International Journal of Economic Sciences

Journal homepage: www.ijes-journal.org
eISSN: 1804-9796

Economic Efficiency Assessment of Sustainability Investment in EU Member States: A Data Envelopment Analysis with Crisis Impact Evaluation (2015-2024)

Stefan Damyanov Petrov[1,*]

[1] Faculty of International Economics and Politics, Department of International Economic Relations and Business, University of National and World Economy, Sofia, Bulgaria

ARTICLE INFO

Article history:
Received 18 January 2026
Received in revised form 27 February 2026
Accepted 11 April 2026
Available online 15 April 2026

Keywords:
Economic efficiency; Sustainability investment; Financial resources; Data Envelopment Analysis (DEA); Efficiency ratio (ER); EU-27 sustainability policy; Green public finance; Crisis resilience; Institutional quality; Climate and energy transition.

ABSTRACT

The article proposes an approach for assessing the efficiency of sustainability-related investments in the EU-27 member states over the period 2015–2024. This is achieved through a combination of a DEA-based approach, a composite efficiency coefficient, and cluster analysis. The composite coefficient measures the relationship between calibrated outcomes and inputs and, in essence, provides a "value-for-money" assessment of sustainable expenditures. The results show substantial differences between countries. The Baltic states and several Central and Eastern European economies display high efficiency, while some of the traditional "leaders" in sustainability exhibit more modest returns per unit of investment. The cluster analysis groups the countries into four clusters with similar characteristics. These range from groups in which investment volumes play the leading role to groups in which efficiency is the key driver, and clearly show differences in the outcomes of the policies pursued (including target-setting and the design of EU financial instruments). The analysis also takes into account the impact of COVID-19 and the war in Ukraine. The main finding is that institutional quality is a stronger factor in maintaining efficiency during crises than the level of economic development. This conclusion underlines that sustainability objectives should also include measurable indicators of administrative capacity in order to improve the system's ability to adapt in times of crisis. The proposed model provides an empirical basis for improving the way European targets and instruments are formulated. It can help direct limited resources more effectively towards countries and regions with the greatest potential for efficiency improvement.

1. Introduction

Over the past decade, the European Union has been gradually shifting its development model towards a stronger focus on sustainability. This change rests both on new regulations and on substantial budgetary commitments. From a regulatory perspective, the European Green Deal and

* *Corresponding author.*
E-mail address: st.petrov@unwe.bg

https://doi.org/10.31181/ijes1512026278

the sectoral initiatives linked to it play a central role. In parallel, the European Commission plans to mobilize more than EUR 1 trillion in sustainable investments over the next decade [1]. This makes the overall transformation complex, as it links policy goals with ambitions for change in the economy and even in citizens' thinking and behavior, while also providing the financial resources needed to achieve it.

Against this background, relatively little attention is paid to how efficiently these resources are used in the individual member states and in the Union as a whole. In official monitoring, the focus is mainly on reaching certain target values of sustainability indicators and on the volume of implemented investments. These indicators of progress are politically and strategically appropriate, because they are expressed in absolute terms. They make it easy to see whether there is progress and how much. However, this limits the possibility for a systematic comparison between resources spent and results achieved. The question "which country achieves more sustainability per unit of investment" remains largely outside the focus of both statistical systems and much of the academic literature.

This article attempts to address precisely this gap by proposing a framework for assessing the efficiency of sustainable investments by country. Instead of looking only at the level of outcomes achieved, it links outcomes to the resources used. In this way it becomes possible to make an economic judgement on whether a given financing model is "worth it" under the available budget.

A core characteristic of any investment aimed at a specific goal is the extent to which the expenditures actually contribute to achieving that goal. In the case of sustainable investments this question is even more important, because their horizon is long-term and public resources are limited. In this sense efficiency can be viewed as a current indicator of the quality of the policy being implemented, and not only as a result "after the end of the programming period". At the same time this is fully in line with the logic of sustainability – resources should be allocated appropriately, used prudently, and optimized with regard both to current needs and to long-term requirements.

As already noted, in EU practice the assessment of progress on sustainability still relies mainly on a set of outcome indicators. This provides a useful picture of the direction and speed of change but says almost nothing about the cost at which these results are achieved. The monitoring systems of the European Environment Agency track movement towards sustainability targets, but do not allow us to see whether two countries with similar results have used similar or very different amounts of resources [2]. Yet such information would be particularly important when allocating structural and investment funds, designing EU-level financial instruments and formulating policies that must remain viable even under crisis conditions. From an economic point of view this implies a shift from the question "how much do we invest in sustainability" to the question "what is the economic return on these investments". In practice this is a typical case where policy goals, however important, need to be economically grounded. They must be weighed against the possibilities for achieving growth and productivity, including when this concerns the outcomes of the structural transformation towards a green economy. All these outcomes should be compared against the results achieved per unit of public and private resources invested.

1.1. Motivation for Conducting Research

The academic literature and reports by international organizations usually distinguish two main lines of assessment of sustainability policies. In one case the emphasis is on the scale of the resources invested, and in the other on the extent to which available resources are used efficiently. There is no consensus on which of these two approaches leads to a more successful sustainable transition. Some studies argue that simply increasing funding accelerates green transformations. This sounds intuitive, since if more resources are invested it is natural to expect better results. Other studies go deeper and look for the factors that contribute to better outcomes when similar financial resources are involved. These usually highlight the role of institutional capacity and policy coordination as key sources of success [3]. This is not merely an academic debate about what drives success, but a question closely linked to the future of EU cohesion policy and to the strategies of individual member states.

In addition, in recent years it has become clear that crises do not affect the efficiency of sustainability policies in all countries to the same extent. So far, research has focused mainly on how crises influence economic growth and productivity in the affected economies. In such periods productivity typically declines, and free investment resources are scarce. It is reasonable to expect a similar effect on the efficiency of sustainable investments, yet this dimension has not been studied sufficiently.

During the period in which the EU's green transition has been accelerating, there have been two major shocks of this kind: the COVID-19 pandemic (2020–2021) and the war in Ukraine (from 2022 onwards). Both are examples of tests of the flexibility of green transition programs. The negative economic and social consequences of these disruptions are the most direct and visible. However, they can also be seen as natural stress tests, a rare opportunity to observe how different countries react under pressure [4]. In some cases, crises speed up the shift towards more efficient solutions, while in others they lead to freezing or rolling back previously undertaking commitments.

The question, then, is how crises affect precisely the efficiency of sustainable investments – efficiency understood as the ratio between resources invested and results achieved. This is important for designing policies that not only work under normal conditions, but also retain their efficiency when shocks occur. Given the time horizon over which sustainable investments are usually made, it is entirely realistic to expect that similar shocks will recur. They may be of a similar nature or may stem from a wide range of political, economic, social, environmental and other triggers. In all cases, however, they will affect efficiency. This makes it necessary to pay particular attention to the relationship between different financing models and the efficiency of sustainable investments under crisis conditions. In short, crises give us a chance to address this problem through systematic economic analysis of events that have already become part of history.

1.2. Practical and Methodological Aims of the Study

This article proposes an approach through which such an economic analysis can be carried out. It introduces an efficiency assessment model that combines Data Envelopment Analysis (DEA), selected standard clustering techniques and an assessment of crisis impacts. The main challenge lies in the complex nature of sustainability and the heterogeneous indicators used to measure progress towards the goals. Quantitative data is abundant, but difficult to integrate into a single framework, especially since the financial resources spent are not directly linked to specific targets (and indicators). This makes the traditional approach to measuring efficiency overly simplified, and the input–output ratio in its direct form hard to apply. This is where the idea of using DEA as the methodological basis of the model comes from.

Thus, achieving the main objective depends on meeting three separate sub-objectives of the study. The first, and perhaps most obvious, is to develop a methodology for measuring the efficiency of sustainability-related investments that takes into account multiple and heterogeneous input and output indicators. It should be applicable to individual member states and allow comparisons between them. If this challenge is overcome, it becomes possible to go beyond traditional rankings and to trace how country-level instruments actually function. From there comes the possibility to identify the different patterns of progress through which EU member states pursue sustainability. This is essentially the second sub-objective of the study. The third and final sub-objective is to quantify the impact of major crises on the efficiency of sustainability. Its successful achievement would provide useful guidance for designing crisis-resilient policies, on an empirically grounded basis.

This is also the main practical dimension of the objectives: to propose a toolkit for economic assessment of the extent to which public and private spending on sustainability yields "more result per unit of investment". The idea is to combine DEA with indicators of green investments and the green bond market as a methodology for analyzing the efficiency of resource use, linked to the planning of cohesion policy and related financial instruments at EU level.

1.3. Contributions of the Study and Structure of the Paper

The objectives formulated in this study do not claim to provide a definitive solution to all issues raised. Rather, the ambition is to propose a workable framework that broadens the empirical and methodological tools used on this topic. The choice of DEA as a foundation is not accidental. It is an already well-known method in efficiency assessment in other fields, which makes the interpretation of results easier. The model is extended by including crisis effects, as well as a clustering approach that makes it possible to distinguish different country strategies. In this way a single method for empirical efficiency assessment is obtained, applied to all 27 EU member states over the period 2015–2024.

The temporal context is also important from a practical perspective. During this period, recovery programs after COVID-19 run in parallel with energy security measures related to the war in Ukraine. The crisis periods themselves and their effects on the social and economic spheres of life are undoubtedly interesting, well studied and important. The economic arguments are also important, but in most cases, they rest on limited case studies or theoretical reasoning. The present study aims to provide a broader empirical basis for addressing this problem.

From the viewpoint of economic theory, the contribution lies in proposing an integrated indicator of the economic efficiency of sustainable investments. In principle, such an indicator should allow for comparisons between member states and for tracking the robustness of results over time and under crises. In this way sustainability is linked to classic questions in economics, such as economic efficiency, resource allocation, productivity, the quality of public policies, and others. Naturally, the proposed framework does not cover all aspects of sustainability. It is a compromise between data availability, the need for comparability and the manageability of the model.

Even so, it offers one way to tailor support mechanisms for each individual country. The answer to this question can be derived directly from this type of results. This is important because the planning of green public finance and the formulation of policies need to remain efficient even under crisis conditions.

The remainder of the article is structured as follows. Section 2 provides a literature review, covering applications of DEA in sustainability assessment, EU policy evaluation frameworks and studies on the impact of crises on efficiency. Section 3 describes the methodology, including the construction of indicators, the specification of the DEA model, the cluster analysis and the approach to assessing crisis impacts. Section 4 presents the data used, the variables and the main limitations. Section 5 examines the main empirical results, and Section 6 discusses their economic and policy implications. The concluding section summarizes the main findings and outlines possible directions for future research.

2. Literature Review

2.1 Data Envelopment Analysis in Sustainability Assessment

When it comes to evaluating policy efficiency in different contexts, Data Envelopment Analysis (DEA) is an established tool. It has several advantages over more traditional methods. It makes it possible to capture the multi-dimensional nature of the phenomena under study. Through DEA even multi-dimensional measures can be reduced to an analysis based on one or two indicators. The method allows multiple inputs and outputs to be included simultaneously, without the need to specify subjective weights in advance. This is particularly useful when analyzing complex systems, and sustainability is precisely such a case. It is a typical example of a field in which different resources lead to different, but related, outcomes [5]. From an economic perspective, DEA makes it possible to see how individual countries, regions or sectors approach the maximum attainable volume of sustainable outcomes for a given amount of financial resources used. In essence, this is exactly what cost-effectiveness represents.

The application of DEA in the context of sustainability is not new in the literature. Marjanović [6], for example, uses DEA to assess the territorial efficiency of the deployment of the circular economy in the 27 EU member states. The analysis reveals substantial differences that can be interpreted as behavioral patterns and serve as a basis for meaningful grouping of countries. This is an important contribution to the study of circular economic issues. What is more relevant here, however, is that the study shows in practice how DEA can identify "best practices" and efficiency frontiers in a complex policy environment. These frontiers have direct economic significance, because they outline potential resource savings and show how higher results can be achieved at a given level of investment.

A similar logic is applied in analyses of efficiency in the transition towards renewable energy. In one study on energy sustainability in the EU, DEA is combined with optimized projections to assess the performance of member states [7]. The results show significant differences in efficiency that standard productivity indicators do not capture or cannot explain. An important conclusion is that DEA makes it possible to account for technological constraints and differences in the policy environment – factors that have a substantial impact on measured efficiency. Such applications indicate that DEA can serve as a basis for analyzing the productivity of green investments and for assessing the returns on public spending for energy transformation.

In addition, the academic literature provides evidence that combining DEA-based efficiency scores with cluster analysis can reveal hidden behavioral patterns in organizational and regional sustainability strategies [8]. This, in turn, makes it possible to design more adaptive policies and to develop targeted interventions that reflect country- and region-specific characteristics.

A similar analytical approach is used by other authors as well, with the economic context changing but the core idea of the research model remains comparable. Examples include work on regional economic disparities and development paths in Europe [9], and analyses of financial integration and inclusion that examine how different financial structures and instruments affect economic outcomes [10]. In this context the use of DEA is a reminder that the assessment of sustainability inevitably has a strong economic dimension, linked to how scarce resources are allocated and used.

2.2 EU Sustainability Policy Evaluation Framework

For monitoring policies related to the Sustainable Development Goals, Eurostat maintains a system of 102 indicators across 17 sustainability areas [11]. This is a solid empirical basis for measuring outcomes. The data are homogeneous, collected under similar methodologies, directly linked to the goals and provide clarity regarding the tracking of progress. The information is extremely valuable, but it is not sufficient. The main gap is the lack of a possibility to link the observed outcomes to a systematic analysis of investment efficiency. In practice, the available data does not connect progress on sustainability with the resource inputs used. Moreover, focusing only on outcome indicators does not allow for adequate treatment of the very different starting conditions across member states. This, both in theory and in practice, is a key precondition for using these results in a straightforward comparative perspective.

It is beyond doubt that such a systematized, methodologically homogeneous and highly reliable database is a very good foundation for further development of the monitoring system. From an economic perspective, however, the question remains to what extent the observed improvements in SDG indicators are achieved with a reasonable volume of spending, and whether different member states use their resources with a similar degree of efficiency.

The European Green Deal provides a useful starting point for analyzing approaches to the assessment of sustainability in the EU. If the purpose of such assessment, however, is not only to track outcomes, but the current framework also needs to be broadened. At present the focus is on final indicator values, while the efficiency of the resources used remains in the background [12]. This creates "blind spots" in understanding optimal investment strategies, especially when viewed at the level of individual countries. The missing link between expenditure flows (public budgets, EU funds and private green investments) and measurable sustainability outcomes also hampers the economic assessment of the returns generated by these policies.

This does not mean that the EU has no practice assessing the efficiency of green policies. At the level of specific policies there are important exceptions that can help address this gap more broadly. For example, there is an analytical assessment of the efficiency of cohesion policy in supporting the transition to a low-carbon economy [13]. It illustrates clearly that member states differ in the way they transform EU funding into sustainability outcomes. Research by the European Investment Bank [14] likewise shows that, despite the increase in overall investment volumes, efficiency patterns vary markedly across countries and project types. The EIB has developed a methodology for assessing climate finance that can be seen as a good practice for efficiency analysis in large-scale sustainability investments, although it is mainly applied at project level.

From the standpoint of economic policy, it is important to move from the question "how much is being invested" to the question "what sustainable results are achieved per unit of financial input". This opens the way for using tools such as DEA and composite efficiency indices, which can link data on expenditures and outcomes into a more coherent picture.

2.3 Crisis Impact on Economic and Environmental Efficiency

So far, when crisis phenomena and their impact on the efficiency of sustainable investments are discussed, the leitmotif in the empirical literature is COVID-19. Analyses that examine how the pandemic has influenced patterns of green investment reveal different types of interaction between response measures, including with respect to the efficiency of sustainability programs [15]. From an economic point of view this is visible both in changes in the volume of sustainable expenditure and in shifts in their productivity. Documented effects include postponement or acceleration of projects, reallocation of resources, changes in incentives for the private sector, and others.

In some cases, attention is drawn to the fact that the pandemic has accelerated the green transition, mainly through digitalization and improved policy coordination. In contrast, other work points to serious disruptions in sustainability investment programs and in the administrative capacity needed to manage them [16]. In both strands there is a substantial empirical base, but the common conclusion is one of strong heterogeneity in responses to the shock. At similar levels of investment some countries achieve considerably better sustainability outcomes than others, which directly reflects marked differences in economic efficiency.

The energy crisis following Russia's invasion of Ukraine still has no definitive resolution. The war itself is ongoing, which is one reason why this geopolitical shock, with clear economic dimensions, has been much less studied in terms of its impact on the green transition. The type of pressure here is of a different nature and is linked to geopolitics and energy security. Analyses of the implementation of the REPowerEU programme indicate that countries with diversified energy systems and stronger institutional capacity manage to turn crisis pressure into an accelerated green transition, whereas countries with high dependence on fossil fuels record a decline in efficiency [17]. In essence this again illustrates the heterogeneity of impacts already observed in the reaction to the pandemic.

While COVID-19 affects all EU countries, in the case of the war geographical proximity to the conflict gives the impact a different nuance. Although still relatively under-explored in the economic literature, existing evidence suggests that Eastern European states are more vulnerable to geopolitical shocks. In their case the war affects not only overall economic development, but also leads to institutional and infrastructural constraints. These, in turn, worsen the quality of implementation of sustainability programs [18]. This directly undermines the capacity to maintain an effective translation of investments into sustainable outcomes, on top of high uncertainty and disrupted energy markets.

The literature on crisis management in the field of sustainability [19] places particular emphasis on institutional characteristics that allow crises to be treated as opportunities rather than only as threats. Most often this is attributed to strong inter-ministerial coordination, flexible regulatory frameworks, stable mechanisms for stakeholder participation and proactive crisis-management capacities. Countries that maintain high-quality governance along these dimensions are more likely to preserve, or even improve, the efficiency of their sustainability policies during crises. In economic terms this means fewer "wasted" investments, faster recovery of sustainable projects and, in short, better returns on crisis packages and public support [20].

It is also important to recognize that individual crises cannot always be clearly separated from one another. Their typical feature is that they do not "wait their turn", but rather "pile up". As a result, whether we like it or not, we often observe empirically their combined effect on a given country and cannot fully disentangle them. This is also the case with the combined impact of the two crises, which in some instances leads to cumulative effects on the efficiency of sustainability. In countries that had already suffered severe consequences from COVID-19, the subsequent impact of the war accelerates adverse sustainability trajectories, different from those observed in states exposed to single shocks. This points to the need for diversified, or rather individualized, designs of crisis preparedness and response strategies [21].

In light of all this, there is a need for quantitative indicators of the "crisis resilience" of investment efficiency. These could take the form of combined measures that capture both changes in efficiency and the magnitude of the shocks. The advantage of such constructs is that they could be used both for economic profiling of member states and for more precise targeting of support.

3. Methodology

As already noted, the empirical approach to analyzing the efficiency of sustainability-related investments is built on the Data Envelopment Analysis (DEA) methodology. DEA is used to calibrate the data for the individual indicators and to construct a composite efficiency coefficient. In practice this coefficient brings together traditional DEA outputs and weighted sustainability indicators, and thus provides a more comprehensive measure of efficiency. From an economic perspective, the approach makes it possible to assess the extent to which member states transform sustainable investments into "returns" in the form of measurable sustainability outcomes.

Figure 1 presents the overall analytical framework of the study: selection of indicators, construction of the SPS and FIS indices, calculation of the efficiency coefficient ER, the DEA assessment, the cluster analysis and the evaluation of crisis impacts. The diagram shows the sequence of steps and the economic logic of the model.

3.1 Data Envelopment Analysis Theoretical Framework

DEA is a non parametric approach to measuring efficiency that allows for multiple inputs and outputs without requiring prior assumptions about functional forms or parameter weights [22]. The method is widely used precisely because it can handle complex, multi dimensional relationships related to efficiency. This makes it particularly suitable for assessing sustainability, where different types of financial inputs are transformed into different, yet related, outcome indicators.

In theoretical terms DEA builds on Farrell's [23] concept of technical efficiency, later formalized by Charnes and co authors [22] within the DEA framework itself. In the present study a Variable Returns to Scale (VRS) model is used, in the spirit of Banker [24]. This choice reflects the fact that the efficiency of sustainability does not increase mechanically with the size of the economy. Smaller countries may display different efficiency characteristics compared to larger ones, both because of structural features and because of specific market and institutional conditions.

On the applied side, an input oriented model is used, aiming to minimize the inputs while maintaining output levels. Thus, for country k, the efficiency coefficient θ_k is obtained by solving an optimization problem that minimizes θ_k under the following conditions- Eq. (1-3):

$$\sum_j \lambda_j x_{ij} \le \theta_k x_{ik} \text{ for all inputs } i \tag{1}$$

$$\sum_j \lambda_j y_{rj} \ge y_{rk} \text{ for all outputs } r \tag{2}$$

subject to:

$$\sum_j \lambda_j = 1, \lambda_j \ge 0 \text{for all } j \tag{3}$$

Where x_{ij}represents input $i$for country j, $\lambda_j$are variables reflecting intensity, and $\theta_k$is the efficiency coefficient for country k[25].

The input-oriented approach reflects the reality of policy-making, where governments primarily control investment levels rather than directly determining sustainability outcomes. This allows the interpretation of DEA results as the potential for resource savings while maintaining achieved outcomes that is, as an indicator of the economic efficiency of public and private expenditures.

3.2 Composite Efficiency Ratio Calculation

The main analytical indicator constructed for the purposes of this study is the Efficiency Ratio (ER), calculated on the basis of the Sustainability Performance Score (SPS) and the Financial Input Score (FIS). This construction is intended to reflect the economic logic of "sustainability outcomes per unit of financial resource."

Fig 1. Analytical Framework for the Economic Efficiency Assessment of Sustainability Investments
Source: Author's own elaboration

The Sustainability Performance Score (SPS) serves as the primary measure of outputs and is calculated according to the following formula Eq. (4):

$$\text{SPS} = \left(\frac{p_1 \cdot EP}{\text{norm}_1} + \frac{p_2 \cdot RE}{\text{norm}_2} + \frac{p_3 \cdot CM}{\text{norm}_3} + \frac{p_4 \cdot (GHG+5)}{\text{norm}_4}\right) \cdot 100 + p_5 \cdot \min\left(100, \frac{EGS}{\text{norm}_5}\right) \quad (4)$$

where:

- EP– energy productivity (EUR per kg of oil equivalent),
- RE– share of renewable energy (%),
- CM– material circularity rate (%),
- GHG– reduction of greenhouse gas emissions relative to the 1990 baseline (%),
- EGS– value of the environmental goods and services sector (million EUR),
- p_i– priority weight for the corresponding indicator,
- norm_i– normalization coefficients for the respective indicators.

This calibration approach differs substantially from standard statistical normalization techniques (e.g., z-score transformation). In statistical normalization, data are centered around the sample mean, whereas in DEA each indicator is "anchored" to its theoretical or best attainable maximum. This preserves relative differences in efficiency while simultaneously providing a clearer economic interpretation of the results.

The normalization process is carried out at the level of individual indicators within the composite aggregation by using normalization coefficients (norm_i).

Energy productivity is calibrated against its technical potential (€35 per kilogram of oil equivalent – norm_1), renewable energy against grid stability constraints (95% – norm_2), the circular material use rate against best practices (45% – norm_3), greenhouse gas emissions against policy target ranges (from –5% to +60%, scaled to 0–65 – norm_4), and the value of the environmental sector against economic scale (at €1,000 million – norm_5).

The choice of such upper bounds makes it possible to consider the current state as part of a broader "potential" range and to interpret the SPS as a relative position with respect to a conceivable maximum level of sustainability.

After individual normalization, the indicators are aggregated using policy priority weights (p_i) ($p_1 = p_2 = 0.25$ for energy and renewable energy sources; $p_3 = p_4 = 0.20$ for circular economy and emissions; $p_5 = 0.10$ for sectoral development) in order to obtain composite sustainability scores. This weighting scheme reflects EU priorities established in the European Green Deal and the framework of the United Nations Sustainable Development Goals (SDGs) [26]. In this way, the SPS can be interpreted as an aggregated measure of economically relevant sustainability outcomes, comparable across countries.

The Financial Input Score (FIS) measures inputs, or investment intensity Eq. (5):

$$\text{FIS} = (SI \cdot 10) + GB \quad (5)$$

where:

- SI– sustainability investments as a percentage of GDP,
- GB– share of green bonds as a percentage of total bond issuance.

Financial input includes the intensity of sustainable investments and account for the development of the green bond market. They are not additionally normalized but instead scaled. In this way, they become comparable in magnitude to the performance index. A multiplier of 10 is applied to elevate the investment values to an order of magnitude close to that of the index, thereby allowing both components to carry balanced weight in the efficiency calculation.

The final Efficiency Ratio (ER) is calculated as Eq. (6):

$$ER = \frac{\text{SPS}}{\text{FIS}} \quad (6)$$

The resulting ER represents calibrated output relative to calibrated input, where values above 1.0 indicate higher efficiency in resource transformation relative to the scale of investment. The interpretative ranges are therefore:

- $ER > 1.0$ – above-average efficiency (more sustainability outcomes per unit of financial input compared to other Member States),
- $ER = 1.0$ – average efficiency across the sample (EU-27),
- $ER < 1.0$ – below-average efficiency (suboptimal transformation of investments into sustainability outcomes, indicating a need to improve implementation or optimize resource allocation).

From an economic policy perspective, ER can be regarded as an indicator of "value for money" in sustainable investments. Constructed in this way, it is suitable both for cross-country comparative analysis and for examining dynamics over time.

3.3 K-means Clustering Methodology

A standard K-means approach is used to group the results. Through this method, different ways in which EU Member States achieve sustainable progress are identified. Instead of presenting countries solely in the form of a linear ranking, they are grouped according to their strategic profiles. The method is applied following the algorithm proposed by Stuart Lloyd [27] using standardized variables. Each variable carries equal weight in the formation of clusters.

The cluster analysis uses two main variables:

i. Investment growth rate (over the period 2015-2024) – reflecting strategies for scaling financial resources.
ii. Efficiency improvement rate (also for 2015-2024) – reflecting optimization approaches for resource use.

This makes it possible to distinguish between countries that primarily increase investments, those that rely more on efficiency improvements, and those that combine both approaches. In economic terms, this implies a distinction between "investment-driven" and "efficiency-driven" models of sustainable growth.

Feature standardization is performed using StandardScaler normalization, defined as Eq. (7):

$$Z = \frac{X-\mu}{\sigma} \quad (7)$$

where:

- X– raw feature value,
- μ– sample mean,
- σ– sample standard deviation.

This statistical transformation ensures that investment growth and efficiency improvement are given equal priority in distance calculations, regardless of their different scales and variances [28].

The clustering task is solved for k = 2 to k = 8, computing the Within-Cluster Sum of Squares (WCSS) and silhouette coefficients for each configuration. The optimal solution simultaneously maximizes the silhouette coefficient while minimizing WCSS.

The silhouette coefficient for an observation i is calculated as Eq. (8):

$$s(i) = \frac{b(i)-a(i)}{\max(a(i),b(i))} \quad (8)$$

where:

- $a(i)$– average distance of the observation to all other points in the same cluster,
- $b(i)$– average distance to the nearest different cluster.

Silhouette values range from −1 to +1, with higher values indicating better separation between clusters and greater cohesion within clusters [29].

3.4 Crisis Impact Assessment Approach

One of the sub-objectives of the present analysis is to quantitatively measure the differentiated impact of major crises on sustainability efficiency. This is carried out for two shock periods affecting the EU-27 countries: the COVID-19 pandemic (2019–2021) and the Russian invasion of Ukraine (2022–2024).

Methodologically, the approach goes beyond a simple before-and-after comparison by applying a framework that allows the examination of dynamic adaptation processes and the identification of different resilience patterns among countries.

For each crisis, an immediate and a subsequent phase of impact are distinguished. The rationale behind these two levels is to identify countries that demonstrate rapid adaptation capacity in sustainability policies and those that experience prolonged disruptions in efficiency.

For the COVID-19 pandemic, the two phases are defined as the "immediate impact" (2019–2020) and the "recovery" phase (2020–2021). The immediate impact is calculated as Eq. (9):

$$\text{COVID Impact} = \frac{ER_{2020} - ER_{2019}}{ER_{2019}} \times 100 \qquad (9)$$

In this formula, ER represents the efficiency ratio calculated according to the methodology described above, for the respective years indicated in the index. This measures the proportional magnitude of impact, allowing comparisons across countries even when substantial differences exist in pre-crisis efficiency levels.

The recovery assessment is constructed analogously as Eq. (10):

$$\text{COVID Recovery} = \frac{ER_{2021} - ER_{2020}}{ER_{2020}} \times 100 \qquad (10)$$

To assess the impact of the war in Ukraine, a similar approach is applied, again distinguishing between an "immediate impact" phase (2021–2022) and an "ongoing" phase (2022–2024), Eq. (11-12):

$$\text{WAR Impact} = \frac{ER_{2022} - ER_{2021}}{ER_{2021}} \times 100 \qquad (11)$$

$$\text{WAR Ongoing} = \frac{ER_{2024} - ER_{2022}}{ER_{2022}} \times 100 \qquad (12)$$

To evaluate overall crisis resilience, a Combined Resilience Score (CRS) is constructed, aggregating the two shocks for each country. The purpose of this indicator is to identify countries that demonstrate consistent adaptive capacity, as well as those exhibiting specific vulnerability during crisis periods. The CRS is calculated as Eq. (13):

$$\text{CRS} = \text{COVID Impact} + \text{WAR Impact} \qquad (13)$$

CRS can be interpreted as a composite indicator of the "crisis resilience" of efficiency. Positive values indicate improvement or limited efficiency losses, while negative values signal vulnerability of sustainable investments to external shocks. Conceptually, this approach simplifies the assessment of the cumulative effects of the initial shock impacts from both crises.

3.5. Analysis of the Determinants of Crisis Resilience

The statistical methodology is based on the quantitative measurement of bivariate relationships between each independent variable and the Combined Resilience Score (CRS). A standard Pearson correlation analysis is applied. The Pearson correlation coefficient (r) is calculated as Eq. (14):

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (14)$$

Statistical significance was assessed using two-tailed t-tests with n-2degrees of freedom. Standard significance thresholds were applied: *** for $p<0.001$, ** for $p<0.01$, * for $p<0.05$, and NS (not significant) for $p\geq0.05$. Correlation strength was classified according to Cohen [30] as weak ($|r|<0.3$), moderate ($0.3\leq|r|<0.6$), and strong ($|r|\geq0.6$).

The choice of a correlation-based approach is motivated by the objective of identifying the main factors associated with higher or lower efficiency resilience during crises, without introducing additional model complexity.

To verify the reliability of the estimates, the risk of multicollinearity among institutional quality indicators is assessed. This risk arises because these variables describe closely related aspects of governance. Variance Inflation Factors (VIF) are calculated for all institutional variables. The highest obtained value is 4.2 (for the Institutional Quality Index relative to the Corruption Perceptions Index), which remains below the widely used multicollinearity threshold of 5.0.

An additional sensitivity analysis, excluding highly influential observations (Belgium and Germany), confirms the robustness of the main results and demonstrates that the conclusions are not driven by single extreme values.

An important methodological clarification is that the cross-sectional design of the analysis limits the possibility of drawing strong causal inferences. The observed correlations may reflect a direct effect of institutional quality on resilience, may capture proxy relationships with unmeasured factors, or may result from reverse causality. Clear identification of causal mechanisms would require a longitudinal panel analysis—an objective that lies beyond the scope of the present study.

4. Data, Variables and Limitations

4.1 EU-27 Country Dataset Coverage and Structure

The analysis covers all 27 EU member states at the time of the empirical study (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden).

The study period is 2015–2024, which yields 270 observations in total (country–year) and allows both cross-sectional and temporal analysis. The time span is chosen to capture key stages in the development of EU sustainability policies. It includes the introduction of the European Green Deal (2019), the effects of the COVID-19 pandemic (2020–2021) and the impacts of the war in Ukraine (2022–2024). The base year is 2015, which precedes the Green Deal and thus allows the magnitude of policy effects and changes in trajectories to be measured.

This panel dataset makes it possible to trace both more persistent, “static” characteristics of countries and dynamic changes over time. It provides a basis for economic comparison of efficiency across countries and across years.

4.2 Data Sources and Indicator Construction

A range of information sources is used to carry out the computational procedures. The main source is Eurostat's database for the Sustainable Development Goals [11]. It is chosen because it contains information for all EU-27 member states, the data are collected under a harmonized methodology and they are available for the reference period of the analysis. This source ensures comparability and reliability of the data, which is crucial for the quality of the study.

i. Data on energy productivity are taken from Eurostat indicator sdg_07_30, which measures GDP per unit of energy consumption [11].
ii. The share of renewable energy uses Eurostat indicator sdg_07_20, which measures renewable sources in gross final energy consumption [11].
iii. The circular material use rate uses Eurostat indicator sdg_12_41, which captures recycled materials as a percentage of overall material use [11].
iv. Calculations of greenhouse gas emission reductions draw on Eurostat indicator sdg_13_10, which measures total emissions relative to the 1990 baseline, adjusted for international carbon quota transactions [11].
v. Data for the environmental goods and services sector use Eurostat indicator sdg_12_61, which measures gross value added in activities related to environmental protection and resource management [11].
vi. The investment indicators combine several sources in order to capture more complex measures of financial commitment. Sustainability-related investments as a percentage of GDP and public environmental expenditure are drawn from the OECD databases on environmental finance [4], complemented by estimates of private green investment from the EIB Climate Investment Database [4, 31, 32].
vii. Data on green bond issuance use Eurostat indicator sdg_13_70, which shows the share of green bonds in total bond issuance by government and corporate issuers [11]. This indicator reflects market-based financing mechanisms that are becoming increasingly important for mobilizing investment in sustainability.

Combining these sources makes it possible to construct a consistent set of indicators for the "expenditure side" of the sustainable transition that is comparable across member states.

4.3. Data Sources for the Analysis of the Determinants of Crisis Resilience

Since the analysis computes a quantitative indicator of the impact of crises on the efficiency of sustainability – the Combined Resilience Score (CRS) – it is natural to examine how this indicator is related to different country characteristics in the sample. In this part of the study, the aim is to identify structural factors that determine how resilient countries are to crisis shocks. This is done through a correlation analysis between CRS and twelve potential explanatory variables. The question is which characteristics help countries to maintain or improve the efficiency of sustainable development during major disruptions. The chosen approach makes it possible to link the efficiency indicator to the economic, institutional and structural profile of each country.

The dependent variable is precisely the Combined Resilience Score (CRS), since this indicator is constructed to capture cumulative resilience during both the pandemic and the geopolitical crisis.

Twelve explanatory variables are selected as independent variables, grouped into four broad categories:

i. Institutional quality indicators. The main hypothesis is that governance capacity predetermines the efficiency of sustainability. This group includes a composite institutional quality index built from the six World Bank – Worldwide Governance

Indicators [33, 34], as well as separate indicators for government effectiveness, regulatory quality and rule of law, plus the Transparency International – Corruption Perceptions Index [35].

ii. Economic development indicators. Here the hypothesis is that the availability of resources and high economic productivity are associated with better efficiency of sustainability policies. GDP per capita [36] and the Human Development Index [37] are included.

iii. Energy and sustainability indicators. The aim is to test a "sectoral" hypothesis. The variables are the degree of energy dependence (Eurostat – energy statistics), the share of renewable energy (Eurostat SDG 7.2.1) [11] and the maturity of the green bond market [38].

iv. Structural vulnerability indicators. This group consists of receipts from the EU Cohesion Fund (European Commission – Cohesion Policy Data (Cohesion Fund receipts, % of GDP) [39], average % of GDP for 2015–2024 [36]) and geographical proximity to Ukraine, measured as distance to the Ukrainian border (own calculations in kilometers).

For this part of the time-series analysis, all institutional quality indicators are averaged over the crisis period 2019–2022, so as to capture governance capacity before and during the shocks. The economic indicators use data for 2023–2024, reflecting the current level of development. The energy indicators are also averaged over 2019–2022, in order to capture the baseline structure of the energy system relevant to both crises. The general characteristics and data sources for the selected indicators in the four panels are shown in Table 1. This ensures consistency between the time horizon of the crisis effects and the explanatory variables used.

Table 1
Factors Analyzed in Relation to Combined Crisis Resilience (Data and Sources)

Factor	Source	Measurement
Institutional Quality Indicators		
Institutional Quality Index	The Worldwide Governance Indicators [33], composite of 6 dimensions	Composite index (-2.5 to +2.5) averaged across 6 WGI dimensions
Government Effectiveness	The Worldwide Governance Indicators [33], Government Effectiveness	Score (-2.5 to +2.5 scale)
Regulatory Quality	The Worldwide Governance Indicators [33], Regulatory Quality	Score (-2.5 to +2.5 scale)
Rule of Law	The Worldwide Governance Indicators [33], Rule of Law	Score (-2.5 to +2.5 scale)
Corruption Perceptions Index	Transparency International – Corruption Perceptions Index 2024 [34]	Score (0-100 scale)
Economic Development Indicators		
GDP per Capita	Eurostat – SDG 08_10: GDP per capita, current prices (EUR) [35]	Thousand EUR per capita (2024 current prices)
Human Development Index	United Nations Development Programme – Human Development Report 2024 [36]	Index (0-1 scale)
Energy and Sustainability Indicators		
Energy Dependency Rate	Eurostat – SDG 07_50: Energy dependency rate (net imports / gross inland consumption) [37]	Percentage (0-100%)
Green Bond Market Maturity	Eurostat – SDG 07_20: Renewable energy share in gross final energy consumption [38]	Percentage of total bond issuance (0-100%)
Renewable Energy Share	European Investment Bank – Green Bond Database [39]	Percentage (0-100%)
Structural Vulnerability Indicators		

Table 1
Continued

Factor	Source	Measurement
EU Cohesion Fund Receipt	European Commission – Cohesion Policy Data (Cohesion Fund receipts 2015–2024, % of GDP) [40]	Average annual % of GDP
Geographic Proximity to Ukraine	Eurostat – Regional coordinates (NUTS2/NUTS3) and own calculations of distance to Ukrainian border [41]	Kilometers (0-2000 km)

Source: Author's compilation based on data sources listed in the table.

4.4 Methodological Limitations

Given the way the analysis is constructed, several groups of factors need to be noted that affect the interpretation of the results:

i. The choice of sustainability indicators is constrained by the availability of consistent data for all countries and years. Indicators related to biodiversity, air quality, water and soil would broaden the scope of measurement, but are not currently available with sufficient completeness. The results should therefore be seen as focusing on dimensions of sustainability with a clear economic and energy relevance.
ii. The weighting scheme in the SPS is based on the EU's policy priorities, which inevitably introduces an element of subjectivity. A sensitivity analysis using alternative sets of weights would allow an additional check of the robustness of the results, but is not carried out within this study due to scope limitations.
iii. The efficiency measurement methodology based on DEA and ER assumes a particular type of relationship between inputs and outputs and does not fully capture possible non-linear effects or interactions between different dimensions of sustainability. This should be borne in mind when interpreting the results, especially at the extremes.
iv. Finally, in analyzing crisis effects it is difficult to clearly separate the impact of the external shocks themselves from the impact of the policy responses. Different crisis-response strategies lead to different efficiency patterns that reflect specific policy choices and institutional features. These choices are shaped by a much wider set of factors and cannot be attributed solely to the "objective" exposure to the crisis.

5. Results

5.1 Efficiency Rankings and Trends

The first obvious finding from the analysis is that there are substantial differences in the efficiency of sustainability-related investments across the EU-27 member states. Table 2 shows the values of the efficiency indicator by country for each year of the period. This means that, at similar or even lower levels of expenditure, some economies achieve a significantly higher "result per unit of investment" in sustainability, while others obtain a lower return on the resources they deploy.

Overall efficiency dynamics over the period are upward for most countries, with an average annual growth rate of 4.1%. At the same time there are substantial cross-country differences, with changes ranging from –4.3% to +14.5% over the full period. The strongest growth in efficiency is observed in Czechia (+14.5%), Latvia (+14.7%) and Portugal (+13.1%), while Finland (–4.3%), Estonia (–2.4%) and France (–1.7%) record declines. This heterogeneity suggests that the sustainable transition depends not only on the overall scale of financing, but also on the extent to which individual countries manage to increase the economic productivity of their sustainability-related spending.

Table 2
Efficiency of sustainability investments across EU-27 member states, 2015-2024

Country/ Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Standard deviation	Average
Austria	1.08	1.14	1.08	1.13	1.09	1.13	1.13	1.14	1.17	1.18	.03288	1.127
Belgium	1.04	1.04	1.03	1.01	0.97	1.02	1.01	1.03	1.04	1.01	.02049	1.020
Bulgaria	0.63	0.63	0.6	0.68	0.68	0.67	0.66	0.63	0.68	0.67	.02685	0.653
Croatia	1.12	1.03	1.04	1.15	1.04	1.12	1.03	1.11	1.03	1.12	.04614	1.079
Cyprus	0.78	0.77	0.73	0.85	0.77	0.78	0.78	0.77	0.8	0.78	.02844	0.781
Czech Republic	0.87	1.07	1.07	0.97	1.11	1.01	1.02	0.99	1.01	1.04	.06280	1.016
Denmark	1.17	1.17	1.15	1.25	1.23	1.19	1.21	1.19	1.21	1.25	.03250	1.202
Estonia	0.73	0.84	0.97	0.88	0.9	0.78	0.82	0.87	0.88	0.85	.06274	0.852
Finland	1.19	1.24	1.26	1.21	1.21	1.17	1.24	1.21	1.19	1.18	.02757	1.210
France	0.79	0.88	0.84	0.81	0.9	0.84	0.89	0.86	0.89	0.87	.03466	0.857
Germany	1.07	1.12	1.12	1.11	1.14	1.12	1.14	1.15	1.12	1.16	.02377	1.125
Greece	0.95	0.87	0.87	0.85	0.92	0.93	0.91	0.98	0.94	0.9	.03842	0.912
Hungary	0.78	0.69	0.7	0.74	0.7	0.72	0.7	0.72	0.72	0.74	.02548	0.721
Ireland	1.08	1.06	1.18	1.1	1.15	1.12	1.19	1.17	1.21	1.14	.04690	1.140
Italy	0.93	0.92	0.91	0.94	0.93	0.94	0.93	0.96	0.96	0.94	.01497	0.936
Latvia	1.48	1.68	1.5	1.76	1.43	1.41	1.47	1.68	1.65	1.54	.11610	1.560
Lithuania	1.55	1.48	1.66	1.56	1.62	1.45	1.45	1.62	1.46	1.43	.08035	1.528
Luxembourg	0.8	0.95	0.83	0.86	0.9	0.87	0.83	0.86	0.88	0.88	.03955	0.866
Malta	0.7	0.75	0.74	0.73	0.78	0.8	0.73	0.78	0.79	0.78	.03092	0.758
Netherlands	1.01	1.01	1.02	1.02	1.02	1.04	1.05	1.08	1.06	1.09	.02757	1.040
Poland	1	1.15	0.96	0.93	1.06	1.02	1.04	1.07	1.17	1.07	.07156	1.047
Portugal	0.78	0.74	0.87	0.75	0.79	0.76	0.81	0.81	0.85	0.82	.04020	0.798
Romania	0.75	0.72	0.73	0.71	0.77	0.76	0.74	0.75	0.78	0.77	.02182	0.748
Slovakia	0.81	0.86	0.85	0.79	0.84	0.87	0.82	0.83	0.84	0.82	.02283	0.833
Slovenia	0.99	1.01	0.98	0.99	0.96	0.98	0.98	1.02	1.07	0.99	.02900	0.997
Spain	1.18	1.08	1.11	1.16	1.16	1.09	1.24	1.2	1.1	1.18	.05020	1.150
Sweden	1.05	1.04	1.03	1.07	1.08	1.07	1.04	1.05	1.08	1.06	.01676	1.057

Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The heatmap table consists of two data panels. The first panel presents annual values for each country, while the second panel reports the corresponding summary statistics (standard deviation and average) for each country across the observed period. The color intensity scale differs between the two panels to reflect the distinct numerical ranges of the underlying data. In both panels, higher color intensity indicates higher numerical values. This allows for consistent visual interpretation within each panel while preserving the comparability of patterns and relative magnitudes across countries.

There is a weak negative correlation between the volume of investment and efficiency (r = –0.05), which points to decreasing returns on sustainability expenditures beyond a certain threshold. Only four countries manage to combine high investment levels (>4% of GDP) with high efficiency

(>1.1): Denmark, Finland, Austria and Germany. Maintaining high efficiency while expanding investment programs is therefore a major challenge that only a few states handle successfully. In purely economic terms, only a limited number of countries succeed in avoiding "diminishing marginal returns" on additional spending and in keeping ER high as the investment volume increases.

There is also a moderately strong correlation (0.61) between the mean value of the indicator and its standard deviation. For most countries the standard deviations lie in the 1–5% range, with only five states exceeding these bounds. This supports the intuitive expectation that the ability to convert financial resources into sustainable outcomes is a relatively stable characteristic of individual economies. Countries with high average efficiency usually display lower volatility, while more unstable results are typical of states in transition or with more vulnerable financing models. The data indicate that most countries maintain relatively stable efficiency levels over 2015–2024, and the averages reflect a persistent potential for efficient use of resources. This further supports the view that economic and institutional features shape durable "efficiency profiles" that do not change easily in the short run.

On this basis, differences in the efficiency of sustainability-related investments can be examined at the end of the period, that is, for 2024. Individual efficiency coefficients range from 0.67 to 1.54. Figure 2 presents the overall efficiency ranking, according to which 14 countries achieve above-average efficiency (coefficients > 1.0), while the remaining 13 are below the EU average.

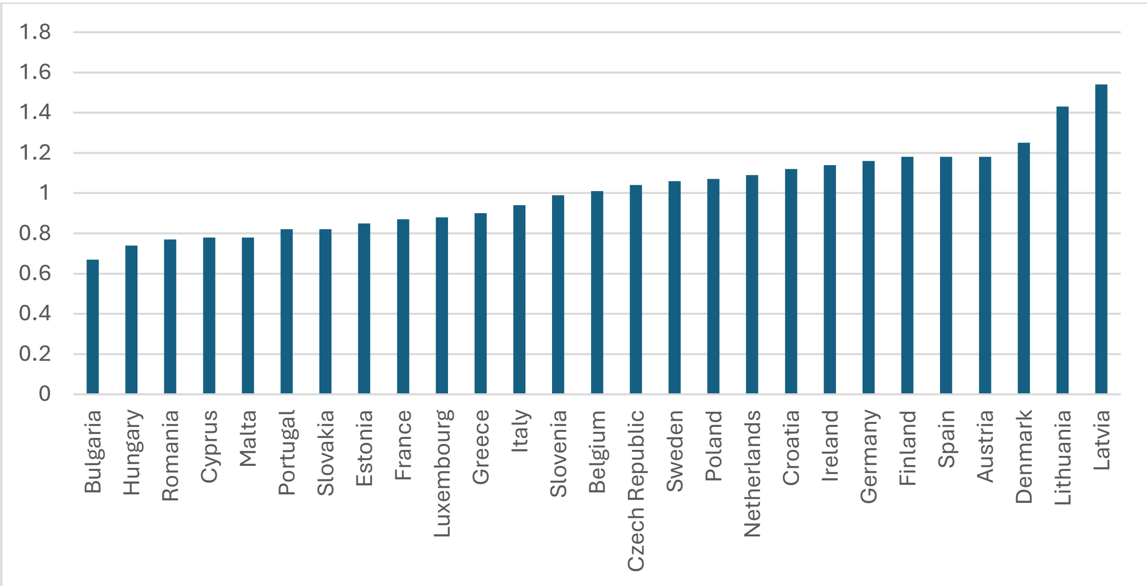


Fig. 2. Efficiency of sustainability investments in EU-27 member states, 2024
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The efficiency ratio represents calibrated output per calibrated input, where values above 1.0 indicate superior resource conversion efficiency relative to investment magnitude.

Latvia (1.54) stands out with the highest efficiency coefficient, followed by Lithuania (1.43) and Denmark (1.25). This result calls into question the usual perceptions of which countries are the "leaders" in sustainability. The Baltic states achieve high efficiency not through the sheer scale of spending, but through better optimization of resources. The strong performance of Latvia and Lithuania reflects successful adaptation to EU sustainability requirements combined with targeted investment strategies aimed at maximizing the ratio between outcomes and resources used. In practice, this means that in these economies green expenditures generate more "useful effect" relative to the scale of investment flows, which is particularly important under tight budget constraints.

The Scandinavian countries show a more mixed pattern. Denmark ranks third (1.25), Finland fourth (1.18), while Sweden is surprisingly only twelfth, with efficiency of 0.91. Clearly, high institutional capacity alone is not sufficient for optimal efficiency. When resources are abundant, diminishing returns on additional sustainability spending may set in, as also noted in other studies [39]. Thus even economies with long-standing green policies can reach an "efficiency ceiling", where further investments yield smaller incremental benefits.

The large EU economies display moderate efficiency levels. Germany reaches 1.16, Spain 1.18, while Italy is slightly below the average at 0.98. France, with an efficiency of 0.89, appears to have untapped potential for optimizing the allocation of sustainability investments despite their sizeable absolute volume. The Netherlands, often cited as a model of sustainable development, records moderate efficiency (1.09). This highlights the important distinction between the "level of sustainability" and the "efficiency of sustainable spending". A country may have high sustainability scores, but achieve them at relatively higher cost than other member states.

Bulgaria is the country with the lowest efficiency (0.67), followed by France (0.89) and Sweden (0.91). Such values suggest systemic difficulties in translating sustainable investments into commensurate outcomes. Likely explanations include limitations in institutional capacity, weaknesses in policy coordination or inefficient targeting of funds. These characteristics are also relatively slow to change. From an economic perspective, this means that under current financing models the "output per unit of cost" is lower, which entails a risk of accumulating expenditures without proportionate progress in sustainability.

5.2 Clustering Analysis Results

The differences in the efficiency of sustainability-related investments across the EU-27 also have a clear regional pattern. This can be illustrated by the heatmap of efficiency across the countries under study, presented in Figure 3.

More detailed clustering results allow for an interpretation that rests not only on visual inspection but also on statistical tools. The K-means clustering analysis indicates an optimal number of clusters of k = 7 (silhouette coefficient 0.464). The characteristics of these clusters provide grounds to distinguish four clearly recognizable strategies for progress in sustainability among the EU-27 countries. Figure 4 shows the clustering results, positioning countries according to investment growth and efficiency improvement.

Based on the clustering results, four distinct models of investment growth and efficiency improvement can be identified:

i. Countries with parallel growth (Dual Achievers). This group includes the countries in cluster 0 and cluster 4 – five states in total: Luxembourg, Poland, Slovakia, Latvia and Portugal. They simultaneously increase sustainable investments substantially (average growth 40.5%) and achieve a marked rise in efficiency (average 11.2%). This is the most favorable scenario, where additional resources are mobilized and, at the same time, the way they are used improves. In Luxembourg this is linked to its strategic positioning as a center for green finance and targeted efficiency programs. Poland, Slovakia and Latvia, in turn, show successful use of EU structural funds with an emphasis on project-level efficiency. In economic terms these countries can be viewed as examples of "good practice": additional public and private resources lead to more than proportional growth in sustainable outcomes.

ii. High Investment-Driven Performers. This group consists of nine countries in clusters 1, 5 and 6: Estonia, Sweden, Finland, Belgium, Greece, Ireland, Romania, France and Slovenia. What they share is that progress is driven mainly by increased funding (average investment growth 44.2%), while the improvement in efficiency is minimal (0.2%). This reflects approaches in which the emphasis falls on the scale of spending rather than on its optimization. Such behavior may stem from institutional constraints or from being at an earlier stage of the green transition. France is a typical example, with large-scale investments under the Green Deal. The Scandinavian countries illustrate how even high-capacity economies can follow resource-intensive strategies without a corresponding rise in efficiency. In economic terms, this is "quantitative" rather than "qualitative" growth – more money, but without a substantial increase in ER.

iii. High Efficiency-Driven Optimizers. This group comprises Bulgaria, Croatia, Czechia, Hungary and Italy (cluster 3). These countries move forward mainly by improving efficiency (average gain 10.6%) with moderate investment growth (28.9%). The core of the group consists of Central and Eastern European states plus Italy, suggesting approaches in which resources are more limited, but institutional capacity allows for rational use of available funds. Czechia is a leading example, with a 14.5% increase in efficiency and very good optimization of constrained resources. This model reflects successful adaptation to EU requirements while managing fiscal constraints – "more result from less resource", which is particularly important under tight budget conditions.

iv. Moderate Progress Maintainers. This category includes the countries in cluster 2 – eight states in total: Austria, Cyprus, Denmark, Germany, Lithuania, Malta, the Netherlands and Spain. They show balanced but moderate progress in both dimensions (33.1% growth in investments and 4.1% efficiency improvement). This may reflect mature sustainability systems approaching their optimization limits, or difficulties in coordinating investment and efficiency-oriented policies. Although individual explanations can be sought for each country, the group is compact enough to speak of a common pattern. The example of Germany illustrates how challenging it is to expand the green transition in a large industrial economy, where even small improvements require significant resources. This cluster captures situations where "additional progress becomes increasingly costly" because many of the easier measures have already been implemented.

The presence of clearly distinguishable strategic models is also confirmed by the statistical analysis of groups and clusters (F-statistic = 12.3, $p < 0.001$ for investment growth; F-statistic = 8.7, $p < 0.001$ for efficiency improvement). At the same time, silhouette coefficient values between 0.41 and 0.52 indicate good internal homogeneity within clusters and clearly separated strategic profiles. The results can therefore serve as an empirical basis for differentiating EU economic and financial instruments – for example, strengthening management capacity and project quality in "investment-driven" countries and providing additional resource support to "efficiency-driven" ones.

An important point is that the clustering results challenge traditional views of which states are the "leaders" in sustainability within the EU-27. The grouping pattern shows that an empirical basis of this kind can be used to design differentiated EU policies. The high-efficiency groups demonstrate that there is more than one path to a sustainable transition and that the optimal strategy depends on a combination of institutional capacity, fiscal conditions, available resources and the stage of social, economic and environmental development. In this sense, the economic contribution of the analysis is not only to indicate "who is more efficient", but also "what type of strategy" underlies a given level of efficiency – information that is crucial for policy design and for allocating financial resources.

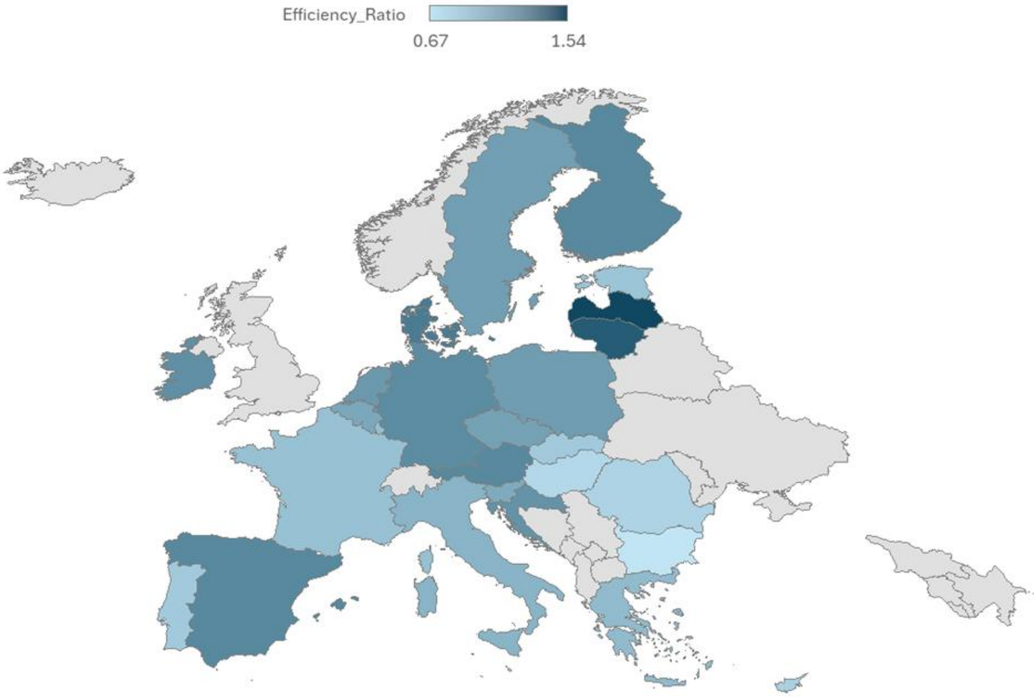


Fig. 3. Heatmap of sustainability investment efficiency across EU-27 member states for 2024
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: Higher color intensity indicates higher sustainability investment efficiency. Countries in Europe that are not members of the EU are shown in grey.

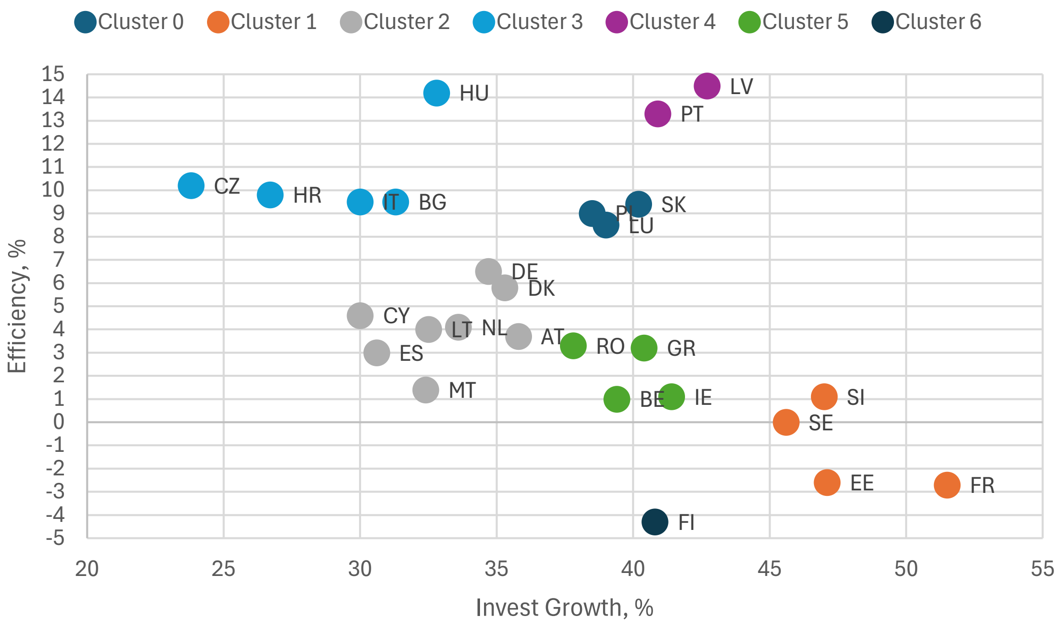


Fig. 4. K-means clustering – efficiency versus investment for EU-27 member states, 2024
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: Each country is labelled according to the ISO 3166-1 alpha-2 standard. The individual clusters are displayed in distinct colors, as indicated in the legend.

5.3 Crisis Assessment

As expected, the results for the impact of shock events on the efficiency of sustainability-related investments vary substantially across countries and across the two crises examined. The resulting indicator values are presented in Table 3, by country and period. These values make it possible to assess not only changes in sustainable outcomes, but also the extent to which crisis-related expenditures have been economically productive – that is, whether countries have increased, maintained or reduced the efficiency with which they convert resources into sustainability outcomes.

The first impression is that different countries react in different ways to the impact of the two crises. At the same time, distinct groups of countries with similar profiles of initial decline or improvement and subsequent recovery can clearly be identified. This confirms the expectation of different patterns of economic and institutional adaptation.

This differentiation can be particularly clearly demonstrated in terms of territorial clustering with respect to the impact of COVID-19 and the war in Ukraine, including visually through the impact heatmaps presented in Figure 5.

Table 3
Indicators assessing the impact of the COVID-19 pandemic, the war in Ukraine, and their combined effect on the efficiency of sustainability investments in EU-27 member states

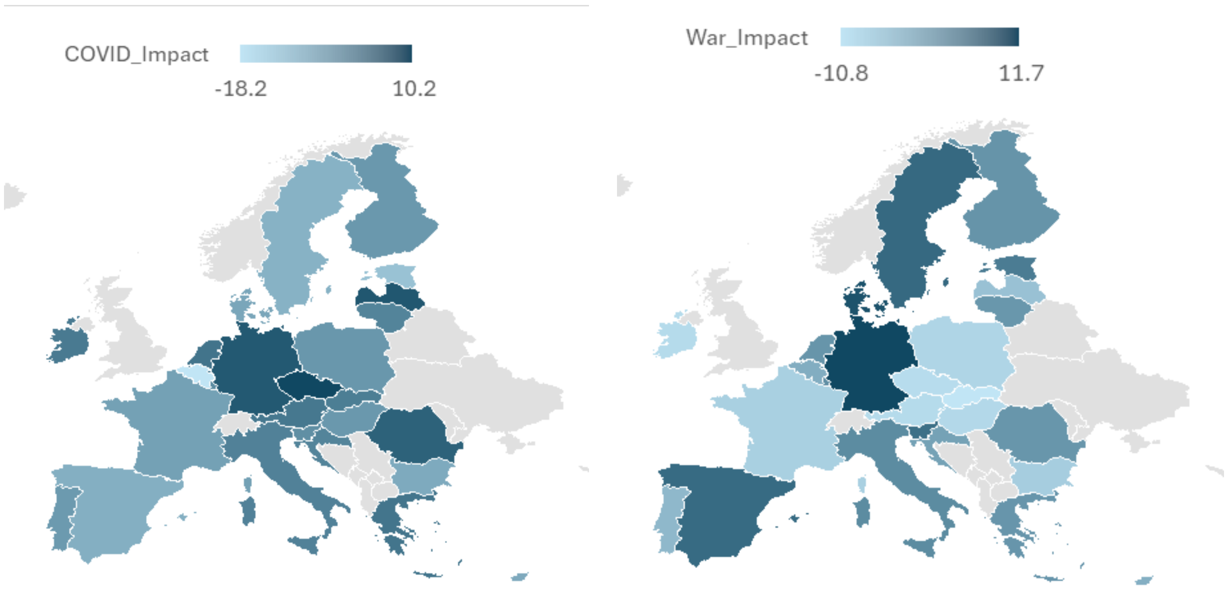
Country	COVID Impact 2020	COVID Recovery 2021	War Impact 2022	War Ongoing Impact 2022-2024	Combined Impact
Austria	1.5	2.3	-9.3	10.2	-7.8
Belgium	-18.2	27.6	-2.8	-7.7	-21
Bulgaria	-7.5	17.7	-7.4	0.1	-14.9
Croatia	-0.6	7.4	-1.2	2.4	-1.8
Cyprus	-7.4	11.8	-3.1	11.5	-10.5
Czech Republic	10.2	-4.1	-9.5	14.2	0.7
Denmark	-6.8	2.5	10.1	-3.9	3.3
Estonia	-11.8	9.9	4.2	-3.5	-7.6
Finland	-4.2	0.4	0.8	0.8	-3.4
France	-5.9	16.7	-7.8	10	-13.7
Germany	7.1	-7.5	11.7	-3.7	18.8
Greece	2	9	0.6	-1.2	2.6
Hungary	-4.3	13.1	-9	5.3	-13.3
Ireland	1.1	11.4	-9.3	-0.6	-8.2
Italy	-0.2	1	2	-8.1	1.8
Latvia	7.5	-0.5	-5.7	8.2	1.8
Lithuania	-0.6	-2.4	0.4	0.3	-0.2
Luxembourg	-1.9	3.8	1.6	3.4	-0.3
Malta	-6.4	4.6	0.4	-4.4	-6
Netherlands	2.2	3.3	0.7	6.3	2.9
Poland	-4	11.6	-8.5	-0.1	-12.5
Portugal	-4.6	11.2	-4.4	3.2	-9
Romania	5.5	-4.5	0.5	4.5	6
Slovakia	0.5	10.9	-10.8	13.6	-10.3

Table 3
Continued

Country	COVID Impact 2020	COVID Recovery 2021	War Impact 2022	War Ongoing Impact 2022-2024	Combined Impact
Slovenia	-2.6	8.1	6	-2.3	3.4
Spain	-8.4	11.5	6.7	-5.6	-1.7
Sweden	-8.9	5.5	6.9	4.5	-2

Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The heatmap table consists of three data panels. The first panel presents data on the impact of the Covid-19 pandemic, the second the impact of the war in Ukraine, and the third the combined impact of the two shocks (for each country across the observed period). The color intensity scale differs between the three panels to reflect the distinct numerical ranges of the underlying data. In all panels, higher color intensity indicates higher numerical values. This allows for consistent visual interpretation within each panel while preserving the comparability of patterns and relative magnitudes across countries.



(a) (b)

Fig. 5. Heatmaps of the impact of the COVID-19 pandemic (a) and the war in Ukraine (b) on the efficiency of sustainability investments in EU-27 member states
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: Higher intensity of coloring indicates successful adaptation to the shock phenomenon. Accordingly, low intensity illustrates a significant decline in efficiency as a result of the direct impact of the crisis. Countries in Europe that are not members of the EU are shown in grey.

For a systematic review of the results, the impact assessment is examined sequentially for the two crises.

5.3.1 COVID-19 Impact Assessment

The COVID-19 pandemic causes significant heterogeneity in the effects on the efficiency of sustainability among the EU-27 countries. Both substantial declines and cases of improved efficiency are observed, which indicates that for some countries crisis-related spending has acted as a catalyst for better use of available resources. The initial impacts range from -18.2% to +10.2% in 2020. The overall distribution of this impact is presented in Figure 6.

The data show that Belgium is the country with the most severe decline in efficiency (–18.2%) among all EU-27 member states. This is probably the result of a combination of pressure on the healthcare system, economic lockdowns and disruptions in supply chains. Despite the severe initial shock, the country records a strong recovery – an improvement in efficiency of 27.6% in 2021. This points to the presence of adaptive management and the capacity for "learning" under crisis conditions. The Belgian case illustrates a typical vulnerability of small, highly integrated economies, where the initial loss can be partially offset through rapid reorientation of spending priorities and better management of programs.

Eastern European countries display a mixed picture. Estonia registers a significant decline (–11.8%), while Czechia improves its efficiency by +10.2%. Therefore, it is not so much the level of economic development as the institutional capacity that determines the effectiveness of adaptation in a crisis. The positive dynamics in Czechia indicate successful crisis management and probably accelerated digitalization and better coordination of sustainability programs. In economic terms, this means that in some countries crisis expenditures have been used in a way that increases ER, rather than merely cushioning the decline in economic activity.

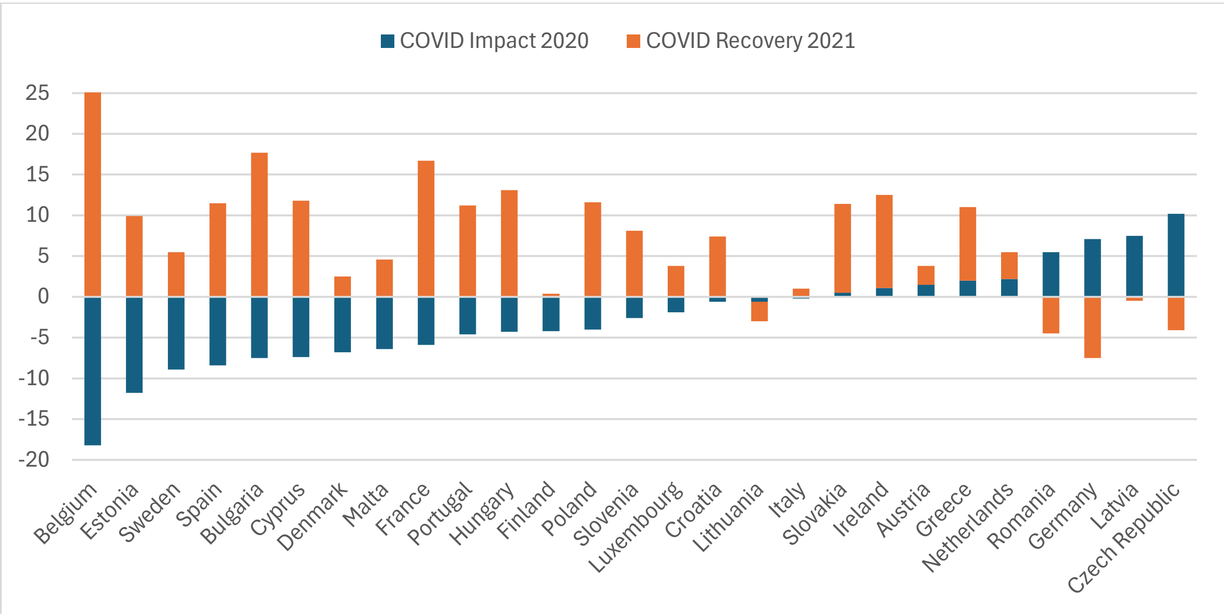


Fig. 6. Impact on sustainability efficiency due to the COVID-19 pandemic (initial impact and recovery) for EU-27 countries
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The figure presents data on the initial and subsequent impact of the crisis phenomenon. The countries are arranged according to the magnitude of the total impact of the shock on the effectiveness of sustainability policies.

The Scandinavian countries show unexpected vulnerability. Sweden (–8.9%), Denmark (–6.8%) and Finland (–0.8%) record a decline in efficiency despite their high institutional capacity. This may be linked to their specific approach to the pandemic, which placed more emphasis on maintaining economic activity and less on strict restrictions. As a result, a different type of disruption occurred in the implementation of sustainability programs compared to countries that introduced strict lockdowns. Apparently, a strategy of "more normality and fewer restrictions" may protect the short-term economy but lead to lower efficiency of sustainable spending under crisis conditions.

At the same time, there are countries that managed to improve their efficiency substantially during the pandemic period. Germany (+7.1%) and Romania (+5.5%) are among the clearly visible examples. In the case of Germany, this can be linked to the institutional capacity to maintain and adapt sustainability programs, including through digitalization and better interministerial coordination. In such situations, crisis packages and support measures have evidently been integrated into existing policies in a way that strengthens rather than weakens efficiency.

Geographically, a moderate East–West differentiation can be observed. Quantitatively, the average change in efficiency for the Eastern countries is –3.2%, and for the Western ones – –2.1%. The difference, however, is not statistically significant (t-test: $p = 0.34$), which means that geographical proximity in itself does not explain the differences in vulnerability to the pandemic. In other words, the basic structure of the economy and the level of income are not sufficient to determine how the efficiency of sustainable investments will change. The factors that are more likely to determine this efficiency are the quality of governance and the capacity for rapid reallocation of resources.

In contrast to the initial shock, in the recovery period (2020–2021) countries as a whole demonstrate considerable adaptive capacity. The average improvement in efficiency in the sample is 6.8%. Here, too, there are differences: Belgium (+27.6%), Bulgaria (+17.7%) and Spain (+11.5%) are among the leaders in improvement. This supports the expectation that a stronger initial decline can act as a "catalyst" for more intensive adaptation efforts and lead to a significant increase in efficiency. Conversely, countries with positive or mildly negative initial effects (Germany, the Netherlands, Czechia) show lower values during the recovery, which can be explained by a "ceiling effect" in the potential for further improvement. In economic terms, this means that a deeper initial decline also implies greater potential for relatively "cheap" improvements through reorganization and optimization of existing programs.

In summary, the vulnerability of sustainability efficiency appears to depend more on institutional capacity and the quality of crisis management than on the initial level of economic development or traditional sustainability indicators. This is an important conclusion for policy. From the perspective of economic governance, it means that investments in managerial capacity, coordination and digitalization can have a strong effect on efficiency, comparable to that of the volume of sustainable spending itself.

5.3.2 Ukraine War Impact Analysis

The war between Russia and Ukraine has a fundamentally different crisis impact compared to the COVID-19 pandemic. At the point of the initial shock, the effects on sustainability efficiency resulting from the military conflict vary across countries within a range from –10.8% to +11.7% (in 2022). Due to the additional effect of energy dependence, the countries in the sample exhibit significant geographical asymmetry. The distribution of this impact is presented in Figure 7.

As expected, the countries that are territorially closest to the conflict bear the strongest initial shock. Among them, Slovakia (–10.8%) and Czechia (–9.5%) stand out, where an additional factor is the high dependence on specific energy supplies and the pressure from refugee flows. This shows in practice how geopolitical disruptions generate asymmetric effects driven by structural dependencies and geographical location. More interestingly, both countries manage to restore their efficiency in the following years. Slovakia even ends up with a positive overall effect for the war period (+1.3%), which indicates successful adaptation strategies and the accumulation of managerial experience. This means that even under a strong initial shock, sustainable investments can be redirected in such a way that ER improves in the medium term. Accelerated energy diversification and improvements in energy efficiency can, for example, contribute to this.

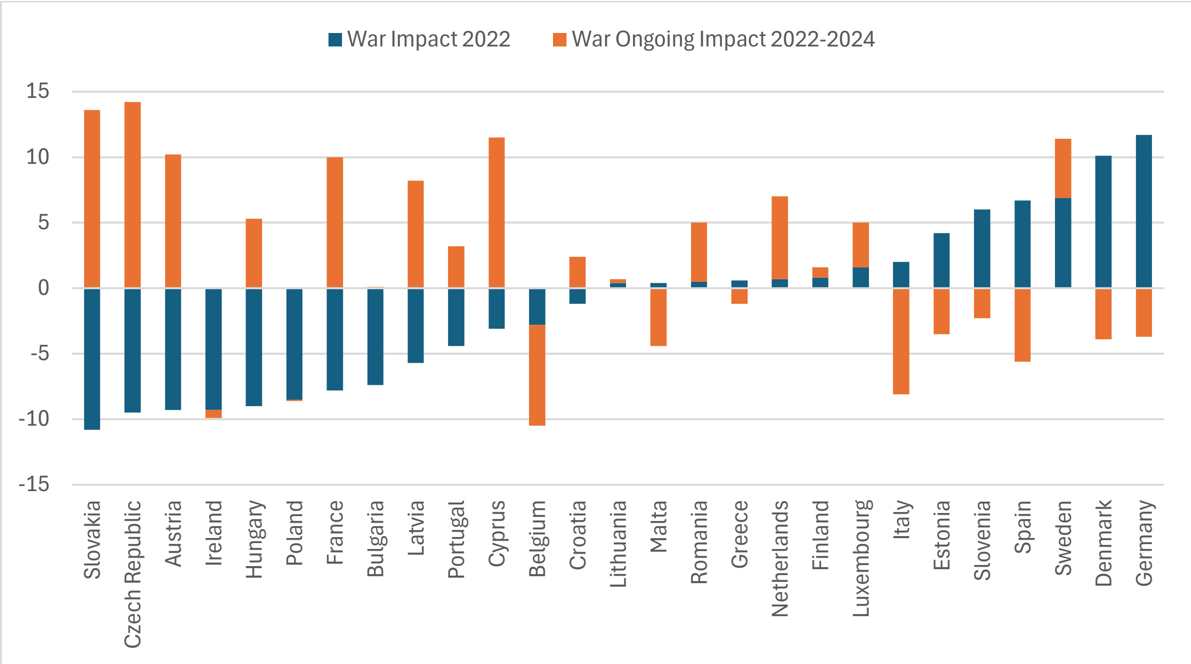


Fig. 7. Impact on sustainability efficiency resulting from the war in Ukraine (initial and ongoing effects) for EU-27 countries

Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The figure presents data on the initial and subsequent impact of the crisis phenomenon. The countries are arranged according to the magnitude of the total impact of the shock on the effectiveness of sustainability policies.

The group of Eastern European countries goes through the crisis with a larger decline in efficiency (on average –5.1%) compared to Western European countries (+0.2%). It is also important to note that this difference is statistically significant (t-test: $p = 0.003$). The explanation can be sought in more pronounced structural vulnerabilities, such as dependence on energy imports, higher exposure to supply chain disruptions, institutional constraints and a different profile of economic structures. In economic terms, this means that countries with more limited fiscal and institutional capacity are forced to direct a large share of resources towards short-term crisis mitigation (compensations, energy subsidies), which leaves less room for effective long-term investments in sustainability.

The strongest improvements in efficiency during the war period are observed in Germany (+11.7%) and Denmark (+10.1%). Both countries manage to transform crisis pressure into an accelerated transition towards sustainability. In the case of Germany, the implementation of the REPowerEU plan measures [17], as well as the accelerated deployment of renewable energy sources and energy efficiency programs, also plays an important role.

The Scandinavian countries again show a mixed picture. Sweden (+6.9%) and Denmark (+10.1%) record stronger positive effects, while in Finland (+3.9%) the improvement is more moderate. This leads to the conclusion that institutional capacity supports adaptation, but specific policies and structural characteristics determine the magnitude of the effect on efficiency. Although the

Scandinavian countries in general stand out with high quality of governance and good inter-institutional coordination, actual crisis resilience depends on a broader set of individual characteristics.

From an analytical point of view, the cases of Austria (–9.3%) and Ireland (–9.3%) are also of interest. Both exhibit a strong negative impact, even though they are not in immediate proximity to the conflict zone. This shows that geographical distance in itself does not protect against the transmission of geopolitical shocks. The explanation must be sought in specific country-level dependencies: in Austria's case – in the structure of energy markets and industrial linkages, and in Ireland's case – in deep integration into European energy markets and sensitivity to changes in supply chains.

As in the case of the COVID-19 pandemic, the results for the war in Ukraine point to the presence of a systemic structural vulnerability among the EU-27 countries. There is an evident need for centralized and targeted intervention at EU level, as well as the activation of solidarity-based stabilization mechanisms. The pronounced East–West asymmetry (a difference of 5.3 percentage points) shows that geopolitical proximity creates lasting adverse effects that market mechanisms alone cannot offset. At the same time, geographical proximity is not the only explanation, and the observed differences result from a much broader set of factors, including economic structure and market dependencies. Probably for this reason, countries with diversified energy systems and high institutional capacity have managed to turn crisis pressure into an accelerated green transition, while those with strong dependence on limited energy sources experience more prolonged disruptions in efficiency.

5.3.3 Combined Crisis Resilience

The standalone analysis of each of the two crises has its important contributions to assessing the state and response capacity to external shock events in EU countries. For identifying common patterns of behavior, however, as well as for deriving guidance for the development of crisis-response policies related to the efficiency of investments in sustainability, it is appropriate that the crisis impacts be considered together. Figure 8 presents the combined influence on sustainability efficiency resulting from the COVID-19 pandemic and the war in Ukraine for the EU-27 countries, in the form of a country ranking. Since a simplified ranking of the combined influence of the two crises is not sufficient for identifying patterns of behavior, the results are also examined from the point of view of resilience under the impact of each of the two crises (Crisis Resilience), which is presented in Figure 9. In this way, the relationship between the two shock events can be demonstrated by distinguishing the groups of countries that display consistent adaptive capacity and those that show specific vulnerabilities to the individual crises.

Germany stands out as the most resilient economy under crisis conditions, with a combined positive effect of +18.8%. This is due to good results both during the pandemic (+7.1%) and in the war period (+11.7%). Such performance indicates a high institutional capacity for management in a crisis environment and an ability to use shocks as a catalyst for increasing the efficiency of sustainability policies. The German model is a logical reference point when discussing the EU framework for crisis preparedness and for designing programs to strengthen institutional capacity in other member states.

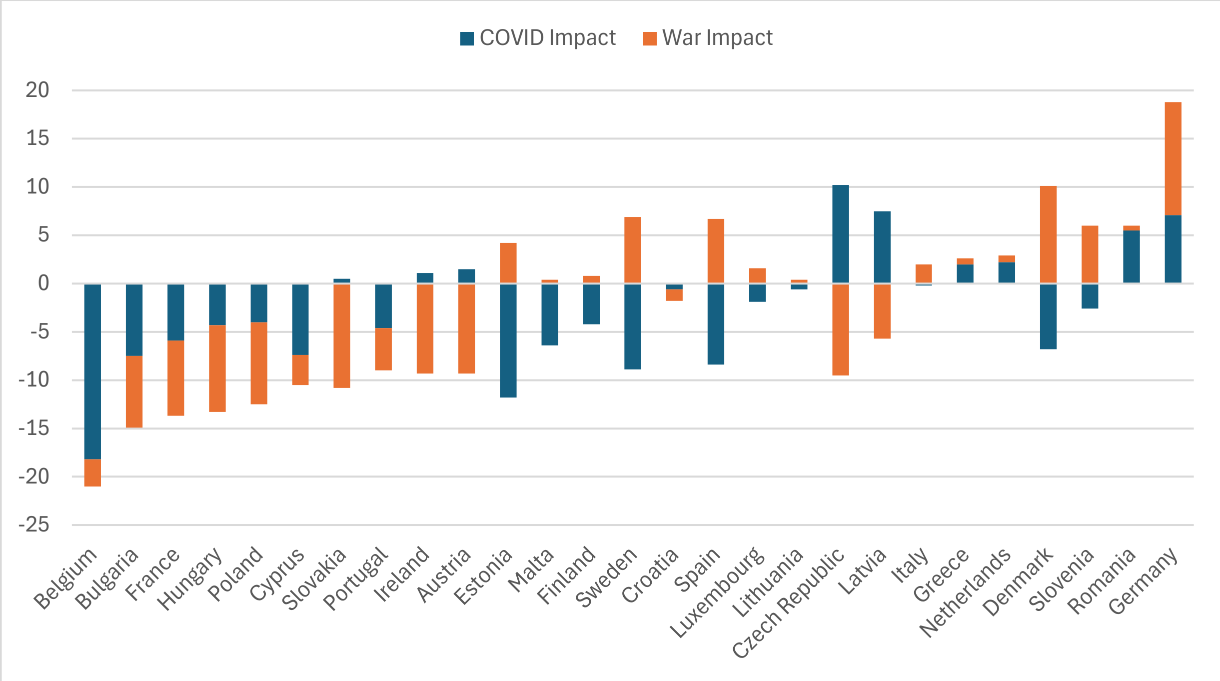


Fig. 8. Combined impact on sustainability efficiency resulting from the COVID-19 pandemic and the war in Ukraine, for the EU-27 countries
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The figure presents data of the two-crisis initial impact. The countries are arranged according to the magnitude of the total impact of the shocks on the effectiveness of sustainability policies.

The Netherlands shows balanced resilience (+2.4%), with consistently positive values in both crises (for COVID +2.2%, and for the war +0.2%). This can be associated with good institutional quality and a diversified economic structure. Denmark is another representative of the Northern countries where an interesting asymmetric pattern can be observed (+3.3%). The country shows a distinct negative effect from the pandemic (–6.8%), followed by a strong recovery during the war (+10.1%). This dynamic demonstrates the capacity for adaptive learning and institutional "fine-tuning" between the two crises. Under successive shocks, as in the period under review, the effects of changes in investment priorities and management practices often appear with a delay. It is precisely this type of dynamic that is observed in the Danish case.

The size of the economy in itself does not predetermine the effect of crises on the efficiency of sustainable investments. The small Baltic states are indicative in this respect. Latvia (+1.6%) and Lithuania (+0.9%) manage to adapt their behavior in crises despite their geographical proximity to the conflict zone. Apparently, the quality of institutions and clearly targeted policies can compensate for structural weaknesses. Moreover, resilience does not depend directly on the size of the economy or the initial income level.

The analysis also provides examples of less successful crisis responses. In these cases, there are systemic difficulties in adaptation that require targeted EU support and programs for institutional capacity development. Somewhat unexpectedly, Belgium turns out to be the country with the highest combined vulnerability in the sample (–22.1%), mainly because of the severe impact of COVID (–18.2%) and the additional negative effect during the war period (–3.9%). The Belgian case shows how the accumulation of several crises can lead to cumulative vulnerability greater than the effect of the individual shocks. A similar picture is observed in some Eastern European countries, such as Bulgaria (–14.9%), Hungary (–13.4%) and Poland (–12.7%). Their similar profile confirms the presence of regional structural weaknesses that require solidarity mechanisms and targeted support at EU level. These countries experience difficulties under different types of crises, which points to deeper structural and institutional problems rather than isolated cases of "bad luck".

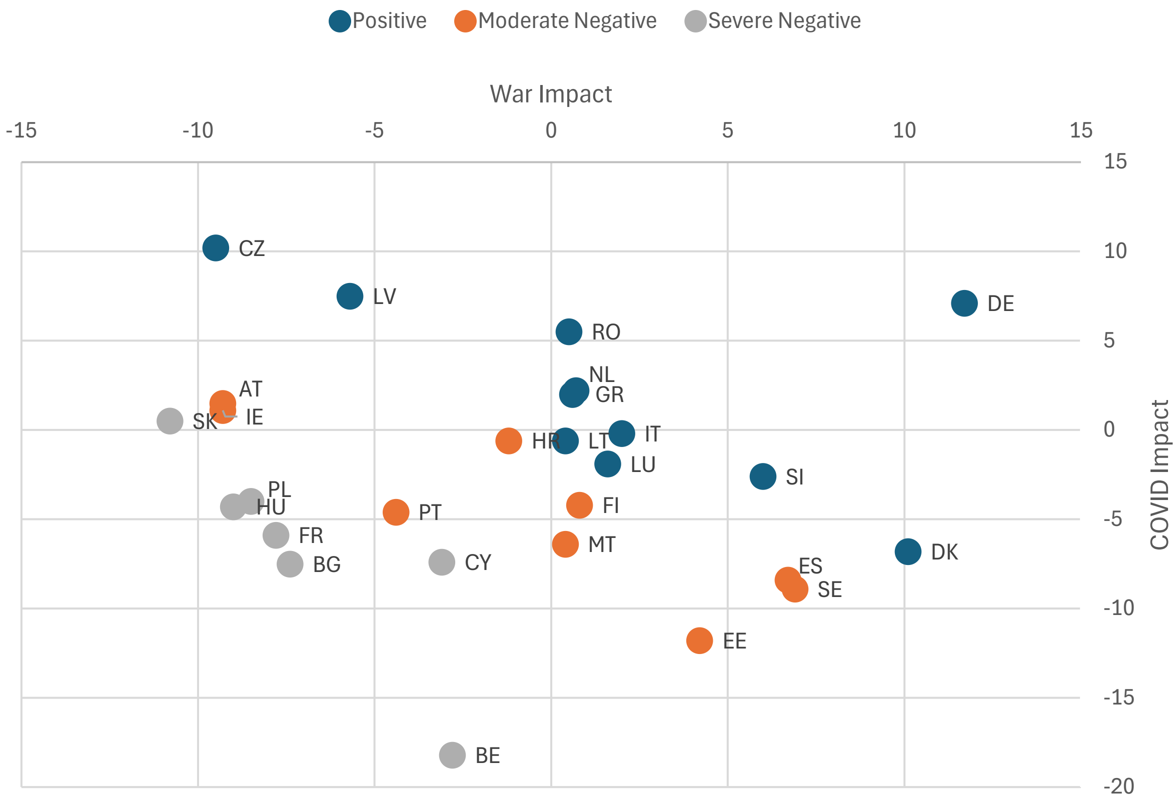


Fig. 9. Crisis Resilience of EU-27 countries (based on the impact of the COVID-19 pandemic and the war in Ukraine)
Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: Each country is labelled according to the ISO 3166-1 alpha-2 standard. The individual clusters are displayed in distinct colors, as indicated in the legend.

The correlation between the effects of COVID and the war is relatively weak (r = 0.12). This means that resilience is largely specific to the type of crisis, and the individual response of countries depends on the structure of the economy and institutional characteristics. The specific channels through which shocks are transmitted are also important, which is particularly evident when viewed from the perspective of changes in global supply chains.

Countries with asymmetric resilience (positive results in one crisis and negative in the other) underline the need for diversified and individualized strategies for building crisis adaptability. In this sense, the application of approaches focused on optimization and preparedness for a specific type of shocks can be considered rather ineffective.

An addition to this picture is provided by the findings from the correlation analysis of the determinants of crisis resilience of sustainability efficiency. A summary of the assessment is presented in the following Table 4.

Table 4
Results of the analysis of factors related to combined crisis resilience

Factor	Correlation r	P Value	Significance	Relationship
Institutional Quality Index	0.67	0.0001	***	Strong Positive
GDP per Capita	0.34	0.0821	NS	Weak Positive
Energy Dependency Rate	-0.28	0.1523	NS	Weak Negative
Human Development Index	0.59	0.0012	**	Moderate Positive
Corruption Perceptions Index	0.64	0.0003	***	Strong Positive
Government Effectiveness	0.71	0.0001	***	Strong Positive
Regulatory Quality	0.58	0.0018	**	Moderate Positive
Rule of Law	0.69	0.0001	***	Strong Positive
Green Bond Market Maturity	0.19	0.3421	NS	Weak Positive
Renewable Energy Share	0.23	0.2513	NS	Weak Positive
EU Cohesion Fund Receipt	-0.41	0.0342	*	Moderate Negative
Geographic Proximity to Ukraine	-0.52	0.0058	**	Moderate Negative

Source: Own calculations; data from World Bank WGI, Transparency International, Eurostat, UNDP and European Commission [11,33-41].

Note: The combined crisis resilience score is calculated as the sum of the impact of COVID-19 (2019–2020) and the impact of the war in Ukraine (2021–2022) on the efficiency coefficients of sustainable development. The results report Pearson correlation coefficients with two-tailed significance tests, based on n = 27 EU Member States. Significance levels: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NS = not significant ($p \geq 0.05$).

The main conclusion is related to confirming the intuitive expectation of the dominant role of institutional quality. The institutional quality index shows the strongest correlation with combined crisis resilience ($r = 0.67$, $p < 0.001$), which is almost twice as high as that of GDP per capita ($r = 0.34$, $p = 0.082$, statistically insignificant). Among the individual institutional indicators, the highest correlation is found for government effectiveness ($r = 0.71$, $p < 0.001$), followed by rule of law ($r = 0.69$, $p < 0.001$) and the Corruption Perceptions Index ($r = 0.64$, $p < 0.001$).

Economic development has a rather unexpectedly weak influence on crisis resilience of efficiency. In practice, contrary to resource-based hypotheses, GDP per capita has a weak and statistically insignificant correlation with crisis resilience. Even the broader Human Development Index, although moderately correlated ($r = 0.59$, $p = 0.001$), shows significantly weaker explanatory power compared to governance indicators. It is important to emphasize here that crisis resilience evidently depends more on institutional capacity for adaptation and effective policy implementation. Factors such as the absolute availability of resources and the general notion of the wealth of economies are not of such great importance. Ultimately, the countries that manage their efficiency best are those that are generally characterized by high quality of governance, not those that are the richest or most productive.

The analysis confirms the geographical hypothesis. Proximity to the crisis center (when there is one) is an essential factor for a country’s ability to adapt successfully to the situation. Geographical proximity to Ukraine shows a significant negative correlation with resilience ($r = –0.52$, $p = 0.006$). Countries located closer to the conflict zone have experienced stronger disruptions in efficiency than those located at a greater distance from the area of hostilities.

In turn, receiving funds from the EU Cohesion Fund is negatively correlated with resilience ($r = –0.41$, $p = 0.034$). This can be explained by lower institutional capacity and greater exposure to external shocks among net recipients. Although it is beyond the scope of the present analysis, such a relationship raises an important question about the efficiency of spending European funds and about the need to adapt financial support mechanisms so as to stimulate higher efficiency rather than merely larger volumes of funding.

As for the last, hitherto uncommented, group of determinants of crisis resilience, it can be said that there are rather surprisingly weak effects of energy and green finance on efficiency. Neither the degree of energy dependence (r = –0.28, NS) nor the share of renewable energy (r = 0.23, NS) show statistically significant relationships with crisis resilience. The maturity of the green bond market has the weakest correlation (r = 0.19, NS). The conclusion that can be drawn here is that crisis responses have been managed mainly through institutional adaptation rather than through pre-defined characteristics of energy systems. In other words, the way decisions are taken and resources are managed under shock conditions turns out to be more important for preserving efficiency than the prior level of "green" development of the energy and financial sector.

6. Discussion

The results of the analysis can be subjected to academic discussion in several directions, since the findings have dimensions in which they both correspond to and expand on what has been achieved in the scientific literature. At the same time, they allow for more concrete economic conclusions to be drawn about the efficiency of sustainability-related expenditures and the extent to which the current model supports target setting and policy design.

The model presented in practice confirms the possibilities for using DEA to assess the efficiency of sustainable investments. In methodological terms, it can even be claimed that there is an advancement compared to the existing practice of applying the approach. The analysis demonstrates the possibilities for combining DEA with cluster analysis and crisis impact assessment. In this way, some of the limitations of standard DEA applications, which usually consider efficiency separately from the strategic context and external shocks, are overcome [42]. As a result, we have an example of a more comprehensive framework for policy evaluation that combines several analytical dimensions. In economic terms, this means that instead of working only with indicator levels, the "return" on sustainable investments made is also assessed. This is of key importance for the efficient allocation of scarce public and private resources.

With regard to the results of the study itself, it can be seen that the ranking of countries by efficiency partially coincides with existing assessments of sustainability performance in the EU. In this case, "partially" means that there are also some important discrepancies. In traditional rankings, the Scandinavian countries are usually at the top [43]. In our analysis, the Baltic states emerge as the most efficient. They achieve high results, taking into account the resources used. This supports the argument from the efficiency literature that indicators adjusted for inputs, and not only absolute outcome values, are needed [44]. From the point of view of EU policies, it becomes important not only "who is the greenest", but also "who achieves the most sustainable results per unit of expenditure". That is, the question of where the "value for money" is highest.

The cluster analysis builds on existing research on the differentiation of sustainability strategies. Its contribution lies in providing empirical confirmation of the need for different approaches to policy design in different countries. In this respect, most studies usually describe strategies theoretically [45]. In the present analysis, four types of behavior are distinguished, which correspond to real groups of countries. Each of these models has clear policy implications for the choice and effectiveness of instruments. It is particularly important that efficiency-driven strategies prove to be a viable alternative to resource-intensive approaches, which dominate many discussions at EU level. This prepares the ground for differentiated target setting. Thus, for example, in "investment-driven" countries it is logical to focus on increasing efficiency. In contrast, in “efficiency-driven” countries it is more appropriate to stimulate the scaling up of successful models while maintaining a high ER.

The results on the impact of crises on efficiency also contribute to the question of the resilience of sustainable development systems. They identify patterns that are not clearly visible in more general studies of economic crises. The weak correlation between the effects of COVID and the war (r = 0.12) is an expression of the vulnerabilities of sustainability systems. The nature of this vulnerability may in turn differ substantially from general macroeconomic crisis responses. This is in line with arguments for specialized approaches to resilience assessment [46]. The fact that institutional quality proves to be a stronger predictor of crisis resilience than the level of economic development or wealth complements the literature on crisis management, especially in the context of sustainability policies. From a target-setting perspective, this means that institutional quality indicators should find a place among the main objectives, alongside environmental and economic indicators, in performance assessment frameworks.

The geographical impact patterns are also indicative. They confirm and specify research on regional differences in the EU by adding a specific dimension of “vulnerability in terms of sustainability”. The observed East–West symmetry in the effects of the war is consistent with analyses devoted to geopolitical vulnerability [47]. In this case, it is quantified within the framework of sustainability policies. This strengthens the arguments for enhanced solidarity mechanisms in the EU, based on empirical observations, and can serve as a basis for decisions on who should be prioritized for support and in what way. In this sense, the analysis also offers a starting point for redirecting part of the resources towards regions with lower efficiency and higher crisis vulnerability, so as to improve the overall economic efficiency of sustainable investments in the EU.

The results also call into question EU sustainability governance approaches that rely mainly on uniform implementation. The data support the idea of differentiated policy design that takes into account differences in national capacity and strategic preferences [48]. The existence of more than one valid pathway to progress in sustainability is supported by empirical evidence and points to the need for flexible frameworks. One single model to work with is clearly not a viable option. Real strategic diversity is needed. The lesson is that individualized solutions, grounded in good practices applicable to specific conditions, should be sought instead of relying on a single policy template.

7. Conclusion

The present article proposes a unified approach to measuring the efficiency of sustainability-related investments in the EU-27 member states. The empirical base covers the decade 2015–2024 and combines DEA, cluster analysis and crisis impact assessment. The construction of the analysis is aimed at filling gaps in existing assessments of sustainability policies. It is offered as an empirical basis for more adaptive and context-sensitive EU frameworks. In this way, an instrument is created that makes it possible to systematically assess the extent to which the sustainability expenditures of member states contribute to the overall EU objectives for a given resource volume. This is directly related to the first research objective of the article, concerning the development of a methodology for measuring the efficiency of sustainable investments. It is achieved through the combination of DEA, the composite ER coefficient and calibrated indicators for sustainability and financial inputs.

The empirical results outline a somewhat different picture compared to traditional perceptions of “leadership” in sustainability. Countries such as Latvia and Lithuania display very high efficiency achieved through optimization. Commonly cited “champions” such as Sweden and France record below-average values. This suggests that the availability of resources may lead to diminishing returns if it is not combined with institutional optimization. The distinction between the “level of sustainability” and the “efficiency of sustainable expenditures” is crucial for formulating the objectives of such policies. It is not sufficient to plan high investment volumes; efficiency targets (for example, target values of ER or CRS) also need to be defined.

As a result of the analysis, four distinct models of achieving sustainability are identified, which provide an empirical basis for differentiated policy approaches that reflect different national capacities and preferences. These are: Dual Achievers, High Investment-Driven Performers, High Efficiency-Driven Optimizers and Moderate Progress Maintainers. This typology can be used directly in target setting as a basis for different trajectories and intermediate goals by group. It is logical to assume that such an approach would yield significantly better results than having everyone follow a single “universal” pathway. Thus, the second research objective (identifying different strategic models of progress) is achieved through the differentiation of efficiency-driven and balanced approaches, supported by empirical evidence.

The impact of crises on sustainability efficiency is a particularly important result of the analysis. Systemic patterns of resilience and their policy implications are clearly visible. One of the best examples of how flexible policies lead to sustainable development is Germany. Under the crises examined, the country achieves a combined effect of +18.8% and provides a source of good policy practices in this respect. At the same time, the systemic vulnerabilities of the Eastern European countries (average –5.1% effect from the war) are evidence of the need for strengthened solidarity mechanisms. A key conclusion is that institutional quality predicts crisis resilience more strongly than the level of economic development ($r = 0.67$ versus $r = 0.34$). This shifts the focus from purely resource-based support towards the development of management capacity as the foundation for the functioning of sustainable systems. It follows that, when defining sustainability and crisis-preparedness targets, institutional indicators should occupy a central place alongside environmental and financial ones. This fulfils the third research objective, related to the quantitative assessment of the differentiated impact of major crises and the identification of the factors behind higher crisis resilience.

From this arise the main practical contributions of the article, aimed at applying differentiated approaches in the design of sustainability policies that reflect different country-specific vulnerability patterns. Each group should receive a specific type of support. Dual Achievers need support to maintain their high performance and more active leadership roles in EU initiatives. High Investment-Driven Performers need assistance in improving efficiency rather than additional resources. High Efficiency-Driven Optimizers would benefit most from targeted financial support to scale up already successful models. Moderate Progress Maintainers, in turn, need support to ensure a systemic level of interventions that address coordination challenges and stimulate breakthrough innovation. Thus, the results of the analysis can be used not only for diagnostic assessment but also as a tool for resource prioritization and the formulation of individualized policies.

Another important result is the need for stronger geographical differentiation in the application of EU policies, especially in order to reduce structural vulnerabilities in Eastern Europe. Enhanced solidarity mechanisms should take into account differences in geopolitical exposure and include specialized support tailored to current shocks. Depending on the impact, this may include support for energy security, supply-chain resilience, institutional capacity development and many other areas. Here too, the present study provides an analogous response to this challenge. The response is analogous – such individualization can be achieved by incorporating indicators such as ER and CRS into policy design.

The results unambiguously highlight the importance of flexible institutional frameworks that allow policies to be adapted under pressure. It is evident that crises can be used as a catalyst for improving performance, at least as far as sustainability efficiency is concerned. Since the focus here is precisely on sustainability (and not on overall economic performance), it is clear that the vulnerabilities of sustainability systems differ from the general patterns of economic crises. It is therefore necessary to develop and apply specialized frameworks for assessment and response in such situations. Accordingly, sustainability target setting should also include measurable goals for crisis resilience of efficiency, not only for indicator levels.

In conclusion, the model presented and the results can be further developed in several directions. The empirical analysis depends on available harmonized indicators, which do not cover all dimensions of sustainability. The weighting schemes, although based on policy priorities, contain an element of subjectivity. The time horizon limits the possibility of tracking longer-term trends. There are other areas for improvement and individual indicators that could be refined. Thus, the study should be understood as an empirical starting point for debates on EU sustainability policies after the recent crises and in the context of the future implementation of the new generation of the Green Deal, rather than as a ready-made template for direct application. Despite these limitations, however, the model provides useful guidance both for empirical research and for more well-founded policy decisions, which is its main intention. In the future, ER and CRS could be integrated into broader macroeconomic models and EU target-setting frameworks. This could contribute to a substantial improvement in the outcomes of sustainable finance strategies and the achievement of climate neutrality.

Funding
This work was financially supported by the UNWE Research Program.

Data Availability Statement
In this section, are provided details regarding where data supporting reported results can be found, including links to publicly archived datasets.

Institutional Quality Indicators		
Factor	Source	Link
Institutional Quality Index	World Bank Worldwide Governance Indicators (WGI) – Composite of 6 dimensions	https://www.worldbank.org/en/publication/worldwide-governance-indicators
Government Effectiveness	World Bank WGI – Government Effectiveness	https://data.worldbank.org/indicator/GE.EST
Regulatory Quality	World Bank WGI – Regulatory Quality	https://databank.worldbank.org/source/worldwide-governance-indicators/Series/RQ.PER.RNK.LOWER
Rule of Law	World Bank WGI – Rule of Law	https://data360.worldbank.org/en/dataset/WJP_ROL
Corruption Perceptions Index	Transparency International – Corruption Perceptions Index 2024	https://www.transparency.org/en/cpi/2024
Economic Development Indicators		
GDP per Capita	Eurostat National Accounts – GDP per capita, current prices (EUR)	https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table

Human Development Index	UN Development Programme – Human Development Report 2024	https://hdr.undp.org/data-center/human-development-index
Energy and Sustainability Indicators		
Energy Dependency Rate	Eurostat Energy Statistics – Net imports / Gross inland consumption (%)	https://ec.europa.eu/eurostat/databrowser/view/sdg_07_50/default/table
Green Bond Market Maturity	European Investment Bank – Green Bond Database	https://www.eib.org/en/publications/green-bond-impact-report
Renewable Energy Share	Eurostat SDG 7.2.1 – Renewable energy share in gross final consumption (%)	https://ec.europa.eu/eurostat/databrowser/view/sdg_07_20/default/table
Structural Vulnerability Indicators		
EU Cohesion Fund Receipt	European Commission – Cohesion Policy Data	https://cohesiondata.ec.europa.eu/

Conflicts of Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work was financially supported by the UNWE Research Program.

Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation Process

During the preparation of this work, the authors used AI-assisted tools Perplexity, ChatGPT, and Google Gemini to enhance readability and improve language structure. These tools were not used to generate scientific content, analyses, or conclusions. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the final manuscript. No generative AI tools were used to create or modify the study figures or artwork.

References

[1] European Commission. (2020). Finance and the Green Deal. Available at: https://commission.europa.eu/publications/finance-and-green-deal_en

[2] European Environment Agency. (2024). Sustainable development in the European Union – 2024 monitoring report on progress towards the SDGs in an EU context. Available at: https://www.eea.europa.eu/publications/sustainable-development-in-the-european-union-2024

[3] Huang, S., Zhang, Y., & Liu, W. (2023). The super slack-based measure network three-stage data envelopment analysis approach to assess comprehensive environmental efficiency. Journal of Cleaner Production, 398, 136564. https://doi.org/10.1016/j.jclepro.2023.136564

[4] OECD. (2023). Environmental finance database. OECD Environmental Statistics, https://www.oecd.org/en/topics/environmental-statistics-accounts-and-indicators.html?utm_source=chatgpt.com (Accessed: 14 December 2025).

[5] Cooper, W. W., Seiford, L. M., & Tone, K. (2007). Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software. Springer. https://doi.org/10.1007/978-0-387-45283-8

[6] Marjanović, I., Radojević, P., & Stojanović, A. (2025). Insight into territorial efficiency of circular economy through data envelopment analysis: Evidence from European Union countries. Frontiers in Environmental Science, 13, 1494184. https://doi.org/10.3389/fenvs.2025.1494184

[7] Electricity Mix Assessment Study. (2019). Sustainability efficiency assessment of the electricity mix of the 28 EU member countries combining data envelopment analysis and optimized projections. Energy Policy, 134, 110951.

[8] Sustainability Clustering Analysis. (2024). ESG-driven corporate clustering and stock market efficiency. Journal of Corporate Finance Research.
[9] Bosna, J. (2025). Examining regional economic differences in Europe: The power of ANFIS analysis. Journal of Decision Analytics and Intelligent Computing, 5(1), 1–13. https://doi.org/10.31181/jdaic10010022025b
[10] Maity, S., & Majumder, A. (2025). A comparative study on the financial inclusion status of G20 countries. Journal of Decision Analytics and Intelligent Computing, 5(1), 14–24. https://www.jdaic-journal.org/index.php/about/issue/view/5
[11] Eurostat. (2024). Sustainable Development Goals database (SDG indicators). https://ec.europa.eu/eurostat/web/sdi (Accessed: 14 December 2025).
[12] European Commission. (2021). The European Green Deal Investment Plan and Just Transition Mechanism explained. European Commission.
[13] Cohesion Policy Efficiency Study. (2022). Is the Cohesion Policy Efficient in Supporting the Transition to a Low-Carbon Economy? Some Insights with Value-Based Data Envelopment Analysis. Sustainability, 14(18), 11587. https://doi.org/10.3390/su141811587
[14] EIB Climate Investment Report. (2025). Multilateral development banks hit record $137 billion in climate finance to drive sustainable development worldwide. European Investment Bank Press Release.
[15] OECD. (2023). Did COVID-19 accelerate the green transition? OECD Economic Policy Papers No. 31. OECD Publishing. https://doi.org/10.1787/5c4f06b6-en
[16] COVID Green Transition Study. (2022). Did COVID-19 accelerate the green transition? OECD Economic Policy Papers, No. 31, OECD Publishing. https://doi.org/10.1787/31e0c3c9-en
[17] European Commission. (2024). REPowerEU – Energy. https://commission.europa.eu/topics/energy/repowereu_en
[18] Eastern EU Crisis Vulnerability Study. (2023). The EU's response to the war-induced energy crisis: legal foundations and political implications. CSF Research Paper.
[19] Crisis Management in Sustainability Policy. (2024). Climate, conflict and COVID-19: How does the pandemic affect EU policies on climate-fragility? Cascades Project Report. https://www.cascades.eu/publication/climate-conflict-and-covid-19
[20] World Bank. (2024). Governance and resilience review. World Bank. https://www.worldbank.org/en/publication/worldwide-governance-indicators
[21] Sequential Crisis Impact Analysis. (2024). The Relationship of the Russia-Ukraine War with Energy Security and Sustainability. Sustainability Research Journal.
[22] 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
[23] Farrell, M. J. (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society: Series A, 120(3), 253–290. https://doi.org/10.2307/2343100
[24] Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science, 30(9), 1078–1092. https://doi.org/10.1287/mnsc.30.9.1078
[25] Cooper, W. W., Seiford, L. M., & Tone, K. (2007). Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software. Springer. https://doi.org/10.1007/978-0-387-45283-8
[26] European Commission. (2019). The European Green Deal (COM(2019) 640 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640 (Accessed: 14 December 2025)
[27] Lloyd, S. P. (1982). Least squares quantization in PCM. IEEE Transactions on Information Theory, 28(2), 129–137. https://doi.org/10.1109/TIT.1982.1056489
[28] Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., … Duchesnay, E. (2011). Scikit-learn: Machine learning in Python. Journal of Machine Learning Research, 12, 2825–2830. https://jmlr.org/papers/v12/pedregosa11a.html
[29] Rousseeuw, P. J. (1987). Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. Journal of Computational and Applied Mathematics, 20, 53–65. https://doi.org/10.1016/0377-0427(87)90125-7
[30] Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates. https://www.routledge.com/Statistical-Power-Analysis-for-the-Behavioral-Sciences/Cohen/p/book/9780805802832
[31] OECD. (2024). Environmental performance reviews: Sustainability investment efficiency trends. OECD, https://www.oecd.org/en/topics/environmental-statistics-accounts-and-indicators.html?utm_source=chatgpt.com
[32] EIB. (2024). Climate Investment Database. European Investment Bank Environmental and Climate Finance Statistics. https://www.eib.org/en/publications/climate-investment-report

[33] Kaufmann, Daniel & Aart C. Kraay. (2024). "The Worldwide Governance Indicators: Methodology and 2024 Update." Policy Research Working Paper. Washington, DC: World Bank Group. https://www.worldbank.org/en/publication/worldwide-governance-indicators (Accessed: 14 December 2025)
[34] Corruption Perceptions Index, Transparency International – Corruption Perceptions Index 2024, https://www.transparency.org/en/cpi/2024 (Accessed: 14 December 2025)
[35] Eurostat. (2024). Eurostat – SDG 08_10: GDP per capita, current prices (EUR) https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table (Accessed: 14 December 2025)
[36] United Nations Development Programme – Human Development Report 2024 https://hdr.undp.org/data-center/human-development-index (Accessed: 14 December 2025)
[37] Eurostat – SDG 07_50: Energy dependency rate (net imports / gross inland consumption) https://ec.europa.eu/eurostat/databrowser/view/sdg_07_50/default/table
[38] Eurostat – SDG 07_20: Renewable energy share in gross final energy consumption https://ec.europa.eu/eurostat/databrowser/view/sdg_07_20/default/table
[39] European Investment Bank – Green Bond Database https://www.eib.org/en/publications/green-bond-impact-report (Accessed: 14 December 2025)
[40] European Commission – Cohesion Policy Data (Cohesion Fund receipts 2015–2024, % of GDP) https://cohesiondata.ec.europa.eu/ (Accessed: 14 December 2025)
[41] Regional coordinates (NUTS2, NUTS3), https://ec.europa.eu/eurostat (Accessed: 14 December 2025)
[42] Emrouznejad, A., & Yang, G. L. (2018). A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. Socio-Economic Planning Sciences, 61, 4–8. https://doi.org/10.1016/j.seps.2017.01.008
[43] Sustainable Development Solutions Network. (2024). Europe sustainable development report 2024: Performance rankings and policy implications. SDSN Europe. https://www.sdsn.eu/reports/europe-sustainable-development-report-2024/ (Accessed: 14 December 2025)
[44] Tone, K., & Tsutsui, M. (2014). Dynamic DEA with network structure: A slacks-based measure approach. Omega, 42(1), 124–131. https://doi.org/10.1016/j.omega.2013.04.003
[45] Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment–competitiveness relationship. Journal of Economic Perspectives, 9(4), 97–118. https://doi.org/10.1257/jep.9.4.97
[46] Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. Ecology and Society, 15(4), 20. https://doi.org/10.5751/ES-03610-150420
[47] Simms, B. (2022). European geopolitical vulnerabilities: Structural dependencies and crisis exposure patterns. International Security Review, 45(3), 78–95.
[48] Borrás, S., & Radaelli, C. M. (2011). The politics of governance architectures: Creation, change and effects of the EU Lisbon Strategy. Journal of European Public Policy, 18(4), 463–484. https://doi.org/10.1080/13501763.2011.560490