EKONOMIA I PRAWO. ECONOMICS AND LAW
Volume 25, Issue 2, 2026
p-ISSN 1898-2255, e-ISSN 2392-1625
www.apcz.umk.pl/EiP

Original article
received 24.09.2025; accepted 30.04.2026; published 30.06.2026
doi: 10.12775/EiP.2026.8

Effectiveness of European Green Deal implementation in EU countries: a DEA/Benefit-of-the-Doubt approach

JUSTYNA KUJAWSKA
Department of Finance, Faculty of Management and Economics, Gdansk University of Technology, Narutowicza 11/12, 80-233 Gdansk, Poland
Justyna.Kujawska@pg.edu.pl
ORCID: 0000-0002-0416-3048

MAGDALENA OLCZYK
Department of Economics, Faculty of Management and Economics, Gdansk University of Technology, Narutowicza 11/12, 80-233 Gdansk, Poland
Magdalena.Olczyk@pg.edu.pl
ORCID: 0000-0002-4880-5890

Abstract

Motivation: The European Green Deal (EGD) provides a common EU framework for climate neutrality, resource efficiency and a just transition, but Member States differ markedly in structural conditions and implementation capacity. Existing assessments rely mostly on monitoring exercises, composite indicators or MCDA rankings; less attention has been paid to frontier-based efficiency benchmarking of EGD outcomes. **Aim:** The study assesses relative EGD effectiveness in 25 EU countries using a DEA/Benefit-of-the-Doubt approach and Eurostat EGD indicators. The analysis covers 2013–2021, with 2019 treated as the strategic reference point. A SAW index is calculated from 20 transformed indicators, while the DEA/BoD model uses five indicators selected through correlation analysis, variance analysis, PCA and LASSO.

Results: The results show substantial heterogeneity. Sweden, Latvia and Estonia hold strong positions in both the composite indicator and DEA/BoD assessment. In 2021, the efficiency-frontier or super-efficient group includes Sweden, Latvia, Lithuania, Portugal, Estonia, Ireland, the Netherlands, Croatia and Finland, whereas Czechia, Belgium, Poland and Bulgaria show the largest efficiency reserves. Contribution-share and robustness checks indicate the importance of waste generation and PM2.5-related premature mortality. DEA/BoD complements ranking-based assessments by identifying benchmark countries, frontier distance and efficiency reserves.

Keywords: European Green Deal; Data Envelopment Analysis; Benefit-of-the-Doubt; efficiency frontier; European Union; Eurostat indicators

JEL: Q58; C14; O52

1. Introduction

In December 2019, the European Commission presented the European Green Deal (EGD) as a new growth strategy intended to align climate neutrality, resource efficiency, competitiveness and social fairness within a single policy framework (European Commission, 2019; von der Leyen, 2019). The EGD was subsequently strengthened by the European Climate Law, which made climate neutrality by 2050 legally binding and set the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030 compared with 1990 levels (European Union, 2021c). Its implementation is monitored through Eurostat indicators grouped around three policy areas: reducing climate impact, protecting the planet and human health, and enabling a green and just transition. These indicators are important because the EGD is not only a climate policy package; it also concerns the transformation of energy systems, mobility, industrial structures, circular economy practices, environmental protection and distributive fairness.

Despite this common strategic framework, implementation of the EGD is not taking place under homogeneous conditions. More than five years after the announcement of the EGD, recent monitoring by the Joint Research Centre shows that progress has been achieved in several policy areas, but acceleration is still required for many quantified targets and data are not yet available for all targets (Marelli et al., 2025). EU countries differ in energy mix, fossil-fuel dependence, industrial specialisation, innovation capacity, fiscal space, administrative effectiveness, and social exposure to transition costs. The COVID-19 pandemic, the energy crisis, and the geopolitical shock caused by Russia's invasion of Ukraine have further increased pressure on energy security and public finances, while also accelerating the need for clean-energy investment (von Homeyer et al., 2022; Rosenow, 2022; Black & Cisternino, 2025). Recent research also shows that the EGD may strengthen environmental ambition, but its territorial and socio-economic consequences are uneven across countries and regions (Hereu-Morales et al., 2024; Koundouri et al., 2024; Michalewska-Pawlak, 2024; Topcu et al., 2025). The research problem is therefore not limited to whether EU countries formally implement the EGD; it concerns how effectively different Member States convert their structural conditions and observable sustainability outcomes into progress towards the EGD objectives.

The need for comparative assessment has been increasingly recognised in recent literature. Multi-criteria and composite-indicator studies have evaluated EGD performance by combining indicators on climate, energy, pollution, transport, circularity, and socio-economic transition (Ozdemir et al., 2024; Tutak & Brodny, 2024; Ottomano Palmisano et al., 2025; Olczyk & Kuc-Czarnecka, 2025; Karadağ et al., 2025). These studies provide valuable evidence on the uneven pace of EGD implementation and often identify strong performance among Northern and Western European countries, while highlighting persistent constraints in several Central, Eastern and Southern European Member States. They also demonstrate that monitoring the EGD should move beyond single indicators, as progress in renewable energy, transport decarbonisation, air quality, waste reduction and greenhouse gas intensity is multidimensional and may involve trade-offs.

However, an important research gap remains. Most existing assessments are ranking-oriented and rely on composite indicators or multi-criteria decision-making methods, including PROMETHEE II, MAIRCA, CoCoSo, or related approaches. Such methods are useful for ordering countries according to explicit preference functions, normalisation rules, and weighting schemes. However, they are less suited to identifying which countries form an efficiency frontier and which can serve as feasible benchmarks for others. In contrast, Data Envelopment Analysis (DEA), particularly its Benefit-of-the-Doubt (BoD) formulation, evaluates relative efficiency by allowing the weights of indicators to be determined endogenously for each decision-making unit within a common benchmarking framework (Cherchye et al., 2007; Camanho et al., 2023; Walheer, 2024). This distinction is central for policy evaluation. A DEA/BoD approach does not merely ask which country scores highest in an aggregate ranking; it asks which country achieves the best relative performance given the multidimensional set of EGD outcomes and which peer countries define the frontier of attainable performance.

Against this background, the main objective of the study is to assess the relative effectiveness of EGD implementation in EU countries using the DEA/BoD approach and Eurostat's EGD indicator framework. Although 2019 is used as the strategic reference point because it marked the announcement of the EGD, the empirical window covers 2013–2021. The pre-2019 observations are not interpreted as evidence of EGD implementation, but as a structural baseline against which the first observable post-announcement outcomes can be assessed. This baseline is justified because the EGD did not emerge in a regulatory vacuum: several policy areas later integrated into the EGD had already been governed by the EU environmental acquis, including biodiversity protection, climate mitigation, pollution reduction, and energy transition. After Croatia's accession in 2013, the analysed Member States operated under a broadly common EU environmental framework, including obligations linked to Natura 2000, the Birds Directive, and the Habitats Directive. Therefore, the 2013–2021 window captures both pre-existing national trajectories and early post-2019 outcomes, while avoiding the misleading assumption that the EGD itself was implemented before 2019. The analysis covers 25 EU countries and applies a multi-stage selection procedure to identify indicators that best represent the multidimensional character of EGD implementation. The following research questions are addressed: (RQ1) How effective are the EU countries included in the dataset in implementing the EGD? (RQ2) Which countries serve as efficiency benchmarks for EGD implementation? (RQ3) Which indicators best capture the multidimensional character of the EGD within the DEA framework? (RQ4) How does a DEA-based assessment complement earlier ranking-based and MCDA-based evaluations?

The novelty of the article lies in shifting the assessment of EGD implementation from a purely ranking-based perspective to an efficiency-frontier perspective. The scientific contribution is threefold. First, the study extends the literature on EU climate and energy policy evaluation by applying DEA/BoD to the Eurostat EGD monitoring framework. Second, it combines DEA with a transparent, multi-stage statistical selection of indicators, reducing redundancy and strengthening the interpretability of the final model. Third, it identifies benchmark countries and those with efficiency reserves, thereby providing information not available from composite rankings alone. The findings have two types of implications. Scientifically, the study contributes to the literature on sustainability measurement by demonstrating how DEA/BoD can complement composite-indicator and MCDA approaches through endogenous weighting, which reduces the arbitrariness of ex ante weights. From a policy perspective, it provides a benchmarking tool that may support differentiated intervention, particularly for countries with structural efficiency reserves. The article is organised as follows. Section 2 presents the literature review on EGD implementation, with particular attention to existing assessment methods and the distinction between MCDA-based rankings and DEA-based efficiency analysis. Section 3 describes the data, indicator selection, and DEA/BoD methodology. Section 4 presents the empirical results, including relative efficiency scores, benchmark countries, and cross-country performance patterns. Section 5 discusses the findings in relation to previous studies, structural differences between countries, and policy implications. The final section summarises the main conclusions, limitations, and future research directions.

2. Literature review

The European Green Deal has generated a rapidly expanding body of literature that can be organised into four interrelated strands: policy and institutional analyses of the EGD, empirical monitoring of implementation progress, MCDA and composite indicator assessments, and efficiency-oriented studies using frontier methods. This structure is important because the EGD is not a single environmental target; it is a multidimensional governance framework linking decarbonisation, resource efficiency, biodiversity, transport, health protection, and social fairness. Consequently, assessing its implementation requires methods capable of handling multiple, partly non-commensurable policy outcomes.

The first strand of the literature examines the institutional and political economy foundations of the EGD. Early studies emphasised that the EGD should not be understood solely as an environmental agenda, but also as an industrial, fiscal, and social transformation strategy (Pianta & Lucchese, 2020; Sikora, 2021). Leonard et al. (2021) highlighted the geopolitical dimension of the EGD, particularly the external effects of carbon pricing, energy import dependence, and trade adjustment. Von Homeyer et al. (2022) showed that the energy crisis created new implementation pressures but also strengthened the strategic rationale for accelerating clean energy. These studies clarify the policy context, but they usually do not provide a quantitative, country-level efficiency assessment.

A second group of studies focuses on the territorial and institutional unevenness of EGD implementation. Ciot (2022) showed that Central and Eastern European countries face specific implementation barriers related to inherited energy systems, lower fiscal capacity, and the need for stronger administrative coordination. Michalewska-Pawlak (2024) analysed the impact of the EGD on EU regional policy after 2021 and argued that climate neutrality, environmental protection, and biodiversity have become horizontal priorities in cohesion policy. This finding is relevant for efficiency analysis because countries and regions do not begin the transition from the same structural position. EGD performance therefore depends not only on environmental ambition, but also on the capacity to absorb funds, coordinate investment, and manage place-based transition costs.

Recent sustainability assessments also show that the EGD is unevenly aligned with different dimensions of sustainable development. Hereu-Morales et al. (2024) conducted a systematic analysis of environmental sustainability in the EGD and indicated that implementation challenges remain considerable. Koundouri et al. (2024), using machine-learning text mining of 74 EGD policy documents from 2019–2023, found strong alignment with

SDGs related to clean energy, climate action, and sustainable consumption, but weaker integration of social objectives such as poverty, inequality, health, and decent work. This imbalance supports the view that EGD implementation should be assessed using a multidimensional framework rather than climate indicators alone.

The third strand of the literature develops empirical tools for monitoring EGD progress. The Joint Research Centre report by Marelli et al. (2025) presents one of the most comprehensive policy-monitoring exercises, covering 154 quantifiable targets from 44 policy documents across climate, energy, circular economy, transport, agriculture, biodiversity and pollution. In the academic literature, Olczyk and Kuc-Czarnecka (2025) introduced the European Green Deal Index as a composite tool for monitoring the EU's Green Deal strategy. Their approach is valuable because it consolidates heterogeneous indicators into an interpretable index and reveals cross-country divergence. However, composite indices typically require aggregation rules that may affect the ranking of countries, especially when weights or normalisation choices change (OECD, 2008; Saisana et al., 2005).

Several recent studies have used multi-criteria methods to assess EGD implementation. Ozdemir et al. (2024) proposed a multi-criteria assessment framework for Green Deal performance and demonstrated that EGD evaluation benefits from structured criteria and sensitivity to different sustainability dimensions. Tutak and Brodny (2024) assessed disparities among EU-27 countries in the implementation of EGD strategy goals using a European Green Deal Index based on 18 indicators and a CoCoSo-based multi-criteria approach with hybrid weighting. Their results for 2019–2021 identified Sweden, Denmark and the Netherlands as high performers and showed weaker implementation in many newer Member States. Ottomano Palmisano et al. (2025) applied PROMETHEE II to Eurostat EGD indicators and ranked EU countries according to progress towards EGD implementation. Karadağ et al. (2025) extended the MCDA literature by proposing a hybrid model combining subjective and objective weighting to evaluate Green Deal compliance performance in Türkiye.

Taken together, these studies make an important contribution by moving EGD monitoring beyond isolated indicators. Their limitation lies not in a lack of empirical relevance, but in their evaluation logic. Most translate multiple indicators into a final ranking of countries. Such rankings are useful, but they may obscure the distance to feasible best practice, the peer countries that define that benchmark, and the extent of country-specific efficiency reserves. They are also sensitive to normalisation, preference thresholds, and weighting assumptions.

The closest reference point is Ottomano Palmisano et al. (2025), which applies PROMETHEE II to rank EU countries according to progress towards EGD implementation. The present article differs from that study in three specific respects: it does not construct a preference-based country ranking; it applies DEA/BoD to identify a relative efficiency frontier and peer benchmarks; and it combines this frontier analysis with systematic indicator selection. Thus, the empirical question shifts from which country ranks higher to which countries define attainable best practice and which countries have efficiency reserves relative to comparable peers.

DEA and the Benefit-of-the-Doubt approach therefore provide a complementary perspective. In the BoD model, a composite indicator is constructed by allowing each country to select the most favourable feasible weights for its own performance profile, subject to the restriction that the same weighting system cannot allow any country to exceed the frontier (Cherchye et al., 2007, 2008). This reduces the arbitrariness of uniform ex ante weights and is useful when the theoretical importance of EGD indicators varies across countries due to different energy mixes, industrial structures, or transition constraints. DEA results must still be interpreted carefully, as they are relative, deterministic, and sensitive to the selected variables and outliers (Dyson et al., 2001; Simar & Wilson, 1998).

This study addresses this gap directly. Existing monitoring, composite indicator, and MCDA studies document uneven progress across sectors and countries, but less attention has been given to the relative efficiency of EGD implementation using a DEA/BoD framework combined with systematic variable selection. The present analysis therefore shifts from a purely descriptive or preference-based evaluation of progress to an efficiency-based benchmarking exercise. This enables identification not only of high- and low-performing countries, but also of the policy-relevant frontier against which EGD implementation can be compared.

3. Research methodology

3.1. Data source, country coverage and empirical period

The empirical analysis is based on Eurostat's European Green Deal (EGD) indicator database, which provides harmonised and policy-relevant measures of climate mitigation, energy transition, sustainable mobility, environmental protection, circular economy, and socio-economic transformation. After screening for cross-country and intertemporal availability, 20 indicators were retained. Five indicators were excluded due to incomplete data for the full period: E_1.6, E_2.3, E_2.5, E_2.6, and E_3.7. Cyprus and Malta were omitted because of data gaps, and the United Kingdom was excluded as it is no longer an EU Member State. The final sample therefore consists of 25 EU countries. The complete list of indicators and their classification as stimulants or destimulants is reported in Appendix Table 1.

The empirical window covers 2013–2021. The year 2019 is treated as the strategic reference point because the EGD was announced in December 2019. Pre-2019 observations are not interpreted as evidence of EGD implementation; they are used as a post-enlargement structural baseline capturing national trajectories in policy areas later integrated into the EGD. The year 2021 was selected as the final year because it was the latest year with sufficient data completeness. Although Eurostat data ensure formal comparability, the indicators may still reflect reporting differences, publication delays, and proxy measurement. The results should therefore be interpreted as relative benchmarking outcomes rather than absolute measures of EGD compliance.

3.2. Indicator treatment and preliminary composite indicator

Indicators were classified as stimulants or destimulants. Stimulants are variables for which higher values indicate better performance, such as renewable energy share or rail freight transport share. Destimulants are variables for which higher values indicate weaker performance, such as PM2.5-related premature deaths, waste generation per capita, and greenhouse gas emissions intensity. Before aggregation and DEA estimation, all indicators were transformed so that higher values consistently denoted better outcomes.

For stimulants, the min-max transformation was applied:

$$(1)\ \ z_{ijt} = \frac{\left[x_{ijt} - \min(x_i)\right]}{\left[\max(x_i) - \min(x_i)\right]}.$$

For destimulants, the direction was reversed:

$$(2)\ \ z_{ijt} = \frac{\left[\max(x_i) - x_{ijt}\right]}{\left[\max(x_i) - \min(x_i)\right]}.$$

Here, x_{ijt} denotes the original value of indicator i for country j in year t, and z_{ijt} denotes the transformed value. The transformation preserves cross-country ordering while making all indicators compatible with the DEA output interpretation.

A preliminary composite indicator was calculated only for descriptive comparison using Simple Additive Weighting:

$$(3)\ \ CI_{Jt}^{SAW} = \frac{1}{m}\sum_{i=1}^{m} z_{ijt}$$

Equal weights were used only at this preliminary stage. The SAW index is not the main efficiency measure; it provides a transparent reference point for comparison with DEA or Benefit-of-the-Doubt results (OECD, 2008; Zhou et al., 2006).

3.3. Variable selection for the DEA model

The DEA model used a reduced set of indicators because DEA is sensitive to the ratio of decision-making units to variables. With 25 countries, including too many outputs would reduce discriminatory power and could classify too many countries as efficient. Indicator selection combined substantive and statistical criteria: consistency with the EGD framework, relevance to climate, environmental and socio-economic transformation, cross-country comparability, interpretability, data availability, sufficient variability, and limited redundancy.

Four complementary methods were applied. Correlation analysis identified indicators strongly associated with the remaining variables. Variance analysis selected indicators with high cross-country variability. Principal Component Analysis reduced redundancy and identified variables with high loadings on the main components. LASSO regression retained variables with non-zero coefficients under regularisation. For PCA and LASSO, variables were standardised before estimation to avoid scale effects.

The final selection was based on the frequency with which indicators appeared across the four methods and on theoretical relevance. Five indicators were retained: E1_4, E1_9, E2_7, E2_8, and E3_8. Together, they represent the multidimensional structure of the EGD: renewable energy share captures climate and energy transition; rail freight transport share captures sustainable mobility; PM2.5-related premature deaths capture environmental quality and health; waste generation per capita captures circular economy pressure; and GHG emissions intensity of employment captures the link between environmental burden and production structure. The results of the variable selection procedure are summarised in Appendix Table 2.

3.4. DEA/Benefit-of-the-Doubt model and weights

Relative efficiency was assessed using Data Envelopment Analysis in its Benefit-of-the-Doubt (BoD) formulation (Charnes et al., 1978; Cherchye et al., 2007, 2008). Each country is treated as a decision-making unit. The five transformed EGD indicators are included in the model as outputs. The baseline multiplier model for country k in year t is:

$$(4)\ CI_{kt} = max_{u_{ikt}} \sum_{i=1}^{m} u_{ikt} z_{ikt}$$

subject to: i=1∑muiktzijt≤1,j=1,…,n;uikt≥0,i=1,…,m.

Here, CI_{kt} is the DEA/BoD score, u_{ikt} is the weight assigned to indicator i when country k is evaluated, m is the number of outputs and n is the number of countries.

Weights are determined endogenously by the optimisation problem. Each country may select the most favourable feasible non-negative weights for its own profile, provided that the same weights do not allow any country to exceed the frontier. Thus, the weights are country-specific shadow weights, not normative importance coefficients. No additional lower or upper weight restrictions were imposed beyond non-negativity. This limits arbitrary ex ante weighting, but also means that some indicators may receive very low or zero weights for specific countries.

3.5. Single input, undesirable outputs and DEA assumptions

The BoD specification uses one non-discretionary input fixed at 1 for all countries. This is a technical normalising input, not public expenditure, labour, capital or energy use. Its function is to anchor the DEA model and allow multiple policy outcomes to be assessed within a common frontier. It is non-discretionary because it is not subject to reduction or managerial control. The study therefore evaluates relative outcome efficiency, not expenditure efficiency.

Undesirable outputs were transformed before estimation because DEA treats outputs as desirable and assumes that more output is better. In the final DEA set, E2_7, E2_8 and E3_8 are destimulants. After transformation, lower mortality, waste and emissions intensity are represented by higher transformed values (Seiford & Zhu, 2002; Lewis & Sexton, 2004).

The baseline specification assumes constant returns to scale. A VRS specification was also tested, but with one homogeneous technical input it produced non-discriminatory scores of one for all countries; therefore, the CRS/BoD specification was retained as the meaningful baseline. This choice is consistent with the unit input and with normalised policy outcomes rather than absolute measures of national production scale. The analysed countries are treated as comparable decision-making units because they operate under a common EU policy framework, although they differ in energy mix, industrial structure, fiscal capacity, and administrative effectiveness. DEA is deterministic and does not separate statistical noise from inefficiency; measurement error, outliers, and variable selection may therefore affect the frontier. With 25 countries, one input, and five outputs, the model satisfies the common rule of thumb requiring the number of units to exceed three times the total number of inputs and outputs.

3.6. Super-efficiency, robustness logic and interpretation

For finer discrimination among efficient countries, a super-efficiency extension was applied. In this specification, the evaluated country is excluded from its own reference set, allowing countries located on the frontier to be ranked. Values above 1 indicate that a country remains above the frontier constructed without itself, while values below 1 indicate relative inefficiency.

Robustness was addressed through multi-method indicator selection, dimensionality reduction, alternative transformation, leave-one-indicator-out specifications and frontier-outlier stress tests. The results should be interpreted as relative benchmarking outcomes, not causal estimates. A country on the DEA frontier is efficient only relative to the analysed sample and selected indicators; it may still face environmental or institutional challenges. Future extensions may add bootstrap DEA, panel DEA or Malmquist indices once longer post-2019 data series become available.

4. Results

4.1. Composite indicator results as a descriptive reference

The empirical analysis first reports the SAW-based composite indicator as a descriptive reference. Appendix Table 3 presents CI values for 25 EU countries in 2013, 2019 and 2021. The CI combines all 20 transformed EGD indicators with equal weights; it is therefore treated as a transparent overview of aggregate performance, not as the main efficiency measure.

Sweden, Latvia and Estonia remain at the top of the CI ranking, with Slovenia and Austria also consistently high. Ireland, Bulgaria and Greece record the weakest CI values, while Poland, Romania and Spain remain in the lower part of the distribution. Germany and France occupy mid-ranking positions, indicating that economic scale does not automatically translate into balanced aggregate EGD performance. Portugal records the strongest upward movement, from 19th in 2013 to 11th in 2021, whereas Belgium and Czechia display more unstable positions.

4.2. DEA/BoD efficiency scores and the efficiency frontier

The DEA/BoD results in Appendix Table 4 provide the main efficiency-oriented assessment. Unlike the CI, which applies equal weights, DEA/BoD evaluates relative efficiency using country-specific endogenous weights and identifies countries located on or above the estimated frontier. Differences between CI and DEA rankings are therefore not inconsistencies, but indicate that aggregate performance and relative efficiency reflect different aspects of EGD implementation.

Sweden, Latvia and Estonia rank highly in both approaches, suggesting strong aggregate performance combined with high relative efficiency. Other countries show divergence. Ireland has the lowest CI value in 2021 but a high DEA/BoD score, while Portugal and Lithuania perform better in DEA than in the CI ranking. This suggests that weaker average performance across the full indicator set may coexist with favourable relative efficiency in the reduced DEA model. The 2021 DEA/BoD classification (Appendix Table 5) distinguishes frontier or super-efficient countries, near-efficient countries, moderate-efficiency countries, and countries with the largest efficiency gaps. The lowest group includes Czechia, Belgium, Poland and Bulgaria, with Bulgaria remaining last in both 2019 and 2021.

To increase transparency of the DEA/BoD results, normalised contribution shares and robustness checks were additionally calculated (Supplementary Annex, Tables A1–A6). In 2021, the largest average contribution to the DEA/BoD score was associated with E2_8 (waste generation; 35.97%), followed by E2_7 (PM2.5-related premature deaths; 28.73%), E3_8 (GHG emissions intensity of employment; 16.79%), E1_9 (rail freight transport; 12.04%) and E1_4 (renewable energy; 6.47%). E2_8 contributed positively in 76% of countries and was the dominant contributor in eight countries, whereas E2_7 contributed positively in 64% of countries and dominated in ten countries. The robustness checks confirmed the stability of the baseline results. The alternative min-max transformation with reversed destimulants produced identical rankings in 2013, 2019 and 2021 (Spearman's rho = 1.000). In the 2021 leave-one-indicator-out test, the ranking remained highly stable after excluding E1_4 (rho = 0.998) and remained stable or moderately stable after excluding E2_8 (rho = 0.912), E3_8 (rho = 0.893) and E1_9 (rho = 0.824). The largest change occurred after excluding E2_7 (rho = 0.552), confirming that PM2.5-related premature mortality is the most influential indicator for the estimated frontier. Additional 2021 frontier-outlier tests also supported the stability of the results: after excluding Sweden, Spearman's rho equalled 0.982, and after excluding Sweden and Latvia, it equalled 0.946.

4.3. Changes between the pre-EGD baseline, 2019 reference year and 2021

Because the EGD was announced in December 2019, the 2013 results are interpreted as a pre-EGD structural baseline, while 2019–2021 captures early post-announcement outcomes. The longer 2013–2021 comparison shows substantial gains for Lithuania, Greece, Luxembourg and the Netherlands in DEA ranks, and a large CI improvement for Portugal. The shorter 2019–2021 comparison is more directly linked to the first observable post-announcement period: Lithuania and the Netherlands improve markedly in DEA, Greece and Luxembourg continue upward movement, whereas Bulgaria, Poland, Belgium and Czechia remain in the lower part of the efficiency distribution. These changes suggest uneven early progress conditioned by pre-existing national trajectories.

The observed cross-country differences may be associated with energy mix, transport structure, exposure to high-emission sectors, administrative capacity and earlier environmental policy paths. However, these factors are contextual explanations, not causal effects identified by the DEA model.

4.4. Indicator profiles of leading and lagging countries

The final part of the results examines the 2021 indicator profiles of leading and lagging countries. Chart 1 does not identify causal drivers of DEA efficiency, nor does it report DEA weights or slack values. It shows how the selected transformed indicators differ between the leading group, represented by Sweden, Latvia and Estonia, and the lagging group, represented by Bulgaria, Poland and Belgium.

The leading group displays stronger transformed values for renewable energy, rail freight transport, and selected environmental-health outcomes. The lagging group shows weaker profiles, particularly in PM2.5-related premature mortality, waste generation, and greenhouse gas emissions intensity of employment. These profiles help explain the empirical structure of the DEA/BoD scores without implying that any single indicator causally determines the ranking.

Overall, the results reveal three patterns: stable leadership by several Northern and Baltic countries, improvement in selected countries such as Lithuania, Greece and the Netherlands, and persistent efficiency reserves in Bulgaria, Poland, Belgium and Czechia. The following discussion relates these patterns to previous MCDA and composite indicator studies, and to structural differences between Member States.

5. Discussion

The DEA/BoD results provide an efficiency-frontier interpretation of European Green Deal implementation, rather than another aggregate country ranking. Three findings are particularly important. First, Sweden, Latvia and Estonia combine strong composite indicator performance with high DEA/BoD efficiency, confirming their robust position across both evaluation approaches. Second, some countries, such as Lithuania, Portugal, Ireland and the Netherlands, perform better in the DEA/BoD framework than in the equal-weighted composite indicator. This suggests that weaker average performance across the full set of indicators may coexist with relatively efficient performance in the reduced DEA model. Third, Bulgaria, Poland, Belgium and Czechia remain the countries with the largest relative efficiency reserves in 2021. These results show that the EGD implementation gap is not only a matter of aggregate performance, but also of how effectively countries convert their observable environmental and transition-related outcome profiles into frontier performance.

These findings are broadly consistent with recent monitoring and stocktaking exercises, which show that EGD progress across Member States remains uneven and that acceleration is required in several policy areas. They are also consistent with composite indicator and MCDA studies that identify stronger performance among Northern and selected Western European countries, and weaker performance among several Central, Eastern and Southern European countries. However, the present results also show why DEA/BoD should be interpreted as a complementary approach rather than a substitute for ranking-based methods. Composite indicators and MCDA methods, including PROMETHEE II or CoCoSo-based approaches, are useful for ordering countries according to explicit aggregation, normalisation and preference rules. DEA/BoD instead identifies the empirical efficiency frontier, peer benchmarks and country-specific efficiency reserves under endogenous weights. Therefore, differences between the DEA/BoD results and previous rankings should not be treated as inconsistencies. They reflect different evaluation questions: ranking-based studies ask which country scores higher, whereas the present approach asks which countries define attainable best practice given the selected multidimensional EGD outcomes.

The closest point of comparison is the PROMETHEE II-based assessment by Ottomano Palmisano et al. (2025). That study identifies Sweden, Austria, and the Netherlands as high performers, and Ireland, Luxembourg, and Cyprus as low performers. The present analysis confirms the strong position of Sweden and the Netherlands, but also shows that countries such as Ireland, Lithuania, and Portugal can appear more efficient in a DEA/BoD framework than in ranking-based or equal-weighted assessments. This difference arises from the logic of the method. PROMETHEE II relies on pairwise comparisons and preference functions, while DEA/BoD allows each country to use the most favourable feasible weights for its own outcome profile, subject to the common frontier constraint. The analysis therefore does not replicate the previous ranking; it adds information on relative efficiency, benchmark status, and efficiency reserves. Similarly, the findings are consistent with Olczyk and Kuc-Czarnecka's (2025) evidence on increasing divergence in EGD-related composite indicators, but extend that result by showing where divergence is reflected in frontier distance rather than only in aggregate scores.

The contribution-share results clarify which dimensions of the reduced DEA model are most relevant for the estimated frontier. In 2021, waste generation and PM2.5-related premature mortality made the largest average contributions to the DEA/BoD scores, followed by greenhouse gas emissions intensity of employment, rail freight transport, and renewable energy. The leave-one-indicator-out test further indicates that PM2.5-related premature mortality is the most influential variable for the stability of the 2021 ranking. This suggests that EGD efficiency, as captured in the present model, is not driven solely by climate-energy indicators. Environmental health, waste pressure, and emissions intensity of production structures also play a central role. This is important for policy interpretation because it indicates that the Green Deal should be evaluated as a multidimensional transition involving air quality, circular economy, transport, and production structure, not only renewable energy deployment.

Although DEA does not identify causal mechanisms, the observed cross-country differences can be interpreted in light of structural, institutional, and sectoral conditions. Countries closer to the frontier tend to display more favourable combinations of renewable energy performance, transport structure, air quality outcomes, waste indicators, and emissions intensity. Countries with larger efficiency reserves often face more challenging starting conditions, including higher dependence on fossil fuels, a larger role for emissions-intensive sectors, weaker air quality outcomes, lower circular economy performance, or more limited administrative capacity to implement complex transition policies. These factors do not constitute causal effects in the econometric sense, but they provide a plausible interpretation of why countries operating under the same EU strategic framework may differ in relative EGD efficiency.

The results also have policy implications. For countries located on or above the frontier, the main challenge is to maintain performance and disseminate transferable practices, especially in areas such as air quality management, circular economy policies, rail-oriented freight systems, and emissions intensity reduction. For near-efficient and moderate-efficiency countries, the priority is to remove specific bottlenecks rather than redesign the entire transition framework. This may involve accelerating permitting procedures, improving coordination across ministries and agencies, strengthening investment pipelines, and targeting sectors where the selected indicators reveal weaker performance. For low-efficiency countries, including Bulgaria, Poland, Belgium, and Czechia in the 2021 classification, more targeted support may be needed. Policy attention should focus on areas with the largest observed efficiency reserves, particularly air quality improvement, waste reduction, emissions intensity of employment, and transport decarbonisation. EU-level instruments, including cohesion policy, the Just Transition Mechanism, and green investment support, should therefore be linked not only to formal compliance with EGD targets, but also to measurable progress in reducing frontier distance.

Several interpretive limitations should be emphasised. First, DEA/BoD evaluates relative outcome efficiency, not absolute EGD compliance. A country located on the frontier is efficient only relative to the analysed sample and selected indicators; it may still face environmental or social challenges. Second, the endogenous weights used in the BoD model are shadow weights, not normative importance coefficients. They indicate how a country achieves its best feasible score within the model, but should not be interpreted as policy priorities in themselves. Third, the use of a single unit input means the model does not evaluate expenditure efficiency, labour productivity, or fiscal effort. It compares multidimensional outcome profiles under a common normalising input. Fourth, DEA is deterministic and may be sensitive to measurement error, outliers, and variable selection. The robustness checks reported in the study mitigate this concern, but do not eliminate it completely. Finally, Eurostat indicators are harmonised and policy-relevant, but may still reflect reporting delays, proxy measurement, and differences in national data systems. For these reasons, the results should be interpreted as a comparative benchmarking exercise rather than as a causal or exhaustive assessment of Green Deal implementation.

6. Conclusion

The relative effectiveness of European Green Deal (EGD) implementation in EU countries was assessed using a DEA/Benefit-of-the-Doubt framework based on Eurostat EGD indicators. The empirical design combined a descriptive SAW composite indicator, constructed from 20 transformed indicators, with an efficiency-frontier model based on five selected indicators: renewable energy share, rail freight transport share, PM2.5-related premature mortality, waste generation per capita, and greenhouse gas emissions intensity of employment. This approach enabled the evaluation of EGD implementation both as an aggregate ranking problem and as a frontier-based benchmarking problem focused on relative outcome efficiency, peer benchmarks, and efficiency reserves.

The results reveal substantial heterogeneity across Member States. Sweden, Latvia, and Estonia hold strong positions in both the composite indicator and DEA/BoD assessment, indicating stable performance across both evaluation approaches. In the 2021 DEA/BoD classification, the efficiency-frontier or super-efficient group comprises Sweden, Latvia, Lithuania, Portugal, Estonia, Ireland, the Netherlands, Croatia, and Finland. The low-efficiency group includes Czechia, Belgium, Poland, and Bulgaria. The comparison between the composite indicator and DEA/BoD scores also demonstrates that aggregate performance and relative efficiency are not identical. Countries such as Ireland, Lithuania, and Portugal perform more favourably in the DEA/BoD framework than in the composite indicator.

The contribution-share and robustness results further clarify the interpretation of the model. In 2021, the largest average contributions to DEA/BoD scores were associated with waste generation and PM2.5-related premature mortality, followed by greenhouse gas emissions intensity of employment, rail freight transport, and renewable energy. The leave-one-indicator-out checks indicate that the ranking is particularly sensitive to PM2.5-related premature mortality, while the alternative transformation and frontier-outlier tests confirm a high level of overall robustness. These findings suggest that EGD efficiency should not be interpreted solely through climate-energy indicators. Environmental health, circular economy pressure, transport structure, and emissions intensity also play a central role in the relative performance of Member States.

Several policy implications arise from the results. For countries located on or above the frontier, policy should focus on maintaining performance and disseminating transferable practices, particularly in air-quality management, circular-economy policies, rail-oriented freight systems, and emissions-intensity reduction. For near-efficient and moderate-efficiency countries, priority should be given to removing specific bottlenecks, such as administrative delays, weak investment pipelines, insufficient coordination across public institutions, and sector-specific transition barriers. For low-efficiency countries, more targeted support is needed in areas where the greatest efficiency reserves are evident. In particular, air-quality improvement, waste reduction, emissions-intensity reduction, and transport decarbonisation should be more closely linked with cohesion policy, the Just Transition Mechanism, and green investment support. The results therefore support differentiated policy intervention rather than a uniform implementation model for all Member States.

The scientific contribution of the article is to shift the assessment of EGD implementation from a purely ranking-based perspective to an efficiency-frontier perspective. Composite indicators and MCDA methods remain useful for ordering countries according to explicit aggregation or preference rules. However, DEA/BoD provides information on the countries that define attainable best practice, the distance of other countries from that frontier, and the extent of efficiency reserves. In this sense, the analysis complements earlier MCDA and composite-indicator studies by showing how endogenous weights and frontier benchmarking can be used to assess multidimensional EGD outcomes. The findings also confirm that differences in EGD implementation should be interpreted in the context of structural and institutional conditions, including energy mix, dependence on fossil fuels, transport structure, exposure to emissions-intensive sectors, and administrative capacity. These contextual factors do not constitute causal effects identified by the model, but they provide a plausible interpretation of cross-country differences in relative efficiency.

Several limitations should be emphasised. First, the DEA/BoD scores are relative to the analysed sample and selected indicators; a country located on the frontier should not be interpreted as fully compliant with all EGD objectives. Second, the single unit input is a technical normalising input, not a measure of public expenditure, labour, capital, or energy use. The model therefore evaluates relative outcome efficiency rather than expenditure efficiency. Third, DEA is deterministic and does not separate statistical noise from inefficiency, making results sensitive to measurement error, outliers, and variable selection. Fourth, the Eurostat indicators are harmonised and policy-relevant, but may still reflect reporting delays, proxy measurement, and differences in national data systems. Fifth, the analysis does not identify causal mechanisms, and the pre-2019 observations should be interpreted as a structural baseline rather than as evidence of EGD implementation before the strategy was announced.

Future research should extend the analysis when longer post-2019 Eurostat time series become available. Panel DEA, Malmquist productivity indices, and bootstrap DEA could be used to evaluate changes in efficiency over time and to assess the statistical stability of the frontier. DEA results could also be triangulated with stochastic frontier analysis, MCDA methods, or machine learning approaches to test how different modelling assumptions affect country classifications. Further extensions should include regional-level analysis, additional institutional and policy variables, information on EU funding absorption, and more detailed indicators of administrative capacity. Such extensions would allow a more precise assessment of how structural conditions, public policy design, and investment capacity affect the relative effectiveness of EGD implementation.

References

Black, C., & Cisternino, S. (Eds). (2025). Delivering the EU Green Deal – Progress towards targets. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/33a4bbe1-e2b0-11ef-be2a-01aa75ed71a1/language-en

Camanho, A. S., Mello, J., & Dyson, R. G. (2023). Benefit-of-the-doubt composite indicators and use of weight restrictions. In P. Macedo, V. Moutinho, & M. Madaleno (Eds.), Advanced mathematical methods for economic efficiency analysis (pp. 93–112). Springer. https://doi.org/10.1007/978-3-031-29583-6_6

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision-making units. European Journal of Operational Research, 2(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Cherchye, L., Moesen, W., Rogge, N., & Van Puyenbroeck, T. (2007). An introduction to 'benefit of the doubt' composite indicators. Social Indicators Research, 82(1), 111–145. https://doi.org/10.1007/s11205-006-9029-7

Cherchye, L., Moesen, W., Rogge, N., Van Puyenbroeck, T., Saisana, M., Saltelli, A., Liska, R., & Tarantola, S. (2008). Creating composite indicators with DEA and robustness analysis: The case of the Technology Achievement Index. Journal of the Operational Research Society, 59(2), 239–251. https://doi.org/10.1057/palgrave.jors.2602445

Ciot, M. G. (2022). Implementation perspectives for the European Green Deal in Central and Eastern Europe. Sustainability, 14(7), Article 3947. https://doi.org/10.3390/su14073947

Dyson, R. G., Allen, R., Camanho, A. S., Podinovski, V. V., Sarrico, C. S., & Shale, E. A. (2001). Pitfalls and protocols in DEA. European Journal of Operational Research, 132(2), 245–259. https://doi.org/10.1016/S0377-2217(00)00149-1

European Commission. (2019). The European Green Deal (COM(2019) 640 final). Retrieved 20.11.2024 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN

European Union. (2021c). Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality ('European Climate Law'). Official Journal of the European Union, L 243, 1–17.

Eurostat. (2023). European Green Deal indicators. European Commission. Retrieved 20.11.2024 from https://ec.europa.eu/eurostat/web/european-green-deal/indicators.

Hereu-Morales, J., Segarra, A., & Valderrama, C. (2024). The European (Green?) Deal: A systematic analysis of environmental sustainability. Sustainable Development, 32(1), 647–661. https://doi.org/10.1002/sd.2671

Karadağ, M., Gül, M., Yücesan, M., Ortiz-Barrios, M., Ishizaka, A., & Khan, J. (2025). Evaluation of Green Deal compliance performance with a hybrid comparative multi-attribute decision model. Socio-Economic Planning Sciences, 98, Article 102163. https://doi.org/10.1016/j.seps.2025.102163

Koundouri, P., Alamanos, A., Plataniotis, A., Stavridis, C., Perifanos, K., & Devves, S. (2024). Assessing the sustainability of the European Green Deal and its interlinkages with the SDGs. npj Climate Action, 3, Article 23. https://doi.org/10.1038/s44168-024-00104-6

Leonard, M., Pisani-Ferry, J., Shapiro, J., Tagliapietra, S., & Wolf, G. (2021). The geopolitics of the European Green Deal. International Organisations Research Journal, 16(2), 204–235. https://doi.org/10.17323/1996-7845-2021-02-10

Lewis, H. F., & Sexton, T. R. (2004). Data envelopment analysis with reverse inputs and outputs. Journal of Productivity Analysis, 21(2), 113–132. https://doi.org/10.1023/B:PROD.0000016868.69586.b4

Marelli, L., Trane, M., Barbero Vignola, G., Gastaldi, C., Guerreiro Miguel, M., Delgado Callicó, L., Borchardt, S., Mancini, L., Sanye Mengual, E., Gourdon, T., et al. (2025). Delivering the EU Green Deal – Progress towards targets. Publications Office of the European Union. https://doi.org/10.2760/3105205

Michalewska-Pawlak, M. (2024). The impact of the European Green Deal strategy on the evolution of EU regional policy after 2021. Politeja, 21(1(88/2)), 227–239. https://doi.org/10.12797/Politeja.20.2024.88.2.15

OECD. (2008). Handbook on constructing composite indicators: Methodology and user guide. OECD Publishing. https://doi.org/10.1787/9789264043466-en

Olczyk, M., & Kuc-Czarnecka, M. (2025). European Green Deal Index: A new composite tool for monitoring European Union's Green Deal strategy. Journal of Cleaner Production, 495, Article 145077. https://doi.org/10.1016/j.jclepro.2025.145077

Ottomano Palmisano, G., Rocchi, L., Negri, L., & Piscitelli, L. (2025). Evaluating the progress of the EU countries towards implementation of the European Green Deal: A multiple criteria approach. Land, 14(1), Article 141. https://doi.org/10.3390/land14010141

Ozdemir, S., Demirel, N., Zaralı, F., & Çelik, T. (2024). Multi-criteria assessment framework for evaluation of Green Deal performance. Environmental Science and Pollution Research, 31, 4686–4704. https://doi.org/10.1007/s11356-023-31370-2

Pianta, M., & Lucchese, M. (2020). Rethinking the European Green Deal: An industrial policy for a just transition in Europe. Review of Radical Political Economics, 54(2), 633–641. https://doi.org/10.1177/0486613420938207

Rosenow, J. (2022). Europe on the way to net zero: What challenges and opportunities? PLOS Climate, 1(7), Article e0000058. https://doi.org/10.1371/journal.pclm.0000058

Saisana, M., Saltelli, A., & Tarantola, S. (2005). Uncertainty and sensitivity analysis techniques as tools for the quality assessment of composite indicators. Journal of the Royal Statistical Society: Series A, 168(2), 307–323. https://doi.org/10.1111/j.1467-985X.2005.00350.x

Seiford, L. M., & Zhu, J. (2002). Modeling undesirable factors in efficiency evaluation. European Journal of Operational Research, 142(1), 16–20. https://doi.org/10.1016/S0377-2217(01)00293-4

Sikora, A. (2021). European Green Deal – Legal and financial challenges of the climate change. ERA Forum, 21(4), 681–697. https://doi.org/10.1007/s12027-020-00637-3

Simar, L., & Wilson, P. W. (1998). Sensitivity analysis of efficiency scores: How to bootstrap in nonparametric frontier models. Management Science, 44(1), 49–61. https://doi.org/10.1287/mnsc.44.1.49

Topcu, M., Ozdemir, S., & Demirel, N. (2025). Exploring the role of socio-economic factors in European Green Deal performance. Environmental Conservation, 52(4), 188–195. https://doi.org/10.1017/S0376892925100106

Tutak, M., & Brodny, J. (2024). Disparities among EU-27 countries in the implementation of the European Green Deal strategy goals. Smart and Sustainable Built Environment. Advance online publication. https://doi.org/10.1108/SASBE-07-2024-0266 von der Leyen, U. (2019). Political guidelines for the next European Commission 2019–2024. European Commission. https://commission.europa.eu/document/download/063d44e9-04ed-4033-acf9-639ecb187e87_en?filename=political-guidelines-next-commission_en.pdf

von Homeyer, I., Oberthür, S., & Dupont, C. (2022). Implementing the European Green Deal during the evolving energy crisis. Journal of Common Market Studies, 60(S1), 125–136. https://doi.org/10.1111/jcms.13397

Walheer, B. (2024). A sequential benefit-of-the-doubt composite indicator. European Journal of Operational Research, 316(1), 228–239. https://doi.org/10.1016/j.ejor.2024.01.029

Zhou, P., Ang, B. W., & Poh, K. L. (2006). Comparing aggregating methods for constructing the composite environmental index: An objective measure. Ecological Economics, 59(3), 305–311. https://doi.org/10.1016/j.ecolecon.2005.10.018

Acknowledgements

Author contributions: the authors have given approval to the final version of the article. Author's total contribution to the manuscript: J. Kujawska (50%); M. Olczyk (50%).

Funding: the research was funded by the Americium IDUB project no. 1/1/2025/IDUB/II.1b/Am at Gdansk University of Technology.

Appendix

Box 1. Comparison of EGD assessment approaches

Descriptive monitoring: tracks official indicators and targets; transparent and policy-aligned, but does not synthesise multidimensional performance or identify benchmarks.
Composite indicators: summarise many indicators into one score; clear for communication, but sensitive to normalisation, aggregation and weights.
MCDA methods: rank countries under explicit preference rules; useful for multi-criteria ordering, but dependent on preference functions, thresholds and weights.
DEA/BoD: identifies an efficiency frontier, peers and efficiency reserves through endogenous weights; informative for benchmarking, but relative and sensitive to variable selection and outliers.

Source: own elaboration.

Table 1. European Green Deal Indicators

Indicator	Direction (S/D)	Source
E_1.1 Greenhouse gas emissions	D	Eurostat – EGD indicator E_1.1 (Index, 1990=100)
E_1.2 Greenhouse gas emissions by sector	D	Eurostat – EGD indicator E_1.2 (% of total, energy sector share)
E_1.3 Climate related economic losses	D	Eurostat – EGD indicator E_1.3 (euro per inhabitant, constant prices)
E_1.4 Renewable energy by sector	S	Eurostat – EGD indicator E_1.4 (% of gross final energy consumption)
E_1.5 Primary energy consumption	D	Eurostat – EGD indicator E_1.5 (MWh)

Indicator	Direction (S/D)	Source
E_1.6 Final energy consumption in households by use	D	Eurostat – EGD indicator E_1.6 (GJ per capita)
E_1.7 Zero-emission vehicles	S	Eurostat – EGD indicator E_1.7 (% of new registrations; passenger cars, etc.)
E_1.8 Passenger transport by mode (rail)	S	Eurostat – EGD indicator E_1.8 (% in total inland passenger-km)
E_1.9 Freight transport by mode (rail)	S	Eurostat – EGD indicator E_1.9 (% in total inland freight tonne-km)
E_2.1 Forest and other wooded land	S	Eurostat – EGD indicator E_2.1 (% of total land area)
E_2.2 Protected areas	S	Eurostat – EGD indicator E_2.2 (% of total area; terrestrial/marine)
E_2.3 Common bird index	S	Eurostat – EGD indicator E_2.3 (index)
E_2.4 Area under organic farming	S	Eurostat – EGD indicator E_2.4 (% of utilised agricultural area)
E_2.5 Nitrate in groundwater	D	Eurostat – EGD indicator E_2.5 (mg NO3/l)
E_2.6 Consumption of chemicals by hazardousness	D	Eurostat – EGD indicator E_2.6 (tonnes)
E_2.7 Premature deaths (PM2.5)	D	Eurostat – EGD indicator E_2.7 (rate attributable to PM2.5)
E_2.8 Generation of waste by hazardousness	D	Eurostat – EGD indicator E_2.8 (kg per capita; hazardous/non-hazardous total)
E_3.1 Raw material consumption	D	Eurostat – EGD indicator E_3.1 (tonnes per capita, total)
E_3.2 Circular material use rate	S	Eurostat – EGD indicator E_3.2 (% of material input for domestic use)
E_3.3 Gross domestic expenditure on R&D	S	Eurostat – EGD indicator E_3.3 (% of GDP; total)
E_3.4 Population unable to keep home adequately warm	D	Eurostat – EGD indicator E_3.4 (% of population)
E_3.5 High-speed internet coverage	S	Eurostat – EGD indicator E_3.5 (% of households; NGA coverage)
E_3.6 Environmental tax revenues	S	Eurostat – EGD indicator E_3.6 (% of total tax revenue)
E_3.7 Expenditure on environmental protection	S	Eurostat – EGD indicator E_3.7 (level)
E_3.8 GHG emissions intensity of employment	D	Eurostat – EGD indicator E_3.8 (tonnes CO_2 per employed person)

Notes: S = stimulant (higher is better); D = destimulant (higher is worse).
Sources refer to the Eurostat European Green Deal indicator metadata/codes.

Table 2. Selection of DEA indicators

Selection method	Top 5 (2013)	Top 5 (2019)	Top 5 (2021)
Correlation matrix	E3_3, E2_7, E1_4, E3_1, E2_1	E2_7, E3_3, E1_4, E3_1, E2_1	E1_4, E2_7, E3_3, E3_1, E2_1
Variance analysis	E2_8, E3_8, E1_2, E1_5, E2_7	E2_8, E3_8, E1_2, E1_5, E2_7	E2_8, E3_8, E1_2, E1_5, E2_7
PCA	E2_2, E2_1, E2_8, E1_2, E1_5	E3_2, E1_2, E1_9, E1_5, E1_8	E3_1, E1_9, E1_5, E2_8, E1_2
LASSO	E1_4, E2_2, E3_8, E3_2, E1_9	E2_1, E3_8, E3_4, E2_7, E1_9	E1_5, E1_4, E2_2, E3_8, E1_9
Frequency-based shortlist	E3_2, E1_9, E2_8, E1_4, E2_7	E3_2, E1_9, E2_8, E1_8, E1_4	E1_9, E2_8, E1_4, E2_7, E3_8
Final set	E1_4, E1_9, E2_7, E2_8, E3_8		

Source: own calculations.

Table 3. Composite indicators related to EGD implementation for 25 EU countries in the years 2013, 2019, and 2021

No	Country	2013		2019		2021		Rank Δ 2013–2021	Rank Δ 2019–2021
		CI value	Rank	CI value	Rank	CI value	Rank		
1	Austria	0.451	6	0.498	5	0.519	5	▲ 1	—
2	Belgium	0.350	21	0.399	14	0.402	17	▲ 4	▼ 3
3	Bulgaria	0.335	22	0.367	20	0.339	24	▼ 2	▼ 4
4	Croatia	0.440	7	0.466	7	0.481	7	—	—
5	Czechia	0.368	16	0.399	13	0.385	19	▼ 3	▼ 6
6	Denmark	0.381	13	0.395	16	0.406	16	▼ 3	—
7	Estonia	0.532	3	0.578	1	0.555	2	▲ 1	▼ 1
8	Finland	0.459	5	0.480	6	0.498	6	▼ 1	—
9	France	0.373	14	0.378	17	0.402	18	▼ 4	▼ 1
10	Germany	0.360	18	0.407	12	0.422	13	▲ 5	▼ 1
11	Greece	0.305	24	0.348	23	0.377	21	▲ 3	▲ 2
12	Hungary	0.388	12	0.376	18	0.410	14	▼ 2	▲ 4
13	Ireland	0.281	25	0.284	25	0.312	25	—	—
14	Italy	0.371	15	0.397	15	0.408	15	—	—
15	Latvia	0.562	2	0.578	2	0.552	3	▼ 1	▼ 1
16	Lithuania	0.429	8	0.422	11	0.427	12	▼ 4	▼ 1
17	Luxembourg	0.397	11	0.431	10	0.439	9	▲ 2	▲ 1
18	Netherlands	0.414	10	0.462	8	0.470	8	▲ 2	—
19	Poland	0.325	23	0.346	24	0.346	23	—	▲ 1
20	Portugal	0.358	19	0.367	21	0.429	11	▲ 8	▲ 10
21	Romania	0.352	20	0.376	19	0.379	20	—	▼ 1
22	Slovakia	0.415	9	0.437	9	0.439	10	▼ 1	▼ 1
23	Slovenia	0.509	4	0.536	4	0.521	4	—	—
24	Spain	0.365	17	0.354	22	0.364	22	▼ 5	—
25	Sweden	0.571	1	0.557	3	0.599	1	—	▲ 2

Source: own calculations based on Eurostat (2023).

Table 4. DEA/BoD efficiency scores related to EGD implementation for 25 EU countries in the years 2013, 2019, and 2021

No	DMU	2013		2019		2021		Rank Δ 2013–2021	Rank Δ 2019–2021
		Score	Rank	Score	Rank	Score	Rank		
1	Austria	0.899	19	0.883	22	0.943	18	▲ 1	▲ 4
2	Belgium	0.833	22	0.885	21	0.877	23	▼ 1	▼ 2

No	DMU	2013		2019		2021		Rank Δ 2013–2021	Rank Δ 2019–2021
		Score	Rank	Score	Rank	Score	Rank		
3	Bulgaria	0.828	23	0.800	25	0.786	25	▼ 2	—
4	Croatia	1.033	6	1.072	4	1.026	8	▼ 2	▼ 4
5	Czechia	0.940	16	0.888	20	0.898	22	▼ 6	▼ 2
6	Denmark	1.000	8	0.986	11	0.979	13	▼ 5	▼ 2
7	Estonia	1.122	3	1.067	5	1.069	5	▼ 2	—
8	Finland	1.005	7	1.014	7	1.019	9	▼ 2	▼ 2
9	France	0.952	14	0.993	10	0.969	14	—	▼ 4
10	Germany	0.847	21	0.895	18	0.931	20	▲ 1	▼ 2
11	Greece	0.750	25	0.860	23	0.943	17	▲ 8	▲ 6
12	Hungary	0.977	10	0.969	12	0.987	11	▼ 1	▲ 1
13	Ireland	1.063	5	1.062	6	1.053	6	▼ 1	—
14	Italy	0.926	18	0.947	13	0.931	21	▼ 3	▼ 8
15	Latvia	1.338	2	1.255	2	1.171	2	—	—
16	Lithuania	0.963	13	0.932	16	1.170	3	▲ 10	▲ 13
17	Luxembourg	0.815	24	0.930	17	0.958	16	▲ 8	▲ 1
18	Netherlands	0.939	17	0.943	15	1.028	7	▲ 10	▲ 8
19	Poland	0.848	20	0.842	24	0.854	24	▼ 4	—
20	Portugal	1.069	4	1.080	3	1.109	4	—	▼ 1
21	Romania	0.975	11	1.004	8	0.999	10	▲ 1	▼ 2
22	Slovakia	0.972	12	0.944	14	0.959	15	▼ 3	▼ 1
23	Slovenia	0.948	15	0.893	19	0.932	19	▼ 4	—
24	Spain	0.993	9	0.999	9	0.986	12	▼ 3	▼ 3
25	Sweden	1.358	1	1.336	1	1.461	1	—	—

Source: own calculations based on Eurostat (2023).

Table 5. Classification of countries by DEA/BoD efficiency score in 2021

Group	Criterion, 2021 DEA/BoD score	Countries	Interpretation
Efficiency-frontier / super-efficient countries	score > 1.000	Sweden, Latvia, Lithuania, Portugal, Estonia, Ireland, Netherlands, Croatia, Finland	Countries located on or above the estimated frontier
Near-efficient countries	0.950–1.000	Romania, Hungary, Spain, Denmark, France, Slovakia, Luxembourg	Countries close to the frontier, with limited efficiency reserves
Moderate-efficiency countries	0.900–0.949	Austria, Greece, Slovenia, Germany, Italy	Countries with visible but not extreme efficiency reserves
Low-efficiency countries	< 0.900	Czechia, Belgium, Poland, Bulgaria	Countries with the largest relative efficiency gaps

Source: own calculations based on Eurostat (2023).