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RESEARCH ARTICLE

Socioeconomic determinants of environmental efficiency: the case of the European Union

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Abstract
The study's main objective is to assess and evaluate the models of socioeconomic determinants of environmental efficiency in the European Union countries from 2010 to 2018. The two-step data envelopment analysis is implemented, using both constant and variable returns to scale assumption. Moreover, the results of the model of environmental efficiency determinants from four areas—tourism, circular economy, energy and resources use and quality of life—are presented. Based on our findings, it can be concluded that it is necessary to develop the concept of sustainable tourism because the enormous increase in foreign tourists harms environmental efficiency. It is also necessary to gradually transform economies into less energy-intensive towards knowledge-based economies. The positive impact of measures related to the pain of the circular economy was also demonstrated. In conclusion, we present several recommendations for EU policies concerning the current economic and energy situation.

Keywords Tourism · Quality of life · Efficiency · Data envelopment analysis · European Union · Bootstrap

Introduction

Environmental efficiency is currently one of the most considered topics. Therefore, governments are directing their recovery policies towards improving the economy and quality of life, the circular economy, energy intensity and efficiency. According to Reinhard et al. (2000), the ratio of minimum feasible to observed use of environmentally detrimental inputs, which are conditional on levels of the desirable outputs and conventional inputs, is the most appropriate definition of environmental efficiency.

The current development of knowledge and the political situation indicates serious shortcomings in slowing climate change and reducing greenhouse gas emissions. Therefore, improving environmental efficiency is a critical aspect of evaluating the effectiveness of environmental policies. However, this is not enough if the determinants of this efficiency are not evaluated. There are many reasons for the deterioration of the environment and the constant increase in greenhouse gases. Some are probably natural processes, but most are anthropogenic, so it is appropriate to investigate how and why humans worsen the state of the environment (Ji et al. 2018). In addition, it can be noted that the differences in the environmental significance between high-income and low-income countries are deepening (Li and Wang 2014; Woo et al. 2015). These differences can also be found within the countries of critical political groupings, such as the European Union (EU) (Duman and Kasman 2018; Lacko and Hajduová 2018; Halkos and Petrou 2019; Tenente et al. 2020). More developed regions are also more efficient to a greater extent (Borozan 2018). In doing so, we must emphasise that EU policies are based on convergence goals (Arbolino et al. 2018), and the EU Green Deal is proof of this. One of the solutions is the increase taxes related to behaviour, but this affects the competitiveness of subjects

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to the extent of the environment (Moutinho et al. 2017). One of the possibilities for increasing the environment's efficiency is eco-innovation and improving the awareness of citizens (Cai and Li 2018; Vaninsky 2018; Liu et al. 2018b; Halkos and Petrou 2019). Research also contributes to human capital and innovation's positive potential in improving performance (Borozan 2018). That is why research should be oriented not only on economic determinants but also on the state of the society in the given countries.

A significant source of greenhouse gas emissions is travel and tourism transport, as noted by several studies (Sun 2016; Peng et al. 2017; Liu et al. 2018a; Zha et al. 2020). In addition, increasing greenhouse gas emissions may lead to climate change, impacting tourism performance and unique destinations (Day et al. 2013). According to the current literature, there is still a lot of space for increasing eco-efficiency in tourism (Zha et al. 2020). In addition, the environment is damaged by tourism, mainly in developed countries, where there are a large number of tourist arrivals (Usman et al. 2021). On the other hand, tourism economic development can in the short term lead to the improvement of ecological efficiency, while the relationship of inverted *U* shape has been proven (Balsalobre-Lorente et al. 2020; Haibo et al. 2020). One of the possibilities for improving the state of the environment affected by tourism is the adoption of measures and tools for sustainable tourism (Jiang et al. 2022). Sustainable growth can ultimately contribute to increasing the number of tourists and improving the state of the environment at the same time (Azam et al. 2018; Sellers-Rubio and Casado-Díaz 2018). One of the possibilities is also increasing the energy efficiency of buildings—tourism facilities (Hossain and Ng 2018). Investments in tourism, the structure of industry, urbanisation and also environmental regulation help to improve the eco-efficiency of tourism (Song 2019; Guo et al. 2022).

Unsustainable economic growth is one of the reasons why pollution occurs (Neves et al. 2020). Another option for solving the problems of environmental efficiency is the orientation towards the circular economy (De Pascale et al. 2020; Mhatre et al. 2021). In recent years, environmental awareness and tools of the circular economy have also been widespread in the scientific field (Hossain and Ng 2018; Aguilar-Hernandez et al. 2021). There are still large differences between the countries of the world in the efficiency of the use of resources and tools of the circular economy (Mavi and Mavi 2019). Countries that use intensive tools of the circular economy are more efficient when dealing with municipal solid waste, which is still a big problem in many countries of the world but also in the EU (Halkos and Petrou 2019). In addition, reducing waste also helps to reduce energy consumption (Wu et al. 2019). It is also important to examine the share of renewable resources that are inputs for economic growth (Liu et al. 2019). The rate of use of renewable resources has a positive effect on improving environmental efficiency (Neves et al. 2020). Increasing the output of economies following the idea of a circular economy is one of the possibilities for improving the state of the living environment, but it turns out that reducing the generation of waste and reducing emissions are not the only way (Robaina et al. 2020). In addition, closed-loop principles help to increase efficiency (Camilleri 2018).

However, other indicators express the level of quality of life in the countries of the world. Such indicators can include indicators related to education, the level of health concern, the degree of urbanisation and many others (Ma et al. 2021). Furthermore, there are many indicators of the use of energy resources, while the relationship between the efficient use of resources and the reduction of emissions is proven (Iram et al. 2020). Only a few studies comprehensively connect selected industries as the main causes of increasing emissions and growth in the level of pollution in the countries of the world, and there are even fewer of these studies in the area of EU countries, while precisely, such a comprehensive perception of the problem can also help to improve the state of the environment (Abbasi et al. 2021).

The inclusion of some indicators, such as the use of renewable resources and energy use (Li and Wang 2014), directly in the models for measuring efficiency may not provide an answer to what effect these indicators have when using different technologies in different countries (Lacko and Hajduová 2018).

All of the above-mentioned areas have a demonstrable impact on environmental efficiency, but they are comprehensively used relatively little extensively in the evaluation of efficiency. Therefore, it is necessary to research how the selected indicators affect the change in environmental efficiency in a complex way. However, a study that includes the factors mentioned above is absent; therefore, we identified the need for such a study to expand scientific research. Furthermore, we identified some research gaps in environmental efficiency. Thus, the primary goal of the study is to assess and evaluate socioeconomic determinants from the fields of tourism, quality of life, circular economy and energy consumption in the environmental efficiency in the European Union countries.

Material and methods

Efficiency measurement

Based on the literature review, we found that the most used method for evaluating environmental efficiency is the data envelopment analysis (DEA) (Mardani et al. 2017). Farrell (1957) laid its theoretical foundations and developed them in many other studies. Charnes et al. (1984) and Cooper et al. (2007) have contributed to significant theoretical development. We will use input-oriented models assuming constant returns to scale (CRS) and variable returns to scale (VRS). For the decision-making unit (DMU) to be efficient, it must achieve efficiency equal to 1 (Charnes et al. 1984, 1994; Cooper et al. 2007).

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

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

where the θ_B values of efficiency, $X = (x_j) \in R^{m\times n}$ and $Y = (y_j) \in R^{s\times n}$, are the matrix of inputs and outputs; e is a vector whose elements are equal to 1, $\lambda \in R^n$—non-negative vector; and x_o and y_o are the vectors of the inputs and outputs. For completeness, m is the number of inputs, s is the number of outputs, and n is the number of DMUs.

Input efficiency values are within the range $<0;1>$, and an entity that has reached 1 is efficient. We will also use the two-step DEA method in this work to help us achieve the study's goal. This method is often used in other studies (Afonso and Aubyn 2011; Liu et al. 2013; Tajudeen et al. 2018; Lacko and Hajduová 2018).

Research object

In this study, we will research the environmental efficiency in the countries of the European Union. We will therefore examine 27 countries (without Great Britain). Based on the availability of data and also the fact that we want to measure efficiency in the so-called 'inter-crisis' period (between the economic crisis of 2008 and 2009 and the crisis caused by the global pandemic), we decided to monitor the years 2010 to 2018, i.e. 9 years. Therefore, we created a data panel with 243 observations (DMU). Data for the needs of our work were collected from Eurostat (Eurostat 2022) and World Bank databases (The World Bank 2021).

Data

The variables have been chosen based on previous studies that have addressed the measurement of efficiency in these areas. The rationale for selecting variables will be given in Table 1. Table 1 presents the input and output variables of the environmental efficiency model.

As inputs, DEA models measure the environmental efficiency use variables related to primary production factors—labour, land and capital. The number of people employed in the country is a variable which is linked to a labour factor and shows how the country's labour capacity is relatively often used in various researches (Woo et al. 2015; Madaleno et al. 2016; Toma et al. 2017; Zeng et al. 2018; Busu and Trica 2019). Another input representing the capital area is the gross fixed capital formation. Capital is the primary driver of progress and development in many areas; this variable is used in many studies (Dinda 2005; Moutinho et al. 2015; Alsaleh et al. 2017; Halkos and Petrou 2019). The last input variable is the arable land area, which indicates the soil's production factor. Authors use different categories of land, and we decided not to use the area of the whole country, as it also includes areas that cannot be used industrially or agriculturally, such as forests (which in turn improve the status of the environment) or protected areas (Vlontzos et al. 2014; Toma et al. 2017).

We included two variables in the outputs. The first variable is gross domestic product, which measures the performance and output of a given economy. The second variable is CO_2 emissions, but it is an undesirable output. In the calculation process, it will be used as a negative input. These output variables are the most commonly used in environmental efficiency assessment (Vaninsky 2009; Kwon et al. 2017; Iftikhar et al. 2018).

Subsequently, regressions can be performed where dependent variables are efficiency values after a double bootstrap (Simar and Wilson 2007). Based on the study of literature as well as current trends in policies aimed at improving the state of the environment, quality of life and socioeconomic factors, we decided to build model (3), which has the following form:

$$\widehat{\widehat{\delta_{EE}}} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} \varepsilon_i \tag{3}$$

where $\widehat{\widehat{\delta_{EE}}}$ are CRS and VRS environmental efficiency values calculated using a second algorithm developed by Simar and

Table 1 Variables used in the environmental model of efficiency

DEA model of environmental efficiency		
	The name	Units
Inputs	Number of employed persons	Thousand people
	Gross fixed capital formation	m. EUR
	Arable land	Thousand hectares
Outputs	Greenhouse gas emissions	Thousand tons
	Gross domestic product (current prices)	m. EUR

Wilson (2007). The individual variables of the model are described in Table 2.

In Table 2, we describe the selected characteristics of the explanatory variables, which will be modelled using truncated regression.

As seen in Table 2, we have chosen these variables from 4 categories which have impact on environmental efficiency, which we would like to verify in the next chapter. Based on the "Introduction" section and literature review, we have found that the tourism sector, circular economy management, energy use and quality of life indicators are commonly used in the present literature as determinants of environmental and eco-efficiency. These four categories are currently the objectives of many of the policies of the European Union and the world. Moreover, many of these areas are in the future recovery plans following the devastating consequences of the coronavirus pandemic.

- Tourism—we have chosen the country's openness to tourism as an explanatory variable in this area. This is expressed as a proportion of the expenditure of all tourists leaving but also coming to GDP. The higher this ratio, the greater the country's openness to tourism. The numbers of domestic and foreign tourist arrivals were selected as explanatory variables two and three. We expect that the higher the number of tourists, the higher the inefficiency. This will happen in countries with low levels of sustainable tourism.
- Energy and agriculture—there are five indicators in this category, which point to using energy and other resources and using fertilisers in the country. These indicators are essential in terms of the environment, as countries with higher productivity, lower energy consumption, a higher share of renewable energy and less fertiliser use could tend to be more efficient.
- Quality of life—this is a very up-to-date area that directly impacts the population, and based on a verification of the impact of the selected variables, the effects of selected attributes of the population on the environment can be verified. So, for example, in countries where life expectancy is higher, at-risk-of-poverty rates are lower and the share of the population with tertiary education is higher, they could be higher in terms of efficiency. These are the areas of healthcare, education and economic levels.
- Circular economy—this area includes variables related to waste management and its further use in economic processes. Recycling and use rates vary considerably across the EU; therefore, we want to verify the impact these differences can have on individual efficiency values.

We have chosen these variables, which descriptive statistics are presented in Table 3, primarily based on data availability and current trends in EU policies. Since this is a unique research, their validation will be more experimental, and these models may or may not have high explanatory power. Some of these variables are also used directly in DEA models, but (Martín et al. 2017; Nurmatov et al. 2021) when used in DEA models, quantification of their impact is difficult.

Table 2 Description of explanatory variables

Area	Variable	Symbol	Description	Units
Tourism	Tourism openness	X_1	Expenditures of inbound and outbound tourists	%
	Arrivals of foreign tourists	X_2	Arrivals of non-residents at tourist accommodation establishments	m. persons
	Arrivals of domestic tourists	X_3	Arrivals of residents at tourist accommodation establishments	m. persons
Energy measures	Renewable energy share	X_4	Share of renewable energy to total energy consumption	%
	Source productivity	X_5	Share of GDP and material consumption of households	PPS/kg
	Energy consumption in industry	X_6	Energy consumption of companies according to NACE—industry	Ton/capita
	Energy consumption in services	X_7	Energy consumption of companies according to NACE—services	Ton/capita
	Use of an organic fertilisers	X_8	Consumption of nitrogen fertilisers	Ton/capita
Quality of life	Life expectancy	X_9	The expected average length of life	Years number
	Risk of poverty and social exclusion	X_{10}	Share of citizens at risk of poverty and exclusion	%
	Tertiary educated citizens	X_{11}	Share of citizens with tertiary education (ISCED 5–8)	%
Circular economy	Municipal solid waste recyclation	X_{12}	The volume of recycled MSW	Thousand tons
	Use of circular materials	X_{13}	Share of materials returned to the economy for further use	%

Table 3 Descriptive statistics of explanatory variables

Variable	Mean	Median	Standard deviation	Sample variance	Kurtosis	Skewness	Range	Minimum	Maximum
*X*1	7.89	6.00	4.52	20.40	0.78	1.29	19.40	2.10	21.50
*X*2	11.79	4.39	15.87	251.96	2.34	1.85	64.98	0.79	65.77
*X*3	18.47	6.98	31.50	992.37	4.81	2.39	140.45	0.05	140.49
*X*4	19.28	15.90	11.49	132.04	0.48	0.89	53.67	0.98	54.65
*X*5	1.77	1.59	0.77	0.59	0.21	0.82	3.57	0.62	4.19
*X*6	0.57	0.43	0.38	0.14	4.21	1.95	1.92	0.10	2.02
*X*7	0.30	0.28	0.13	0.02	3.06	1.42	0.74	0.09	0.83
*X*8	0.02	0.02	0.02	0.00	2.24	1.34	0.08	0.00	0.08
*X*9	79.59	80.90	2.88	8.28	−0.93	−0.69	10.40	73.10	83.50
*X*10	24.36	23.00	7.52	56.53	0.74	1.00	37.10	12.20	49.30
*X*11	26.14	26.90	7.20	51.82	−1.07	−0.07	28.60	11.90	40.50
*X*12	33.38	32.50	15.73	247.37	−0.94	0.15	63.20	4.00	67.20
*X*13	8.42	6.90	6.27	39.26	1.29	1.25	28.50	1.20	29.70

Results

Environmental efficiency in EU countries

In this section, we will interpret environmental efficiency modelling results using the DEA method. First, we compute the individual efficiencies using the DEA window approach. In the second step, we bias-correct efficiency values computed in the first step and use them as dependent variables, as proposed in the methodology section. Table 4 presents the results of the CRS and VRS environmental efficiency models. As the scoreboard for each country in each year of examination would be extensive, only the essential descriptive characteristics of the resulting efficiencies are given.

The best average results were for the CRS models of Greece, Luxembourg and Malta. The results for VRS models are slightly different; Denmark, Germany and the Netherlands achieve the highest efficiency, but countries that have been relatively highly efficient for CRS models are performing well for VRS models. For CRS models, Romania, Czechia and Latvia are the least effective. Romania, Hungary and Latvia are the least efficient VRS models. In general, the CRS and VRS models do not show too much variation. It should also be noted that countries that are less industry-oriented and more service-oriented perform better, helping them to produce lower emissions at comparable levels of GDP. Individual values were bias-corrected and used as dependent variables in the next step.

Determinants of the environmental efficiency

In this section, we will discuss the results of environmental efficiency modelling. Table 5 presents the results of correlations for the explanatory variables of the models.

Based on the correlation results, some correlations can be considered high. For example, there is a high correlation between the arrival of foreign tourists and the arrival of domestic tourists. However, this is expected, and using a variable that captures the summary value of arrivals would not give us a detailed view of the issue. It is also the case with variables relating to energy consumption in industry and services. Table 6 presents the results of the environmental efficiency modelling.

From tourism-related variables, in both models, arrivals of foreign tourists harm the environmental efficiency. This may be caused by tourism transport, as foreign tourists use more air transport and other pollution-extensive types of transport. On the contrary, domestic tourists even increase environmental efficiency in the case of the VRS model. For the CRS model, this variable is not statistically significant. In the case of the CRS model, tourism openness is not statistically significant, and in the VRS model, it has a negative impact.

It is interesting from industrial indicators that there is lower environmental efficiency in countries with a higher share of renewable sources. It may be linked to the fact that even the use of these sources of energy generates various by-products. On the contrary, resource productivity has a positive impact on environmental efficiency. Research has confirmed the expected and that industrial energy consumption has a negative impact on environmental efficiency and vice versa. On the other hand, energy consumption in services is affected positively by environmental efficiency.

Concerning the quality of life indicators, there is also higher efficiency in countries with higher population life expectancy. An interesting fact, however, is that countries with higher poverty rates also have higher environmental efficiency. This may, of course, be due to a lower degree of

Table 4 Summary statistics of environmental efficiency measurement

RTS	CRS				VRS			
Country	Average	Mr Stdev	MIN	MAX	Average	Mr Stdev	MIN	MAX
Belgium	0.7143	0.0114	0.6967	0.7352	0.9005	0.0402	0.8611	1.0000
Bulgaria	0.7642	0.1297	0.6132	1.0000	0.8295	0.1040	0.7080	1.0000
Czechia	0.5023	0.0171	0.4758	0.5318	0.5273	0.0233	0.4970	0.5656
Denmark	0.7981	0.0385	0.7320	0.8437	0.9922	0.0058	0.9814	1.0000
Germany	0.7546	0.0093	0.7384	0.7645	0.9965	0.0084	0.9729	1.0000
Estonia	0.5896	0.1606	0.4671	1.0000	0.7720	0.1547	0.5887	1.0000
Ireland	0.7819	0.1047	0.6188	0.9524	0.9652	0.0442	0.8689	1.0000
Greece	0.9578	0.0667	0.7926	1.0000	0.9640	0.0551	0.8282	1.0000
Spain	0.7346	0.0378	0.6505	0.7766	0.8761	0.0534	0.7663	0.9489
France	0.6918	0.0110	0.6799	0.7118	0.9611	0.0292	0.9153	1.0000
Croatia	0.5604	0.0149	0.5271	0.5797	0.5795	0.0150	0.5425	0.5977
Italy	0.8357	0.0438	0.7539	0.8813	0.9826	0.0289	0.9194	1.0000
Cyprus	0.8454	0.1264	0.6725	1.0000	0.8527	0.1198	0.6843	1.0000
Latvia	0.5224	0.0366	0.4614	0.5678	0.5768	0.0493	0.5002	0.6735
Lithuania	0.5855	0.0264	0.5566	0.6398	0.6293	0.0418	0.5856	0.7138
Luxembourg	0.9864	0.0148	0.9549	1.0000	0.9940	0.0084	0.9732	1.0000
Hungary	0.5268	0.0235	0.4948	0.5618	0.5328	0.0253	0.5015	0.5712
Malta	0.9457	0.0614	0.8092	1.0000	0.9977	0.0052	0.9837	1.0000
Netherlands	0.8439	0.0478	0.7546	0.9305	0.9825	0.0247	0.9238	1.0000
Austria	0.6845	0.0117	0.6653	0.7083	0.8412	0.0206	0.8138	0.8729
Poland	0.5629	0.0326	0.5210	0.6155	0.9544	0.0651	0.8308	1.0000
Portugal	0.8097	0.0620	0.6721	0.8648	0.8844	0.0690	0.7307	0.9515
Romania	0.4422	0.0377	0.3918	0.5124	0.4500	0.0475	0.3946	0.5530
Slovenia	0.7575	0.0371	0.6918	0.8226	0.7862	0.0368	0.7179	0.8527
Slovakia	0.5554	0.0223	0.5157	0.5821	0.5611	0.0215	0.5228	0.5831
Finland	0.6904	0.0208	0.6609	0.7286	0.8257	0.0247	0.7767	0.8572
Sweden	0.6747	0.0221	0.6378	0.7045	0.9092	0.0215	0.8608	0.9393

Table 5 Correlation matrix of explanatory variables

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_1	1.00												
X_2	-0.25	1.00											
X_3	-0.37	0.80	1.00										
X_4	-0.18	-0.09	-0.11	1.00									
X_5	0.02	0.53	0.38	-0.44	1.00								
X_6	-0.25	-0.08	0.01	0.30	0.10	1.00							
X_7	-0.01	-0.06	0.09	-0.03	0.42	0.75	1.00						
X_8	-0.25	-0.20	-0.07	0.03	-0.23	-0.08	0.01	1.00					
X_9	0.12	0.49	0.37	-0.13	0.61	0.29	0.42	-0.38	1.00				
X_{10}	0.09	-0.07	-0.18	0.01	-0.36	-0.51	-0.59	0.16	-0.55	1.00			
X_{11}	0.08	-0.09	-0.01	0.08	0.16	0.36	0.54	0.33	0.36	-0.29	1.00		
X_{12}	-0.34	0.32	0.43	0.10	0.45	0.51	0.52	0.05	0.45	-0.49	0.39	1.00	
X_{13}	-0.24	0.39	0.40	-0.24	0.63	0.35	0.50	-0.23	0.38	-0.49	0.22	0.56	1.00

Table 6 Results of truncated regression model

Explanatory variables	Dependent variable			
	CRS DB EE		VRS DB EE	
	Estimate	Significance	Estimate	Significance
Intercept	−3.22009427	***	−5.49636282	***
X1	0.00054986		−0.00371363	*
X2	−0.00263558	***	−0.00745529	***
X3	−0.00022504		0.00354060	***
X4	−0.00216031	***	−0.00029968	
X5	0.02518974	**	0.02110514	
X6	−0.07834813	***	−0.15586555	***
X7	0.43359585	***	0.55397655	***
X8	−0.83007752	*	1.68750903	*
X9	0.04566588	***	0.07361613	***
X10	0.00893056	***	0.01255099	***
X11	−0.00191737	*	−0.00234422	
X12	0.00231901	***	0.00274507	***
X13	−0.00275734	**	0.00449347	*
Sigma	0.06941549	***	0.09204174	***
Log-likelihood	309.78		329.79	
R-squared	0.7150		0.6497	

significance levels: *0.1; **0.05; ***0.01. Double bootstrap. EE, environmental efficiency

industrialisation in these countries. Similarly, the population's education may be due to poor qualifications, the population and consequently fewer investors, which increases production and, inevitably, greenhouse gas emissions.

In terms of circular economy indicators, we have found interesting facts. Recycling rates and the use of circulating materials have a positive impact on improving environmental efficiency for the VRS model.

The results of the CRS and VRS models are slightly different. Their further testing, or a slight modification of the variables used can produce more consistent results. This analysis confirmed that the presented socioeconomic factors have a largely expected and, moreover, statistically significant impact.

Robustness testing

Although Simar and Wilson's (2007) procedure of double bootstrap procedure brings consistent and robust estimates, we decided to conduct a robustness check for our key result which is the regression model. In this way, we have used several procedures to check for robustness as proposed by Wolszczak-Derlacz and Parteka (2011).

At first, we raised the number of replications in the second loop to 2000; the next step was raising the number to 5000 (originally 200 replications were used). The next step was changing the truncation point to 0.99 (originally 1) which caused omitting efficient DMUs. The last test was performed by using only 2 input variables instead of 3. In this way, we have omitted the variable arable land—one can argue arable land could be autocorrelated with some explanatory variables so this check would be an advantage. Individual results of the computations are presented in Table 7, constant returns to scale efficiency model, and Table 8, variable returns to scale efficiency model.

Compared to the originally computed model, there are no significant changes when changing the number of replications, or truncation points. Only differences arise when removing one input in the first step of the analysis. It has changed the signs and significance of the tourism-oriented explanatory variables. Changing the number of inputs in our output could always lead to even more significant changes. The first step of DEA model and its variables have already been proven relevant and useful in many studies before.

The differences between original estimates and estimates computed using different considerations are even smaller when it comes to the VRS model. All the signs (impacts) remained unchanged, and only slight changes in values and statistical significance were encountered. Therefore, we can conduct that using VRS assumption models are more appropriate.

Discussion

Discussion on efficiency measurement

During the research period, high levels of environmental efficiency were mainly achieved by countries such as Germany, Ireland, the Netherlands, Cyprus, Luxembourg and Italy. It

Table 7 Robustness check of the CRS model

Explanatory variables	Number of replications				Truncation point		2 input model	
	2000		5000		0.99			
	Est	Sig	Est	Sig	Est	Sig	Est	Sig
Intercept	−3.2541	***	−3.2243	***	−3.2052	***	−2.4882	***
X1	0.0007		0.0007		0.0007		−0.0014	
X2	−0.0028	***	−0.0027	***	−0.0026	***	0.0002	
X3	−0.0002		−0.0002		−0.0002		−0.0007	**
X4	−0.0021	***	−0.0022	***	−0.0022	***	−0.0019	***
X5	0.0265	**	0.0256	**	0.0264	**	0.0044	
X6	−0.0770	***	−0.0778	***	−0.0789	***	−0.0574	**
X7	0.4273	***	0.4295	***	0.4517	***	0.5511	***
X8	−0.8404	*	−0.8436	*	−0.8496	*	−0.1552	
X9	0.0461	***	0.0457	***	0.0454	***	0.0352	***
X10	0.0089	***	0.0089	***	0.0090	***	0.0086	***
X11	−0.0020	*	−0.0019	*	−0.0019	*	−0.0006	
X12	0.0023	***	0.0023	***	0.0023	***	0.0025	***
X13	−0.0027	**	−0.0028	**	−0.0030	**	−0.0031	**
Sigma	0.0697	***	0.0699	***	0.0696	***	0.0657	***
Log-likelihood	308.6400	308.2800	310.5400	319.8500				
R-squared	0.7150	0.7130	0.7124	0.7046				

Table 8 Robustness check of the VRS model

Explanatory variables	Number of replications				Truncation point		2 input model	
	2000		5000		0.99			
	Est	Sig	Est	Sig	Est	Sig	Est	Sig
Intercept	−5.5105	***	−5.5157	***	−5.7652	***	−4.6326	***
*X*1	−0.0038	*	−0.0040	*	−0.0033		−0.0042	*
*X*2	−0.0074	***	−0.0074	***	−0.0087	***	−0.0047	***
*X*3	0.0035	***	0.0034	***	0.0046	***	0.0032	***
*X*4	−0.0004		−0.0003		−0.0003		−0.0011	
*X*5	0.0197		0.0207		0.0319		0.0037	
*X*6	−0.1549	***	−0.1582	***	−0.1664	***	−0.1401	***
*X*7	0.5545	***	0.5484	***	0.6259	***	0.6830	***
*X*8	1.7270	*	1.7015	*	2.0446	**	1.9664	**
*X*9	0.0738	***	0.0740	***	0.0764	***	0.0617	***
*X*10	0.0127	***	0.0124	***	0.0133	***	0.0124	***
*X*11	−0.0024		0.0740		−0.0028		−0.0006	
*X*12	0.0028	***	0.0027	***	0.0029	***	0.0023	***
*X*13	0.0046	**	0.0049	**	0.0043	*	0.0059	**
Sigma	0.0924	***	0.0921	***	0.0926	***	0.0917	***
Log-likelihood	329.3700	329.7900	347.0000	319.8300				
R-squared	0.6487	0.6527	0.6235	0.6400				

should be noted that countries such as Cyprus, Luxembourg or Malta are omitted in many research to measure environmental efficiency. It would, in our view, be unprofitable for this work, as these countries are essential precisely in the field of tourism. Furthermore, efficiency gains (CRS and VRS) were increasing in most countries. The results of modelling environmental efficiency have demonstrated this. This fact is a very good signal for further progress during the next period.

Based on the current trends in research and authorities' measures in implementing policies, we decided to use variables oriented to tourism, resource productivity, industry and services energy consumption, the quality of life and indicators focused on the circular economy.

Based on the results, it can be concluded that the presented models have good explanatory power, and the VRS model is especially robust. Indeed, some variables of the model are not statistically significant. This is also an opportunity for future research, whereby these variables can be replaced and the statistical significance of similar variables from the given research area tested. In the overall evaluation, it can be concluded that the growth of tourism volumes and tourism openness towards foreign tourists in the period before the pandemic could have a negative impact precisely on environmental efficiency. It is also necessary to note that energy measures may not have a direct impact on environmental efficiency, but the indirect effects of cost reduction can, together with other measures, help to improve the environment. The transformation of economies into knowledge-based ones encourages the development of services, and thus, we can more effectively reduce energy consumption and thus also the state of the living environment. The development of the quality of life in the EU countries can also help to improve the state of the environment; in our case, the improvement of the state of health has proved to be significant, which of course also has an impact as a prevention of diseases caused by the deterioration of the state of the environment. The risk of poverty indicator pointed out that as well-being increases, non-environmental efficiency may not always improve. A strong positive impact was also demonstrated in the case of circular economy indicators.

Comparing the results of this study with other research could be biased since no research has examined the same period. It should be noted that the regression models developed can be adapted to the needs and trends of setting up EU policies. Instead, they are model concepts which indicate which areas should be affected by explanatory variables and can be continuously examined and tested depending on the availability of new indicators.

Limitations

This research has been affected by some limitations. One of the main limitations is the unavailability of some data. In many cases, only one or several countries are missing. In addition, during data collection, we encountered relevant variables that could be used in research, but such situations made using these variables impossible.

In many cases, for example, there were variables related to the circular economy and tourism of the EU countries. Another limitation is that the scientific community has disagreed on which DEA models are more suitable for the types of efficiency. Therefore, the results are presented for models with constant and variable returns to scale. Indeed, models do not show considerable differences; even in regression models, there are more minor differences. In the literature survey, we have often met that the authors claimed that their model was the most appropriate, but they differed in their opinions. It is also worth mentioning that, because of the size of some data, we have been made more effective clarity about the presentation of data and results and, therefore, for example, the detailed development of explanatory variables of DEA models is not mentioned in this work.

Conclusions and policy implications

The theme of this study was environmental efficiency. We measured these efficiencies at the EU-27 level. The period we studied was from 2010 to 2018. The efficiencies we measured were then modelled using various economic, travel and tourism, energy, quality of life and circular economy aspects.

The European Union is an interesting research subject because the diversity of performance and attributes of its countries is considerable. It leads to the possibility of exploring the causes and consequences of this diversity. Moreover, the subject of this work is very topical because the policy of the EU's authorities is currently being targeted at several areas, including tourism, which is probably the most affected by a post-health pandemic. The current energy crisis pushes governments and people, even more, to make energy use more efficient. This is especially evident in energy-intensive industries, which are currently extremely affected by the increase in energy prices. Ultimately, this may lead to their demise and the transformation of some countries from industrial and knowledge-based economies, in which the service sector is the focus of attention. Another area is the improvement of the state of the environment by reducing greenhouse gas emissions and related areas such as the circular economy and energy efficiency. The quality of life of citizens is no less critical. All these areas are part of recovery plans following the profound economic and health crisis the world is still going through.

The main benefit lies in broadening the investigation and outlining new scientific challenges in the search for interdisciplinary efficiency. Research that has been carried out in this work can be explored on other objects of investigation. The benefits of science can also be reflected in the benefits of the learning process in the various economic fields, as this work has a strong interdisciplinary character. It explores the environment; tourism; the circular economy, i.e. production processes and materials processing; quality of life, i.e. social aspects; economic growth; and many others. It may be an appropriate methodological complement to practical application in modelling the efficiency of production units.

It should also be pointed out that recovery plans need to be tailor-made, as our research has also shown that there are still clusters of countries with different attributes within the EU. The EU aims to converge countries to the same standard of living, but these objectives will not be met long because economic and political crises negatively influence convergence.

Therefore, we will summarise several recommendations for EU policies, which are changing rapidly mainly due to the current economic and security situation in Europe: (1) it is necessary to support the attractiveness of countries for foreign tourists mainly due to economic growth, but this is conditioned by the very intensive application of sustainable tourism tools; (2) it is necessary to increase the use of renewable resources, but it is necessary not only to make the efficiency of these devices more efficient, but also to reduce the burden on the environment caused by their production in other parts of the world; (3) to emphasise the shift of countries with extensive industry towards knowledge-based forms of economy service-oriented; (4) increasing the level of health systems towards prevention, and also environmental education and awareness with an emphasis on the quality of the education provided, as it seems that the number of educated people does not necessarily indicate the quality; and (5) continue to support the principles of the functioning of the circular economy and municipal waste recycling, in order to save resources, the prices of which are increasing significantly.

Of course, all these recommendations are synergistically applicable and, in the long term, help to significantly improve the efficiency of countries in using inputs and converting them into economic outputs with the lowest possible production of harmful emissions.

Therefore, future research must undoubtedly be directed into this area. Future research can also be directed towards smaller groupings, individual countries or regions of countries. Examining the efficiency of these clusters could make detailed recommendations to authorities who decide on measures and policies to improve the state of the environment and related factors. Research possibilities also lie in research into new methods that may focus on artificial intelligence, networks and other ever-increasing modifications of the DEA method.

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Data availability All the data used in this study are available online at the Eurostat and The World Bank databases. Please contact the corresponding author for a data request.

Declarations

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