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The Relationship Between Growth, Co_2 Emission and Energy Consumption: A Panel Cointegration Approach for Selected Country Groups

Büyüme, CO2 Emisyonu ve Enerji Tüketimi İlişkisi: Seçilmiş Ülke Grupları İçin Bir Panel Eşbütünleşme Yaklaşımı

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Abstract: Nowadays, the increasing environmental pollution and efforts to alleviate the negative effects of global warming have raised the problem of using energy resources that cause CO2 emissions. Economic development and further economic growth accelerate the use of energy resources. This process causes a rise in the level of CO2 emission as well as the depletion of energy reserves. Therefore, it is necessary to formulate the optimal level of these three variables together in terms of decreasing CO2 emission, preserving energy, and improving economic performance. Therefore, this study aims to investigate whether there is a relationship between CO2 emission, energy consumption, and economic growth using data set from developed countries groups (the EU19, EU28, G7, G20, OECD-Europe, OECD-Total, BRICS, OECD-America and Eastern Europe, Caucasus and Central Asia). For this purpose, using the 2000-2018 data of developed countries, the preliminary estimation tests were used for panel unit root, Westerlund panel co-integration, and cross-section dependency. According to the unit root test results, variables that are not stationary at the level are found stationary taking their first differences. Westerlund (2007) panel cointegration test results show that there is cointegration among the variables and they move together in the long run. Further, Dimutrescu- Hurlin (2012) panel causality test results show that there is a bidirectional causality relationship between CO2 emissions and growth, and a unidirectional causality relationship between energy consumption and growth, from growth to energy. The results of this study suggest prioritizing the improvement of energy efficiency in developed countries in terms of technology and making the implementation of joint action plans in environmentally friendly policies a priority for policymakers.

Keywords: CO2 Emission, Energy Consumption, Economic Growth, Panel Cointegration

JEL Classification: C23, 044, C33

Öz: Günümüzde artan çevre kirliliği ve küresel ısınmanın olumsuz etkilerini hafifletme çabaları, CO2 emisyonlarına neden olan enerji kaynaklarının kullanılması sorununu gündeme getirmiştir. Ekonomik gelişme ve daha fazla ekonomik büyüme, enerji kaynaklarının kullanımını hızlandırır. Bu süreç, CO2 emisyon seviyesinin yükselmesine ve enerji rezervlerinin tükenmesine neden olur. Bu nedenle CO2 emisyonunun azaltılması, enerjinin korunması ve ekonomik performansın iyileştirilmesi açısından bu üç değişkenin optimal düzeyinin birlikte formüle edilmesi gerekmektedir. Bu nedenle bu çalışma, gelişmiş ülkelerden (EU19, EU28, G7, G20, OECD-Avrupa, OECD-Total, BRICS, OECD-Amerika ve Doğu Avrupa, Kafkaslar ve Orta Asya) veriler alarak CO2 emisyonu, enerji tüketimi ve ekonomik büyüme arasında bir ilişki olup olmadığını araştırmayı amaçlamaktadır. Bu amaçla gelişmiş ülkelerin 2000-2018 verileri kullanılarak panel birim kök, Westerlund panel eşbütünleşme ve yatay kesit bağımlılığı için ön tahmin testleri kullanılmıştır. Birim kök testi sonuçlarına göre düzeyde durağan olmayan değişkenler uzun döneme entegre edilir. Westerlund (2007) panel eş bütünleşme testi sonuçları, değişkenler arasında eşbütünleşmenin olduğunu ve uzun dönemde birlikte hareket ettiğini göstermektedir. Dimutrescu- Hurlin (2012) panel nedensellik test sonuçları ise, gelişmiş ülkelerde CO2 emisyonu ile büyüme arasından çift yönlü, enerji tüketimi ile büyüme arasında ise büyümeden enerjiye doğru tek yönlü bir nedensellik ilişkisinin olduğunu göstermiştir. Bu çalışmanın sonuçları, gelişmiş ülkelerde enerji verimliliğinin artırılmasına teknoloji açısından öncelik verilmesini ve çevre dostu politikalarda ortak eylem planlarının uygulanmasını politika yapıcıları için bir öncelik haline getirmeyi önermektedir.

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1. Introduction

One of the goals of an economy is to enhance economic development. Nevertheless, with the realization that there are environmental changes during the growth process, the relation between environment and growth has begun to be questioned. Particularly, climate changes, global warming, and environmental degradation have come to the fore since the early 1990s. The increase in carbon dioxide gas in the air is shown as a cause of these adverse developments regarding the environment. Thus, attention was drawn to the rise in the amount of carbon dioxide, and the possible relationship of this rise with profit was examined. Therefore, the relationship between the environment and economic growth has obtained its position in the environmental economy.

Along with globalization and the accompanying economic activities, the economic growth experienced in a fast and uncontrolled manner in both industrialized and industrializing countries has brought environmental effects. Although industrialization has caused radical changes in the economic, social, and cultural lives of societies, it has also caused a rapid change and pollution of the natural environment since the 20th century. This is because industrialization was not planned, only industrialization was targeted, and the environmental factor was ignored (Guha, 2000: 10). From the industrial revolution until today, the greenhouse gas emissions and deforestation movements created primarily by developed countries and then by developing countries, whose industrialization process has rapidly increased, have resulted in global warming to move a critical amount (Çınar et al., 2012: 213). The development stages of the world countries and the environmental problems that develop in parallel with each passing day become more evident day by day, making it necessary to address these problems with a holistic approach. Environmental problems, which were previously evaluated at the national level, started to move to the international level after the 1970s, and since then the environment has been accepted as an argument for sustainable development. The publication of the "Limits to Growth Report" in 1972 and the United Nations Environment Conference held in Stockholm are the first global steps taken in this field. Following the Brundtland Report in which the first official definition of the concept of sustainable development was made in the Rio Conference held in 1992, the environment and strategies for development were investigated in detail and the agenda (Agenda 21) of the 21st century was determined. With the Kyoto Protocol, the framework of the fight against global warming and climate change was determined. "Millennium Development Goals" were determined at the United Nations Millennium Summit held in 2000. In 2002, "The World Sustainable Development Summit" was held in Johannesburg to create more effective sustainable development strategies in the implementation of Rio Conference decisions. Although global warming depends on Greenhouse Gas emission and especially CO2 emission worldwide, its results vary according to the social and natural characteristics of the countries (Tiwari, 2011: 86). However, greenhouse gas emissions have been higher in developed countries from the past to the present. On the other hand, developing countries, which constitute 85% of the world population, constitute approximately half of the greenhouse gas emissions. According to the European Commission's Global CO2, Emission Report (2016), among the six largest countries/regions in terms of CO2 emissions globally; China (with 29% share) ranks first, followed by the United States (14%), European Union (EU-28-10%), India (7%), Russian Federation (5%) and Japan (3.5%). Up to five emission countries and the European Union account for two-thirds of the total global emissions (EC, 2017, p.5). In this context, the increasing damage of global warming and climate change on the environment has drawn attention to the relationship between economic growth, energy consumption, and environmental pollution. When we look at the literature, some studies are investigating the causality relationship between CO_2 emission, energy consumption, and economic development in terms of country or country groups. These studies are Apergis and Payne (2009), Lean and Smyth (2010), Pao and Tsai (2010), Niu et al., (2011), Hossain (2011), Menegaki, (2011). The fact that the causality relationship between these three variables has not been sufficiently tested for developed countries can be considered as an indicator of the contribution of this study to the literature.

The goal of this study is to analyze whether there is a mutual relation between the variables of CO2 emission, energy consumption, and economic growth for developed countries by using annual data between 2000-2018. In the study, panel data analysis, which is frequently used in literature, was used to test the existence and direction of the relationship between variables in multi-country models. The limitation of the study is that the research covers only a part of the developed countries, and therefore the results cannot be generalized for all developed countries. In the second part, studies investigating the relationship between CO2 emission, energy consumption, and economic growth in the literature will be examined. The third part of the study will analyze the econometric method used in the study, the fourth chapter of the study will be about the empirical findings on the issue, and the final part of the study will present a general evaluation and discussion of the empirical findings of the study.

2. Literature Review

When the literature review of the related topic is considered, there are important studies on the topic. Kuznets (1955), in his hypothesis, argued that in the periods when the economic development and development of the countries accelerated, with the rapid industrialization, the income and savings of the capital owners would increase and this increase would cause income inequality. Later, he showed that the benefits of growth could affect other individuals in the form of higher wages and savings over time, and he argued that there is an inverted U-shaped relationship between income and growth. In the literature, this curve is called the Kuznets Curve. It has been suggested that a relationship similar to the hypothesis put forward by Kuznets in the 1990s is between income and environmental pollution, and this situation was discussed by many economists. Grossman and Krueger (1991) for the first time suggested that there is a relationship similar to the Kuznets Curve between environmental pollution and income. The Environmental Kuznets Curve-EKC hypothesis led to a discussion that countries that focus on increasing their production and per capita income in the early stages of economic growth initially ignore environmental problems, but when the growth exceeds a certain threshold level, pollution will tend to decrease (Aydin et al., 2019).

Since 1991, when the EKC hypothesis was put forward, the empirical validity of the relations between economic growth and environmental pollution, which is valid at the theoretical level, has been the subject of many studies. When the empirical studies in the literature are examined, it is seen that the empirical validity of the EKC hypothesis has been tested empirically within the scope of time series or panel data analysis on different countries and country groups. However, it is understood that while the relations between economic growth and environmental pollution ($CO2$) level are investigated in a predominantly part of the studies, the relations between the amount of energy consumption and ($CO2$) level are examined in a limited part of the studies.

In most of the studies within this scope, there is a long-term relationship between the variables of economic growth, amount of energy consumption and environmental pollution level and/or there is a causal relationship between the variables in question and the EKC hypothesis is generally valid although at different levels. Cole et al, (1997), Coondoo and Dinda (2002), Bruvoll and Medin (2003), Deacon and Norman (2004), Ang (2007), Tamazian et al. (2009), Zhang (2011), Burnett, Bergstrom and Wetzstein (2013), Uysal and Yapraklı (2016), Başar and Akyol (2018), Nguyen (2021) studies can be shown as examples.

In a limited part of the studies within this scope, there is no long-term relationship between the variables of economic growth, amount of energy consumption and environmental pollution level and/or that there is no causal relationship between the variables in question and that the EKC hypothesis is not valid. As an example of the studies that concluded that the EKC approach is not valid; The studies Koçak (2014), Özokçu and Özdemir (2017), Moghadam and Dehbashi (2018) can be shown.

A summary of the empirical literature on studies of energy consumption, economic development, and CO2 emission variables is presented in Table 1.

Table 1. The Literature Review

Author(s)	**Country**	**Period**	**Variables**	**Method**	**Conclusion**
Kraft and Kraft (1978)	The USA	1947-1974	CO2, energy consumption and GDP	Granger Causality	GDP→EC
Stern (1993)	ABD	1947-1990	CO2, energy consumption	VAR	EC→GDP
Apergis and Payne (2009	6 Central American Countries	1971-2004	CO2, energy consumption and GDP	Pedroni Cointegration, Panel Regression Analysis, panel VECM	EC↔ GDP EC→CO2 GDP →CO
Jalil and Mahmud (2009)	China	1975-2005	CO2, energy, GDP, trade	ARDL bound test, Time series Regression Analysis, VECM	GDP →CO2 Reverse-U
Lean and Smyth (2010)	Association of Southeast Asian Nations (ASEAN)	1980-2006	CO2 emission, electricity consumption and GDP	Johansen Fisher Panel cointegration, panel VECM	EC→ GDP CO2→ GDP
Pao and Tsai(2010)	BRIC Countries	1971-2005	CO2 emission, Real GDP, Energy cons.	Panel data, Panel causality	EC↔ CO2 EC↔GDP

Niu et. al., (2011)	Asia-Pacific countries (8 countries)	1971-2005	Energy consumption, GDP and CO2	Toda-Yamamoto Granger causality	GDP→CO2 GDP→E
Lotfalipour et. al., (2010)	Iran	1967-2007	CO2 emission, GDP, Energy (petroleum products and natural gas) consumption	Toda-Yamamoto Granger causality	GDP→CO2 GDP→EC
Menegaki (2011)	27 EU countries	1997-2007	GDP, Share of RES in Energy Consumption, Energy Consumption, CO2 Emission and Employment Rate	Panel Cointegration and Granger Causality test	CO2↔GDP IST↔GDP
Ergün and Polat (2015)	OECD Countries	1980-2010	CO2 Emission Per Capita GDP and Electricity Consumption per Capita	Panel Unit Root, Cointegration and Panel VECM	GDP↔EC GDP→CO2
Twerefou, Poku and Bekoe (2016)	Ghana	1970-2010	CO2 Emission, energy consumption, economic growth	ARDL Cointegration	EKC hipotezi geçerli değil
Akay, Abdieva, Oskonbaev (2015)	MENA Countries	1988-2010	Renewable Energy Consumption, CO2 Emission, GDP	Panel VAR, Panel Causality	GSYH↔EC CO2 → EC GSYH→CO2
Doğan and Türkekül (2016	The USA	1960-2010	CO2 Emission, energy consumption	ARDL Cointegration	EKC hipotezi geçerli değil

Hossain (2011)	9 Countries with Industrialization	1971-2007	CO2 Emission, energy consumption, economic growth	Panel Cointegration and Granger Causality test	GDP→CO2 GDP→EC
Payne (2009)	The USA	1949-2006	CO2 emission, Real GDP, Energy consumption	Toda-Yamamoto Causality	GDP ---- EC
Karanfil (2008)	Turkey	1970-2005	CO2 emission, Real GDP, Energy consumption	Granger Causality and Cointegration	Co-integrated relationship between EC and GDP and GDP → Energy

When the empirical literature in Table 1 was examined, it was seen that different results were obtained in terms of the relationship between CO2 emission, energy consumption and economic growth variables in terms of country examples, the period considered and the direction and degree of causality relationship between these three variables according to the econometric method used.

3. Empirical Framework

3.1. Data Sources and Variables

The data set were taken from the OECD statistics database. The sample consists of the averaged data set for 10 different country groups covering the period 2000-2018. These groups include the EU 19, EU 28, G7, G20, OECD-Europe, OECD-Total, BRICS economies[1], OECD-America and Eastern Europe, Caucasus and Central Asia. In the analysis, GDP was measured as the Real GDP index (the year 2000 = 100). The variable of energy was measured as the total primary energy supply index, taking the year 2000 equals to 100. The final variable CO_2 was measured as production-based carbon monoxide intensity which reflects energy-related CO_2 per capita, expressed in metric tons.

Hereafter, the real GDP index is denoted ***G***, per capita CO_2 emissions $\boldsymbol{CO_2}$ and the measure of energy supply as ***E***.

3.2. Empirical Model

As mentioned in the introduction, this paper examines the relationship among growth, CO_2

[1] Brazil, Russia, India, China and South Africa.

emissions and energy supply. The empirical analysis follows four steps: First, each variable was tested against cross-section dependence (CD). Based on the CD test, we choose between appropriate panel unit root test in the second step: if cross-section dependence is detected across units, the first-generation panel unit root tests are not appropriate, therefore, the second-generation unit root test need to be employed, since these tests allow dependence across units. For this purpose, the CADF test proposed by Pesaran (2007) is employed, which controls for cross-dependence. In the third step, Westerlund panel cointegration test by Westerlund (2007) is performed to examine whether the variables are cointegrated. Finally, Dumitrescu-Hurlin Panel Granger Causality test is applied to reveal causality relationship among variables.

Cross Section Dependence Test

Even though the cross-sectionally independence assumption of the disturbances in panel data models is common, considerable literature has shown that panel regression settings suffer from cross-sectional dependence. Therefore, ignoring the dependency across panel units in model estimation can have serious consequences such as efficiency loss in estimators and invalid test statistics in the case of large cross-section dimensions.

On the other hand, a cross-sectional dependency test is essential for assessing which generation of unit root test is to be used before parameters estimation. If cross dependence is present in the panel setting, then first-generation unit root tests are not valid since they assume that panel series are independent.

There are a variety of tests for cross-section dependence in the literature. Among the tests, Breusch- Pagan (1980) CDLM 1, Pesaran (2004) CDLM2, Pesaran (2004) CDLM, and tests developed by Pesaran-Yamagata (2005) are more commonly used test procedures. This study starts with a test for error cross-sectional dependence (CD) as suggested by Pesaran (2004). Since developed countries are globally integrated, it is meaningful to use this test.

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

CD_{LM} test can be used when T > N and N > T. It is also clear that since the mean of CD is exactly equal to zero for all fixed T > k +1 and N, the test is likely to have good small sample properties (for both N and T small) (Pesaran, 2004: 9). While the null hypothesis for this test states that there is no relationship between cross-sections; the alternative hypothesis asserts that there is a relationship between cross units. In equation (1), $\hat{p}_{i,j}$ stands for pair-wise correlation coefficients.

Panel Unit Root Test

As a second step, the order of integration of the three series in the model must be determined. Testing for unit root is performed using the panel unit root test of Pesaran (2003). This test runs the t-test for unit roots in heterogeneous panels with cross-section dependence. To eliminate the cross dependence, the standard DF (or ADF) regressions are augmented with the cross-section averages of lagged levels and first differences of the individual series (CADF statistics). Considered is also a truncated version of the CADF statistics which has finite first and second-order moments. It allows avoiding size distortions, especially in the case of models with residual serial correlations and linear trends (Pesaran, 2003).

According to Pesaran (2007), if the idiosyncratic errors with zero mean and homoscedastic variance and the common factor f_t are independently distributed across units and time, as N → ∞ and T → ∞, cross-sectionally augmented Dickey-Fuller (CADF) test statistics is given by

$$CADF_{if} = \frac{\int_0^1 W_i(r)dW_i(r) - \psi'_{if}\Lambda_f^{-1}\kappa_{if}}{\left(\int_0^1 W_i^2(r)dr - \kappa'_{if}\Lambda_f^{-1}\kappa_{if}\right)^{1/2}} \tag{2}$$

where

$$\Lambda_f = \begin{pmatrix} 1 & \int_0^1 W_f(r)dr \\ \int_0^1 W_f(r)dr & \int_0^1 W_f^2(r)dr \end{pmatrix} \tag{3}$$

and

$$\psi_{if} = \begin{pmatrix} W_i(1) \\ \int_0^1 W_f(r)dr\, W_i(r) \end{pmatrix}, \quad \kappa_{if} = \begin{pmatrix} \int_0^1 W_i(r)dr \\ \int_0^1 W_f(r)\, W_i(r)dr \end{pmatrix} \tag{4}$$

In equations (3) and (4), $W_i(r)$ and $W_f(r)$ stand for weighted matrices with independent standard Brownian motions.

Error Correction based Panel Cointegration

In the third step of the study, to test for the presence of long-run relationships among three variables, Westerlund (2007) introduced four new panel cointegration tests which are known as error correction-based panel cointegration (ECM) models. While, among these tests, two tests are used to test the alternative hypothesis based on a cointegrated panel set as a whole, the other two tests assume that there is at least one cointegrated vector in the model. The error correction models are expressed in the following equations, in which all variables are assumed to be $I(1)$:

$$\Delta G_{i,t} = \alpha_i^G + \lambda_i^G(G_{i,t-1} - \beta_i^E CO_{2,it-1} - \gamma_i^G E_{i,t-1}) + \sum_{j=1}^{m}\theta_{i,j}^G \Delta G_{i,t-j} + \sum_{j=1}^{n}\delta_{i,j}^G \Delta CO_{2,it-j} + \sum_{j=1}^{p}\phi_{i,j}^G \Delta E_{i,t-j} + u_{i,t} \tag{5}$$

$$\Delta CO_{2i,t} = \alpha_i^C + \lambda_i^C(CO_{2,it-1} - \beta_i^C G_{i,t-1} - \gamma_i^C E_{i,t-1}) + \sum_{j=1}^{p}\delta_{i,j}^C \Delta CO_{2,it-j} + \sum_{j=1}^{n}\theta_{i,j}^C \Delta G_{i,t-j} + \sum_{j=1}^{m}\phi_{i,j}^C \Delta E_{i,t-j} + \varepsilon_{i,t} \tag{6}$$

$$\Delta E_{i,t} = \alpha^E + \lambda_i^E(E_{i,t-1} - \beta_i^E CO_{2,it-1} - \gamma_i^E G_{i,t-1}) + \sum_{j=1}^{n}\phi_{i,j}^E \Delta E_{i,t-j} + \sum_{j=1}^{m}\delta_{i,j}^E \Delta CO_{2,it-j} + \sum_{j=1}^{p}\theta_{i,j}^E \Delta G_{i,t-j} + e_{i,t} \tag{7}$$

In equations (5), (6) and (7) λ_i^k where $k \in \{G, CO_2, E\}$ are the parameters of ECM term estimating the speed of error correction towards the long-run equilibrium for country i, while $\varepsilon_{i,t}$, $u_{i,t}$ and $e_{i,t}$ stand for white noise random disturbances.

4. Estimation Results

4.1. Cross-section dependency

The existence of cross-sectional dependency across panel, Pesaran CD test is applied and results are presented in Table 2.

Table 2. Pre-estimation Test on Cross-section dependence

Variable	CD Test	p-value	Average Correlation Coefficient	Absolute Correlation Coefficient
CO_2	24.39	0.000	0.958	0.958
E	5.57	0.000	0.219	0.636
G	24.71	0.000	0.971	0.971

According to Table 2, the CD test rejects the null hypothesis of no cross-sectional dependence in the series, at the 1% significance level. In addition, the correlation coefficients are rather high for the variables CO_2 and G. These findings support the presence of cross-section dependence in variables and lead us to use second-generation panel unit root tests.

4.2. Panel Unit Root Tests

Since cross-section independence is rejected, this study uses the 2^{nd} generation CADF panel unit root test. Augmenting ADF regression with lagged cross-sectional mean and its first difference eliminates cross-sectional dependence by of the individual series (CADF statistics). The panel unit root test results for CO_2, E, and G over the full sample are summarized in Table 3. The decision of whether or not to reject the null hypothesis of unit root for the panel as a whole is based on the Pesaran Z-statistic.

Table 3. Pesaran Panel Unit Root Test

	At levels				First differences			
	without trend		with trend		without trend		with trend	
	Z(t-bar)	p-value	Z(t-bar)	p-value	Z(t-bar)	p-value	Z(t-bar)	p-value
CO_2	12.641	1.000	11.822	1.000	-4.943***	0.000	-3.924***	0.000
E	-1.558*	0.060	5.437	1.000	-5.118***	0.000	-3.856***	0.000
G	0.382	0.649	2.629	0.996	-3.625***	0.000	-3.696***	0.000

Note: The null hypothesis for all tests is that the variables are *I(1)*. Stata routine "pesacdf" is used.

According to the test results, the null unit root hypothesis of the non-stationarity of series cannot be rejected. Taking the first differences of series, the null hypothesis is strongly rejected at the 1% level of significance for variables in the model, showing that the series are stationary.

4.3. Panel Cointegration Test

Panel cointegration tests indicate the possibility of a linear combination of G, E, and CO_2.

Among the cointegration tests, Pedroni (1999), Kao (1999), Johansen- Fisher cointegration tests do not take into account the cross-sectional dependency; while Westerlund Error Correction (2007) does. This test, which takes into account the cross-section dependence, was preferred to use in the study. This test can also be used in cases of no cross-sectional dependency. If there is a cross-sectional dependency in the series, the bootstrap distribution is used; if there is no cross-sectional dependence in the series, the standard normal distribution is used. Also, this test is suitable if the series are integrated at the *I(I)* level.

This study proceeds by testing whether our variables are co-integrated. The lead and lag orders of Westerlund panel cointegration tests were selected according to the minimum values of Akaike's Information Criterion (AIC). The cointegration tests are performed with constant and no trend, and constant with the trend. For estimation purposes, the robust p-values are gathered after 500 bootstrap replicates. While G_t and G_a are group mean tests, *Pa* and *Pt* statistics are panel mean tests.

For the growth variable, test statistics with no trend based on robust p-values suggest that the hypothesis of no cointegration can be rejected at $p < 0.01$ by G_a, P_a and P_t and $p < 0.10$ by G_t statistics. However, including a constant and a linear trend in the test equations, only P_a and P_t statistics confirm the existence of a long-run relationship between cointegrated variables. *P*-values for the CO_2 equation indicate that the null hypothesis can be rejected at $p < 0.05$ for the tests with constant, except G_t test. However, including a time trend makes the results somehow ambiguous, where considerable a weak cointegration relationship can only be accepted at $p < 0.10$ by G_t and P_t statistics.

Table 4. Westerlund Panel Cointegration Test

		Constant				Constant and Trend			
Model	Test	Value of test	z-value	p-value	Robust p-value	Value of test	z-value	p-value	Robust p-value
	G_t	-3.425	-4.529	0.000	0.080	-3.311	-2.791	0.003	0.340
	G_a	-4.965	1.990	0.977	0.000	-1.354	5.024	1.000	0.140
G	P_t	-18.28	-12.72	0.000	0.000	-17.31	-11.58	0.000	0.000
	P_a	-10.01	-2.224	0.013	0.000	-2.567	3.515	1.000	0.000
	G_t	-2.667	-2.060	0.020	0.140	-3.833	-4.656	0.000	0.050
CO₂	G_a	-6.542	1.235	0.892	0.020	-3.103	4.309	1.000	0.730
	P_t	-6.992	-1.794	0.036	0.040	-8.325	-1.621	0.053	0.080
	P_a	-5.070	0.426	0.665	0.040	-3.465	3.117	0.999	0.430
	G_t	-2.251	-0.704	0.241	0.230	-4.366	-6.555	0.000	0.013
E	G_a	-4.105	2.401	0.992	0.130	-2.620	4.507	1.000	0.577
	P_t	-6.763	-1.573	0.058	0.070	-8.064	-1.331	0.092	0.090
	P_a	-4.521	0.721	0.765	0.040	-2.297	3.635	1.000	0.620

Note: This paper used xtwest to test for cointegration, using the AIC to choose the optimal lag and lead lengths for each series and with the Bartlett kernel window width set to 4(T/100)2/9 ≈ 3.

Finally, for the energy equation (E), the equation including just a constant term produces considerably better results than the second model with a constant and trend. Although the possibility of at least one cointegrated vector is not supported by all tests, panel mean tests can not reject the null hypothesis just at 5% and 10% levels of significance. In short, results for three equations show that real GDP, energy supply, and CO_2 are considered to be cointegrated in the long run and that sample data are more appropriate for panel group means tests.

4.4. Panel Causality Test

Causality analysis is used to test the existence and direction of a causal relationship between two variables. This relationship may be unidirectional or a bidirectional causality relationship may occur. While the Dumitrescu-Hurlin panel causality test is applicable both when T > N and N > T, it is also used for balanced and heterogeneous panels in cases with and without cross-section dependence.

Table 5. Dumitrescu-Hurlin Panel Granger Causality Test Results

Direction of causality	W^{HNC}	Z_{NT}^{HNC}
$CO_2 \rightarrow G$	3.7437***	2.6155***
	(0.0000)	(0.008)
$G \rightarrow CO_2$	6.1341***	6.2011***
	(0.0000)	(0.0001)
$E \rightarrow G$	2.2118	0.3177
	(0.1477)	(0.7507)
$G \rightarrow E$	3.9806***	2.9709***
	(0.0001)	(0.0030)
$CO_2 \rightarrow E$	5.6717***	3.3392***
	(0.0000)	(0.008)
$E \rightarrow CO_2$	4.0540***	1.6881*
	(0.0021)	(0.0914)

Note: Probability values are presented in the parenthesis. ***, **, * denote 1%, 5% and 10% levels of significance.

Table 5 presents the results of Dumitrescu – Hurlin homogenous non-causality hypothesis test between CO_2 and growth, CO_2 and energy supply, and energy and economic growth based on two test statistics; the average Wald statistics (W^{HNC}) and the asymptotic standardized statistic (Z^{HNC}). According to Table 5, in the first row, findings show a bidirectional relationship between CO_2 emissions and economic growth, at 1% statistical significance. That means that, in the long run, while CO_2 emissions seem to be one of the driven sources of growth, *vice versa*, the opposite causality is also valid. In the second row of the table, while it has been found that growth is a driven force of energy supply, it has not found any statistical significance indicating that energy supply is also a granger cause of growth. This unidirectional causality relationship could be linked with the demand size of growth necessities an increase in energy supply for the country groups under investigation. The last row, as expected, shows a statistically significant bidirectional causal relationship between CO_2 and energy supply in the long term.

5. Conclusion

Since the 1990s, global warming and climate change have been among the issues that are constantly on the agenda. The effect of climate changes on the economy has risen the significance of both politicians and academics on the growth-environment relationship. In addition, various organizations point out that the amount of greenhouse gas and carbon dioxide in the air should be reduced by taking various activities to draw attention to climate changes. The Kyoto Protocol, arranged in 1997 under the leadership of the United Nations, was submitted to the approval of the nations for this goal. Yet, despite the presence of international compulsory agreements like the Kyoto Protocol, the greenhouse gas emissions in the world have not reached the maximum turning point, at least on a world scale, as they continue to increase.

In this study, using the annual data for the period 2000-2018, it was analyzed by panel data method whether there is a mutual relation between energy consumption, economic improvement and CO2 emission variables for developed countries. Based on this purpose, firstly the stationarities of the series of variables used in the study were analyzed with second generation panel unit root tests. According to CADF and CIPS unit root test results, CO_2 emission, GDP and energy consumption series of developed countries contain unit root at various significance levels. Hence, it can be said that the CO_2 emission, GDP and energy consumption series are in a non-stationary process in all developed countries that were studied between 2000 and 2018.

In the study, Westerlund Error Correction (2007) panel cointegration test was applied to test whether there is a cointegration relationship among the variables. According to cointegration test outcomes, there is no cointegration relationship between CO2 emission, GDP and energy consumption series. Based on the panel DOLS estimator, a 1% rise in energy consumption in developed countries increases CO_2 emission by 0.90%. According to the results of the Pre-estimation Test on Cross-section dependence test, it has been observed that there is a two-way relation between GDP and CO_2 emission and GDP and energy consumption in developed countries.

To prevent climate change, which has become a growing problem, politicians should focus on green growth rather than absolute economic growth. Green growth will also positively affect economic growth. Because green growth will increase the quality of life, social welfare and enable sustainable growth, and will increase productivity in the long term, provided that the general health level of human capital is increased together with continuous increases in environmental quality.

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