Uluslararası İktisadi ve İdari İncelemeler Dergisi
International Journal of Economic and Administrative Studies
https://dergipark.org.tr/tr/pub/ulikidince

UİİİD-IJEAS, 2025 (48) ISSN 1307-9832

ENVIRONMENTAL AND ECONOMIC GROWTH ORIENTED ENERGY EFFICIENCY IN G-11 COUNTRIES: EVIDENCE FROM DEA AND MALMQUIST TOTAL FACTOR PRODUCTIVITY INDEX

Fatih Volkan AYYILDIZ [1]

Abstract

The aim of this study is to examine the energy efficiency oriented environmental and economic growth in G-11 countries in the time period 2000-2023. Data envelopment analysis (DEA) and Malmquist total factor productivity (TFP) index methods were used in the analysis. The findings obtained in the study, respectively, indicate that the input-oriented model findings established under the assumption of constant returns to scale indicate that the efficiency of decision-making units decreased in the period in question, however, the USA, Japan, Australia, Netherlands and Switzerland were effective in all periods. The country with the lowest efficiency value in the relevant period is Canada. The input-oriented model findings established under the assumption of variable returns to scale indicate that the efficiency of decision-making units decreased in the period 2000-2023, furthermore, the USA, Japan, Australia, Belgium, Netherlands and Switzerland were effective in all periods. As a result of the study, according to the Malmquist TFP index findings, environmental and growth-oriented energy efficiency is achieved in Canada, Italy, Spain, Sweden and Switzerland.

Keywords: *Energy Efficiency, Data Envelopment Analysis, Malmquist Total Factor Productivity Index*
JEL Classification: *E01, 013, C39*

G-11 ÜLKELERİNDE ÇEVRESEL VE EKONOMİK BÜYÜME ODAKLI ENERJİ VERİMLİLİĞİ: VZA VE MALMQUIST TOPLAM FAKTÖR VERİMLİLİĞİ ENDEKSİNDEN KANITLAR

Öz

Bu çalışmanın amacı, 2000-2023 zaman diliminde G-11 ülkelerinde çevresel ve ekonomik büyümeye odaklanan enerji verimliliğini incelemektir. Veri zarflama analizi (VZA) ve Malmquist toplam faktör verimliliği (TFV) endeksi yöntemleri analizde kullanılmıştır. Çalışmada elde edlen bulgular sırasıyla ölçeğe göre sabit getiri varsayımı altında kurulan girdi yönelimli model bulguları, söz konusu dönem aralığında karar verme birimlerinin etkinliğinin azaldığını, bununla birlikte ABD, Japonya, Avustralya, Hollanda ve İsviçre'nin tüm dönemlerde etkin olduklarını belirtmektedir. İlgili dönemde etkinlik değeri en düşük olan ülke Kanada'dır. Ölçeğe göre değişken getiri varsayımı altında kurulan girdi yönelimli model bulguları, 2000-2023 döneminde karar verme birimlerinin etkinliğinin azaldığını, ayrıca ABD, Japonya, Avustralya, Belçika, Hollanda ve İsviçre'nin tüm dönemlerde etkin olduklarını açıklamaktadır. Çalışmanın sonucunda Malmquist TFP endeksi bulgularına göre ise Kanada, İtalya, İspanya, İsveç ve İsviçre'de çevresel ve büyüme odaklı enerji verimliliğinin gerçekleştiğini göstermektedir.

Keywords: *Enerji Verimliliği, Veri Zarflama Analizi***,** Malmquist Toplam Faktör Verimliliği Endeksi
JEL Sınıflandrması: *E01, 013, C39*

[1] *Assist. Prof. Dr., Ordu University, f.volkanayyildiz@odu.edu.tr, ORCID: 0000-0000-5991-3574*

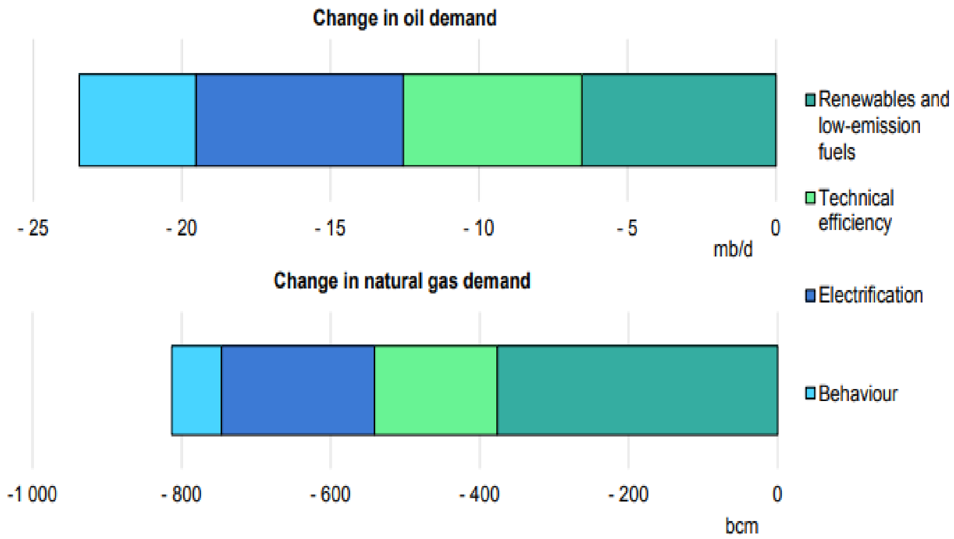
Makalenin Geliş Tarihi (Recieved Date): 28.04.2025
Araştırma Makalesi *Yayına Kabul Tarihi (Acceptance Date): 28.05.2025*

Ayyıldız, F.V. (2025). Enviromental and Economic Growth Oriented Energy Efficiency in G-11 Countries Evidence from DEA and Malmquist Total Factor Productivity Index. *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, 48, 365-376. https://doi.org/10.18092/ulikidince.1685643

1. Introduction

Energy efficiency and environmental energy sustainability are important worldwide problems. Since global energy demands are growing quickly, mostly as a result of rising populations in developing nations, efficient energy use is essential. Under current practices, the world's primary energy needs will rise approximately 56% between 2004 and 2030. The G7 countries currently account for 44% of global primary energy consumption. Due to increased energy consumption per person, the countries in the G7 have increased their R&D expenditures and implemented more effective technology in the cleanest possible coal use processes. Energy use in the context of environmental sustainability has progressively drawn greater attention due to serious ecological concerns that serve as examples of global challenges that include climate change and the fostering of sustainable development (Leonhardt et al., al,.2022). In this context, a strong global cooperation and action plan has been established to reduce carbon emissions, especially with the Kyoto Protocol and the Paris Climate Agreements (Kucuk and Yuce Dural, 2020).

Figure1: **IEA COP28 -Relation to the Stated Strategies Situation 2030**



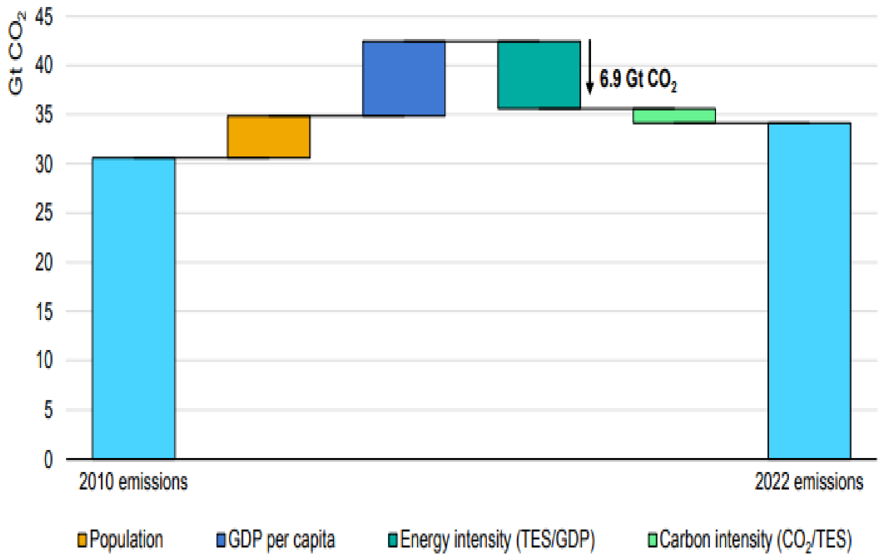
Source:(IEA, 2024).

According to the IEA energy efficiency (2024) report, about two-thirds of the decline in oil demand by 2030 is attributable to energy efficiency measures, based on the IEA COP28 Full Completion Case. Around 30% of the reduction in demand is attributable to electrification, including the transition to electric vehicles. About 25% of the reduction can be attributed to technological improvements, such as improvements in the fuel efficiency of heavy-duty vehicles, while over 15% can be attributed to behavioral regulations, such as encouraging the use of public transportation or biking. In the IEA COP28 Full Completion Case, energy efficiency initiatives are responsible for over fifty percent of the decrease in natural gas demand, with the remaining portion being attributed to renewables and low-emission fuels. Electrical power, including the substitution of gas boilers with heat pumps, contributes approximately 25% to the decline, whereas technical efficiency measures, such as construction insulation, represent 20% of the reduction. The rest results from behavioral modifications, such as lowering the thermostat's set.

The problems brought by population growth and global warming have caused decision-making units and researchers to focus more on this field. Energy efficiency means managing and restraining the energy consumption. It implies more output for the same energy input or less energy input for the same output. The true effectiveness of energy efficiency must be assessed by taking into account all facets of sustainable development. The primary issue is the integration of economic factors, energy considerations, and the concurrent analysis of usage of energy, economic growth, and the impact on the environment (Vaninsky, 2018; Fathi et al., 2021).

In providing energy efficiency, the demand side is more effective than the supply side. On the demand side, especially for environmentally sustainable growth, the use of renewable resources contributes more to efficiency than focusing on reducing costs associated with production, transmission, and distribution phases (Planning Commission 2006).

Figure 2: **Relationship between Energy Intensity and CO_2 Emissions (2010-2022 Years)**



Source: (IEA, 2024).

From 2010 to 2022, advancements in energy concentration accounted for more than 82% of the total reduction in CO_2 emissions worldwide. Not only has the commitment to energy concentration for emission reduction been significant on a global scale, but its impact has also been more pronounced in certain regions. These regions have implemented innovative technologies and policies that prioritize renewable energy sources, leading to a remarkable decline in their carbon footprints. As a result, they serve as models for other areas aiming to achieve similar environmental goals.

Consequently, amid soaring worldwide energy demands, the necessity of transitioning to sustainable energy is emphasized. A sustainable energy pathway is regarded not merely as a necessary measure to alleviate the detrimental effects of contemporary development but also as an inherent trajectory for the future. Energy, economic, and environmental regulations are frequently interrelated. These regulations not only aim to reduce carbon emissions but also promote innovation and investment in renewable technologies. As nations collaborate to create comprehensive frameworks, the momentum toward a greener economy continues to build, paving the way for a more sustainable and resilient global community. This is especially true regarding energy policy, primarily because of the significant economic and societal implications of energy (Lian, 2024). Economic growth based on DEA brings many economic advantages, such as reducing inflation, reducing costs, and providing competitiveness against competitors in the market (Khadimee, 2016:621). One of these advantages is energy efficiency based on DEA.

In this study, it was aimed to test the environmental growth model based on energy efficiency. For the purpose, the time constraint was the 2000-2023 period, and the G-11 countries, which are mostly developed countries and have significant financial power, were selected as a sample. In the econometric analysis part of the study, DEA and Malmquist TFP index methods were used to test energy efficiency. The study was planned as an introduction, followed by literature research on the subject, econometric analysis, and a conclusion. The findings from the analysis are expected to provide valuable insights into how energy efficiency impacts environmental growth within these nations. Additionally, this research aims to highlight potential policy implications that could enhance sustainable development strategies in the G-11 countries.

2. Literature Summary

In academic literature, analyses using the DEA technique in studies on energy efficiency and environment have generally been concentrated on the years 2000 and later. In this context, the main works that stand out in the literature are mentioned chronologically.

Hu and Wang (2006) used DEA analysis to analyze the energy efficiency of China's administrative regions between 1995 and 2002. Bian and Yang (2010) analyzed the energy and environmental efficiency in 30 provinces in China using the DEA technique based on the Shannon entropy model. As a result of their study, it was determined that energy and environmental efficiency were different on a provincial basis, and this situation was interpreted.

In Simsek's (2011) research, the DEA method was employed to conduct a comparative analysis of Turkey's energy efficiency and productivity among the OECD sample during the 1995-2008 timeframe. From his research, he determined that Turkey needs to cut employee numbers by 65%, reduce oil and natural gas use by 28%, lower hydropower and nuclear consumption by 60%, diminish coal usage by 61%, cut capital use by 3%, and decrease CO_2 emissions by 43%.

Santana et al. (2014) used the DEA method in their study to create rankings in BRICS countries using economic and environmental criteria in the period 2001-2007. In their study, Brazil, one of the BRICS countries, stood out in income distribution and environmental modeling at the same time, indicating that GDP growth could be the result of a more humane production model.

In the study of Shen et al. (2020), stochastic frontier analysis was used based on sustainable total factor productivity in 30 provinces in China during the period 2006-2016. As a result of their studies, they found that while labor productivity and environmental factors contribute to sustainable technological efficiency, capital deepening and industrial structure negatively affect sustainable technological efficiency.

Liu et al. (2021) analyzed the effects of financing on renewable energy and energy efficiency in the period 2016-2020 using the DEA method. It was determined that there were areas required to increase energy efficiency focused on growth and carbon emissions in 28 countries.

In Unlu's (2021) study, the panel reached the conclusion that environmental innovations increased the total factor efficiency with ARDL analysis in the period 1999-2014 in Turkey. Seyhan and Seyhan (2022) determined the relationship between renewable energy and growth in their study by using the Malmquist TFP index for the 2008-2015 period for the productivity of Turkey and EU countries based on five different variables. As a result of their study, they found that Luxembourg was also in first place. They also stated that Turkey was successful in the context of the TFP index.

Hermoso-Orzáez et al. (2020) analyzed the energy efficiency in the environmental dimension in 28 member countries of the European Union with the DEA method in the period 2005-2012. Analysis results indicate that 14 EU countries are successful in terms of environmental efficiency. Zhang et al. (2024) examined total factor productivity and green economy-based energy transitions in 171 countries for the period 1990-2019 with panel data analysis. As a result of their study, they found that total factor productivity is the main factor in the transition to green energy. Maya et al. (2024) also examined energy efficiency in 18 Latin American countries in the period 2008-2019 using the radial DEA analysis method. As a result of their study, they found that Argentina and Costa Rica had the lowest energy efficiency in the sample group, while Prague and Chile had the highest energy efficiency.

Campoli et al. (2025) investigated the use of clean energy in line with sustainable growth targets in G-20 countries in the period 2000-2019 using DEA and Malmquist TFP index analyses. As a result of their study, it was concluded that the developed countries in the G-20 were consistent in their policies towards environmental sustainability, while it was emphasized that the developing countries in the G-20 should develop their energy use policies in line with environmental sustainability targets.

Noveiri et al. (2025) analyzed the practices of OECD countries in achieving their circular economy and renewable energy targets in the period 2018-2020 with DEA. As a result of their study, they found that while some countries made improvements in line with the targets, there were deviations from the targets in some countries.

In literature studies, it has been noticed that DEA and Malmquist TFP index based analyses, especially on energy efficiency, are relatively few. This study was conducted to contribute to filling the relevant gap in the literature.

3. Data Set and Method

In the study, environmental and economic growth-oriented energy efficiency in developed country economies in the 2000-2023 period is determined by DEA and Malmquist-TFP index method. The developed country economies that make up the sample set of the analysis are the USA, Germany, the United Kingdom, Japan, Canada, Australia, Belgium, France, Italy, the Netherlands, Spain, Sweden and Switzerland.

The countries of G-11 in question are decision-making units. There are specific conditions to consider for validity in the DEA methodology. At least one condition must be met for the model to be applicable. In the case of Y number of inputs and Z number of outputs in explaining the decision units (Telli, 2023; Uzgören and Sahin, 2013).

It is essential to ensure that the data used is both accurate and relevant. Furthermore, the selection of inputs and outputs should reflect the operational realities of the decision-making units to achieve meaningful results.

$$A \geq \max(Y + Z + 1) \tag{1}$$

$$A \geq \max 2x(Y + Z) \tag{2}$$

$$A \geq \max\{(Y + Z)| \ 3x(Y + Z)\} \tag{3}$$

Since the sample G-11 countries consist of 12 countries, it was decided that the model could be applied since the first two conditions were met. Explanations regarding the preferred input and output data sets in the efficiency model created within the scope of the literature review are included in Table 1.

Table 1: **Input and Output Data Sets**

Variable	Dimensions	Indicator	Measure	Source
Input	Emergy İnput	Oil cons.	Mil tons	BP Stat (2024)
Input	Energy input	Energy cons.	Exajoule	BP Stat (2024)
Input	Non-energy	Inflation rate	%	Worldbank (2024)
Output	Undesirable	C02	Mil tons	BP Stat (2024)
Output	Desired output	GDP	Per capita	Worlbank (2024)

Table 2 shows the descriptive statistics of the input and output variables. In this context, the skewness values indicate a left-skewed distribution for all variables; the kurtosis values indicate a sharp distribution. It is known that the model does not exhibit a normal distribution for skewness and kurtosis values that differ from 0.

The condition in question is also confirmed by Jarque-Bera and probability values for the normal distribution assumption. It can be seen that the probability values are p <0.00. Since DEA is a non-parametric approach, it is not necessary to meet the normality condition in the model.

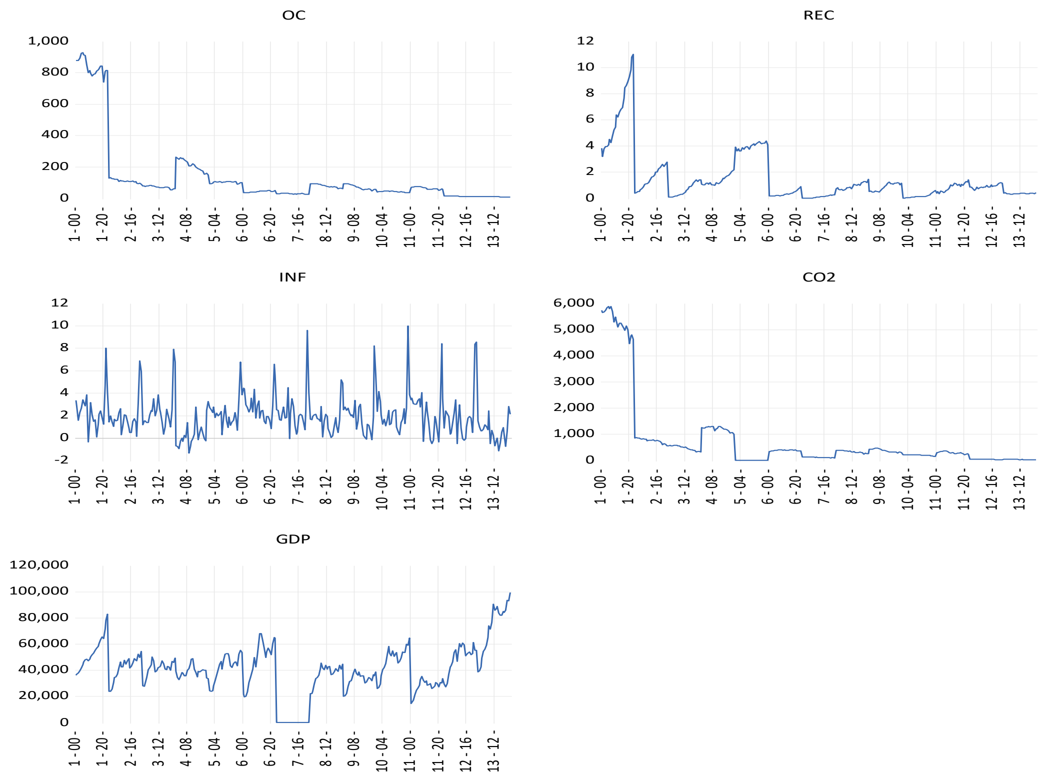
Table 2: **Descriptive Test Statistics**

Statistics	OC	REC	INF	CO2	GDP
Mean	130.4681	1.43633	1.96639	740.0864	41284.5200
Median	68.9121	0.85354	1.78767	332.8099	41363.5900
Maximum	927.0350	10.9892	10.0012	5885.0340	99564.7100
Miniunum	8.4709	0.011	-1.3528	12.8595	111.4067
St. Deviation	211.7350	1.8809	1.76073	1365.7640	18771.6900
Skewness	2.8955	2.5793	1.76073	1365.7640	0.01080
Kurtosis	10.0381	10.3965	7.2730	10.2357	3.9889
Jarque-Bera	1079.9260*	1057.1790*	369.9288*	1125.7050*	12.7196*
Total	40706.0400	448.1361	613.5114	230907	12880770
Observation	312	312	312	312	312

Note: * symbol indicates probability value (p <0.00).

Graph 1 shows the temporal trajectory of the input and output sets. In this context, oil consumption, renewable energy and emissions are generally decreasing. It can be said that GDP generally has an increasing tendency. However, it is observed that the inflation input variable has a fluctuating structure.

Graph 1: **Time Path of Variables**



3.1. Findings

Spearman correlation analysis was conducted to determine the direction and magnitude of the predicted relationships between the variables. The general decision range values for Spearman's rank correlation coefficient are shown in Table 3.

Table 3: **General Decision Range of the Correlation Level**

Absolute value	Level of relationship	Absolute value	Level of relationship
-	Linear	IrI>0.95	Significant
IrI≥0.80	Strong	0.50≤ IrI≤0.80	Medium
IrI<0.80	Weak	IrI=0	Insignificant

Source: (Sahin,2022:376).

The findings regarding the correlation are summarized in Table 4. When the table is evaluated, it is seen that energy-related CO_2 emissions are positive and statistically significant with oil consumption (0.6968) and renewable energy consumption (0.2467); however, it is insignificant with inflation. When the decision intervals in Table 3 regarding the relationships between the variables are taken into consideration, it can be said that the relationship level between emissions and oil consumption is medium; and the relationship level between emissions and renewable energy consumption is weak. It is stated that GDP has negative (-0.0950) relationships with oil consumption and positive (0.2211) and significant relationships with renewable energy consumption. Considering the decision ranges, it is seen that the relationship level is weak. However it is reported to be statistically insignificant with inflation and CO_2 emissions.

Table 4: **Spearman's Rank Correlation Analysis Findings**

Matrix	OC	REC	INF	CO2	GDP
OC	1.000				
REC	0,6574 153626* 0.0000**				
INF	0.0294 0.5178* 0.6049**	-0.0317 -0.5592* 0.5764**	1.000 - -		
CO2	0.6968 17.1062 0.0000**	0.2467 4.4832* . 0.0000**	0.0300 0.5292* 0.5970**	1.0000	-
GDP	0.0000** -0.0950 -1.6803* 0.0939**	0.0000** 0.2211 3.9932* 0.0001**	0.5970** -0.0822 -1.4527* 0.1473**	-0.0721 -1.2737* 0.2037**	

Note: * symbol describes t-statistics; ** symbol describes probability values

Table 5: **Input Oriented Constant Returns to Scale Model Findings**

Unit periods	2000-2007	2008-2015	2016-2023	Mean value
USA	1.000	1.000	1.000	-1.000
Germany	1.000	1.000	0.922	-0.974
UK	1.000	1.000	0.716	-0.865
Japan	1.000	1.000	1.000	-1.000
Canada	0.247	0.064	0.155	-0.155
Australia	1.000	1.000	1.000	1.000
Belgium	1.000	0.738	0.778	0.839
France	0.603	0.612	0.595	0.603
Italy	0.682	0.743	0.738	0.721

The input-oriented CCR (Charnes, Cooper, and Rhodes, 1978) model findings, established under the assumption of constant returns to scale (CRS), are included in Table 5. In this direction, the USA, Germany, the United Kingdom, Japan, Australia, Belgium, the Netherlands and Switzerland were active in the period 2000-2007; Canada, France, Italy, Spain and Sweden appear to be inactive. In the period 2008-2015, the USA, Germany, Japan, Australia, the Netherlands and

Switzerland were active; It is announced that the United Kingdom, Canada, Belgium, France, Italy, Spain and Sweden are not active.

It is said that the USA, Japan, Australia, the Netherlands, and Switzerland were effective in the period 2016-2023, while Germany, the United Kingdom, Canada, Belgium, France, Italy, Spain, and Sweden were ineffective. According to the findings, it is seen that the effectiveness of decision-making units decreased in the 2000-2023 period, however, the USA, Japan, Australia, the Netherlands and Switzerland were effective in all periods. The country with the lowest efficiency value in the relevant period is Canada.

Table 6 presents the results of the input-oriented BCC (Banker, Charnes, and Cooper, 1984) model, which is grounded in the concept of variable returns to scale (VRS). The findings, consistent with those of the fixed-return model, indicate that during the period from 2000 to 2007, the decision-making units in the USA, Germany, the United Kingdom, Japan, Australia, Belgium, the Netherlands, and Switzerland were effective, whereas those in Canada, France, Italy, Spain, and Sweden were ineffective.

Furthermore, it is noted that in the period from 2008 to 2015, the decision-making units in the USA, Germany, Japan, Australia, Belgium, the Netherlands, and Switzerland remained effective, while the UK, Canada, France, Italy, Spain, and Sweden were ineffective.

This trend suggests a persistent divide in decision-making efficacy among these countries, raising questions about the underlying factors that contribute to such disparities. It would be beneficial for policymakers to analyze the strategies employed by the effective units to identify best practices that could potentially enhance performance in the less effective nations. In the period 2016-2023, the countries of the USA, Japan, Australia, Belgium, the Netherlands, and Switzerland were effective, while Germany, the UK, Canada, France, Italy, Spain, and Sweden were ineffective.

Table 6: **Input Oriented Variable Returns to Scale Model Findings**

Unit periods	2000-2007 period	2008-2015 period	2016-2023 period	Mean value
USA	1.000	1.000	1.000	-1.000
Germany	1.000	1.000	0.922	-0.974
UK	1.000	0.879	0.716	-0.865
Japan	1.000	1.000	1.000	-1.000
Canada	0.247	0.064	0.155	-0.155
Australlia	1.000	1.000	1.000	1.000
Belgium	1.000	0.738	0.778	0.839
France	0.603	0.612	0.595	0.603
Italy	0.682	0.743	0.738	0.721
Netherlands	1.000	1.000	1.000	1.00
Spain	0.600	0.631	0.591	0.600
Sweden	0.723	0.705	0.666	0.698
Mean value	0.835	0.798	0.782	0.805

The data indicate a decline in the efficiency of decision-making units from 2000 to 2023; nevertheless, the USA, Japan, Australia, Belgium, the Netherlands, and Switzerland maintained effectiveness during all years. During the specified period, Canada had the lowest efficiency score. The comparison of fixed and variable return models based on the input-oriented scale reveals that the efficiency score is superior, with a greater number of decision-making units achieving success in the variable return model. The reference sets created for ineffective decision-making units are presented in table 7.and table 8. Within the scope of the findings, it is seen that the decision-making unit with the most references for countries with low efficiency scores is Switzerland, while the decision-making unit with the least references is the Netherlands.

Table 9 summarizes the findings of the Malmquist TFP index values regarding the effectiveness of decision-making units. An examination of the table reveals that the efficiency values for decision-making units are highest for pure technical efficiency (0.979), which is the highest value. As a result, we have noticed that decision-making units perform exceptionally well in terms of managerial efficiency values. If, on the other hand, the value is less than one, the result indicates that the managerial efficiency is low. It indicates that decision-making units operate at an appropriate scale; the scale efficiency value is 0.978, which indicates that the scale is appropriate for maximizing outputs relative to inputs. This high-scale efficiency, combined with the strong technical efficiency, suggests that these decision-making units are not only effective in their operations but also well-aligned in their resource utilization strategies.

Table 7: **Findings of Reference Sets (Constant Returns to Scale Model**)

Decision	2000-2007 period	2008-2015 period	2015-2023 period
Germany			Japan, Australia
UK		USA, Australia	Australia, Japan
Canada	Switzerland, Japan	Switzerland	Switzerland
Belgium		Australia, Netherlands	Australia
France	Germany, Switzerland, UK	Germany, Switzerland, USA	Switzerland, Australia, Japan
Italy	Australia, UK, Switzerland	Germany, Switzerland, Australia	Japan, Australia
Spain	Australia, UK, Switzerland	Germany, Switzerland, Australia	Switzerland Australia, Japan
Swedish	Australia, Switzerland	Switzerland, Australia	Switzerland, Australia

Table 8: **Findings of Reference Sets (Variable Returns to Scale Model)**

Decision	2000-2007 period	2008-2015 period	2015-2023 period
Germany			Japan, Australia
UK		Australia, USA, Switzerland, Japan	Australia, Japan, Switzerland
Canada	Switzerland, Japan	Switzerland	Switzerland
Belgium			
France	UK, Switzerland, Germany, Japan	Australia, USA, Switzerland, Germany	Australia, USA, Switzerland, Germany
Italy	Switzerland, UK, Australia	Germany, Switzerland, Australia	Australia, Japan, Switzerland
Spain	Australia, Switzerland, UK	Australia, Switzerland, Germany	Australia, Japan, Switzerland
Swedish	Australia, Switzerland	Switzerland, Australia	Switzerland, Australia

Table 9: **Malmquist TFP Index Findings**

Decision making units	Technical efficiency	Technological activity	Pure technical efficiency	Scale efficiency	TFP
USA	1.000	0.773	1.000	1.000	0.773
Germany	0.960	0.959	0.968	0.991	0.921
UK	0.843	0.683	0.853	0.988	0.576
Japan	1.000	0.776	1.000	1.000	0.776
Canada	0.792	1.479	0.862	0.918	1.170
Australia	1.000	0.789	1.000	1.000	0.789
Belgium	0.882	0.434	1.000	0.882	0.383
France	0.985	1.006	0.976	1.010	0.991
Italy	1.040	0.976	1.053	0.988	1.015
Holland	1.000	0.616	1.000	1.000	0.616
İspanya	1.010	0.998	1.026	0.984	1.008
Swedish	0.971	1.237	1.014	0.957	1.201
Switzerland	1.000	1.354	1.000	1.000	1.354
Mean	0.957	0.884	0.979	0.978	0.846

As the primary determinants of environmental and growth-oriented energy efficiency, the findings highlight the importance of pure technical efficiency and scale efficiency values. The value of technological efficiency is 0.884, while the value of technical efficiency is 0.957. This difference is explained by the fact that the value of technological efficiency reflects the best production limit effect of decision-making units.

The technological efficiency figure indicates a downward push on countries' production limits. It has been determined through the findings of the total factor efficiency that countries such as Canada, Italy, Spain, Sweden, and Switzerland are efficient in terms of energy that is both growth-oriented and environmentally friendly.

4. Conclusion

The quality of life and non-energy production are negatively impacted by energy inefficiency. The population and macroeconomic variables, which are some of the factors that led to this predicament, must also be highlighted. Threats from the environment to human life have increased as a consequence of economic activity. It indicates that regardless of rising energy and carbon productivity, emerging economies are unable to completely protect their economies from damage caused by economic activity. The challenge of increasing the environmental productivity of growing economies in terms of carbon, energy, and non-energy materials is also brought on by the population.

This growing population exerts additional pressure on resources, leading to unsustainable practices that exacerbate environmental degradation. As a result, it becomes imperative for policymakers to implement strategies that not only focus on economic growth but also prioritize sustainable development to ensure a balance between human needs and environmental conservation.

This research has determined that sustainability of growth-oriented environmental energy efficiency in G-11 countries is an important key factor. DEA and Malmquist TFP index methods are examined in the model within the framework of an input-based model. The input-oriented model findings established under the assumption of constant returns to scale indicate that the efficiency of decision-making units decreased in the period in question; however, the USA, Japan, Australia, the Netherlands, and Switzerland were effective in all periods. The country with the lowest efficiency value in the relevant period is Canada.

The input-oriented model findings established under the assumption of variable returns to scale indicate that the efficiency of decision-making units decreased in the period 2000-2023; furthermore, the USA, Japan, Australia, Belgium, the Netherlands, and Switzerland were effective in all periods. The country with the lowest efficiency score, similar to the fixed-return model findings, is again Canada. The comparison of both models indicates that the efficiency score is higher and more decision-making units are effective in the variable-return model.

Malmquist TFP index findings show that Canada, Italy, Spain, Sweden, and Switzerland are efficient in environmental and growth-oriented energy. This suggests that these countries have successfully integrated sustainable practices while promoting economic growth. Additionally, the results highlight the importance of innovative policies and technologies in improving overall energy efficiency across various contexts.

References

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*, 30(9), 1078-1092.

Bian Y, Yang F (2010) Resource and Environment Efficiency Analysis of Provinces in China: A DEA Approach Based on Shannon's Entropy. *Energy Policy,* 38(4),1909–1917.

BP-British Petroluem (2024) Statiscal Review of Energy [Online] https://www.bp.com/en /global/corporate/energy-economics.html Accessed 02/03/2025

Campoli, J. S., Junior, P. N. A., Kodama, T. K., Nagano, M. S.and Burnquist, H. L. (2024) G20 Countries' Progress on the 7th SDG Under Circular Economy DEA Model. *Environmental Science & Policy*, 160, 103839.

Charnes, A., Cooper, W. W., and Rhodes, E. (1978) Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research*, 2(6), 429-444.

Fathi, B., Ashena, M. and Bahari, A. R. (2021) Energy, Environmental, and Economic Efficiency in) Energy Exporting Countries: A Modified Data Envelopment Analysis Approach. *Sustainable Production and Consumption,* 26, 588-596.

Hermoso-Orzáez, M. J., García-Alguacil, M., Terrados-Cepeda, J. and Brito, P. (2020) Measurement of Environmental Efficiency in the Countries of the European Union with the Enhanced Data Envelopment Analysis Method (DEA) During the Period 2005–2012. *Environmental Science and Pollution Research*, 27(13), 15691-15715.

Hu J.L, Wang S.C. (2006) Total-factor Energy Efficiency of Regions in China. *Energy Policy* 34(17),3206–3217.

IEA-International Energy Agency (2024) Energy Efiiciency Report 2024 [Online]. https://www.iea. org/reports/energy-efficiency-2024 Accessed 05/02/2025

Khadimee, M. (2016) The Sources of Economic Growth in Iran's Economy, *Journal of Economics Library*, 3(4), 621-630.

Kucuk, G. and Yuce Dural, B. (2022) Avrupa Yesil Mutabakatı ve Yesil Ekonomiye Gecis: Enerji Senaryoları Uzerinden Bir Degerlendirme. *Anadolu Universitesi Sosyal Bilimler Dergisi*, 22(1), 137-156.

Lian, M. (2024) The Impact of Cleaner Energy Sources, Advanced Technology Firms and Economic Expansion on Ecological Footprints is Critical in Sustainable Development. *Heliyon,* 10(11),

Liu, Z., Xu, J., Wei, Y., Hatab, A. A., and Lan, J. (2023) Nexus Between Green Financing, Renewable Energy Generation and Energy Efficiency: Empirical Insights through DEA Technique. *Environmental Science and Pollution Research*, 30(22), 61290-61303.

Maya, N. X., Prieto, M. M., and Megido, L. (2024) Energy Efficiency in Middle-Income Countries with DEA: An Approach for Latin America. *Sustainable Futures*, 8, 100345.

Noveiri, M. J. S., Shabani, M., and Kordrostami, S. (2025) Assessing Circular Economy Performance of OECD Countries: A Double-frontier Multi-period DEA with Flexible Measures. *Renewable Energy,* 246, 122851.

Planning Commission (2006) Integrated Energy Policy- Report of the Expert Committee [Online]. http://planningcommission.gov.in/reports/genrep/repintengy.pdf Accessed: 18/02/2025

Sahin, G. (2022) Dogal Gaz Talep Tahmininin Yapay Sinir Agları ile Modellenmesi: Danimarka Ornegi. *Ankara Hacı Bayram Veli Universitesi İktisadi ve İdari Bilimler Fakultesi Dergisi*, 24(1), 360-385.

Seyhan, N. and Seyhan, B. (2022) Yenilenebilir Enerji Ekonomik Buyume İlişkisi Acisindan Turkiye ve AB Ulkelerinin Malmquist Endeksi ile Performans İncelemesi. *Insan ve Toplum Bilimleri Arastırmaları Dergisi*, 11(2), 1022-1044.

Shen, Y., Yue, S., Sun, S. and Guo, M. (2020) Sustainable Total Factor Productivity Growth: The Case of China. *Journal of Cleaner Production*, 256, 120727.

Telli, R. (2023) Beseri Kalkınmada Yuksekogretim Kalite Guvencesi Sisteminin Etkinligine Yonelik Bir Analiz. *Uluslararası Sosyal ve Beseri Bilimler Araştırma Dergisi*, 10(99), 2213-2226.

Tugcu, C. T. and Tiwari, A. K. (2016) Does Renewable and/or Non-Renewable Energy Consumption Matter for Total Factor Productivity (TFP) Growth? Evidence from the BRICS, *Renewable and Sustainable Energy Reviews*, 65, 610-616.

Uzgoren, E. and Sahin, G. (2013) Dumlupınar Universitesi Meslek Yuksekokullari'nin Performanslarinin Veri Zarflama Analizi Yontemiyle Olcumu. *Uluslararasi Yonetim Iktisat ve İsletme Dergisi*, 9(18), 91-110.

Vaninsky, A. (2018) Energy-Environmental Efficiency and Optimal Restructuring of the Global Economy. *Energy,* 153, 338-348.

Worlbank (2024) World Development Indicators [Online]. https://databank.worldbank.org/ indicator/NY.GDP.MKTP.KD.ZG/1ff4a498/PopularIndicators Accessed 20/03/2025

Wu, J., Zhu, Q., Yin, P., and Song, M. (2017) Measuring Energy and Environmental Performance for Regions in China by Using DEA-Based Malmquist Indices. *Operational Research*, 17, 715-735.

Zhang, C., Zhu, H., and Li, X. (2024) Which Productivity Can Promote Clean Energy Transition—Total Factor Productivity or Green Total Factor Productivity? *Journal of Environmental Management*, 366, 12189.