Ankara Hacı Bayram Veli Üniversitesi
İktisadi ve İdari Bilimler Fakültesi Dergisi 24/3 (2022) 1057-1076
E-ISSN 2667-405X

Effects of Energy Efficiency Index on Economic Activity: The Case of G7 Countries

Muhammed Şehid GÖRÜŞ* Önder ÖZGÜR**

Geliş Tarihi (Received): 19.04.2022– Kabul Tarihi (Accepted): 29.09.2022

Abstract

This investigation aims to examine the effects of energy efficiency improvements on economic growth for G7 countries during 1971-2018. To measure energy efficiency, we calculate the energy efficiency index (EEI) using the Fisher Ideal index decomposition method. This study utilizes capital and labor as control variables, in addition to the EEI variable, as determinants of economic growth. Methodologically, this paper conducts the LM (Lagrange Multiplier) bootstrap panel cointegration test which is developed by Westerlund ve Edgerton (2007), and the AMG (Augmented Mean Group) estimator of Eberhardt ve Teal (2010). Both methodologies take into consideration of cross-sectional dependency (CD) issue in the panel setting. The empirical results of this paper indicate that there is a cointegration relationship between the aforementioned variables. In detail, the impact of capital formation on economic growth is positive for all countries, while the effect of labor varies across countries. Besides, it is found that an improvement in energy efficiency leads to an advancement in economic growth for five out of seven G7 countries. The empirical findings of this paper provide some implications for policymakers.
Keywords: Capital formation, economic growth, energy efficiency index, G7 countries, labor, panel data analysis

Enerji Verimliliği Endeksinin Ekonomik Faaliyet Üzerindeki Etkileri: G7 Ülkeleri Örneği

Öz

Bu çalışmanın temel amacı 1971-2018 yılları için G7 ülkelerindeki enerji verimliliği gelişmelerinin ekonomik büyüme üzerindeki etkisini incelemektir. Bu çalışmada, enerji verimliliğinin hesaplanması için Fisher İdeal Endekse dayalı ayrıştırma yöntemi kullanılmıştır. Bununla birlikte, çalışmada ekonomik büyümenin belirleyicileri olarak enerji verimliliği endeksinin yanı sıra sermaye ve emek de kontrol değişkeni olarak kullanılmıştır. Metodolojik olarak çalışmada Westerlund ve Edgerton (2007) tarafından literatüre kazandırılan LM bootstrap panel eşbütünleşme testinden ve Eberhardt ve Teal (2010) tarafından geliştirilen AMG tahmincisinden yararlanılmıştır. Bu iki yöntem de panel veri ekonometrisinde önemli bir yere sahip olan yatay kesit bağımlılığı sorununu dikkate almaktadır. Çalışmanın ampirik sonuçlarına göre, bahsi geçen değişkenler arasında uzun dönemli bir ilişkinin olduğu tespit edilmiştir. Sermaye oluşumunun ekonomik büyüme üzerindeki etkisi bütün ülkeler için pozitifken, emeğin etkisinin ise ülke bazında farklılıklar gösterdiği görülmüştür. Bununla birlikte, enerji verimliliğinin ekonomik büyüme üzerindeki etkisi irdelendiğinde ise enerji verimliliğindeki iyileşmelerin ekonomik büyümeyi G7'deki yedi ülkeden beşinde olumlu yönde etkilediği tespit edilmiştir. Çalışmadan elde edilen sonuçlar politika yapıcılar için birtakım öneriler sunmaktadır.
Anahtar Kelimeler: Ekonomik büyüme, emek, enerji verimliliği endeksi, G7 ülkeleri, sermaye oluşumu, panel veri analizi

* Asst. Prof., Ankara Yıldırım Beyazıt University, Faculty of Political Sciences, Economics, Ankara, Turkey; e-mail: msgorus@aybu.edu.tr, ORCID: 0000-0002-7614-4567.
** Assoc. Prof., Ankara Yıldırım Beyazıt University, Faculty of Political Sciences, Economics, Ankara, Turkey; e-mail: oozgur@aybu.edu.tr, ORCID: 0000-0001-5221-4842.

Introduction

The traditional growth models argue that capital and labor are two main factors of production (Soytaş, 2019). In a well-known production function, an increase in capital stock and labor force positively affects the output level in an economy. Simply, a traditional production function can be constructed as follows:

$$Output = f(Capital, Labor)$$

However, the extensive use of natural resources in the production process increased over time, and the production function was extended with natural resources by the works of Solow (1974) and Stiglitz (1974) as follows:

$$Output = f(Capital, Labor, Energy\ Resources)$$

One may contend that the addition of energy sources to the traditional manufacturing process means that energy has a considerable bearing on how well a nation's economy grows. Because of this, the importance of energy resources has dramatically increased since the second half of the 20th century for both developed and developing nations. Energy sources played a significant role in the 20th century's global economic downturns (see 1973 and 1979 oil crises), both as a direct cause and an aggravating factor.

As noted, global energy use has increased dramatically over time. Since 2000, global primary energy consumption has increased by more than 40%, reaching 557.10 exajoules in 2020. Even though emerging economies have increased their consumption of primary energy sources at a rapid rate, advanced nations' share of global energy consumption remains larger. The G7 countries absorb nearly a third of the world's primary energy demand (British Petroleum, 2021).

The surge in demand for energy sources in many industries, as in all scarce resources, caused energy prices to rise, raising production costs, and expressing concern about energy security. The continued rise in energy use has also exacerbated environmental challenges and prompted countries to focus on sustainable economic growth (Apergis et al., 2015). The concept of *energy efficiency* has lately come into existence due to factors such as high energy prices, high production costs, energy security, a lack of energy resources, environmental concerns, and others.

The productivity of inputs in the production process is increasing as a result of technological advancements. Thus, technological progress results in increased energy efficiency, as energy is a key input in the manufacturing process (Adom et al., 2021). Energy efficiency is referred to as the more effective and efficient use of the available energy sources (Akram et al., 2021), and could be viewed as a strategy to provide a secure energy supply and offer a sustainable or environmentally friendly tool for economic growth for advanced economies (Bayar & Gavriletea, 2019). As a major benefit of energy efficiency, there would be less amount of energy used to produce the same level of output. At the same time, energy efficiency decreases energy bills, helps to provide energy security, reduces production costs, and mitigates environmental threats (Linares & Labandeira, 2010).

In this context, the United Nations Sustainable Development Goals 7 (SDG7) also directs countries to increase their efforts in increasing energy efficiency. Figure 1 provides the energy efficiency index (EEI) for G7 countries throughout 1971 to 2018.

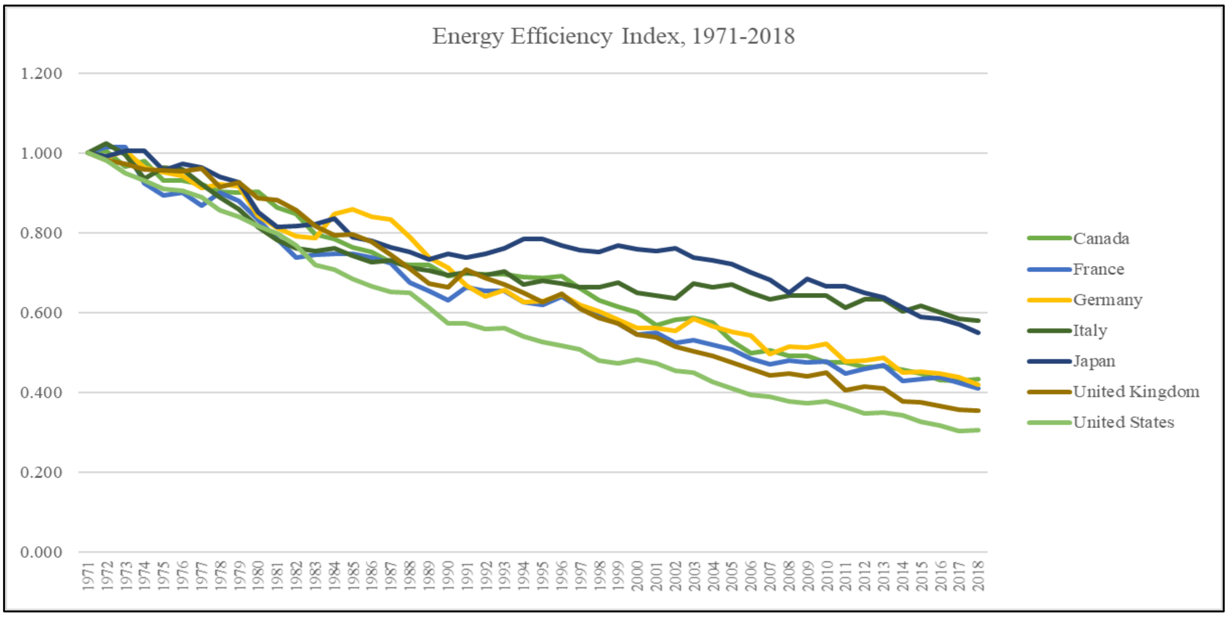

Figure 1. Time series plots of EEI across G7 countries, 1971-2018

Source: Authors' own calculation.

Figure 1 indicates clearly that the G7 countries have tried to improve their energy efficiency levels in order to reap the benefits of energy-efficient manufacturing processes. For instance, the EEI decreased from 1.00 in 1971 to 0.549 in 2018 for Japan. We could state that the energy intensity in Japan is approximately 55% of its base year value when the economic structure is fixed to its base year value. In other words, a decrease in the EEI shows an improvement in energy efficiency.

Although some studies argue that the energy efficient technologies provide certain benefits in reducing environmental pollution and boosting economic competitiveness

(Rajbhandari & Zhang, 2018), and increasing productivity (Adom et al., 2021). However, counter-arguments propose that cost-saving energy efficiency creates a room for higher energy consumption (Herring, 2006). These counter-arguments mainly justify their reasoning on the potential rebound effect. The rebound effect measures whether energy efficiency increases energy demand in some portion (Linares & Labandeira, 2010). The rebound effect is supposed to take place when energy efficiency tends to result in a decrease in energy prices and costs. However, when energy-conservative policies are combined with energy-efficient technologies, the trade-off between energy use and economic growth is expected to become less significant (Smulders & Nooij, 2003).

Therefore, the controversy of whether energy efficiency is growth-friendly is a continuing debate. On the one hand, there are several studies that used energy intensity as a proxy for energy efficiency and focused on the relationship between energy intensity and economic growth, but the literature concentrating on energy efficiency is still thin. On the other hand, it is necessary to evaluate the role of energy efficiency to enable sustainable economic growth and direct policymakers on whether to adopt energy conservative policies.

In this context, this study concentrates on the G7 countries and aims to investigate the effects of the energy efficiency index on economic activities throughout 1971-2018. Our study makes use of a Fisher Ideal index decomposition method to calculate an EEI. Therefore, the contribution of the study is as follows: First, almost all the empirical papers have studied the impact of energy efficiency on economic growth for developing countries. However, this study mainly focuses on the developed countries, namely, G7 countries. Second, this study constructs the EEI to decompose the advancement in energy-efficient technologies from energy intensity. Lastly, we employ second-generation panel data techniques to take into consideration of cross-sectional dependency (CD).

The outline of the study can be presented as follows. Section 1 section surveys the empirical literature, while Section 2 gives a piece of brief information on the data and methods utilized. The third section discusses the empirical results, while the last section summarizes the main findings of this paper and provides policy suggestions to the economic agents.

1. Literature Review

In the empirical literature, a growing body of literature recognizes the significance of energy efficiency on economic growth. In most studies, authors use energy intensity

$\left(\frac{Energy\ Consumption}{GDP}\right)$ or inverse of energy intensity as a proxy for energy efficiency. The related empirical literature about the issue mentioned above is provided below in chronological order.

Sinha (2015) used the reduction in energy waste as a proxy for energy efficiency and examined its effects on the economic activities in India for 1971-2010. The empirical results showed a bidirectional causal link between the reduction in energy waste and economic growth in the short-run. Cantore et al.'s (2016) empirical findings revealed a positive relationship between energy intensity and per capita economic growth in 29 emerging economies. Bataille and Melton (2017) handled a dynamic recursive general equilibrium model to estimate the impact of energy efficiency on Canadian economic activity between 2002 and 2012. Their study constructed a scenario analysis and found that improvements in energy efficiency over this period contributes to Canadian GDP by 2 percent. Also, Mahmood and Kanwal (2017) examined a similar relationship between these two variables for Pakistan for 1980-2016. The authors utilized the Error Correction Model to find the causal linkage between variables. According to the results, they found that economic activity Granger causes energy efficiency for Pakistan.

Bayar and Gavriletea (2019) found that energy efficiency affected economic growth positively for 12 out of 22 emerging countries during the period 1992-2014. The authors employed the Durbin-Hausman panel cointegration test and AMG (Augmented Mean Group) estimator to reveal the long-run relationship between variables. Marques et al. (2019) concentrated on the industrial sector in 11 European countries and examined whether energy efficiency accelerates economic growth over the period between 1997 and 2015. They used the nonlinear ARDL model and found that energy efficiency significantly boosts economic growth in both upturns and downturns. Moreover, Go et al. (2020) studied the long-run relationship between economic activities and energy efficiency (aggregated and sectoral levels) for the Malaysian economy for 1971-2013. It was found that the cointegration relationship exists only in the tertiary sector. The empirical results suggested that energy efficiency affects economic growth positively. For forty-six African economies, Ohene-Asere et al. (2020) used a battery of empirical tools and analyzed the period between 1980-2011. Their findings supported the role of energy efficiency in achieving sustainable economic growth and found a bi-directional causal relationship between energy efficiency and economic development. Their study also demonstrated that technological improvements and energy prices lead to higher efficiency in energy use.

Among the recent studies, Adom et al. (2021) examined the effect of energy efficiency on economic growth for 51 African countries for data spanning from 1991 to 2017. The authors conducted the two-step GMM (Generalized Method of Moments) and found that advancements in energy efficiency increase economic growth for the countries examined. Besides, Akram et al. (2021) investigated the impacts of energy efficiency on economic growth for BRICS (Brazil, Russia, India, China, South Africa) countries covering 1990-2014. The empirical results of the study confirmed the positive effect of energy efficiency on income level across quantiles. Razzaq et al.'s (2021) findings based on the bootstrap-ARDL model showed that an improvement in energy efficiency triggers economic growth in the U.S. both in the short-run and long-run, covering the period 1990-2017. Recently, Gorus and Karagol (2022) investigated the effects of per capita income on the energy efficiency index for 27 OECD countries, 1980-2018. The authors proved that per capita income level is a significant factor affecting countries' energy efficiency levels.

As seen, there is limited literature on the effects of energy efficiency on income level, especially in developed countries. Most of the studies investigated this relationship for emerging markets. Also, it is essential to note that utilizing energy intensity may not reflect the advancement in energy-efficient technologies. For instance, the decrease in energy intensity can also be attributed to the change in the economic structure, like moving from an energy-intensive industrial economy to a less energy-intensive service economy. Therefore, a more specific measure should be used for energy efficiency. In this study, an EEI is constructed through the Fisher Ideal index decomposition method. Then, its effects on economic growth for G7 countries are investigated by novel panel data methods for the period 1971-2018.

2. Data, Model, and Methodology

This study aims to examine the impact of energy efficiency on economic growth for G7 countries during period 1971-2018. Also, this study uses capital and labor as control variables in the economic growth model. In this study, we utilize annual GDP per capita (2010$) ($lnPGDP$), gross fixed capital formation (2010$) ($lnK$), and population (15-64) (lnL) data for the empirical analysis. The population (15-64) data is used as a proxy for labor in this study. These series are gathered from the World Development Indicators dataset. Also, the energy efficiency index ($lnEFF$) is computed by the Fisher Ideal index decomposition[†] (see data in

[†] The computational steps of the Fisher Ideal index are presented in the Appendix.

Table A.1). In short, this study aims to estimate the parameters of the following model in the long-run:

$$lnPGDP_{i,t} = \beta_0 + \beta_1 lnK_{i,t} + \beta_2 lnL_{i,t} + \beta_3 lnEFF_{i,t} + \varepsilon_{i,t} \quad (1)$$

All the series utilized are in logarithmic forms. The descriptive statistics of all the series are given below:

Table 1. Descriptive statistics

Statistics	$lnPGDP$	lnK	lnL	$lnEFF$
Mean Value	10.417	27.013	17.734	-0.428
Median Value	10.450	26.844	15.528	-0.403
Maximum Value	10.909	28.986	19.181	0.022
Minimum Value	9.793	25.248	16.437	-1.195
Standard Deviation	0.260	0.807	0.651	0.283
Jarque-Bera Statistics	15.007***	10.817***	17.778***	13.912***
Number of Observation	336	336	336	336

Note: *** shows the 1% significance level.

This paper conducts the LM bootstrap panel cointegration test introduced by Westerlund and Edgerton (2007). Also, it uses a bunch of auxiliary panel data techniques, including, CD tests, panel unit root test, and slope homogeneity test. In addition, the long-run parameters of the model are estimated through the AMG. All of these methods help us to determine whether first-generation or second-generation panel data techniques are proper, or not.

The LM bootstrap panel cointegration test considers the CD of the residuals of the model, and the test statistics is calculated through the following equation Westerlund and Edgerton (2007):

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{t=1}^{T} \widehat{w}_i \, s_{it}^2 \quad (2)$$

Here, N is the sample size, while T shows the time period. Besides, $\widehat{w}_i$ is the long-run variance of the residuals and s_{it} denotes the partial sum process of error terms. According to this panel cointegration test, the null hypothesis is that a cointegration relationship exists between cross-section units, while the alternative one asserts that there is no cointegration among variables (Wang et al., 2020).

The AMG estimator is introduced by Eberhardt and Teal (2010). This estimator uses FMOLS to estimate country regressions for endogeneity. The main advantage of this estimator is that taking into consideration of CD issue (Eberhardt & Teal, 2010; Ulucak & Bilgili, 2018). This paper also employs the Cross-Sectionally Augmented Error-Correction approach (CS-ECM) to set out an error-correction model.

3. Empirical Results and Discussion

In this section, we present the empirical results derived from the CD tests, the panel unit root test, the panel cointegration test, and the AMG estimator. First of all, this paper examines the CD issue of each variable. The empirical results are provided in Table 2; it is seen that this study rejects the null hypothesis of no CD. Therefore, it is rational to conduct the second-generation panel unit root tests in this analysis.

Table 2. Results of CD test for the series

Variables	Breusch-Pagan LM Test Statistics	Pesaran Scaled LM Test Statistics	Bias-Corrected Scaled LM Test Statistics	Pesaran CD Test Statistics
$lnPGDP$	946.046^{***}	142.737^{***}	142.663^{***}	30.747^{***}
lnK	783.992^{***}	117.732^{***}	117.657^{***}	27.883^{***}
lnL	607.633^{***}	90.519^{***}	90.445^{***}	23.532^{***}
$lnEFF$	928.535^{***}	140.035^{***}	139.961^{***}	30.457^{***}

Note: *** shows the 1% significance level.

Table 3 shows the stationarity properties of each variable based on the CADF test. The CIPS statistics exhibit that all series are nonstationary at their level values while stationary at their first differences; in other words, all of them are I(1). Thus, this paper can investigate whether these series are cointegrated in the long-run, or not.

Table 3. Panel unit root test results for the series

Variables	CIPS Unit Root Test		
	Constant	Constant and Trend	Result
$lnPGDP$	-2.055	-2.380	I(1)
$\Delta lnPGDP$	-4.364^{***}	-4.420^{***}	
lnK	-2.207	-2.328	I(1)
ΔlnK	-5.440^{***}	-5.409^{***}	
lnL	-1.516	-3.586^{***}	I(1)
ΔlnL	-2.328^{*}	-2.988^{**}	

Variables	CIPS Unit Root Test		
	Constant	Constant and Trend	Result
$lnEFF$	-2.561***	-2.529	I(1)
$\Delta lnEFF$	-7.127***	-7.231***	

Note: ***, **, and * show the 1%, 5%, and 10% *** shows the 1% significance level, in order.

This study employs three basic tests considering the CD for the residuals of the model, namely, the Breusch-Pagan LM test, bias-adjusted LM test, and Pesaran CD test. All the test statistics reveal that the CD dependency exists in the residuals of the model. So, this study needs to employ the second-generation panel cointegration test to find out the long-run relationship between variables. This study tests this potential relationship between the variables as mentioned earlier through the LM bootstrap panel cointegration test introduced by Westerlund and Edgerton (2007). According to the LM test statistics, this investigation cannot reject the null of cointegration in panel data. In other words, one can say that economic growth, capital, labor, and EEI move together in G7 countries in the long-run.

Table 4. Results of CD test for the model and panel cointegration test

Tests	Test Statistics	p-value
Breusch-Pagan LM test	57.690***	0.000
Bias-adjusted LM test	20.290***	0.000
Pesaran CD test	2.116***	0.034
LM test statistics	2.454$^{\phi}$	0.487

Note: *** shows the 1% significance level. $^{\phi}$ denotes that there is a cointegration relationship between variables.

The AMG long-run estimation results are given in Table 5. According to the empirical findings, a rise in the capital level causes to increase in economic growth in all the countries examined. Besides, it is found that an increase in labor has a positive impact on it in Canada and Japan, while its effect is negative in France and Italy. Also, the empirical findings prove that advancements in energy efficiency lead to increase economic growth in 5 out of 7 countries, namely, Canada, France, Italy, and Japan. In the remaining countries, its effects are statistically insignificant in the long-run.

Table 5. AMG long-run estimation results

Countries	Constant	Trend	lnK	lnL	$lnEFF$
Canada	-10.561***	-0.004*	0.293***	0.803***	-0.275***
France	23.524***	-0.002***	0.109***	-0.951***	-0.152***

Countries	Constant	Trend	lnK	lnL	$lnEFF$
Germany	6.607**	0.004***	0.154***	-0.462	-0.081
Italy	13.983	-0.013***	0.165***	-0.490**	-0.200***
Japan	-13.491***	0.107***	0.291***	0.851***	-0.201***
United Kingdom	-2.132	-0.004*	0.283***	0.264	-0.195*
United States	6.556*	0.003	0.253***	-0.184	-0.060
Panel	3.368	-0.000	0.226***	0.038	-0.168***

Note: ***, **, and * show the 1%, 5%, and 10% significance level, in order. The Delta test results support that the coefficients are heterogeneous across units.

Overall, one can say that energy efficiency is one of the significant drivers of the economic growth process of G7 countries throughout the recent economic history. In detail, especially, Canada, France, Italy, Japan, and the United Kingdom got benefit from advancements in energy-saving technologies for the period examined, 1971-2018. Besides, since the gross fixed capital formation covers i) land improvements, ii) plant, machinery, and equipment purchases, iii) construction of infrastructure, and iv) construction of commercial and industrial buildings, an increase in capital formation leads to a rise in income level of countries, as expected. Lastly, it is found that an increase in labor affects the economic growth of countries differently (positive for Canada and Japan, negative for France and Italy). This finding can be attributed to the production technology of the economies. Some countries still use labor-intensive technologies, while others utilize capital-intensive technologies to produce goods and services.

In addition to the AMG long-run estimation results, this paper also employs the CS-ECM approach to find out the short-run parameters and the adjustment term of the model by following Ditzen (2021). Also, this method presents the long-run results of the model. The CS-ECM estimation results are exhibited in Table 6. According to the findings, the adjustment term is estimated as -0.502. This means that any deviation from the long-run equilibrium between per capita economic growth, capital, labor, and the energy efficiency index is corrected about two years, approximately. In other words, about 50.2% of the disequilibrium of the shocks is corrected within the next year. Besides, it is found that only capital has a positive and statistically significant impact on economic growth for G7 countries in the short-run. The long-run estimation results partially support the AMG results presented above.

Table 6. CS-ECM estimation results

Short-Run Estimates	Coefficient	Standard Error	p value
ΔlnK	0.058***	0.020	0.004

ΔlnL	0.113	0.562	0.840
$\Delta lnEFF$	0.049	0.043	0.259
Adjustment Term	**Coefficient**	**Standard Error**	**p value**
$L.lnPGDP$	-0.502***	0.043	0.000
Long-Run Estimates	**Coefficient**	**Standard Error**	**p value**
lnK	0.302***	0.029	0.000
lnL	-0.529	0.332	0.112
$lnEFF$	-0.241**	0.095	0.011

Note: *** and ** show the 1% and 5% significance level, in order. $L.lnPGDP$ is the cointegration variable.

The long-run empirical findings of this paper show some similarities with the existing empirical literature considering energy efficiency. Our empirical results partially support the findings of Cantore et al. (2016) for 29 developing countries, Bataille and Melton (2017) for Canada, Bayar and Gavriletea (2019) for developing countries, Adom et al. (2021) for African countries, and Akram et al. (2021) for BRICS economies. Also, these studies asserted that an increase in energy efficiency has a positive impact on economic growth.

4. Conclusion

The main purpose of the investigation was to explore the impact of energy efficiency on economic growth for G7 countries for 1971-2018. Besides, we used capital and labor as control variables in the growth model. This study employed several panel data techniques to determine the long-run relationship between these variables, including the LM bootstrap panel cointegration test of Westerlund and Edgerton (2007) and the AMG estimator of Eberhardt and Teal (2010).

The empirical results of the paper indicated that the abovementioned variables are cointegrated in the long-run. According to the long-run estimation results, an increase in capital and an improvement in energy efficiency trigger economic growth in most of these countries. Furthermore, this study found that a rise in labor affects the income level of countries differently. Its sign and magnitude vary across countries for the period examined.

The empirical results of this study provide some implications for policymakers. Energy-saving technologies should be considered significantly by policymakers to sustain economic growth. For this purpose, energy-related research and development projects should be supported, and the required level of subsidies should be given by governments. Further work is needed to utilize a more advanced empirical methodology to assess the relationship between the abovementioned variables such as time-varying analyses. In addition, a similar analysis can be conducted considering different income groups for making inference for developed and developing economies.

References

Adom, P. K., Agradi, M., & Vezzulli, A. (2021). Energy efficiency-economic growth nexus: What is the role of income inequality? *Journal of Cleaner Production*, *310*, Article 127382.

Akram, R., Chen, F., Khalid, F., Huang, G., & Irfan, M. (2021). Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis. *Energy, 215*, Article 119019.

Apergis, N., Aye, G. C., Barros, C. P., Gupta, R., & Wanke, P. (2015). Energy efficiency of selected OECD countries: A slacks-based model with undesirable outputs. *Energy Economics, 51*, 45-53.

Bataille, C., & Melton, N. (2017). Energy efficiency and economic growth: A retrospective CGE analysis for Canada from 2002 to 2012. Energy Economics, *64*, 118-130.

Bayar, Y., & Gavriletea, M. D. (2019). Energy efficiency, renewable energy, economic growth: Evidence from emerging market economies. *Quality & Quantity, 53(4),* 2221-2234.

British Petroleum (2021). BP statistical review of world energy 2021. Statistical Review of World Energy.

Cantore, N., Calì, M., & te Velde, D. W. (2016). Does energy efficiency improve technological change and economic growth in developing countries? *Energy Policy, 92,* 279-285.

Ditzen, J. (2021). Estimating long-run effects and the exponent of cross-sectional dependence: An update to xtdcce2. *The Stata Journal, 21(3),* 687-707.

Eberhardt, M., Teal, F. (2010). Productivity analysis in global manufacturing production. Economics Series Working Papers 515, University of Oxford, Department of Economics.

Go, Y. H., Lau, L. S., Yii, K. J., & Lau, W. Y. (2020). Does energy efficiency affect economic growth? Evidence from aggregate and disaggregate levels. *Energy & Environment, 31(6),* 983-1006.

Gorus, M. S., & Karagol, E. T. (2022). Reactions of energy intensity, energy efficiency, and activity indexes to income and energy price changes: The panel data evidence from OECD countries. *Energy,* Article 124281.

Herring, H. (2006). Energy efficiency—A critical view. *Energy, 31(1),* 10-20.

Linares, P., & Labandeira, X. (2010). Energy efficiency: Economics and policy. Journal of *Economic Surveys, 24(3),* 573-592.

Mahmood, T., & Kanwal, F. (2017). Long run relationship between energy efficiency and economic growth in Pakistan: time series data analysis. *Forman Journal of Economic Studies, 13,* 105-120.

Metcalf, G. E. (2008). An empirical analysis of energy intensity and its determinants at the state level. *The Energy Journal, 29(3),* 1-26.

Marques, A. C., Fuinhas, J. A., & Tomás, C. (2019). Energy efficiency and sustainable growth in industrial sectors in European Union countries: A nonlinear ARDL approach. *Journal of Cleaner Production, 239,* Article 118045.

Ohene-Asare, K., Tetteh, E. N., & Asuah, E. L. (2020). Total factor energy efficiency and economic development in Africa. *Energy Efficiency, 13(6),* 1177-1194.

Özbuğday, F. C., & Erbas, B. C. (2015). How effective are energy efficiency and renewable energy in curbing CO_2 emissions in the long run? A heterogeneous panel data analysis. *Energy, 82*, 734-745.

Rajbhandari, A., & Zhang, F. (2018). Does energy efficiency promote economic growth? Evidence from a multicountry and multisectoral panel dataset. *Energy Economics, 69,* 128-139.

Razzaq, A., Sharif, A., Najmi, A., Tseng, M. L., & Lim, M. K. (2021). Dynamic and causality interrelationships from municipal solid waste recycling to economic growth, carbon emissions and energy efficiency using a novel bootstrapping autoregressive distributed lag. *Resources, Conservation and Recycling, 166,* Article 105372.

Sinha, A. (2015). Modeling energy efficiency and economic growth: Evidences from India. *International Journal of Energy Economics and Policy, 5(1),* 96-104.

Smulders, S., & De Nooij, M. (2003). The impact of energy conservation on technology and economic growth. *Resource and Energy Economics, 25(1),* 59-79.

Solow, R. M. (1974). Intergenerational equity and exhaustible resources. *The Review of Economic Studies, 41(5),* 29–45.

Soytaş, U. (2019). Enerji ve Makroekonomi. *Enerji Ekonomisi-Politika, Piyasa, Düzenleme*, 41-56. Umuttepe Yayınları, Kocaeli.

Stiglitz, J. E. (1974). Growth with exhaustible natural resources: The competitive economy. *The Review of Economic Studies*, *41*, 139-152.

Ulucak, R., & Bilgili, F. (2018). A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. *Journal of Cleaner Production, 188*, 144-157.

Wang, Z., Bui, Q., & Zhang, B. (2020). The relationship between biomass energy consumption and human development: Empirical evidence from BRICS countries. *Energy, 194,* Article 116906.

Westerlund, J., & Edgerton, D. L. (2007). A panel bootstrap cointegration test. *Economics Letters*, *97(3),* 185-190.

Appendix

Table A.1. Energy efficiency index data for G7 countries (1971-2018)

Year	Canada	France	Germany	Italy	Japan	United Kingdom	United States
1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	1.005	1.014	0.988	1.023	0.991	0.981	0.981
1973	0.966	1.014	1.006	0.996	1.005	0.972	0.948
1974	0.980	0.924	0.962	0.936	1.005	0.957	0.930
1975	0.931	0.893	0.951	0.963	0.957	0.956	0.909
1976	0.930	0.899	0.941	0.958	0.973	0.953	0.905
1977	0.922	0.867	0.913	0.921	0.962	0.961	0.888
1978	0.902	0.901	0.920	0.889	0.940	0.915	0.856
1979	0.900	0.880	0.916	0.859	0.925	0.926	0.839
1980	0.902	0.833	0.843	0.814	0.851	0.887	0.816
1981	0.863	0.783	0.811	0.781	0.813	0.881	0.797
1982	0.848	0.738	0.790	0.760	0.816	0.855	0.768
1983	0.796	0.744	0.787	0.753	0.821	0.816	0.718
1984	0.784	0.746	0.847	0.762	0.835	0.793	0.708
1985	0.763	0.746	0.858	0.741	0.789	0.795	0.684
1986	0.751	0.737	0.840	0.725	0.779	0.777	0.665
1987	0.725	0.722	0.832	0.730	0.763	0.744	0.652
1988	0.720	0.676	0.789	0.711	0.751	0.709	0.650
1989	0.719	0.655	0.738	0.704	0.734	0.673	0.612
1990	0.690	0.630	0.711	0.694	0.747	0.663	0.573
1991	0.697	0.664	0.668	0.700	0.738	0.708	0.573
1992	0.696	0.653	0.639	0.693	0.746	0.687	0.559
1993	0.695	0.653	0.655	0.704	0.760	0.670	0.560
1994	0.690	0.626	0.625	0.669	0.783	0.648	0.541
1995	0.685	0.618	0.628	0.678	0.783	0.627	0.525
1996	0.691	0.640	0.645	0.673	0.767	0.648	0.517
1997	0.660	0.611	0.619	0.664	0.756	0.609	0.506
1998	0.629	0.594	0.603	0.664	0.752	0.587	0.480
1999	0.614	0.572	0.582	0.675	0.768	0.571	0.472
2000	0.600	0.544	0.560	0.650	0.759	0.545	0.481
2001	0.568	0.549	0.560	0.643	0.753	0.538	0.472
2002	0.580	0.524	0.553	0.635	0.761	0.514	0.454
2003	0.586	0.531	0.583	0.673	0.738	0.503	0.448
2004	0.575	0.518	0.565	0.664	0.730	0.490	0.427
2005	0.527	0.508	0.552	0.671	0.721	0.474	0.410
2006	0.498	0.484	0.543	0.648	0.699	0.459	0.394
2007	0.504	0.471	0.496	0.632	0.681	0.442	0.387
2008	0.492	0.479	0.513	0.642	0.649	0.447	0.378
2009	0.492	0.474	0.512	0.641	0.685	0.440	0.372
2010	0.475	0.478	0.521	0.642	0.665	0.448	0.377
2011	0.476	0.446	0.476	0.612	0.666	0.405	0.362
2012	0.463	0.459	0.479	0.634	0.649	0.415	0.347

Year	Canada	France	Germany	Italy	Japan	United Kingdom	United States
2013	0.466	0.468	0.487	0.632	0.637	0.409	0.350
2014	0.456	0.427	0.449	0.602	0.611	0.376	0.343
2015	0.446	0.433	0.452	0.616	0.590	0.375	0.326
2016	0.431	0.437	0.447	0.599	0.584	0.365	0.316
2017	0.429	0.424	0.438	0.583	0.571	0.355	0.303
2018	0.432	0.410	0.419	0.580	0.549	0.352	0.305

Note: These series are constructed by the authors based on the Fisher Ideal index decomposition method.
Source: Authors' calculations.

Decomposition of Energy Efficiency Index

Metcalf (2008) states that energy intensity can be written as a function of energy efficiency and activity:

$$Energy\ Intensity_t \equiv \frac{Aggregate\ Energy\ Consumption_t}{Aggregate\ Economic\ Activity_t} =$$

$$\sum_i \left(\frac{Sectoral\ Energy\ Consumption_{it}}{Sectoral\ Economic\ Activity_{it}}\right) * \left(\frac{Sectoral\ Economic\ Activity_{it}}{Aggregate\ Economic\ Activity_t}\right) = \quad (3)$$

$$\sum(sector - specific\ energy\ efficiency_{it}) * (sector - specific\ economic\ activity_{it})$$

Then, the Energy Intensity Index (EII) can be decomposed into the Energy Efficiency Index and the Activity Index according to the Fisher Ideal index approach (Özbuğday & Erbas, 2015; Gorus & Karagol, 2022):

$$EII_t = F_t^{eff} * F_t^{act} \quad (4)$$

The above Fisher Ideal indexes can be calculated by the Laspeyres and the Paasche indexes:

$$F_t^{eff} = \left(L_t^{eff} * P_t^{eff}\right)^{\frac{1}{2}} \quad (5)$$

$$F_t^{act} = (L_t^{act} * P_t^{act})^{\frac{1}{2}} \quad (6)$$

To construct the Laspeyres Indexes and the Paasche Indexes, it is needed to use the following formulas:

$$L_t^{eff} = \frac{\sum_i e_{it} s_{i0}}{\sum_i e_{i0} s_{i0}}, \qquad P_t^{eff} = \frac{\sum_i e_{it} s_{it}}{\sum_i e_{i0} s_{it}}$$
$$L_t^{act} = \frac{\sum_i e_{i0} s_{it}}{\sum_i e_{i0} s_{i0}}, \qquad P_t^{act} = \frac{\sum_i e_{it} s_{it}}{\sum_i e_{it} s_{i0}}, \quad (7)$$

where e_{it} represents sector-specific energy efficiency, while s_{it} denotes sectoral activity.

Genişletilmiş Özet

İktisadi büyüme teorisinde sermaye ve emek üretimin iki ana faktörü olarak ele alınmaktadır. Bir ekonomide sermaye ve emek artışının çıktı düzeyini olumlu yönde etkilediği literatürde yaygın olarak kabul edilmektedir. İktisat yazınındaki gelişmelere paralel olarak, üretim fonksiyonu, Solow (1974) ve Stiglitz'in (1974) çalışmalarının da katkısıyla birlikte doğal kaynaklarla genişletilmiştir. Yani artık sadece sermaye ve emek değil, enerji kaynakları da bir üretim faktörü olarak iktisat teorisinde kullanılmaktadır.

Enerji kaynaklarının ülkelerin ekonomik büyüme performansları üzerindeki anlamlı etkileri olduğunun farkına varılmasıyla birlikte enerji üretim fonksiyonu içerisine dahil edilmiştir. Özellikle enerji kaynaklarının hem gelişmiş hem de gelişmekte olan ülkeler için önemi 20. yüzyılın ikinci yarısından itibaren önemli ölçüde artmıştır. Bu noktada 20. yüzyılda meydana gelen enerji arz şokları neticesinde artan enerji fiyatlarının global ekonomik daralmaları derinleştirici etki yapması oldukça çarpıcı bir örnektir.

Enerji tüketimi verileri incelendiğinde, özellikle 2000 yılından bu yana, küresel birincil enerji tüketiminin önemli bir artış eğiliminde olduğu görüşmektedir. Enerji tüketimi 2000 yılına göre %40'tan fazla bir artış göstererek 2020'de 557,10 exajoule seviyelerine ulaşmıştır. Gelişmekte olan ekonomiler birincil enerji kaynaklarının tüketimini hızlı bir oranda artırsalar da gelişmiş ülkelerin küresel enerji tüketimindeki payı hala önemini korumaya devam etmektedir. Bu ülkeler arasında sayılabilecek olan G7 ülkeleri, dünyanın birincil enerji talebinin yaklaşık üçte birini karşılamaktadır (British Petroleum, 2021).

Tüm kıt kaynaklarda olduğu gibi birçok sektörde de enerji kaynaklarına olan talebin artması, enerji fiyatlarının yükselmesine ve firmaların üretim maliyetlerinin artmasına neden olmuş, aynı zamanda enerji güvenliği konusunda da endişeler yaratmıştır. Enerji kullanımındaki devam eden bu artış, aynı zamanda çevresel sorunları daha da kötüleştirmiş ve ülkeleri sürdürülebilir ekonomik büyümeye odaklanmaya sevk etmiştir (Apergis vd., 2015). Bu gelişmeler enerji verimliliği kavramının son zamanlarda önem kazanmasına neden olmuştur.

Enerji verimliliği kabaca mevcut enerji kaynaklarının daha etkin ve verimli kullanılması olarak ifade edilmektedir (Akram vd., 2021). Bununla birlikte, enerji arzını daha güvenli bir hale getirmek ve gelişmiş ekonomiler için sürdürülebilir ekonomik büyüme sağlamak için büyük bir öneme sahiptir (Bayar & Gavriletea, 2019). Enerji verimliliğinin en önemli faydası olarak, daha az miktarda enerji kullanımıyla aynı düzeyde çıktı miktarına ulaşılabilmesi sayılabilmektedir. Enerji verimliliğinin artması aynı zamanda ülkelerin enerji ithalatı faturasını düşürür, enerji güvenliğini sağlamaya yardımcı olur, firmaların üretim maliyetlerini düşürür ve çevresel tehditleri azaltır (Linares & Labandeira, 2010). Bu sebeplerle, enerji verimliliğinin ekonomik büyüme üzerindeki etkisi son yıllarda ampirik literatürde sıklıkla araştırılmaya başlanmıştır.

Enerji verimliliğinde meydana gelen artışların enerji tüketimini azaltarak çevre kirliliğini azaltması beklentisi genel görüş iken 'rebound' etkisinden kaynaklı aksi görüşler de mevcuttur. Bu görüşü savunanlara göre enerji verimliliği nedeniyle düşen enerji talebi neticesinde azalan enerji fiyatları enerji tüketiminin ve çevre kirliliğinin artmasına neden olabilecektir. Ancak, enerji verimliliğine yönelik atılacak adımların enerji-tutucu politikalar ile desteklenmesi enerji tüketiminin artmasının önüne geçebilecektir.

Bu bağlamda, bu çalışma G7 ülkeleri için 1971-2018 yılları arasında enerji verimliliği endeksinin (EEI) ekonomik büyüme üzerindeki etkisini araştırmayı amaçlamaktadır. Çalışmada kullanılacak enerji verimliliği endeksini hesaplamak için Fisher İdeal indeks ayrıştırma yöntemi kullanılmıştır. Çalışmanın literatüre katkısı şu şekilde özetlenebilir: İlk olarak, neredeyse tüm ampirik makaleler, gelişmekte olan ülkeler için enerji verimliliğinin ekonomik büyüme üzerindeki etkisini incelemiştir. Ancak bu çalışma daha çok gelişmiş ülkelere yani G7 ülkelerine odaklanmaktadır. İkinci olarak, bu çalışma, enerji verimli teknolojilerdeki ilerlemeyi enerji yoğunluğundan ayrıştırmak için bir enerji verimliliği endeksi oluşturmuştur. Literatürde enerji verimliliğinin bir göstergesi olarak sıklıkla enerji yoğunluğu kullanılmaktadır fakat bu değişkenin kullanılması araştırmacıların yanlış çıkarımlar yapmasına sebep olabilmektedir çünkü enerji yoğunluğundaki değişimlerin enerji verimliliğindeki artıştan mı yoksa ekonomideki sektörel değişimden mi kaynaklandığı tam olarak ayrıştırılamamaktadır. Bu çalışmada oluşturulacak olan enerji verimliliği endeksi ise yapılacak analizlerin daha doğru sonuçlar vermesini sağlayacaktır. Son olarak, bu çalışmada yatay kesit bağımlılığını dikkate alan ikinci nesil panel veri teknikleri kullanıldığı için ampirik sonuçların daha güvenilir olacağı düşünülmektedir.

Literatürde enerji verimliliği ve ekonomik aktivite ilişkisinin analiz edildiği çalışmalarda genel olarak enerji yoğunluğu endeksi bir enerji verimliliği ölçüsü olarak kullanılmıştır. Aynı zamanda literatürdeki söz konusu çalışmalar çoğunlukla gelişmekte olan ülkelere odaklanmaktadır. Literatürde yer alan çalışmalarda da eşbütünleşme analizleri ve çeşitli panel veri tekniklerine dayalı katsayı tahminleri ve regresyon modelleri ampirik araçlar olarak kullanılmıştır. Bu bağlamda bu çalışma enerji verimliliği-ekonomik aktivite ilişkisi literatürüne hem örneklem ülke grubu hem de enerji verimliliğinin ayrıştırılabilmesine imkân veren enerji verimliliği endeksi kullanarak katkıda bulunmaktadır.

Bu çalışmada, yukarıda bahsedildiği gibi enerji verimliliği endeksinin ekonomik büyüme üzerindeki etkisi araştırılmıştır. Buna ek olarak, ekonomik büyüme modelinde kontrol değişkenleri olarak sermaye ve emek kullanılmıştır. Ampirik analiz için kişi başına düşen yıllık GSYİH (2010$), brüt sabit sermaye oluşumu (2010$) ve 15-64 yaş arası nüfus verileri kullanılmıştır. Bu seriler, Dünya Bankası'nın veri setinden elde edilmiştir. Ayrıca, enerji verimliliği indeksi, Fisher İdeal indeks ayrıştırması ile hesaplanmıştır.

Metodolojik olarak çalışmada Westerlund ve Edgerton (2007) tarafından literatüre kazandırılan LM bootstrap panel eşbütünleşme testinden ve Eberhardt ve Teal (2010) tarafından geliştirilen AMG tahmincisinden yararlanılmıştır. Bu iki yöntem de panel veri ekonometrisinde önemli bir yere sahip olan yatay kesit bağımlılığı sorununu dikkate almaktadır. Buna ek olarak, hata düzeltme modelini tahmin etmek için ise Yatay-Kesitle Genişletilmiş Hata Düzeltme (CS-ECM) yaklaşımından faydalanılmıştır. Çalışmada yatay kesit bağımlılığını dikkate alan yöntemlerin kullanılması özellikle küreselleşen dünyada özellikle benzer ekonomik büyüklükteki ülkelerin herhangi birinde meydana gelen bir şokun etkisinin diğer ülkelere de yayılması temel varsayımına dayanmaktadır. Çalışmada kullanılan uzun dönem katsayı tahmincileri ile ise değişkenler arasındaki uzun dönemli ilişkinin yönü ve parametresi elde edilerek bu parametreler çeşitli çıkarımlar yapılabilmesi imkânı vermektedir.

Çalışmanın ampirik sonuçlarına göre, öncelikle tüm değişkenler için istatistiksel olarak anlamlı yatay kesit bağımlılığı bulunduğu anlaşılmıştır. Böylelikle ampirik analizin ilerleyen bölümlerinde yatay kesit bağımlılığını dikkate alan eşbütünleşme analizi yapılabilecektir. Sonrasında değişkenlerin durağanlık analizleri yapılmış ve kullanılan durağanlık testlerinin sonuçlarına göre modelde yer alan değişkenlerin tamamının birinci farkında durağan oldukları anlaşılmıştır. Eşbütünleşme ilişkisinin test edilmesi neticesinde ise bahsi geçen değişkenler arasında uzun dönemli bir ilişkinin olduğu tespit edilmiştir.

Modelde yer alan değişkenlerden sermaye oluşumunun ekonomik büyüme üzerindeki etkisi bütün ülkeler için pozitifken, emeğin etkisinin ise ülke bazında farklılıklar gösterdiği görülmüştür. Emek değişkeninin katsayısı bazı ülkelerde istatistiksel olarak anlamlı ve ngatif iken bazı ülkelerde ise pozitiftir. Diğer taraftan, enerji verimliliğinin ekonomik büyüme üzerindeki etkisi irdelendiğinde ise enerji verimliliğindeki iyileşmelerin ekonomik büyümeyi G7'deki yedi ülkeden beşinde olumlu yönde etkilediği tespit edilmiştir.

Modelin karşılaştığı şoklar neticesinde oluşan hataların ne kadarlık bir sürede dengeye geleceğini gösteren hata düzeltme yaklaşımı sonuçlarına göre ise uyumlama katsayısı -0.502 olarak tahmin edilmiştir. Bu, kişi başına ekonomik büyüme, sermaye, emek ve enerji verimliliği endeksi arasındaki uzun dönemli dengedeki bir sapmanın yaklaşık iki yılda dengeye geleceği anlamına gelmektedir. Diğer bir deyişle, şoklardaki dengesizliğin yaklaşık %50,2'si bir sonraki yıl içinde düzelmektedir. Ayrıca G7 ülkeleri için kısa dönemde sadece sermaye stokunun ekonomik büyüme üzerinde pozitif ve istatistiksel olarak anlamlı bir etkiye sahip olduğu tespit edilmiştir. Bununla birlikte, CS-ECM'nin uzun dönemli tahmin sonuçlarının, AMG tahmincisine göre elde edilen sonuçlarla özellikle uzun dönem katsayısı sonuçları bakımından benzerlikler göstermektedir. Bu yöntemin uzun dönem sonuçlarına göre gelişmiş ülke örnekleminde ve incelenen dönemde sermaye stoku ve enerji verimliliği ekonomik büyümeye katkısı istatistiksel olarak anlamlı bir şekilde desteklemektedir.

Çalışmadan elde edilen sonuçlar politika yapıcılar için birtakım öneriler sunmaktadır. Öncelikle iki değişken arasında uzun dönemli eşbütünleşme ilişkisinin varlığı enerji verimliliğine yönelik herhangi bir politika değişikliği vasıtasıyla ekonomik aktivitenin etkilenebileceğini ortaya koymaktadır. Bu bağlamda enerji tasarrufu sağlayan teknolojilerin teşvik edilmesi gerekmektedir. Özellikle firmaların enerji verimliliği konusunda farkındalığın arttıracak teşviklerin verilmesi, hanelerin enerji kullanımında gerekli özeni göstermesi için gerekli adımların atılması bu politika önerilerinin başını çekebilir. Diğer taraftan sürdürülebilir bir ekonomik büyüme için enerji verimliliğinin öneminin de farkında olunmalıdır. Bu amaçla enerji ile ilgili araştırma ve geliştirme projeleri desteklenmeli ve hükümetler tarafından ilgili firmalara gerekli sübvansiyonlar verilmelidir.