EFFICIENCY ANALYSIS OF THE NEXUS BETWEENCLIMATE INVESTMENTS AND AIR POLLUTION

IUSTINA ALINA BOITAN

Faculty of Finance and Banking, Bucharest University of Economic Studies, Romania
E-mail: iustina.boitan@fin.ase.ro

Abstract - The paper aims to answer the question of how efficient the EU countries are in channeling public climate investments for mitigating GHG emissions. It is followed the Data Envelopment Analysis methodological framework to compute the efficiency score and investigate the positioning on the best practice frontier of the 27 European Union countries from 2020 to 2023. By analyzing historical data, one conclusion is that Denmark, Luxembourg, and Ireland persistently record the highest GHG emissions. The DEA findings show that Denmark occupies the best position, always placed on the best practice frontier with an efficiency score of 100%, and hence acting as a benchmark for the other countries. Luxembourg exhibited fully efficient conduct in 2020 and 2021, while Ireland achieved efficiency in 2022 and 2023. When computing the 4-year average efficiency score, it appears that most EU countries register a below-average efficiency, the smaller the score the highest the inefficiency in achieving the climate target of curbing gas emissions.

I. INTRODUCTION AND LITERATURE BACKGROUND

The paper's scope is to generate new knowledge on the efficiency of public spending when interacting with a major sustainable development goal, SDG 13: Take urgent action to combat climate change and its impacts. Specifically, it is considered exclusively the 13.2 target (integrate climate change measures into national policies, strategies, and planning) by focusing on the total greenhouse gas emissions per year indicator.

The United Nations (2024) progress report related to meeting Target 13.2 warns that concentrations of greenhouse gas emissions reached record high levels in 2022 and maintained this increasing rhythm in 2023, too. At the same time, the year 2023 broke every single climate indicator and was the warmest year on record, according to the World Meteorological Organization.

In the EU, the monitoring of SDG 13 focuses on climate mitigation, adaptation, and financing climate action. The European Commission's (2024) report on climate action explains that SDG 13 aims to achieve a climate-neutral world by 2050 and to limit global warming to well below 2°C. The achievement of this goal is expected to strengthen countries' climate resilience and readiness capacity. From the standpoint of using public resources to achieve SDG, the European Court of Auditors (2022) highlights that, if reported as climate-relevant, EU government spending should be relevant towards climate change mitigation or adaptation, contribute to the EU energy and climate objectives, or address the impact and risks of climate change. However, it is signaled that in the public reporting on climate spending, most countries do not differentiate between the budget allocated for climate change mitigation and respectively for adaptation measures.

According to Cristobal et al. (2021) there is a deficit of widely accepted general guidelines related to linking public spending to the achievement of the SDGs. To this point of view is added the one expressed by Lin et al. (2025), who argue that the existing literature faces two main shortcomings: environmental efficiency studies that consider climate change in their analysis are still seldom, and most research related to examining GHG emission efficiency preponderantly focuses on carbon dioxide emissions. Consequently, the present paper aims to fill a literature gap and advance knowledge on the efficient use of public funds channeled to the achievement of the climate targets.

In the following it is summarized the findings of similar recent studies. Zhu et al. (2022) estimate the environmental efficiency of the EU member states and reveal that, over all, the progress towards greenhouse gas emission reduction is stagnant although there are great differences between individual countries. They conclude that improvements in environmental efficiency are catalyzed by enhanced coordination and information sharing among countries, and by active investments in environmental infrastructure. Ziaei (2025) investigates whether changes in public spending on R&D for renewable and non-renewable energy sources may influence the level of CO_2 emissions. Findings indicate an asymmetric impact: an increase in the public budget for R&D for renewable energy will trigger a subsequent decrease of CO_2 intensity in the long run while a positive relationship exists in the short run. Disparities in terms of both direct and indirect effects of local government expenditure for air quality on CO_2 emissions are found by Oh (2023). Findings reveal that the direct effect of local government expenditure acts by diminishing CO_2 emissions, while the indirect effect is associated with an increase of CO_2 emissions through the

economic growth channel. Overall, it appears that the direct effect is greater than the indirect one, thus the initiatives for increasing local government expenditure for air quality do reduce CO_2 emissions.

II. DATA AND METHOD

To evaluate the degree of efficiency in using climate investments for mitigating GHG emissions, the non-parametric method Data Envelopment Analysis (DEA) is employed, which solves a mathematical optimization problem. The outcome is the relative efficiency score, which may be 1 signaling efficient conduct and positioning on the best practice frontier, or a less efficient one (Benicio and Soares de Mello, 2019). This technique is superior to others that limit the decision-maker with various constraints due to its reliance on mathematical programming algorithms in which multiple variables and constraints are considered at the same time (Özçağ and Akkaya, 2024). In the process, the inputs and outputs of the decision units are evaluated, the ones with the best performance among the units are selected and an efficient frontier is formed by using these units.

The DEA model tested is input-oriented (the algorithm minimizes the value of inputs used for obtaining a given level of outputs), with variable returns to scale and a single-input single-output configuration. DEA analysis is conducted distinctly for each year during the period 2020–2023 and 27 EU countries. This allows making comparisons in terms of the improvement or downgrade of a given country's degree of efficiency over successive years, to identify potential patterns of efficiency or inefficiency persistence as well as benchmarks of best performance.

The specificity of the DEA framework is to classify the selected indicators into input and output variables. Accordingly, in this analysis, the input variable is represented by the public investments in climate change mitigation as a percentage of GDP that are under the direct control of the government and can be adjusted to reflect the state's involvement and conduct in supporting the smooth transition to a carbon neutral economy. The output variable consists of the greenhouse gas emissions (GHG) from production activities, measured in Kilograms per capita.

Before proceeding to the validation of the research hypothesis, it is recommended to perform a quick overview of the main descriptive statistics and historical pattern of the data, to uncover some data features that may further influence the findings.

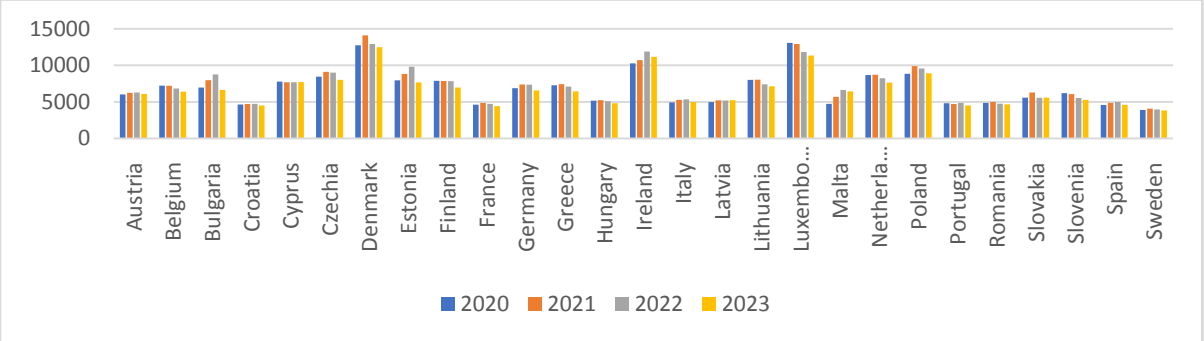


Figure 1. GHG emissions - 4-year dynamics
Source: author,based on Eurostat data

Figure 1 illustrates that, historically, Denmark, Luxembourg, and Ireland recorded the highest GHG emissions, with a peak of 14,096 kg per capita in 2021, in Denmark. Hence, the next stage of the analysis will show whether these largely polluting countries succeed in efficiently managing this environmental challenge, by relying on climate investments and optimizing their spending. The years 2020 and 2023 witnessed the lowest levels of the GHG emissions. The standard deviation indicates how the data is spread around the sample's mean, being an important clue on the presence of data variability or heterogeneity. The year 2021 shows the highest deviation (2,520), suggesting the most heterogeneous sample of data, and the presence of many outlier values among countries. The evidence of a slightly more homogenous dataset appears in 2023, with a deviation of 2,225.

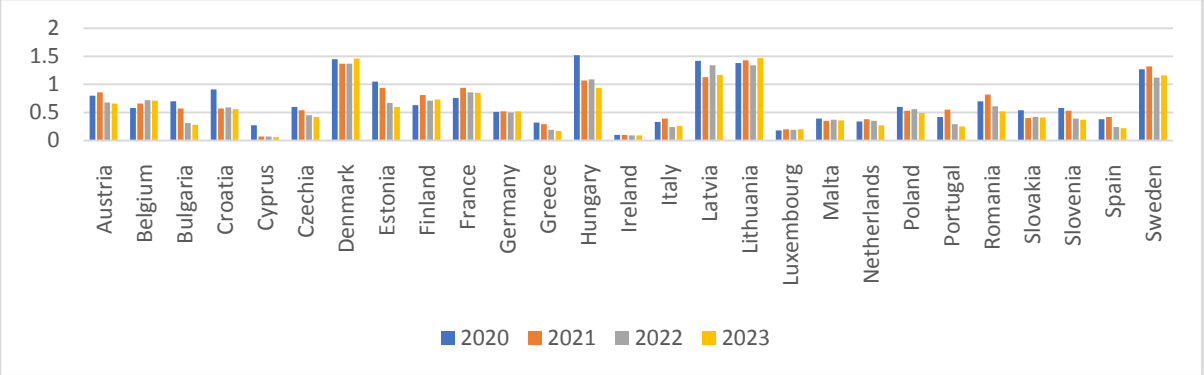


Figure 2. Climate investments (% in GDP) - 4-year dynamics
Source: author, based on Eurostat data

Figure 2 displays the amount of investments in climate change mitigation (as % of GDP) and reveals that Denmark is leading with around 1.4% of GDP, closely followed by Lithuania, Latvia, and Sweden. Therefore, although Denmark is a large GHG emitter, it also attempts to alleviate the negative effects by keeping the level of public investments at steady, high levels. Regarding the maximum values, they range between 1.37 – 1.52 (% of GDP), while the minimum ones are between 0.06-0.1%. The largest standard deviation occurs in 2020 (0.41), closely followed by 2023 (0.39), suggesting an increased presence of outlier, heterogenous values.

III. DISCUSSION OF FINDINGS

The results obtained by conducting DEA are represented by the technical efficiency scores, computed for each year included in the sample (table 1).

	Eff. Scores 2020	Eff. Scores 2021	Eff. Scores 2022	Eff. Scores 2023	4-year average eff. score	4-year country ranking
Austria	1,9%	0,1%	4,1%	2,3%	2,1%	23
Belgium	4,9%	0,3%	0,9%	14,3%	5,1%	19
Bulgaria	2,6%	5,2%	28,9%	2,9%	9,9%	17
Croatia	1,7%	0,4%	0,7%	75,6%	19,6%	13
Cyprus	6,7%	0,4%	78,1%	3,9%	22,3%	12
Czechia	4,3%	22,5%	31,9%	10,6%	17,3%	14
Denmark	100,0%	100,0%	100,0%	100,0%	100,0%	1
Estonia	3,0%	1,7%	81,5%	70,4%	39,2%	5
Finland	4,2%	6,9%	10,4%	4,3%	6,5%	18
France	3,7%	0,2%	2,8%	4,2%	2,7%	22
Germany	3,1%	100,0%	4,2%	28,8%	34,0%	6
Greece	27,1%	0,2%	100,0%	2,7%	32,5%	7
Hungary	2,1%	9,6%	0,7%	1,1%	3,38%	21
Ireland	80,5%	6,8%	100,0%	100,0%	71,8%	3
Italy	1,2%	0,2%	3,1%	2,9%	1,9%	24
Latvia	100,0%	0,2%	22,7%	3,8%	31,7%	8
Lithuania	11,9%	24,9%	23,0%	5,8%	16,4%	15
Luxembourg	100,0%	100,0%	64,5%	49,3%	78,5%	2
Malta	1,1%	0,3%	2,0%	3,7%	1,8%	25
Netherlands	100,0%	2,6%	49,8%	6,0%	39,6%	4
Poland	15,0%	2,6%	39,0%	44,7%	25,3%	11
Portugal	1,1%	0,2%	0,8%	100,0%	25,5%	10
Romania	1,1%	3,6%	1,2%	1,6%	1,9%	24

Slovakia	5,8%	0,1%	1,3%	12,2%	4,9%	20
Slovenia	37,4%	1,3%	0,6%	2,9%	10,6%	16
Spain	5,0%	0,1%	100,0%	1,5%	26,7%	9
Sweden	1,1%	0,9%	0,7%	1,4%	1,0%	26
average eff. score	23,2%	14,5%	31,6%	24,3%	23,4%	

Table 1. Summary of the efficiency scores
Source: author, based on using the DEAP software. The scores in red represent the minimum value recorded in a given year, while the scores in green show the best performance, the achievement of a full efficiency status.

The annual average efficiency shows an up-and-down fluctuation, the largest value being recorded in 2022 (31.6%) and the lowest in 2021 (14.5%). A similar pattern of evolution can be noticed at the country-level, too, with sharp shifts from one year to another. A notable example is Portugal, with an abrupt shift from 0.2% in 2021 and 0.8% in 2022 to 100% in 2023. The broad volatility and inconsistency in the estimated scores suggest that investments made to mitigate the climate effects are not appropriately tailored and targeted to slow down gas emissions. This may be the result of not appropriately substantiated policies and measures, of a lack of impact analyses to reliably and soundly calibrate the financial resources invested with the climate outcome.

Apart from the annual efficiency, we can compute the 4-year average efficiency at the country level. It appears that 11 countries record above-average efficiency scores (23.4% for the 4 years), with Denmark always attributed fully efficient conduct and serving as a benchmark (peer) for the other EU countries. Luxembourg and Ireland exhibit good performance, with average efficiency levels of over 71% while the other countries are placed in the range of 25-39%. It can be noticed that most EU countries register a below-average efficiency, the smaller the score the highest the inefficiency in achieving the climate target of curbing gas emissions.

In terms of a longitudinal, time-series analysis, the years2020 and 2022 showcase 4 cases of full efficiency that are recorded byDenmark, Latvia, Luxembourg, and Netherlands, respectively by Denmark, Greece, Ireland, and Spain while 2021 and 2023 display only 3 cases, for Denmark, Germany and Luxembourg, respectively for Denmark, Ireland and Portugal. To sum up the above findings, we may conclude that the government in some countries (Denmark, Luxembourg, and Ireland) and in some particular years (2022) proves the capability to appropriately size the level of public investments in climate change mitigation to achieve the climate desideratum of mitigating the GHG emissions.

Another outcome of applying the DEA method is the possibility of classifying or ranking the countries, given their efficiency level. Denmark occupies the best position, always on the best practice frontier, with an efficiency score of 100%, acting as a benchmark for the other countries. On the opposite is Sweden, which persistently occupies the last place in the ranking according to the 4-year average efficiency score (only 1%).

IV. CONCLUSIONS

The paper has identified a literature gap concerningthe assessment of the efficiencyof public spending and investment in the achievement of the SDGs. Specifically, the analysis developed focuses on SDG no. 13 related to adoptingmeasuresfor combating climate change, byconsidering the total greenhouse gas emissions indicator as an important outcome.For the empirical approach it has relied on a novel technique for this strand of literature, namely a nonparametric method called Data Envelopment Analysis. By solving an optimization problem,it is computed the efficiency score that characterizes whether the limited financial resources of the government, channeled to mitigate climate change and curb GHG emissions, are employed wisely to generate the desired outcome.

The findings can be interpreted at both country-level and year-level. A singular country has recorded fully efficient conduct in appropriately sizing the amount of public investments in climate change mitigation, according to the amount of GHG emissions (Denmark). The highest inefficiency is obtained by Sweden. The largest value of the annual average efficiency was recorded in 2022. Overall, the efficiency scores recorded for a given country broadly vary one year from another, suggesting a lack of substantiation in terms of public policies and measures thatshould be implemented consistently. The low predictability in sizing the public investments and the wide shifts from one year to another suggest that most EU countries do not follow an orderly transition path to climate neutrality.

This main finding is consistent with the current European initiatives. For example, Panzeri (2024) outlines that “the challenge for policymakers between now and 2040 is to manage the transition in as orderly a manner as possible” to comply with the desired pace of decarbonization. Importantly, the European Commission (2024b) launched in public debate its recommendation on setting newdecarbonization targets for 2040, by considering three possible emission reduction scenarios: up to

80%, between 85% and 90%,or between 90% and 95%.

REFERENCES

[1] Benicio, J. and Soares de Mello, J.C. (2019). Different types of return to scale in DEA, PesquisaOperacional, Vol. 39(2), pp. 245-260, Brazilian Operations Research Society, https://doi.org/10.1590/0101-7438.2019.039.02.0245

[2] Cristóbal, J., Ehrenstein, M., Domínguez-Ramos, A., Galán-Martín, A., Pozo, C., Margallo, M., Aldaco, R., Jiménez, L., Irabien, A., Guillén-Gosálbez, G. (2021). Unraveling the links between public spending and Sustainable Development Goals: Insights from data envelopment analysis,Science of The Total Environment,Volume 786,147459,https://doi.org/10.1016/j.scitotenv.2021.147459

[3] European Commission (2024). SDG 13- Climate action. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=SDG_13_-_Climate_action

[4] European Commission (2024b). Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM/2024/63 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A63%3AFIN

[5] European Court of Auditors. (2022). Climate spending in the 2014-2020 EU budget. Not as high as reported, https://www.eca.europa.eu/lists/ecadocuments/sr22_09/sr_climate-mainstreaming_en.pdf

[6] Lin, T-Y., Chiu, Y-H., Chen, C-H., Ji, L. (2025). Renewable energy consumption efficiency, greenhouse gas emission efficiency, and climate change in Europe,Geoenergy Science and Engineering,Volume 247,213665,https://doi.org/10.1016/j.geoen.2025.213665

[7] Oh, J. (2023). The Effects of Local Government Expenditures on Carbon Dioxide Emissions: Evidence from Republic of Korea. Sustainability, 15(20), 14913. https://doi.org/10.3390/su152014913

[8] Özçağ, M., Akkaya, O. (2024). Sustainability, climate change and energy efficiency, Reference Module in Social Sciences.https://doi.org/10.1016/B978-0-44-313776-1.00198-7

[9] Panzeri, D. (2024). New EU Target for 2040: An opportunity to concretely address the transition, February 2024, The Italian Climate Change Think Tank, https://eccoclimate.org/new-eu-target-for-2040-an-opportunity-to-concretely-address-the-transition/

[10] United Nations. (2024). Sustainable development, https://sdgs.un.org/goals/goal13#progress_and_info

[11] Zhu, Y., Yang, F., Wei, F., Wang, D. (2022). Measuring environmental efficiency of the EU based on a DEA approach with fixed cost allocation under different decision goals,Expert Systems with Applications,Volume 208,118183,https://doi.org/10.1016/j.eswa.2022.118183

[12] Ziaei, S.M. (2025). Public spending on Energy innovations and CO2 impacts: Evidence from selected OECD countries,Green Technologies and Sustainability,Volume 3, Issue 1,100137,https://doi.org/10.1016/j.grets.2024.100137

★★★