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Development of environmental performance and circular economy in the European Union countries: the case of "post-2004" members

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The study aims to compare the environmental efficiency within the group of European Union countries that joined the European Union in 2004 and later, and to identify the common circular economy determinants of efficiency. For this purpose, we performed Data Envelopment analysis and correlation analysis. We applied both constant and variable returns to scale models. Findings reveal that countries with a significant focus on services, particularly tourism, are more environmentally efficient. However, most countries are still heavily industry-oriented, with Bulgaria, Romania, and Croatia being the least efficient. The study also highlights the need for significant efforts to reduce greenhouse gas emissions. Interestingly, a positive correlation was found between resource productivity and the circular materials used, suggesting the importance of circular economy tools in improving the environment. Despite having a higher material and consumption footprint, these countries still produce a relatively high product and relatively low CO_2 emissions. Based on these analyses, we found regional differences and the need for setting cluster policies within the circular economy at the European Union level.

KEYWORDS

environmental performance, European Union, circular economy, late-joiners, data envelopment analysis

1 Introduction

Creating policies and strategies by the European Union member states contributes to the dynamics of integration aimed at sustainable economic growth. The circular economy represents a change in how society interacts with nature, aiming to prevent the depletion of all resources, close material and energy loops, create sustainable business development, and improve the efficiency of circular economies as a pivotal factor in enhancing global GDP growth through circular means (European Commission, 2018). To achieve this, ecological innovations must be developed to protect natural capital, which can only be achieved by promoting renewable resources and expanding the use of materials through reuse and recycling. Companies that have already implemented sustainable environmental practices in conjunction with the circular economy have seen positive returns in terms of material cost savings, opening up new markets, increased turnover, and other economic benefits. The question of the circular economy of economies, precisely their efficiency, is a current topic evidenced by many literary sources. Using circular economy tools is often associated with improving environmental efficiency (Ghisellini et al., 2016). However, these relationships may not generally apply to all entities of the global economy, which, in many cases, is caused by different social, economic, and political developments (Ferronato et al., 2019). These differences at the national and regional levels are only examined at a limited level in the existing literature. They often only deal with larger regional groupings, such as the European Union, OECD, or specific countries and their regions. Therefore, we want to contribute to filling the gap in research with this study. We will examine countries that lag significantly (even in convergence) behind the environmental performance of Western European countries in the most extensive research but are part of the same political grouping—the European Union. In the Literature Review section, we will examine the current perception of the issue at the global and local levels and set the goal of this study. The Research Methodology section will describe the methods used to thoroughly analyze the existing literature to help fulfill this study's objective. In the results section, we will focus on the specific position of selected countries in the field of environmental efficiency concerning the circular economy and possible reasons for ranking these countries. In the last part of the study, we will present implications, related proposals, limitations, and possibilities of future research direction based on the results of this study.

2 Literature review

Environmental policy can be defined as any measure by a government, corporation, public, or private organization relating to the effects of human activity on the environment, particularly those measures aimed at preventing or reducing the harmful effects of human activities on ecosystems. We characterize it as a worldview to understand the need to respect the environment and lead a life that does not destroy the possibility of its subsequent existence and, thus, human existence on Earth (Tobin, 2017). At the end of the 20th century, the European Union transition successfully transitioned to a common currency, the political division of Europe was eliminated, and the countries of Central and Eastern Europe applied for membership (Bertossi, 2011). The negatives of this period were the inability to eradicate the enormous unemployment of 15 million people out of work in figures, the internal market, which had weaknesses in trade in services between the Member States, and the low volume of research expenditure and the associated low level of innovation (Pollex and Lenschow, 2020). In 2000, the European Union drew the consequences of this situation and adopted the Lisbon Strategy, which was to have three pillars: economic, social, and ecological. At the Gothenburg Summit in 2001, an objective on quality of life and sustainable development was added under the green pillar, covering the management of natural resources, greenhouse gas emissions, and ultimately sustainable transport (Graziano and Vink, 2012).

The EU extends its policy to the Member States by harmonizing laws that preceded its accession to the EU. The change is due to the focus on the adaptation of the national administration, the organizational logic of national policy, policy-making, or, more generally, the changes that have taken place in the national political systems linked to European integration (Goetz and Hix, 2001). Thus, implementation depends on a good match between the requirements of EU policies and existing national policies (Börzel and Risse, 2003). Good agreement is the extent to which compliance with the EU depends on consistency between the directive in question and the two national institutions, namely, the organization of interest groups and the legacy of national policy (Falkner, 2005). On the contrary, implementation will be weak if significant policy changes and reorganization of interest groups are needed. Parliaments that act as guardians of the *status quo* are critical and essential in this relationship (Mastenbroek and Kaeding, 2006).

Haverland questioned the importance of good correspondence between European provisions and national rules and practices in explaining the degree of national adaptation to European requirements. It bases its argument on analyses of the Packaging and Packaging Waste Directive in Germany, the Netherlands, and the United Kingdom (Haverland, 2000). We can conceptualize adaptation processes in response to Europeanization in two ways, resulting in a different emphasis on supporting factors. They point to two variants of the new institutionalism. It follows from the logic of rational institutionalism that Europeanism leads to domestic changes through the different empowerment of actors resulting from the redistribution of resources at the domestic level (Borzel, 2000). Implementation can be defined as the process of transposing and applying EU policies at the domestic level through national authorities (Melidis and Russel, 2020). Transposition means introducing supranational rules into national legal orders by adopting new laws, ratifications, or administrative measures (Domaradzki, 2019).

Environmental performance is often measured using methods that determine the environmental efficiency. Many research studies address this issue at the supranational level (Giannakitsidou et al., 2020; Matsumoto et al., 2020; Ríos and Picazo-Tadeo, 2021) as well as at the national or local level (Wolsink, 2010; Di Maria et al., 2020) and also combined (Sanz-Díaz et al., 2017). A large number of studies also deal with the European Union, and many of them indicate significant differences in the environmental efficiency of Central and Eastern European countries, which they believe is also caused by an insufficient level of efficiency of technological processes and related investments in innovation (Vlontzos et al., 2014). When looking at the research methodology, it is essential to note that the benchmark for less efficient countries is highly developed countries with a relatively high environmental awareness. This fact is, to some extent, limiting the perception of differences directly in the group of less developed countries. Suppose we want to achieve convergence of these countries. In that case, it is essential to realize the common characteristics of these countries but also differences that arise from geographical, political, and socio-economic realities (Adam and Tsarsitalidou, 2019), as was done, for example, for countries that joined the EU among the first authors of other studies (Kwon et al., 2017). Concerning environmental performance, in many cases, the question of the effects of circular economy tools also arises, where resource productivity, recycling rate, and use of renewable resources seem to be vital in improving the state of the environment even under EU conditions (Busu, 2019; Halkos and Petrou, 2019). Despite the efforts of EU authorities, there is still significant room for improvement in these policies and processes (Calisto Friant et al., 2021). In this contribution, we will examine common

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TABLE 1 Description of variables.

	Variable name	Variable symbol	Units	Source
Input	Total Environmental Taxes	Taxes	mil. €	Eurostat
	Total Employment	Empl	Thousand persons	Eurostat
Output	CO_2 emissions (undesirable)	CO_2	Thousand tonnes	Eurostat
	Gross domestic product	GDP	mil. € (market prices)	Eurostat

Source: Own processing.

patterns and the possible impact of the circular economy on the environmental performance of selected countries.

The objective of this study is to evaluate the development of the environmental performance of EU countries that joined the EU structures after 2004 based on identified research gaps. We also want to verify the significance of the circular economy and its impact on changes in the environmental efficiency of selected countries. The research question of this study is, then, what are the differences in environmental efficiency among "late-joiners" when the efficiency frontier shifts lower? Are they increasing their environmental efficiency, or do they stagnate?

3 Research methodology

In this section, we will focus on the methods used to achieve the objective of this study. In some of the studies mentioned in the previous section, the Data Envelopment Analysis (DEA) method was used to evaluate environmental performance or efficiency. It is one of the most commonly used methods for measuring environmental performance, including for the EU, as confirmed by other current studies (Angelakoglou and Gaidajis, 2015; Giannakitsidou et al., 2020; Matsumoto et al., 2020; Musa et al., 2021; Ríos and Picazo-Tadeo, 2021; Dechezleprêtre et al., 2023).

Technical efficiency is commonly measured using linear programming models presented and modified by (Charnes et al., 1985; Färe et al., 1994; Cooper et al., 2007). In this study, we will use CCR (CRS) Equation 1 and BCC (VRS) Equation 2, input-oriented slack-based DEA models. Moreover, we will compute the excess of Emissions as undesirable output.

$$\begin{aligned} &\min_{\theta_B,\lambda} \ \theta_B \\ &\text{s.t.}\ \theta_B X_o - X\lambda \geq 0 \\ &Y\lambda \geq y_o \\ &\lambda \geq 0. \end{aligned} \tag{1}$$

$$\begin{aligned} &\min_{\theta_B,\lambda} \ \theta_B \\ &\text{s.t.}\ \theta_B X_o - X\lambda \geq 0 \\ &Y\lambda \geq y_o \\ &e\lambda = 1 \\ &\lambda \geq 0. \end{aligned} \tag{2}$$

Table 1 describes the input and output variables used in your performance modeling.

We have collected data for our study from the Eurostat database (Eurostat, 2024). There are many studies in which the environmental DEA model was implemented. Inputs are commonly connected to labor, capital, and land (Alsaleh et al., 2017) as the three main production factors. As capital, we decided to use environmental taxes, which we want to be as low as possible and should be used to motivate lower emissions and as capital input for environmental efficiency improvement. Total employment is the input related to labor (Woo et al., 2015; Toma et al., 2017). Because of the data unavailability, we decided to omit the factor land–using it would lead to data inconsistency. The most used inputs are the number of companies in selected industries or services, arable land, and others. Outputs are mostly connected to emissions factors, which are undesirable outputs (Zofío and Prieto, 2001; Wang et al., 2013; Halkos and Petrou, 2019), and Gross domestic product–which is the desirable output of production function (Madaleno et al., 2016; Cheng et al., 2018; Iram et al., 2020).

Because the research focused only on "late joiners" is missing, we decided to measure the environmental efficiency of countries that joined the EU in 2004 or later. These countries often have higher rates of industrial/services production ratio and could be less environmentally efficient. We will assess the environmental efficiency during the period from 2014 to 2022. This could also help us evaluate the effects of the COVID-19 pandemic. We collected data for a total of 13 countries, so we created a panel of 117 observations (Decision-making units–DMU). For the efficiency measurement DEA Window approach will be used (Wang et al., 2013; Farantos and Koutsoukis, 2022).

Table 2 presents descriptive statistics of data collected from the Eurostat database by individual country.

Many indicators of measuring circular economy were proposed (De Pascale et al., 2020), but only a few are accessible from online databases for the countries we have selected. We will use Pearson's correlations to assess the correlation between environmental efficiency and circular economy indicators. The individual indicators of the circular economy were also collected from the Eurostat (2024) database. We will use these indicators:

- Circular material use rate–percentage
- Resource productivity–PPS per kilogram
- Material footprint–tonnes *per capita*
- Consumption footprint–single weighted score per inhabitant.

Using data from freely available databases provides a reliable proxy for conducting research in this study. Moreover, data availability makes it possible to continue and replicate similar research for the broader scientific community. Our sample of countries is representative as it includes all countries that joined the EU after 2004, and this is not the only common feature. They are also geographically, historically, and economically close, albeit with specific existing differences.

TABLE 2 Descriptive statistics of inputs and outputs of the DEA models.

Country	Var.	Mean	Std Dev	Variance	Minimum	Maximum
Bulgaria	CO_2	−42942.91	3,601.34	12,969,682.85	−47102.04	−35190.45
	Taxes	1,859.46	876.7357842	768,665.64	1,220.69	4,095.16
	Emp	3,475.68	39.3497569	1,548.40	3,434.17	3,533.58
	GDP	58,475.06	13,504.83	182,380,494	43,024.70	85,800.70
Croatia	CO_2	−12745.43	605.5019825	366,632.65	−13684.70	−11634.19
	Taxes	2,125.56	204.0721001	41,645.42	1,746.44	2,366.11
	Empl	1,648.49	50.5764911	2,557.98	1,574.99	1,724.44
	GDP	52,514.18	7,442.69	55,393,658.83	44,084.20	67,989.50
Cyprus	CO_2	−5,549.98	205.4617165	42,214.52	−5,868.11	−5,246.70
	Taxes	569.1777778	34.2762592	1,174.86	519.5000000	613.1000000
	Emp	418.2722222	37.1123705	1,377.33	364.9400000	465.6700000
	GDP	21,599.71	3,365.69	11,327,873.96	17,482.80	27,777.00
Czechia	CO_2	−81305.24	5,127.50	26,291,265.70	−86095.35	−71644.95
	Taxes	3,974.63	405.5883208	164,501.89	3,346.96	4,594.86
	Empl	5,284.64	99.4407725	9,888.47	5,094.54	5,385.11
	GDP	207,317.28	37,203.83	1,384,125,281	157,821.30	276,265.70
Estonia	CO_2	−14801.47	4,359.94	19,009,110.51	−19999.35	−8,471.43
	Taxes	692.4177778	114.4824374	13,106.23	533.0700000	889.5500000
	Emp	657.0966667	16.3924243	268.7115750	627.7000000	684.0600000
	GDP	26,083.82	5,241.10	27,469,097.39	20,048.20	36,011.10
Hungary	CO_2	−37274.85	1773.78	3,146,297.14	−39850.66	−34965.58
	Taxes	3,028.24	239.2414140	57,236.45	2,557.84	3,366.50
	Empl	4,530.28	157.2281836	24,720.70	4,222.60	4,695.55
	GDP	133,932.78	20,471.56	419,084,656	106,263.80	168,549.50
Latvia	CO_2	−6,970.80	590.5730800	348,776.56	−7,796.19	−6,130.20
	Taxes	898.0866667	54.7108410	2,993.28	790.2500000	982.7300000
	Emp	898.5944444	12.8294789	164.5955278	876.0100000	916.9500000
	GDP	29,124.97	4,694.68	22,040,020.05	23,625.80	38,386.20
Lithuania	CO_2	−13,643.16	1,324.26	1,753,653.95	−16,153.50	−12,026.75
	Taxes	859.2600000	146.1531994	21,360.76	633.8800000	1,038.90
	Empl	1,366.29	31.5239675	993.7605278	1,319.30	1,431.91
	GDP	47,039.49	10,072.31	101,451,392	36,581.30	67,436.50
Malta	CO_2	−1,585.80	310.8777242	96,644.96	−2,364.76	−1,316.12
	Taxes	290.5255556	30.9856019	960.1075278	240.6500000	347.8200000
	Emp	236.0655556	31.7967310	1,011.03	192.1200000	282.7600000
	GDP	12,741.48	2,749.97	7,562,350.41	8,751.10	17,432.30
Poland	CO_2	−2,86,269.68	12,534.83	157,121,961	−3,01982.35	−270055.39
	Taxes	13,477.17	2,515.22	6,326,334.24	10,562.10	18,321.85
	Emp	16,456.00	433.0473415	187,530.00	15,862.00	17,369.00
	GDP	501,709.78	80,596.79	6,495,842,116	406,412.50	654,594.40
Romania	CO_2	−62241.81	4,014.71	16,117,894.90	−66239.88	−54472.46
	Taxes	4,577.71	1,278.17	1,633,718.10	3,587.37	7,674.61
	Empl	8,731.06	85.3175417	7,279.08	8,579.20	8,828.50
	GDP	204,580.61	43,208.41	1,866,966,269	150,522.40	284,173.60
Slovakia	CO_2	−28148.23	1975.47	3,902,487.69	−30294.99	−24972.69
	Taxes	2,230.08	241.5082336	58,326.23	1932.31	2,707.77
	Emp	2,502.18	69.7195342	4,860.81	2,363.05	2,583.64
	GDP	90,007.22	10,671.31	113,876,851	76,354.50	109,645.20
Slovenia	CO_2	−10231.49	453.1709080	205,363.87	−10866.94	−9,517.17
	Taxes	1,585.81	97.1987011	9,447.59	1,452.74	1795.79
	Empl	1,014.15	54.3687509	2,955.96	935.4500000	1,090.67
	GDP	45,640.16	6,410.39	41,093,095.84	37,634.30	57,037.70

Source: own processing according to Eurostat (2024) data.

4 Results and discussion

This section will analyze the findings from the environmental efficiency modeling performed using the DEA method. Table 3 displays the results of the CRS and VRS environmental efficiency models. Given that a detailed table for each country in every year of the study would be too extensive, we provide only the essential descriptive characteristics of the efficiencies obtained.

Estonia, Cyprus, and Malta achieved the best average results in the CRS models. In the VRS models, the results are slightly different,

TABLE 3 Descriptive statistics of the DEA CRS and VRS efficiency results.

Country	CRS				VRS			
	Mean	StDev	Min	Max	Mean	StDev	Min	Max
Bulgaria	0.66	0.15	0.43	0.89	0.70	0.17	0.47	1.00
Czechia	0.83	0.07	0.78	1.00	0.89	0.07	0.79	1.00
Estonia	0.90	0.09	0.76	1.00	0.91	0.09	0.77	1.00
Croatia	0.52	0.05	0.47	0.64	0.58	0.07	0.50	0.73
Cyprus	0.90	0.04	0.86	1.00	0.93	0.03	0.89	1.00
Latvia	0.55	0.08	0.47	0.72	0.57	0.09	0.47	0.77
Lithuania	0.81	0.07	0.75	0.97	0.87	0.07	0.80	1.00
Hungary	0.65	0.06	0.58	0.79	0.66	0.06	0.59	0.79
Malta	0.88	0.06	0.78	1.00	0.98	0.02	0.92	1.00
Poland	0.66	0.03	0.63	0.73	0.99	0.02	0.95	1.00
Romania	0.67	0.07	0.58	0.78	0.68	0.06	0.60	0.78
Slovenia	0.75	0.06	0.67	0.86	0.80	0.08	0.71	0.96
Slovakia	0.65	0.05	0.60	0.74	0.68	0.07	0.61	0.82

Source: own processing.

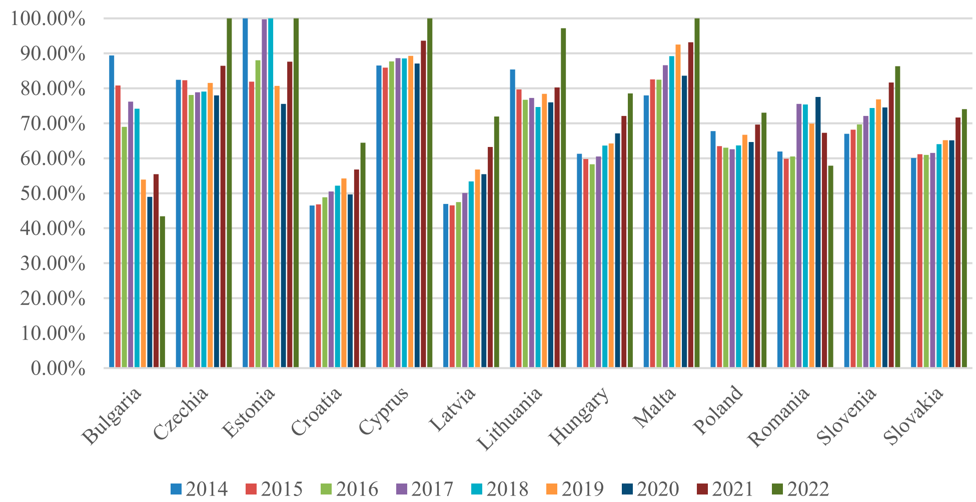

FIGURE 1
Development of the DEA CRS scores in selected EU countries. Source: Own processing.

with Poland and Czechia achieving the highest efficiencies. However, countries that were highly efficient in the CRS models also performed well in the VRS models. Croatia, Latvia, Slovakia, and Hungary are the least efficient in the CRS and VRS models.

Overall, the CRS and VRS models do not show significant differences, indicating that the discrepancies between these two models are minimal. It is also important to note that countries with lower industrial intensity and a greater focus on services achieve better results. This service orientation helps them produce lower emissions at a comparable level of GDP. In other words, countries that focus more on the service sector can reduce emissions more efficiently while maintaining economic growth. Focusing on the service sector helps these countries maintain lower emissions while achieving economic growth. In Figure 1, a comparison of environmental efficiency development is presented.

During the observed period, we recorded improvements in the values of technical environmental efficiency in most countries. When comparing the beginning and end of the observed period, we identified several interesting facts. The most significant decrease was recorded between 2014 and 2022 in the case of Bulgaria. Specifically, the efficiency decreased by 51.43%. A slight reduction in efficiency also occurred in Romania – 6.54%. In all

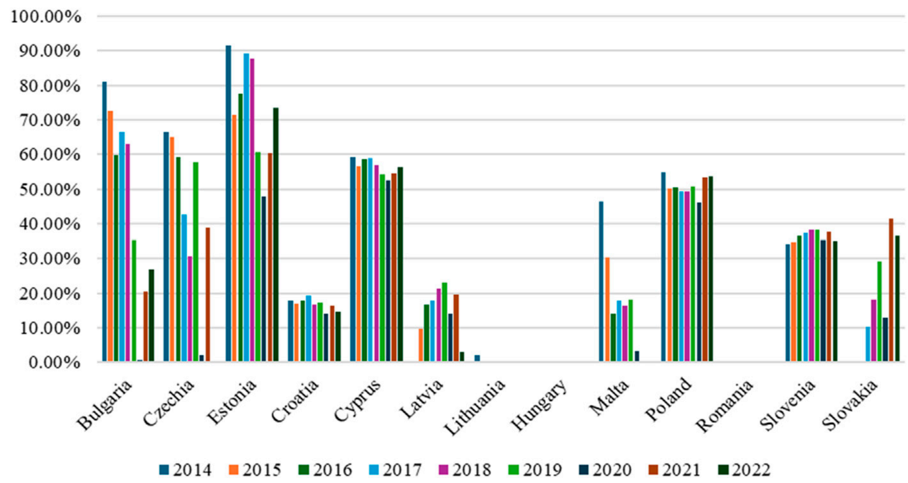

FIGURE 2
The excess CO_2 emissions in selected EU countries (DEA CRS assumption). Source: Own processing.

other countries, there was an increase in efficiency, with Latvia (53.2%), Croatia (38.52%), and Slovenia (28.86%) being among the strongest growing countries. The most efficient countries during the observed years are Malta, Cyprus, Estonia, and the Czech Republic. Malta and Cyprus are countries that are significantly oriented towards services, specifically tourism. We also examined the direct impact of the COVID-19 pandemic on the values of environmental efficiency. In most countries, there was a slight decrease of up to 10%. Romania was the only country with a minimal increase in efficiency values (10.9%). Figure 2 shows the slack values of excessive CO2 production, meaning the percentage needed to reduce CO_2 emissions to achieve efficiency within the observed group of countries.

Within the scope of our results, we recorded a significant need to reduce CO_2 emissions in several countries. The most pronounced surpluses of CO_2 emissions were observed in Estonia, Cyprus, Poland, and other countries, highlighting the urgent need for targeted emission reduction strategies in these regions. These surpluses indicate areas where current environmental policies and practices may not meet the desired efficiency and sustainability targets, necessitating more robust and effective interventions.

Despite these challenges, some countries have demonstrated significant improvement in reducing their CO_2 emission surpluses over the years. For instance, Bulgaria has shown a remarkable reduction, with emission surpluses decreasing from approximately 81% in 2014 to 27% in 2022. This substantial improvement reflects successful policy implementation and a shift towards more sustainable practices. Similarly, Malta has made impressive strides, reducing its CO_2 emission surplus from nearly 46.5% to 0% within the same period. These examples underscore the potential for significant progress when appropriate measures are adopted and effectively executed.

On the other hand, countries such as Lithuania, Hungary, and Romania have maintained low or no CO_2 emission surpluses, positioning them as leaders in environmental efficiency within the post-2004 EU member states. Their success can serve as a benchmark and provide valuable lessons for other countries striving to improve their environmental performance.

The efficiency results for the Variable Returns to Scale (VRS) model, which accounts for scale efficiency and offers a more tailored assessment of each country's performance, are shown in the following Figure 3. This figure illustrates the comparative efficiency scores, highlighting the countries leading in environmental performance and those requiring further improvement. By visualizing these results, stakeholders can better understand the relative efficiency of each country and identify critical areas for policy intervention and resource allocation to promote a more sustainable and circular economy across the European Union.

Similar results as in the case of the Constant Returns to Scale (CRS) model were also recorded in the case of the Variable Returns to Scale (VRS) model. Some countries consistently achieved high-efficiency values under both models, demonstrating solid environmental performance and effective resource management. These countries include Poland, Malta, Cyprus, Estonia, and the Czech Republic. Their consistent high efficiency indicates robust environmental policies and practices that have enabled them to maintain low CO_2 emissions relative to their economic output.

In contrast, some other countries showed an increasing trend in efficiency, reflecting gradual improvements in their environmental performance. Notable among these are Bulgaria and, to some extent, Romania. In Bulgaria, significant efforts have led to substantial gains in efficiency, showcasing the impact of targeted environmental policies and initiatives. Although showing less dramatic improvements, Romania also indicates positive trends toward better environmental management.

Figure 4 illustrates the necessary percentage reductions in CO_2 for each country. This figure provides a clear visual representation of the CO_2 reduction targets required to achieve optimal efficiency. It highlights the percentage reductions each country needs to align with best practices and reduce its environmental impact. By identifying these targets, the figure is a crucial tool for

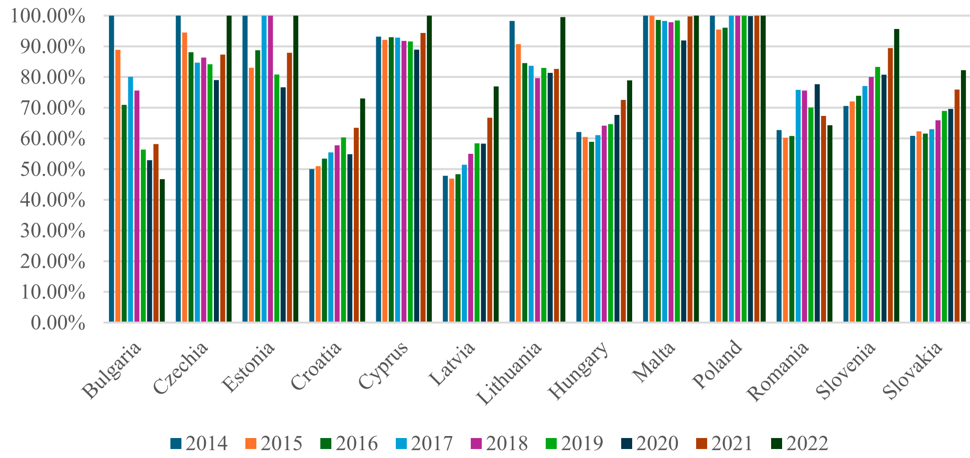

FIGURE 3
Development of the DEA VRS scores in selected EU countries. Source: Own processing

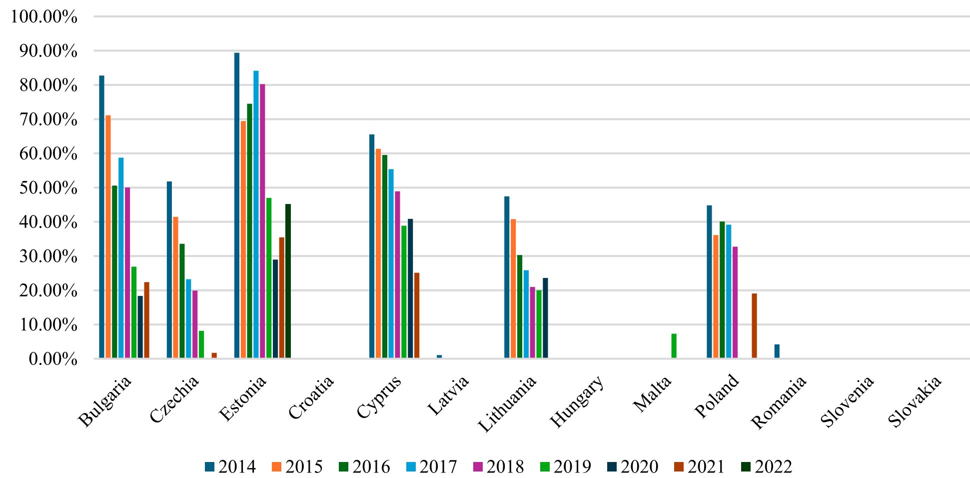

FIGURE 4
The excess CO_2 emissions in selected EU countries (DEA CRS assumption). Source: own processing

policymakers and ecological planners, enabling them to prioritize actions and allocate resources effectively to achieve sustainability goals.

The surpluses of CO_2 emissions in the Variable Returns to Scale (VRS) model are significantly lower than those in the Constant Returns to Scale (CRS) model. This indicates that the VRS model, which accounts for scale efficiency, reflects more realistic and achievable CO_2 reduction targets for the evaluated countries. The VRS model's ability to provide a more nuanced understanding of efficiency variations due to scale is crucial in policy formulation and resource allocation for environmental management.

Estonia, Lithuania, Poland, and Bulgaria recorded more pronounced surpluses of CO_2 emissions. These countries have exhibited higher levels of inefficiency in CO_2 emissions relative to their peers, indicating a need for targeted interventions and policies to address these surpluses. Despite these high surpluses, an essential finding of our study is that the CO_2 emission surpluses had a decreasing trend over the observed period. Despite room for improvement, these countries are on a positive trajectory toward better environmental performance and more efficient resource utilization.

Table 4 presents the correlation matrix between the individual input and output variables of the Data Envelopment Analysis (DEA) model and the circular economy indicators. This correlation matrix is pivotal as it provides insights into the relationships between resource inputs, economic outputs, and environmental outcomes. Understanding these correlations helps identify key leverage points for enhancing circular economy practices and improving overall environmental efficiency. The matrix elucidates how inputs (such as energy consumption and material usage) and outputs (such as GDP and waste generation) interact with circular economy indicators like recycling rates, waste reduction, and resource productivity. This

TABLE 4 Correlation matrix of individual variables, including circular economy indicators.

	CO_2	Taxes	Empl	GDP	Circ MatUse	Res Prod	Mat Footpr	Cons Footpr	CRS	VRS
CO_2	1.00	0.96	0.95	0.95	0.19	−0.24	0.03	−0.30	−0.14	0.31
		<.0001	0.00	0.00	0.04	0.01	0.72	0.00	0.14	0.00
Taxes	0.96	1.00	0.95	0.98	0.13	−0.19	0.04	−0.34	−0.23	0.20
	0.00		0.00	0.00	0.15	0.04	0.64	0.00	0.01	0.03
Empl	0.95	0.95	1.00	0.96	0.04	−0.33	0.10	−0.47	−0.22	0.17
	0.00	0.00		0.00	0.70	0.00	0.28	0.00	0.02	0.07
GDP	0.95	0.98	0.96	1.00	0.14	−0.19	0.07	−0.36	−0.15	0.24
	0.00	0.00	0.00		0.14	0.04	0.46	0.00	0.11	0.01
Circ MatUse	0.19	0.13	0.04	0.14	1.00	0.27	−0.07	0.29	0.31	0.37
	0.04	0.15	0.70	0.14		0.00	0.47	0.00	0.00	0.00
Res Prod	−0.24	−0.19	−0.33	−0.19	0.27	1.00	−0.70	0.49	0.15	0.15
	0.01	0.04	0.00	0.04	0.00		0.00	0.00	0.12	0.12
Mat Footpr	0.03	0.04	0.10	0.07	−0.07	−0.70	1.00	0.03	0.29	0.16
	0.72	0.64	0.28	0.46	0.47	0.00		0.79	0.00	0.09
Cons Footpr	−0.30	−0.34	−0.47	−0.36	0.29	0.49	0.03	1.00	0.57	0.51
	0.00	0.00	0.00	0.00	0.00	0.00	0.79		0.00	0.00
CRS	−0.14	−0.23	−0.22	−0.15	0.31	0.15	0.29	0.57	1.00	0.85
	0.14	0.01	0.02	0.11	0.00	0.12	0.00	0.00		0.00
VRS	0.31	0.20	0.17	0.24	0.37	0.15	0.16	0.51	0.85	1.00
	0.00	0.03	0.07	0.01	0.00	0.12	0.09	0.00	0.00	

Source: own processing.

comprehensive analysis aids policymakers and stakeholders in making informed decisions to foster sustainable development in the post-2004 EU member states.

The first row of the correlation pair shows the value of the Pearson correlation coefficient, while the second row displays its *p*-value at the 0.05 significance level. Generally, it can be stated that the use of circular economy materials and increasing resource productivity (statistically insignificant) correlates with higher values of environmental efficiency. An unexpected result is the positive correlation between Material (statistically insignificant in the case of the VRS model) and Consumption footprint. Given the research sample, we must point out that these correlation pairs do not indicate causality but only suggest possible situations that may play a specific role in shaping national and supranational EU policies. The unexpected existence of a positive correlation between environmental efficiency and the variables of Material Footprint and Consumption Footprint also indicates the specificity of these countries. One possible reason for this positive correlation could be that these countries are still dependent on heavy industry (automotive industry, engineering industry, raw materials processing), but increasing energy efficiency and reducing greenhouse gas emissions significantly contribute to improving the situation in the field of the circular economy despite still high carbon footprint indicators.

5 Conclusion

In this section, we focus on evaluating the results of our study. Generally, we must highlight the importance and uniqueness of the chosen research object, where we compare countries with similar geopolitical and economic development. This is particularly important from the perspective of understanding benchmarking methods. In many cases (Vlontzos et al., 2014; Halkos and Petrou, 2019; Matsumoto et al., 2020), if these countries are also compared with Western EU countries, they are significantly undervalued, and the differences within this more minor (and still lagging) group of countries are not sufficiently highlighted. Using this research object, the benchmark becomes precisely the countries from this group.

The results of the DEA CRS and VRS models pointed out the differences within this group of countries. They indicate that countries that are significantly oriented towards services—in our case, tourism-are more environmentally efficient. However, it should be emphasized that tourism is also a significant producer of greenhouse gas emissions, but in many cases, such as aviation emissions, are not included in the indicators. Most of the countries studied are still significantly oriented towards industry. This was also reflected in the results of DEA modeling. Countries such as Bulgaria, Romania, and Croatia are among the most inefficient. It should be noted that they joined the EU later than the other states in our sample. This reflects that even though they are significant countries in the field of tourism, their economy still has to be driven by industrial sectors and the extraction of mineral resources.

Another important finding is the level of emission surpluses that countries produce when converting equilibrium factors into their country's GDP. We found that most countries still need to significantly reduce environmental pollution from greenhouse gas emissions. This can be challenging to some extent, as industrial technologies pollute the environment the most and require significant expenditure on innovation. However, these are pretty extensively supported by the EU. The third important finding is the positive correlation between resource productivity and the use rate of circular materials, which indicates that using circular economy tools significantly improves the environment in these countries. A surprising finding is that the material and consumption footprint indicators positively correlate. This suggests that even though countries have a significantly higher material and consumption footprint, they still bring a relatively high product and relatively low CO_2 emissions at a given rate of inputs.

This study also has its limitations, which stem from the timing of the countries' entry into the EU, as the year of entry varies for some countries. This can delay the effects of the EU's convergence goals and policies on countries that joined the EU later. Another limitation is that some indicators in the field of the circular economy are inconsistent and, therefore, had to be excluded from the study's database, which, to some extent, impacted the examination of other specific processes and relationships.

Despite not being part of the main agenda when the EU was founded, environmental policy has become a key focus area. Based on the development of environmental policy, we can state that the EU has created extensive legislation for environmental protection. In the presented work, we focused on comparing the results in this area among the member countries that joined the EU at the same time in 2004. This study reflects significant differences in this development.

This area of research is widely discussed in the scientific sphere, which only stimulates the possibilities for future research directions. Since the environmental aspect is dominant in EU policies, it is possible to expect broader databases that can expand the possibilities of examining and linking environmental efficiency with other economic, social, and political determinants.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

RL: Conceptualization, Formal Analysis, Supervision, Visualization, Writing–original draft, Writing–review and editing. ZH: Investigation, Methodology, Project administration, Resources, Writing–original draft. RD: Data curation, Funding acquisition, Software, Validation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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