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The efficiency of eco-innovation activities in EU countries. The DEA approach

Abstract

RESEARCH OBJECTIVES: Innovation is a significant factor in socio-economic development, and it is principal in achieving a competitive advantage among enterprises, regions, and countries. The purposes of this paper are: (1) to present, on the basis of the available literature, the essence and metrics of eco-innovation activities in EU countries, (2) to analyze the effectiveness of eco-innovation activities in EU countries using the *Data Envelopment Analysis* (DEA) method.

THE RESEARCH PROBLEM AND METHODS: The research primarily focuses on a review of the recent literature and an analysis of the efficiency of eco-innovation activity using the *DEA method*. The empirical analysis is based on the *Eco-innovation Scoreboard*.

THE PROCESS OF ARGUMENTATION: The analysis mainly determines the efficiency of eco-innovation. The theoretical basis for the considerations is a diagnosis of the existing state of eco-innovation in EU countries.

RESEARCH RESULTS: The results illustrate the efficiency of eco-innovation activity in some EU countries against the backdrop of other EU countries. The analysis of eco-innovation activities and strategies to support them in the EU countries presented in this study is based on a diagnosis of the current state of their economies in this area using the methods of DEA and literature review. The results of this research enable us to draw concrete conclusions on the efficiency of eco-innovation activities.

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CONCLUSIONS, INNOVATIONS, AND RECOMMENDATIONS: The results of the Eco-innovation Scoreboard for these countries illustrate an inefficient use of materials, water and energy resources, as well as low resource productivity. The gaps in this scope between Central-Eastern and Western EU countries are diminishing, but there are still institutional, legislative, and economic shortcomings in eco-innovation that should be addressed. The analysis indicates the level of eco-innovation development in EU countries, its efficiency, and the potential for supporting activity in this field by these countries.

Keywords:

eco-innovations, Eco-innovation Index (EII), Data Envelopment Analysis (DEA), efficiency, EU countries

INTRODUCTION

Eco-innovation means the implementation of a new or significantly improved product (article or service), process, organizational change, or marketing solution that reduces the use of natural resources (including materials, energy, water, and land) and limits the release of harmful substances throughout the life cycle (Eco-Innovation Observatory, 2020). Innovativeness itself is a feature of economic entities or economies, meaning the ability to create and implement innovations, which is associated with active involvement in innovative processes and taking appropriate action in this respect. It also means involvement in acquiring the resources and skills that are indispensable to participate in these processes.

When introducing the problem, it should be highlighted that the definitions of innovation proposed by the Oslo Manual are economic and commercial. Certainly, eco-innovation is inextricably linked with sustainable development (OECD/Eurostat, Oslo Manual, 2005).

Within the international context, which sometimes includes inherent conflicts between economic progress, limited natural resources, and environmental issues and threats, eco-innovation has become a heated topic for top researchers and policy makers, being regarded as a key driver of long-term stable economic development that is able to reconcile economic growth and environmental resource management (Chen et al., 2017). A strong connection has been established between economic and environmental performance (Rachisan et al., 2015; Tilina et al., 2016) in the sense that environmental improvements, as a source of innovation, can heighten marketability, while simultaneously aiming to reduce the negative effects of the use of natural resources on environmental quality by using less harmful and more productive methods (Adede, 1992). In this sense, green growth refers to the possibility of making economic activities resource-efficient, cleaner, and more resilient to economic and environmental shocks and pressures, without slowing down overall economic growth (Hallegatte et al., 2011).

Eco-innovation results in integrated solutions aimed at reducing resource and energy inputs, while increasing product and service quality. Eco-innovation means any form of innovation that aims to make significant and demonstrable progress toward sustainable development by reducing environmental impact or achieving a more efficient and responsible use of natural resources, including energy (Sobczak et al., 2022).

The purposes of the paper are:

1. to present, on the basis of the available literature, the essence and measures of eco-innovation activities in EU countries;
2. to analyze the effectiveness of eco-innovation activities in EU countries using the *Data Envelopment Analysis* (DEA) method.

The paper formulates the thesis that there is a relatively strong variation in the effectiveness of eco-innovation activities among the EU-27 countries surveyed, with the Central and Eastern European countries, especially the Baltic states of Estonia, Lithuania and Latvia, as well as Bulgaria, Croatia, Romania and Slovakia, being characterized by the highest effectiveness in this respect. As for the approach to the research problem formulated in this way, it can be considered as filling an existing research gap mainly for two reasons: (1) the use of an approach rarely used in this type of analysis, and (2) the results obtained indicate that the effectiveness of eco-innovative activities is mostly higher in EU countries characterized by a relatively lower level of socio-economic development than in the 'old' EU countries.

RESEARCH METHODS

Description of the DEA method and its empirical applications

In the traditional DEA approach, the term *Decision Making Units* (DMUs) refers to the economic (or more specifically production) units whose technical efficiency we are studying. For these, we assume they use the same technology, expressed using a set T, so that comparing them in terms of efficiency is legitimate. We also assume we have data on their inputs and outputs.

Each *Decision-Making Unit* (DMU) consumes specific quantities m of different inputs in order to produce s different effects (*outcomes*). Specifically, a DMUj object consumes a quantity xij of a specific input and produces with them a quantity yrj of effect (*outcome*) r. A data envelopment model of the BCC (effect (*output*) oriented) type is specified based on the following relationships (Thanassoulis, 2001):

$$Max\ z + \varepsilon\left[\sum_{i=1}^{m=1} I_i + \sum_{r=1}^{s} O_r\right] \tag{1}$$

subject to:

$$\sum_{j=1}^{N} \alpha_j x_{ij} = x_{ij_0} - I_i \qquad i = 1........m \tag{2}$$

$$\sum_{j=1}^{N} \alpha_j y_{rj} = O_r - z y_{rj_0} \qquad r = 1........s \tag{3}$$

$$\sum_{j=1}^{N} \alpha_j = 1 \tag{4}$$

$$\alpha_j \geq 0,1...N, I_i \qquad O_r \geq 0 \forall \quad i \quad and \quad r, z \quad free \tag{5}$$

where:

ε – non-Archimedean constant (infinitesimal),

I_i, O_r – the so-called slacks denoting additional reduction in inputs or increase in effects (results).

The optimal value of z denotes the maximum coefficient by which the levels of effects (results) achieved by object j^0 can be increased radially without increasing the level of inputs.

Thus, by definition $1/z_{j0}^*$ is a measure of the efficiency of object j^0 and also a measure of the so-called *Pure Technical Efficiency* (PTE) of effects for that object. The occurrence of so-called slacks denotes its remaining inefficiency. Even if the object under study is not able to reach the efficiency frontier after a proportional increase in effects (results), the use of slacks becomes necessary in order to 'push' it towards reaching this frontier (Kumar, Gulati, 2008).

In a DEA-based analysis, it is essential to distinguish between three types of efficiency: technical, pure technical, and in terms of economies of scale. *Technical Efficiency* (TE) refers to the productivity of inputs (Sathye, 2001). This efficiency reports how efficiently a firm (compared to other firms) transforms inputs (inputs) to produce outputs, compared to its maximum potential to do so, as shown by *the Production Possibility Frontier* (PPF) *curve* (Barros & Mascarenhas, 2005).

Thus, in the case of an EU country, *Technical Efficiency* (TE) refers to the efficiency of its government in using specific social policy tools to influence the achievement of specific policy outcomes (outputs). An EU country can be considered technically inefficient when it is below the *Production Possibilities Frontier* (PPF). The measure of technical efficiency, assuming *Constant Return to Scale* (CRS), is referred to in the literature as the measure of *Overall Technical Efficiency* (OTE). It helps to estimate inefficiencies related to inappropriate input/output configurations (1) and those resulting from an inappropriate size/scale of a firm's operations (2). In the case of an EU country, these can be interpreted as: (1) an inappropriate choice by the government of the tools of its social policy or (2) an inappropriate scope/scale of their impact. Using the DEA method, *Overall Technical Efficiency* (OTE) can be decomposed into two mutually exclusive and non-additive components: *Pure Technical Efficiency* (PTE) and *Scale Efficiency* (SE). This decomposition allows the sources of inefficiency to be identified.

The Pure Technical Efficiency (PTE) index is obtained by estimating the *Efficient Frontier*, assuming *Variable Returns to Scale* (VRS). It is a measure of technical efficiency that does not take into account *Scale Efficiency* (SE) and reflects only the efficiency of input management in the production process. In the case of an EU country, it identifies inefficiencies in the way economic policy is conducted, or inefficiencies in the application of its tools (for example, in the form of social spending). Dividing the measure of *Overall Technical Efficiency* (OTE) by the measure of *Pure Technical Efficiency* (PTE) yields a measure in the form of *Scale Efficiency* (SE), which shows the ability of managers to choose the optimal size of resources, i.e., to choose the optimal scale of production.

Inadequate firm size/production scale may indicate the presence of technical inefficiencies known as scale inefficiencies, which can take two forms: decreasing and increasing *Returns to Scale* (RTS). The existence of decreasing RTS, also referred to as diseconomies of scale, means that the firm is too large to achieve optimal returns to scale, whereas the existence of increasing *RTS* can be interpreted as a situation where the firm is too small to achieve optimal scale in its operations. In contrast, a company achieves optimal size/scale of production when it is in the *Constant Returns to Scale* (CRS) area.

For EU countries, this can be interpreted as follows: declining economies of scale mean that a country is pursuing a social policy that is too broadly designed, while increasing economies of scale mean that it is pursuing a social policy that is too small in scale. In the former case, the country should reduce the scope of the policy, while in the latter case it should increase the scale of its impact. The aim of this type of action should be to be within the area of permanent economies of scale so the policy can reach its optimal size/scale.

Input and output variables as a key element of the Eco-Innovation Index (EII)

Input and output variables that are elements of the aggregate EU Eco-Innovation Index (EII) were included in the analysis. The Eco-Innovation Observatory (EIO), established in 2009, is an initiative financed by the European Commission's Directorate-General for the Environment, from the Competitiveness and Innovation Framework Programme, which works to observe the types, degrees, and impacts of eco-innovation in the European Union. The EIO developed the Eco-Innovation Scoreboard (Eco-IS) in 2010 as a tool to assess and illustrate eco-innovation performance across the EU member states. As of 2015, the Eco-IS presented the eco-innovation of 28 European Union Member States. This index consists of 16 indicators grouped into five components: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes, and socio-economic outcomes. Eco-innovation input includes three indicators that trigger eco-innovation in a country, research, and investment: a government's environmental and energy R&D appropriations and outlays, total R&D personnel and researchers, and the total value of green early-stage investments (Eco-Innovation Observatory, 2020).

Eco-innovation activities include three indicators representing firms' innovative activities for reducing material input and energy input per unit output and for creating an environmental management system: firms having implemented innovation activities aimed at a reduction in material input per unit output; firms having implemented innovation activities aimed at a reduction in energy input per unit output; and ISO 14001 registered organizations. Eco-innovation outputs include three indicators representing the degree of advancement and implementation of eco-innovation in corporations, and communication between scientists and media, eco-innovation related patents, eco-innovation-related academic publications and eco-innovation related media coverage. Resource Efficiency Outcomes include four indicators representing outcomes of eco-innovation activities in the environmental area with the focus on productivity and intensity: material productivity, water productivity, energy productivity, and greenhouse gas emission intensity.

Socio-Economic Outcomes include three indicators relating to eco-industries: exports of products from eco-industries, employment in eco-industries, and turnover in eco-industries. According to a technical note from Eco-IS (Giljum & Lieber, 2016), country-specific figures of the single indicator are weighted with the share of population to calculate an EU average which corrects for the bias of smaller member states. Therefore, the EU average of a sub-indicator presents the weighted mean of all country-specific data for the EU member states. The EU average of indicators that display absolute numbers is built directly by summing up the underlying data. The particular components and indicators included in the above-mentioned indices are shown in Table 1.

Table 1. Components and indicators of the EU Eco-Innovation Scoreboard (Eco-IS)

Component	Indicator
1. Eco-innovation inputs	1.1. Governments' environmental and energy R&D appropriations and outlays
	1.2. Total R&D personnel and researchers
	1.3. Total value of green early-stage investments
2. Eco-innovation activities	2.1. Firms having implemented innovation activities aiming to reduce material input per unit output
	2.2 Firms having implemented innovation activities aiming to reduce energy input per unit output
	2.3. ISO 14001 registered organizations
3. Eco-innovation outputs	3.1. Eco-innovation-related patents
	3.2. Eco-innovation-related academic publications
	3.3. Eco-innovation-related media coverage
4. Resource efficiency outcomes	4.1. Material productivity
	4.2. Water productivity
	4.3. Energy Productivity
	4.4. GHG emission intensity
5. Socio-economic outcomes	5.1. Exports of products from eco-industries
	5.2. Employment in eco-industries
	5.3. Turnover in eco-industries

Source: Sun Park et. al., 2017.

A climate-neutral circular economy is the overarching objective enshrined in the European Green Deal's vision for the future European economy. Hence, the monitoring and measurement of progress with regard to eco-innovation is crucial in order to ensure that Europe is moving towards such a vision (Al-Ajlani et al., 2022). One of the best ways to measure eco-innovation activity in EU countries is through the analysis below, which includes elements of the EU Eco-Innovation Index (EEI). This index contains 12 items and is an updated and reduced version of Eco-IS, which contains 16 items. The elements of the eco-innovation index are presented in Table 2.

Table 2. Components and indicators of the EU Eco-Innovation Index* (EII)

Component	Indicator
1. Eco-innovation inputs	1.1. Governments' environmental expenditures
	1.2. Total R&D personnel and researchers
2. Eco-innovation activities	2.1. ISO 14001 certifications
3. Eco-innovation outputs	3.1. Eco-innovation-related patents
	3.2. Eco-innovation-related academic publications
4. Resource efficiency outcomes	4.1. Material productivity
	4.2. Water productivity
	4.3. Energy productivity
5. Socio-economic outcomes	5.1. Export of products from eco-industries
	5.2. Employment in eco-industries
	5.3. Value added in eco-industries

* In order to distinguish between the previous and the current eco-innovation indicator, the Eco-Innovation Scoreboard (Eco-IS) and the Eco-Innovation Index (EII) are named respectively.

Source: Eco-Innovation Observatory, 2020.

MAIN PART OF THE ARGUMENTATION: RESEARCH ON ECO-INNOVATION ACTIVITY IN THE LITERATURE

Determining the degree of development of eco-innovation activity in the EU countries surveyed using the EU Eco-Innovation Index (EII)

The concept of eco-innovation

The concept of eco-innovation is the development and application of innovative business models and innovative business strategies with a top-down management process to enable sustainable development based on the assessment of its impact on the production cycle, in cooperation with stakeholders. Along with eco-innovations, new solutions and connections between products (goods and services), production processes, and organizational structure markets are modified and adopted to improve the quality of business of a company or enterprise as well as its competitiveness. Innovations can be technologically related to institutional or organizational innovation, or marketing, or they can be guided by the interests of shareholders or stakeholders (Ilić, Petrovic, Dukić, 2022). Some innovations relate to a specific purpose: (1) environmental technologies – which are for wastewater treatment, i.e. pollution control; (2) green energy technologies, for cleaner production; (3) organizational innovations which are for new methods and management systems related to protection of the environment; (4) innovations of green products and services that contribute to the environmental benefits of green development (Kemp & Pearson, 2007).

Drivers of eco-innovation and sustainable growth

Internal drivers, according to Cai and Zhou (2014), are a company's ability to introduce eco-innovation: (1) physical capital, i.e., the internal knowledge base and education of employees; (2) investment in research and development (R&D); (3) technology; (4) environmentally friendly products that are acceptable to the market, such as green products; (5) organizational activities, i.e., reduction of pollution sources and recycling, which has positive effects on reduced costs; (6) activity management and management's commitment to environmental innovation because it influences companies to align their business with social norms, values, and expectations in order to build the *green image* of the company. The integrative capacity of the company includes internal and external drivers that are connected where the external regulatory framework has a positive impact on the development of eco-innovation. External drivers are external pressures that include environmental regulations, green requirements, and competitiveness (Szutowski, Szulczewska-Remi, & Ratajczak, 2017).

Managing eco-innovation is becoming an increasingly important issue for firms (Guoyou et al., 2013; Ormazabal & Sarriegi, 2012) because customers' environmental awareness is increasing, there is rising social and government pressure on companies to reduce their environmental impact, and sustainable development is becoming a financially astute matter. For example, Guagnano (2001) found that over 86 per cent of consumers are willing to pay extra for common household products that are less ecologically harmful. Tsen et al. (2006) support this finding in their study of consumers who were willing to pay a premium for green products.

Moreover, eco-industries in Europe are a significant part of the economy: their annual turnover is estimated at 319 billion euros, which represents approximately 2.5 per cent of the EU GDP (Action Plan for Eco-Innovation EcoAP) (European Economic and Social Committee, 2012).

As stated by Haila and Rundquist (2011), eco-innovations are not only environmentally important but also have an important impact on economic development. It is even claimed that eco-industry has the capability to help the world recover from economic crises.

Conceptual framework

Eco-innovation is defined by the European Commission as "changing consumption and production patterns and developing technologies, products and services to reduce our impact on the environment" (European Commission, 2009). The main objective of eco-innovation is to boost Europe's environmental and competitive standing by supporting innovative solutions that protect the environment while creating a larger market for 'green' technologies, management methods, products, and services. Also eco-innovation may be defined as

> the creation of new, or significantly improved, products (goods and services), processes, marketing methods, organizational structures, and institutional arrangements that – with or without intent – lead to environmental improvements compared to relevant alternatives (OECD, 2008).

RESULTS OF THE EMPIRICAL ANALYSIS: ECO-INNOVATION EFFICIENCY IN EU COUNTRIES USING DATA ENVELOPMENT ANALYSIS (DEA)

Stages of the empirical analysis

The empirical analysis carried out in this paper includes the following stages:

1. Presentation of the aggregate Eco-Innovation Index (EII) and its 12 components.
2. Gathering and grouping input-effect data on the basis of the Eco-Innovation Index (EII) elements.
3. Performing different variants of calculations in MaxDEA (output-oriented: CRS (*Constant Returns to Scale*) and VRS (*Variable Returns to Scale*) models, with fixed and variable Returns to Scale (RTS), in order to obtain more precise information on the causes of inefficiency in some EU-27 countries in the eco-innovation sphere.
4. Selection and interpretation of the optimum option, allowing the results obtained to be interpreted as precisely as possible.
5. Tabular and graphic presentation of the results obtained and their interpretation.

The calculations were based on the DEA method of assessing the efficiency of Decision Making Units (DMUs) – EU-27 countries using data from the *Eco-Innovation Scoreboard* database. Four countries were excluded from the analysis (the UK, because it is no longer formally a member state of the European Union as of 1 February 2020; and Cyprus, Luxembourg and Malta because these countries have undersized economies). A version of the model with Constant Returns to Scale (CRS) was chosen due to the fact that all the countries under consideration are members of the European Union, which means that their innovation systems operate under similar economic, social and formal-legal conditions and have to adapt their innovation policies to the requirements of this grouping. In addition, the use of a model with Variable Returns to Scale (VRS) results in too many countries proving to be fully efficient, which causes problems in differentiating the scale of their eco-innovation.

The analysis carried out was based on a DEA model oriented towards outputs rather than inputs. This is due to the research objective adopted, namely to identify the maximum possibilities for inefficient countries to increase their effects (outputs) under the assumption of constancy of expenditures incurred to finance eco-innovative activities. An input orientation, on the other hand, is unsuitable for an analysis objective that is formulated in this way. Its adoption would lead to a logical contradiction, as the countries under consideration cannot strive to set outputs at a constant level while minimizing inputs. The latter are, in fact, increased in practice in order to broaden the scope of impact of policy tools to support eco-innovation.

The adoption of an effects-oriented model determines the need to calculate the inverse of the coefficients (scoreboards) obtained with the analysis carried out in MaxDEA. This is because their values should be greater than or equal to one, and only then can they be correctly interpreted. In the case of the present study, relative, normalized indices of both inputs (inputs) and outputs (outputs) were used as the basis for the research, rather than their actual values measured in absolute terms. The research was conducted for normalized coefficients describing inputs and outputs. The relevant data are presented in Table 3.

Table 3. Normalized indicators of eco-innovation inputs and outputs in EU-24 countries

Countries	**Eco-Innovation inputs**	**Eco-Innovation activities**	**Eco-Innovation outputs**	**Resource efficiency outcomes**	**Socio-economic outcomes**
Austria	0.486	0.542	0.652	0.500	0.500
Belgium	0.446	0.533	0.557	0.701	0.701
Bulgaria	0.090	0.293	0.282	0.062	0.062
Croatia	0.152	0.460	0.337	0.456	0.456
Cyprus	0.011	0.211	0.517	0.386	0.386
Czechia	0.375	0.677	0.372	0.536	0.536
Denmark	0.810	0.566	0.866	0.531	0.531
Estonia	0.205	0.292	0.588	0.073	0.073
Finland	0.620	0.596	0.801	0.164	0.164
France	0.642	0.634	0.507	0.565	0.565
Germany	0.711	0.256	0.730	0.585	0.585

Greece	0.473	0.289	0.432	0.296	0.296
Hungary	0.252	0.339	0.277	0.234	0.234
Ireland	0.350	0.506	0.530	0.624	0.624
Italy	0.345	0.430	0.423	1.000	1.000
Latvia	0.194	0.317	0.504	0.503	0.503
Lithuania	0.180	0.312	0.382	0.523	0.523
Luxembourg	0.486	0.346	0.759	1.000	1.000
Malta	0.070	0.831	0.100	0.857	0.857
Netherlands	0.394	0.464	0.599	0.685	0.685
Poland	0.216	0.302	0.362	0.296	0.296
Portugal	0.307	0.690	0.451	0.267	0.267
Romania	0.109	0.299	0.315	0.170	0.170
Slovakia	0.116	0.631	0.340	0.550	0.550
Slovenia	0.406	0.373	0.483	0.378	0.378
Spain	0.389	0.499	0.398	0.528	0.528
Sweden	0.567	0.752	0.786	0.434	0.434

Source: Eurostat database.

Results of the analysis (model with Constant Returns to Scale (CRS), output-oriented)

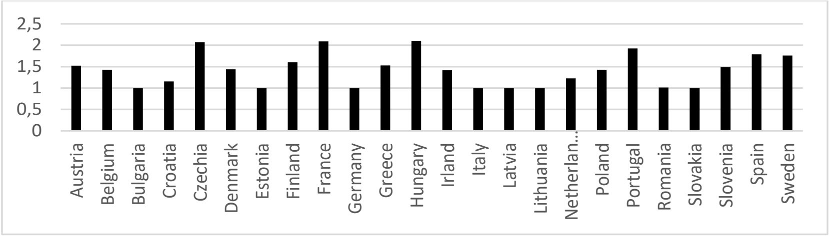
Countries with a maximum efficiency level, where the value of the *Lambda* efficiency rating coefficient is 1 (in brackets next to each country, numbers are given showing the quantity of its occurrence as a benchmark for other countries: Bulgaria (2), Estonia (9), Lithuania (2), Latvia (16), Germany (14), Slovakia (3), Italy (7)). Particularly noteworthy is the presence of three Baltic countries (Estonia, Lithuania and Latvia) in this group. Among the EU-15 countries, only Germany and Italy are fully efficient. In contrast, in the group of less developed EU-12 countries, as many as four are fully effective (Bulgaria, Estonia, Latvia, and Lithuania), which may indicate that less developed EU-12 countries are catching up in terms of efficiency. Subsequent values of the *Lambda* coefficient for the analyzed countries are presented in Table 4, while they are shown graphically in Figure 1.

Table 4. Score and benchmark (*Lambda*) values for EU-24 (based on normalized indicators); Constant Returns to Scale – CRS, output oriented

EU-24 countries	Efficiency score	Benchmark (Lambda)	Times as a benchmark for another DMU
Austria	1.521602186	Latvia (1.155841); Estonia (0.372762); Germany (0.260691)	0
Belgium	1.428277611	Latvia (1.013762); Italy (0.399291); Germany (0.157813)	0
Bulgaria	1.0	Bulgaria (1.0)	2
Croatia	1.1540015	Slovakia (0.468737); Lithuania (0.273228); Latvia (0.249023)	0
Czechia	2.072328406	Lithuania (1.793559); Italy (0.113176); Slovakia (0.109896)	0
Denmark	1.439443338	Estonia (0.707542); Latvia (0.484846); Germany (0.802716)	0
Estonia	1	Estonia (1.0)	9
Finland	1.602199499	Estonia (1.708171); Germany (0.380554)	0
France	2.088755394	Latvia (1.239340); Germany (0.412457); Italy (0.316067)	0
Germany	1.0	Germany (1.0)	14
Greece	1.528801863	Germany (0.522273); Estonia (0.255583); Latvia (0.254225)	0
Hungary	2.100160872	Latvia (0.868773); Estonia (0.156666); Germany (0.071905)	0
Ireland	1.422450826	Latvia (1.239396); Italy (0.241960); Germany (0.037311)	0
Italy	1.0	Italy (1.0)	7
Latvia	1.0	Latvia (1.0)	16
Lithuania	1.0	Lithuania (1.0)	2
Netherlands	1.222217469	Latvia (1.025627); Italy (0.225198); Germany (0.164809)	0
Poland	1.428147065	Latvia (0.759585); Estonia (0.168735); Germany (0.048284)	0
Portugal	1.927640241	Bulgaria (1.325601); Latvia (0.842136); Estonia (0.120303)	0
Romania	1.011330952	Bulgaria (0.704722); Latvia (0.208995); Slovakia (0.042389)	0
Slovakia	1.0	Slovakia (1.0)	3
Slovenia	1.492989667	Latvia (0.731085); Germany (0.310456); Estonia (0.213004)	0
Spain	1.786326741	Latvia (0.922776); Italy (0.429013); Germany (0.087016)	0
Sweden	1.761149397	Latvia (1.189792); Estonia (1.162526); Germany (0.138682)	0

Source: own calculations based on MaxDEA software

Graph 1. Efficiency score and benchmark (*Lambda*) values for EU-24 countries (based on normalized Indicators, Constant Returns to Scale – CRS, output oriented)



Source: own calculations based on MaxDEA software.

Subsequent groups of countries with different ranges of efficiency, in which the coefficient of its *Lambda* assessment is contained, are presented in Table 5.

Table 5. Score of efficiency value ranges (based on normalized indicators), Constant Returns to Scale (CRS), output oriented

***Score* value ranges**	**Countries**
1.0	Bulgaria, Estonia, Germany, Italy, Latvia, Lithuania Slovakia
1.0–1.1	Romania
1.1–1.2	Croatia
1.2–1.3	Netherlands
1.3–1.4	–
1.4–1.5	Belgium, Denmark, Ireland, Poland Slovenia
1.5–1.6	Austria, Greece
1.6–1.7	Finland
1.7–1.8	Spain, Sweden
1.8–1.9	–
1.9–2.0	Portugal
2.0–2.1	Czechia, France, Hungary

Source: own elaborations based on calculations in *MaxDEA* software.

Analysis of the Returns to Scale (RTS)

Based on the DEA method, the type of economies of scale obtained by the EU countries when analyzed in terms of their eco-innovation activities are identified below.

The data from column 2 of Table 5 above and column 2 of Table 6 below were used to calculate the SE indicators.

Table 6. Efficiency score and benchmark (*Lambda*) values for EU-24 countries (based on normalized indicators), Variable Returns to Scale (VRS), output oriented

EU-24 countries	Efficiency score	Benchmark (Lambda)	Times as a benchmark for another DMU
Austria	1.059111109	Netherlands (0.468592); Sweden (0.277309); Denmark (0.152051); Estonia (0.102048);	0
Belgium	1.065817423	Netherlands (0.565697); Italy (0.275090); Denmark (0.159213)	0
Bulgaria	1.0	Bulgaria (1.0)	1
Croatia	1.14790662	Slovakia (0.461380); Lithuania (0.302186); Latvia (0.213792); Romania (0.022641)	0
Czechia	1.457572966	Netherlands (0.669350); Italy (0.315376); Latvia (0.015274)	0
Denmark	1.0	Denmark (1.0)	8
Estonia	1.0	Estonia (1.0)	6
Finland	1.0	Finland (1.0)	0
France	1.313853269	Denmark (0.549406); Italy (0.450594)	0
Germany	1.0	Germany (1.0)	4
Greece	1.500726352	Germany (0.496202); Latvia (0.236890); Estonia (0.234539); Denmark (0.032369)	0
Hungary	1.970548187	Latvia (0.757169); Estonia (0.122600); Denmark (0.077914); Netherlands (0.042316)	0
Ireland	1.072533281	Netherlands (0.733767); Latvia (0.201352); Italy (0.064881)	0
Italy	1.0	Italy (1.0)	5
Latvia	1.0	Latvia (1.0)	8
Lithuania	1.0	Lithuania (1.0)	2
Netherlands	1.0	Netherlands (1.0)	7
Poland	1.283127135	Lithuania (0.619174); Estonia (0.313234); Germany (0.055237); Bulgaria (0.012354)	0
Portugal	1.355030075	Latvia (0.423776); Sweden (0.294191); Estonia (0.282033)	0
Romania	1.0	Romania (1.0)	1
Slovakia	1.0	Slovakia (1.0)	1
Slovenia	1.297114439	Latvia (0.575324); Denmark (0.258219); Germany (0.101548); Estonia (0.064910)	0
Spain	1.421068189	Netherlands (0.771019); Italy (0.215594); Denmark (0.013387)	0
Sweden	1.0	Sweden (1.0)	2

Source: own elaborations based on calculations in MaxDEA software.

In the case of column 3 of Tables 4 and 6, we obtain information on the ideal/optimal value of the indicator, i.e., how much improvement in a given indicator of outputs can be obtained for each of the inefficient countries, based on the benchmark countries listed there, in terms of fixed (Table 4) and variable (Table 6) Returns to Scale, respectively. To take Poland as an example, it can be increased by 28.3%.

The data in Table 7 shows the coefficients of scale efficiency, Returns to Scale (RTS), and the intensity of scale inefficiencies. Scale efficiencies reflect the impact of the scale of a policy to promote socio-economic balancing on its effectiveness in a country. The greater the discrepancy in scale efficiency ratings, the lower the scale efficiency and the more adverse the impact of scale on efficiency (Thanassoulis, 2001). Information on Returns to Scale is important for deciding on the desired magnitude of the policy. If a country is at a point where there are increasing Returns to Scale, it makes sense to increase the scale of the eco-innovation policy to obtain greater benefits as the increase in the inputs involved in implementing the policy will be more than compensated for by the increase in the size of the outputs/results obtained.

Table 7 illustrates that the 17 countries considered reveal Variable Returns to Scale (RTS), suggesting the need to expand their activities in terms of their policies to support the sustainability of socio-economic development. The remaining 7 countries (Bulgaria, Estonia, Germany, Italy, Latvia, Lithuania and Slovakia) are efficient in the OTE sense and show Constant Returns to Scale, as defined by the CCR model.

Table 7. Scale Efficiency – SE* (based on normalized indicators), output oriented model

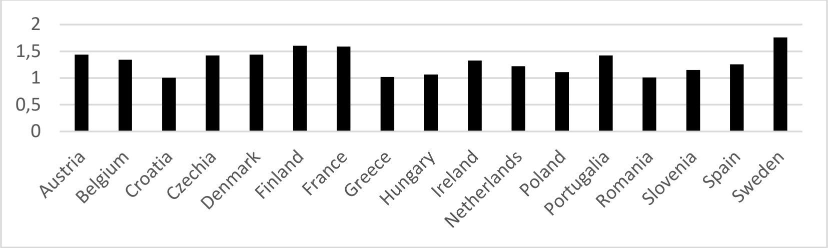
EU-24 countries	Efficiency score	Returns to Scale (RTS)
Austria	1.436678525	VRS**
Belgium	1.340077184	VRS
Croatia	1.005309561	VRS
Czechia	1.421766494	VRS
Denmark	1.439443338	VRS
Finland	1.602199499	VRS
France	1.589793506	VRS
Greece	1.018707948	VRS
Hungary	1.065774938	VRS
Ireland	1.326253321	VRS
Netherlands	1.222217469	VRS
Poland	1.113020702	VRS
Portugal	1.422581149	VRS
Romania	1.011330952	VRS
Slovenia	1.15100844	VRS
Spain	1.257030982	VRS
Sweden	1.761149397	VRS

*RTS Indicators were calculated by dividing the Overall Technical Efficiency (OTE) Indicators obtained from Table 3 (column 2) by the Pure Technical Efficiency (PTE) Indicators from Table 5 (column 2).

**DRS – Decreasing Returns to Scale

Source: own elaborations based on calculations in MaxDEA software.

Graph 2. Scale Efficiency – SE* (based on normalized indicators), Constant Returns to Scale – CRS, input oriented



Source: own calculations based on MaxDEA software.

Taking into account one of the analyzed countries (e.g., Poland, which takes the value 1/0.700 = 1.428), one can interpret the result: at the current level of inputs, the effects ratio can be increased by 42.8%. This is the scale of the inefficiency of Poland's eco-innovation policy. Column 3 of Table 4, on the other hand, illustrates which countries can serve as a model for Poland and how. These are: Estonia, Latvia and Germany (their shares in the benchmark for Poland are given in brackets).

Based on the data in Table 7, it can be concluded that there are Variable Returns to Scale (VRS) for countries for which the value of the analyzed efficiency factor (scoreboard) is greater than 1. However, it is impossible to determine whether these are increasing or decreasing benefits. To determine their nature for the countries identified as inefficient in Table 6, the coefficient defined by the formula should be calculated for each of them:

When it takes on the value of 1, there are Increasing Returns to Scale (IRTS) in a country; when it is below 1, there are Decreasing Returns to Scale (DRTS).

The types of economies of scale obtained by each EU country are shown in Table 8.

Table 8. Types of Returns to Scale (RTS) in inefficient analyzed countries

EU countries	Score	Returns to Scale (RTS)
Austria	0.69605	DRTS
Belgium	0.746226	DRTS
Croatia	0.994718	DRTS
Czechia	0.70335	DRTS
Denmark	0.694713	DRTS
Finland	0.624142	DRTS
France	0.629013	DRTS
Greece	0.981636	DRTS
Hungary	0.938284	DRTS
Irland	0.754004	DRTS
Netherlands	0.818185	DRTS
Poland	0.898456	DRTS
Portugal	0.702948	DRTS
Romania	0.988796	DRTS
Slovenia	0.868803	DRTS
Spain	0.795525	DRTS
Sweden	0.567811	DRTS

Source: own calculations based on MaxDEA software.

As illustrated in Table 8, Decreasing Returns to Scale (DRTS) were found in all inefficient countries.

CONCLUSIONS AND RECOMMENDATIONS

Eco-innovation activity is an essential element in balancing socio-economic development. For this reason, it is crucial to compare the level of eco-innovation using specific metrics, of which composite indicators composed of multiple elements are the most appropriate. An example is the EU Eco-innovation Index (EII), which is commonly used by researchers. In this study, the components of this indicator are used to analyse the effectiveness of policies that support the eco-innovation carried out by EU countries.

The purposes of the paper were:

1. to present, on the basis of the available literature, the essence and measures of eco-innovation activities in EU countries;
2. to analyze the effectiveness of eco-innovation activities, especially in EU countries, using the Data Envelopment Analysis (DEA) method;
3. to present policy directions to support eco-innovation.

A Data Envelopment Analysis (DEA) of inputs and outputs relating to the functioning of the eco-innovation sphere revealed that the most effective policies to support eco-innovation were conducted in Bulgaria, Estonia, Germany, Italy, Latvia, Lithuania, and Slovakia.

Consequently, the governments of the countries which revealed Decreasing Returns to Scale (DRTS) should strive to increase investment in policies to support eco-innovation, especially in spheres where it is still too low. This means these governments should place a fundamental emphasis not on increasing the scope of their eco-innovation support policies but on taking eco-innovation policy measures to increase their effectiveness in terms of impact on eco-innovation outcome indicators. These expenditures should not only stimulate the sustainability of socio-economic development, but also contribute to accelerating economic growth.

The remaining countries should be based on the benchmark countries: they should select the most effective spheres of influence for policies to support eco-innovation and target their limited financial resources at these, using co-financing from European funds.

The results of the research also provide guidance for investors in choosing the most effective geographical directions for making investments in supporting eco-innovation. They can also form the basis for decisions on the allocation of funds by the European Union.

The research may be a suitable starting point for more detailed analyses based on an extended DEA approach or in the form of panel regression. The results of this type of research can help analyze the effectiveness of environmental policy in terms of its impact on balancing socio-economic development. In addition, the results provide an opportunity to better target EU governments' policies to support eco-innovation by identifying areas where a country is least effective in relation to benchmark countries for the optimal impact of these policies.

Future research could include a more comprehensive analysis of the issues at stake, but this would require additional inputs and outputs related to eco-innovative activities, for example receipts from environmental taxes and other types of taxes not included in the eco-innovation index. However, the increase in the number of inputs studied will make it impossible to apply the DEA method in the analysis due to the insufficient number of sites studied (according to the assumptions of this method, the total number of inputs and effects analyzed should be no more than one-third of the number of sites (countries) studied). In this situation, it would be necessary to use the panel regression method, which requires detailed data verification, mainly comprising the assessment of the collinearity and stationarity of the data, as well as the selection of an appropriate model for this regression. In such a situation, the analysis would have to be multistage. It could also be based on a selection of inputs and effects based on the principal component method and factor analysis. An additional problem is that the impact of environmental taxes on the effectiveness of eco-innovative activities is too weak and sometimes even ambiguous.

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