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Mapping circular pathways: a bibliometric exploration and Multilinear Regression Model of Romania's circular economy

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Abstract. *Circular economy represents a key concept in the contemporary era of sustainable development, with the potential to revolutionize how our society consumes, manages resources, and addresses ecological issues. In this context, Romania, a country with a rapidly developing economy, has gradually embraced the principles of the circular economy and has begun to chart its own path towards a more sustainable and resource-efficient future. The primary objective of this study is to conduct a bibliometric analysis of the concept of the circular economy in Romania and apply a multilinear regression model where the dependent variable is GDP per capita, and the independent variables include the circularity rate, imports and exports of waste. The time frame analyzed for the multilinear regression model is 2012-2021, and for the bibliometric analysis, it spans from 1999 to October 2023.*

Keywords: circular economy, multilinear regression model, bibliometric analysis.

JEL Classification: A11, B41, C18, C31.

1. Introduction

Circular economy (CE) refers to the circular flow and efficient (re)use of resources, materials, and products. The lifespan of products and materials is extended, while waste is minimized. Products and industrial processes are designed to keep resources in use, with inevitable waste or residues being recycled or recovered. The transition to a circular economy is vital to achieving the EU's goal of carbon dioxide emissions neutrality by 2050, while also ensuring sustainable economic growth and employment (European Commission, 2023). It carries significant political and regulatory implications that will impact future job opportunities. According to the Department for Sustainable Development, although progress is being observed in Romania's transition from a linear to a circular economy, the level of circularity remains low in comparison to the European Union.

On the other hand, according to the Action Plan for the National Circular Economy Strategy proposed in the National Circular Economy Strategy approved by Government Decision No. 1172/2022 (European Union, 2023), strategies have been developed on how to promote the transition to a circular economy in Romania. The plan introduces new economic sectors with the highest circularity potential in Romania, along with a description of 52 priority actions within these sectors. Among these priority actions are increasing the utilization of biomass from agricultural and forestry activities for energy and biofertilizer production (timeframe 2024-2030, funding through CAP, The National Recovery and Resilience Plan (PNRR), and private investments), the construction of logistics centers and infrastructure for the storage and distribution of Agri-forestry and food products (timeframe 2024-2030, funding from the European Maritime Affairs Fund, PNRR, and private investments), professional training for future engineers and technicians (timeframe 2024-2029, funded by the Ministry of Education), or the description of a national system for the collection, sorting, and recycling of textile waste and used clothing (timeframe 2024-2030, funding from the state budget, PNRR, local budgets, and manufacturers).

The main hypothesis of our research is driven by the desire to formulate a vision that maps out the directions and benefits of Romania's transition to a Circular Economy (CE). It also aims to illustrate the level of interest in this field from the perspective of the current state of knowledge. Among the benefits of transitioning to a CE, it can promote the efficient use of resources, reduce waste and dependence on raw materials, stimulate innovation in microeconomic systems, enhance competitiveness by improving product and service quality, and generate new job opportunities. Our study is structured into several sections.

The first section outlines the fundamental concepts of the circular economy, highlighting the differences between a linear and a circular economy, as well as the current state of knowledge in the field. The following section presents the bibliometric analysis technique that we will employ in the practical section to provide a comprehensive overview of research in the field of the circular economy. We will also introduce the multilinear regression model at a methodological level. The last section is a practical approach in which

we conduct a bibliometric analysis using the bibliometrix library in R Studio. Additionally, we employ a multilinear regression model to analyze the influence of independent variables such as circular rate, imports waste, and exports waste on the dependent variable, GDP per capita. The research concludes with a conclusions section, where we discuss the results of the analyses conducted and outline potential avenues for future research.

2. Fundamental concepts of the circular economy and the current state of knowledge in the field

According to The National Academies, even a superficial review of major international economic trends in recent decades reveals revolutionary changes in global financial markets. During the decades of the 1950s and 1960s, financial institutions and their regulatory bodies in industrialized countries experienced a period of relative autonomy from external influences. This period was characterized by strict restrictions on capital flows between countries, a common practice adopted by many nations, including the United States of America. The concept of the circular economy has been described in numerous ways, with various definitions offered by researchers and practitioners, as highlighted by Kirchherr et al. (2017). Economic circularity is closely linked to the concept of sustainable development and the sustainability of a country. Although the concept of economic circularity has significant potential to promote sustainability, there are some issues related to its definition and its connection to sustainable development, as discussed by Farmer et al. (2015), Irving (2016), and Bullus (2017).

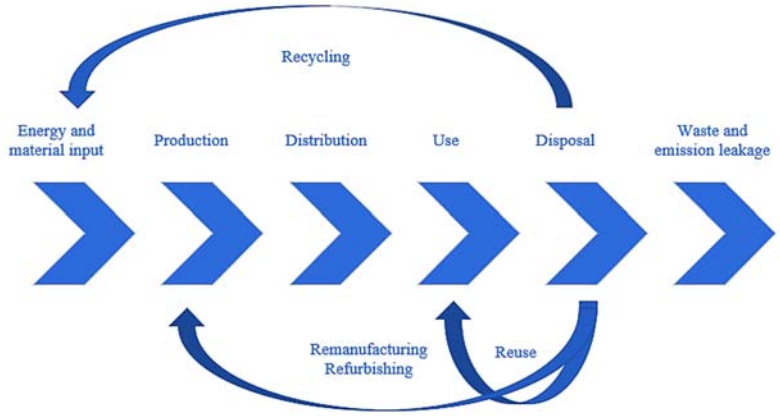
The concept of the circular economy first emerged in the 1970s and 1980s as environmental concerns related to waste and resource depletion began to gain prominence. The initial use of the term “circular economy” is attributed to industrial designer Walter R. Stahel in the late 1970s, who was a proponent of the idea. However, it wasn't until the 2000s that the circular economy began to gain broader recognition and interest.

The increasing emphasis on sustainability and the need to reduce the environmental impact of economic activities have led to a growing recognition of the potential benefits of the circular economy. The necessity for a more sustainable approach to economic activity has been further underscored by the depletion of finite resources, such as oil and minerals, as well as increasing concerns about waste and pollution.

In recent years, the concept of the circular economy has gained widespread recognition and has been embraced by businesses, governments, and other organizations worldwide. The European Union (Eisenriegler, 2020) has made the circular economy one of its key priorities and has set ambitious targets for the transition to a circular economy, including a goal to recycle 65% of municipal waste by 2030. In the past 200 years, people have created an incredible industrial economy that has brought unparalleled wealth. This economy, the result of our collective wisdom, has been built over many years of gradual improvement

and is driven by new technology. To sustain rapid global expansion of the middle class without being overwhelmed by its negative effects on the environment and society, this system must be changed.

Figure 1. *Circular economy versus Linear Economy*



Source: Authors computation according to (Info Diagram, 2023).

The diagram in Figure 1 presents a comparison between the circular economy and the linear approach. The fundamental difference lies in the fact that in the circular economy, the primary focus is on reusing raw materials through recycling and other methods, whereas in the linear economy, the end result is waste generation after the use of a product. The steps of the linear economy include the introduction of energy and materials, production, distribution, use, disposal, waste generation, and emission leakage.

The circular economy offers a significant advantage because, as soon as a product becomes waste, it is recycled, undergoes remanufacturing and refurbishment during production, and is ultimately prepared for reuse. This business model has been widely accepted as a more sustainable management solution, gradually leaving the linear approach behind. Given the ongoing global challenges we face, these principles of the circular economy should be seriously considered.

Linear economy is an economic model in which raw materials are extracted, transformed into products, used, and then discarded as waste. This model involves a "take-make-dispose" approach, where resources are rapidly depleted, and waste production significantly increases.

Circular economy, on the other hand, is an economic model that focuses on minimizing the use of freshly extracted resources and waste. In this model, raw materials are recycled, reused, and remanufactured as much as possible to extend the product lifecycle and reduce the impact on natural resources. It promotes a closed-loop system where materials are kept within the economy, and resources are used efficiently.

In recent years, there has been a growing recognition of the importance of sustainable development, and many countries have adopted sustainable development goals and policies. However, achieving sustainable development remains a significant challenge, and continuous efforts are needed to promote sustainable practices and behaviors at all levels of society (D'Adamo, 2020).

In economic terms, sustainable development can be seen as a way to balance economic growth and environmental protection. The idea is to create a development model that maximizes short-term economic benefits while minimizing negative impacts on the environment and preserving resources for future generations.

In practical terms, this means that economic activities should be designed and implemented in a way that considers their impact on the environment and society. For example, businesses may need to adopt more sustainable practices, such as waste and emissions reduction, to reduce their environmental footprint and contribute to sustainable development.

Governments can also play a role in promoting sustainable development by implementing policies and regulations that encourage sustainable economic activities and discourage environmentally harmful ones. Additionally, governments can invest in renewable energy, green technologies, and sustainable infrastructure to help drive economic growth in a more sustainable direction.

Romania, like many other countries, is working towards achieving specific sustainable development goals (Nica et al., 2023). The Romanian government has taken measures to promote this endeavor, including adopting policies and regulations aimed at reducing greenhouse gas emissions, protecting natural resources, and enhancing the country's energy efficiency. In recent years, progress has been made in areas such as renewable energy, with increased utilization of wind, solar, and hydroelectric power. The country has also taken steps to improve energy efficiency and reduce carbon footprint through measures like building modernization and the promotion of energy-efficient products and technologies (Eisenriegler, 2020).

3. Bibliometrix analysis technique and Multilinear Regression Model

Bibliometric analysis is a form of statistical analysis of academic publications, be they articles, book chapters, or conference papers. Overall, this type of analysis is valuable as it reveals the patterns and trends within various research topics.

Bibliometric analysis has seen a significant surge in popularity within the field of business research in recent years, as indicated by the works of Donthu et al. (2020b), Donthu, Kumar, Pattnaik, & Lim (2021), and Khan et al. (2021). This surge in popularity can be attributed to several key factors:

- Advancements, availability, and accessibility of bibliometric software such as Gephi, Leximancer, VOSviewer, and comprehensive scientific databases like Scopus and Web of Science.
- The cross-disciplinary exchange and integration of bibliometric methodology from information science into the realm of business research.

What's more, it's essential to recognize that the rising popularity of bibliometric analysis in the business research field is not a passing trend; rather, it mirrors its practical utility in two main aspects:

- Managing and analyzing vast quantities of scientific data efficiently.
- Generating research outcomes with a substantial impact.

Bibliometric analysis techniques can be categorized into two main groups: performance analysis and science mapping. Performance analysis primarily involves assessing the contributions of research elements, while science mapping concentrates on examining the relationships among those research elements.

According to Donthu et al. (2021) the methodological steps for developing a bibliometric analysis are as follows:

- Define the objectives and scope of the bibliometric study.
- Select the bibliometric analysis techniques.
- Gather the data for bibliometric analysis.
- Execute the bibliometric analysis and present the results.

Multiple linear regression is a statistical technique used to analyze the relationships between a dependent variable and multiple independent variables (Narula et al., 1980). Essentially, it extends simple linear regression, which deals with a single independent variable, to include several independent variables. This type of analysis is used in research and data analysis to quantify the simultaneous impact of multiple factors on a variable of interest.

In multiple linear regression, the goal is to find a mathematical relationship between the dependent variable and the independent variables so that predictions or estimates can be made based on the values of these independent variables. This technique provides a more realistic approach to complex relationships in the real world, where multiple variables can influence the dependent variable simultaneously.

Multiple linear regression analysis involves estimating coefficients that quantify the contribution of each independent variable to the dependent variable while controlling for the effects of other independent variables. It is a powerful tool in research and data analysis, used in various fields, from economics and social sciences to natural sciences and engineering, to gain a better understanding of complex relationships between variables in different contexts.

The mathematical model for multiple linear regression can be represented as follows:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i1} + \cdots + \beta_p x_{ip} + \varepsilon \quad (1)$$

In equation (1), y – represent the dependent variable, we are trying to predict or explain. β_0 is the intercept, a constant that represents the value of y when all independent variable is zero. β_1, β_2, $\beta_3 \ldots \beta_k$ are the regression coefficients for each independent variable $x_1, x_2 \ldots x_k$. These coefficients measure the impact of each independent variable on the dependent variable. ε represents the residual error, which is the difference between the actual value of the dependent variable and the value predicted by the model. Multiple linear regression is a fundamental mathematical technique in data analysis and scientific research, used to understand complex relationships between variables across various fields.

The methodological steps we followed in constructing a multiple linear regression model for the case study are as follows (Nica et al., 2023):

- Problem Definition: I began by defining the problem based on the study's initial objectives, identifying the variables that could be considered for inclusion in the model.
- Data Collection: I sought official sources from which I obtained the dataset containing the relevant variables.
- Data Exploration and Preprocessing: I thoroughly examined and cleaned the collected data to prepare them for modeling. This stage involved addressing missing values, performing normalization, and implementing data transformation.
- Variable Selection: Typically, variable selection techniques, such as correlation analysis, or specific methods like forward elimination and backward elimination, were employed to determine which variables should be included in the model.
- Model Construction: The data was used to construct the multiple linear regression model.
- Model Evaluation and Validation: Various statistical metrics, including R-squared, F-test, and t-tests for coefficients, were employed to assess and validate the model's quality.

4. Case study: bibliometric analysis and the use of Multilinear Regression Model in designing the circular economy system in Romania

4.1. Bibliometric analysis

The series of queries from table 1 performed in the Web of Science (WoS) database are aimed at retrieving relevant documents for conducting a bibliometric analysis on the topic of the circular economy in Romania. Timespan is 1999-2023, with a total of 390 documents extracted from 165 sources.

Table 1. *Bibliometric Search Results for Circular Economy in Romania*

Exploration steps	Questions on Web of Science	Description	Query	Query number	Count
1	Title	Contains one of the circular economy or circularities in Romania specific keywords	((((((((((TI=(Circular Economy in Romania)) OR TI=(Recycling in Romania)) OR TI=(Material Reuse in Romania)) OR TI=(Waste Management in Romania)) OR TI=(Circularity and the Romanian Industry)) OR TI=(Circular Economy Policies in Romania)) OR TI=(Circular Innovation and Technology in Romania)) OR TI=(Sustainability and the Circular Economy in Romania)) OR TI=(Resource Efficiency in Romania)) OR TI=(Construction Industry and the Circular Economy in Romania)) OR TI=(Closed-Loop Economy in Romania) OR TI=(Romania's Circular Economy) OR TI=(Towards a Sustainable Future in Romania)	#1	79
2	Abstract	Contains one of the circular economy or circularities in Romania specific keywords	((((((((((AB=(Circular Economy in Romania)) OR AB=(Recycling in Romania)) OR AB=(Material Reuse in Romania)) OR AB=(Waste Management in Romania)) OR AB=(Circularity and the Romanian Industry)) OR AB=(Circular Economy Policies in Romania)) OR AB=(Circular Innovation and Technology in Romania)) OR AB=(Sustainability and the Circular Economy in Romania)) OR AB=(Resource Efficiency in Romania)) OR AB=(Construction Industry and the Circular Economy in Romania)) OR AB=(Closed-Loop Economy in Romania) OR AB=(Romania's Circular Economy) OR AB=(Towards a Sustainable Future in Romania)	#2	701
3	Keywords	Contains one of the circular economy or circularities in Romania specific keywords	((((((((((AK=(Circular Economy in Romania)) OR AK=(Recycling in Romania)) OR AK=(Material Reuse in Romania)) OR AK=(Waste Management in Romania)) OR AK=(Circularity and the Romanian Industry)) OR AK=(Circular Economy Policies in Romania)) OR AK=(Circular Innovation and Technology in Romania)) OR AK=(Sustainability and the Circular Economy in Romania)) OR AK=(Resource Efficiency in Romania)) OR AK=(Construction Industry and the Circular Economy in Romania)) OR AK=(Closed-Loop Economy in Romania) OR AK=(Romania's Circular Economy) OR AK=(Towards a Sustainable Future in Romania)	#3	2
4	Title and Abstract and Keywords	Contains one of the circular economy or circularities in Romania specific keywords	#1 OR #2 OR #3	#4	720
5	Language	Limit to English	(#4) AND LA=(English)	#5	714
6	Document Type	Limit to Article	(#5) AND DT=(Article)	#6	390

Source: Authors computation.

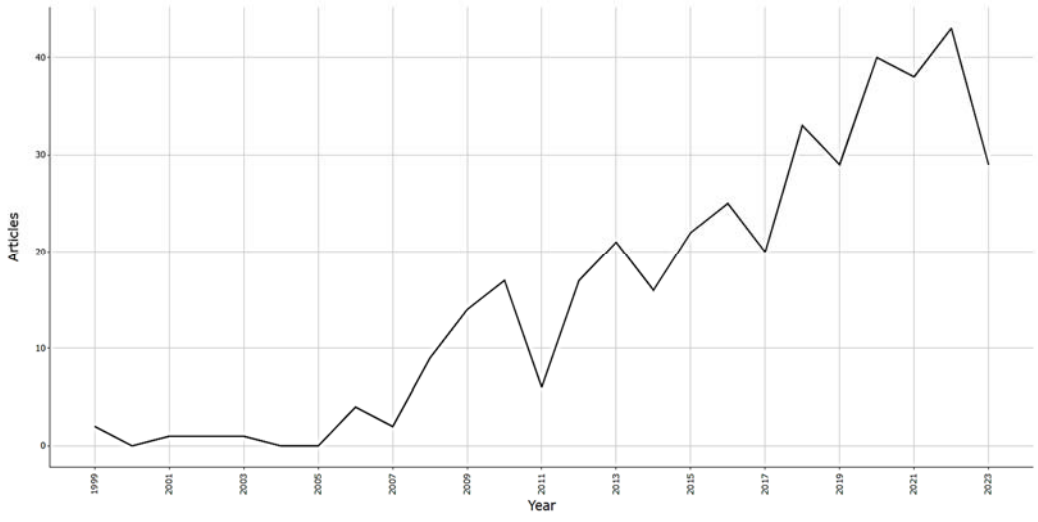
The series of queries performed in the Web of Science (WoS) database are aimed at retrieving relevant documents for conducting a bibliometric analysis on the topic of the circular economy in Romania.

To explore the research landscape related to the circular economy in Romania, we conducted a comprehensive search using the WoS database. Our goal was to identify and retrieve articles that focus on various aspects of the circular economy within the context of Romania. The following steps were employed to gather a substantial dataset for our bibliometric analysis:

- Title (79 results): We initiated our search by targeting articles with titles that explicitly included specific keywords related to the circular economy in Romania. This initial search yielded 79 articles.
- Abstract (701 results): We expanded our search to include articles with abstracts containing the same specific keywords, further broadening our scope. This step resulted in 701 articles with relevant abstracts.
- Keywords (2 results): We also explored documents with keywords featuring the circular economy in Romania, adding 2 more articles to our dataset.
- Title and Abstract and Keywords (720 results): A comprehensive search was performed by combining the results from the Title, Abstract, and Keywords queries. This approach ensured that documents contained the specified keywords in either the title, abstract, or keywords section, resulting in a total of 720 articles.
- Language (714 results): We refined our dataset by limiting it to articles published in English, as it is the most accessible language for our analysis. This step led to a final dataset of 714 English-language articles.
- Document Type (390 results): To ensure that our analysis focused on scholarly articles, we further filtered the dataset to include only articles, resulting in a total of 390 articles.

These queries and filters collectively provide a robust and extensive collection of documents that will serve as the foundation for our bibliometric analysis. They encompass a wide range of topics related to the circular economy in Romania and will be invaluable for our research and subsequent article.

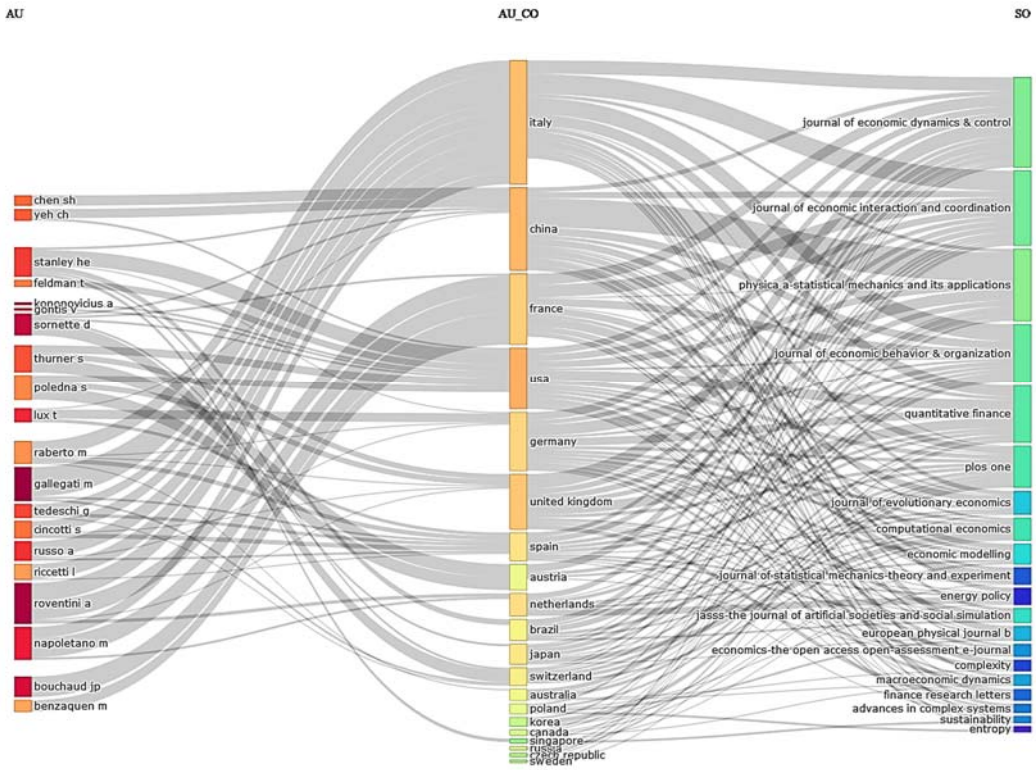
Figure 2. *Annual Scientific Production*



Source: Authors computation.

In Figure 2, the annual scientific production of the extracted articles based on WoS criteria is depicted. It is evident that from 1999 to the present, there has been a consistent increase in researchers' interest in the subject under investigation. In the year 2022, the total number of documents reached over 40, reflecting a annual growth rate of 11,79%.

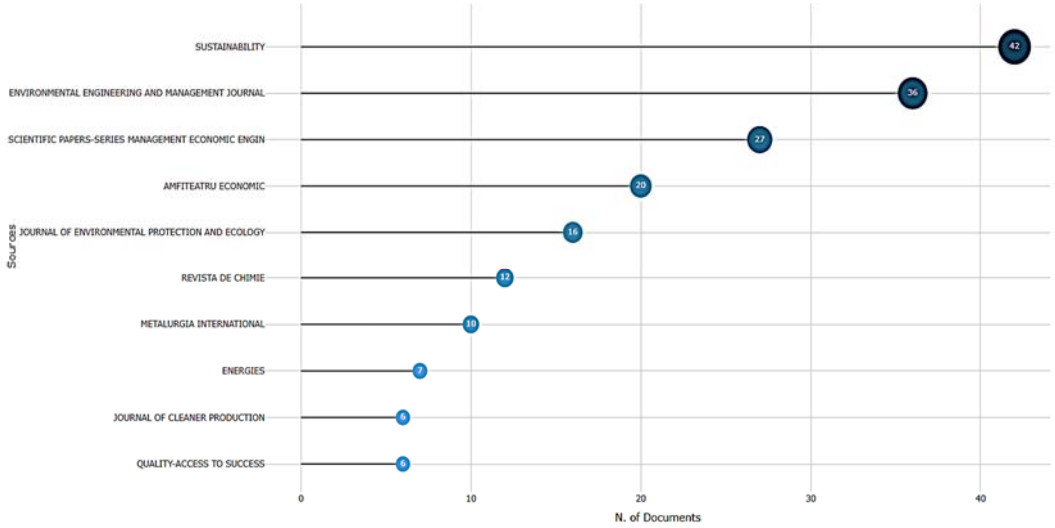
Figure 3. *Three-fields plot: titles (left), authors (middle), keywords (right)*



Source: Authors computation.

In Figure 3, a three-field plot was presented. On the left, we have the article titles, in the center are the authors, and on the right are the keywords. It is notable that a significant number of authors have written articles with titles containing keywords such as green efficiency, economy, sustainable development, Romania. Furthermore, the keywords used in the articles are centered around concepts like waste management, circular economy, recycling, green economy, and so on.

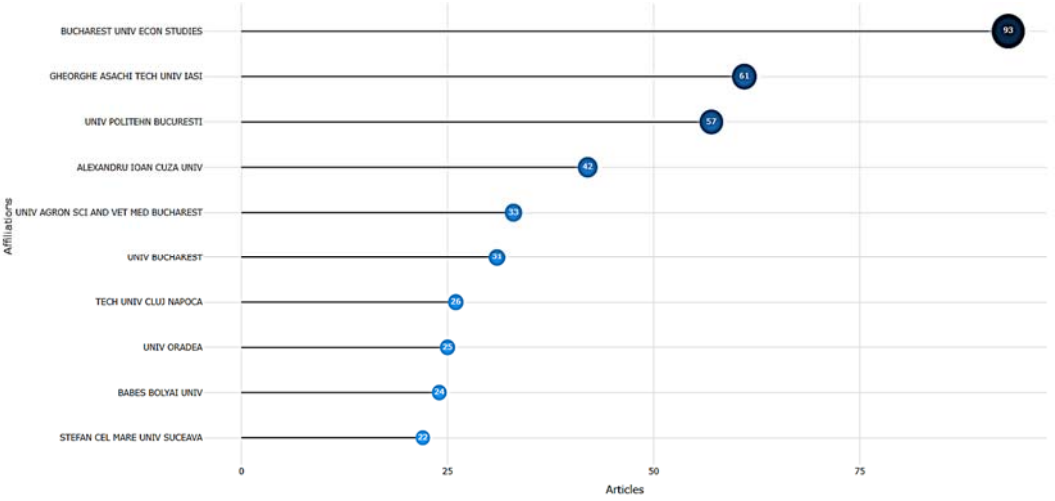
Figure 4. *Most relevant sources*



Source: Authors computation

Regarding the most relevant sources for identifying articles (figure 4) related to the circular economy, the journal *Sustainability* has the highest number of relevant sources, with a total of 42, followed by the *Environmental Engineering and Management Journal* with 36 documents. *Amfiteatru Economic* ranks fourth with 20 documents.

Figure 5. *Most relevant affiliations*



Source: *Authors computation.*

In Figure 5, we can observe the most relevant affiliations or institutions that have published about the circular economy in Romania. Bucharest University of Economic Studies ranks at the top with a total of 93 articles.

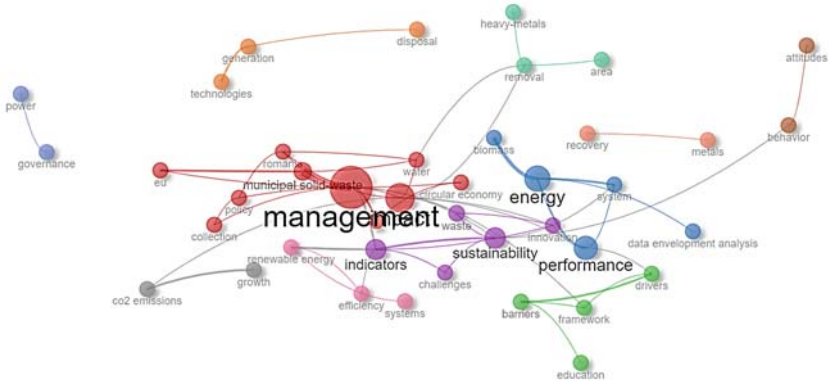
Figure 5. *World cloud*

Source: Authors computation.

The word cloud analysis from figure 5 highlights key terms central to discussions on the circular economy. The words "management" and "impact" suggest a focus on efficient resource management and the evaluation of circular economy effects. "Performance" and "indicators" point to an emphasis on assessing and monitoring the performance of circular economy practices, while "sustainability" underscores the importance of environmental principles within this framework. "Energy" indicates an interest in efficient energy management, a crucial aspect of the circular economy. "Municipal solid-waste" reflects increased interest in managing municipal solid waste within the circular economy. "Circular economy" is evidently a central and defining term in the analyzed discussions, signifying the significance of this concept. "Barriers" illustrates the obstacles and challenges encountered in adopting the circular economy, and the mention of "China" may suggest an interest in examples and developments related to the circular economy in a specific context.

These key words illustrate the concerns, priorities, and central aspects of discussions regarding the circular economy, providing insight into research directions and developments in this field.

Figure 6. *Co-occurrence network*



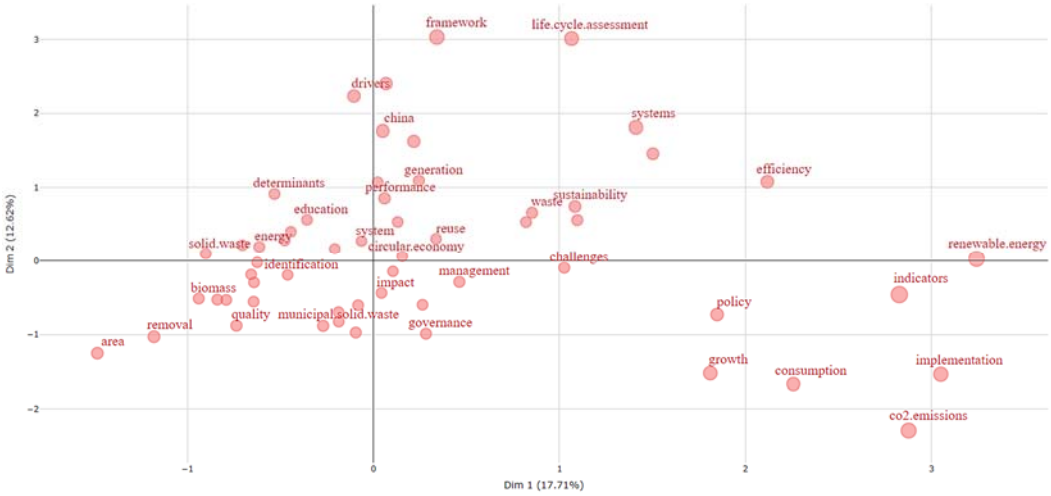
Source: Authors computation.

The co-occurrence network analysis provides valuable insights into the relationships between key terms in the context of circular economy research in Romania. “Management” and “impact” are central themes within the literature, forming a closely connected cluster. Their high Betweenness and PageRank scores indicate their significant influence and frequent co-occurrence in the analyzed documents. This suggests that these terms are fundamental in discussions about the circular economy's management and its impact.

“Circular economy” is a pivotal concept, appearing in the same cluster as “management” and “impact”. Although it has a lower Betweenness, its noteworthy PageRank score highlights its importance as a central term within circular economy discussions. “Municipal solid-waste” and “water” are also integral to the discussions, with substantial Betweenness and PageRank values. These terms are closely related to the central topics of "management" and “impact”, emphasizing the significance of waste management and water resources in the context of the circular economy. “Model”, “Romania”, “policy”, “EU”, and “collection” are also part of the network, although they exhibit lower Betweenness and PageRank values. This implies that these terms may be mentioned less frequently or within more specific contexts in the analyzed literature.

In summary, the co-occurrence network underscores the centrality of “management” and “impact” in discussions about the circular economy in Romania. “Circular economy” plays a pivotal role, while “municipal solid-waste” and “water” are crucial subtopics. The other terms, such as “model”, “Romania”, “policy”, “EU”, and “collection”, contribute to the overall discourse but with potentially less prominence. These findings provide a nuanced understanding of the key themes and connections in the field of circular economy research in Romania.

Figure 7. *Factorial Analysis*



Source: Authors computation.

Factorial Analysis in Bibliometrix within R Studio is a technique used to identify patterns or structures in a collection of keyword-based documents. Our results from Figure 7 present a graphical representation of the factor analysis with two principal dimensions (Dim 1 and Dim 2), which represent the most significant dimensions of variability within the document collection.

In the first quadrant, we find words such as "area", "identification", "biomass". These words may suggest a connection between the identification of areas of interest, including the field of biomass, in the extracted document collection. The second quadrant is the largest and contains keywords such as "management", "impact", "waste", "governance", "policy", "consumption". This implies that these terms are closely correlated in the selected research and may reflect subjects related to impact management, waste management policies, governance, and sustainable consumption. The third quadrant includes keywords such as "education", "solid", "waste", "determinants". Here, the words suggest a connection between education, determinants of solid waste management, and related subjects. The fourth quadrant contains keywords such as "sustainability", "China", "systems", "efficiency", "renewable energy". These words may indicate an association between sustainability, China, efficient systems, and renewable energy in the selected research.

4.2. Multiple Linear Regression (MLR)

In order to examine how specific variables related to the circular economy, such as circular rate, imports, and exports of waste, impact GDP per capita in Romania, we conducted a multiple linear regression model. The variables were extracted for the period 2012-2021, with their source being Eurostat.

Table 2. *Summary statistics of GDP, Circular_rate, imports_waste, exports_waste.*

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max
GDP	2.178	2.184	2.196	2.196	2.209	2.216
Circular_rate	0.2624	0.4055	0.5306	0.5615	0.6891	0.9555
Imports_waste	0.460	0.054	0.064	0.063	0.073	0.082
Exports_waste	0.090	0.116	0.126	0.124	0.135	0.152

The summary statistics provided in Table 2 offer a general insight into the characteristics of four variables: GDP, Circular_rate, Imports_waste, and Exports_waste.

In terms of GDP, the data appears to be relatively stable, with values ranging from 2.178 to 2.216. The median and mean GDP values are close to each other, indicating that the data is roughly symmetric.

Circular rate exhibits a wider range, spanning from 0.2624 to 0.9555, suggesting greater variability in this variable. The mean circular rate (0.5615) is closer to the median (0.5306), indicating a relatively balanced distribution, but with the potential for outliers.

Imports waste and Exports waste both have small ranges, from 0.046 to 0.082 and from 0.090 to 0.152, respectively. These variables show lower variability. The means and medians for both are close, implying relatively symmetric distributions.

These summary statistics provide a high-level view of the data and are essential for understanding the central tendencies and variability of the variables under consideration.

Table 3. *Multicriteria Linear Regression Output*

Residuals				
Min	**1Q**	**Median**	**3Q**	**Max**
-0.0019	-0.0015	0.0002	0.0009	0.002
Coefficients	**Estimate**	**Std. Error**	**t-value**	**Prob.**
(Intercept)	2.173	0.008	266.42	1.89e-13***
Circular_rate	5.73	0.43	13.30	0.0006***
Imports_waste	-0.13	0.03	-3.48	0.0101*
Exports_waste	0.06	0.02	2.34	0.0139*
Performance metrics of MLR				
Residual standard error	0.0019 on 6 degrees of freedom			
Multiple R-squared	0.988			
Adjusted R-squared	0.982			
F-statistic	164.5 on 3 and 6 DF			
p-value	3.775e-06			

The output above (Table 3) represents the results of a multiple linear regression analysis with GDP (Gross Domestic Product) as the dependent variable and circular rate, imports of waste, and exports of waste as independent variables.

Coefficients are estimates of the coefficients for each independent variable and the intercept. The coefficient values indicate the contribution of each variable to the prediction of GDP. For example, the coefficient for circular rate is 5.73, suggesting that an increase in the circular rate is associated with a significant increase in GDP. At the same time, the negative coefficient for imports waste (-0.13) indicates that an increase in waste imports is associated with a decrease in GDP, while the positive coefficient for Exports_waste (0.06) suggests that an increase in waste exports is associated with an increase in GDP.

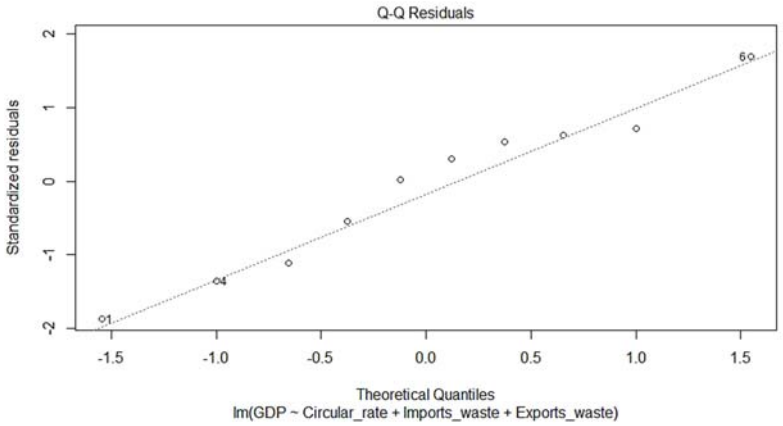
Model Performance provides several metrics for evaluating the quality of the model. The residual standard error indicates the dispersion of unexplained data by the model. A low value (0.0019) suggests a good fit of the model to the observed data. The Multiple R-squared is 0.988, meaning that approximately 98.8% of the variability in GDP is explained by the independent variables included in the model. The Adjusted R-squared adjusts R-squared for the number of independent variables, and the F-statistic and p-value are used to test the overall significance of the model. A low p-value (3.775e-06) indicates that the model has statistical significance.

Overall, these results suggest that circular rates, waste imports, and waste exports have a significant influence on GDP, and the model appears to fit the observed data well.

The mathematical form of the linear regression (equation (2)) can be expressed as followed:

$$GDP = 2.173323 - 0.038749 * Circular_{rate} + 0.411254 * Imports_{waste} + 0.149726 * Exports_{waste} + 0.001947 \quad (2)$$

Figure 8. *Quantile-Quantile Residuals*



Source: Authors computation

Q-Q (Quantile-Quantile) plots are used to assess whether the residuals of a regression model or other data follow a normal distribution or another theoretical distribution. In a Q-Q plot, on the Y-axis, we have standardized residuals (z-scores), and on the X-axis, we have theoretical quantiles from a reference distribution, typically the standard normal distribution (with a mean of 0 and a standard deviation of 1).

The points in the Q-Q plot represent the observed values of the standardized residuals, and the dashed diagonal line represents the expected values of the residuals if they were to follow a normal distribution (Marill, 2004). If the points closely align with the diagonal line, it means that the residuals are approximately normally distributed. If the points deviate significantly from the diagonal line, it suggests that the residuals do not follow a normal distribution. We observe in figure 8 that the points are close to the diagonal line, emphasizing that the residuals are approaching a normal distribution.

Table 4. *Cross-validated*

Linear regression		
10 samples		
3 predictors		
Resampling Cross-Validated 5 fold		
RMSE	R-squared	MAE
0.0024	1	0.002

Source: Authors computation

Cross-validation is a technique used to evaluate the performance of a model on independent test data, thus avoiding overlap between training and test data. In this case, cross-validation was performed using 5 folds (data partitions). RMSE (Root Mean Square Error) is an

indicator of the root mean squared error. According to table 4, RMSEW has a value of 0.0024, it suggests that the predicted model had a relatively small root mean squared error when applied to the test data. The lower the RMSE, the higher the precision of the model.

R-squared measures how well the variability of the dependent variable is explained by the model. A value of 1 indicates a perfect fit to the data, and in this case, R-squared is 1, suggesting that the model completely explained the variability of the test data.

MAE (Mean Absolute Error) is a measure of the average absolute error. With a value of 0.002, it suggests that the mean absolute error of the model was relatively small on the test data. The lower the MAE, the higher the precision of the model.

The results indicate a very good fit of the model to the test data, with low error and a strong ability to explain the variability of the dependent variable (an R-squared of 1). This suggests that the model performs exceptionally well in predicting the test data.

5. Conclusions

In this study, we conducted a comprehensive bibliometric exploration of Romania's circular economy, shedding light on the key themes and influential research sources in this field. Additionally, through the multilinear regression model, we found compelling evidence that variables such as Circular Rate, imports, and exports waste significantly impact Romania's GDP per capita.

However, it's important to acknowledge certain limitations. The data utilized in this analysis is subject to potential biases and inaccuracies, and further refinement and validation of the model are necessary to enhance its predictive power. Additionally, our study primarily focused on specific variables, and other potentially relevant factors were not included in the model.

As we move forward, future research should consider an expanded set of variables and a more robust dataset, providing a deeper understanding of the circular economy's impact on economic growth. Furthermore, investigations into policy implications, innovation, and sustainable development in the context of the circular economy could yield valuable insights. By addressing these limitations and exploring these research directions, we can continue to advance our understanding of Romania's circular economy and its intricate interplay with economic prosperity.

Notes

(1) For recommendations, suggestions or observations, you can contact the authors Ionuț Nica (ionut.nica@csie.ase.ro).

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