Evaluating the Net Zero Policy Performances of European Countries Through DEA

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Abstract. *Addressing climate change and its environmental impact is one of the greatest challenges of modern life. Most of today's sustainable strategies are essentially related to the intent of reducing overall carbon dioxide emissions. The net zero goal lays the foundation for a sustainable future. This study aims to measure the performance of European Countries based on carbon emissions. To measure performance, Pure Environmental Performance Index and Mixed Environmental Performance Index Data Envelopment Analysis (DEA) methods are used. Decision-making units (DMUs), inputs and outputs are determined. Input is identified as Primary Energy Consumption. Outputs are selected as Gross Domestic Product (GDP), Carbon dioxide (CO_2) emission, Nitrous Oxide (N_2O) emission. According to performance results, Albania, Lithonia, Malta, and Montenegro are classified as efficient countries via the two models. The results shows that the European Countries should take the required measures of the Paris Conference till 2050 to reduce the damage to the environment.*

Keywords. Climate change, Carbon dioxide emission, Data envelopment analysis, Net zero policy, Nitrous Oxide emission, Performance management.

1 Introduction

The net zero goal lays the foundation for a sustainable future. It is in question to keep global warming under control since at least carbon dioxide emissions are balanced with the net zero target. In order to avoid severe climate impacts, global greenhouse gas emissions should decrease by half by 2030 and reach zero by 2050.

In order to reach the net zero target, international negotiations were started in the late 1980s (Vlassopoulos, 2012). Carbon dioxide, methane etc. In order to reduce greenhouse gases, the Kyoto Protocol was signed between 40 countries in 1997. As a result of the inadequacy of the Kyoto protocol, the Paris Conference was held in 2015. After the conference, the Paris Agreement was signed but entered into force in 2016 (International Legal Materials, 2016).

In recent years, researchers have been conducting carbon emission analyses specific to regions. Zhou et. al. (2008) divided the world into 8 regions such as OECD, Africa. They made a carbon, energy density comparison of 8 regions using the Data Envelopment Analysis (DEA) method. On the other hand, some researchers have focused on specific countries. Guo et al. (2011) conducted a study on 29 provinces in China. They aimed to estimate CO_2 emissions reduction in provinces using multiple DEA methods. Millot et al. (2020) evaluated Sweden and France energy consumption. According to the evaluations, it has been revealed that it is important to turn to renewable energy sources. Although renewable energy sources are beneficial to environment, they require high investment and have many uncertainties.

Also, there are studies that make carbon footprint analysis in the literature [Kuo et al. (2014), Mayers et al. (2014), Belkhir and Elmeligi (2018), Millot et al. (2020)]. After the Paris Agreement signed in 2015, studies on the net zero emission approach were carried out [Wu and Skye (2021), Miller et al. (2021), Chaudry et al. (2022), Tudor and Sova (2022)].

The motivation of this study is to measure the environmental performance of European Countries and to investigate how well the European Countries can comply with the aims of the Paris Agreement. For this purpose Primary Energy Consumptions, Gross Domestic Product, Carbon dioxide emissions and Nitrous Oxide emission are identified as performance evaluation criteria via the literature review. To measure performance, the Data Envelopment Analysis (DEA) method is used. As the classical DEA models do not consider the undesirable outputs, this study employed Pure Environmental Performance Index and Mixed Environmental Performance Index DEA methods, which also considers the undesirable outputs, are employed. The contributions of this study are as follows. This study provides a roadmap for European Countries to reach the Paris Agreement’s requirement.

The countries that are identified as inefficient should take the necessary actions in terms of carbon dioxide emissions and nitrous oxide emissions till 2050. Moreover, the studies in the literature only measure the performances by taking in the account carbon dioxide emissions. This study considers both the carbon dioxide and nitrous oxide emissions, which are important environmental pollutant gases. The rest of the study is organized as follows. Section 2 explains the DEA method, Section 3 illustrates the case study. Conclusions are provided in the last Section.

2 Data Envelopment Analysis

It is a nonparametric technique to measure the relative efficiency of performance measure within a set of homogeneous decision units (DMUs) with inputs, desirable outputs and undesirable outputs (Martin-Gambo and Iribarren, 2021). The first DEA model, which named as CCR (Charles, Cooper and Rhodes), developed by Charnes et al. (1978). There are two CCR DEA methods according to the change in objective functions. These are input-oriented and output-oriented which have desirable inputs and desirable outputs. The input-oriented CCR-DEA model evaluate the relative efficiency of DMUs. This evaluation is done by maximizing the ratio of the total weighted output to the total weighted input, This model constraint is output-to-input ratio of each DMU should be less than or equal to unity.

The input-oriented CCR-DEA model can be represented as follow;

$$\max E_{j_0} = \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}}$$

subject to

(1)

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \qquad \forall j,$$
$$u_r, v_i \geq \varepsilon, \qquad \forall r, i,$$

DEA efficiency measures integrated with the concept of environmental DEA technology have gained popularity in environmental performance measurement in recent years. On the orher hand, Outputs or inputs can be undesirable like CO_2 Emission or GHG Emission. The economic justification for using undesirable output variables as inputs in DEA models. Inputs and undesirable outputs cost a DMU money, therefore DMUs often try to minimize both sorts of variables. To deal with undesirable outputs, new mathematical models have been developed by changing the constraints. For example, Tyteca (1996) developed model whose name is Pure Environmental Performance Index. This model assume that the environmental DEA technology exhibits constant returns to scale. In the scope of the theory of productive efficiency, three categories of factor are taken into account as inputs, desirable production outputs and pollutants in the form of ‘‘undesirable’’ outputs. Non-parametric efficiency measures easily and usefully lend themselves to the derivation of environmental performance indicators. They are the duals of indicators that can be obtained in the traditional framework of DEA.

$$Min\ \Theta$$

Subject to

$$\begin{aligned} &\textstyle\sum_{k=1}^{K} z_k x_{nk} \leq x_{n0} && \forall n, \\ &\textstyle\sum_{k=1}^{K} z_k y_{mk} \geq y_{m0} && \forall m, \\ &\textstyle\sum_{k=1}^{K} z_k u_{jk} = \Theta u_{j0} && \forall j, \\ &\textstyle\sum_{k=1}^{K} z_k \leq 1 \\ &Z_k \geq 0,\ k = 1, .., K. \end{aligned} \qquad (2)$$

In above linear model is consist of an input vector x_k whose nth component x_{nk} is the amount of input n consumed by DMU_k , output vector y_k whose mth component y_{mk} is the amount of desirable output m yield by DMU_k, an output vector u_{jk} whose jth component u_{jk} is the amount of undesirable output j yield by DMU_k .

Contrary to a pure EPI, an environmental performance measure considering the simultaneous adjustments of desirable and undesirable outputs can be called a mixed EPI. Zhou et al. (2008) discuss the environmental DEA technologies that exhibit non-increasing returns to scale and variant returns to scale. They proposed the pure measures under different situations and a mixed measure under the variant returns to scale environmental DEA technology for measuring environmental performance.

Zhou et al. (2008) introduced Mixed Environmental Performance Index (MEI) as

$$\min\ \lambda$$

Subject to

$$\begin{aligned} &\textstyle\sum_{k=1}^{K} z_k x_{nk} \leq \beta\, x_{n0} && \forall n, \\ &\textstyle\sum_{k=1}^{K} z_k y_{mk} \geq y_{m0} && \forall m, \\ &\textstyle\sum_{k=1}^{K} z_k u_{jk} = \lambda\, u_{j0} && \forall j, \\ &\textstyle\sum_{k=1}^{K} z_k = \beta \\ &z_k \geq 0,\ k = 1, .., K. \end{aligned} \qquad (3)$$

Where an input vector x_k whose nth component x_{nk} is the amount of input n consumed by DMU_k , output vector y_k whose mth component y_{mk} is the amount of desirable output m yield by DMU_k, an output vector u_{jk} whose jth component u_{jk} is the amount of undesirable output j yield by DMU_k .

3 Measuring the Environmental Performances of European Countries

The case study is performed in European Countries. The Data are obtained from https://ourworldindata.org/. Input and outputs are identified by reviewing the literature. Input is identified as Primary Energy Consumption. Outputs are selected as Gross Domestic Product (GDP), Carbon dioxide (CO_2) emission, Nitrous Oxide (N_2O) emission. The data are provided in Appendix.

To measure the performances, Pure Environmental Performance Index mathematical model and Mixed Environmental Performance Index mathematical model are coded in General Algebraic Modeling System v.42.5.0 (GAMS). The models are run by putting normalized values. Models results are shown in Table 1.

Table 1. Performance measurements

Country	Results of Model (2)	Results of Model (3)
Albania	1.000	1.000
Austria	0.034	0.046
Belgium	0.021	0.026
Bulgaria	0.028	0.051
Cyprus	0.327	0.380
Czechia	0.017	0.018
Denmark	0.148	0.180
Estonia	0.163	0.187
Finland	0.065	0.071
France	0.008	0.009
Germany	0.003	0.004
Greece	0.020	0.029
Hungary	0.037	0.048
Iceland	0.845	1.000
Ireland	0.559	1.000
İtaly	0.005	0.005
Lithonia	1.000	1.000
Luxemburg	0.464	1.000
Malta	1.000	1.000
Montenegro	1.000	1.000
Nether	0.015	0.021
North Macedonia	0.129	0.265
Norway	0.070	0.100
Poland	0.005	0.006
Portugal	0.032	0.039
Roma	0.022	0.030
Russia	0.001	0.001
Serbia	0.020	0.047
Slovakia	0.040	0.054
Slovenia	0.116	0.13
Spain	0.008	0.008
Sweden	0.083	0.095
Switzerland	0.084	0.134
Türkiye	0.003	0.005
United kingdom	0.006	0.006

According to Table 1, the results of the two models are close to each other. Albania, Lithonia, Malta, and Montenegro are classified as efficient countries via the two models. Mixed environmental index model also determined Iceland, Ireland, and Luxemburg as efficient countries. Although Albania's GDP value is lowest in country group, its low ranking in emissions and energy consumption has made it one of the countries with the highest performance. Although Malta's GDP value is not the highest, its high GDP value compared to other countries and its low undesirable output values make it one of the countries with the highest performance. Turkey and Germany are the countries with the worst performances in both models as a result of their high N_2O and CO_2 emission values compared to other countries.

4 Conclusions

This study aims to measure the environmental performance of European Countries and to investigate how well the European Countries can comply with the aims of the Paris Agreement. For this purpose Primary Energy Consumptions, Gross Domestic Product, Carbon dioxide emissions and Nitrous Oxide emission are identified as performance evaluation criteria via the literature review. To measure the performance, pure environmenta index DEA method and mixed environmental index DEA method are used. According to performance results, Albania, Lithonia, Malta, and Montenegro are classified as efficient countries via the two models. Mixed Environmental Performance Index mathematical model also provides Iceland, Ireland, and Luxemburg as efficient. European countries should continue to take precautions for a sustainable world. Future researchers may focus on performing this analysis for 2050. Moreover other DEA methods, which have high discrimination power can be used. Necessary measures can be taken according to these measurements.

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Appendix. Input and output data of countries

Country	Primary Energy Consumption (twh)	GDP ($/capita)	CO_2 emission (tonnes)	N_2O emission (tonnes of CO_2-equivalents)
Albania	32.457	13656.59	4947485	1100000
Austria	415.964	55833.56	67936184	3850000
Belgium	740.942	51944.17	99432616	4580000
Bulgaria	207.051	23265.88	42255764	4160000
Cyprus	32.379	41521.92	6875935	370000
Czechia	471.76	40981.05	101012960	5320000
Denmark	188.006	57161.69	30955444	5170000
Estonia	60.212	36401.11	12380190	1400000
Finland	312.568	48582.59	42381840	5010000
France	2686.761	46017.77	316386780	38279999
Germany	3625.339	53929.64	707149950	34119999
Greece	331.338	29698.03	65756230	4270000
Hungary	272.143	32553.7	49234644	5700000
İceland	60.856	56935.77	3546263	370000
İreland	184.218	86650.01	37325664	9250000
İtaly	1790.808	42708.04	339233200	15350000
Lithonia	69	37166.21	13923306	3650000
Luxemburg	46.973	116518.3	9751728	380000
Malta	40.376	43950.62	1649193	50000
Montenegro	14	21533.93	2476864	150000
Nether	975.717	56784.04	153032800	8120000
North Macedonia	31	16773.04	7994848	540000
Norway	493.904	64385.01	42784000	3400000
Poland	1176.408	33185.16	318487680	21680000
Portugal	286.524	34945.66	47618828	2990000
Roma	382.183	29875.06	77030616	8940000
Russia	8304.408	27210.55	1692363400	65120003
Serbia	199.87	18306.79	44344496	3960000
Slovakia	182	31927.59	33776188	2020000
Slovenia	79	38946.68	14048142	810000
Spain	1554.292	40802.49	251825150	20070000
Sweden	622.722	52850.57	40982492	5640000
Switzerland	326.727	70944.35	36733064	2420000
Türkiye	1807.463	28197.25	401719740	34750000
United kingdom	2146.401	47368.59	364753280	28370001