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TOWARDS A CIRCULAR ECONOMY: EVALUATION OF WASTE MANAGEMENT PERFORMANCE IN EUROPEAN UNION COUNTRIES

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Abstract

Achieving the goals of the circular economy implies taking actions aimed at waste reduction which can be implemented through suitable waste management principles. The idea of the paper is to evaluate and compare the performance of waste management at the level of the European Union (EU). The paper aims to construct a composite index based on selected indicators from the Eurostat database using multi-criteria analysis methods. The CRITIC method was used as a method for determining weight coefficients, while Grey Relational Analysis (GRA) was used as a method for calculating the composite index of waste management performance. The results indicate that the countries of Western and Central Europe record the best results in creating adequate waste management practices (Belgium, the Netherlands, Slovenia, Luxembourg and Austria). It is also noticeable that the countries that joined the EU much later have the lowest values of the index that measures waste management performance, such as Bulgaria, Romania, Cyprus, Slovakia, Croatia, Malta and Poland, respectively. In the coming period, policymakers must pay more attention to respect for the principles of waste management in the newer member states of the EU, in order to reach convergence in the future.

Keywords: circular economy, waste management, Criteria Importance Through Intercriteria Correlation (CRITIC) method, Grey Relational Analysis (GRA), European countries

1. INTRODUCTION

On the road to sustainable development, the circular economy has replaced the earlier paradigm of the linear economy (Marković et al., 2020). Import dependence on resources, disruptions in supply chains, as well as environmental problems have led to

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the transition to a sustainable economic model. This newer concept is aimed primarily at reducing the consumption of natural and other resources. As one of the basic pillars of sustainability, ecological sustainability implies the sustainable use of natural resources to meet the needs of present generations while preserving the biodiversity and capacity of global ecosystems for the needs of future generations.

The circular economy is a concept that aims to reduce the consumption of resources and to allow them to remain in the economy as long as possible (Karstensen et al., 2020). This concept relies on recycling, reusing and waste reduction. The essence is that the waste (which is the result of one production process) is used as a raw material in another production process in the same or another industry. The return of waste to the production process can enable the progress of the country both in the ecological and economic sense. In this way, water, soil and air pollution is reduced. On the other hand, the development of the waste industry will enable the protection of the environment and human health, but also economic development through additional production and increased employment. The ultimate goal is to create the so-called environmental economics and realize sustainable socio-economic development.

The sustainability of the circular economy can only be achieved by creating a sustainable waste management system, primarily through encouraging recycling and/or reuse practices. Therefore, the goal of this paper is to construct composite indices of waste management in order to evaluate progress towards waste reduction using the methods of multi-criteria analysis. The authors will analyze the ranking, i.e. the effectiveness of the EU countries waste management practices in order to accomplish the goals of circular economy and sustainable development. The main research question is which countries of the European Union (EU) have the best waste management practices towards a circular economy, as a high-ranking goal of this integration. The importance of the paper is reflected in the fact that the score of waste management in any country can be monitored based on the value of the proposed composite index.

The paper begins with an introductory part, followed by four logical sections, from which concluding considerations are derived at the end of the text. The first section is devoted to the theoretical background of the importance of waste management as a form of the wider concept of circular economy. The second section presents the methodological framework and explains the importance of creating composite indices, the chosen method for determining weight coefficients, as well as the Grey Relational Analysis (GRA) procedure. After that, there is a presentation of the variables used in the research, as well as their values. The fourth section deals with the research results and discussion.

2. THEORETICAL FRAMEWORK

Rapid economic progress and increased exploitation of resources have conditioned the global environmental crisis characterized by the irrational use of limited resources and the creation of unsustainable amounts of waste. The predominant way of using resources, known as the linear economy, implies the transformation of resources into waste, which leads to the reduction of natural capital and degradation of the environment.

According to predictions, global waste is projected to grow up to 3.40 billion tons by 2050 (Kaza et al., 2018), with the growth rate that will overtop the population growth rate. The problem of growing waste accumulation is especially pronounced in the underdeveloped and developing countries where the growth rate of waste generation is twice as high compared to the waste generation growth rate in the developed countries (Hoornweg & Bhada-Tata, 2012).

The transition to a circular economy largely depends on waste management practices (Deselnicu et al., 2018). The key challenges in the area of waste management on the way to a circular economy relate to overcoming the perception of "waste as a problem" to "waste as a resource" (Lee et al., 2017). The concept of circular economy aims to establish the idea of "zero waste" (Li et al., 2018). Despite some progress, more than a quarter of waste in the EU is stored in landfills, while less than half is recycled (Taušová et al., 2019). Without the adoption of the adequate waste management strategies, the entire ecosystem can be threatened, which will further cause economic and environmental problems and endanger the achievement of sustainable development.

As the basic goals of waste management are to preserve resources and protect the environment and improve the quality of life, the adoption of appropriate waste management principles can facilitate the path to creating sustainability at both the micro and macro levels. Waste management includes a set of practices related to waste collection, transport, treatment and disposal, i.e., all actions from waste generation to its final disposal. In the previous period, waste was considered unusable and was disposed in the landfill, which over time created significant environmental pressures, primarily characterized by soil, water and air pollution. Recently, the potential of waste in terms of its processing and reuse has been noticed, which can enable the reduction of the use of scarce natural resources, reduce pollution and enhance the conservation of biodiversity. In addition, there are studies that emphasize the link between the circular economy and economic development.

There is an increasing interest in the problem of circular economy at the level of the EU. The implementation of the circular economy concept at the EU level began in 2014-2015 (Stankevičius et al., 2020). The circular economy is such an approach that connects the issues of people's lives and the preservation of the environment. Achieving environmental sustainability is one of the key components of the European Green Deal, with a special emphasis on encouraging the transition to circular economy policies. In particular, European Green Deal embodies an action plan aimed at ensuring sustainable use of resources through the adoption of practices that enable pollution reduction and preservation of the biodiversity.

EU countries have a legal obligation to reduce the amount of waste disposed in landfills and to increase the rate of recycling and reuse, respecting the principle of sustainable waste management (Halkos & Petrou, 2016). Circular economy, sustainable development and waste management were the priorities of the EU in accordance with the Strategy 2020, so many regulations were adopted to regulate it, among which is the Circular Economy Package of Directives (Zarbà et al., 2021). Adequate waste management in the countries of the EU is also regulated by the Circular Economy Action Plan (Hartley et al., 2020). It includes

various waste prevention programs specifically aimed at reaching a municipal waste recycling rate of 65% by 2023, which only Germany has achieved so far. Fura et al. (2020) state that the highest development of circular economy practices is achieved by the Benelux countries - Belgium, the Netherlands and Luxembourg.

In recent years, the creation of composite indices has become especially topical, primarily due to the increasing use of multi-criteria analysis methods as aggregation procedures. There are some works that were interested in the development of a composite index based on the circular economy and waste management indicators (Saidani et al., 2019; Garcia-Bernabeu et al., 2020; Stanković et al., 2021; Ūsas et al., 2021; Ahmed et al., 2022; Milanović et al., 2022). About 10% of the total peer-reviewed studies assess waste management topics using multi-criteria decision-analysis methods (Allesch & Brunner, 2014). The authors used the following indicators in building the multi-criteria model and composite index: Recycling rate of municipal waste, Recycling rate of all waste excluding major mineral waste, Packaging waste recycling rate, Recycling of bio-waste per capita and Recovery rate of construction and demolition waste.

3. METHODOLOGY AND DATA

Numerous countries have started to address the problem of excessive waste through the creation of waste management strategies. However, in order to monitor progress on the path towards waste reduction, it is necessary to establish a set of indicators that will quantify that progress. Quantifying complex phenomena, such as waste management, is a problem that can be addressed by creating composite indices. Composite indices represent aggregate measures that can monitor the performance of waste management and allow comparisons, both with other countries and over time.

The construction of composite indices was performed using the GRA approach. GRA represents a methodological framework based on the application of a mathematical method to optimize a multi-objective system. The essence of GRA is in determining the relationship of similarity between the reference series and alternative series, where the alternative with the greatest similarity to the reference series is chosen as optimal (Arce et al., 2015). However, before explaining the procedure for obtaining the composite index using this method, the authors will present the chosen method for calculating the weighting coefficients that will be assigned to each criterion in the multi-criteria model.

The CRITIC (CRiteria Importance Through Intercriteria Correlation) method was created by Diakoulaki et al. (1995) with the purpose of calculating the weight coefficients that would be used to determine the importance of each of the criteria in the multi-criteria decision-making process. This method belongs to the objective methods used for weighting the criteria values (Adali & Işık, 2017; Marković et al., 2022). Application of the CRITIC method requires compliance with the following procedure: (Diakoulaki et al., 1995; Puška et al., 2018):

Step 1. Normalization of criteria values and the creation of a decision matrix:

a) for revenue criteria:

$$r_{ij}^{+} = \frac{\left(x_{ij} - x_{ij}^{\min}\right)}{\left(x_{ij}^{\max} - x_{ij}^{\min}\right)} \quad (1)$$

b) for cost criteria:

$$r_{ij}^{-} = \frac{\left(x_{ij}^{\max} - x_{ij}\right)}{\left(x_{ij}^{\max} - x_{ij}^{\min}\right)} \quad (2)$$

where:

$x_{ij}^{\max} = \max(i)\, x_j$ and $x_{ij}^{\min} = \min(i)\, x_j$,
$i = 1, 2, ..., m,\ j = 1, 2, ..., n.$

Step 2. Determination of standard deviation σ_j for each vector r_j within the decision matrix.

Step 3. Constructing a symmetric matrix with R_{ij} elements, which is the linear correlation coefficients between each pair of normalized criteria values.

Step 4. Calculating the measure of conflict between indicator j and the rest of the criteria:

$$\sum_{j=1}^{n}\left(1 - R_{ij}\right) \quad (3)$$

Step 5. Calculating the quantity of the information C_j in relation to each criterion:

$$C_j = \sigma_j \sum_{j=1}^{n}\left(1 - R_{ij}\right) \quad (4)$$

Step 6. Obtaining the objective weights:

$$w_j = \frac{c_j}{\sum_{j=1}^{n} c_j} \quad (5)$$

GRA, as a multi-criteria decision-making method, was developed by Deng Ju-Long in 1982 (Ju-Long, 1982; Kuo et al., 2008). This method is widely used in various fields - medicine, economics, computer science, agriculture, i.e. wherever there are complicated relationships among the attributes (Patil et al., 2019). In fact, it is used in any sector where process or service optimization is necessary, as well as for ranking alternatives. By applying GRA, it is easy to compare alternatives that have been reduced to a single value. The selection process using this method requires the following steps (Kuo et al., 2008; Singh et al., 2004; Jozić et al., 2015; Patil et al., 2019):

Step 1. Determining the problem to be solved using this technique.

Step 2. Selection of variables and data collection.

Step 3. Data normalization for *i*) "larger - the better" or *ii*) "smaller - the better" quality characteristics (Grey relational generating):

i) for revenue criteria:

$$x_{ij} = \left(\frac{y_{ij} - \min\left(y_{ij}\right)}{\max\left(y_{ij}\right) - \min\left(y_{ij}\right)}\right) \quad (6)$$

ii) for cost criteria:

$$x_{ij} = \left(\frac{\max\left(y_{ij}\right) - y_{ij}}{\max\left(y_{ij}\right) - \min\left(y_{ij}\right)}\right) \quad (7)$$

where:

y_{ij} are the original attribute values.

Step 4. Calculation of grey relational coefficient:

$$\gamma\left(X_{0j}, X_{ij}\right) = \frac{\left(\Delta_{\min} + \xi\Delta_{\max}\right)}{\left(\Delta_{ij} + \xi\Delta_{\max}\right)} \quad (8)$$

where:

$$\Delta_{ij} = \left|X_{0j} - X_{ij}\right| \quad (9)$$

$$\Delta_{\min} = \min\left\{\Delta_{ij}, i = 1,2,...,m; j = 1,2,...,n\right\} \quad (10)$$

$$\Delta_{\max} = \max\left\{\Delta_{ij}, i = 1,2,...,m; j = 1,2,...,n\right\} \quad (11)$$

ξ - is distinguishing coefficient and mostly in studies it has a value of 0.5.

Step 5. Obtaining a grey relational grade. It is calculated by weighting the coefficients from the previous step.

$$\Gamma\left(X_0, X_i\right) = \sum_{j=1}^{n} w_{j\gamma}\left(x_{0j}, x_{ij}\right) \quad (12)$$

where:

$$\sum_{j=1}^{n} w_{ij} = 1 \quad (13)$$

Step 6. Ranking of alternatives and selection of the best based on the value of grey relational grade. The best alternative is the one with the highest value.

The model was developed to compare the success of the waste management policy of all 27 EU countries. The study will use five indicators from the Eurostat database (Part: Circular economy indicators) for all EU countries for the last available year: *Recycling rate of municipal waste* (2019), *Recycling rate of all waste excluding major mineral waste* (2018), *Packaging waste recycling rate* (2019), *Recycling of bio-waste per capita* (2019) and *Recovery rate of construction and demolition waste* (2018). For several countries, for which data were

Table 1. Description of criteria

Label	Criteria name	Definition
C1	Recycling rate of municipal waste (in %)	The indicator represents the percentage of recycled municipal waste in relation to the total production of municipal waste.
C2	Recycling rate of all waste excluding major mineral waste (in %)	The indicator measures the share of recycled waste in the total treated waste. Total treated waste includes all waste from the economic sector and the household sector, including secondary waste, but excluding mineral waste.
C3	Packaging waste recycling rate (in %)	This indicator is presented as a percentage of recycled packaging waste in the total packaging waste (paper, cardboard, plastic, wooden, metal and glass packaging).
C4	Recycling of bio-waste (in kg per capita)	The indicator shows the ratio of composted/methanized waste and the number of inhabitants in the country.
C5	Recovery rate of construction and demolition waste (in %)	'The indicator is the ratio of construction and demolition waste that is prepared for reuse, recycled or subject to material recovery, including backfilling operations, divided by the construction and demolition waste treated as defined in Regulation (EC) No 2150/2002 on waste statistics.'

Source: Eurostat, 2022.

not available, data from the first previous year available were taken. Table 1 shows a description of the selected criteria used in the creation of the composite index.

Table 2 provides descriptive statistics of the used performance indicators of waste management in the EU countries. The minimum, maximum and average values, as well as the standard deviation based on data from the Eurostat database, are shown.

Based on the descriptive statistics, it can be concluded that there is a significant variation between the countries of the EU in terms of the observed criteria, with the greatest dispersion of values recorded for the criterion - *Recycling of bio-waste per capita.*

4. RESULTS AND DISCUSSION

At the beginning of the analysis, the weight coefficients obtained by the CRITIC method are calculated (Table 3). In previous works, the authors mainly applied subjective approaches or the approach of equal weighting. However, the approach of equal weighting has certain disadvantages, which are primarily reflected in the fact that in reality not all criteria are of equal importance for the multi-criteria problem being analyzed. Furthermore, although the individual indicators would have equal relative importance, the relative importance of the categories into which the indicators are grouped would be in direct proportion to the number of indicators that make up each of the categories, which does not provide an objective indicator of the importance of each of the categories (Dobbie & Dail, 2013). Moreover, the application of equal weighting coefficients would cause for the composite index to represent simply the arithmetic average of the normalized indicator values (Karagiannis, 2017), while the application of an objective approach would allow obtaining weighting coefficients more appropriate to economic reality, which would result in unbiased composite indices. On the other hand, subjective approaches to determining the weighting coefficients of criteria rely on the knowledge and experience of the evaluators, which results in weighting coefficients that reflect their preferences, which may not always correspond to

Table 2. Descriptive statistics of criteria

	Minimum	Maximum	Average	Std. Deviation
Recycling rate of municipal waste	9.1	66.7	39.6	14.7
Recycling rate of all waste excluding major mineral waste	10.0	82.0	50.6	17.8
Packaging waste recycling rate	33.7	83.5	63.5	10.5
Recycling of bio-waste per capita	0.0	189.0	70.3	52.5
Recovery rate of construction and demolition waste	24.0	100.0	86.3	17.9

Source: Authors' calculation.

Table 3. Criteria weights (CRITIC method)

Criteria	Weights
Recycling rate of municipal waste	0.1607
Recycling rate of all waste excluding major mineral waste	0.1785
Packaging waste recycling rate	0.1954
Recycling of bio-waste per capita	0.1858
Recovery rate of construction and demolition waste	0.2795

Source: Authors' calculation.

empirical reality. Therefore, the contribution of this paper is reflected in the application of an objective method of determining the weighting coefficients of the criteria (CRITIC method), which eliminates subjectivity during the evaluation and the weighting coefficients are calculated directly on the basis of the criterion values. One of the advantages of the CRITIC method is that it allows consideration of the conflicting nature of indicators as well as the incorporation of interdependent indicators. The results of CRITIC methods are relatively similar to those obtained by applying other objective approaches, however, CRITIC is a simpler approach that requires less computational effort. Compared to the entropy method, the advantage of the CRITIC method is that it takes into account both the intensity of contrast and the conflict between indicators, unlike entropy, which takes into account only the intensity of contrast (Krishnan et al., 2021).

The results show that *Recovery rate of construction and demolition waste* has the highest relative importance in the ranking of countries, with a coefficient of 0.2795. On the other hand, Recycling rate of municipal waste, with a coefficient of 0.1607, has the least participation in the calculation of the composite index.

Table 4 summarises the ranking of each of the European countries according to the composite index of waste management performance. The seven highest-ranked countries belong to Western and Central Europe (Belgium, the Netherlands, Slovenia, Luxembourg, Austria, Denmark). On the other hand, it can be noted that at the bottom of the list there are mostly countries that joined the EU at the latest (Bulgaria, Romania, Cyprus, Slovakia, Croatia, Malta and Poland), so this may be the cause of their lagging on the way to implementing the principles of circular economy and adequate waste management operations. Finland stands out as a more developed country of the EU which is positioned low on the displayed list.

Figure 1 shows the position of the EU countries on the map depending on the value of the synthetic index of waste management performance.

Benelux countries, as old member states, stand out as countries that are among the leaders in the application of sustainable

Table 4. Composite index of the waste management performance (GRA method)

Country	Composite index	Rank	Country	Composite index	Rank
Belgium	0.8305	1	Hungary	0.5937	15
Netherlands	0.8283	2	France	0.5678	16
Slovenia	0.7774	3	Greece	0.5608	17
Luxembourg	0.7642	4	Estonia	0.5573	18
Austria	0.7612	5	Spain	0.5539	19
Denmark	0.7348	6	Finland	0.5493	20
Italy	0.7214	7	Poland	0.5405	21
Lithuania	0.7161	8	Malta	0.5316	22
Germany	0.7069	9	Croatia	0.4988	23
Ireland	0.6272	10	Slovakia	0.4917	24
Czech Republic	0.6261	11	Cyprus	0.4577	25
Latvia	0.6114	12	Romania	0.4342	26
Portugal	0.6016	13	Bulgaria	0.3997	27
Sweden	0.5991	14			

Source: Authors' calculation.

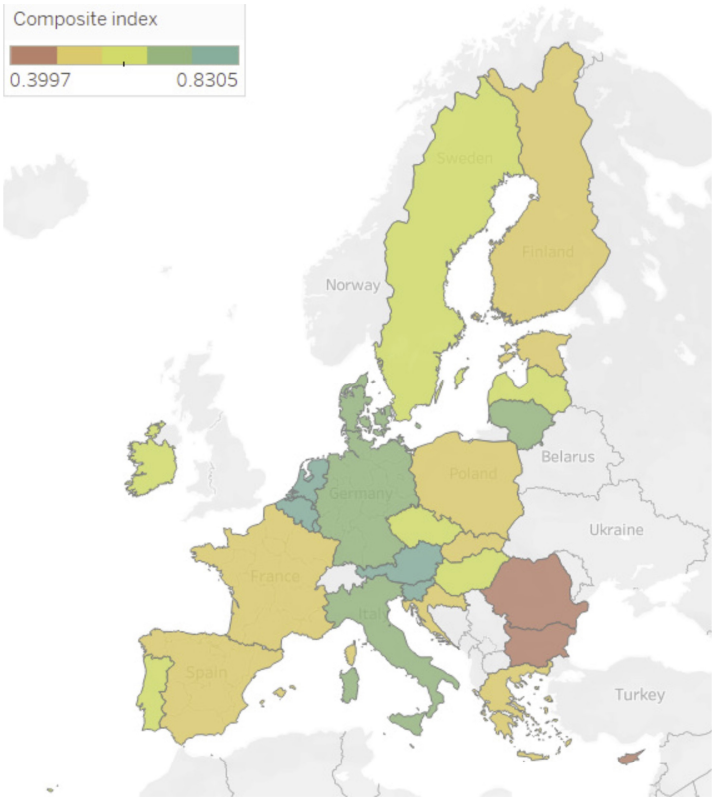

Figure 1. Graphic representation of EU countries according to the values of the composite index of waste management performance

waste management practices. Belgium is the best-ranked country according to the *Packaging waste recycling rate indicator*, the Netherlands is highly positioned according to all criteria, while Slovenia is the leader when it comes to *Recycling rate of all waste excluding major mineral waste*. Belgium and the Netherlands are the only countries that have achieved the European target regarding the recycling rate of packaging waste of 75% by 2030. Additionally, the Netherlands is at the top according to the aggregate circular economy indicator (which includes all its four segments: production and consumption, waste management, secondary raw materials and competitiveness and innovation), which is the result of its strategic goal to fully transition to the concept of circular economy by 2050 (Stanković et al., 2021). Finally, Slovenia is a country that was declared the green capital of Europe in 2016; it is a country where 70% of population sort eight types of waste (Lee et al., 2017).

In order to examine the influence of the weighting coefficients on the ranking results, the next part of the analysis is dedicated to the examination whether the application of objectively determined weighting coefficients when creating composite indices leads to rank inversion compared to the application of methods of equal weighting coefficients. The analysis was performed using correlation analysis, and the results indicate that there is a moderate inversion of rank between composite indices where the

CRITIC method is used as a weighting method compared to composite indices where equal weighting coefficients are used during weighting (the value of Spearman's rank correlation coefficient is 0.712). The obtained results indicate a significant influence of the selected weighting scheme on the order of alternatives (in this case, countries). It can be concluded that the selection of the weighting scheme is one of the critical steps when creating composite indices, whereby the advantage of objective approaches can be emphasized, since they are not burdened by the subjectivity of the composite index creator or experts, and they provide a more realistic and unbiased assessment of the importance of indicators.

5. CONCLUSION

Waste management is one of the main issues of the circular economy concept. In the earlier period, in conditions of rapid population growth, there was a model of economy that sought to end hunger and provide a sufficient amount of food for the growing population. However, after a certain period, the problem of uneven distribution of food in the world appeared. In fact, in the developed EU countries, as well as in the United States of America, it was shown that there is a surplus of food, which influenced the creation of more waste in those countries. On the other hand, developing countries are facing increased industrial waste as a result of inadequate production practices and the transfer of older technology.

The transition to a circular economy, which is a significant issue of sustainable development and a more sustainable economy, largely depends on the efficiency of waste management. The research conducted is important for both scientists and policymakers. Based on the developed composite index, the countries of the EU can be ranked and compared according to the success in implementing the principles of circular economy related to waste management. The research clearly highlights the leaders, as well as those countries with worse results. The best performance of waste management is achieved by the Benelux countries, Slovenia and Austria, while the countries that joined the EU much later are lagging behind. Belgium, the Netherlands, Luxembourg, Austria and Germany are countries that have been making great efforts in the field of waste management for several decades. Additional reasons that explain the position of certain countries on the list are the level of environmental awareness and the degree of economic and technological development. In addition, it is noted that EU countries differ greatly in the performance of waste management, which was also been observed in previous studies (Ribić et al., 2017; Stanković et al., 2021).

This research, like most others, has certain shortcomings. The shortcomings are related to the out-of-date database, as the last available data is for 2019. Also, due to the lack of recent data, it is not possible to monitor the trend of waste management performance over time in the form of a composite index. Future research could observe the progress of European countries in the area of waste management after data for the following years is available.

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КА ЦИРКУЛАРНОЈ ЕКОНОМИЈИ: ЕВАЛУАЦИЈА ПЕРФОРМАНСИ УПРАВЉАЊА ОТПАДОМ У ЗЕМЉАМА ЕВРОПСКЕ УНИЈЕ

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Извод

Остваривање циљева циркуларне економије подразумева предузимање акција у циљу смањења отпада које се могу спровести кроз одговарајуће принципе управљања отпадом. Идеја рада је да се процени и упореди учинак управљања отпадом на нивоу Европске уније (ЕУ). Рад има за циљ да конструише композитни индекс на основу одабраних индикатора из базе података Еуростата коришћењем метода вишекритеријумске анализе. Као метода за одређивање тежинских коефицијената коришћена је метода "CRITIC", док је за израчунавање композитног индекса перформанси управљања отпадом коришћена "Grey Relational Analysis" (ГРА). Резултати показују да земље западне и централне Европе бележе најбоље резултате у креирању адекватне праксе управљања отпадом (Белгија, Холандија, Словенија, Луксембург и Аустрија). Приметно је и да земље које су много касније приступиле ЕУ имају најниже вредности индекса који мери учинак управљања отпадом, као што су Бугарска, Румунија, Кипар, Словачка, Хрватска, Малта и Пољска. У наредном периоду креатори политике морају посветити више пажње поштовању принципа управљања отпадом у новијим државама чланицама ЕУ, како би у будућности достигли конвергенцију.

Кључне речи: циркуларна економија, управљање отпадом, "CRITIC", "Grey Relational Analysis" (ГРА), европске земље

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