RESEARCH ARTICLE

https://doi.org/10.17059/ekon.reg.2023-2-20
UDC 330.35 + 330.354
JEL Codes: F43, O13, O47, R11, Q43

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WHICH HYPOTHESIS IS VALID FOR OECD COUNTRIES IN THE CONTEXT OF THE RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND ECONOMIC GROWTH? A PANEL DATA ANALYSIS[1]

Abstract. In the study, panel data analysis was conducted on 32 OECD countries covering the period 1990-2018. To analyse the effect of energy consumption on economic growth, first, a cross-section dependence test of the variables was carried out, then CADF Test, which is the most suitable unit root test based on the obtained results results, was applied. According to the findings of the Hausman, autocorrelation, and heteroscedasticity tests, it has been decided to use the Driscoll-Kraay test for the model's forecast. The forecast results demonstrate that energy consumption positively affects economic growth. Westerlund ECM Panel Cointegration Test was conducted to determine the long-term relationship, and it concluded that the variables acted together in the long term. Emirmahmutoglu & Kose and Dumitrescu & Hurlin tests were used to determine the direction of the relationship between energy consumption and growth. Through the results of both tests, a maximum number of countries emerged respectively in the null hypothesis with no causality relationship and then in the growth hypothesis explaining the causality relationship from energy to growth. Along with the panel fisher and panel Z_NT test results of both causality tests, a causality relationship has been detected from energy to growth.

Keywords: OECD countries, energy, energy consumption, energy policies, energy and growth relationship hypotheses, economic growth, economic policies, panel data analysis, panel causality test, CADF test

For citation: Sugözü, İ. H. & Yaşar, S. (2023). Which Hypothesis is Valid for OECD Countries in the Context of the Relationship between Energy Consumption and Economic Growth? A Panel Data Analysis. *Ekonomika regiona / Economy of regions, 19(2)*, 560-574. https://doi.org/10.17059/ekon.reg.2023-2-20

ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ

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Взаимосвязь между энергопотреблением и экономическим ростом в странах ОЭСР: анализ панельных данных

Аннотация. В данном исследовании проведен анализ панельных данных по 32 странам Организации экономического сотрудничества и развития (ОЭСР) за 1990-2018 гг. Для оценки влияния энергопотребления на экономический рост сначала была оценена кросс-зависимость переменных, затем применен расширенный тест Дики — Фуллера (CADF) — наиболее подходящий тест на единичный корень. По результатам теста Хаусмана, а также тестов на автокорреляцию и гетероскедастичность было принято решение использовать тест Дрисколла — Крэя для прогноза модели. Результаты прогноза показывают, что энергопотребление положительно влияет на экономический рост. Тест Вестерлунда на коинтеграцию продемонстрировал взаимосвязь между исследуемыми переменными в долгосрочной перспективе. Направление зависимости между энергопотреблением и экономическим ростом было определено при помощи тестов Эмирмахмутоглу — Косе и Думитреску — Хурлина. Согласно полученным данным, для большинства стран подтвердилась нулевая гипотеза (отсутствие причинно-следственной связи); при этом, для отдельных государств верной является гипотеза роста (энергопотребление влияет на экономический рост).

Ключевые слова: страны ОЭСР, энергия, энергопотребление, энергетическая политика, гипотезы взаимосвязи экономического роста и энергопотребления, экономический рост, экономическая политика, анализ панельных данных, причинность панельных данных, CADF-тест

Для цитирования: Сугёзю И. Х, Яшар С. (2023). Исследование гипотез взаимосвязи между энергопотреблением и экономическим ростом в странах ОЭСР: анализ панельных данных. *Экономика региона, 19(2)*, С. 560-574. https://doi.org/10.17059/ekon.reg.2023-2-20

Introduction

The concept of energy has begun to significantly impact society and the economy with the industrial revolution. The introduction of the steam engine then the rapid growth of countries after World War II also increased the energy demand. The day-to-day decline of traditional energy resources has led to concerns, especially in developed countries that are energy importers. The first steps of the European Union have also been taken within the framework of energy policies. And in the 1970s, as a result of successive oil crises, it was once again understood how important energy is as a source for economic growth. With the development of technology and the transformation of industries, as a result, developments and changes have begun in the issues of energy type, quality, and density. Problems such as the exhaustion of energy resources, environmental pollution, and outward dependence have accelerated these developments. Countries were not indifferent to these developments while shaping their economic policies because the shocks and crises in energy sources along with structural transformations have forced financial decision-makers to make new decisions about economic solutions.

These developments related to energy have accelerated the work on the relationship between energy and economic growth in terms of economic science. Especially after the increases in oil prices in 1973–1974 and 1978–1979, the energy issue has attracted the attention of all countries around the world, and studies on the relationship between energy consumption and economic growth have increased (Reddy, 1998; Saidi & Hammami, 2014). Previously, scientific studies focusing on the relationship between economic growth and energy have been related to how it will take part in its growth function. In this regard, theories with increasing density in economic thinking have been revealed. The majority of recent studies on the relationship between energy consumption and economic growth have focused on causality analysis.

Therefore, the part related to the determination of the effect of energy on growth, as well as the shape and degree of this effect has been partially neglected. It should be stated that one of the aims of the present study is to eliminate this deficiency. Based on the growth hypothesis that occurs mainly in this study and as a result of recent causality analyses, panel regression analysis that reveals the shape and degree of the relationship and panel cointegration test indicating the long-term relationship were conducted.

For this purpose, firstly unit root tests were performed for variables whose cross-section dependence was detected, and the variables were found to be static in the first difference. Driscoll-Kraay regression analysis selected according to the results of autocorrelation and heteroscedasticity showed that the shape of the relationship between energy and growth is positive and significant. However, panel cointegration tests showed that variables had a significant relationship with each other in the long term and move together. The theoretical framework was briefly explained below and then econometric analyses were performed along with methodology and findings.

The Organisation for Economic Cooperation and Development (OECD) countries were chosen as the region in the study. The most important reason for this is that OECD countries have approximately 60 % of the world gross domestic product (GDP) and 40 % of their energy consumption. Most OECD countries are developed countries. Other countries are industrialised countries that are on the way to entering the group of developed countries. With 36 member countries as of 2018, the OECD covers a large part of the world, from North and South America to Europe and Asia-Pacific. Therefore, this study aims to reveal a significant result both regionally and globally.

Theoretical Framework: Energy Consumption and Growth Relationship

Before the relationship between growth and causality, different views were put forward on whether energy was a production factor in the economy and therefore whether it was the main source of growth. Neoclassical Economics theory has constructed production on capital, labour, and technology factors. According to it, the technology consists of an accumulation of knowledge. The energy was mostly considered intermediate input and excluded from production factors. The point of origin for this idea is the Solow Growth Theory, which accepts technology externally. Accordingly, those who determine economic growth while in a stable state are technological change and population growth that participate externally in the model.

The biophysical approach related to the effect of energy on economic growth takes attention. This approach considers energy to be the basic input. Ecological economists also consider energy as the primary input in growth departing from biophysical aspects (Cetin & Seker, 2012). Although energy input was later added into the Solow model, it was not enough to eliminate criticism of neo-classical theory's approach to technology and indirectly to energy.

The endogenous growth theory was developed in response to neoclassical exogenous growth theories. One of the most important reasons for this is the acceptance of technology as external and constant in the neo-classical model. In endogenous growth theory, technology, capital, and labour are intrinsic factors in the production function. Accordingly, technology is considered an intrinsic factor that includes energy. The usefulness of most technological innovation is seen to be bounded to the efficient use of energy and it is stated that technology cannot function practically without adequate energy supply. Energy is not the only determinant for technology, but it is seen as a necessary factor for developing technology.

The causality relations between energy consumption and growth take as much attention as factor discussions and have become the focus of scientific studies, especially recently. Some economists who examined the energy growth relationship saw energy as a critical entry of economic growth, while others suggested that energy consumption was increasing depending on growth. These thoughts have led to the emergence of new energy-related hypotheses. According to the results of the studies in the literature review below, hypotheses concerning the causality relationship between energy consumption and economic growth are collected in four groups:

a. The Growth Hypothesis shows a situation in which there is a one-way causality from energy consumption and growth. In this case, energy consumption is the cause of economic growth, and economic growth is not the cause of energy consumption. Therefore, where the growth hypothesis applies, economic decision-makers are expected to focus on policies aimed at increasing energy consumption to sustain economic growth.

b. The Consumption/Protection Hypothesis shows that the direction of causality is from economic growth to consumption. A situation opposite of the growth hypothesis is the case. When the growth hypothesis or feedback hypothesis applies, conservation policies will negatively affect economic growth. Energy consumption should be controlled if the consumption/protection hypothesis is valid, and therefore it will be expected to choose protectionist policies (protection savings, indirect taxes, price policies, etc.).

c. The Feedback Hypothesis shows the situation in which there is a two-way causality between energy consumption and economic growth. In this case, energy consumption and economic growth are the reason for each other. In economies where the feedback hypothesis applies, protection policies, environmental policies and policies to reduce energy intensity are on the agenda as economic growth brings with it an increase in energy consumption while energy consumption is needed for economic growth.

d. The Unbiasedness / Neutral Hypothesis means that there is no causality relationship between energy consumption and economic growth. In this case, there is no significant relationship between the two variables. Since there is no significant relationship between the two variables in the Unbiasedness/Neutral Hypothesis, decisions on energy consumption in economic policies will not affect economic growth. However, the neutral relationship can also occur as a result of energy consumption causing economic growth, while on the other hand, it has an adverse effect on growth due to external dependence on energy and the inability of energy production to meet consumption. In this case, energy policies will need to be handled sectoral and created more precisely.

Literature Review

In the studies examining the relationship between energy consumption and economic growth, generally, the impact of energy consumption on economic growth was examined and it was concluded that a positive relationship occurred. Lee (2005) conducted panel cointegration analysis between the relevant variables for 18 developing countries from 1975 to 2001, while Mehrara (2007) conducted panel cointegration analysis among the relevant variables for 11 selected oil-exporting countries and found a positive-directional relationship between variables, as in the previous study. In the same way, Korkmaz and Yilgor (2011) conducted a cointegration analysis by applying CADF and CIPS tests with annual data for the period of 1980–2004 for 26 countries and achieved a result in the same direction as previous studies.

Adhikari and Chen (2012) who achieved a positive relationship result, analysed the relationship with long-term cointegration analysis for a total of 80 countries divided into three groups: upper middle income, low middle income, and low-income countries. Streimikiene and Kasperowicz (2016) conducted cointegration analysis, including fixed capital investments and total employment data, in addition to the relevant variables, to examine the relationship for 18 European Union member states from 1995 to 2012. Bozkurt and Yanardag (2017) examined the relationship between energy consumption and economic growth with data from 19 developing countries from 1971 to 2011, and Bozma et al. (2018) examined BRICS (Brazil, Russia, India, China, and South Africa) and MINT (Mexico, Indonesia, Nigeria, and Turkey) countries by conducting Westerlund Cointegration analysis with data from 1990 to 2014. Tunali and Ulubas (2017) examined the 1970–2015 period data for G7 countries by using the least-squares method, as well as LR, LM, Score F tests, which are panel regression models.

Gozgor et al. (2018) examined the relationship between both renewable and non-renewable energy consumption and economic growth with data from 1990–2013 for 29 OECD countries with panel ARDL and PQR approach. In each of these studies mentioned, a result indicating a long-term positive relationship between energy consumption and economic growth has been obtained.

In the results of the analyses carried out for different countries, a positive relationship is dominating. In the studies carried out for Turkey, Soytas et al. (2001), Agir and Kar (2010), Bayrac and Dogan (2015), Arac and Hasanov (2014) and Aydin (2010) found a positive relationship between variables. Mucuk and Sugozu (2011) also examined the impact of sectoral energy consumption on economic growth in their work on the Turkish economy and concluded that energy consumption in the agricultural and industrial sectors positively affected economic growth. Ngoc (2019) and Nguyen and Ngoc (2020) have also revealed a positive relationship between economic growth and energy consumption in their work on the Vietnamese economy.

There are also studies in the literature that reveal the existence of a negative or inverse U relationship, as well as a positive relationship between energy consumption and economic growth or stating that there is no relationship between the relevant variables. Narayan and Popp (2012), in their study of 93 countries, both nationally and regionally, found that there were significant differences in the results of the effect of energy consumption on real GDP. According to country-level results, greater evidence was found to support that energy consumption has a negative causal effect on real GDP. Regionally, they found that the impact sign was positive for Asia, Africa, and the world (even if the point estimates were all zero or close to zero) and negative for the G7 (except for Germany). Karagol et al. (2007) applied the Pesaran border test and ARDL analysis in their study, which examined the relationship between electricity consumption and economic growth for Turkey during the 1974–2014 period. As a result of their studies, they found a positive relationship between variables in the short term, but in the long term, there was a negative-directional relationship. Lee and Chang (2007) applied the Threshold Regression Model with data from the 1955–2003 period for Taiwan, resulting in an inverse U relationship between economic growth and energy consumption.

Yalta (2011), on the other hand, conducted a cointegration analysis to examine the long-term relationship between the relevant variables for the Turkish economy from 1950 to 2006 and found no relationship between energy consumption and GDP.

The literature review for causality relationship is explained according to the hypotheses put forward based on the direction of the causality relationship between energy consumption and economic growth. In the first study in this sense by Kraft and Kraft (1978) and the study by Abosedra and Baghestani (1989) for the U.S. economy, the study by Zamani (2007) for the Iranian economy with data from 1967 to 2003, in the study by Bartleet and Gounder (2010) for New Zealand from 1960 to 2004, and in the study by Guvenek and Alptekin (2010) for 25 OECD countries from 1980 to 2005, a one-way causality relationship from economic growth to energy consumption was found, and it was concluded that the consumption hypothesis applies.

As a result of the causality analyses done by Stern (1993) for the U.S. economy with data for 1947–1990, by Hondroyiannis et al. (2002) for the Greek economy in 1960–1996, by Mucuk and Uysal (2009) for the economy of Turkey, by Odhiambo (2009) with data from 1971–2006 for Tanzania, a one-way causality relationship from energy consumption to economic growth was identified and results that supported the growth hypothesis were obtained.

Having investigated the relationship between the aforementioned variables, numerous studies, including Glasure and Lee (1998) for Singapore and South Korea, Erdal et al. (2008) for Turkey in 1970–2006, Kar and Kinik (2008) for the Turkish economy from 1975–2005, Belloumi (2009) for the Tunisian economy in the period 1971–2004, Balli et al. (2018) for 12 countries in the Commonwealth of Independent States with data from 1993–2012, have reached conclusions that support the feedback hypothesis in which the two-way causality applies.

As for studies done by Yu and Hwang (1984) for 1947–1979 U.S. economy, by Cetintas and Sarikaya (2015) for England and U.S. economies in 1960–2014, Jobert and Karanfil (2007) moving from 1960–2003 period data for the Turkish economy, the results supporting the unbiasedness hypothesis indicating that there is no causal relationship between the variables have been found. The analysis results using heterogeneous tests show which hypotheses apply in which country.

In their work for Canada, Germany, Italy, England, France, and Japan for the period 1952–1982, Erol and Yu (1987) found that the growth hypothesis was valid in Canada, the consumption hypothesis in Germany and Italy, the feedback hypothesis in Japan, and the wrongness hypothesis in the UK and France. After examining the period 1955–1990 in India, Taiwan, South Korea, Indonesia, Malaysia, Philippines, Singapore and Pakistan, Masih and Masih (1996) found that the feedback hypothesis is valid in Pakistan, Taiwan and South Korea, the growth hypothesis in India, the consumption hypothesis in Indonesia and the wrongness hypothesis in Singapore and Malaysia. In their study for 18 European Union countries from 1990 to 2018, Yasar and Sugozu (2019) found that the growth hypothesis is valid in Austria, Belgium, Southern Cyprus and Slovakia, the feedback hypothesis in Spain, and the wrongness hypothesis in other EU countries. In addition to all these direct effects, there are also studies on the existence of an effect from growth to energy intensity (Tsybatov, 2020). Energy intensity is defined as the amount of energy used to produce a unit level of output.

Data Set and Model

In 32 OECD countries, including Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and lastly the U.S., panel data analysis was conducted using data including energy consumption, GDP as control variables, gross fixed capital investments to examine the relationship between energy consumption and economic growth.

Data from the four OECD member states were not included in the analysis since some of their observation data could not be accessed. The variables used in the model are as follows: Gross domestic product (ln*GDP*), energy consumption (ln*EC*), gross fixed capital formation (ln*GFCF*). Energy consumption dataset was obtained from BP Statistical Review of World Energy and the others are employed from World Development Indicators (World Bank).

The model used in the study is below.

Model 1:

$$lnGDP_t = \beta_1 \ln EC_t + \beta_2 \ln GFCF_t \quad (1)$$

In this study, which examined the relationship between energy consumption and economic growth, annual data for the period 1990–2018 were used.

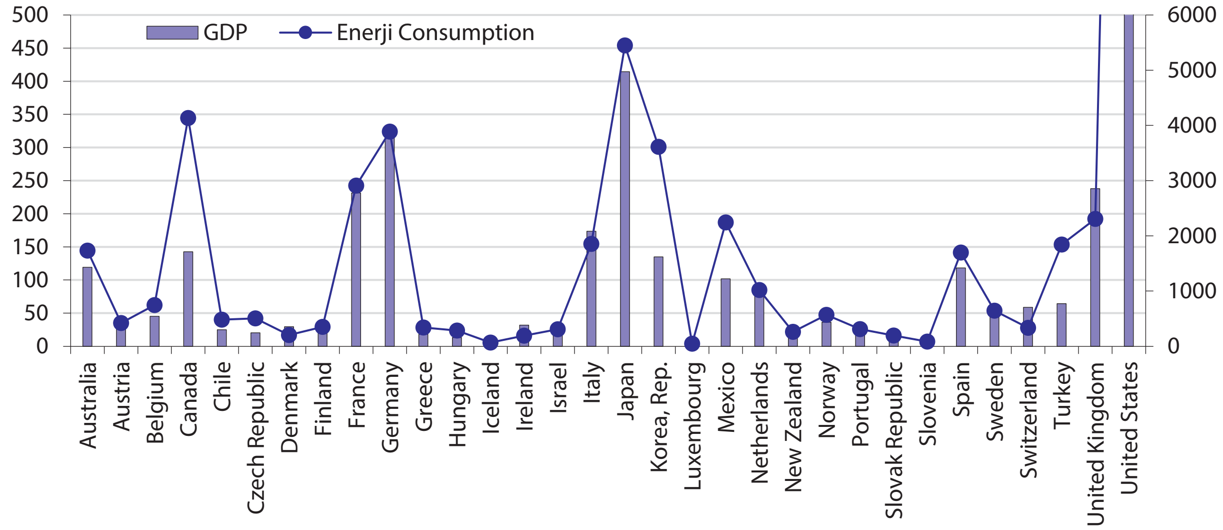

Fig. *GDP (billion \$) and Energy Consumption (Million tonnes of oil equivalent) in OECD countries (2018) (Note: GDP is 20600 and Energy Consumption is 2300 for United States. Source: BP Statistical Review of World Energy 2019)*

Methodology

In the study, firstly, the cross-section dependencies of the variables and the model were tested. Then, the CADF unit root test, which is one of the second-generation unit roots tests accounting for cross-section dependence, was applied. Later, respectively, Hausman Test, autocorrelation, and fixed variance tests were performed. The Driscoll-Kraay test, which is used in the case of cross-section dependence between variables and offers predictors resistant to autocorrelation and heteroskedasticity problems, was applied. Finally, Westerlund ECM Panel Cointegration analysis was performed to test the existence of a long-term relationship between variables.

The cross-section dependence test is a test that needs to be done to determine whether an economic shock in one country has an impact on other countries that have been examined. There are many tests used for this purpose. CD testing developed by Pesaran (2004) that can be used in $T > N$ and $T < N$ conditions is the most preferred cross-section dependence test for this purpose and is expressed as follows (Pesaran et al., 2008):

$$CD_{LM3} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}\right). \quad (2)$$

The hypotheses of the test in question are as follows:

H_0 = There is no cross-section dependence.
H_1 = There is cross-section dependence.

Second generation panel unit root tests are used in the event of cross-section dependence of the variables. Due to the cross-section dependence resulting from the tests carried out in this study, CADF (Cross-sectional Augmented Dickey-Fuller) unit root test, one of the second-generation unit root tests developed by Pesaran (2006) was used.

The aforementioned test is valid in both cases: $T > N$ and $N > T$. CADF test statistic is as follows (Pesaran, 2007):

$$y_{it} = (1-\varphi_i)\mu_i + \varphi_i y_{i,t-1} + u_{it}, \quad (3)$$

$i = 1, \ldots, N$ and $t = 1, \ldots, T$,

$$u_{it} = y_i f_t + \varepsilon_{it}, \quad (4)$$

f_t = Unobservable common effect, ε_{it} = Individual error.

Unit root test hypotheses are as follows:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + y_i f_t + \varepsilon_{it}. \quad (5)$$

$H_0 : \beta_i = 0$ (not fixed) for all i's.
$H_1 : \beta_i < 0, i = 1, 2, \ldots, N_1, \beta_i = 0, i = N_1 + 1, N_1 + 2, \ldots, N$ (fixed).

A statistic called *CIPS* (*Cross-Sectionally Augmented IPS*) was obtained by taking the average of the unit-roots of all countries corresponding to each of the cross sections in the panel data analysis.

CIPS statistics constitute a general unit root statistic for the panel and are expressed as follows (Pesaran, 2007):

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i. \quad (6)$$

In panel data analysis, Hausman testing is performed to determine whether the model is a fixed effects model or a random effects model. The aforementioned test is dependent on the Chi-square distribution with k degrees of freedom. It also examines whether there is a correlation between the effects caused by the units and the independent variables contained in the model (Baltagi, 2001). In the Hausman test, it has been stated that the coefficients derived from the H_0 hypothesis fixed effects model and those derived from the model of random effects are identical. In this case, the rejection of the H_0 hypothesis means that the fixed effects model is valid.

The hypotheses of the Hausman Test are as follows:

H_0: The difference between coefficients is not systematic (Random Effects Model).

H_1: The difference between coefficients is systematic (Fixed Effects Model).

Since it is very important to determine whether the model has a heteroskedasticity problem in terms of econometric analysis, the modified Wald test was applied to determine the existence of the problem. The hypotheses of the test in question are as follows:

H_0: There is homoskedasticity.

H_1: There is no homoskedasticity.

To determine whether the model created in the study was in accordance with the assumptions in the econometric sense, the Durbin-Watson autocorrelation test by Bhargava, Franzini and Narendranathan (Bhargava et al., 1982), and the LBI test developed by Baltagi and Wu (1999) were applied. In these tests, the probability values are not calculated and if the results of the test statistics are less than 2, it is evaluated that there is autocorrelation in the model.

The existence of a long-term relationship between the variables involved, along with the shape and strength of the relationship between energy consumption and economic growth, is also very important. For this reason, cointegration analysis was carried out to examine the existence of a long-term relationship between these variables. However, it is very important to determine the type of cointegration analysis to be applied. In this respect, the unit root test and cross-section dependence test results are guiding. As a result of the related tests, the Westerlund Bootstrap Panel Cointegration test was conducted, which was developed by Westerlund (2007), assuming that the first differences of the series were fixed and that the group and panel statistics were discussed separately. The model created for this test is as follows (Westerlund, 2007):

$$\Delta y_{it} = \delta_i d_t + \lambda_i x_{it-1} + \sum_{j=1}^{P_i} \alpha_{ij} \Delta y_{it-j} + \sum_{j=0}^{P_i} \lambda_{ij} \Delta x_{it-j} + e_t, \quad (7)$$

$$y_{it-1} = \delta_i d_t + \lambda_i x_{it-1} + \sum_{j=1}^{P_i} \alpha_{ij} \Delta y_{it-j} + \sum_{j=0}^{P_i} \lambda_{ij} \Delta x_{it-j} + \varepsilon_t. \quad (8)$$

Later, the error correction coefficient for the entire panel model and the standard error of this coefficient are also included in the calculation (Westerlund, 2007):

$$\alpha_i = \left(\sum_{i=1}^{N} \sum_{t=2}^{T} \tilde{y}_{it-1}^2 \right)^{-1} \sum_{i=1}^{N} \sum_{t=2}^{T} \frac{1}{\alpha_i(1)} \tilde{y}_{it-1} \Delta \tilde{y}_{it}, \quad (9)$$

$$SE(\alpha_I) = \left(\left(\hat{S}_N^2 \right) \sum_{i=1}^{N} \sum_{t=2}^{T} \tilde{y}_{it-1}^2 \right)^{-1/2}. \quad (10)$$

Finally, panel statistics are calculated. The calculation equation in question is as follows:

$$P_t = \frac{\alpha}{se(\alpha)} \sim N(0,1) P_a = T_\alpha \sim N(0,1). \quad (11)$$

The hypotheses of panel cointegration statistics are created as follows:

$H_0 : \alpha_i = 0$;

$H_1 : \alpha_i = \alpha < 0$; there is cointegration for all cross-sections.

The panel cointegration test developed by Westerlund (2007) assumes that there is no cross-section dependence. However, in the case of cross-section dependence, Westerlund stated that calculated cointegration statistics should be compared to the bootstrap critical values recommended by Chang (2004) (Nazlioglu, 2010).

However, in the case of cross-section dependence, Westerlund stated that calculated cointegration statistics should be compared to the bootstrap critical values recommended by Chang (2004) (Nazlioglu, 2010). Emirmahmutoglu & Kose (2011) and Dumitrescu & Hurlin (2012) tests were conducted from panel causality analyses to measure the validity of theories about the relationship between energy consumption and economic growth. These two analyses are among causality analyses that take into account cross-section dependence and can provide results for each country within the scope of the model as well as general results of the model.

The Emirmahmutoglu & Kose test is the form of the Toda-Yamamoto test transformed into heterogeneous panel data, which addresses the causality relationship between variables in the time series with the Meta-Analysis approach proposed by Fisher (1932). Meta-analysis is a test that aims to achieve one common result by combining multiple study results that test the same hypothesis. One of the advantages of the Toda-Yamamoto test is that it does not require preliminary tests that are needed before the Granger causality test and are done to determine the unit roots and cointegration of series. Since it is the expanded form of the relevant test Emirmahmutoglu & Kose causality test does not require preliminary tests (Emirmahmutoglu, 2011).

The VAR model developed by Emirmahmutoglu and Kose (2011) and estimated for each cross-section of the causality test that takes into account cross sectional dependence, is as follows (Emirmahmutoglu & Kose 2011):

$$x_{i,t} = \mu_i^x + \sum_{j=1}^{k_i+d\max_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i+d\max_i} A_{12,ij} y_{i,t-j} + u_{i,t}^x, \quad (12)$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i+d\max_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i+d\max_i} A_{22,ij} y_{i,t-j} + u_{i,t}^y. \quad (13)$$

For each i in the model;

k_i = Lag length.

$d\max_i$ = It means maximum integration of variables in the system.

The hypotheses of the test are as follows (Emirmahmutoglu & Kose 2011):

$H_0 : R_1\alpha_i = 0$ for all i's;

$H_1 : R_1\alpha_i \neq 0, i = 1, \ldots, N_1; R_1\alpha_i = 0, i = N_1 + 1, \ldots, N.$

The causality analysis developed by Dumitrescu and Hurlin (2012) also takes into account the panel's cross-section dependence. T is a test that can be applied when N is cross-section size, both in the case of T-N and if it is N.T. One of the reasons this test is preferred is that it can be applied in these two cases. However, the relevant test first converges to the ordinary standard normal distribution. In addition, a semi asymptotic distribution has been determined for a fixed T instance. The heterogeneous model created for each unit at T time is shown below (Dumitrescu & Hurlin, 2012):

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t}. \quad (14)$$

The hypotheses of the test in question, which indicates that the Granger causality relationship is not in the zero hypothesis and that there is a causality relationship between these variables in the alternative hypothesis, is shown below (Dumitrescu & Hurlin, 2012):

$H_0 : \beta_1 = 0 \ \forall_i = 1, \ldots, N,$

$H_1 : \beta_1 = 0 \ \forall_i = 1, \ldots, N_1,$

$\beta_1 \neq 0 \ \forall_i = N_1 + 1, N_1 + 2, \ldots, N.$

Findings

Table 1 provides the outcomes of tests for cross-section dependence on the variables and the model. Due to the rejection of H_0 hypothesis, there is a cross-section dependence in variables. The results of the analysis show that cross-section dependence exists in both the variables and the model.

Table 2 includes the CADF unit root test results for the model. When the results of the CADF unit root test in which statistical values determined according to the Akaike Information Criterion are examined, it is seen that there is a trend effect in *GDP* and *GFCF* variables, that all variables have a unit root at the level, and that when the first differences are taken, they are fixed.

Table 3 includes the Hausman, homoskedasticity and autocorrelation test results for the model. When the Hausman Test results for the model are examined, it is observed that the H_0 hypothesis is rejected and the H_1 hypothesis is accepted. In this case, the fixed effects model that indicates a systematic difference between coefficients appears to be valid. In the fixed effects regression model applied to detect the heteroskedasticity problem, it

Table 1

Cross-Section Dependence Test Results for the Variables

Variables	ln*GDP*	ln*EC*	ln*GFCF*	Model
Pesaran CD_{LM3}	110.8795	41.77636	91.64691	86.37859
Probability Value	0.0000	0.0000	0.0000	0.0000
Decision	Reject	Reject	Reject	Reject

Cross-Section Dependence Test Results for the Model

Test	Test Statistics	Probability Value	Decision
Pesaran Scaled LM	287.8745	0.0000	Reject

Table 2

CADF Unit Root Test Results for Fixed Effects Model

Variable	Level			1. Difference		
	Lag	Intercept/ Trend	CIPS statistics	Lag	Intercept /Trend	CIPS statistics
ln*GDP*	1	1	–2.561	1	1	–4.358*
ln*EC*	2	0	–2.020	2	0	–4.880*
ln*GFCF*	3	1	–2.178	3	1	–3.611*

Critical values of the individual cross-sectionally augmented Dickey-Fuller distribution averages:

Intercept(0)	%1	%5	%10	Trend(1)	%1	%5	%10
N:32 T:29	–2.30	–2.15	–2.07	N:32 T:29	–2.81	–2.66	–2.58

Statistical values have been determined according to the Akaike Information Criterion.

* symbol indicates that the statistical value is significant at %1 and the variable is fixed.

Table 3

Hausman, Homoskedasticity and Autocorrelation Test Results

Hausman Test Result*		Homoskedasticity Test Result**		Result of the Autocorrelation Test in Fixed Effects Model**	
chi2 (2)	5.46	chi2 (32)	7976.56	Modified Bhargava et al. Durbin-Watson	0.20322221
Prob > chi2	0.0651	Prob > chi2	0.0000	Baltagi-Wu LBI	0.29455486

* (b–B)'[(V_b–V_B)^(–1)](b–B)

** H_0: sigma(i)^2 = sigma^2 for all *i*.

is seen that when the results of the Modified Wald test for group heteroscedasticity are examined, the results are significant, that the H_0 hypothesis is rejected, and accordingly, the H_1 hypothesis that indicates that there is heteroscedasticity is accepted. When Table 3 is examined, which includes the results of the tests carried out in order to determine the presence of the autocorrelation problem in the model, it is seen that the test statistics are less than 2, as a result of autocorrelation in the model.

Table 4 has Driscoll-Kraay test results. According to the Driscoll-Kraay Test results, which examined the regression relationship between energy consumption and economic growth for 32 OECD countries, a 1 % increase in energy consumption has led to a 0.16 % increase in *GDP*. In accordance with the results obtained as a result of the Driscoll-Kraay test, the relevant model can be written as follows:

$$\ln GDP = 1{,}35 + 0{,}16 \ln ENGY + 0{,}91 \ln GFCF. \quad (15)$$

Panel cointegration test results for the model are included in Table 5. Although both bootstrap and asymptomatic values were found in Table, bootstrap values were taken into account due to the detection cross-section dependence in the model.

When the results are evaluated, it is seen that the hypothesis of H_0, which states that there is no cointegration relationship between variables at both intercept and trend, is rejected. In this case, as a result of the model established in the study, energy consumption and economic growth variables move together in the long term, i. e. the result of a long-term relationship between variables.

The results of panel causality analyses are below. Table 6 shows individual statistics and possibilities according to countries that have a representation of heterogeneous panel data results. Table 7 includes the results of panel fisher and panel Z_NT. Finally, based on the results of the analysis, countries are classified in Table 7 as countries that meet the growth, protection, feedback, and unbiasedness hypotheses.

The hypotheses explaining the relationship between energy and growth are analysed with two different causality tests. If a general assessment is made, the unbiasedness hypothesis covers the largest group of countries where two cau-

Table 4

Driscoll-Kraay Standard Errors Regression Test

Method: Fixed Effects Regression						
Probability Value (Prob.) > *F* = 0.0000						
F (2, 31) = 1080.26						
within *R*-squared = 0.9104						
lnGDP	**Coefficient**	**Drisc/Kraay Stand. Error**	***t*-value**	***P* > |*t*|**	**[95% Confidence Interval]**	
ln*EC*	0.160346	0.044516	3.60	0.001	0.069555	0.251137
ln*GFCF*	0.909599	0.023077	39.42	0.000	0.862533	0.956665
_cons	1.352730	0.224219	6.03	0.000	0.895433	1.810027

Table 5

Westerlund Bootstrap Panel-ECM Cointegration Test

	Stat.		asym *p*-val		bootstrap *p*-val	
	intercept	**trend**	**intercept**	**trend**	**intercept**	**trend**
g_tau	–7.296	–7.430	0.000	0.000	0.000	0.063
g_alpha	–2.914	–4.267	0.002	0.000	0.020	0.080
p_tau	–4.676	–5.260	0.000	0.000	0.006	0.176
p_alpha	–3.522	–7.176	0.000	0.000	0.029	0.021

Bootstrap probability values are derived from 1000 repetitive distributions.
Lag and lead levels were taken as 1.

Table 6

Country Results of the Panel Causality Test

	Energy consumption is not the cause of GDP				GDP is not the cause of energy consumption			
	Emirmahmutoglu & Kose		Dumitrescu & Hurlin		Emirmahmutoglu & Kose		Dumitrescu & Hurlin	
Countries	**Wald**	***p*-val**	**Wald**	***p*-val**	**Wald**	***p*-val**	**Wald**	***p*-val**
US	0.198	0.657	0.639	0.424	0.525	0.469	0.115	0.735
Germany	0.044	0.833	0.178	0.673	0.004	0.947	1.054	0.305
Australia	0.003	0.954	3.310*	0.069	0.101	0.751	0.595	0.441
Austria	2.064	0.151	4.640**	0.031	0.084	0.772	0.054	0.816
Belgium	3.130*	0.077	1.007	0.316	0.128	0.721	0.492	0.483
Czech Rep.	4.004**	0.045	0.257	0.612	0.672	0.412	0.563	0.453
Denmark	0.248	0.618	0.003	0.955	0.000	0.997	0.929	0.335
Finland	8.646***	0.003	8.426***	0.004	0.461	0.497	0.002	0.968
France	0.120	0.728	2.290	0.130	0.633	0.426	0.006	0.939
South Korea	11.689***	0.001	3.071*	0.080	0.179	0.672	2.156	0.142
Holland	0.970	0.325	2.171	0.141	0.784	0.376	2.288	0.130
England	0.957	0.328	1.223	0.269	0.230	0.631	0.183	0.669
Ireland	0.050	0.823	0.257	0.612	0.191	0.662	6.101**	0.014
Spain	0.068	0.795	4.573**	0.032	4.727**	0.030	3.358*	0.067
Israel	1.466	0.226	0.115	0.734	0.188	0.664	0.044	0.834
Sweden	0.134	0.714	0.044	0.833	1.132	0.287	0.572	0.450
Switzerland	1.071	0.301	1.400	0.237	0.275	0.600	0.388	0.534
Italy	1.743	0.187	2.741*	0.098	1.502	0.220	0.004	0.948
Iceland	4.610**	0.032	0.072	0.789	1.949	0.163	0.655	0.418
Japan	0.359	0.549	0.977	0.323	0.976	0.323	3.065*	0.080
Canada	2.043	0.153	0.082	0.775	0.047	0.828	1.026	0.311
Luxembourg	1.572	0.210	8.246***	0.004	2.631	0.105	0.356	0.551
Hungary	0.120	0.729	0.099	0.753	0.194	0.659	3.925**	0.048
Mexico	0.012	0.914	5.457**	0.019	0.599	0.439	1.179	0.278
Norway	0.000	0.987	0.013	0.911	0.204	0.652	0.223	0.637
Portugal	0.106	0.745	1.273	0.259	4.491**	0.034	0.000	0.996
Slovakia	2.006	0.157	3.160*	0.075	0.050	0.823	0.226	0.634
Slovenia	0.059	0.807	0.762	0.383	0.421	0.516	2.287	0.130
Chili	2.471	0.116	1.860	0.173	4.168**	0.041	2.614	0.106
Turkey	0.028	0.868	0.562	0.453	0.026	0.871	0.122	0.727
New Zealand	0.047	0.828	2.627	0.105	3.494*	0.062	0.438	0.508
Greece	3.814*	0.051	4.817**	0.028	0.052	0.820	8.468***	0.004

Note: The analysis was conducted according to 1000 bootstrap repetition, 1 lag, 1 integration and Akaike information criterion. For the Dumitrescu & Hurlin (2012) Panel Causality Test since N > T critical values of semi-asymptomatic distribution have been taken.

sality tests give the same result. According to the unbiasedness hypothesis, there is no causal relationship between energy and growth for these countries. According to both causality tests, OECD countries US, Germany, Denmark, France, Holland, England, Israel, Sweden, Switzerland, Canada, Norway, Slovenia, Turkey are in this group. Other countries in which both tests give the same result are Finland and South Korea, which support the growth hypothesis. There is causality running from energy consumption to economic growth in these countries.

The growth hypothesis is valid in Australia, Austria, Belgium, Czech Republic, Italy, Luxembourg, Mexico and Slovakia, where a causal relationship is confirmed at least one test. It has been concluded that energy consumption affects economic growth in these countries. In Chili, Hungary, Ireland, Japan, New Zealand, Portugal, the causality is from economic growth to energy. The protection hypothesis is valid in the mentioned countries. There are two different results obtained in Greece and Spain. Accordingly, the Growth Hypothesis and Feedback Hypothesis are valid for Greece, and the Protection Hypothesis and Feedback Hypothesis have emerged for Spain.

Based on the results of the analysis, countries are classified in Table 7 as countries that meet the

Table 7

Distribution of Countries by Energy Growth Relationship Hypotheses

Growth Hypothesis	Emirmahmutoglu & Kose	Belgium, Czech Republic, Iceland, Greece	Finland, South Korea
	Dumitrescu & Hurlin	Australia, Austria, Italy, Luxembourg, Mexico, Slovakia	
Protection Hypothesis	Emirmahmutoglu & Kose	Spain, Portugal, Chili, New Zealand	
	Dumitrescu & Hurlin	Ireland, Japan, Hungary	
Feedback Hypothesis	Emirmahmutoglu & Kose		
	Dumitrescu & Hurlin	Spain, Greece	
Unbiasedness Hypothesis	Emirmahmutoglu & Kose	Australia, Ireland, Italy, Japan, Luxembourg, Hungary, Mexico, Slovakia	USA, Germany, Denmark, France, Holland, England, Israel, Sweden, Switzerland, Canada, Norway, Slovenia, Turkey
	Dumitrescu & Hurlin	Belgium, Czech Republic, Iceland, Portugal, Chile, New Zealand	

Note: According to the results of both causality analysis, countries that are not involved in the same hypotheses were in two different groups.

Table 8

Panel Causality Test Model Results

Study	Test	Variables	Ist.	Boots. (%1)	Boots. (%5)	Boots. (%10)	Probability Value
Emirmahmutoglu & Kose (2011)	Panel Fisher	$GDP \Leftarrow EC$	90.381	100.970	90.225	83.601	0.017
		$GDP \Rightarrow EC$	62.352	102.077	91.414	85.600	0.535
Dumitrescu & Hurlin (2012)	Panel Z_NT	$GDP \Leftarrow EC$	3.396	2.756	1.768	1.270	0.001
		$GDP \Rightarrow EC$	0.936	2.897	1.813	1.358	0.349

Note: The analysis was conducted according to 1000 bootstrap repetition, 1 delay, 1 integration and Akaike information criterion. For the Dumitrescu & Hurlin Panel Causality Test since $N > T$ critical values of semi-asymptomatic distribution have been taken.

growth, protection, feedback, and unbiasedness hypotheses. According to the results of the analysis, the highest distribution is observed for the unbiasedness hypothesis, and second for the growth hypothesis. In the same way, common results were only realised in the growth hypothesis, except for the hypothesis of unbiasedness.

The causality test results suggest a causality relationship between energy consumption and growth in Table 8. Both Panel Fisher and Panel Z_NT tests verified causality between energy consumption and economic growth; however, the hypothesis that economic growth is not the cause of energy cannot be rejected. Accordingly, the model results of both causality tests support the growth hypothesis.

Conclusions and Policy Implications

The proliferation of high-tech use did not trivialise energy consumption, it has had an impact on the type and quantity of energy consumed. But industries that use traditional and high-density energy, especially in developing or underdeveloped countries, still maintain their numerical magnitude. Therefore, it is not crucial nowadays to debate whether energy consumption has an impact on growth when it is examined as an input of production. Recent research is mainly about the causality aspect of the relationship of energy with growth. However, the shape and strength of the relationship between the two variables have not lost its importance. The economic decision is very important for buyers to determine economic policies as well as the relationship between energy consumption and economic growth, and the shape and degree of the relationship. The first one is a choice between protection policies or increasing consumption, while the second will be a policy preference between growth or foreign balance.

After the theoretical framework and literature review of the study, regression analysis was performed to determine the shape of the relationship between energy consumption and economic growth. However, the cross-section dependence of the model was tested and it was determined that dependency occurred. With the Hausman Test done afterwards, the hypothesis that the model was a fixed effects model was accepted. Depending on cross-section dependence, variables were found to be constant in the first differences according to CADF unit root tests from the second-generation analysis.

In the fixed effects model, autocorrelation and homoskedasticity tests were done, in both tests, the H_0 hypothesis was rejected, meaning that the model has both autocorrelation and heteroskedasticity. According to these results, it was decided that the prediction of the relationship between the variables should be made with the predictive Driscoll-Kraay fixed effects panel regression test which is resistant to both autocorrelation and heteroskedasticity. According to the test results, energy consumption has been shown to positively affect economic growth. Finally, the panel cointegration test was applied based on the result that the variables were stationary at the same level, and it was concluded that there was a long-term relationship between variables or that the variables moved together in the long term in other words.

In the study, the causality direction of energy consumption and economic growth was determined as a complement to regression analysis. Emirmahmutoglu & Kose and Dumitrescu & Hurlin tests, which yield results according to heterogeneity and cross-section dependence, were used for causality analyses. According to the common results of both tests, it was observed that for OECD countries (such as United States, Germany, Denmark, France, the Netherlands, England, Israel, Sweden, Switzerland, Canada, Norway, Slovenia, Turkey) the unbiasedness hypothesis was valid, while for Finland and South Korea the growth hypothesis was valid. Countries characterised by the valid unbiasedness hypothesis should follow a balanced policy by considering energy consumption by sectors.

The growth hypothesis is valid for Finland, South Korea (they have a causal relationship from energy consumption to growth in both tests), and Australia, Austria, Belgium, Czech Republic, Italy, Luxembourg, Mexico and Slovakia (these countries have causality confirmed by at least one test). Since it is a crucial factor for economic growth, energy consumption should not be cut back and protective policies should not be implemented. In other OECD countries (Chile, Hungary, Ireland, Japan, New Zealand and Portugal), the causal relationship is from economic growth to energy. The results of these countries confirm protectionist hypothesis based on savings-oriented protectionist policies.

Two different results are found for Greece and Spain by two different tests. Thus, the Growth Hypothesis and Feedback Hypothesis are valid for Greece, the Protection Hypothesis and Feedback Hypothesis have emerged in Spain. Protectionist policies are recommended for these two countries since there is a two-way causality relationship. However, since test results for Greece support the growth hypothesis, it is recommended that protectionist and growth policies are designed in a balanced way. Without slowing growth, policies to reduce energy intensity can also be suggested for these countries. Since the feedback hypothesis is valid in both countries, energy policies for these countries should also be considered together with environmental quality (Ozcan et al., 2020).

Besides individual test results of OECD countries, according to the panel fisher and panel Z_NT test results of both causality tests, a causality relationship has been detected from energy to growth. Therefore, it is recommended that policymakers decide to remove barriers to energy consumption used as input in production to sustain growth and realise development, avoid energy protection policies as much as possible, use advanced technologies with low energy density to avoid increasing the external deficit arising from energy imports, use energy more in external balance-oriented production, or to switch to renewable energy sources that are not imported from outside, and other/new native energy sources that are not imported from outside and do not break the ecological balance and to take decisions towards avoiding energy dependence.

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Дата поступления рукописи: 10.09.2021.
Прошла рецензирование: 07.02.2022.
Принято решение о публикации: 24.03.2023.

Received: 10 Sep 2021.
Reviewed: 07 Feb 2022.
Accepted: 24 Mar 2023.