BRITISH JOURNAL of MANAGEMENT
BRITISH ACADEMY OF MANAGEMENT
British Journal of Management, Vol. 00, e70036 (2025)
DOI: 10.1111/1467-8551.70036

Dynamics of Circular Economy Transformation Processes in Relation to Individual Waste Types Recycling – Net Zero for Sustainable Development

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The main goal of the study is the quantification of the disparities in the recycling rates of the individual types of waste in the European Union member countries. The data on the waste recycling rates for the period 2004–2021 come from Eurostat. A linear regression analysis is engaged for the analytical processing. The outcomes confirm the statistically significant differences among the explored countries – the European Union members. The most extreme increases reach the levels as follows and occur in the particular countries. The plastic packaging waste recycling rate causes an increase of 1.0965 percentage points for Belgium, the metallic packaging waste recycling rate an increase of 0.7763 for Italy, the glass packaging waste recycling rate an increase of 0.9105 percentage points, and the construction and demolition waste recovery rate an increase of 5.5667 percentage points for Italy. These rates are important for achieving net zero. The study outcomes are desired for policymakers, authorities, creators of strategic development plans and methodologies to support global economy aimed at the circular economy strategies, sustainable development and economic growth. Setting an appropriate mixture of policies and regulations can determine outcome of the recycling procedures that is used for further processing.

Introduction

The European Union economic policy provides a suitable environment for the transformation of the countries' economies into a circular economy. The European Commission have adopted a plenty of the directives, allowing and leading to this transition. The recycling rate in the individual countries is not sufficient, but there are the significant differences among them (Hondroyiannis *et al.*, 2023). The countries carry out various political decisions and the related active policies that should ensure this planned transition and at the same time, they look for the optimal methodologies to reach net zero. Their effects can only be seen with a certain delay. Nevertheless, it is important to examine not only the process trajectories of digital transformation but also the determinants that influence it, such as increasing transparency, investment in education, promoting waste management infrastructure, eliminating income disparities and so on. There is also a directive of the European Union that is intended to prepare regulative mechanisms and environment for practicing net zero in the manufacturing industrial sectors. The so-called net zero industry act introduces several principles that could collectively help and promote net zero within the industrial sectors through enhancing the processes employed for the sake of the sustainable development goals (European Parliament and Council of the European Union, 2024). The intersection of the mentioned aspects with the sustainability dimensions and the circular economy processes creates multidimensional dimensions for investigating the causal effects of the circular economy on achieving the sustainable development goals as well as its action plan.

Circular economy concept

The circular economy concept has become a wider coverage in the terms of its interconnection also with the current lifestyle. This plays a partial role in today's life and it brings new insights into the people's thinking (Esposito, Tse and Soufani, 2018).

For the successful implementation of the circular economy processes in the economies, the development of strategies for the optimal management of energy, material, information and financial flows and stocks within the economy is essential. These strategies have long-term strong institutional support at the international level, primarily in the legislative and legal field and in several European Union support mechanisms. Although the circular economy implementation issue is intensively researched and discussed at the macroeconomic level, less attention is paid to the microeconomic level and organizational alteration supporting the smooth transformation process of an enterprise to circular economy entity (Önder, 2018). Many studies declare the growing interest of enterprises to adopt circular economy principles for the sustainability of the country, but the role of the individual and their management is little studied as well as the practical consequences of circular economy on human resources in organizations (Malibari *et al.*, 2025). Some research and case studies try to capture the broader social impacts of introducing the circular economy processes into enterprises – for instance, creating new jobs, improving working conditions, as well as altering organizational culture (Madzík *et al.*, 2024; Nsiah, Asamoah and Chovancová, 2024). Sustainability should be in the centre of happening when investigating goals with a perspective of preparing driving forces for integration of the circular economy principles into common procedures of waste processing (Johurul Islam *et al.*, 2025). Although there is a belief in the environmental support of their employees in some enterprises, it is important to systematically create environmental education programmes and purposeful advertising campaigns adapted to different contexts. This can support higher organizational efficiency as well as improve environmental behaviour, awareness and attitudes of employees that is subsequently transferred to customer relations, their satisfaction and loyalty.

Research motivation

Despite the available research studies, there is still no comprehensive investigation of the waste recycling rate influenced by the share of individual types of waste and the number of inhabitants, which will allow quantifying meeting the goals of the circular economy transformation processes within the individual countries. Their knowledge will make it possible to quantify the level of their fulfilment to support the development of a methodological platform for the evaluation mechanisms and for international benchmarking. There are several quantitative approaches applied in this field in order to offer novel analytical techniques (Lapinskienė, Podviezko and Tvaronavičienė, 2023). Such an aspect represents the research gap of the study, whose main goal is the quantification of the disparities in the recycling rates of the materials according to the individual types of waste in the European Union member countries. The circular economy paradigm has reached a momentum in form of a strategy to improve the environmental quality and preserve natural resources (Bongers and Casas, 2022).

Study structure

The Introduction section offers a general entrance to the discussed topic, while the Theoretical Background section introduces the so far research knowledge. Successively, the Data section describes the examined data and the Methodology section demonstrates the applied techniques along with the research hypotheses. The Analysis section provides the obtained outcomes, while the subsequent Discussion section compares them to the other studies. Finally, the Conclusion section summarizes the obtained findings.

Theoretical background

One of the priority goals of the European Union economic policy is the transformation of the countries' economies into a circular economy. The European Commission has adopted a number of the measures and the regulations, through which it also defined the legal framework for the transition of the economies to the circular economy in such a way as to increase the competitiveness of the countries and their future economic growth (European Parliament and Council of the European Union, 2019). Many documents focus on the defined priority areas, such as critical raw materials, plastics, food waste, construction and demolition waste, biomass and bioproducts and so on. The circular economy action plan (European Commission, 2015) also identifies a proposal for the transition of the European Union member countries from a linear economy model to a circular economy, as well as the role of innovation in these processes (Korhonen, Honkasalo and Seppälä, 2018). Digital transformation, whose part is a circular economy concept too, is not possible without implementation of innovation processes (Mazur-Wierzbicka, 2021). Moreover, this concept considerably impacts the business models as sustainability has become a crucial point of the future perspectives of the current innovation activities of enterprises (Evans *et al.*, 2017).

Waste types distinguishment

Biowaste, including food waste and biomass, are considered the priority fields for the transition of the European Union member countries to a circular economy. Agricultural waste is a significant source of unused biomass that can represent a strong economic and environmental burden (Gontard *et al.*, 2018). Decarbonization or at least an approach with an emphasis on low carbon use solutions represent the absolute basement in the field of food waste treatment as well as it reduces the climate change impact (Kurniawan *et al.*, 2024).

Zeller *et al.* (2020) point out the complexity of biowaste systems and thus, they suggest to construct databases and models from local data. They confirm that the transition processes towards circular economy does not always lead to environmental benefits. Optimal strategies can emerge if the combined management of food and green waste is understood, representing an under-researched area of urban management. In addition to the introduction of new processes, a qualitative and quantitative evaluation of the availability of secondary raw materials and the classification of the various systems is essential for the transition to circular economy. Santagata *et al.* (2021) point to the great interest currently in the recovery of mixed food waste and in the biological type of the conversion processes. The transformation of the energy systems has to include the technological, social, cultural, economic and environmental aspects too (Serrano-Arévalo *et al.*, 2024). This is because bioenergy systems are subject to the economic, environmental, legal, technical and social conditions. The global bioenergy sector is affected by the new demand for biomaterials from the same sources. The selection of the biologically sustainable ways should be influenced by their high efficiency and the concepts of cascade and integrated biorefineries (Zabaniotou, 2018). Similarly, Gontard *et al.* (2018) recommend an application of the innovative, ecologically and cost-effective processes, representing one of the most mature conversion technologies. Local knowledge, public health and community resilience are also important, with prevention always being the most important task. As reported by Mazzanti, Mazzarano and Zecca (2022), the effectiveness of prevention programmes should be evaluated together with the assessment of the applied policies.

The agricultural residues create a potential source for the production of high-value chemicals, with an assumption that their complex and heterogeneous molecular structures are changed via conversion to the competitive products. Hence, innovative, ecologically efficient and cost-effective cascade conversion processes should be developed. The potential of the created waste refineries can be strong, from ensuring the energy and land saving, the creation of new enterprises and jobs, saving costs for landfills, reducing greenhouse gas emissions, saving natural resources of water, land and so on (Shen, Li and Wang, 2020). These benefits were also pointed out by Nizami *et al.* (2017) also within the developing countries. Mihai and Ingrao (2018) points to the regional differences and issues of biowaste management in the countryside of Romania, especially its uncontrolled disposal. The situation in the urban area is much more positive and it is systematically monitored and evaluated in the large cities in the developed countries, which is confirmed by Zeller *et al.* (2019). A situation with the biowaste is evaluated via $H_{0,1}$. Their outcomes show that up to a half of the 1.5 million tons of waste collected in Brussels is processed in the local facilities, while the construction sector had the highest intensity of waste production and households had the highest intensity of combustion. Thus, the urban conditions can restrict the local valorization of the waste streams, cities and thus, to contribute to close the material cycles at the national or global levels. Besides various types of waste, which is recycled in order to gain further resources, food plays its own role, as it has a considerable impact in the climate change (Kharayat and Gupta, 2025). The future development of food waste management should use the multifunctionality of the products and thus, to create a compromise between food waste and resources (Mak *et al.*, 2020).

The cellulose sector is considered a significant producer of global greenhouse gas emissions and the other environmental burdens over the past decade, despite the significant improvements. In order to reduce the negative impact on the environment, it is necessary to introduce new processes in production and material requirements. van Ewijk, Stegemann and Ekins (2018) point to the need to change the metrics that would enable the evaluation of the efficiency of the recycling processes. They recommend applying the Sankey diagram of the global material flows in the life cycle of paper from inputs to end-of-life waste treatment in order to gain net zero. This diagram is also applicable for decarbonization as it an essential step at the basement of a net zero principle (Román-Collado and Casado Ruíz, 2024). De Feo *et al.* (2021) also see the necessity to set optimal methodologies and metrics when implementing the paper and cardboard recycling procedures. This is reflected in $H_{0,2}$. Their methodologies have made it possible to reveal a large amount of the recyclable materials contained in the unsorted residual waste. They recommend to apply the two indicators for the environment, that is, carbon footprint and ecological footprint, two ones for the society, that is, health footprint and occupational benefits, and the two ones for the economy, that is, economic profit and economic saving. Mitigating carbon footprint is an essential role not only for the society, but also for all the stakeholders (Čábelková *et al.*, 2021).

Even though the European Union member countries have set their environmental goals based on the European Union directive (European Parliament and Council of the European Union, 2018). The current recycling rate is not sufficient to achieve the goal of 55% by the year 2025. For this reason, the analysis of the countries' positions and the quantification of their differences was the subject of interest for the authors Hondroyiannis *et al.* (2023), who examined both the short-run and long-run relationship between the macroeconomic variables. The analytical outcomes show that economic performance, institutional quality and achieved higher education significantly contribute to net zero (Khan *et al.*, 2020). The changes in agricultural intensification and population density significantly affect the recycling rate.

Coelho *et al.* (2020) confirm that it is necessary to carry out research to evaluate the usefulness of reusable packaging for the different market segments and products along with their relation to the supply chain. Hence, it is necessary to monitor effectiveness and efficiency of the current systems in order to simultaneously reveal new opportunities (Rigamonti, Biganzoli and Grosso, 2019). The conclusions of many research studies show that the economic, regulatory, commercial and cultural concepts have not been created during the transition from reusable to disposable packaging. For the adoption of the reusable packaging systems, it is required to manage the organization of the supply chain, which includes the integration of reverse logistics, transport distances, location monitoring technologies and so on.

Pires and Martinho (2019) criticize the European Union waste framework directive (European Commission, 2019), because it only measures the individual activities related to recycling, combustion and landfilling of waste, but does not measure the implementation of the waste hierarchy principle in the member countries. Hence, they propose the waste hierarchy index to measure it applied to municipal solid waste. Its application potential at the different geographical levels gives it a strong comparative potential.

Environmental impact

The impacts of the environmental processes for the individual types of waste are not satisfactory. The comparative analyses of these waste types have strong methodological limitations caused by data and process incompatibility. The insufficient success in the recycling processes and strategies are declared even in those studies that focus only on a single type of waste. For instance, Eriksen *et al.* (2020) evaluated the potential circulation of the polyethylene and polypropene flows in the European Union member countries based on dynamic material flow, product lifetime, demand growth rate and reduction in quality of recyclable plastics (Eriksen *et al.*, 2020). A low recycling rate at level of 13%–20% and dependence on primary plastic in the volume of 85%–90% of the annual demand for plastics has been demonstrated. In the future, a share of 40%–65% of annual demand could be covered by recycled plastic. A strict focus on the recycling rates will not allow for effective evaluation of the transition processes to the circular economy. It cannot be achieved only through technological improvements, but it is also necessary to stabilize demand.

Lorang *et al.* (2022) evaluate the management of plastic packaging waste in the five most populous European Union member countries – France, Germany, Italy, Spain and Poland, while applying the extended producer responsibility schemes that are mandatory in the European Union by the end of the year 2024. These schemes improve the financial and operational capacity of plastic waste management, leading to the higher plastic waste collection and recycling rate. The European recycling capacity covers only 23% of the cumulative production of plastic waste from consumers (Lorang *et al.*, 2022), while the main obstacle to achieve a 50% recycling rate of plastic packaging waste in the European Union by the year 2025 may also be the local recycling infrastructure (Domenech and Bahn-Walkowiak, 2019; Ferronato et al., 2019; Knickmeyer, 2020; Liu *et al.*, 2023; Neves and Marques, 2022; Oluwadipe *et al.*, 2022). Nowadays, there is a pressure to implement the circular economy model mainly through the chemical recycling of plastic wate in the European union (Kubiczek *et al.*, 2023). Besides this, decarbonization is a crucial term in this field too, as the main strategy in order to reduce plastic waste generation is to increase biomass utilization (Zhao and You, 2025). Also, the packaging takeback requirements can stimulate manufacturers to limit sending plastic packaging to the market and to support net zero (Nogueira *et al.*, 2022; Vimal, Agarwal and Mathiyazhagan, 2022). The plastic packaging is evaluated via $H_{0,\,3}$.

Warrings and Fellner (2019) investigate the sixteen selected European countries and confirmed that only six of eleven recycle at least two thirds of aluminium packaging from municipal solid waste and only two countries report a low recycling rate of 20%. A direct comparison of the recycling rates within the European Union member countries is very problematic due to different or misattributed data, incomplete or estimated and assumptions (Marino and Pariso, 2020; Salmenperä, 2021). The total recycling rate, which is reported by the individual countries, cannot be linked to the circular system with a net zero attribute. Not only the waste recycling contributes to the net zero basement, but also electrofuel is a part of the system along with the wastewater treatment (Rusmanis *et al.*, 2023). A deposit refund system and selective collection lead to a higher overall collection rate, but it may not lead to a higher recycling rate (i Puigvert *et al.*, 2020; Simon, Amor and Földényi, 2016). Electronic waste represents also a type of important waste because of its high reuse rate (Kianpour *et al.*, 2017). Besides all the above listed research hypotheses, a specific position of the wooden packaging is evaluated via $H_{0, 4}$.

The outcomes of the research studies confirm the significant differences in achieving the goals of the circular strategies and thus, they criticize the lack of development of the relevant comparative methodologies, inconsistency in reporting data on the circular processes and the heterogeneous comparative basement in the different research studies.

Data

The data set covers the period beginning in the year 2004 and ending in the year 2021, while not all the included years are involved in everyone explored indicator. It comes from the online Eurostat database provided by Eurostat – the statistical office of the European Union. It includes all the current member countries of the European Union with the former member representing the United Kingdom of Great Britain and Northern Ireland. Hence, the involved countries are Republic of Austria – AT, the Kingdom of Belgium – BE, the Republic of Bulgaria – BG, the Swiss Confederation – CH, the Republic of Cyprus – CY, the Czech Republic – CZ, the Federal Republic of Germany – DE, the Kingdom of Denmark – DK, the Republic of Estonia – EE, the Hellenic Republic – EL, the Kingdom of Spain – ES, the Republic of Finland – FI, the French Republic – FR, the Republic of Croatia – HR, Hungary – HU, Ireland – IE, Iceland – IS, the Italian Republic – IT, the Principality of Liechtenstein – LI, the Republic of Lithuania – LT, the Grand Duchy of Luxembourg – LU, the Republic of Latvia – LV, the Republic of Malta – MT, the Netherlands – NL, the Kingdom of Norway – NO, the Republic of Poland – PL, the Portuguese Republic – PT, Romania – RO, the Kingdom of Sweden – SE, the Republic of Slovenia – SI, the Slovak Republic – SK and the United Kingdom of Great Britain and Northern Ireland – UK. The standard abbreviations for the countries are applied (International Organization for Standardization, 2013). Their order is sorted according to the abbreviations.

The explained indicator is represented by the variable circular material use rate (Eurostat, 2022a).

There are the following explanatory variables included in the regression models:

- the biowaste to population ratio – BTPR (Eurostat, 2022b);
- the paper and cardboard packaging waste recycling rate – PACPWRR (Eurostat, 2022c);
- the plastic packaging waste recycling rate – PPWRR (Eurostat, 2022c);
- the wooden packaging waste recycling rate – WPWRR (Eurostat, 2022c);
- the metallic packaging waste recycling rate – MPWRR (Eurostat, 2022c);
- the glass packaging waste recycling rate – GPWRR (Eurostat, 2022c);
- the construction and demolition waste recovery rate – CADWRR (Eurostat, 2022d);
- the electronic waste recovery rate – EWRR (Eurostat, 2022e).

Methodology

A linear regression analysis with constant value is employed as the primary methodological approach (Galton, 1989). The statistical significance is considered from a perspective of a 5% threshold. The tables demonstrating the regression models show the estimation of the regression coefficients along with its test statistic value and *p*-value. Each model represents an individual observed indicator. The comprised variables are denoted as C meaning the constant value and I meaning the indicator itself. The maximum and minimum ratios are calculated for each regression model in order to provide multiplication to the lowest estimation of the impact to the circular material use rate and the highest one. All the numbers are rounded to the four decimal points in the tables and to the two decimal points in the scientific notation.

The determination of the research hypotheses comes from an investigation of a plenty of the research studies, whose selection is visualized by Table 1.

As it is seen in Table 1, there are the multiple studies, which the explored indicators are based on. It is not a comprehensive list, but it offers the studies that create a research environment altogether. Additional information represents the approaches employed in the particular studies whether they examine single or multiple indicators.

Hypotheses determination

Taken into consideration all the explored indicators as seen in Table 1, the following research hypotheses are set:

- $H_{0, 1}$: the circular material use rate is impacted by the biowaste to population ratio from the geographical perspective;
- $H_{1, 1}$: the circular material use rate is not impacted by the biowaste to population ratio from the geographical perspective;

Table 1. Setting of the research hypotheses

Research hypothesis	Indicator	Study	Approach
1	BTPP	Zabaniotou (2018)	Multiple
		Thiriet, Bioteau and Tremier (2020)	Single
		Zeller *et al.* (2020)	Single
		Santagata *et al.* (2021)	Multiple
2	PACPWRR	Seyring *et al.* (2016)	Multiple
		Oliveira *et al.* (2018)	Single
		van Ewijk, Stegemann and Ekins (2018)	Multiple
		De Feo *et al.* (2021)	Single
		Castillo-Benancio *et al.* (2022)	Single
3	PPWRR	Bucknall (2020)	Single
		Eriksen *et al.* (2020)	Multiple
		Ajwani-Ramchandani *et al.* (2021)	Multiple
		Di *et al.* (2021)	Single
		Hahladakis, Iacovidou and Gerassimidou (2024)	Multiple
4	WPWRR	Sommerhuber, Welling and Krause (2015)	Multiple
		Husgafvel *et al.* (2018)	Multiple
		Meherishi, Narayana and Ranjani (2019)	Single
		Khan *et al.* (2021)	Multiple
		Balanay, Varela and Halog (2022)	Multiple
5	MPWRR	de Sa and Korinek (2021)	Multiple
		Mulvaney *et al.* (2021)	Multiple
		Warrings and Fellner (2019)	Single
		Tan *et al.* (2021)	Single
		Peng and Shehabi (2023)	Single
6	GPWRR	Schmidt and Laner (2021)	Single
		Westbroek *et al.* (2021)	Multiple
		Del Rio *et al.* (2022)	Multiple
		Dolci *et al.* (2025)	Multiple
		Ezeudu and Kennedy (2024)	Single
7	CADWRR	Arm *et al.* (2017)	Single
		Jin, Yuan and Chen (2019)	Single
		Ruiz, Ramón and Domingo (2020)	Single
		Papastamoulis *et al.* (2021)	Single
		Sharma, Kalbar and Salman (2022)	Single
8	EWRR	Akcil, Agcasulu and Swain (2019)	Single
		Althaf and Babbitt (2021)	Multiple
		Deva and van der Weijden (2021)	Multiple
		Sundar *et al.* (2023)	Single
		Bagwan (2024)	Single

Source: Own elaboration by the authors.

- $H_{0,2}$: the circular material use rate is impacted by the paper and cardboard packaging waste recycling rate from the geographical perspective;
- $H_{1,2}$: the circular material use rate is not impacted by the paper and cardboard packaging waste recycling rate from the geographical perspective;
- $H_{0,3}$: the circular material use rate is impacted by the plastic packaging waste recycling rate from the geographical perspective;
- $H_{1,3}$: the circular material use rate is not impacted by the plastic packaging waste recycling rate from the geographical perspective;
- $H_{0,4}$: the circular material use rate is impacted by the wooden packaging waste recycling rate from the geographical perspective;
- $H_{1,4}$: the circular material use rate is not impacted by the wooden packaging waste recycling rate from the geographical perspective;
- $H_{0,5}$: the circular material use rate is impacted by the metallic packaging waste recycling rate from the geographical perspective;
- $H_{1,5}$: the circular material use rate is not impacted by the metallic packaging waste recycling rate from the geographical perspective;
- $H_{0,6}$: the circular material use rate is impacted by the glass packaging waste recycling rate from the geographical perspective;
- $H_{1,6}$: the circular material use rate is not impacted by the glass packaging waste recycling rate from the geographical perspective;

- $H_{0,7}$: the circular material use rate is impacted by the construction and demolition waste recovery rate from the geographical perspective;
- $H_{1,7}$: the circular material use rate is not impacted by the construction and demolition waste recovery rate from the geographical perspective;
- $H_{0,8}$: the circular material use rate is impacted by the electronic waste recovery rate from the geographical perspective;
- $H_{1,8}$: the circular material use rate is impacted by the electronic waste recovery rate from the geographical perspective.

All the analytical processes are performed in the R statistical environment (R Core Team, 2022) with help of the additional packages – lmtest (Hothorn *et al.*, 2022) and reshape2 (Wickham, 2020).

Analysis

The entire analytical section involves the eight subsections devoted to the separate indicators assigned to every research hypothesis. The subsequent space is dedicated to the testing phase of the constructed regression models.

Biowaste

Firstly, the biowaste to population ratio is explored in Table 2.

As it is seen in Table 2, the biowaste to population ratio represents an indicator demonstrating the weighted perspective of the biowaste in the individual countries. The highest impact is kept by the United Kingdom peaking at 0.3410, while the highest negative impact is held by Finland peaking at −0.3041. From an absolute perspective, the lowest impact lowering at 0.0067 is reached by Portugal, meaning it is 51.1555 times lower than the highest one and 45.6235 times higher than the lowest one in a negative way. Conversely, from the negative side, the highest impact at a level 0.0068 is achieved by Ireland, meaning it is 49.9880 times lower than the highest one in a negative way on the one hand, while 44.5823 times higher than the lowest one on the other hand.

Paper and cardboard packaging waste

Secondly, the paper and cardboard packaging waste recycling rate is examined in Table 3.

Table 3 shows that the paper and cardboard packaging waste recycling rate is demonstrated at the highest level of 0.5643 by Belgium, while the lowest level of −1.3026, representing the lowest absolute level too, is kept by Luxembourg. The absolute lowest impact with a value of 0.0203 is held by Ireland, connotating it is 27.7859 times lower than the maximum regression coefficient and at the same time, 64.1399 times higher than the minimum regression coefficient in a negative way. The largest disparity is shown for Slovakia with the highest negative regression coefficient at a level of −0.0071, meaning it represents 79.7555 times lower than the maximum regression coefficient in a negative way and simultaneously, 184.1043 times higher than the minimum regression coefficient.

Plastic packaging waste

Thirdly, an investigation of the plastic packaging waste recycling rate indicator is following in Table 4.

As demonstrated by Table 4, the plastic packaging waste recycling rate behaves considerably similarly to the previous one. Its positive amplitude is represented by Belgium at a level of 1.0965, while the negative side is represented by Austria at a level of −1.1919. The highest maximum ratio is reached by Ireland peaking at 75.5760 times lower impact, meaning it embodies the lowest positive regression coefficient with a value of 0.0145, while the absolutely highest maximum ratio, originally lowering at −167.1661 times lower impact is achieved by Slovakia, signifying the lowest impact in a negative way with a value of 0.0066. Whereas, the first one is 82.1482 times lower than the most impactful estimation, the latter one is 181.7031 lower than the most impactful estimation too.

Wooden packaging waste

Fourthly, the wooden packaging waste recycling rate is explored in Table 5.

There are several comparable characteristics of the wooden packaging waste recycling rate to the plastic packaging waste recycling rate mentioned above in Table 5. Again, Austria plays a key role in a field of reaching the highest negative impact of −0.1296, while Italy stands on the opposite side reaching the highest impact at all peaking at 0.7766, that is, several times more from an absolute way. The highest maximum ratio is represented by Hungary with a amplitude of 328.3739, while the most negative amplitude of −284.23498 is represented by Czechia. On the other hand, the minimum ratio reaches multiplication of −54.7920 in the first case and 47.4462 in the latter case.

Metallic packaging waste

Fifthly, the metallic packaging waste recycling rate is scrutinized in Table 6.

In Table 6, the metallic packaging waste recycling rate shows the great disparities between the observed countries too. Italy represents the most impactful country in

Table 2. The biowaste to population ratio regression models

Country	Variable	Estimation		t Test		Ratio	
		Regression coefficient	Standard error	Statistic value	p-Value	Maximum	Minimum
AT	C	31.3500	16.7033	1.8769	9.33×10^{-2}	1.0000	−0.5336
	I	−0.1173	0.0906	−1.2948	2.28×10^{-1}	−2.9061	2.5918
BE	C	13.0840	4.5680	2.8643	1.86×10^{-2}	2.3961	−1.2785
	I	0.0529	0.0477	1.1108	2.95×10^{-1}	6.4423	−5.7456
BG	C	1.9861	0.3358	5.9136	2.25×10^{-4}	15.7850	−8.4227
	I	0.0320	0.0130	2.4574	3.63×10^{-2}	10.6551	−9.5029
CY	C	2.3595	0.2531	9.3219	6.40×10^{-6}	13.2870	−7.0898
	I	0.0076	0.0208	0.3662	7.23×10^{-1}	44.7426	−39.9041
CZ	C	5.2009	0.3217	16.1669	5.88×10^{-8}	6.0278	−3.2164
	I	0.1059	0.0090	11.7713	9.07×10^{-7}	3.2194	−2.8713
DE	C	2.7092	2.7034	1.0021	3.42×10^{-1}	11.5718	−6.1746
	I	0.0818	0.0241	3.3995	7.88×10^{-3}	4.1674	−3.7167
DK	C	3.6412	2.2752	1.6004	1.48×10^{-1}	8.6098	−4.5941
	I	0.0289	0.0159	1.8217	1.06×10^{-1}	11.7948	−10.5193
EE	C	16.5072	2.6741	6.1729	1.64×10^{-4}	1.8992	−1.0134
	I	−0.1921	0.1651	−1.1638	2.74×10^{-1}	−1.7749	1.5830
EL	C	0.1804	0.6258	0.2882	7.81×10^{-1}	173.8194	−92.7480
	I	0.1277	0.0341	3.7398	5.71×10^{-3}	2.6713	−2.3824
ES	C	8.6433	1.8109	4.7729	1.01×10^{-3}	3.6271	−1.9354
	I	0.0078	0.0260	0.2982	7.72×10^{-1}	43.9201	−39.1705
FI	C	29.4831	10.8136	2.7265	2.34×10^{-2}	1.0633	−0.5674
	I	−0.3041	0.1577	−1.9288	8.58×10^{-2}	−1.1213	1.0000
FR	C	3.7458	4.9690	0.7538	4.70×10^{-1}	8.3693	−4.4657
	I	0.1584	0.0527	3.0066	1.48×10^{-2}	2.1536	−1.9207
HR	C	2.7401	0.5439	5.0378	7.02×10^{-4}	11.4412	−6.1049
	I	0.1618	0.0531	3.0500	1.38×10^{-2}	2.1074	−1.8795
HU	C	3.5535	0.5317	6.6831	9.03×10^{-5}	8.8223	−4.7075
	I	0.1102	0.0196	5.6244	3.24×10^{-4}	3.0952	−2.7605
IE	C	2.0658	0.2235	9.2412	3.59×10^{-5}	15.1755	−8.0975
	I	−0.0068	0.0051	−1.3289	2.26×10^{-1}	−49.9880	44.5823
IT	C	1.2993	1.8139	0.7163	4.92×10^{-1}	24.1279	−12.8744
	I	0.1742	0.0203	8.5730	1.27×10^{-5}	1.9576	−1.7459
LT	C	3.5560	0.1732	20.5338	7.20×10^{-9}	8.8162	−4.7042
	I	0.0068	0.0022	3.0637	1.35×10^{-2}	49.8241	−44.4361
LU	C	24.5625	9.4702	2.5937	2.90×10^{-2}	1.2763	−0.6810
	I	−0.0767	0.0669	−1.1473	2.81×10^{-1}	−4.4434	3.9628
LV	C	1.9363	0.6039	3.2063	1.07×10^{-2}	16.1908	−8.6392
	I	0.1063	0.0256	4.1590	2.45×10^{-3}	3.2078	−2.8609
MT	C	6.3411	0.4545	13.9515	2.11×10^{-7}	4.9439	−2.6380
	I	−0.2186	0.1085	−2.0142	7.48×10^{-2}	−1.5603	1.3916
NL	C	−16.7280	11.5290	−1.4510	1.81×10^{-1}	−1.8741	1.0000
	I	0.3087	0.0801	3.8527	3.89×10^{-3}	1.1048	−0.9854
PL	C	11.0819	0.5637	19.6606	1.06×10^{-8}	2.8289	−1.5095
	I	−0.0265	0.0266	−0.9990	3.44×10^{-1}	−12.8528	11.4629
PT	C	1.6679	0.2986	5.5863	3.40×10^{-4}	18.7961	−10.0294
	I	0.0067	0.0043	1.5486	1.56×10^{-1}	51.1555	−45.6235
RO	C	0.2112	0.3182	0.6638	5.23×10^{-1}	148.4190	−79.1947
	I	0.0917	0.0152	6.0173	1.98×10^{-4}	3.7200	−3.3177
SE	C	9.5734	2.3275	4.1132	2.62×10^{-3}	3.2747	−1.7473
	I	−0.0376	0.0339	−1.1083	2.96×10^{-1}	−9.0716	8.0905
SI	C	6.9637	0.7516	9.2649	6.73×10^{-6}	4.5019	−2.4022
	I	0.0476	0.0139	3.4249	7.57×10^{-3}	7.1646	−6.3898
SK	C	4.1589	0.2534	16.4102	5.16×10^{-8}	7.5381	−4.0222
	I	0.0360	0.0081	4.4291	1.65×10^{-3}	9.4831	−8.4576
UK	C	−11.7974	10.8116	−1.0912	3.11×10^{-1}	−2.6574	1.4179
	I	0.3410	0.1392	2.4504	4.41×10^{-2}	1.0000	−0.8919

Source: Own elaboration by the authors.

Table 3. The paper and cardboard packaging waste recycling rate regression models

		Estimation		*t* Test		Ratio	
Country	Variable	Regression coefficient	Standard error	Statistic value	*p*-Value	Maximum	Minimum
AT	C	57.7542	36.0575	1.6017	1.44×10^{-1}	2.0051	−0.5758
	I	−0.5708	0.4286	−1.3319	2.16×10^{-1}	−0.9885	2.2819
BE	C	−33.2537	46.5084	−0.7150	4.93×10^{-1}	−3.4824	1.0000
	I	0.5643	0.5115	1.1032	2.99×10^{-1}	1.0000	−2.3084
BG	C	5.1562	1.9416	2.6557	2.90×10^{-2}	22.4587	−6.4492
	I	−0.0299	0.0232	−1.2855	2.35×10^{-1}	−18.8847	43.5926
CY	C	−2.1263	1.2212	−1.7412	1.20×10^{-1}	−54.4611	15.6390
	I	0.0474	0.0129	3.6629	6.37×10^{-3}	11.8965	−27.4613
CZ	C	45.0977	26.1650	1.7236	1.19×10^{-1}	2.5678	−0.7374
	I	−0.4146	0.2931	−1.4143	1.91×10^{-1}	−1.3611	3.1419
DE	C	30.7268	6.2919	4.8835	8.67×10^{-4}	3.7688	−1.0822
	I	−0.2171	0.0725	−2.9963	1.50×10^{-2}	−2.5994	6.0003
DK	C	5.0515	1.2743	3.9640	3.28×10^{-3}	22.9244	−6.5830
	I	0.0316	0.0145	2.1698	5.81×10^{-2}	17.8761	−41.2644
EE	C	0.2927	13.1426	0.0223	9.83×10^{-1}	395.6434	−113.6125
	I	0.1648	0.1627	1.0129	3.38×10^{-1}	3.4241	−7.9040
EL	C	−0.7147	3.3292	−0.2147	8.35×10^{-1}	−162.0183	46.5250
	I	0.0354	0.0372	0.9504	3.70×10^{-1}	15.9570	−36.8345
ES	C	27.0793	9.5391	2.8388	1.94×10^{-2}	4.2764	−1.2280
	I	−0.2367	0.1260	−1.8781	9.31×10^{-2}	−2.3838	5.5027
FI	C	49.0815	8.3587	5.8719	3.73×10^{-4}	2.3594	−0.6775
	I	−0.3766	0.0782	−4.8141	1.33×10^{-3}	−1.4985	3.4591
FR	C	35.4635	10.4978	3.3782	8.15×10^{-3}	3.2654	−0.9377
	I	−0.1829	0.1140	−1.6036	1.43×10^{-1}	−3.0856	7.1227
HR	C	7.9641	2.1995	3.6209	8.50×10^{-3}	14.5405	−4.1754
	I	−0.0383	0.0255	−1.5041	1.76×10^{-1}	−14.7380	34.0207
HU	C	9.2756	2.6556	3.4929	6.80×10^{-3}	12.4847	−3.5851
	I	−0.0370	0.0341	−1.0832	3.07×10^{-1}	−15.2674	35.2428
IE	C	−0.1972	0.8608	−0.2291	8.24×10^{-1}	−587.3101	168.6513
	I	0.0245	0.0106	2.3015	4.69×10^{-2}	23.0730	−53.2609
IT	C	17.2042	37.8272	0.4548	6.61×10^{-1}	6.7311	−1.9329
	I	−0.0139	0.4692	−0.0297	9.77×10^{-1}	−40.4568	93.3888
LT	C	6.3460	2.9799	2.1296	6.21×10^{-2}	18.2481	−5.2401
	I	−0.0282	0.0356	−0.7912	4.49×10^{-1}	−20.0288	46.2338
LU	C	115.8024	55.1527	2.0997	6.52×10^{-2}	1.0000	−0.2872
	I	−1.3026	0.7044	−1.8492	9.75×10^{-2}	−0.4332	1.0000
LV	C	−20.8870	8.5820	−2.4338	4.10×10^{-2}	−5.5442	1.5921
	I	0.3158	0.1085	2.9115	1.95×10^{-2}	1.7867	−4.1243
MT	C	12.6374	1.7316	7.2981	4.57×10^{-5}	9.1635	−2.6314
	I	−0.1196	0.0306	−3.9146	3.54×10^{-3}	−4.7173	10.8893
NL	C	21.4685	29.7412	0.7218	4.91×10^{-1}	5.3941	−1.5490
	I	0.0669	0.3386	0.1975	8.48×10^{-1}	8.4411	−19.4851
PL	C	11.7252	1.8895	6.2054	2.58×10^{-4}	9.8764	−2.8361
	I	−0.0151	0.0268	−0.5625	5.89×10^{-1}	−37.4364	86.4167
PT	C	0.7337	1.6708	0.4391	6.71×10^{-1}	157.8346	−45.3236
	I	0.0203	0.0245	0.8295	4.28×10^{-1}	27.7859	−64.1399
RO	C	5.0357	1.3524	3.7236	5.84×10^{-3}	22.9962	−6.6036
	I	−0.0370	0.0170	−2.1822	6.07×10^{-2}	−15.2311	35.1589
SE	C	10.8471	3.6168	2.9990	1.50×10^{-2}	10.6759	−3.0657
	I	−0.0495	0.0465	−1.0647	3.15×10^{-1}	−11.4024	26.3209
SI	C	−26.5160	9.2153	−2.8774	1.83×10^{-2}	−4.3673	1.2541
	I	0.4575	0.1179	3.8803	3.73×10^{-3}	1.2333	−2.8469
SK	C	5.6759	2.0116	2.8216	2.00×10^{-2}	20.4025	−5.8588
	I	−0.0071	0.0262	−0.2698	7.93×10^{-1}	−79.7555	184.1043
UK	C	21.0502	4.4358	4.7455	2.09×10^{-3}	5.5012	−1.5797
	I	−0.0786	0.0547	−1.4370	1.94×10^{-1}	−7.1783	16.5701

Source: Own elaboration by the authors.

Table 4. The plastic packaging waste recycling rate regression models

		Estimation		t Test		Ratio	
Country	Variable	Regression coefficient	Standard error	Statistic value	p-Value	Maximum	Minimum
AT	C	49.4792	10.1355	4.8818	8.69×10^{-4}	1.0000	−0.5824
	I	−1.1919	0.3037	−3.9240	3.49×10^{-3}	−0.9200	1.0000
BE	C	−28.8149	13.8615	−2.0788	6.74×10^{-2}	−1.7171	1.0000
	I	1.0965	0.3240	3.3847	8.07×10^{-3}	1.0000	−1.0870
BG	C	0.3875	1.1618	0.3336	7.47×10^{-1}	127.6800	−74.3563
	I	0.0446	0.0222	2.0090	7.94×10^{-2}	24.5944	−26.7332
CY	C	1.5892	0.4139	3.8399	4.95×10^{-3}	31.1344	−18.1316
	I	0.0151	0.0081	1.8613	9.97×10^{-2}	72.6877	−79.0087
CZ	C	22.0176	7.9372	2.7740	2.16×10^{-2}	2.2473	−1.3087
	I	−0.2442	0.1388	−1.7596	1.12×10^{-1}	−4.4894	4.8798
DE	C	19.5094	8.3308	2.3419	4.39×10^{-2}	2.5362	−1.4770
	I	−0.1638	0.1788	−0.9160	3.84×10^{-1}	−6.6937	7.2758
DK	C	6.6130	1.0656	6.2057	1.58×10^{-4}	7.4821	−4.3573
	I	0.0387	0.0344	1.1254	2.90×10^{-1}	28.2991	−30.7601
EE	C	7.4464	5.0263	1.4815	1.73×10^{-1}	6.6447	−3.8697
	I	0.1881	0.1519	1.2381	2.47×10^{-1}	5.8299	−6.3369
EL	C	−1.3780	2.2928	−0.6010	5.64×10^{-1}	−35.9076	20.9113
	I	0.1078	0.0644	1.6738	1.33×10^{-1}	10.1724	−11.0571
ES	C	10.1497	2.0778	4.8849	8.66×10^{-4}	4.8750	−2.8390
	I	−0.0228	0.0478	−0.4772	6.45×10^{-1}	−48.0477	52.2260
FI	C	14.6531	6.5333	2.2428	5.52×10^{-2}	3.3767	−1.9665
	I	−0.2082	0.2349	−0.8863	4.01×10^{-1}	−5.2673	5.7253
FR	C	22.0928	8.0288	2.7517	2.24×10^{-2}	2.2396	−1.3043
	I	−0.1374	0.3195	−0.4302	6.77×10^{-1}	−7.9778	8.6716
HR	C	8.8282	1.0187	8.6663	5.45×10^{-5}	5.6047	−3.2640
	I	−0.1040	0.0253	−4.1094	4.52×10^{-3}	−10.5453	11.4624
HU	C	7.8063	2.5035	3.1181	1.24×10^{-2}	6.3384	−3.6913
	I	−0.0464	0.0830	−0.5590	5.90×10^{-1}	−23.6334	25.6886
IE	C	1.2992	0.2392	5.4317	4.15×10^{-4}	38.0841	−22.1788
	I	0.0145	0.0071	2.0495	7.07×10^{-2}	75.5760	−82.1482
IT	C	−14.3205	4.4130	−3.2451	1.18×10^{-2}	−3.4551	2.0121
	I	0.7671	0.1110	6.9127	1.23×10^{-4}	1.4294	−1.5537
LT	C	2.7242	0.4034	6.7538	8.33×10^{-5}	18.1631	−10.5775
	I	0.0230	0.0071	3.2343	1.03×10^{-2}	47.6869	−51.8338
LU	C	3.6094	37.5123	0.0962	9.25×10^{-1}	13.7083	−7.9832
	I	0.3098	1.1341	0.2731	7.91×10^{-1}	3.5399	−3.8477
LV	C	−3.5780	1.5237	−2.3482	4.68×10^{-2}	−13.8286	8.0533
	I	0.2450	0.0479	5.1121	9.16×10^{-4}	4.4760	−4.8652
MT	C	9.5082	0.9299	10.2248	2.97×10^{-6}	5.2038	−3.0305
	I	−0.1577	0.0392	−4.0241	3.00×10^{-3}	−6.9518	7.5563
NL	C	7.9325	8.4345	0.9405	3.74×10^{-1}	6.2375	−3.6325
	I	0.3850	0.1671	2.3046	5.01×10^{-2}	2.8481	−3.0958
PL	C	11.5934	1.2546	9.2406	1.53×10^{-5}	4.2679	−2.4855
	I	−0.0313	0.0414	−0.7559	4.71×10^{-1}	−35.0521	38.1003
PT	C	1.2392	0.3717	3.3340	8.74×10^{-3}	39.9294	−23.2534
	I	0.0255	0.0106	2.3960	4.02×10^{-2}	43.0361	−46.7785
RO	C	2.8294	1.2805	2.2096	5.81×10^{-2}	17.4876	−10.1842
	I	−0.0167	0.0293	−0.5702	5.84×10^{-1}	−65.6788	71.3903
SE	C	9.2293	0.6300	14.6505	1.38×10^{-7}	5.3611	−3.1221
	I	−0.0512	0.0142	−3.5933	5.81×10^{-3}	−21.4316	23.2953
SI	C	15.7996	2.3637	6.6843	9.01×10^{-5}	3.1317	−1.8238
	I	−0.1052	0.0372	−2.8253	1.99×10^{-2}	−10.4219	11.3282
SK	C	5.4833	3.5417	1.5482	1.56×10^{-1}	9.0236	−5.2550
	I	−0.0066	0.0668	−0.0981	9.24×10^{-1}	−167.1661	181.7031
UK	C	11.6186	0.6397	18.1629	3.79×10^{-7}	4.2586	−2.4801
	I	0.0871	0.0176	4.9415	1.67×10^{-3}	12.5910	−13.6859

Source: Own elaboration by the authors.

Table 5. The wooden packaging waste recycling rate regression models

		Estimation		*t* Test		Ratio	
Country	Variable	Regression coefficient	Standard error	Statistic value	*p*-Value	Maximum	Minimum
AT	C	12.5979	2.8984	4.3465	1.86×10^{-3}	1.9176	−2.3455
	I	−0.1296	0.1284	−1.0096	3.39×10^{-1}	−5.9931	1.0000
BE	C	4.4990	6.5771	0.6840	5.11×10^{-1}	5.3696	−6.5677
	I	0.1848	0.0890	2.0766	6.76×10^{-2}	4.2019	−0.7011
BG	C	3.5682	0.9412	3.7909	5.30×10^{-3}	6.7704	−8.2810
	I	−0.0221	0.0226	−0.9797	3.56×10^{-1}	−35.0735	5.8523
CY	C	1.8625	0.2174	8.5668	2.66×10^{-5}	12.9705	−15.8645
	I	0.0437	0.0183	2.3851	4.42×10^{-2}	17.7615	−2.9637
CZ	C	8.2321	2.7106	3.0370	1.41×10^{-2}	2.9346	−3.5894
	I	−0.0027	0.0573	−0.0477	9.63×10^{-1}	−284.3498	47.4462
DE	C	12.3308	2.6558	4.6429	1.21×10^{-3}	1.9591	−2.3963
	I	−0.0165	0.0973	−0.1698	8.69×10^{-1}	−47.0198	7.8457
DK	C	6.9711	0.6650	10.4836	2.41×10^{-6}	3.4654	−4.2386
	I	0.0130	0.0101	1.2905	2.29×10^{-1}	59.5358	−9.9341
EE	C	14.3362	2.2825	6.2810	1.44×10^{-4}	1.6851	−2.0611
	I	−0.0164	0.0445	−0.3677	7.22×10^{-1}	−47.4139	7.9114
EL	C	2.3561	0.5251	4.4865	2.04×10^{-3}	10.2534	−12.5411
	I	0.0029	0.0155	0.1862	8.57×10^{-1}	268.9330	−44.8738
ES	C	7.4922	2.6677	2.8085	2.04×10^{-2}	3.2244	−3.9438
	I	0.0258	0.0405	0.6355	5.41×10^{-1}	30.1404	−5.0292
FI	C	9.7115	5.0835	1.9104	9.25×10^{-2}	2.4875	−3.0426
	I	−0.0428	0.2836	−0.1510	8.84×10^{-1}	−18.1406	3.0269
FR	C	11.3424	2.6147	4.3380	1.88×10^{-3}	2.1299	−2.6051
	I	0.2510	0.0889	2.8225	2.00×10^{-2}	3.0947	−0.5164
HR	C	3.9979	0.3454	11.5758	8.09×10^{-6}	6.0426	−7.3908
	I	0.2651	0.1219	2.1758	6.60×10^{-2}	2.9291	−0.4887
HU	C	6.3640	1.0529	6.0440	1.92×10^{-4}	3.7960	−4.6430
	I	0.0024	0.0437	0.0541	9.58×10^{-1}	328.3739	−54.7920
IE	C	1.0460	0.2853	3.6664	5.18×10^{-3}	23.0953	−28.2483
	I	0.0096	0.0037	2.6029	2.86×10^{-2}	81.0999	−13.5322
IT	C	−29.5478	14.3274	−2.0623	7.31×10^{-2}	−0.8176	1.0000
	I	0.7766	0.2436	3.1878	1.28×10^{-2}	1.0000	−0.1669
LT	C	3.7717	0.4697	8.0306	2.15×10^{-5}	6.4050	−7.8341
	I	0.0064	0.0131	0.4889	6.37×10^{-1}	121.2114	−20.2252
LU	C	14.4557	7.9245	1.8242	1.01×10^{-1}	1.6712	−2.0440
	I	−0.0185	0.2344	−0.0788	9.39×10^{-1}	−42.0709	7.0199
LV	C	2.3022	3.3485	0.6875	5.11×10^{-1}	10.4936	−12.8349
	I	0.0487	0.0909	0.5362	6.06×10^{-1}	15.9384	−2.6595
MT	C	6.1064	0.5958	10.2492	2.91×10^{-6}	3.9561	−4.8388
	I	−0.1047	0.2445	−0.4281	6.79×10^{-1}	−7.4190	1.2379
NL	C	24.1578	0.9074	26.6222	4.26×10^{-9}	1.0000	−1.2231
	I	0.0694	0.0182	3.8254	5.05×10^{-3}	11.1851	−1.8663
PL	C	9.2273	1.0810	8.5356	2.73×10^{-5}	2.6181	−3.2022
	I	0.0444	0.0316	1.4038	1.98×10^{-1}	17.4986	−2.9198
PT	C	1.3328	0.2992	4.4543	1.59×10^{-3}	18.1253	−22.1694
	I	0.0088	0.0033	2.6736	2.55×10^{-2}	88.2906	−14.7321
RO	C	2.4749	1.1799	2.0975	6.92×10^{-2}	9.7611	−11.9389
	I	−0.0127	0.0404	−0.3149	7.61×10^{-1}	−61.0396	10.1850
SE	C	6.6463	0.2208	30.1025	2.41×10^{-10}	3.6348	−4.4458
	I	0.0060	0.0029	2.0746	6.79×10^{-2}	128.4077	−21.4259
SI	C	5.6358	1.4536	3.8772	3.75×10^{-3}	4.2865	−5.2429
	I	0.1486	0.0578	2.5731	3.00×10^{-2}	5.2248	−0.8718
SK	C	4.1235	0.5685	7.2530	4.80×10^{-5}	5.8585	−7.1656
	I	0.0242	0.0128	1.8877	9.17×10^{-2}	32.0669	−5.3506
UK	C	16.1968	0.7536	21.4925	1.19×10^{-7}	1.4915	−1.8243
	I	−0.0353	0.0166	−2.1226	7.14×10^{-2}	−22.0149	3.6734

Source: Own elaboration by the authors.

Table 6. The metallic packaging waste recycling rate regression models

Country	Variable	Estimation		t Test		Ratio	
		Regression coefficient	Standard error	Statistic value	p-Value	Maximum	Minimum
AT	C	1.4513	3.3170	0.4375	6.72×10^{-1}	59.5952	−28.5316
	I	0.1066	0.0422	2.5254	3.25×10^{-2}	7.2824	−7.8139
BE	C	38.7842	77.4929	0.5005	6.29×10^{-1}	2.2300	−1.0676
	I	−0.2134	0.7974	−0.2676	7.95×10^{-1}	−3.6376	3.9031
BG	C	4.0691	2.2421	1.8148	1.07×10^{-1}	21.2556	−10.1762
	I	−0.0201	0.0322	−0.6238	5.50×10^{-1}	−38.6697	41.4920
CY	C	1.7880	0.5381	3.3229	1.05×10^{-2}	48.3714	−23.1581
	I	0.0055	0.0053	1.0455	3.26×10^{-1}	139.9918	−150.2088
CZ	C	−11.3733	11.3456	−1.0024	3.42×10^{-1}	−7.6047	3.6408
	I	0.2975	0.1729	1.7207	1.19×10^{-1}	2.6093	−2.7998
DE	C	19.2466	2.5187	7.6416	3.19×10^{-5}	4.4938	−2.1514
	I	−0.0823	0.0281	−2.9316	1.67×10^{-2}	−9.4314	10.1198
DK	C	4.9521	1.0731	4.6149	1.26×10^{-3}	17.4655	−8.3617
	I	0.0411	0.0154	2.6753	2.54×10^{-2}	18.8719	−20.2493
EE	C	8.0991	4.6464	1.7431	1.15×10^{-1}	10.6790	−5.1126
	I	0.0742	0.0619	1.2001	2.61×10^{-1}	10.4570	−11.2202
EL	C	0.2583	0.9174	0.2815	7.85×10^{-1}	334.8653	−160.3187
	I	0.0382	0.0157	2.4396	4.06×10^{-2}	20.3148	−21.7974
ES	C	14.9619	6.6745	2.2416	5.17×10^{-2}	5.7807	−2.7676
	I	−0.0720	0.0828	−0.8685	4.08×10^{-1}	−10.7891	11.5766
FI	C	64.0771	26.0438	2.4604	3.93×10^{-2}	1.3498	−0.6462
	I	−0.6571	0.3103	−2.1177	6.71×10^{-2}	−1.1814	1.2676
FR	C	21.6268	5.1448	4.2037	2.29×10^{-3}	3.9992	−1.9146
	I	−0.0390	0.0670	−0.5823	5.75×10^{-1}	−19.9061	21.3590
HR	C	2.6870	0.7803	3.4433	1.08×10^{-2}	32.1884	−15.4104
	I	0.1274	0.0494	2.5825	3.63×10^{-2}	6.0915	−6.5361
HU	C	12.1242	2.7857	4.3523	1.84×10^{-3}	7.1337	−3.4153
	I	−0.0737	0.0358	−2.0578	6.97×10^{-2}	−10.5344	11.3032
IE	C	1.2318	0.5759	2.1390	6.11×10^{-2}	70.2173	−33.6169
	I	0.0077	0.0081	0.9586	3.63×10^{-1}	100.3472	−107.6709
IT	C	−41.4077	19.0228	−2.1767	6.12×10^{-2}	−2.0887	1.0000
	I	0.7763	0.2567	3.0239	1.65×10^{-2}	1.0000	−1.0730
LT	C	−1.3742	1.3982	−0.9828	3.51×10^{-1}	−62.9384	30.1321
	I	0.0747	0.0194	3.8446	3.94×10^{-3}	10.3948	−11.1534
LU	C	86.4903	14.2954	6.0502	1.90×10^{-4}	1.0000	−0.4788
	I	−0.8330	0.1636	−5.0907	6.53×10^{-4}	−0.9320	1.0000
LV	C	9.3122	3.8708	2.4058	4.28×10^{-2}	9.2878	−4.4466
	I	−0.0834	0.0610	−1.3675	2.09×10^{-1}	−9.3032	9.9822
MT	C	3.7137	1.2833	2.8939	1.78×10^{-2}	23.2897	−11.1501
	I	0.0588	0.0316	1.8577	9.62×10^{-2}	13.2057	−14.1695
NL	C	−25.6021	16.2635	−1.5742	1.54×10^{-1}	−3.3783	1.6174
	I	0.5682	0.1745	3.2562	1.16×10^{-2}	1.3664	−1.4661
PL	C	11.8974	1.3661	8.7092	2.36×10^{-5}	7.2697	−3.4804
	I	−0.0214	0.0233	−0.9188	3.85×10^{-1}	−36.2838	38.9319
PT	C	2.3432	0.3383	6.9263	6.86×10^{-5}	36.9111	−17.6714
	I	−0.0039	0.0057	−0.6818	5.13×10^{-1}	−199.0368	213.5631
RO	C	−0.2742	2.5014	−0.1096	9.15×10^{-1}	−315.4722	151.0341
	I	0.0400	0.0419	0.9566	3.67×10^{-1}	19.3876	−20.8025
SE	C	13.5622	3.2226	4.2084	2.28×10^{-3}	6.3773	−3.0532
	I	−0.0829	0.0407	−2.0382	7.20×10^{-2}	−9.3633	10.0466
SI	C	4.5584	1.9618	2.3236	4.52×10^{-2}	18.9738	−9.0838
	I	0.0826	0.0339	2.4338	3.77×10^{-2}	9.4040	−10.0904
SK	C	4.6414	1.3686	3.3914	7.98×10^{-3}	18.6346	−8.9214
	I	0.0071	0.0194	0.3665	7.22×10^{-1}	109.1345	−117.0994
UK	C	7.0871	1.3903	5.0976	1.40×10^{-3}	12.2039	−5.8427
	I	0.1258	0.0229	5.4956	9.11×10^{-4}	6.1695	−6.6198

Source: Own elaboration by the authors.

a positive way with the regression coefficient peaking at 0.7763 and Luxembourg in a negative way with the regression coefficient lowering at −0.8330. On the other side, the lowest positive estimation is reached by Cyprus at a level of 139.9918 times lower than the highest positive one and 150.2088 times lower than the absolutely highest one. Though, the highest negative regression coefficient is represented by Portugal, whose estimation is 199.0368 times lower than the highest positive one and 213.5631 lower than the absolutely highest one.

Glass packaging waste

Sixthly, the glass packaging waste recycling rate is explored in Table 7.

One of the most differentiated waste types from the explored perspective is epitomized by the glass packaging waste recycling rate in Table 7. Despite this fact, the extreme regression coefficients are held by the same countries as in the case of the metallic packaging waste recycling rate. On the positive side, Italy reaches impact of 0.9105, while Luxembourg −1.9576 on the negative side. The highest maximum ratio of 1856.4841 is reached by Denmark, meaning its impact is 3991.5771 times lower than in the most impactful country. Lithuania possesses the lowest negative impact in an absolute way, demonstrating 389.7728 times lower impact than the highest one and 838.0402 times lower impact than the lowest one actually.

Construction and demolition waste

Seventhly, the construction and demolition waste recovery rate is investigated in Table 8.

Another indicator embodied by the construction and demolition waste recovery rate shows several similar characteristics to the already analysed indicators in Table 8. The highest impact is kept by Italy at a level of 5.5667 and the highest negative impact at a level of −3.1900 by Luxembourg. The lowest positive impact is seen at Malta, where it is 556.6667 lower than in the highest positioned country and 319.0000 higher than in the lowest positioned one. On the other hand, Ireland stands, whose impact is 341.0980 lower the highest positive estimation and 545.5134 higher than the lowest positive estimation in an absolute way. There is to note that the Netherlands is omitted from the analysis here, because the regression model assigned to this country cannot be created as a consequence of singularity.

Electronic waste

Eighthly, the electronic waste recovery rate is analysed in Table 9.

As seen in Table 9, the electronic waste recovery rate demonstrates some likely characteristics than the previous indicators. Belgium shows the strongest performance again, possessing the lowest estimation at a level of 0.4059, while for the minimum estimation Luxembourg stands here repeatedly at a level of −0.6147. The highest maximum ratio is shown for Croatia with multiplication of 139.5428, while it is 211.3312 higher than the lowest impact. The highest negative multiplication of the maximum ratio is reached by Lithuania at a level of 69.7463, meaning it is 105.6275 higher than the lowest estimation.

Analysis summarization

To summarize the obtained outcomes of the carried-out regression analysis, it is to remind that there are the considerable disparities among the explored countries. The higher the differences, the more problematic the setting of circular economy principles. The further examination of these numbers would reveal relationships that are currently not seen.

Discussion

All the explored circular economy indicators possess considerable statistical significance of the highest level. Many countries demonstrate their strong impact on the circular material use rate. The strongest position is kept by the United Kingdom, whose increase of the biowaste to population ratio by one percentage point increases the circular material use rate by 0.3401 percentage points. On the other hand, Portugal stands with the lowest increase of this indicator by 0.0067 percentage points. It is very questionable whether such a low impact brings some benefit to the economy. Also, there are the countries, which possess the negative impact, that is, Austria, Estonia, Finland, Ireland, Luxembourg, Malta, Poland and Sweden. These countries demonstrate a diminishing circular economy principle while increasing the biowaste sorting as evidenced by Mazur-Wierzbicka (2021).

Hypotheses verification

The analytical procedures confirm $H_{0,1}$. The highest impact of the paper and cardboard waste recycling rate is seen in Belgium, where it causes an increase of 0.5643 percentage points, while Luxembourg demonstrates a decrease of 1.3026 percentage points. This represents a very wide spectrum of impact. A group of the 20 countries possess a negative impact and the 11 countries fulfil statistical significance at a 10% threshold, while seven of them a 5% threshold too. Hence, $H_{0,2}$ is rejected only minorly as the basement for its evaluation is composed of several estimations, not only by one. It is not so obvious that paper waste plays a more crucial role than it is

Table 7. The glass packaging waste recycling rate regression models

		Estimation		*t* Test		Ratio	
Country	Variable	Regression coefficient	Standard error	Statistic value	*p*-Value	Maximum	Minimum
AT	C	5.7202	38.7729	0.1475	8.86×10^{-1}	35.3922	−8.5647
	I	0.0480	0.4638	0.1036	9.20×10^{-1}	18.9500	−40.7439
BE	C	193.3565	98.1354	1.9703	8.03×10^{-2}	1.0470	−0.2534
	I	−1.7581	0.9841	−1.7865	1.08×10^{-1}	−0.5179	1.1135
BG	C	−0.6869	2.3246	−0.2955	7.75×10^{-1}	−294.7167	71.3194
	I	0.0533	0.0366	1.4561	1.83×10^{-1}	17.0795	−36.7221
CY	C	0.9023	0.3652	2.4708	3.87×10^{-2}	224.3737	−54.2969
	I	0.0397	0.0099	3.9989	3.96×10^{-3}	22.9436	−49.3304
CZ	C	−18.4129	14.8130	−1.2430	2.45×10^{-1}	−10.9950	2.6607
	I	0.3525	0.1966	1.7926	1.07×10^{-1}	2.5831	−5.5538
DE	C	28.6345	3.0540	9.3762	6.10×10^{-6}	7.0701	−1.7109
	I	−0.1976	0.0360	−5.4898	3.85×10^{-4}	−4.6082	9.9079
DK	C	7.7451	0.7871	9.8395	4.09×10^{-6}	26.1390	−6.3255
	I	0.0005	0.0081	0.0605	9.53×10^{-1}	1856.4841	−3991.5771
EE	C	5.3809	3.8251	1.4067	1.93×10^{-1}	37.6240	−9.1047
	I	0.1188	0.0543	2.1866	5.66×10^{-2}	7.6638	−16.4778
EL	C	2.5697	1.0110	2.5418	3.46×10^{-2}	78.7817	−19.0646
	I	−0.0040	0.0297	−0.1332	8.97×10^{-1}	−229.8837	494.2669
ES	C	12.0478	4.4732	2.6933	2.47×10^{-2}	16.8038	−4.0664
	I	−0.0411	0.0638	−0.6447	5.35×10^{-1}	−22.1385	47.5994
FI	C	26.4948	8.1960	3.2327	1.20×10^{-2}	7.6411	−1.8491
	I	−0.2082	0.0966	−2.1558	6.32×10^{-2}	−4.3729	9.4020
FR	C	−16.6817	8.5084	−1.9606	8.16×10^{-2}	−12.1360	2.9368
	I	0.4720	0.1136	4.1547	2.47×10^{-3}	1.9290	−4.1474
HR	C	9.1012	1.9121	4.7599	2.06×10^{-3}	22.2442	−5.3829
	I	−0.0744	0.0320	−2.3267	5.29×10^{-2}	−12.2344	26.3048
HU	C	8.2967	2.1790	3.8077	4.17×10^{-3}	24.4012	−5.9049
	I	−0.0515	0.0591	−0.8711	4.06×10^{-1}	−17.6773	38.0076
IE	C	0.7045	1.4256	0.4941	6.33×10^{-1}	287.3844	−69.5451
	I	0.0129	0.0170	0.7562	4.69×10^{-1}	70.6419	−151.8853
IT	C	−48.9913	17.2285	−2.8436	2.17×10^{-2}	−4.1323	1.0000
	I	0.9105	0.2409	3.7791	5.40×10^{-3}	1.0000	−2.1501
LT	C	4.1392	1.0357	3.9964	3.13×10^{-3}	48.9103	−11.8359
	I	−0.0023	0.0162	−0.1445	8.88×10^{-1}	−389.7728	838.0402
LU	C	202.4492	60.7917	3.3302	8.80×10^{-3}	1.0000	−0.2420
	I	−1.9576	0.6309	−3.1030	1.27×10^{-2}	−0.4651	1.0000
LV	C	−6.7438	3.4966	−1.9287	8.99×10^{-2}	−30.0202	7.2647
	I	0.1809	0.0581	3.1132	1.44×10^{-2}	5.0332	−10.8218
MT	C	3.6972	0.7765	4.7616	1.03×10^{-3}	54.7578	−13.2510
	I	0.0711	0.0219	3.2438	1.01×10^{-2}	12.8110	−27.5447
NL	C	20.9678	9.7562	2.1492	6.39×10^{-2}	9.6552	−2.3365
	I	0.0767	0.1172	0.6544	5.31×10^{-1}	11.8720	−25.5257
PL	C	11.1831	2.4369	4.5890	1.78×10^{-3}	18.1032	−4.3808
	I	−0.0091	0.0435	−0.2086	8.40×10^{-1}	−100.3179	215.6908
PT	C	3.0954	1.2718	2.4338	3.77×10^{-2}	65.4039	−15.8273
	I	−0.0176	0.0229	−0.7696	4.61×10^{-1}	−51.7191	111.1999
RO	C	1.1210	1.4628	0.7663	4.66×10^{-1}	180.6039	−43.7049
	I	0.0177	0.0259	0.6837	5.13×10^{-1}	51.4315	−110.5814
SE	C	26.7759	5.2065	5.1428	6.09×10^{-4}	7.5609	−1.8297
	I	−0.2142	0.0564	−3.7991	4.22×10^{-3}	−4.2499	9.1375
SI	C	−2.3944	4.3775	−0.5470	5.98×10^{-1}	−84.5507	20.4607
	I	0.1241	0.0466	2.6646	2.59×10^{-2}	7.3343	−15.7693
SK	C	3.3966	2.9713	1.1432	2.82×10^{-1}	59.6033	−14.4236
	I	0.0259	0.0441	0.5871	5.72×10^{-1}	35.1775	−75.6342
UK	C	4.9201	8.1480	0.6038	5.65×10^{-1}	41.1471	−9.9573
	I	0.1474	0.1228	1.1997	2.69×10^{-1}	6.1783	−13.2837

Source: Own elaboration by the authors.

Table 8. The construction and demolition waste recovery rate regression models

		Estimation		*t* Test		Ratio	
Country	Variable	Regression coefficient	Standard error	Statistic value	*p*-Value	Maximum	Minimum
AT	C	59.8448	41.9558	1.4264	2.27×10^{-1}	5.4972	−8.7916
	I	−0.5504	0.4601	−1.1962	2.98×10^{-1}	−10.1139	5.7958
BE	C	14.3287	1.8307	7.8271	1.44×10^{-3}	22.9595	−36.7188
	I	0.0615	0.0259	2.3716	7.67×10^{-2}	90.4712	−51.8449
BG	C	1.8729	0.7108	2.6349	5.79×10^{-2}	175.6532	−280.9199
	I	0.0131	0.0099	1.3227	2.56×10^{-1}	426.2522	−244.2655
CY	C	1.7775	0.3915	4.5404	1.05×10^{-2}	185.0776	−295.9922
	I	0.0139	0.0070	1.9749	1.19×10^{-1}	401.1911	−229.9041
CZ	C	−110.9036	23.4073	−4.7380	1.78×10^{-2}	−2.9664	4.7441
	I	1.2909	0.2544	5.0751	1.48×10^{-2}	4.3122	−2.4711
DE	C	59.1000	75.4953	0.7828	5.16×10^{-1}	5.5665	−8.9024
	I	−0.5000	0.8031	−0.6226	5.97×10^{-1}	−11.1333	6.3800
DK	C	4.2858	14.9414	0.2868	7.93×10^{-1}	76.7597	−122.7608
	I	0.0381	0.1599	0.2380	8.27×10^{-1}	146.2868	−83.8302
EE	C	132.8404	92.5006	1.4361	2.24×10^{-1}	2.4765	−3.9606
	I	−1.2449	0.9651	−1.2900	2.67×10^{-1}	−4.4714	2.5624
EL	C	1.9599	0.6725	2.9145	4.35×10^{-2}	167.8520	−268.4434
	I	0.0186	0.0101	1.8386	1.40×10^{-1}	299.5600	−171.6640
ES	C	5.5994	6.1924	0.9042	4.17×10^{-1}	58.7532	−93.9632
	I	0.0496	0.0808	0.6138	5.73×10^{-1}	112.2952	−64.3512
FI	C	15.0237	1.2239	12.2752	2.53×10^{-4}	21.8974	−35.0202
	I	−0.1131	0.0193	−5.8529	4.25×10^{-3}	−49.2220	28.2069
FR	C	−15.1728	10.3006	−1.4730	2.15×10^{-1}	−21.6822	34.6761
	I	0.4858	0.1467	3.3128	2.96×10^{-2}	11.4579	−6.5660
HR	C	1.5454	0.2234	6.9170	2.29×10^{-3}	212.8701	−340.4403
	I	0.0423	0.0033	12.7247	2.20×10^{-4}	131.7037	−75.4733
HU	C	1.7660	2.5625	0.6892	5.29×10^{-1}	186.2886	−297.9289
	I	0.0548	0.0293	1.8726	1.34×10^{-1}	101.5179	−58.1752
IE	C	−0.9645	4.1407	−0.2329	8.31×10^{-1}	−341.0980	545.5134
	I	0.0276	0.0420	0.6581	5.57×10^{-1}	201.4603	−115.4476
IT	C	−526.1333	170.4956	−3.0859	3.67×10^{-2}	−0.6253	1.0000
	I	5.5667	1.7487	3.1834	3.34×10^{-2}	1.0000	−0.5731
LT	C	2.0806	1.3629	1.5266	2.02×10^{-1}	158.1178	−252.8757
	I	0.0223	0.0149	1.5011	2.08×10^{-1}	249.2524	−142.8351
LU	C	328.9800	334.5823	0.9833	3.81×10^{-1}	1.0000	−1.5993
	I	−3.1900	3.3909	−0.9407	4.00×10^{-1}	−1.7450	1.0000
LV	C	9.3345	21.5627	0.4329	7.07×10^{-1}	35.2435	−56.3645
	I	−0.0431	0.2234	−0.1930	8.65×10^{-1}	−129.1467	74.0080
MT	C	5.1400	2.4323	2.1133	1.02×10^{-1}	64.0039	−102.3606
	I	0.0100	0.0266	0.3763	7.26×10^{-1}	556.6667	−319.0000
NL	C	27.7833	0.8304	33.4566	4.48×10^{-7}	11.8409	−18.9370
	I	27.7833	0.8304	33.4566	4.48×10^{-7}	11.8409	−18.9370
PL	C	2.8575	4.0992	0.6971	5.24×10^{-1}	115.1294	−184.1250
	I	0.0882	0.0462	1.9076	1.29×10^{-1}	63.1018	−36.1607
PT	C	1.1170	0.3265	3.4211	2.68×10^{-2}	294.5143	−471.0127
	I	0.0115	0.0037	3.0989	3.63×10^{-2}	484.4738	−277.6296
RO	C	5.6983	0.7731	7.3705	1.81×10^{-3}	57.7329	−92.3315
	I	−0.0504	0.0107	−4.7179	9.19×10^{-3}	−110.3498	63.2364
SE	C	5.5769	1.6565	3.3666	2.81×10^{-2}	58.9900	−94.3420
	I	0.0201	0.0223	0.9009	4.19×10^{-1}	276.4832	−158.4398
SI	C	−16.0234	37.1658	−0.4311	6.89×10^{-1}	−20.5313	32.8354
	I	0.2614	0.3864	0.6766	5.36×10^{-1}	21.2939	−12.2025
SK	C	2.3500	0.6280	3.7419	6.46×10^{-2}	139.9915	−223.8865
	I	0.0500	0.0103	4.8744	3.96×10^{-2}	111.3333	−63.8000
UK	C	−61.1750	45.8074	−1.3355	2.74×10^{-1}	−5.3777	8.6005
	I	0.7875	0.4752	1.6573	1.96×10^{-1}	7.0688	−4.0508

Source: Own elaboration by the authors.

Table 9. The electronic waste recovery rate regression models

		Estimation		t Test		Ratio	
Country	Variable	Regression coefficient	Standard error	Statistic value	p-Value	Maximum	Minimum
AT	C	−4.3903	3.8659	−1.1356	2.93×10^{-1}	−8.4348	1.0000
	I	0.3368	0.0946	3.5589	9.23×10^{-3}	1.2051	−1.8251
BE	C	3.1915	5.8134	0.5490	6.00×10^{-1}	11.6028	−1.3756
	I	0.4059	0.1714	2.3676	4.98×10^{-2}	1.0000	−1.5145
BG	C	0.3895	0.6035	0.6454	5.39×10^{-1}	95.0709	−11.2713
	I	0.0340	0.0085	4.0157	5.09×10^{-3}	11.9544	−18.1045
CY	C	1.9986	0.1245	16.0509	3.72×10^{-6}	18.5286	−2.1967
	I	0.0102	0.0051	2.0036	9.20×10^{-2}	39.9882	−60.5602
CZ	C	3.3832	1.3322	2.5395	3.87×10^{-2}	10.9454	−1.2977
	I	0.1057	0.0355	2.9766	2.06×10^{-2}	3.8421	−5.8186
DE	C	7.0742	3.4896	2.0272	8.22×10^{-2}	5.2347	−0.6206
	I	0.1242	0.0956	1.2985	2.35×10^{-1}	3.2686	−4.9502
DK	C	8.1711	1.4180	5.7624	6.90×10^{-4}	4.5319	−0.5373
	I	−0.0077	0.0307	−0.2505	8.09×10^{-1}	−52.7263	79.8515
EE	C	14.0683	4.7935	2.9349	2.19×10^{-2}	2.6322	−0.3121
	I	−0.0279	0.1149	−0.2425	8.15×10^{-1}	−14.5646	22.0574
EL	C	1.5234	0.8135	1.8726	1.03×10^{-1}	24.3077	−2.8818
	I	0.0270	0.0291	0.9279	3.84×10^{-1}	15.0125	−22.7358
ES	C	10.5541	0.8269	12.7637	4.20×10^{-6}	3.5087	−0.4160
	I	−0.0573	0.0270	−2.1204	7.17×10^{-2}	−7.0810	10.7239
FI	C	28.8420	3.2410	8.8991	4.59×10^{-5}	1.2839	−0.1522
	I	−0.4978	0.0811	−6.1351	4.74×10^{-4}	−0.8154	1.2349
FR	C	13.6277	0.6794	20.0591	1.92×10^{-7}	2.7173	−0.3222
	I	0.1566	0.0233	6.7289	2.70×10^{-4}	2.5918	−3.9251
HR	C	4.6376	0.4734	9.7962	2.26×10^{-3}	7.9849	−0.9467
	I	0.0029	0.0065	0.4448	6.87×10^{-1}	139.5428	−211.3312
HU	C	4.6021	0.7119	6.4644	3.46×10^{-4}	8.0464	−0.9540
	I	0.0351	0.0165	2.1254	7.12×10^{-2}	11.5640	−17.5131
IE	C	2.1696	0.3074	7.0578	2.01×10^{-4}	17.0679	−2.0235
	I	−0.0088	0.0072	−1.2211	2.62×10^{-1}	−46.1245	69.8534
IT	C	10.1070	16.4575	0.6141	5.72×10^{-1}	3.6639	−0.4344
	I	0.1500	0.5762	0.2604	8.07×10^{-1}	2.7053	−4.0970
LT	C	4.1823	0.5528	7.5661	1.30×10^{-4}	8.8542	−1.0497
	I	−0.0058	0.0135	−0.4302	6.80×10^{-1}	−69.7463	105.6275
LU	C	37.0308	6.8335	5.4190	9.88×10^{-4}	1.0000	−0.1186
	I	−0.6147	0.1812	−3.3925	1.16×10^{-2}	−0.6603	1.0000
LV	C	1.7059	1.9949	0.8552	4.21×10^{-1}	21.7071	−2.5735
	I	0.0858	0.0697	1.2311	2.58×10^{-1}	4.7310	−7.1648
MT	C	3.9099	1.4912	2.6219	3.95×10^{-2}	9.4711	−1.1229
	I	0.0992	0.1099	0.9034	4.01×10^{-1}	4.0899	−6.1939
NL	C	18.4059	2.9124	6.3198	3.97×10^{-4}	2.0119	−0.2385
	I	0.2375	0.0793	2.9931	2.01×10^{-2}	1.7093	−2.5887
PL	C	11.7751	1.7709	6.6490	2.91×10^{-4}	3.1448	−0.3728
	I	−0.0345	0.0567	−0.6087	5.62×10^{-1}	−11.7676	17.8216
PT	C	1.7143	0.4298	3.9885	7.21×10^{-3}	21.6009	−2.5609
	I	0.0103	0.0119	0.8617	4.22×10^{-1}	39.4878	−59.8025
RO	C	3.9160	0.5703	6.8672	1.00×10^{-3}	9.4562	−1.1211
	I	−0.0854	0.0303	−2.8225	3.70×10^{-2}	−4.7529	7.1980
SE	C	3.7153	1.0652	3.4879	1.02×10^{-2}	9.9670	−1.1817
	I	0.0599	0.0190	3.1492	1.62×10^{-2}	6.7711	−10.2546
SI	C	7.6272	1.5685	4.8627	1.83×10^{-3}	4.8551	−0.5756
	I	0.0332	0.0498	0.6677	5.26×10^{-1}	12.2192	−18.5053
SK	C	4.3231	1.2565	3.4406	1.08×10^{-2}	8.5658	−1.0155
	I	0.0124	0.0292	0.4258	6.83×10^{-1}	32.6778	−49.4890
UK	C	12.7058	0.3313	38.3500	2.13×10^{-9}	2.9145	−0.3455
	I	0.0555	0.0086	6.4419	3.53×10^{-4}	7.3075	−11.0669

Source: Own elaboration by the authors.

expected and observed in the waste management system in general. Although numerically quantification of the paper and cardboard waste recycling rate impact does not lie at such levels than the other waste types, it is important to understand that paper waste is able to bring more efficient solutions in the field of decarbonization along with the complementary waste types (Chowdhury *et al.*, 2025). The plastic packaging waste recycling rate causes the highest increase of 1.0965 percentage points in a case of Belgium and the highest negative increase of −1.1919 in a case of Austria. The negative impact is kept by the 14 countries, while just right the 14 countries are assigned a 10% statistical significance, while the 11 ones of them meet a 5% threshold. Therefore, $H_{0,3}$ is not rejected, whilst this outcome is reached by Robaina *et al.* (2020). In this field, only the ambitious goals have to be fulfilled as this represents one of the most critical waste types (Antonopoulos, Faraca and Tonini, 2021). Impact of the plastic packaging waste recycling rate lies at the highest increase of 0.7766 percentage points for Italy and the highest decrease of 0.1296 percentage points for Austria. While the nine countries are impacted negatively, the 12 ones fulfil a 10% statistical significance threshold and the seven ones meet a 5% threshold. So, $H_{0,4}$ is not rejected too. A very equal outcome is reached by Eriksen *et al.* (2020). Similar behaviour is seen for the metallic packaging waste recycling rate with the highest impact of 0.7763 for Italy and the highest negative impact of 0.8330 for Luxembourg. The 12 countries are impacted negatively and the 15 countries in a statistically significant way with the 11 countries meeting a 5% threshold. Hence, $H_{0,5}$ is not rejected. Some metal types are assigned partially equal characteristics (Warrings and Fellner, 2019). Italy holds the highest impact of 0.9105 percentage points for the glass packaging waste recycling rate and Luxembourg the highest negative impact of 1.9576 percentage points. The 12 countries are impacted negatively and the 12 of them are statistically significant with nine ones meeting a 5% threshold. Therefore, $H_{0,6}$ is not rejected. This outcome is demonstrated also in a perspective technical and economic evaluation of the glass waste, showing there are several scenarios how to assess such resources (Yuan *et al.*, 2024). The construction and demolition waste recovery rate behaves with the highest disparities. Italy holds the highest impact of 5.5667 percentage points, while Luxembourg the highest negative impact of 3.1900 percentage points. The seven countries are assigned cause of a decrease in the circular material use rate. There are the nine countries, whose regression models reach statistical significance, while seven of them are under a 5% threshold. Here, $H_{0,7}$ is partially rejected, as its evaluation is composed of several estimations, not only by one. There is to note that construction and demolition waste is a very specific item as it includes many heterogeneous materials. That is why, it is not so effortless to process such a kind of waste. Perhaps at most in this point, artificial intelligence has become a part of the state of the art in the very recent period (Langley *et al.*, 2025). Finally, the electronic waste recovery rate is scrutinized. Belgium reaches the highest impact of 0.4059 percentage points and on the other hand, Luxembourg achieves the highest negative impact of 0.6147 percentage points, while also the other eight countries are impacted negatively. The 13 countries possess statistical significance, which the 11 ones meet a 5% threshold of. Then, $H_{0,8}$ is not rejected. The similar dimensions are revealed by Mazur-Wierzbicka (2021) too. Electronic waste is a specific from a view of the current evaluation as recycling rate is more elastic to the technical factors related to waste (Fizaine, 2020).

Net zero promotion

There are also several methods how to promote net zero in the circular economy with an intention of raising recycling rate, but not only directly through waste processing. Decarbonization is one of these methods along with digital servitization (Gao *et al.*, 2025). Product life cycle plays a crucial role here. Hence, a sustainable approach is necessary throughout the whole market in order to be efficient in collaborating with an aim of creating a net zero system (Deivayanai *et al.*, 2024). Automatic operations in the recycling processes and waste processing can be solved through machine learning that considerably contribute to a desired outcome of the net zero principle (Huang, Huang and Kaewunruen, 2025). Life cycle evaluation in a perspective of carbon emissions represents a new approach in the future framework that will integrate the circular economy principles and the industry 4.0 philosophy in order to obtain an appropriate pathway to net zero (Flores Lara *et al.*, 2025).

The success of any methods, procedures and approaches aimed at ensuring the goal of zero net emissions in the circular economy cannot be achieved without completing management processes within enterprises, which this transformation to circular economy is underway or planned in. In many available studies, a strong appeal is evident to ensure changes in the organizational management of enterprises towards circularity that is a major challenge for many enterprises (Enciso-Alfaro and García-Sánchez, 2024). It is also important to manage the processes of information and knowledge transfer within a particular enterprise, to ensure active approaches to circular equipment, finances and contracts, to adjust relations with contractual partners, and to set internal structures of competency and responsibilities as well as priorities.

The outcomes of the studies demonstrate that a majority of the barriers to innovation in the circular business model exist at the organizational level (Chen and Li, 2025). As Santa-Maria, Vermeulen and

Baumgartner (2021) state, organizational management alteration in enterprises transitioning to circular economy, organizational inertia and systemic change remain under-researched and very important. Within the management alteration processes that enterprises use to develop organizational competencies and capabilities, it is necessary to take into account not only organizational culture but also leadership, strategies, learning and alignment. Systemic changes related to circular economy are strongly related to human behavioural factors. It is planned to explore these aspects in follow-up research. As stated by McMahon, Mugge and Hultink (2024), Du *et al.* (2025) and Gómez *et al.* (2025), there is a discrepancy between the literature on organizational management and circular economy, which prompts further research, requiring access to more deeply structured data.

To summarize all the obtained findings, there is to note that all the research hypotheses are not rejected, although only minorly for some cases. The very similar outcomes are achieved by Zisopoulos *et al.* (2022), who consider the recycling rates considerably important for the circular material use rate indicator. In spite of this, Škrinjarić (2020) applies this indicator as the dynamic ranking for the circular economy showing its relationship to the recycling and recovery rates.

Practical implications and policy creation

The study outcomes enable to formulate implications for policy-making at several levels – firstly at the policy and regulatory level, secondly at the strategic level whether regional or sectoral, thirdly at the corporate and managerial level and fourthly at the societal level.

Policy and regulatory level

The first perspective is represented by the policy and regulatory level. The analytical outcomes show that the individual countries demonstrate the different trends in achieving recycling rates of circular materials according to the individual waste types. This raises the need to create flexible regulatory frameworks instead of universal measures at the European Union level. For wastes, which have experienced a significant decrease – for instance, glass waste in Italy or plastic waste in Belgium, it would be appropriate to tighten regulatory processes and to support infrastructure investments through the multiple methods approach (Kumar and Gembali, 2024; Tian *et al.*, 2023). Based on the analytical outcomes, it can be concluded that the circular economy and the sustainable development goals are not sufficiently achieved, hence the governments should strengthen the implementation of zero waste policies with clear indicators.

Regional and sectoral level

The second view is characterized by the strategic level – both the regional and sectoral levels. There are the countries like Austria, Belgium and Italy that show positive effects, hence their models of recycling of circular materials can be applied as optimal benchmarking models for other member countries. The significant differences by waste type confirm the need to create sectoral strategies in order to waste to be applicable for further processing – for instance, separately for biowaste, construction waste, electronic waste (Moallemi *et al.*, 2024; Ogwumike *et al.*, 2024; Terjanika *et al.*, 2025). Strategies to support innovation and technology could also be effective like for the development of advanced separation systems or mechanical–chemical recycling of plastics and so on.

Corporate and managerial level

The third perspective is represented by the corporate and managerial level. Also at this level, it is necessary to implement optimal processes for increasing the environmental efficiency of companies and for the development of new business models and effective risk management. In the field of increasing the environmental efficiency of enterprises, managers can identify, based on recycling data, which fields of waste management have the strongest potential for improvement. Circular business models are also of particular importance, their development should be focused on building a shared economy, extending the life cycle of products and supporting product as a service (Ciano *et al.*, 2025; Garg *et al.*, 2025). Enterprises operating in the countries with declining recycling rates have to count with the risk of stricter regulations and the risk of increasing costs of complying with the environmental standards (Shobande, Ogbeifun and Tiwari, 2025).

Societal level

The fourth view to be distinguished is the societal level. The differences found between the countries point to the fact that population behaviour and consumer habits are crucial. The creation of innovative educational programmes and campaigns can also effectively support changes in recycling strategies. Local initiatives can also play an important role – for instance, community recycling centres, city composting plants and so on can be highly beneficial that can reduce the burden on the central circular economy system. In this dimension, it is necessary to mention the particular benefit of recycling strategies as a tool for reducing inequalities. Better availability of recycling options for residents of smaller cities and rural areas can reduce environmental as well as social disparities (Liao, Parkhurst and Parker, 2025). The aspect of regional adaptation – adapting recycling strategies to the conditions of individual regions will have a strong impact on reducing regional disparities that will also have an impact on national disparities (Lee *et al.*, 2025).

Practical measures

The above-mentioned proposals for measures – implications for policymakers at the four elementary levels show that practical measures should be differentiated depending on the countries as well as the waste types, confirming the need for continuous and systematic research into this issue categorized at the level of the individual waste types. An important process will also be represented by the relationship of policies with innovations, business models, as well as changes in the society behaviour. Coordination of actors will also be very significant and important, which will allow for strengthening collaboration between municipalities, businesses and initiatives in fulfilling the circular economy goals. High-quality recycling strategies will also allow for increasing the quality of environmental reporting, which will strengthen credibility towards investors and the public. The recycling strategies and the resulting recycling programmes can also be applied as a source of new job opportunities that will also strengthen social inclusion processes. The study outcomes have strong potential to support the creation of policy reforms, the creation of regional strategies, as well as the potential for strengthening regulatory mechanisms that would lead to the achievement of the sustainable circular economy.

Conclusion

The main goal of the study is the quantification of the disparities in the recycling rates of the circular materials according to the individual types of waste in the explored European Union member countries. The data describing the period 2004–2021 are observed. The analytical processing shows the interesting findings. Above all, all the research hypotheses are not rejected, even though some of them only minorly. This means all the explored indicators behave in a statistically significant way. Hence, the computed impacts of the recycling and recovery rates are confirmed.

The global extremes of the explored indicators are as follows. The biowaste to population ratio demonstrates an increase in the circular material use rate by 0.3401 percentage points in the United Kingdom and by 0.0067 percentage points in Portugal. The paper and cardboard waste recycling rate causes an increase of 0.5643 percentage points in Belgium and a decrease of 1.3026 percentage points. The plastic packaging waste recycling rate demonstrates an increase of 1.0965 percentage points for Belgium and of −1.1919 for Austria. The plastic packaging waste recycling rate shows an increase of 0.7766 percentage points for Italy and a decrease of 0.1296 percentage points for Austria. The metallic packaging waste recycling rate provides an increase of 0.7763 for Italy and a decrease of 0.8330 for Luxembourg. Italy possesses an increase of 0.9105 percentage points for the glass packaging waste recycling rate and Luxembourg a decrease of 1.9576 percentage points. The construction and demolition waste recovery rate is kept by Italy with an increase of 5.5667 percentage points and by Luxembourg a decrease of 3.1900 percentage points. The electronic waste recovery rate reaches an increase of 0.4059 percentage points for Belgium and a decrease of 0.6147 percentage points. These findings are also confirmed by the outcomes of the multiple research studies, declaring insufficient achievement of the goals of the circular strategies comprised in the international reports, as well as in the sustainable development goals.

The obtained numerical outcomes are able to validate the impacts of the observed recycling and recovery rates as all the examined indicators are statistically significant in a majority of the explored cases. The key findings highlight the country-specific differences, such as increases in the recycling and recovery rates represent a positive direction of the circular economy regulations towards meeting a net zero principle. For all the examined waste types, there are the countries, whose outcomes fulfil the observed statistical significance level.

The study concludes that the goals of circular economy strategies and sustainable development targets are not being fully met in practice. The comparative analysis offers insights for further research into the factors that affect circular performance and supports policymaking, strategy development and regulatory improvements aimed at achieving economic transformation and sustainability goals.

The performed comparative analysis supports the subsequent investigation of the determinants influencing the different achievement of the circular indicators along with net zero. The study outcomes are beneficial for policymakers, regional and national strategies, developing countries, as well as for managers at the different levels of enterprise management. They will also support the construction of the regulatory and support mechanisms enabling gradual progress in achieving the desired parameters of the economic transformation process and the sustainable development goals.

Author contributions

Beata Gavurova: Conceptualization; methodology; formal analysis; writing – original draft; writing – review and editing; supervision. **Domingo Ribeiro-Soriano**: Data curation; validation; writing – original draft; writing – review and editing. **Eduard Montesinos Sansaloni**: Conceptualization; formal analysis; visualization; writing – original draft. **Viliam Kovac**: Data curation; formal analysis; software; writing – review and editing.

Conflict of interest statement

The authors declare no conflicts of interest.

Funding

This paper was supported by the Slovak Research and Development Agency of the Ministry of Education, Research, Development and Youth of the Slovak Republic within the project APVV-24-0607.

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