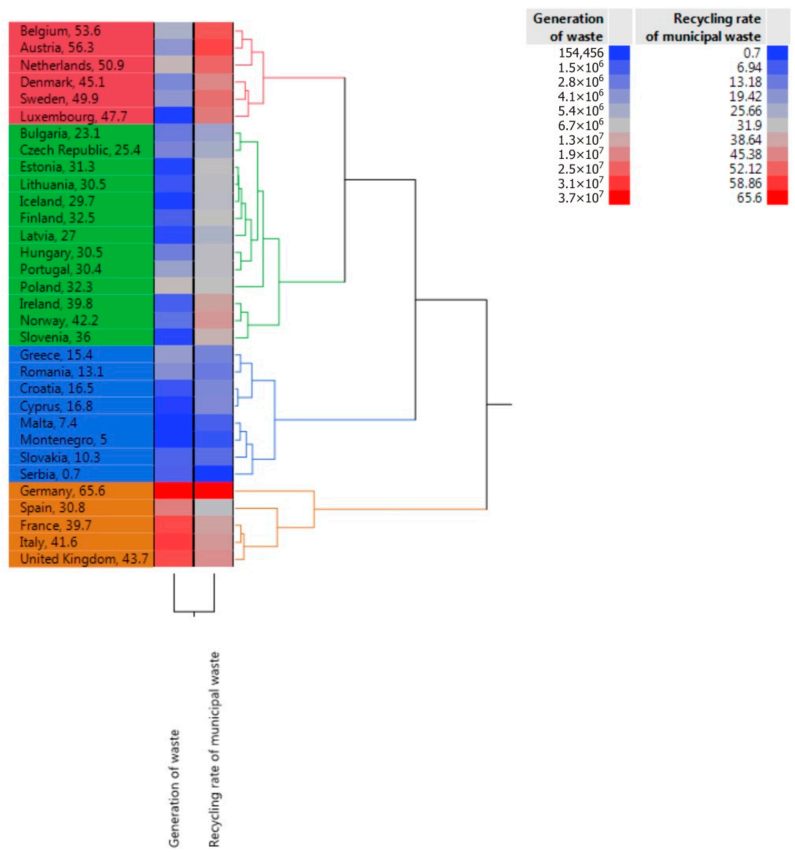



**Figure 7.** Cluster analysis according to creation and recycling of communal waste in 2016.

Production of communal waste was directly dependent on various factors such as social and economic indexes, mainly GDP. Analysis of such dependences can be the subject of future research. The results of the cluster analysis show that, despite clear EU waste management legislation, EU member states have significantly different waste management systems at the national level. This fact is clearly visible when analyzing the relationship between the generation of waste, recycling rate, landfill rate, and landfill taxes (Figure 8) in individual EU member states. The results of the analysis show that three major groups of states exist. The first group (quadrant I) includes countries with high recycling rates (more than 35%) and low landfill rates (up to 45%). The following countries belong to this group: France, Belgium, Austria, Denmark, Sweden, Ireland, Luxembourg, Netherlands, Italy, and Slovenia. Many of these countries have relatively high landfill taxes. The second group (Figure 8, quadrant III) includes countries with low recycling rates and high landfill rates. These countries (Slovakia, Spain, Estonia, Romania, and Bulgaria) have relatively low production of waste per inhabitant (140 to 400 kg) and low landfill taxes. The second quadrant includes the following countries: Lithuania, Portugal, Finland, Poland, and the Czech Republic. These countries are characterized by the low generation of waste, low landfill rates, low to medium recycling rates, and relatively low landfill taxes.

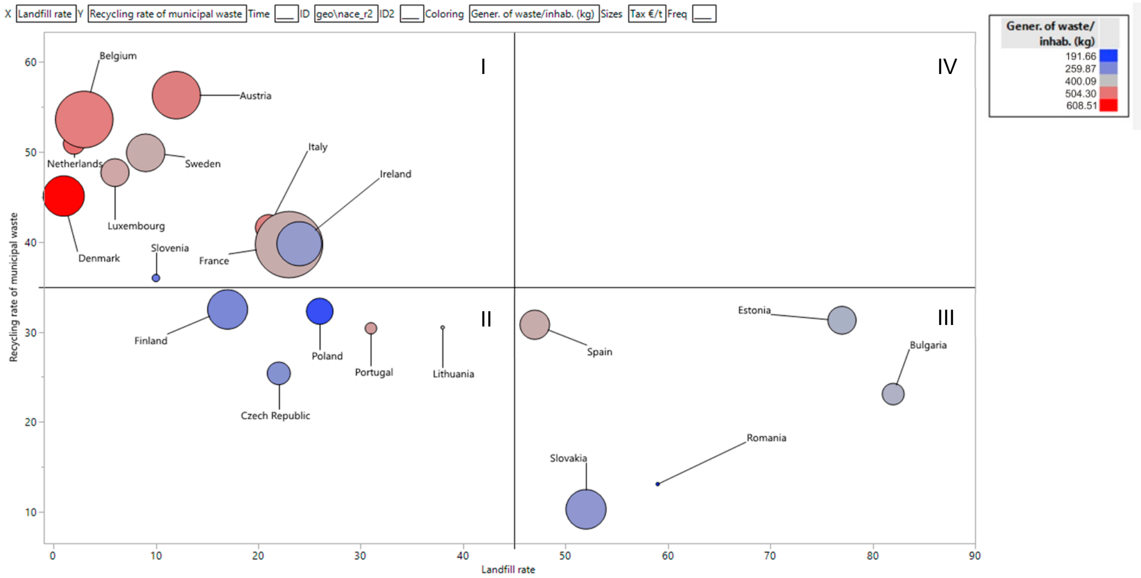



**Figure 8.** Bubble plot of recycling rates of municipal waste by landfill rates sized by landfill tax (€/t) in EU member states.

Figure 9 depicts the positive correlation between the generation of waste per inhabitant and recycling rate. Countries such as Germany, Austria, Belgium, Netherland, and Denmark generate a relatively high volume of waste per inhabitant. However, these countries have the highest recycling rate (more than 45%) and relatively high landfill taxes. On the other side, there are countries (e.g., Slovakia, Poland, Czech Republic, Latvia, Lithuania) with lower generation of waste per inhabitant and significantly lower recycling rates, accompanied by low landfill taxes. These findings indicate that probably the most effective tool for how to reduce landfilling and support waste recycling is landfill taxes. Increase in taxes in countries with low recycling rates (and relatively low levels of landfill taxes) may effectively lead to an increase in the recycling rate. In this regards, there should be a broad discussion on this issue at the EU level. Alternatively, in the case of EU member states, one of the most followable paths of change may be the export of waste to developing countries as discussed by, for example, Horvath et al. [36].

For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable, and socially acceptable [50]. Increasing awareness of both immediate and long-term influences of solid waste management services leads to responsible authorities paying substantial attention to these aspects of sustainability [51].

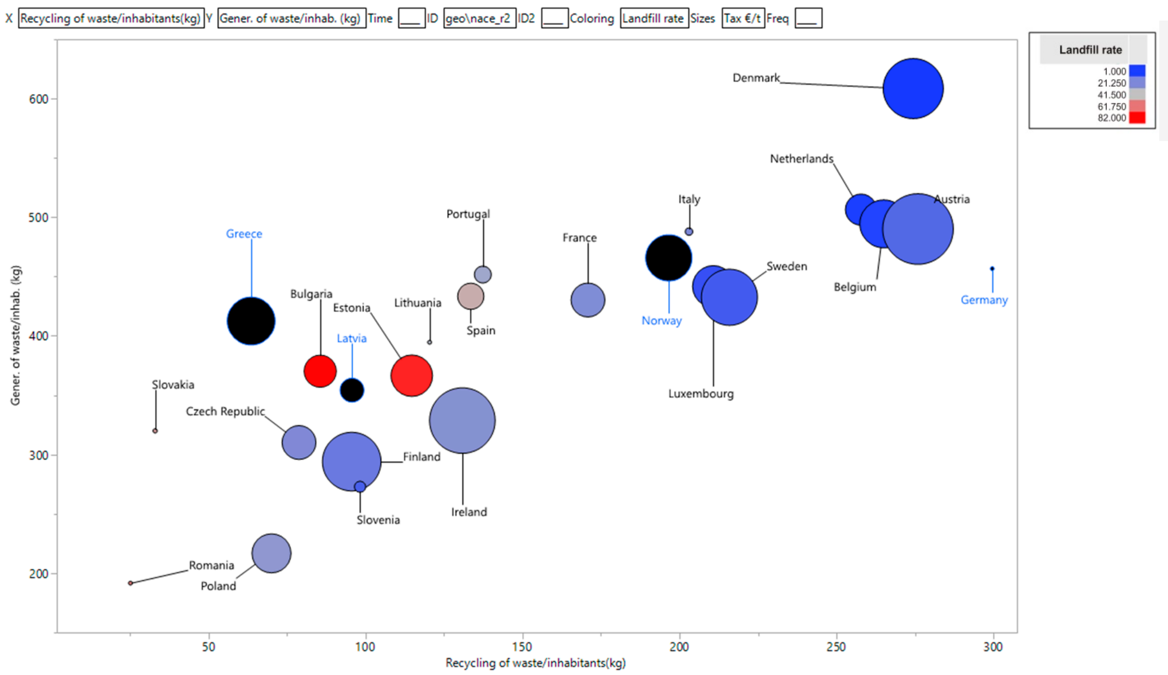



**Figure 9.** Bubble plot of generation of waste per inhabitant (kg) by recycling waste per inhabitant (kg) sized by landfill tax (€/t).

A society that avoids waste increases and, according to the possibilities, uses waste that cannot be avoided as a source of energy can be considered a recycling society. The goal is to evaluate waste from the perspective of energy and material sources helping to minimize "classical" mining of natural resources. Increasing (1) waste evaluation, oriented to repeated use and recycling, (2) support of waste prevention, and (3) society's awareness of the circular economy present the base for decreasing the environmental burden on society and the environment, as well as the possibility for more effective development and prosperity of individual countries and regions, as considered by the Ellen MacArthur Foundation, identifying three basic principles of the circular economy [52]. The key principle is the end of waste through changes in mining approach, design, use, and processing of materials. Through this, existing natural capital is preserved and enhanced. The second principle is based on the increase of materials' utility through better design for a longer life cycle [53], simplified recycling or repair. Through this way, materials could be observed in the economic system over a long time. The third principle means supporting the whole system's effectiveness and decreasing and regulating negative externalities.

Not only does Europe prefer a circular economy [9], but developing economies in Asian countries have rapidly started to consider this system also, and they consider waste as a valuable commodity. For example, China is considered as a country where the concept of a circular economy is obtaining an inreasingly important position, not only in research areas, but also at the political level [54]. Dong et al. [55] studied the development of municipal solid waste in China based on used technologies. However, as the circular economy has been defined for advanced economies primarily, it would not be entirely valid for the rest of the world, which must endure the externalities of developed economies [36].

Waste use has a positive effect on environmental savings, but waste collection systems should be upgraded effectively. In Germany, which has the highest recycling rate among EU member states, as depicted in this study, bio waste is collected, recycled, and ecologically and economically used [56].

The use of biowaste can decrease greenhouse gas emissions, and, in this way, it has its environmental impact. However, such use significantly depends on the separate collection of bio-waste from households.

Special attention should be given to the areas in which waste production is rising. From this perspective, Nayal et al. [57] studied waste from agricultural goods, since this presents the potential for energy carriers. Using waste from agricultural goods has its environmental benefit from the view of global warming, as well as use for electricity and heat generation.

It can be said that no volume of produced waste is so important as the application of modern technologies in the system of waste collection and recycling.

## 5. Conclusions

Recently, great attention has been given to sustainable development which is influenced by a number of aspects, including the state of the living environment. It is necessary to preserve a healthy and variable living environment for future generations. Achieving such a goal is strongly and directly linked to the increase in environmental responsibility and decrease in negative externalities at the national and international level. This paper was focused on one area of environmental protection—waste economy. Using available European statistical data [34], this paper presented an analysis of the production and recycling of communal waste in 36 EU countries. Based on the results, it can be stated that, in spite of the growing volume of communal waste, a positive development was recorded in waste recycling. Waste recycling had an increasing trend in individual EU countries, but the recycling level was still low (average: 24.6%). However, some countries (Malta, Austria, Greece, Norway) recorded a decreasing trend in recycling in the last several years. Germany was the dominant country that produces the majority of communal waste, on the other hand, it was also a country with the highest measure of recycling (65.6%). The reasons for such situations are various and connected with living standards in a specific country. Production of communal waste is directly dependent on social and economic indexes. The evaluation of waste production and recycling can be used for government policy in the area of waste management, as well as for individual communities dealing with communal waste. A study by the EU Commission estimates that if EU waste management legislation is to be fully implemented, it would result in annual savings of € 72 billion, an increase in the EU waste management and recycling sector of € 42 billion and the creation of 400,000 jobs by 2020 [14]. Therefore, we suppose that effective waste management initiatives should be the subject of a broad discussion, including scholars, government officials, stakeholders, local communities, and the general public. Based on the findings in this article, such discussion should include debates on appropriate landfill taxes and waste export possibilities.

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