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Evaluating Environmental Efficiency of European Union Countries with the Approach of Network Data Envelopment Analysis

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ABSTRACT

Background: Today, increasing the world's population and efforts of countries to achieve economic growth, this research, aims to study the variables affecting economic and environmental efficiency.
Methods: In the first part of the envelopment analysis of network data the economic efficiency of European Union (EU) countries was calculated according to the input variables. In the second part, the environmental efficiency of EU countries was evaluated based on the two important outputs of greenhouse gas emissions and the absorption of polluting gases. Finally, countries were ranked accordingly.
Results: Correlation analysis showed that almost all input and output variables are positively correlated and thus meet the isotonic need. Likewise, all of them can be selected for evaluation using the DEA technique. Also the results indicated that 5 countries, including Denmark, France, Germany, the Netherlands, and the United Kingdom were efficient in the first stage. Besides, Cyprus, the Czech Republic, Ireland, Latvia, and Luxembourg were in the second step.
Conclusion: The results of this study showed that none of the countries was recognized as total efficiency. Thus, none of the countries were able to operate simultaneously in both the economic efficiency and the environmental efficiency phase.

1. Introduction

Industrialization and globalization for companies and countries are the main achievements of today's world, however the negative impact of these concepts on the environment has been considered by various stakeholders, governments, international institutions, etc. Recently, achieving a sustainable environment is mandatory for companies [1]. On the other hand, the concept of sustainable development or sustainability is recognized as the most important element for survival on the planet due to the intensification of environmental impacts in various fields, the long and severe global economic crisis, and confusing social issues [2]. As sustainability is defined achieving economic, environmental, and social dimensions that support an organization for long-term competition [3], green development and a low-carbon economy play an important role in achieving a sustainable society [4].

Environmental sustainability is one of the fundamental pillars of sustainable development, which has attracted the attention of researchers at the national and international levels. At present, sustainable development should be called

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the main human challenge to improve living conditions in the third millennium to achieve which various models and perspectives have been developed in most countries. The results show that in a wide range of statistics, the three basic pillars of optimal economic development, environmental protection, and social justice are considered for sustainable development. The study of environmental sustainability, which is one of the main pillars of sustainable development among countries around the world as well as regions of a country, is one of the issues that has attracted the attention of many researchers at the national and international levels in the present century.

Thus, environmental concerns have affected all organizations and companies nationally and internationally. Moreover, reducing environmental risks, increasing environmental and economic performance, and gaining a competitive advantage over competitors are important. Therefore, this study aimed to assess the efficiency and then evaluate the countries with economic and environmental attitudes by considering the importance of economic and environmental factors, their role in environmental degradation, and reducing pollution. The results show that countries will be more efficient in economic development and growth and reduce environmental pollution while consuming resources.

In this part, the history of economic and environmental efficiency is discussed as a factor affecting sustainability and provided a brief overview of research conducted in this field. In this research, an attempt has been made to rank the EU countries according to the importance of resource consumption and on the other hand, greenhouse gas emissions. The results can help countries see which items are efficient in consumption and which resources are inefficient. Accordingly, they can advance their programs to protect the environment and sustainable development.

1.2. Environmental Efficiency

Environmental efficiency was first proposed in 1992 by the World Business Council for Sustainable Development (WBCSD). This idea is based on creating more goods and services using fewer resources, creating less waste and pollution, and minimizing environmental impacts with the maximum efficiency of a production unit's processes. This term is synonymous with a concept that is oriented towards sustainable development. Estimating environmental efficiency emphasizes maximizing economic production, using minimal resources while minimizing environmental impact. Thus, it is a different process from estimating environmental performance. Estimating environmental efficiency is a relatively difficult task because it does not have a universal definition, it is difficult to select indicators, and the data face many shortcomings [5]. Environmental efficiency is a quantitative tool for management that helps to study the environmental impact of the product produced and has three goals: creating added value, optimizing resource use, and reducing environmental impact [6].

1.3. Economic Efficiency

Economic efficiency is a term used to estimate the results of an economic activity compared to the efforts made in the relevant activity. It is the main qualitative factor of economic growth because absolute growth guarantees the result in the same effort. Economic efficiency includes profitability, which is a general indicator of productivity and an important factor for the development of industries [7, 8]. Economic efficiency is divided into two categories. First, technical efficiency, which indicates the ability of the production unit to obtain maximum output from a set of inputs. Second, production technology and allocation efficiency, which represents the ability of a production unit to use inputs in optimal ratios according to prices and production technology.

The point is that economic efficiency does not imply environmental efficiency. Production processes may rely too heavily on fossil fuels or fossil technologies; although technically efficient and inexpensive, they result in high levels of radiation and other environmental effects. However, if there is technical or economic inefficiency, it can lead to environmental inefficiency. For example, waste of raw materials or improper energy use leads to technical, economic, and environmental inefficiencies because it wastes resources and increases pollution [6].

1.4. Analysis of Input, Intermediate, and Output Variables

The selection of inputs and outputs in previous studies and network data envelopment analysis has received much attention. Its importance stems from the fact that inadequate input and output may result in inaccurate results from network data envelopment analysis [9]. However, determining the inputs, outputs, and intermediate variables in calculating performance is still in progress.

Wang *et al.* (2013) conducted a study to investigate efficiency and energy in 29 cities in three regions of China from 2000-2008. The data were extracted from the Chinese Statistical Yearbook. In this study, total energy (gas, oil, coal, electricity) labor, and capital were considered input variables, GDP as desirable output, and CO_2 and SO_2 as undesirable outputs. Data analysis was performed using the DEA method. The results showed that the East China region had higher energy and environmental efficiency than the central region, and the productivity of the West region was at its worst. Productivity in all three areas had changed similarly, and overall, China's energy and environmental productivity have increased slightly from 2000 to 2008. The eastern region's energy efficiency and environment have a more balanced performance than the central and the

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western region. However, effective energy and environmental protection policies implemented by the Chinese government over the past decade have greatly helped to improve energy and environmental efficiency in China [10].

In a similar study by Yang *et al.* (2015), cross-sectional data of 31 regions from 2008 to 2012 were used to evaluate the green efficiency of cities, and to analyze the data, the DEA method was used to find a way to achieve green efficiency. In this study, after double refinement of different variables, factors such as regional GDP, urban residential investment, savings deposits of urban and rural residents, forest cover, and urban green areas were considered as inputs and gross domestic consumption, water consumption, solid waste of general industry, dust emissions, total industrial wastewater discharge, electricity consumption, and discharge of industrial waste gases as outputs. The results indicated that except for the western regions, the efficiency index is low in the other areas [11].

In another study Alves *et al.* (2015) evaluated the efficiency of resources and the environment in the European Union. This study was conducted in two time periods from 2000-2004 and 2005-2011 in EU countries (Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Cyprus, Lithuania, Luxembourg, Hungary, the Netherlands. Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden- and the United Kingdom) to compare environmental performance before and after Kyoto Protocol implementation (2005). The results of this study were analyzed by DEA method in which capital, labor, fossil fuels, and renewable energy consumption were considered as inputs. GDP was considered desirable output, and greenhouse gas emissions were considered an unfavorable output. The results showed that the five most efficient countries in terms of environmental efficiency in the first period were Sweden, the United Kingdom, Latvia, Cyprus, and France. At the same time, Estonia, the Czech Republic, and Greece had the lowest efficiency. However, in the second period, when Sweden, Latvia, the United Kingdom, Hungary, Portugal, and Cyprus were the six most efficient countries, the Czech Republic, Poland and Estonia were the most inefficient countries [6].

Zhou *et al.* (2016) analyzed the variables related to environmental efficiency and productivity using DEA method. The data were collected from 29 OECD member countries for the years 2000 to 2011. This study in this study, capital stock and labor as input, GDP as the desired output and the emission of carbon dioxide (CO_2), methane (CH_4), and nitrogen (N_2O) as undesirable outputs were considered. The results represented that the productivity and efficiency of the environment decreased during the period under review, and the most important factor was technology [12].
Liu and Ji (2017) conducted a study to evaluate industrial green performance in Sichuan province using the malmquist mechanical index". The DEA-Malmquist index was used to assess green industrial efficiency and was examined in 18 cities in Sichuan province, China. The inputs variables consisted of a number of employees, total investment in fixed assets and industrial value-added of energy consumption and output variables were considered as the total value of industrial production and total pollution discharge of industrial waste. The results indicated that industrial efficiency in this province was low, and technology was the most essential factor in reducing green industrial efficiency [13].

Matinho *et al.* (2017) conducted a study to assess economic and environmental efficiency in 26 different EU countries during 2001-2012. . In the first research step, data envelopment analysis method was used to analyze the data. Inputs in this study included labor, capital, share of energy in GDP, and outputs included polluting gases. The main conclusion of the study was that of energy percentage (renewable and non-renewable) was important to explain the differences in greenhouse gas emissions. Further, a big difference in economic and environmental efficiency between EU countries was observed. Moreover, the effect of the tax on environmental income in more efficient countries had a more significant impact, and the resources consumption directly affected environmental efficiency [14].

In a research done by Vaninsky (2018), the opportunities for economic reconstruction, which leads to an increase in the optimal environmental-energy efficiency in the global economy was explored. The study was conducted in the United States, OECD member and non-member countries, Japan, South Korea, Canada, Mexico, Chile, Australia, New Zealand, India, China, the Middle East, South America, and Africa. In this research, DEA method was used to analyze the data. GDP, carbon dioxide (CO_2) emission indices, population, and energy consumption were considered as output and input respectively. Findings revealed that population growth, energy consumption, and greenhouse gas emissions must be adjusted in order to achieve environmental efficiency [15].

Moreover, Holcos *et al.* (2019) conducted a study to examine the performance of 28 EU Member States for 2008, 2010, 2012, and 2014 using data envelopment analysis. In this study, the variables of cost, employment (labor force), capital, population density were input variables and gross domestic product (GDP), sulfur oxide (Sox), nitrogen oxide (NOx), and greenhouse gases (GHG) were used for the respective countries as outputs. The results demonstrated that the rate of waste recycling was higher inefficient countries. Germany had the highest rate of waste recycling. The most efficient countries were Germany, Ireland, and the United Kingdom [16].

Yang and Wei (2019) used the DEA method to evaluate the efficiency of the energy factor in 26 provinces of China from 2005-2016. The required data were obtained from Chinese

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Urban Statistical and Energy Annual Statistical Yearbooks. In this study, input variables were labor, energy, and capital .The output variables were gross domestic product (GDP) as desirable output and environmental pollution (SO_2 gas, sewage and smoke and dust) as undesirable output. Based on the results, urban energy efficiency was calculated by considering the competitive relationship less than efficiency. In addition, urban energy efficiency did not improve during the research period, and economic development and urban scale can improve urban energy efficiency. While government spending, industrial structure, energy prices, foreign investment, research investment, and production investment negatively affected urban energy efficiency [17].

2. Materials and Methods

2.1. Network Data Envelopment Analysis (Network DEA)

The network structure was first introduced by Feir (1991) that connects the intermediate inputs and outputs of a set of processes and has been expanded [18, 19]. Feir and Graskov (2000) have established the relationships between different processes in the network data envelopment analysis model; therefore, more structure can be added to the model to make it more suitable for specific applications [20]. Once these relationships are established, they provide insights into inefficiency resources and specific guidance for unit managers to help them improve their DMU performance [21]. In network DEA models, the network structure is used, and each DMU consists of two or more minor DMUs [22].

A partial DMU consumes each source, and the output generated as input enters the next partial DMU until the final output leaves the last partial DMU [23]. The classical data envelopment analysis model considers the structure of a DMU as a black box that simply measures a DMU's performance based on initial inputs and final outputs. Therefore, the efficiency of a DMU is measured without considering internal communications.

In addition to the primary inputs that enter the system at the beginning of the process and the final outputs that exit the system, network data analysis considers intermediate inputs and outputs. There are generally different forms of input and output in network envelopment analysis models. Initial inputs that enter the first stage 2) Undesirable results that leave the network and do not enter the next stage, 3) Desirable outputs that leave the system from one stage and do not enter the next stage 4) Intermediate outputs that leave the stage and enter the next stage [24].

The proposed model is quite comprehensive and flexible and can consider all forms of input and output. However, in all real cases, we may not encounter input and output types simultaneously.

2.2. Conceptual Model and Research Variables

Figure 1 shows the structure of a multi-step process. Each DMUj decision-making unit (j = 1,..., n) has m input variables Xij, (i = 1,..., m) in the first step that produce output q. The outputs that exit each p-th stage and enter the p + 1 stage as input are indicated by, Z_{ej}^{p} (e=1... q). The final output that leaves the system may be either desirable or undesirable. The symbol denotes desirable outputs y_{rj}^{gp} (r =,..., s) while undesirable outputs are indicated by y_{rj}^{gp} (r =,...,s) which exit the p the $v_{ij,}\eta_{ej}^{p}, u_{rj}^{g}, u_{rj}^{g}$ stage. In addition, the symbols v indicate the weight of the input, intermediate output, final desirable output, and final undesirable output, respectively. In data envelopment analysis, producing more output than less input is the criterion for unit efficiency. However, in the case of unfavorable output, having a more desirable output and less unfavorable output than the amount of lower input consumption will make the decision-making units efficient. There are different methods in modeling adverse output in data envelopment analysis. One of the most common approaches is considering the same nature as the input nature for the undesirable output variable.

2.3. Proposed Network Data Envelopment Analysis Model

In this section, based on the model of Cook *et al.* (2010), a network model of data envelopment analysis is presented to evaluate the performance of the whole network and its components due to the unfavorable output [25]. Based on Figure 1, the efficiency of each step can be calculated as follows:

$$E_1 = \frac{\sum_{e=1}^{q} n_{1j}\, z_{1j}^{1}}{\sum_{i=1}^{m} v_{1j}\, zx_{1j}^{1}} \tag{1}$$

$$E_2 = \frac{\sum_{e=1}^{q} n_{1j}\, z_{1j}^{2}}{\sum_{e=1}^{q} n_{1j}\, z_{1j}^{1} + \sum_{r=1}^{s} u_{1j}^{b}\, y_{1k}^{b2}} \tag{2}$$

$$E_p = \frac{\sum_{e=1}^{q} n_{1j}\, z_{1j}^{p} + \sum_{r=1}^{s} u_{rj}\, y_{rj}^{gp}}{\sum_{e=1}^{q} n_{1j}\, z_{1j}^{1} + \sum_{r=1}^{s} u_{1j}^{b}\, y_{1k}^{b2}} \tag{3}$$

The performance of the whole network can be written as a convex linear combination as follows:

$$E_{overall} = \sum_{e=1}^{q} W_p \; E_p \; where \sum_{p=1}^{q} W_p = 1 \tag{4}$$

Note that the weight of each stage indicates the importance of that stage compared to other network stages.

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Table 1: Summarizes the Similar Research Conducted on Environmental and Economic Performance

Title	Authors	Method	Environmental and Economic Efficiency Indicators							
			Water (Million cubic meters)	Final energy consumption (TOE)	Raw materials (resources)	Greenhouse gases) kt of CO_2 equivalent	Total capital (constant 2010 US$)	Labor force, total (Million)	Technology	GDP (constant 2010 US$)
China's regional energy efficiency and environment: DEA window analysis based on performance evaluation	Wang *et al.* (2013)	DEA		✓		✓	✓	✓		
Evaluation of green efficiency in China provinces using DEA method	Yang *et al.* (2015)	DEA	✓	✓						
A new approach to assessing environmental efficiency in EU countries	Alves *et al.* (2015)	DEA		✓		✓	✓	✓		✓
Evaluation of environmental efficiency using data envelopment analysis	Zhou *et al.* (2016)	DEA				✓	✓	✓		
Evaluation of green industrial efficiency in Sichuan province using Malmquist mechanical index	Liu Waji (2017)	DEA-Malmquist						✓		
Evaluation of crop economic efficiency in Lithuania	Gancon *et al.* (2017)	regression		✓		✓				
Evaluating economic and environmental efficiency in the EU nationwide: evidence from the DEA and the qualitative regression approach	Matinho *et al.* (2017)	DEA and qualitative regression approach		✓		✓	✓	✓		
Measuring the green efficiency of the ocean economy in China	Ding *et al.* (2017)	DEA		✓				✓		✓

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Table 1: Summarizes the Similar Research Conducted on Environmental and Economic Performance (Continue)

Title	Authors	Method	Environmental and Economic Efficiency Indicators							
			Water (Million cubic meters)	Final energy consumption (TOE)	Raw materials (resources)	Greenhouse gases) kt of CO_2 equivalent	Total capital (constant 2010 US$)	Labor force, total (Million)	Technology	GDP (constant 2010 US$)
Assessing economic efficiency through DEA analysis in Latin American countries	Matinho and Foinhas (2018)	DEA		✓		✓				
Environmental efficiency - energy and optimal reconstruction of the global economy	Vaninsky (2018)	DEA		✓				✓		
Green efficiency of industrial sectors in China: a comparative analysis based on segmentation and supply chain evidence	Zhang *et al.* (2018)	DEA	✓	✓					✓	
Measurement and analysis of green efficiency of water factor, in Chinese industry	Yao *et al.* (2018)	DEA	✓	✓		✓	✓	✓		
Green efficiency and environmental subsidies: Evidence from thermal energy companies	Yao *et al.* (2018)	DEA		✓				✓		
Environmental efficiency assessment of 28 EU member states in the production of national waste by DEA method	Halkus *et al.* (2019)	DEA				✓	✓	✓		✓
Measurement and impact of energy efficiency in Chinese cities against environmental pollution: Based on DEA model	Young and Wei (2019)	DEA		✓		✓	✓	✓		✓

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One way to choose the weight for each step is to consider the ratio of the input of each step to the total network inputs, which can be written as follows:

$$W_1 = \frac{\sum_{i=1}^{m} v_{ik}x_{ik}}{\sum_{i=1}^{m} v_{ik}x_{ik}+\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{b2}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{bp}+\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1-p}} \tag{5}$$

$$W_2 = \frac{\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1-p} +\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{bp}}{\sum_{i=1}^{m} v_{ik}x_{ik}+\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{b2}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{bp}+\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1-p}} \tag{6}$$

$$W_P = \frac{\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1-p} +\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{bp}}{\sum_{i=1}^{m} v_{ik}x_{ik}+\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{b2}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{bp}+\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1-p}} \tag{7}$$

Finally,

Therefore, the performance of the whole network can be written as follows:

$$E_{overall} = \sum_{e=1}^{q} W_p E_p = \frac{\sum_{p=1}^{p}\left(\sum_{e=1}^{q} n_{ek}\, z_{ek}^{p}+\sum_{r=1}^{s} u_{rj}^{g}\, y_{rk}^{gp}\right)}{\sum_{i=1}^{m} v_{ik}x_{ik}+\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{b1}+\sum_{p=2}^{p}\left(\sum_{e=1}^{q} n_{ek}\, z_{ek}^{1-p} +\sum_{r=1}^{s} u_{rj}^{b}\, y_{rk}^{bp}\right)} \tag{8}$$

Model 9

$$\text{Max } E_{overall} = \sum_{p=1}^{p}\left(\sum_{e=1}^{q} n_{ek}\, z_{ek}^{p} \sum_{r=1}^{s} u_{rj}^{g}\, y_{rk}^{gp}\right) \tag{9}$$

s.t

$$\sum_{i=1}^{m} \mathbf{v_{ik}x_{ik}} + \sum_{r=1}^{s} \mathbf{u_{rj}^{b}\, y_{rk}^{b1}} + \sum_{p=2}^{p}\left(\sum_{e=1}^{q} \mathbf{n_{ek}\, z_{ek}^{1-p}} + \sum_{r=1}^{s} \mathbf{u_{rj}^{b}\, y_{rk}^{bp}}\right) = \mathbf{1}$$

$$\left(\sum_{r=1}^{s} \boldsymbol{u_{rj}^{g}\, y_{rj}^{g1}} + \sum_{e=1}^{q} \boldsymbol{n_{ej}\, z_{ej}^{1}}\right) \le \sum_{i=1}^{m} \boldsymbol{v_{ij}x_{ij}} + \sum_{r=1}^{s} \boldsymbol{u_{rj}^{b}\, y_{rj}^{b1}}$$

$$\sum_{p=2}^{p}\left(\sum_{r=1}^{s} u_{rj}^{g}\, y_{rj}^{gp} + \sum_{e=1}^{q} n_{ej}\, z_{ej}^{p}\right) \le \sum_{p=2}^{p}\left(\sum_{e=1}^{q} n_{ej}\, z_{ej}^{1-p} + \sum_{r=1}^{s} u_{rj}^{b}\, y_{rj}^{bp}\right)$$

$$n_{ej} \ge 0 \text{ و } u_{rj} \text{ و} v_{ij}$$

The objective function of Model 9 measures the performance of the entire network. The value of the objective function is always between zero and 1. If the total efficiency of the DMU under consideration is equal to 1, then it is called total efficiency. The first constraint ensures that the sum of the system inputs must be equal to 1. Constraint 2 ensures that the output of the first phase must be less than or equal to the inputs of the first phase. Constraint 3 also indicates that the output of the p the stage must be smaller than the inputs of the p stage.

In order to calculate the efficiency of network components, E10 and E11 are used:

$$E_1 = \frac{\sum_{e=1}^{q} n_{ej}^{*}\, z_{ej}^{1}}{\sum_{i=1}^{m} v_{ej}^{*} x_{ij}} \tag{10}$$

$$\boldsymbol{E_p} = \frac{\sum_{p=2}^{p}\left(\sum_{r=1}^{s} \boldsymbol{u_{rj}^{*}\, y_{rj}^{gp}} + \sum_{e=1}^{q} \boldsymbol{n_{ej}^{*}\, z_{ej}^{p}}\right)}{\sum_{p=2}^{p}\left(\sum_{e=1}^{q} \boldsymbol{n_{ej}^{*}\, z_{ej}^{1-p}} + \sum_{r=1}^{s} \boldsymbol{u_{rj}^{*}\, y_{rj}^{b(1-p)}}\right)} \tag{11}$$

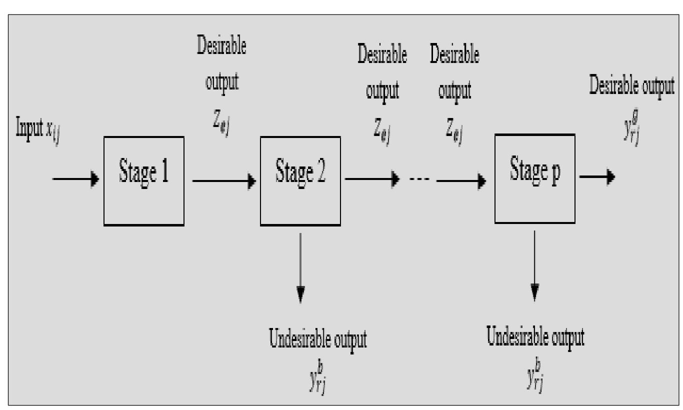

Figure 1: Multi-Step Process

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E1 and Ep indicate the efficiency of the first stage and the efficiency of the p the stage, and also the * sign indicates the optimal amount of weights for inputs and outputs.

2.4. Research Data

This study examined the economic performance of 27 EU countries in terms of sustainability indicators. In order to access country data, data were extracted from worldbank.org and Eurostat. To measure the efficiency of countries, two-stage structure was created. The first and second stages represented economic efficiency and environmental efficiency, respectively. Then, the proposed network DEA model was applied to measure the efficiency of both the production and the distribution phases for each country. This structure is shown in Figure 2.

To measure the efficiency of the 27 EU countries, labor, capital, energy consumption, water consumption, and raw materials were considered as the input of the first stage. Gross domestic product was also considered as the output of the first stage (intermediate outputs) that entered as input to the second stage. This index was an economic dimension of sustainability. Export of technology and the amount of desirable gases that were absorbed by the environment as the final desirable outputs that referred to the economic and environmental dimensions of sustainability, respectively.

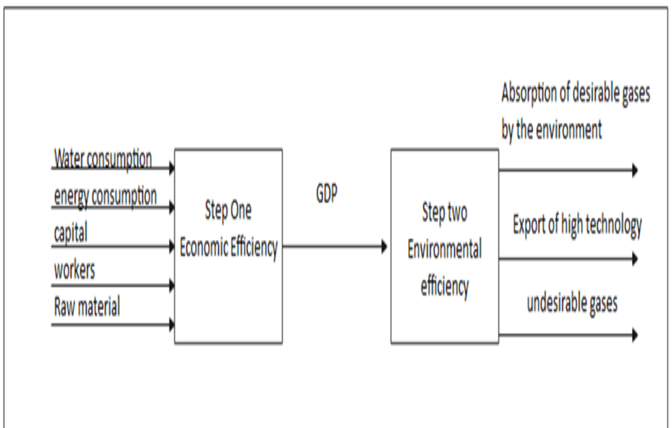

Figure 2: Two-stage structure of the countries under study

Besides, the amount of CO_2 emissions, which refers to the environmental dimension of sustainability, was considered as the final undesirable output. These indicators are shown in Table 2.

The data set dates back to 2018. The most important economic input is capital, including material and financial capital. Moreover, labor is usually used as input as a social indicator. In some research, economic indicators and energy consumption are used as the most common input of the environment. Such an arrangement includes economic theories (such as Cobb Douglas production performance) in which capital, labor, and energy are the main factors of production (GDP). Thus, energy is an important factor in developing industry and the economy, and governments must pursue a balanced approach to economic growth and energy consumption. Energy consumption, GDP growth, and greenhouse gas emissions are closely linked. Reducing carbon emissions and energy consumption must be balanced to protect the environment, while increasing energy consumption is difficult for economic growth. The two-stage structure of the research is shown in Figure 2.

2.5. Correlation test between inputs and outputs

The accuracy of DEA results in evaluation depends on the appropriate input and output variables. The prerequisite for using DEA is that the selected input and output variables maintain an isotonic relationship, verified by correlation analysis.

3. Results and Discussion

Tables 3 and 4 show the correlation between output and input variables in economic and environmental efficiency, respectively. As indicated by Table 3. The average correlation between inputs and outputs is high in the economic efficiency step. This means that the average performance score for this step should be approximately high. It should be noted that a DMU does not always require higher levels of inputs and output levels, especially if there are alternative inputs, in which some inputs (or outputs) may be negatively related.

Table 2: Research variables

Step	Index	Symbol	Average	Standard deviation	Min	Max
Step One: Economic Efficiency	energy consumption	X1	41.61	52.5959	1.86	215.37
	Water consumption	X2	9678.51	18073.04	64.94	87942.78
	Workers	X3	9.22	11.5076	0.297	43.423
	Capital	X4	3447.14	4782.934	132.433	17198.61
	Raw material	X5	320.88	541.415	3.408	2734.176
	GDP	z_1^1	710.34	1024.66	26.35	3939.277
Step 2: Environmental efficiency	Export of high technology	y_1^{g2}	28.55	45.6567	0.096	210.082

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Table 3: Correlation results between the inputs and outputs of the first step

		Inputs					Output
		Energy consumption	Water consumption	Worker	Capital	Raw material	GDP
Inputs	Energy consumption	1.0000	0.4450	0.9850	0.9806	0.6232	0.9858
	Water consumption	-	1.0000	0.5057	0.4243	0.0340	0.4241
	Worker	-	-	1.0000	0.6532	0.6767	0.9695
	Capital	-	-	-	1.0000	0.0343	0.9973
	Raw material	-	-	-	-	1.000	0.6368
Output	GDP	-	-	-	-	-	1.0000

Table 4 describes the correlation between the input and output variables in the environmental efficiency step. This reports a relatively high correlation between the input and the output variables in the second step. Correlation analysis shows that almost all input and output variables are positively correlated and thus meet the isotonic need. Likewise, all of them can be selected for evaluation using the DEA technique.

Table 5 indicates the results of the implementation of the presented model.

The first column shows the names of each of the countries under study. Columns 2 and 3 show the weight and efficiency of the economic efficiency phase of the economic countries, respectively. Columns 4 and 5 represent the weights and performance scores of the countries' environmental performance stage. Finally, the last one shows the total performance for the countries.

The results showed that 5 countries, including Denmark, France, Germany, the Netherlands, and the United Kingdom, were efficient in the first stage. Further, Cyprus, the Czech Republic, Ireland, Latvia. and Luxembourg were in the second step.

The last row of Table 5 indicates the average scores of the efficiency of economic countries in the stage of economic, environmental, and total efficiency. On average, the former efficiency of the economic countries is equal to 0.8802, which shows that the mentioned countries have performed relatively well in the economic efficiency phase. In contrast, the average efficiency score of economic countries in the environmental efficiency stage is equal to 0.5528, indicating most countries' weakness in this stage. The point is that much of this inefficiency is due to poor output ($CO2$ emissions). The average total efficiency score for economic countries is 0.7164. The average total efficiency score for economic countries is 0.7164, which indicates the average performance level for these countries. Note that the weight of each stage of economic and environmental efficiency is determined by the model based on the input variables of each stage and automatically. If the weight of each stage changes, the total efficiency scores for each country will change, and these weights can be determined differently depending on the economic policies of each country.

3.1. Sensitivity Analysis

Table 6 describes the results of the sensitivity analysis which the first column shows the name of each economic country. The second to sixth columns show the efficiency score of each economic country after removing the input variables. Columns 7 to 11 also report the rankings of each of the economic countries after the mentioned entries, and finally, the last column shows the main rankings of the economic countries. Table 6 also It also indicates that the ranking and efficiency scores of some economic countries such as Ireland, Latvia, Luxembourg, the Netherlands, etc. have improved after the elimination of the water consumption index because they have used water resources more efficiently than other economic countries. Moreover, except 7 countries (including Ireland, Latvia, Luxembourg, the Netherlands, Poland and Romania, and Slovakia), the rest of the countries were not very sensitive to the raw material index.

Figure 4 shows the changes in the efficiency score of economic countries after the removal of input variables in order to compare the results of the sensitivity analysis better.

The main economic goal of any country is to increase the value of production, achieve a fair distribution of income, optimize the use of resources, and reduce its environmental impact. Therefore, economic analysis of countries in sustainability can be an important aspect for governments and scientists [14]. On the other hand, today, environmental problems have become increasingly complex and threaten human well-being [26]. This has led to the desire for a sustainable environment to be considered by theorists and experts in the field of sustainable development [27].

Moreover, to maintain financial stability and effective competition in the global market, companies worldwide must integrate environmental sustainability into their strategies and business models. Many of the commercial disasters have emphasized that the company's environmental responsibilities are critical to their economic sustainability, the well-being of society, and future generations. Therefore, companies must turn environmental challenges into opportunities by strengthening their environmental management, adopting global environmental

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Table 4: Correlation results between the inputs and outputs of the second step

		Inputs	Outputs		
		GDP	Export of high technology	Co_2 emissions	Absorption of desirable gases t
GDP	Inputs	1.0000	0.8771	0.5618	0.5161
Outputs	Export of high technology	-	1.0000	-0.0423	0.3549
	Co_2 emissions	-	-	1.0000	-0.0994
	Absorption of desirable gases	-	-	-	1.0000

Table 5: Results of the presented model

Countries	First step weight	First step efficiency	Second step weight	Second step efficiency	Total efficiency
Austria	0.5070	0.9721	0.4929	0.2997	0.6406
Belgium	0.5071	0.9717	0.4928	0.4964	0.7375
Bulgaria	0.5733	0.7439	0.4266	0.7475	0.7454
Croatia	0.5457	0.8323	0.4542	0.5446	0.7016
Cyprus	0.5131	0.9486	0.4868	1.0000	0.9736
Czech	0.5293	0.8890	0.4706	1.0000	0.9412
Denmark	0.5000	1.0000	0.5000	0.1985	0.5992
France	0.5000	1.0000	0.5000	0.2924	0.6462
Finland	0.5347	0.8699	0.4652	0.2118	0.5670
Estonia	0.5608	0.7829	0.4391	1.0000	0.8782
Greece	0.5581	0.7915	0.4418	0.1145	0.4924
Germany	0.5000	1.0000	0.5000	0.3775	0.6887
Hungary	0.5214	0.9179	0.4785	0.8666	0.8933
Ireland	0.5000	0. 6706	0.5000	1.0000	0.8253
Italy	0.5000	0.9981	0.5000	0.1344	0.5667
Latvia	0.5000	0.9540	0.5000	1.0000	0.9770
Lithuania	0.5633	0.7751	0.4366	0.7253	0.7534
Luxembourg	0.5000	0.4349	0.5000	1.0000	0.7174
Netherlands	0.5000	1.0000	0.5000	0.6320	0.8186
Poland	0.5000	0.8059	0.5000	0.2424	0.5241
Portugal	0.5282	0.8930	0.4717	0.5343	0.7238
Romania	0.5243	0.9071	0.4756	0.2952	0.6160
Slovakia	0.5015	0.9936	0.4984	0.9394	0.9666
Slovenia	0.5289	0.8905	0.4710	0.6754	0.7891
Spain	0.5000	0.5405	0.5000	0.0811	0.3108
Sweden	0.5063	0.9747	0.4936	0.3096	0.6464
United Kingdom	0.5000	1.0000	0.5000	0.2090	0.6045
Average	-	0.8802	-	0.5528	0.7164

performance. In addition, it is necessary to study the environmental dimension of sustainability around the world [28].

Sensitivity analysis is one of the tools that can be used to achieve this goal. Thus, each resource is eliminated, and the proposed model is implemented for all economic countries, respectively in order to investigate the impact of each country's resources on the GDP.

The efficiency score of economic countries shows that the ranking of some countries such as Latvia, Luxembourg, the Netherlands, Slovakia, Slovenia and Spain has improved after eliminating the energy consumption index. These countries have used energy more efficiently than other economic countries. Moreover, the ranking of some other countries, such as Denmark, France, Poland, Portugal, Romania, and Sweden, have fallen sharply after removing of this index for sensitivity to energy sources. This means that the named countries have not used this input adequately compared to other countries. Generally, the energy source has a more significant impact on the ranking and efficiency of countries than other sources therefore it can be a competitive advantage for these countries. So that proper or inappropriate use of this resource can significantly change the efficiency and ranking of the countries under study.

However, most economic countries are less sensitive to labor sources than other sources. Therefore, this index cannot be considered as a competitive advantage for economic countries. Excluding this index, the efficiency score and ranking of economic countries have not changed significantly, except Ireland, Latvia, Luxembourg, the

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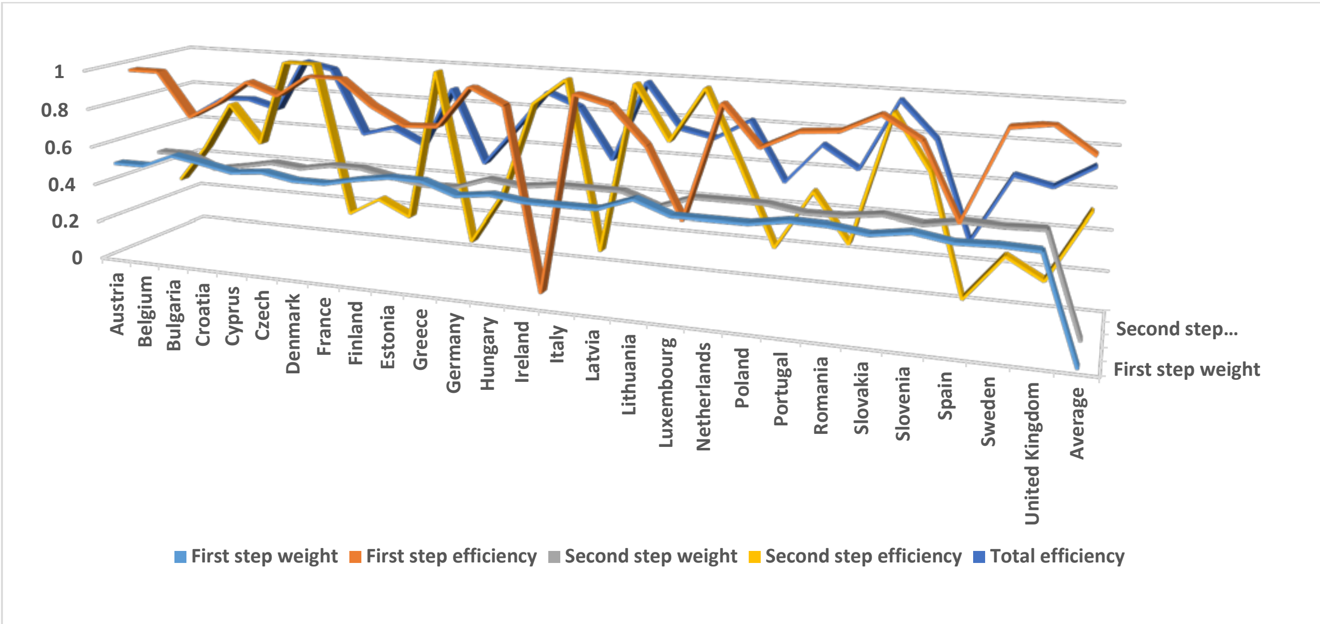

Figure 3: Model Results Chart

Table 6: Results of sensitivity analysis

Economic countries	Country performance score after removing each input					Rank each country after deleting each input					Main rank
	Energy consumption	Water consumption	Worker	Capital	Raw material	Energy consumption	Water consumption	Worker	Capital	Raw material	
Austria	0.9716	0.9171	0.9721	0.6732	0.9721	7	10	3	10	4	5
Belgium	0.9717	0.9660	0.9717	0.8593	0.9254	6	6	4	4	6	6
Bulgaria	0.7439	0.7439	0.7439	0.2288	0.7439	24	24	20	23	19	20
Croatia	0.8323	0.8322	0.8323	0.4320	0.8323	19	19	15	16	14	15
Cyprus	0.9486	0.9486	0.9486	0.6885	0.8931	10	8	8	8	9	8
Czechia	0.8890	0.8890	0.8890	0.3191	0.8890	16	15	13	18	11	13
Denmark	0.8846	0.9097	1.0000	1.0000	1.0000	17	11	1	1	1	1
France	0.9810	0.9786	0.9563	1.0000	1.0000	5	4	5	1	1	1
Finland	0.8699	0.8699	0.8559	0.4765	0.8699	18	18	14	14	13	14
Estonia	0.7829	0.7829	0.7829	0.2788	0.7829	21	22	18	22	16	18
Greece	0.7620	0.7915	0.7915	0.6767	0.7685	23	21	17	9	18	17
Germany	1.0000	1.0000	1.0000	0.8202	1.0000	1	1	1	6	1	1
Hungary	0.9179	0.8743	0.9179	0.4526	0.9165	11	17	9	15	7	9
Ireland	0.9073	1.0000	1.0000	1.0000	1.0000	12	1	1	1	1	21
Italy	0.9875	0.9653	0.9563	0.9494	0.9363	4	7	6	3	5	2
Latvia	1.0000	0.9839	1.0000	0.3867	1.0000	1	3	1	17	1	7
Lithuania	0.7751	0.7751	0.7751	0.2956	0.7751	22	23	19	20	17	19
Luxembourg	1.0000	1.0000	1.0000	1.0000	1.0000	1	1	1	1	1	23
Netherlands	0.9608	0.9463	1.0000	1.0000	1.0000	9	9	1	1	1	16
Poland	0.8059	0.8153	0.7963	0.2838	0.8059	20	20	16	21	15	11
Portugal	0.8930	0.8930	0.8930	0.5763	0.8930	14	14	11	13	10	10
Romania	0.9071	0.9071	0.9071	0.3105	0.9071	13	12	10	19	8	3
Slovakia	0.9936	0.8954	0.9936	0.5860	0.9932	2	13	2	11	2	12
Slovenia	0.8905	0.8785	0.8905	0.5826	0.8807	15	16	12	12	12	22
Spain	1.0000	1.0000	1.0000	0.8503	1.0000	1	1	1	5	1	4
Sweden	0.9644	0.9747	0.9495	0.6948	0.9747	8	5	7	7	3	1
United Kingdom	0.9916	0.9863	1.0000	0.9675	1.0000	3	2	1	2	1	5

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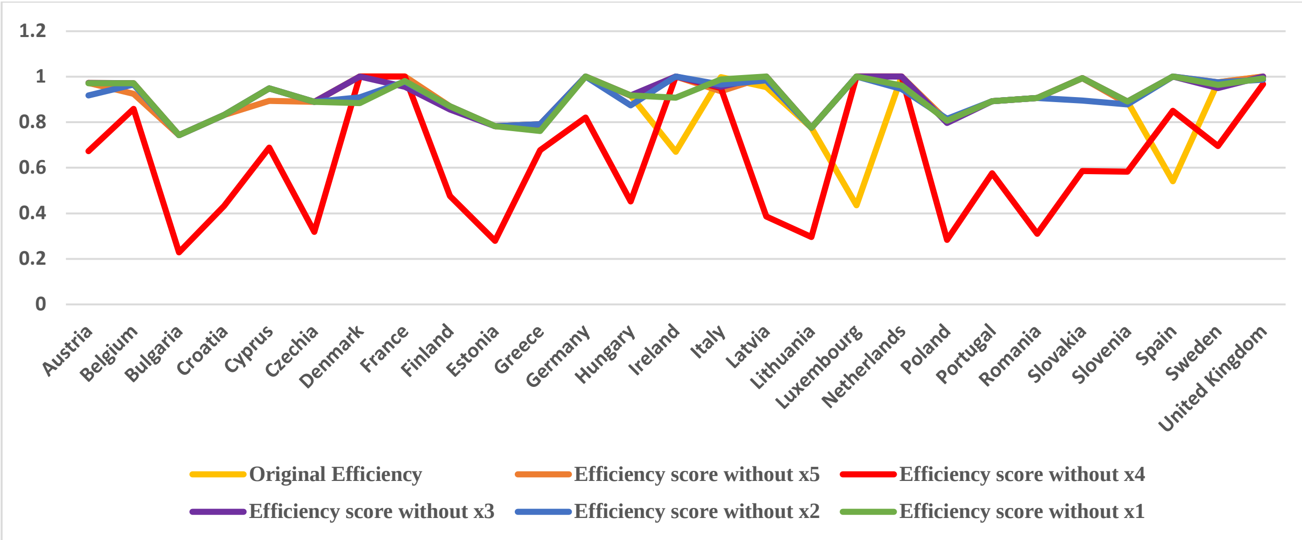

Figure 4: Changes in the efficiency score of economic countries after removing of input variables

Netherlands, and Slovakia.

Besides, the highest sensitivity after the energy source was related to the source of capital. Because the ranking and efficiency score of most countries have changed significantly after removing this index For example, some countries' ranking and performance have improved, such as Ireland and Greece. Hence these countries have performed well in the optimal use of capital resources compared to other countries. In contrast, the efficiency scores and rankings of some other countries have decreased after eliminating the capital index (Austria, Czech Republic, Germany, Latvia, etc.), which indicates the lack of proper performance of these countries in the use of capital. In addition to economic and environmental dimensions, the social dimension can also be paid for further research. Further, the dynamic network of DEA models, as well as mediating variables with further development, can be a topic for future discussions.

4.1. Strengths

In this research, we presented a model of network data envelopment analysis based on which the emission of undesirable greenhouse gases, the absorption of desirable gases by the environment, including forests, technology in environmental efficiency, and the variables of water consumption, energy consumption, labor, capital, raw materials (natural resources) in the economic efficiency sector and GDP as a mediating variable were studied. The proposed method calculates the efficiency, weight, and total efficiency of each stage alone.

4. Conclusion

The findings of this study indicate that none of the countries was recognized as total efficiency and as a result were unable to operate simultaneously in both the economic and the environmental efficiency phases. This is a special feature that belongs to the DEA network models that are not found in the classic models. Based on the results of sensitivity analysis, Germany was the only country that had the least changes after the removal of the indicators so that after the removal of the indicators of energy consumption, water consumption, labor, and raw materials no change in its ranking and efficiency score was observed. Hence, these countries performed very well compared to other countries in terms of optimal use of resources and can be selected as a model for other countries under study.

Authors' Contributions

Afarin Rezaei: Conceptualization ; Data curation ; Formal analysis ; Funding acquisition; Investigation ; Methodology ; Project administration; Resources; Writing-Review and Editing. **Hassan Dehghan Dehnavi:** Conceptualization; Funding acquisition; Investigation; Methodology; Project administration; Writing-Review and editing. **Hamid Babaei Meybodi:** Resources; Supervision; Validation; Visualization; Writing-original draft; Supervision; Validation; Visualization; Writing-original Draft. **Alireza Anvari:** Methodology; Project administration; Resources; Writing-Review and Editing.

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Conflicts of Interest

The Authors declare that there is no conflict of interest.

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References

1. Baah C, Opoku Agyeman D, Acquah IS, Agyabeng Mensah Y, Afum E, Faibil D, *et al*. Examining the Correlations between Stakeholder Pressures, Green Production Practices, Firm Reputation, Environmental and Financial Performance: Evidence from Manufacturing SMEs. *Sustain Prod Consum.* 2021; 27:100-14.

2. Ahmad S, Wong KY, Elahi H. Sustainability Assessment and Analysis of Malaysian food Manufacturing Sector—A Move towards Sustainable Development. *Adv Sci Lett*. 2017; 23(9): 8942-6.

3. Jiang B, Li Y, Lio W, Li J. Sustainability Efficiency Evaluation of Seaports in China: an Uncertain Data Envelopment Analysis Approach. *Soft Comput.* 2020; 24(4): 2503-14.

4. Liu HH, Huang JJ, Chiu YH. Integration of Network Data Envelopment Analysis and Decision-Making Trial and Evaluation Laboratory for the Performance Evaluation of the Financial Holding Companies in Taiwan. *MDE Manage Decis Econ*. 2020; 41(1): 64-78.

5. Grigoroudis E, Petridis K. Evaluation of National Environmental Efficiency underUncertainty Using Data Envelopment Analysis. *Underst Risks Uncertain Energy Clim Policy*. 2019; 161.

6. Robaina Alves M, Moutinho V, Macedo P. A New Frontier Approach to Model the Eco-Efficiency in European Countries. *J Clean Prod.* 2015; 103: 562-73.

7. Geamănu M. Economic efficiency and profitability. *Studia Universitatis Vasile Goldiş, Arad-Seria Ştiinţe Economice*. 2011; 21(2): 116-9 . Available from: URL: https://www.ceeol.com/search/article-detail?id=156526.

8. Pang R, Zhang X. Achieving Environmental Sustainability in Manufacture: A 28-year Bibliometric Cartography of Green Manufacturing Research. *J Clean Prod*. 2019; 233: 84-99.

9. Liu Y, Sun D, Wang H, Wang X, Yu G, Zhao X. An Evaluation of China's Agricultural Green Production: 1978–2017. *J Clean Prod*. 2020; 243: 118483.

10. Wang K, Yu S, Zhang W. China's Regional Energy and Environmental Efficiency: A DEA Window Analysis based Dynamic Evaluation. *Math Comput Model*. 2013; 58(5-6): 1117-27.

11. Yang Q, Wan X, Ma H. Assessing Green Development Efficiency of Municipalities and Provinces in China Integrating Models of Super-Efficiency DEA and Malmquist Index. *Sustain*. 2015; 7(4): 4492-510.

12. Zhou P, Poh KL, Ang BW. Data Envelopment Analysis for Measuring Environmental Performance. *In Handbook of Operations Analytics Using Data Envelopment Analysis. Springer, Boston; MA*. 2016; p. 31-49.

13. Liu X, Jie X. A Malmquist Index- Based Dynamic Industrial Green Efficiency Evaluation in Sichuan Province. *Int Conference Manag Sci Eng Manag. Springer, Cham*. 2017; 1361-73 .

14. Moutinho V, Madaleno M, Robaina M. The Economic and Environmental Efficiency Assessment in EU Cross- Country: Evidence from DEA and Quantile Regression Approach. *Ecol Indic.* 2017; 78: 85-97.

15. Vaninsky A. Energy- Environmental Efficiency and Optimal Restructuring of the Global Economy. *Energy*. 2018; 153: 338-48.

16. Halkos G, Petrou KN. Assessing 28 EU Member States' Environmental Efficiency in National Waste Generation with DEA. *J Clean Prod.* 2019; 208: 509-21.

17. Yang Z, Wei X. The Measurement and Influences of China's Urban Total Factor Energy Efficiency under Environmental Pollution: Based on the Game Cross-Efficiency DEA. *J Clean Prod*. 2019: 439-50.

18. Färe R. Measuring Farrell Efficiency for a Firm with Intermediate Inputs. *Academia Eco Papers*. 1991; 19(2): 329-40.

19. Tone K, Tsutsui M. Dynamic DEA: A Slacks-Based Measure Approach. *Omega*. 2010; 38(3-4): 145-56.

20. Färe R, Grosskopf S. Network DEA. *Socio-Eco Plan Sci*. 2000; 34(1): 35–49.

21. Yu MM. Assessing the Technical Efficiency, Service Effectiveness, and Technical Effectiveness of the World's Railways Through NDEA Analysis. *Transp Res Part A Policy Pract*. 2008; 42(10): 1283-94.

22. Hsieh LF, Lin LH. A Performance Evaluation Model for International Tourist Hotels in Taiwan—an Application of the Relational Network DEA. *Int J Hosp Manag*. 2010; 29(1): 14-24.

23. Holod D, Lewis HF. Resolving the Deposit Dilemma: A new DEA Bank Efficiency Model. *J Bank Financ*. 2011; 35(11): 2801-10.

24. Tavassoli M, Ketabi S, Ghandehari M. Developing a Network DEA Model for Sustainability Analysis of Iran's Electricity Distribution Network. *Int J Electrical Power Energy Sys*t. 2020; 122: 106187.

25. Cook WD, Zhu J, Bi G, Yang F. Network DEA: Additive Efficiency Decomposition. *Eur J Oper Res*. 2010; 207(2): 1122-9.

26. Greenland SJ. Future Sustainability, Innovation and Marketing: A Framework for Understanding Impediments to Sustainable Innovation Adoption and Corporate Social Responsibility. *In the Components of Sustainable Development . Springer; Singapore*. 2019; p. 63-80.

27. Ulman SR, Mihai C, Cautisanu C. Inconsistencies in the Dynamics of Sustainable Development Dimensions in Central and Eastern European Countries. *Pol J Environ Stud*. 2021; 30(3): 2779-98.

28. Rezaee Z, Tsui J, Cheng P, Zhou G. Business Sustainability in Asia: Compliance, Performance, and Integrated Reporting and Assurance. *John Wiley Sons*; 2019.

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