

# Are ERDF Efficient in Strengthening the Switch to a Low-Carbon Economy? Some Insights with Value-Based Data Envelopment Analysis



Maria Gouveia , Carla Henriques , and Ana Amaro 

**Abstract** We assessed the execution of European Regional Development Funds (ERDF) allocated to promote a Low-carbon economy (LCE) in 23 EU Member States (MS). Each MS is evaluated using the Value-Based Data Envelopment Analysis (VBDEA) method. In the first stage, the efficient MS were identified, and the major reasons that might affect the efficient performance of the ERDF. From the results obtained, 43% of the MS were deemed efficient in the application of ERDF committed to fostering an LCE, and these results were mostly justified by their financial spending rate. At the second stage of the analysis, the changes that needed to be done by inefficient MS to “try and replicate” their efficient counterparts were computed. Furthermore, from the robustness assessment conducted it was possible to show that with thresholds of  $\delta = 5\%$  and  $\delta = 10\%$ , 22% of the MS managed to attain a robust efficiency. While Spain is the leading country in terms of robustness efficiency, Romania (robustly inefficient for  $\delta = 5\%$ ), Hungary, and the Czech Republic (the worst in the ranking of inefficient MS) could not apply these funds properly. Given this information, the EU should continue to push policies that secure financial opportunities from engaging in LCE, particularly for MS with limited financial capacities, while still supplying them with improved funding mechanisms and technical expertise.

**Keywords** Low-carbon economy · ERDF · Value-based DEA · Robustness analysis

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# 1 Introduction

The EU policy for mitigating the effects of climate change needs to urgently shift towards an LCE. Simply explained, an LCE is an economy whose organization is sustained by activities that emit minimal quantities of CO<sub>2</sub> into the environment (Levy, 2010). The cohesion policy has been supporting the shift to an LCE, but in the 2014–2020 period this support has expanded dramatically, owing in part to the granting of specific funding for this purpose (Henriques et al., 2022a). As a result, assessment plays an important role in cohesion policy-making since it supports policy planning and development while also delivering solid data about the outcomes and effects of the projects undertaken. In this framework, the Data Envelopment Analysis (DEA) method has been particularly useful in the assessment of the OPs devoted to the “competitiveness of Small and Medium Sized-Enterprises (SMEs)” (Gouveia et al., 2021) to an LCE in SMEs (Henriques et al., 2022a) and to research and in Innovation in SMEs (Henriques et al., 2022b). When conducting an efficiency assessment through the DEA approach, management authorities (MA) will be able to pinpoint the OPs viewed as a reference of best practices and the required changes that have to take place for the set of indicators, which will allow transforming inefficient OPs into efficient ones across the programmatic horizon. Additionally, DEA can likewise be used in the efficiency evaluation of the LCE across distinctive settings, specifically at the national (Chen et al., 2020; Liu & Liu, 2016; Zhang et al., 2019, 2020), regional (Meng et al., 2018; Zhang et al., 2017), and sectoral (Zha, et al., 2019) levels. In this regard, hardly any of the papers available in the scientific literature use DEA in the evaluation of the MS global efficiency in the use of ERDF to promote an LCE. Furthermore, as far as we are aware, the VBDEA has never been employed in this situation. One of the major advantages of the VBDEA above traditional DEA techniques is that it provides an additional understanding of the underlying causes of (in)efficiency. This technique also enables tackling negative or null data, studying the robustness of the results, and incorporating the DM’s preferences in the appraisal through the use of value functions. As a result, we want to contribute to the literature by undertaking an efficiency evaluation of the application of ERDF committed to LCE over 23 European countries. In summary, our main research questions are given below:

RQ1: “What are the main reasons for the (in)efficiency in the utilization of ERDF granted to promote an LCE in EU countries?”

RQ2: “Which countries were considered benchmarks during the last programmatic timeframe?”

RQ3: “Which MS performs better in terms of robustness?”

This paper’s structure is as follows. Section 2 explains the basic premises underlying the methodologies offered to appraise the implementation of the ERDF in the countries under scrutiny. Section 3 explains why the criteria employed herein were chosen. Section 4 highlights the main results. Section 5 reports the main conclusions, discusses prospective political repercussions, highlights important flaws, and proposes future study topics.

## 2 Methodology

We employ a DEA-based approach in this work, which is a classical optimization tool that generates an efficiency frontier by evaluating homogenous decision-making units (DMUs), in this case, the MS. This method enables the consideration of numerous criteria (to be maximized or minimized). This type of tool can provide relevant information, such as the reasons behind (in)efficiency, the efficient peers of inefficient DMUs, and the needed modifications to the criteria used in the assessment to reach efficiency. We focus on the Gouveia et al. (2008) VBDEA model, which integrates the application of DEA with multi-attribute value theory (MAVT) (Keeney & Raiffa, 1993). The VBDEA model, proposed by Gouveia et al. (2008), addresses the scales challenge and the lack of understanding of the value produced by the weighted additive model (Ali et al., 1995). In the realm of MCDA, this last technique allows for the incorporation of the DM's preferences by turning the criteria into value scales. This transformation is very useful for dealing with negative or null data. Besides, inspired by the concept of superefficiency in DEA models (Gouveia et al., 2013), the VBDEA approach allows ranking, in a single step, all DMUs, even the efficient ones, and enables to consider the robustness analysis of the (in)efficiency values obtained.

The VBDEA method involves two stages after all factors have been transformed into value scales. At the first stage, the optimal value difference to the best of all DMUs, excluding itself is computed, i.e., the efficiency score is obtained. If this distance is negative, then the DMU under scrutiny is efficient; otherwise, it is inefficient. The ranking of the DMUs can then be done from the most efficient to the less efficient from the most negative values to the most positive values attained for this value difference. In the second stage, the reference set of efficient DMUs is computed for each inefficient DMU, by instantiating this second model with the optimal values obtained previously. Further details on this method and the corresponding software might be found in Chap. “[Python Implementation of the Value-Based DEA Method](#)” of this book.

## 3 Data

The criteria used in this study were suggested by Henriques et al. (2022a) at the OP level. The numbers evaluated are total figures at the MS level spanning various years reported on November 19, 2021 (corresponding to the programming period of 2014–2020), because they are the most up-to-date statistics for the accomplishment criteria. Just those MS with comprehensive data on ERDF grants were examined in the research. The criteria chosen for evaluating the efficiency of fund execution were drawn from a set of shared criteria officially mandated by the EU (European Commission, 2014) and are explained in Table 1.

Data on the descriptive statistics of these factors are given in Table 2.

**Table 1** Criteria used

	EU co-financing	Total eligible spending	Eligible cost decided	GHG reduction
Description	Percentage of EU financing (calculated as an average)	Eligible costs validated	Financial resources assigned	Estimated annual decrease of GHG
Type of factor	To minimize	To maximize	To minimize	To maximize
Unit	%	Euro	Euro	Tons of CO <sub>2</sub> equivalent
Source	(a)	(a)	(a)	(b), (c)
Explanation	EU subsidy dependency	OPs' execution	OPs' execution	Reaching an LCE

Source Authors' own elaboration based on Henriques et al. (2022a)

(a) List of Structural Funds financial implemented data. Available at: <https://cohesiondata.ec.europa.eu/2014-2020/ESIF-2014-2020-Finance-Implementation-Details/99js-gm52>

(b) List of common indicators legally required and listed in the annexes to the ERDF, Cohesion Fund and ETC regulations. Available at: [https://ec.europa.eu/regional\\_policy/sources/docoffic/2014/working/wd\\_2014\\_en.pdf](https://ec.europa.eu/regional_policy/sources/docoffic/2014/working/wd_2014_en.pdf)

(c) List of Structural Funds achievement data. Available at: <https://cohesiondata.ec.europa.eu/2014-2020/ESIF-2014-2020-Achievement-Details/aesb-873i>

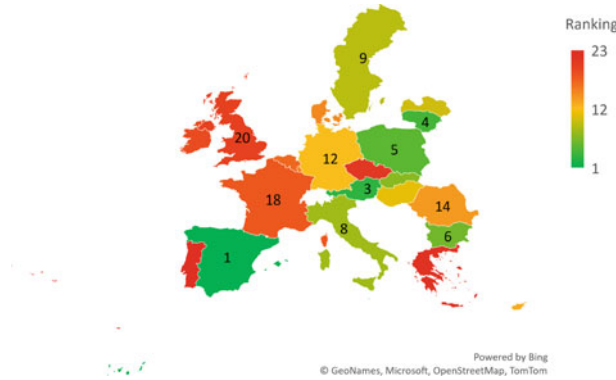
**Table 2** Descriptive statistics of data in their original performances

Statistics	EU co-financing	Eligible cost decided	Total eligible spending	GHG reduction
Mean	64.65	5,003,186,122.35	1,744,268,042.09	181,264.20
Median	65.56	1,740,681,178.00	571,461,318.00	82,646.53
Standard deviation	17.09	5,732,200,879.94	2,096,538,613.08	215,620.69
Minimum	29.46	99,506,488.00	28,265,375.00	37.16
Maximum	85.00	17,105,000,000.00	7,016,881,169.00	829,915.74
Count	23	23	23	23

Source Authors' own elaboration

## 4 Discussion of Results

We could have used non-linear value functions, but because we didn't have an actual DM, we decided to convert all of the criteria into linear value functions, showing neutral preferences. This conversion considered two bounds,  $M_c^L$  and  $M_c^U$ . The lower and upper bounds were obtained, respectively, as  $M_c^L < \min\{p_{cj}^L, j = 1, \dots, n\}$  and  $M_c^U > \max\{p_{cj}^U, j = 1, \dots, n\}$ , where  $p_{cj}^L = p_{cj}(1 - \delta) \leq p_{cj} \leq p_{cj}(1 + \delta) = p_{cj}^U$ , with  $\delta = 10\%$  and  $p_{cj}$  is the performance of criterion  $c$  for DMU <sub>$j$</sub> ,  $c = 1, \dots, q$  and  $j = 1, \dots, n$ . The value scales are then set between the 0 and



**Fig. 1** Ranking of the countries according to in(efficiency) scores. *Source* Authors’ own elaboration

1 levels depending on the type of criteria (maximized or minimized)—see expression (1). Afterward, we obtain the values for each  $DMU_j, j = 1, \dots, n$  employing (1):

$$v_c(DMU_j) = \begin{cases} \frac{pcj - M_c^L}{M_c^U - M_c^L}, & \text{if } c \text{ is being maximized} \\ \frac{M_c^U - pcj}{M_c^U - M_c^L}, & \text{if } c \text{ is being minimized} \end{cases}, j = 1, \dots, n; c = 1, \dots, q \quad (1)$$

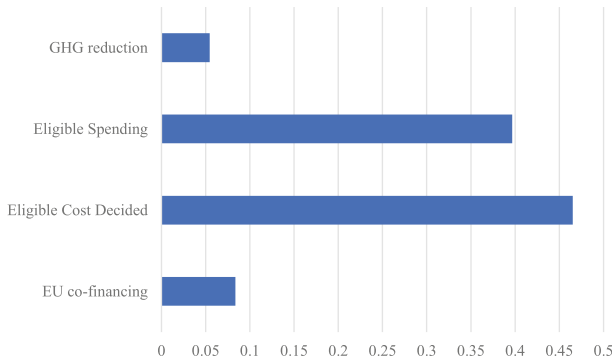
Subsequently, the VBDEA is instantiated with the performance values thus obtained leading to the computation of the results depicted in Fig. 1.

From Fig. 1 it is possible to conclude that only 10 countries attain an efficient status, corresponding to Spain, Malta, Austria, Lithuania, Polonia, Bulgaria, Slovakia, Italy, Sweden, and Latvia (countries identified with different shades of green). The countries that show the best performance are Spain, followed by Malta, and Austria. These MS have outstanding efficiency levels. Besides, as it will be seen further these are also the most robust from the set of efficient MS.

Figure 1 depicts the outcomes as well for inefficient MS. In this case, Portugal, Greece, and the Czech Republic show the worst performance.

Phase 1 of VBDEA allows obtaining the efficiency scores that enable ranking both efficient and inefficient MS, as well as the corresponding weighting vectors that reflect the importance given to each criterion to attain the best efficiency score possible—Fig. 2.

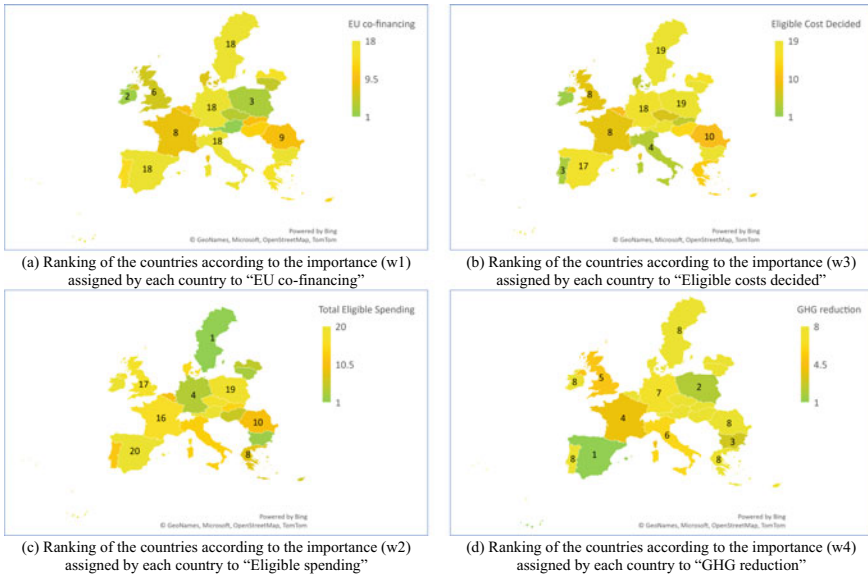
The indicator highly sought by MS to attain the greatest efficient performance was “Eligible costs decided” (w2) followed by “Total eligible spending” (w3) (Fig. 2). Nevertheless, neither of the three leading scoring nations elected the criterion “Eligible cost decided”—see Figs. 2 and 3b. Spain only prioritized the criteria being maximized (“Total eligible spending” and “GHG emission reduction”) (w3 = 0.363 and w4 = 0.637). Malta ranked 3rd based solely on “Total eligible spending” (w3 = 1)—see Fig. 3c, whereas Austria ranked 3rd based solely on “EU co-financing” (w1 = 1) (see Fig. 3a). Only four of the ten efficient MS (Bulgaria, Spain, Italy, and



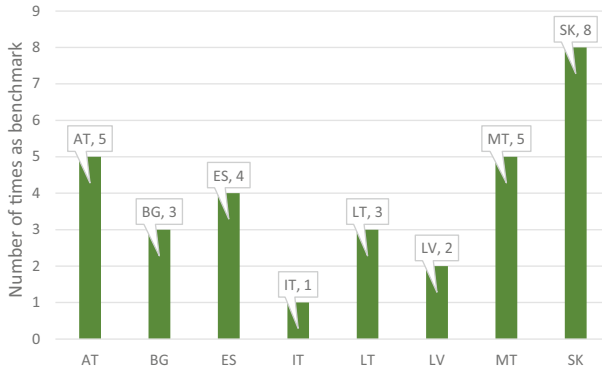
**Fig. 2** Average weights obtained with VBDEA. *Source* Authors’ own elaboration

Poland) choose “GHG reduction” as a crucial factor for achieving efficiency—see Fig. 3d.

The top three MS usually chosen as benchmarks for the non-efficient MS are Slovakia (8 times), Malta (5 times), and Austria (5 times)—see Fig. 4. Furthermore, two of the four Visegrad MS are efficient in the execution of ERDF funding committed to an LCE, with just one being more regularly designated as a benchmark (Slovakia)—see Fig. 4.



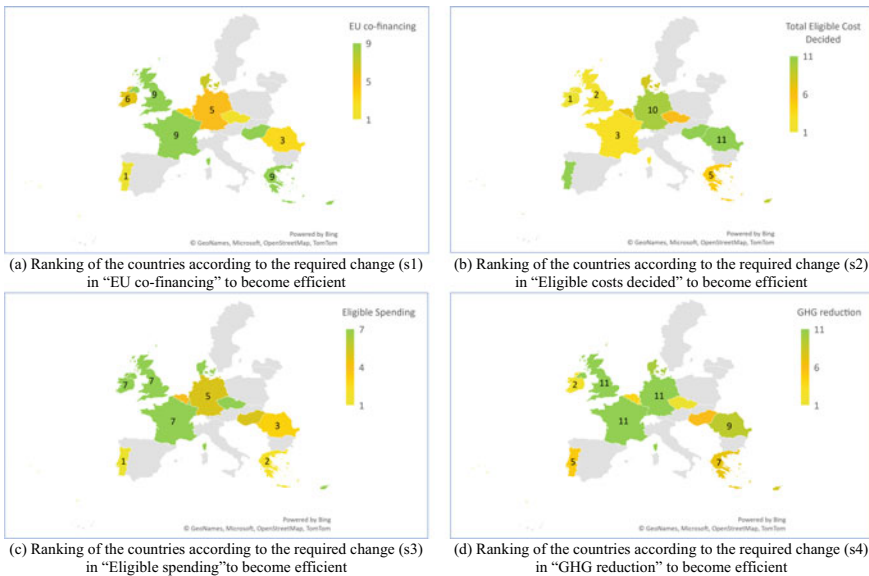
**Fig. 3** Results obtained according to the weight vectors computed with VBDEA (ranking in decreasing order). *Source* Authors’ own elaboration



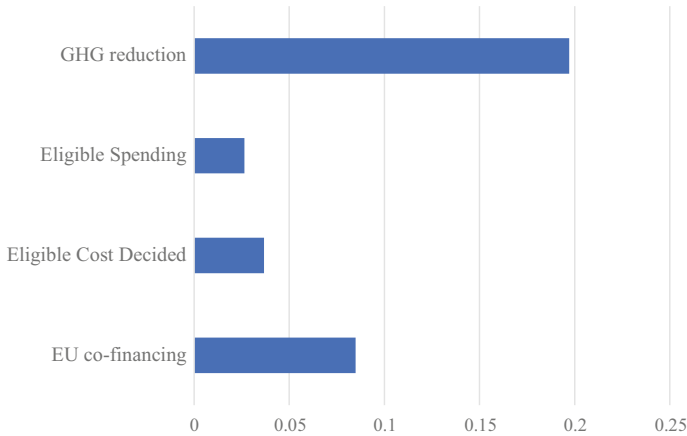
**Fig. 4** Number of times each MS has been selected as benchmark. *Source* Authors’ own elaboration

In Phase 2, the efficient targets (projections) are computed for each inefficient MS. To reach efficiency, these inefficient MS must adjust their performance values in each criterion according to the value obtained for the slacks—see Fig. 5.

The Czech Republic is the country that needs to make the biggest GHG reduction of all countries in the sample, followed by Ireland and Luxembourg (Fig. 5d). Additionally, the only inefficient MS that do not need to further reduce GHG emissions are Germany, France, and the UK. These MS inefficiency resides in their overallocation



**Fig. 5** Results obtained according to the slacks computed for inefficient countries with VBDEA (ranking in decreasing order). *Source* Authors’ own elaboration



**Fig. 6** Average required adjustments given by the slacks. *Source* Authors' own elaboration

of EU funding committed to fostering an LCE (Fig. 5a, b). Germany and France, for example, see a robust climate policy agenda as beneficial to their national economy (Bağ et al., 2021).

From Fig. 6 it can be established that the major required average changes are “GHG reduction”, followed by the dependence on “EU co-financing”.

In Table 3 we can see the improvements to be made in the original performance scale and the projections on the efficient frontier of all the inefficient countries.

The values considered to represent the criteria are occasionally uncertain. In such cases, the original DEA model is transformed into two models, thus enabling to obtain the upper and lower bounds of the efficiency scores. In the first model (the worst scenario), all DMUs' criteria being maximized are raised while all the criteria being minimized are lowered, except for the DMU under study (i.e.,  $DMU_k$  worsens its efficiency performance while the remaining DMUs improve their efficiency performance). In the best scenario, the opposite case is considered (Gouveia et al., 2013). The robustness assessment of the efficiency scores for each MS is illustrated in Fig. 7, applying a rate of change of  $\delta = 5\%$  and  $\delta = 10\%$ .

Spain, Austria, Malta, Lithuania, Bulgaria, and Sweden are robustly efficient (in decreasing order) for both data perturbations used (5 and 10%). Portugal, Belgium, Luxembourg, Greece, and Cyprus are robustly inefficient (in decreasing order) for both tolerances. Latvia is only robustly efficient for a tolerance of 5%, but just potentially efficient with a tolerance of 10% applied to all the criteria. Germany and Romania are robustly inefficient for a data perturbation of 5% and potentially efficient for a data perturbation of 10%. The remaining countries are potentially efficient for both data perturbations. Furthermore, this type of analysis allows concluding that Spain is by far the most robust MS in terms of efficiency. Curiously, Slovakia, which was most frequently selected as a benchmark (see Fig. 4) is just potentially efficient for all data perturbations.



**Table 3** Adjustments in original performances and targets on the efficient frontier

DMU	Slacks in original performances				Projections						
	s1	s2	s3	s4	EU co-financing	Eligible cost decided	Total eligible spending	GHG reduction			
BE	-10.54	-612,108,067.00	96,390,688.00	138,879.69	29.46	1,128,573,111.00	417,572,434.00	138,916.85			
CY	0.00	-243,998,058.00	0.00	64,532.92	67.50	392,204,743.00	186,165,272.00	72,775.88			
CZ	-12.32	-627,994,096.00	0.00	713,452.80	45.05	13,745,000,000.00	4,962,960,249.00	796,099.33			
DE	-8.83	-70,717,200.00	8,982,977.08	0.00	46.17	193,477,203.00	64,476,257.80	250,200.12			
DK	-5.88	-398,001,267.00	0.00	36,110.55	59.68	9,752,309,210.00	4,032,596,628.00	87,115.55			
FR	0.00	-451,573,188.00	0.00	0.00	76.25	6,444,850,860.00	2,409,491,434.00	349,456.89			
GR	0.00	-678,650,182.00	369,323,264.00	86,751.08	73.33	3,364,459,482.00	1,551,398,922.00	161,485.55			
HU	0.00	0.00	10,147,738.00	91,853.16	50.00	932,612,037.00	409,821,324.00	163,391.22			
IE	-6.44	-2,463,000,000.00	0.00	525,764.94	49.74	14,642,000,000.00	5,379,496,576.00	751,081.94			
LU	-3.04	-779,702,734.00	0.00	511,342.41	81.96	914,339,800.00	443,556,817.00	512,180.41			
PT	-15.57	0.00	1,845,133,926.00	110,196.23	68.18	7,505,375,116.00	3,216,915,642.00	112,844.39			
RO	-11.42	0.00	117,966,220.00	58,882.71	37.33	1,667,053,033.00	689,427,538.00	140,152.39			
UK	0.00	-1,284,000,000.00	0.00	0.00	59.07	5,727,973,312.00	2,356,033,638.00	256,424.84			

\* The acronyms for each MS are: BE—Belgium; CY—Cyprus; CZ—the Czech Republic; DE—Germany; DK—Denmark; FR—France; GR—Greece; HU—Hungary; IE—Ireland; LU—Luxembourg; PT—Portugal; RO—Romania; SE—Sweden; SK—Slovakia; UK—the United Kingdom  
Source Authors' own elaboration

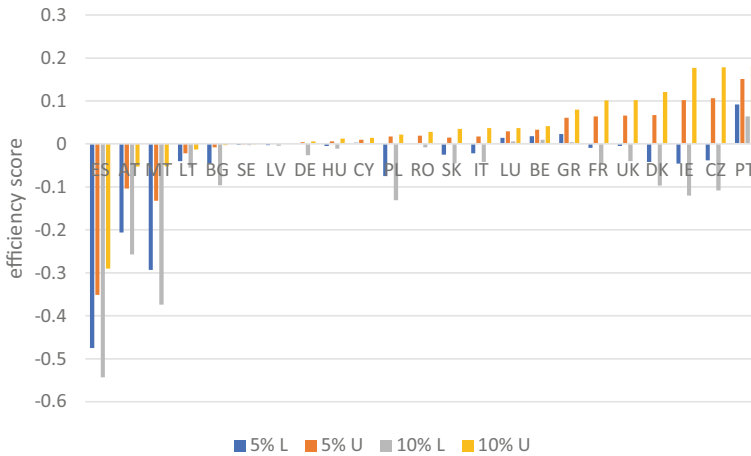


Fig. 7 Lower and upper limits for the value loss, for each MS. Source Authors’ own elaboration

## 5 Conclusions and Further Research

The primary goal of this study was to examine the efficiency of ERDF deployment for LCE assistance in 23 EU countries. To tackle this challenge, we propose a two-stage VBDEA approach. The VBDEA model is used in the initial phase to compute each MS’s efficiency score. In the second step of the analysis, data were gathered on the required changes to close any gaps between inefficient MS and their benchmarks. Differently from other methodologies used in analogous scenarios, the VBDEA approach is especially significant for MA since it allows evaluating all the MS (either efficient or inefficient) under examination at a single level, assisting in the diagnosis of the causes for their (in)efficiency. Furthermore, because it depends on value functions to convert the DMs’ preference information, this approach is straightforward in dealing with null and negative criteria.

The following are the responses to our primary research questions.

RQ1: “What are the main reasons for the (in)efficiency in the utilization of ERDF granted to promote an LCE in EU countries?”

The factors most valued to attain the higher efficiency level possible are “Eligible cost decided” and “Total eligible spending”. Moreover, only 4 out of the 10 most efficient MS (Bulgaria, Spain, Italy, and Poland) consider “GHG reduction” to be a key factor for attaining efficiency. The more significant adjustments required to attain efficiency for inefficient MS should be performed in terms of “GHG reduction” and “EU co-financing”. This implies that inefficient MS should be concerned about both the selection of initiatives to reduce GHG emissions and their reliance on EU funding.

RQ2: “Which countries were considered benchmarks during the last programmatic timeframe?”

The four most frequently elected benchmarks were Slovakia (8 times), followed ex aequo by Austria and Malta (5 times), and then by Spain (4 times).

RQ3: “Which MS performs better in terms of robustness?”

Spain, Austria, Malta, Lithuania, Bulgaria, and Sweden are robustly efficient (in decreasing order) for both data perturbations used (5 and 10%). Contrastingly, Portugal, Belgium, Luxembourg, Greece, and Cyprus are robustly inefficient (in decreasing order) for both tolerances. Spain is by far the most robust MS in terms of efficiency. Slovakia, which was most often selected as a benchmark is just potentially efficient for all data perturbations.

In conclusion, our results indicate that many EU MS that have effectively deployed renewable sources (see, for example, Germany (inefficient), Spain (efficient), France (inefficient), and Italy (efficient)), when efficient in the application of ERDF devoted to an LCE, benefit from the reduction of GHG emissions to achieve their performance, and when inefficient, do not need to even farther reduce GHG emissions towards becoming efficient, thus being regarded as over users of these types of Funds available. These MS see engagement in LCE (namely, increased renewable deployment) as an economic and political opportunity that allows them to diversify their energy supplies while simultaneously reducing energy imports. Most of these MS are in Western European countries, where they have higher GDP and better-developed energy markets as well as advanced infrastructures. Furthermore, these MS employ a significant portion of their workforce in the renewable power business, which offers them financial advantages amid rising taxes and levies (Pérez et al., 2019). It is also interesting to notice a positive change in two Visegrad MS (Poland and Slovakia), which have generally been opposed to an LCE changeover. Indeed, the Visegrad MS developed a coordinated opposition to both the EU renewables regulations and the EU power market changes (Pérez et al., 2019).

It is also worth noting that these MS are very vulnerable to energy supply disruptions, are particularly dependent on oil, and frequently rely on Russia as a sole source, as well as being located on the EU’s periphery. As a result, this change of stance regarding the implementation of an LCE, notably in Poland, Slovakia, and other Eastern EU MS such as Latvia, Lithuania, and Bulgaria, may be partly due to the occupation of Crimea in 2014 (our study covers the period of 2014–2020). Other MS, such as Romania, Hungary, and the Czech Republic, could not manage to effectively apply these funds. Given these findings, the EU must continue to push policies that ensure economic advantages from spending in an LCE, particularly for MS with limited funding.

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