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Effectiveness of European Green Deal: Malmquist Index Analysis on 25 EU Countries*

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Abstract

The aim of the article is to assess the effectiveness of the European Green Deal (EGD) implementation in EU countries. The aim was to be achieved by using the Data Envelopment Analysis (DEA) model. The additional aim is to determine which countries are most effective in achieving the Green Deal goals by analyzing the Malmquist Index.

There are only few studies assessing the relative effectiveness of the EGD implementation through a comparative approach. There is a lack of studies assessing the degree of implementation of the Green Deal. There is also no development of the methods by which member states can achieve the main goal of the Green Deal, i.e. a 55% reduction in greenhouse gases by 2030. The small number of studies on the effectiveness of the implementation of the EGD goals was considered as a research gap.

The research used the DEA approach to assess the effectiveness of EGD implementation in the 25 EU countries in the period of 2013–2021, using the Eurostat indicators. An outcome-oriented DEA model was developed to examine relative efficiency, and Malmquist Index were calculated, which present the change in technical efficiency and technological changes over the two the same periods in the 25 countries studied.

The geometric mean of the Malmquist Index indicates an average increase of around 9% over the period studied. The results reveal significant differences in the efficiency of individual countries, with Finland, Sweden, Estonia and the Netherlands proving to be the most effective in implementing EGD, while Bulgaria, Ireland and Greece are the least effective. Countries with well-established environmental protection policies are better prepared to achieve EGD goals. Countries with a high dependence on fossil fuels, lower investment in green technologies and weaker governance structures have greater difficulties in achieving EGD goals.

Keywords: European Green Deal; DEA; effectiveness; Malmquist Index, European Union

Introduction

In December 2019, the European Commission presented a new climate strategy called the European Green Deal (von der Leyen, 2019). The aim is to transform the EU into a modern, resource-efficient and competitive economy with no net greenhouse gas emissions in 2050 (European Commission, 2019). The two main goals of the strategy are to reduce greenhouse gas emissions by at least 50% by 2030 and to achieve net zero greenhouse gas emissions by 2050. To monitor the implementation of the EDG, Eurostat introduced new statistics in March 2020 covering 26 indicators for the European Union as well as its particular Member States. These indicators are in three main areas: reducing climate impact, protecting the planet and health, and enabling a green and fair transition.

In less than five years since the EGD was launched, this plan has been modified by the adoption of FIT for 55 programme, which assumes quicker reduction of greenhouse gas emissions. These strategies face several challenges that hinder their full implementation and the achievement of ambitious climate and sustainability goals. First, the EGD does not have a comprehensive and detailed vision of the post-coal economy, which makes it

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difficult to define a clear path for further action (Papa *et al.,* 2021), especially for countries rich in hard coal and lignite deposits.

Secondly, the capacity to implement climate policy in individual EU Member States varies. Countries in Western and Northern Europe, which are generally more industrialized, have more resources and opportunities to achieve the EGD goals. On the other hand, Central and Eastern European countries face greater economic, political, and social barriers that contribute to increasing inequality (Hereu-Morales, Segarra and Valderrama, 2024). Key sectors, in particular raw material sourcing and heavy industry, face unique challenges in meeting the decarbonisation targets of the strategies. These industries require significant investments in new technologies, processes, and infrastructure to reduce emissions and fulfil the Green Deal goals, highlighting significant differences between EU countries (Pedersen *et al*., 2023).

There are various proposals in the literature to overcome these challenges. The need to implement a wider range of green industrial policies that focus on environmental sustainability and structural change are described by Pianta and Lucchese (2020). Ciot (2022) highlights the role of national and regional implementation plans, supported by recovery funds, which can provide adequate solutions. Rosenow (2022) argues that achieving the EU's ambitious emissions reduction targets will require the rapid introduction of clean energy technologies in various sectors. In order to implement most of these proposals and achieve the ambitious goals of the EGD, additional resources are needed, which are in fact quite limited. The most important question is therefore how to ensure the effective implementation of the EGD objectives. There are few studies on this subject in the literature. The aim of this study is to assess the effectiveness of the implementation of the European Green Deal in EU countries, using 26 indicators introduced by Eurostat as a comprehensive benchmarking framework. In particular, the study addresses the following questions: which countries are most effective in implementing EGD, and what factors contribute to their success? How can differences in implementation effectiveness between EU Member States be identified and reduced?

The Data Envelopment Analysis (DEA) model was used as a research tool in this paper. On its basis, the Malmquist indices were calculated. The DEA method was adopted due to its methodological rules and ability to assess relative effectiveness in multivariate contexts, as it allows multiple inputs and outputs to be evaluated simultaneously without the need for predefined weights. This approach is particularly suitable for capturing the complexity and multidimensionality of the implementation of the environmental aspects of EGD or the Sustainable Development Goals. The aim of the study is to rank countries based on their relative effectiveness in achieving EGD goals and to systematically assess differences in results. By addressing the under-researched topic of the practical effectiveness of EGD implementation, this study contributes to fill a gap in the literature.

The article is organized in a following way: first section provides a literature review on the indicators of the European Green Deal. The next part details the DEA's methodology. Then an empirical analysis in which EU countries are ranked according to the effectiveness of EGD implementation and the effectiveness of the measures implemented is presented (based on the Malmquist index). The last section contains conclusions.

Literature Review

The European Commission has proposed 26 indicators to measure progress in implementing the EGD targets and grouped them into three areas. Country-to-country comparisons under the first area include: greenhouse gas emissions (1, 2), share of renewable energy in total gross energy (3), primary energy consumption (4) and household energy consumption (5), climate-related economic losses due to extreme weather events (6). Finally, the Sustainable and Smart Mobility Strategy presented by the European Commission on 9th of December 2020 aims to transform the EU's transport system in line with the ambitions of the European Green Deal and its objectives (European Commission, 2020). The transition to low-emission mobility will be ensured through the introduction of zero-emission vehicles (7) and a change in the way people are transported by collective passenger transport (8) as well as freight (9).

The second group of 9 indicators, entitled "Protecting our planet and our health", is also closely linked to several plans and strategies supporting the Green Deal's goals in the areas of health and environmental protection. The Biodiversity and Environment Strategy (European Commission, 2020a) aims to stop the degradation of ecosystems, protect natural habitats and reduce pollution. The strategy aims to protect 30% of the EU's land and sea areas by 2030. This will be monitored by indicators measuring forest area (1), protected areas (2) and bird population size (3). In addition, in May 2021, the European Commission presented a plan (European Commission, 2021) that aims to significantly reduce air, water and soil pollution by 2030. Pollution-free environments must be created by reducing pollution at source, promoting cleaner industrial technologies and supporting sustainable production and consumption patterns. To measure its effectiveness, the plan includes a number of key indicators to track progress, including: use of hazardous chemicals (6), premature deaths (7), nitrate levels in groundwater (5) and generation of hazardous waste (8). Finally, the Farm to Fork Strategy published by the European

Commission in May 2020 (European Commission, 2020b) promotes sustainable agriculture by expanding organic farming (4), reducing the use of pesticides and reducing greenhouse gas emissions in agriculture. Indicators of sustainable food production include the level of pesticide residues in food, the use of antibiotics in livestock farming, and the reduction of various types of waste generation (8).

The last group, named as "enabling a green and just transition", includes 8 indicators: the first four indicators refer to the green transition (expanding renewable energy and reducing resource consumption) and the second four indicators are to perform "just transition" (transition to a low-carbon economy in a fair and acceptable way for all citizens). The strategy includes activities related to: the consumption of raw materials (1) and the use of materials in a circular loop (2). On the other hand, the Industrial Strategy for Europe, originally introduced in March 2020 and updated in May 2021, supports green innovation and sustainable production, *inter alia* measured by investment in R&D (3) and high-speed internet coverage (5) assessed as an investment in digital technologies, as well as overcoming market failures (Barteková and Boerkey, 2022). A just transition means that the majority of citizens accept this process. The key is to find a balance between environmental tax revenues (6), and environmental spending (7), greenhouse gas emissions (8), and having only a small proportion of the population that will not have enough financial resources to heat their homes (4).

As part of the Climate and Energy Strategy, the European Commission also supports the implementation of the EGD objectives through the reform of the EU Emissions Trading System, the extension of carbon prices to new sectors and the introduction of a border correction mechanism to prevent carbon leakage outside the EU (European Commission, 2021a).

Due to the early stage of implementation, there is a small number of publications discussing issues related to the implementation of EGD assumptions and the effects of their implementation. An earlier study (Ciot, 2022) focuses on the factors influencing capacity building and the prospects for Green Deal implementation, the geopolitical implications of the EDG are discussed by Leonard et al. (2021) and the potential pace of EGD implementation (von Homeyer, Oberthür and Dupont, 2022). Only one analysis of the implementation of the European Green Deal was found, using 26 indicators proposed by Eurostat. Ottomano Palmisano *et al.* (2025) used multi-criteria decision analysis (MCDA), in particular the PROME-THEE II method, to classify EU countries based on their EGD scores. Their study revealed significant differences in the progress made by EU countries in introducing EGD. Sweden, Austria and the Netherlands scored the highest, while Ireland, Luxembourg and Cyprus scored the worst.

There are also many publications examining the selection and use of indicators in models related to climate change, care for the natural environment or sustainable development. In the case of a large number of data compared with each other, there is a problem however of choosing a research method that would meet the challenges of an excessive number of variables (Zhou, Fan and Zhou, 2010).

One method of dealing with the problem of a large number of features is to use a composite index. They are used to aggregate variables and determine the rankings of countries according the average value of the composite index (Zhou, Ang and Poh 2006; Rogge, 2018).

Another method used in environmental analyses is Data Envelopment Analysis (DEA). Both the CCR, BCC, SBM and "Benefit of the Doubt" (BoD) method are used, as well as models with undesirable inputs and outputs in DEA models in static and dynamic versions (Lewis and Sexton, 2004; Zhou, Ang and Poh, 2006; Cherchye *et al.*, 2008; Guo, Yu and See, 2024).

Research Methodology

Data

Data from the Eurostat website, focusing on the Green Deal was used - 20 variables for 25 EU countries from 2013 to 2021 were used. Due to data gaps, Cyprus and Malta were omitted, and the United Kingdom was excluded due to Brexit. The analysis did not include 5 indicators with incomplete data for the entire study period E_1.3, E_1.6, E_2.3, E_2.5, E_2.6 (in the case of using the DEA model, the values cannot be zero (variable E_1.3)). (See: appendix). Data from 2013 to 2021 were analysed, to develop a tool for monitoring the EGD, which was launched in 2019. However, numerous EU directives aimed at mitigating climate impact, protecting the environment and public health, and facilitating a green transition have been in effect for many years. For instance, the Natura 2000 program is rooted in the “Birds Directive” (originally adopted in 1979 and revised in 2009) and the “Habitats Directive” of 1992, like the development of organic farming. All EU member states, including those that joined after 2013 (such as Croatia), are required to adhere to these directives. Therefore, 2013 (2014) was selected as the starting point for this analysis.

Methodology

The non-parametric DEA method allows for assessing the relative efficiency of the compared objects, called Decision Making Units (DMUs), described by multiple inputs and multiple outputs. It is not necessary to know a functional relationship between the inputs and the outputs. The evaluation of the efficiency involves determining the DMUs creating the "best practice" and comparing them to other objects (Cooper, Seiford and Zhu, 2011).The CCR (Charnes-Cooper-Rhodes) model, with constant returns to scale, was chosen.

Since only one variable was adopted as the expenditure – E_3.7 Expenditure on environmental protection, in % of GDP, the model was results-oriented. The outputs were E_1.4- renewable energy by sector in % of gross final energy consumption, E_2.7 Premature deaths, in rate per 100 000 people, E_3.2 Circular material use rate, in % of material input for domestic use, E_3.8 Greenhouse gas emissions intensity of employment, in tonnes of GHG emissions per employed person.

In the output-oriented model, the effects are maximized without increasing any of the observed inputs (Cooper, Seiford and Tone, 2000).

The efficiency score θ_o^* of DMU_o $(o = 1, \ldots, n)$ is calculated for given amounts of outputs $y_{rj},\ r = 1, \ldots, s$ and inputs $y_{ij},\ i = 1, \ldots, m$, where $j = 1, \ldots, n$. The output-oriented CCR model is shown below (Zhu and Cook, 2007):

$$max\theta + \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \quad (1)$$

subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_{jo} + s_i^- = x_{io} \quad i = 1,2, \ldots, m \quad (2)$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = \emptyset y_{ro} \quad r = 1,2, \ldots, s$$

$$\lambda_j \geq 0 \quad j = 1,2, \ldots, n \quad (3)$$

Using the model, the 25 countries of the EU were analysed. Data from the years 2013 and 2019 and 2021 from the Eurostat database were used.

Table 1 presents the basic characteristics of the variables used in the DEA model.

Table 1. Basic characteristics of the variables used

Variables	Min	Max	Average	Standard deviation
2013				
I_3.7	0.30	1.50	0.81	0.31
O_1.4	3.49	50.15	20.05	10.98
O_2.7	7.00	187.00	72.12	41.45
O_3.2	1.70	26.80	8.80	6.16
O_3.8	4 573.18	17 544.49	8 267.59	3 395.93
2019				
I_3.7	0.20	1.40	0.73	0.30
O_1.4	7.05	55.79	23.34	11.65
O_2.7	3.00	142.00	51.04	34.06
O_3.2	1.40	25.60	9.19	6.22

O_3.8	4 439.33	14 722.53	7 803.37	2 838.04
2021				
I_3.7	0.20	1.40	0.76	0.30
O_1.4	11.74	62.57	25.26	12.14
O_2.7	3.00	158.00	57.56	41.9
O_3.2	1.40	28.50	9.36	6.95
O_3.8	4 090.76	13 090.83	7 230.68	2 437.85

Source: own calculations

Where: I=input, O=output

All variables used in the model are indicators, which allows for the use of comparative analysis between different countries. The only issue is the values of the 3.8 variable, which are times higher than the values of the other variables.

Monitoring the performance of individual countries over time, in the implementation of the EGD objectives, is essential. The Malmquist Index provides the ability to compare units between two time periods. It was proposed by Malmquist (1953) and eventually developed by Fare, Grosskopf and Knox –Lowell (1994) as an indicator of Malmquist-DEA productivity. An crucial feature of this is that it can decompose the overall measure of efficiency into two components, the EFF measuring changes in technical efficiency (the so-called catching-up effect) and the TCH measuring changes in technology.

$$M_0 = EFF * TCH = \frac{\theta_0^t(x_o^t, y_o^t)}{\theta_0^{t+1}(x_o^{t+1}, y_o^{t+1})} * \left[\frac{\theta_0^{t+1}(x_o^{t+1}, y_o^{t+1})}{\theta_0^t(x_o^{t+1}, y_o^{t+1})} * \frac{\theta_0^{t+1}(x_o^t, y_o^t)}{\theta_0^t(x_o^t, y_o^t)}\right]^{\frac{1}{2}} \quad (4)$$

where: M_o determines the changes in efficiency between period t and period t + 1,

$\theta_0^t(x_o^t, y_o^t)$ – efficiency for the first year within the available technology and variable values,

$\theta_0^{t+1}(x_o^{t+1}, y_o^{t+1})$ – efficiency for the second year within the available technology and variable values,

$\theta_0^t(x_o^{t+1}, y_o^{t+1})$ – efficiency using the production technology from the first year for the data of the second year,

$\theta_0^{t+1}(x_o^t, y_o^t)$ – efficiency using the production technology from the second year for the data from the first year

The EFF component is subject to change in the event of an earlier change at t+1 that, how the units studied managed to catch up with the frontier. The TCH component changes in the “production” frontier (i.e. a shift in best practice technology) option t to the change in t+1. In this way, the change in efficiency can be applied, and also whether this change is due to pure efficiency or is due to changes in technology, e.g. the use of electricity from hydropower sources.

The EFF component measures changes in technical performance from period to period. This means that it measures how the tested individuals managed to reach the limit. The TCH component measures changes in the "production" boundary (i.e., the shift in best practice technology) from period to period. In this way, changes in efficiency can be determined, as well as whether this change is the result of pure efficiency improvements or is due to changes in technology, e.g. consumption of energy from renewable sources

Results

In the first step of empirical analysis used Data Envelopment Analysis. Table 2 presents DEA scores for 25 EU countries in the years 2013, 2019, and 2021, along with their respective rankings. These scores assess the efficiency of European Green Deal implementation, reflecting the ability of each country to convert resource into “green” outcomes effectively. Higher DEA scores indicate greater efficiency in achieving green deal goals, while lower scores suggest challenges in policy implementation and resource allocation.

Table 2 Performance indicators and position in the ranking of countries in 2013, 2019 and 2021

NO	DMU	EF_2013	rank1	EF_2019	rank2	EF_2021	rank3
1	Austria	1.1161	4	1.3127	4	1.2595	4
2	Belgium	0.8688	11	0.8982	8	0.9317	8
3	Bulgaria	0.6331	23	0.6408	23	0.6185	22
4	Croatia	0.8086	14	0.7963	11	0.7814	13
5	Czechia	0.6368	22	0.6767	21	0.6774	18
6	Denmark	0.7891	16	0.7742	14	0.8167	10
7	Estonia	0.9255	8	1.4376	3	1.7172	3
8	Finland	1.5431	2	1.9184	1	2.0662	1
9	France	1.0850	5	1.1558	5	1.1082	5
10	Germany	0.8644	12	0.8699	9	0.8440	9
11	Greece	0.5867	24	0.6119	24	0.6160	23
12	Hungary	0.7725	17	0.6829	20	0.7094	16
13	Ireland	0.5500	25	0.5467	25	0.5753	25
14	Italy	1.0093	6	1.0212	6	0.9877	7
15	Latvia	0.8695	10	0.7867	13	0.7980	11
16	Lithuania	0.6884	20	0.6519	22	0.6499	21
17	Luxembourg	0.8976	9	0.6860	19	0.5889	24
18	Netherlands	1.1236	3	0.9776	7	1.0649	6
19	Poland	0.9347	7	0.7318	16	0.6694	19
20	Portugal	0.7363	18	0.7197	17	0.7366	15
21	Romania	0.7310	19	0.6896	18	0.6540	20
22	Slovakia	0.6442	21	0.7333	15	0.7026	17
23	Slovenia	0.7979	15	0.8100	10	0.7909	12
24	Spain	0.8293	13	0.7893	12	0.7495	14
25	Sweden	1.8802	1	1.7959	2	1.8396	2

Source: own calculations

The results indicate clear performance leaders, with Sweden and Finland consistently achieving the highest DEA scores. Sweden ranks first in the initial period of the survey, in the next two years Finland is the leader, presenting exceptional performance in implementing Green Deal policies. Similarly, Estonia, which in 2013 was 8th, in the next two years took 3rd place. The results of these countries suggest effective policy frameworks, high investment in green technologies and a well-structured transition to sustainable practices. Initially, the 3rd place was held by the Netherlands, but in the following years it was overtaken by Austria, France, Italy. Poland, initially occupying the 7th position, was overtaken by many countries in the following years and finally, in 2021, was in the 19th position.

On the other hand, countries such as Ireland, Greece, Bulgaria, are among the worst rated in terms of DEA effectiveness In 2021, Luxembourg also joins this group of worst countries. Ireland ranks last in all the years studied, suggesting a persistent inefficiency in the implementation of the European Green Deal. Lithuania and Romania also perform poorly, likely due to structural barriers, dependence on carbon-intensive industries and financial constraints to adopt green policies.

Over time, some significant changes in performance rankings are observed. Belgium, Denmark, Czechia and Slovakia, which achieved significant improvements, moving up several places between 2013 and 2021, suggesting progress in green growth efforts. Romania and Spain and Slovakia, on the other hand, are experiencing fluctuations, indicating inconsistent policy effectiveness and potential challenges in maintaining sustainable progress.

In the group with a strong downward trend were Luxembourg and Poland.

In the second stage of the empirical analysis, the Malmquist indices were calculated on the basis of the DEA model established in the first stage. Table 3 presents the results of the Malmquist Index for 25 EU countries in the years 2013 - 2019 - MI 1 and 2019 - 2021 - MI 2.

Since the MI is decomposed for all countries that are in the relevant calculation years (EFF 1 and EFF 2), which are recognized as the units of the study, it was possible to reach the speed limit (catching up). The second component of the Malmquist index is the technological one. This component (TCH 1 and TCH 2) validates the change in the production boundary (i.e. the change in technology) from the first t to the next t+1. In this way, it is possible to determine the effects in the case of also whether this change is a side effect in the scope of the application of European Green Deal.

Since the MI is decomposed for all the countries surveyed in the indicated years, technical efficiency (EFF 1 and EFF 2) was calculated, which measures how the surveyed units managed to reach the limit of effectiveness. The second component of the Malmquist index is technological efficiency. This component (TCH 1 and TCH 2) measures changes in the production frontier (i.e. changes in technology) of a period to a period. In this way, changes in efficiency can be determined, as well as whether this change is the result of efficiency improvements in the implementation of the EGD.

Table 3 Malmquist indicator results in the analyzed years

NO	DMU	MI 1	EFF 1	TCH 1	MI 2	EFF 2	TCH 2
1	Austria	1.2023	1.1761	1.0223	1.1003	0.9595	1.1467
2	Belgium	1.1484	1.0338	1.1109	1.0774	1.0372	1.0387
3	Bulgaria	1.0497	1.0120	1.0372	0.9920	0.9652	1.0277
4	Croatia	1.0466	0.9848	1.0628	1.0319	0.9812	1.0517
5	Czechia	1.1150	1.0626	1.0493	1.0316	1.0011	1.0305
6	Denmark	1.0337	0.9812	1.0536	1.0535	1.0548	0.9987
7	Estonia	1.6277	1.5533	1.0479	1.0028	1.1946	0.8394
8	Finland	1.3789	1.2432	1.1091	1.0050	1.0770	0.9331
9	France	1.1624	1.0652	1.0912	1.0465	0.9589	1.0913
10	Germany	1.1549	1.0065	1.1475	1.0236	0.9702	1.0551
11	Greece	1.0757	1.0428	1.0315	1.0333	1.0067	1.0263
12	Hungary	0.9326	0.8840	1.0549	1.0744	1.0388	1.0343
13	Ireland	1.0325	0.9940	1.0387	1.0410	1.0524	0.9892
14	Italy	1.1464	1.0117	1.1332	0.9742	0.9672	1.0072
15	Latvia	0.9926	0.9048	1.0971	1.0703	1.0144	1.0550
16	Lithuania	0.9868	0.9470	1.0421	1.0259	0.9969	1.0291
17	Luxembourg	0.8720	0.7642	1.1411	0.8845	0.8585	1.0302
18	Netherlands	1.0825	0.8700	1.2443	1.1142	1.0893	1.0228
19	Poland	0.8979	0.7830	1.1468	0.9356	0.9148	1.0228
20	Portugal	1.0522	0.9774	1.0765	1.0886	1.0234	1.0637
21	Romania	1.0112	0.9434	1.0719	0.9970	0.9483	1.0514
22	Slovakia	1.1943	1.1383	1.0492	0.9935	0.9582	1.0369

23	Slovenia	1.1053	1.0151	1.0889	0.9941	0.9765	1.0180
24	Spain	1.0397	0.9518	1.0923	0.9910	0.9495	1.0438
25	Sweden	1.2036	0.9552	1.2601	1.1244	1.0243	1.0976
	Geometric mean	1.0925	1.0019	1.0904	1.0268	0.9987	1.0281
	Max	1.6277	1.5533	1.2601	1.1244	1.1946	1.1467
	Min	0.8720	0.7642	1.0223	0.8845	0.8585	0.8394

Source: own calculations

The geometric mean MI indicates an average increase in productivity in the first period under study by 9.25%. The increase in the Malmquist index was almost entirely due to a technological change, i.e. moving the limit of "production" (9%). The increase in technical efficiency was much smaller (about 0.2%). The highest value of the Malmquist index was achieved in the analysed period by Estonia (62.8%), hence the shift of Estonia in the efficiency ranking from 8th to 3rd place (Table 2). The countries that recorded a high change in IM 1 were Finland (37.9%), Sweden (20.4%), Austria (20.2%), Slovakia (19.4%). There were also 5 countries for which the Malmquist index was below 1. These are: Luxembourg (0.872%), Poland (0.898%), Hungary (0.933%), Lithuania (0.987%) and Latvia (0.993%). All countries during this period achieved an increase in technological efficiency, and 12 countries moved away from the limit of "production" – technical efficiency decreased. In the second period under review, the average increase in the Malmquist index was lower than in the first period (2.68%). There was a regression in technical efficiency, i.e. reaching the limit of efficiency of individual countries, while there were technological changes (TCH index = 2.81%). During this time, the highest value of MI2 was recorded by: Sweden (12.4%), followed by Netherland (11.4%), Austria (10.0%), Portugal (8.9%). In 8 countries, the MI decreased, the most in Luxembourg (0.89%) and in Poland (0.94%). The average technical efficiency was below 1, therefore there was a regression, the highest in Luxembourg (0.86%) and Poland (0.91%, i.e. it decreased by 0.09%). The largest changes in approaching the efficiency limit were achieved by: Estonia (19.5%), Netherland (8.9%) and Finland (7.7%). The largest regression in technical efficiency was recorded in Luxembourg and Poland. As in the previous period, there was a change in the "production" technology. The highest values of the TCH 2 index were achieved by: Austria (14.7), Sweden (9.8%) and France (9.1%). The highest decline in this indicator was recorded in Estonia (0.84%), Finland (0.93%). A value of the technological efficiency index below unity was also recorded by Ireland and Denmark.

Conclusions

The DEA analysis enables to assess the effectiveness of the implementation of the Green Deal in EU countries. The results reveal significant differences in efficiency across countries, with Finland, Sweden, Estonia and Netherland proving to be the most effective in implementing EGD, while Bulgaria, Ireland and Greece have the lowest performance scores, indicating structural and economic challenges. The results indicate that countries with well-established environmental policies, significant financial resources and a strong institutional framework are better equipped to achieve the EGD objectives. By contrast, countries with a high dependence on fossil fuels, less investment in green technologies and weaker governance structures have more difficulty achieving the SDGs. In addition, large EU economies such as Germany, France, Italy have performed above average, suggesting that economic strength alone does not lead to the successful implementation of the Green Deal, but leaves more alternatives and is not proposed as an obstacle to implementation. The Malmquist index showed strong technological changes and very small changes in technical efficiency. The countries with the highest efficiency also had the largest share in technological change. On the other hand, two countries, Luxembourg and Poland, recorded the largest regression.

The DEA nonparametric model test method used has also some limitations. First, the proposed DEA model assumes permanent economies of scale, which may lead to overestimation of efficiency in smaller countries. Second, the analysis does not take into account the dynamic political and economic changes that may affect the implementation of the Green Deal. Third, the availability of data for some Eurostat indicators is limited, which may affect the accuracy of the results, especially for countries with incomplete data sets. Only 5 variables (one input and 4 outputs) were used to assess the effectiveness out of 26 indicators adopted as benchmark indicators. While this study provides valuable insights into the effectiveness of EGD implementation (subject to some limitations). The analysis is based on a specific set of Eurostat indicators, which, while comprehensive, may not cover all aspects of the green transition. Expanding the dataset to include additional socio-economic and policy variables could provide deeper insight into the factors influencing the effectiveness of achieving the Green Deal objectives.

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Appendix 1. European Green Deal Indicators

Indicator
E_1.1 Greenhouse gas emissions
E_1.2 Greenhouse gas emissions by sector
E_1.3 Climate related economic losses (incomplete data)
E_1.4 Renewable energy by sector
E_1.5 Primary energy consumption
E_1.6 Final energy consumption in households by use (incomplete data)
E_1.7 Zero-emission vehicles
E_1.8 Passenger transport by mode
E_1.9 Freight transport by mode
E_2.1 Forest and other wooded land
E_2.2 Protected areas
E_2.3 Common bird index (incomplete data)
E_2.4 Area under organic farming
E_2.5 Nitrate in groundwater (incomplete data)
E_2.6 Consumption of chemicals by hazardousness(incomplete data)
E_2.7 Premature deaths
E_2.8 Generation of waste by hazardousness
E_3.1 Raw material consumption
E_3.2 Circular material use rate
E_3.3 Gross domestic expenditure on R&D
E_3.4 Population unable to keep home adequately warm
E_3.5 High-speed internet coverage
E_3.6 Environmental tax revenues
E_3.7 Expenditure on environmental protection
E_3.8 Greenhouse gas emissions intensity of employment