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The Relationship Between Renewable Energy, Economic Growth and Trade Openness: New Evidence for EU Countries

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Yenilenebilir Enerji, Ekonomik Büyüme ve Ticari Açıklık Arasındaki İlişki: AB Ülkeleri için Yeni Kanıtlar

Abstract

Using panel data analysis, the study analysed the relationship between renewable energy consumption, economic growth, and trade openness for the 27 European Union (EU) member states with the highest energy imports from 1990-2021. The country-specific causality test results showed a unidirectional causality from renewable energy consumption to economic growth in Belgium, Finland, and Italy. However, in Croatia, Greece, Ireland, the Netherlands, Portugal, and Romania, a unidirectional causality was found from economic growth to renewable energy consumption. A bidirectional causality between renewable energy consumption and economic growth was identified in Germany. The causality test results also indicated a unidirectional causality from renewable energy consumption to trade openness across the panel.

Keywords : Renewable Energy, Economic Growth, Trade Openness, EU-27 Countries.

JEL Classification Codes : F1, Q42, Q4.

Öz

Bu çalışmanın amacı, yenilenebilir enerji tüketimi ile ekonomik büyüme ve ticari açıklık arasındaki ilişkinin 1990-2021 döneminde 27 AB üye ülkesi için panel veri yöntemiyle analiz edilmesidir. Ülke genelindeki nedensellik test sonuçları, Belçika, Finlandiya ve İtalya'da yenilebilir enerji tüketiminden ekonomik büyümeye doğru tek yönlü nedensellik ilişkini göstermiştir. Bununla birlikte, Hırvatistan, Yunanistan, İrlanda, Hollanda, Portekiz ve Romanya'da ekonomik büyümeden yenilebilir enerji tüketimine doğru olan tek yönlü nedensellik tespit edilmiştir. Almanya'da ise yenilebilir enerji tüketimi ile ekonomik büyüme arasında çift yönlü nedensellik tespit edilmiştir. Ayrıca, nedensellik test sonuçlarında, panel genelinde yenilenebilir enerji tüketiminden ticari açıklığa doğru olan tek yönlü bir nedensellik ilişkisine ulaşılmıştır.

Anahtar Sözcükler : Yenilenebilir Enerji, Ekonomik Büyüme, Ticari Açıklık, 27-AB Ülkesi.

1. Introduction

Energy ensures economic growth, development, and social welfare, while trade openness is important in renewable energy. In other words, trade openness facilitates technology transfer for renewable energy, thus enabling energy demand to be met in terms of sustainable energy sources (Sebri & Salha, 2014: 15). Additionally, the adoption of advanced technology through technology transfer reduces energy intensity and enables more output to be produced, thus positively affecting economic growth (Nasreen & Anwar, 2014: 82). In this context, energy consumption, international trade and economic growth should be evaluated independently of each other.

In recent years, the acceleration of technological developments and the increase in population, urbanisation, and production have led to a gradual increase in the demand of world economies for fossil fuels/non-renewable energy. Although fossil fuels are the primary energy source of today’s world economies, their reserves are concentrated in certain regions. This situation increases the energy dependence of most countries without such reserves to ensure sustainable growth and development. Therefore, a decrease in the supply of fossil fuels increases energy prices and the imports of energy-dependent countries, leading to a deterioration in their current account balance. Moreover, energy dependence is closely related to energy supply security. Energy supply security depends on financial and geopolitical risks. Namely, wars and geopolitical tensions in the past have negatively affected energy supply security[1]. This situation increased oil prices and led to energy crises. Indeed, in the early 1970s, the Organization of Petroleum Exporting Countries (OPEC) cut oil supply and raised oil prices. This increased production costs, especially in energy-dependent industrialised and industrialising countries. The increase in production costs pushed up inflation rates, leading to stagflation in these economies. The Russia-Ukraine war that started in February 2022 and Russia's cutback in natural gas supply due to the sanctions imposed on Russia led to a global energy crisis by raising energy prices globally. The rise in energy prices increased inflation in energy-dependent countries and reduced the welfare of households. In addition, this situation caused factories in some sectors in energy-dependent countries to reduce their production or even close down. Consequently, economic growth in these countries has been negatively affected, and unemployment has increased. As Russia is the leading supplier of natural gas, oil, and coal to the EU, EU countries were the most affected by the global energy crisis (Eurostat, 2022).

Carbon dioxide (CO2) gas released by fossil fuels into the atmosphere causes serious environmental problems, including global warming and climate change. These environmental problems have escalated sharply in recent years and thus attracted policymakers’ attention. Consequently, the Kyoto Protocol was signed in 2005 to widen the use of renewable energy sources to reduce the emission of greenhouse gases that cause environmental problems, such as CO_2. The EU Commission published a report entitled

[1] *The International Energy Agency (IEA) defines energy supply security as "uninterrupted availability of energy resources at an affordable price".*

"Member State's Energy Dependence: An Indicator-Based Assessment" in 2014 to reduce energy dependence and comply with the Kyoto Protocol. This report emphasised that EU countries have high levels of energy dependence. One of the most effective ways to meet electricity, heating, and cooling needs and improve the security of energy supply in terms of transportation is to boost the production of renewable energy (European Commission, 2014). The EU Commission also announced the European Green Deal in 2019. Following the European Green Deal, EU member states pledged to reduce their greenhouse gas emissions by at least 55% compared to the levels recorded in 1990 by 2030 to transform the EU into the first climate-neutral continent by 2050. The European Green Deal also aims to reduce the energy dependence of EU countries, boost employment and growth, and improve health and welfare (European Commission, 2022). In line with this goal, the EU Commission supports various research programs for technology development to reduce fossil fuel consumption, increase energy efficiency, and promote renewable energy production. Although the EU attaches importance to renewable energy production to reduce energy dependence and eliminate environmental problems caused by fossil fuels, the EU's dependence on energy imports is gradually increasing. According to the Eurostat data[2], the EU's energy imports rose from 55,8% in 2015 to 62,5% in 2022 (Eurostat, 2024).

In summary, the rise in global energy prices increases inflation rates in fossil fuel-dependent countries, worsens their current account balances, negatively impacts economic growth, raises unemployment rates, and reduces household welfare. This situation highlights the importance of expanding renewable energy sources in these countries. Moreover, due to the climate crisis driven by fossil fuel consumption, it is imperative to increase the use of renewable energy in fossil fuel-dependent nations and globally. Additionally, the positive effect of trade openness on economic growth through the technology transfer of renewable energy underscores the need to re-examine the relationship between renewable energy growth and trade openness, particularly in countries reliant on fossil fuels. Furthermore, exploring the relationship between renewable energy and growth in EU countries is crucial, as the global energy crisis more heavily influences their macroeconomic indicators due to their dependence on Russia for energy. The present study used panel data analysis to analyse the link between renewable energy consumption, economic growth, and trade openness for the 27 energy-importing/energy-dependent EU member states from 1990-2021.

A literature review showed that a great deal of research has analysed the relationship between renewable energy consumption and economic growth for various countries using different methods, while there are few studies examining the link between renewable energy consumption, economic growth, and trade openness. Thus, the present study differs from the existing studies because the literature includes no study that analyses EU countries highly dependent on energy. In this regard, this study contributes to the economic literature. The remaining sections of the study are structured as follows: The second section summarises empirical studies in the literature, the third section presents the analysis method and research

2 *Because Eurostat publishes the energy data of the EU countries until 2022, the relevant data could not be provided for the last years.*

data, and the fourth section presents empirical findings. The final section offers conclusions and policy recommendations.

2. Literature Review

Much research has analysed the link between renewable energy consumption and economic growth. The causality between energy consumption and economic growth was first examined by Kraft and Kraft (1978) for the UK using the data from 1947-1974. Kraft and Kraft (1978) reported a unidirectional causality from economic growth to energy for the post-war period. Together with their study, four hypotheses that express the link between energy and growth have been proposed. First, the growth hypothesis postulates that energy indirectly and directly affects growth as a complement to labour and capital inputs. A unidirectional causality flows from energy consumption to growth in the growth hypothesis. This hypothesis also suggests that energy-saving policies to reduce energy consumption may negatively affect economic growth. Second, the conservation hypothesis postulates that unidirectional causality runs from economic growth to energy consumption. In the conservation hypothesis, energy conservation policies aimed at reducing energy consumption and waste may not have a negative effect on economic growth. Third, the feedback hypothesis postulates that there is a bidirectional causality between energy consumption and economic growth, and they are complementary to each other. Last, the neutrality hypothesis postulates that energy consumption has a neutral effect on economic growth. In this hypothesis, energy consumption does not significantly impact economic growth because it has a very small share of GDP (Apergis & Payne, 2010a: 1393).

Table 1 summarises the studies that analysed the link between renewable energy consumption and economic growth for different countries and analysis periods using various econometric methods within the framework of the four hypotheses explained above. As seen in Table 1, no consensus was reached in these studies on the direction of the links between these variables.

Table: 1
An Overview of the Recent Literature on Renewable Energy Consumption and Economic Growth

Study	Data Period	Countries	Methodology	Findings
Apergis & Payne (2010a)	1992-2007	13 Eurasian countries	Panel cointegration test, panel error correction model	REC ↔Y (Feedback hypothesis)
Apergis & Payne (2010b)	1985-2005	20 OECD countries	Panel cointegration test, panel error correction model	REC ↔Y (Feedback hypothesis)
Apergis & Payne (2011)	1980-2006	6 Central American countries	Panel cointegration test, panel error correction model	REC ↔Y (Feedback hypothesis)
Tugcu et al. (2012)	1980-2009	G7 countries	ARDL, Hatemi-J causality test	REC ≠ Y (Neutrality hypothesis) for France, Italy, Canada and the USA. REC ↔Y for England and Japan (Feedback hypothesis)
Yildirim et al. (2012)	1949-2010	USA	Toda-Yamamoto procedure and bootstrap-corrected causality test	One causal relationship biomass REC to real Y (Growth hypothesis). There is no causal relationship between all of the other renewable energy kinds and real Y (Neutrality hypothesis)

Farhani (2013)	1975-2008	13 MENA countries	Panel cointegration test	REC ≠ Y (Neutrality hypothesis) in the short run, Y→REC (Conservation hypothesis) in the long run
Ocal & Aslan (2013)	1990-2012	Türkiye	ARDL, Toda-Yamamoto causality test	Y→REC (Conservation hypothesis)
Lin & Moubarak (2014)	1977-2011	China	ARDL, Johansen cointegration test, Granger causality test	REC ↔Y in the long term (Feedback hypothesis)
Chang et al. (2015)	1990-2011	G7 countries	Panel Granger causality test	REC ≠ Y (Neutrality hypothesis) for Canada, Italy and the US. Y→REC (Conservation hypothesis) for France and the UK. REC→Y (Growth hypothesis) for Germany and Japan
Shahbaz et al. (2015)	1972Q1-2011Q4	Pakistan	ARDL, VECM, Granger causality test	REC ↔Y (Feedback hypothesis)
Alper & Oğuz (2016)	1990-2009	New EU member countries	Asymmetric causality test approach and ARDL	REC ≠ Y (Neutrality hypothesis) for Cyprus, Estonia, Hungary, Poland and Slovenia. Y→REC (Conservation hypothesis) for the Czech Republic. REC→Y (Growth hypothesis) for Bulgaria.
Cetin (2016)	1992-2012	E7 countries	Heterogeneous panel cointegration test	REC has a positive impact on real GDP in E-7 countries
Dogan (2016)	1988-2012	Türkiye	Johansen cointegration test, Hatemi-J cointegration test, ARDL test, VECM Granger causality test.	REC ↔Y (Feedback hypothesis)
Inglesi-Lotz (2016)	1990-2010	34 OECD countries	Panel cointegration test	The influence of renewable energy consumption on economic growth is positive.
Kahia et al. (2016)	1980-2012	MENA net oil exporting countries (NOECs)	Panel cointegration test, panel ECM, panel causality test	Y→REC (Conservation hypothesis)
Destek & Aslan (2017)	1980-2012	17 emerging countries	Bootstrap panel causality	REC→Y (Growth hypothesis) for Peru, Y→REC (Conservation hypothesis) for Colombia and Thailand, REC ↔Y (Feedback hypothesis) for Greece and South Korea, REC ≠ Y (Neutrality hypothesis) for the other 12 emerging countries.
Rafindadi & Ozturk (2017)	1971Q1-2013Q4	Germany	ARDL test, VECM Granger causality test	REC ↔Y (Feedback hypothesis)
Magazzino (2017)	1970-2007	Italy	Cointegration test, Toda-Yamamoto causality test	REC→Y (Growth hypothesis)
Ozcan & Ozturk (2019)	1990-2016	17 emerging countries	Bootstrap panel causality	REC ≠ Y (Neutrality hypothesis-except for Poland) REC→Y (growth hypothesis) for Poland
Chen et al. (2020)	1995-2015	103 countries	Threshold model	REC has no significant effect on economic growth in developed countries and a positive significant impact on Y in OECD countries
Chica-Olmo et al. (2020)	1991-2015	26 European countries	Spatial panel data model	1% increase in the REC of one country will increase Y by up to 0.054% in the Y of its neighbouring countries.
Rahman & Velayutham (2020)	1990-2014	5 South Asian countries	Panel cointegration test, panel FMOLS and DOLS, Dumitrescu-Hurling panel causality test	Y→REC (Conservation hypothesis)
Shahbaz et al. (2020)	1990-2018	38 countries	Pedroni panel cointegration analysis, panel FMOLS and DOLS, Dumitrescu-Hurling panel causality test	Twenty-two countries have shown a positive relationship between REC and Y. REC has a negative impact on Y in 9 countries.
Wang & Wang (2020)	2005-2016	34 OECD countries	Panel threshold regression models	The effect of REC on Y is positive
Gyimah et al. (2022)	1990-2015	Ghana	Cointegration test, Granger causality test.	REC ↔Y (Feedback hypothesis), REC→FDI→Y
Alkasasbeh et al. (2023)	2000-2020	Jordan	ARDL	REC has a positive effect on economic growth (Growth hypothesis).
Aswadi et al. (2023)	1990-2019	Indonesia	Johansen cointegration test, FMOLS and DOLS cointegrating regression.	REC has a negative effect on economic growth.
Guliyev (2023)	1965-2019	G-7 countries	NARDL model, PNARDL model	Although REC positively affects economic growth in the long run, this relationship is statistically insignificant.

Note: The abbreviations are as follows: REC; Renewable Energy Consumption, Y; Economic Growth, ARDL; Autoregressive Distributed Lag, VECM; Vector Error Correction model, DOLS; Dynamic Ordinary Least Squares, FMOLS; Fully Modified Ordinary Least Squares, NARDL; (Nonlinear Autoregressive Distributed Lag) PNARDL; (Panel Nonlinear Autoregressive Distributed Lag).

Minh and Van (2023) investigated the relationship between renewable energy consumption and economic growth in Vietnam using data from the 1995-2019 period, applying the autoregressive distributed lag (ARDL) and Granger causality test. The results of the Granger causality test indicated a unidirectional causal relationship between economic growth and renewable energy consumption. Based on these results, the authors concluded that the conservation hypothesis was valid for Vietnam during the study period. Mohammadi et al. (2023) analysed the relationship between renewable energy, non-renewable energy, and economic growth for 30 developed and 29 developing countries between 1993 and 2019, using the Pedroni co-integration test, Kao co-integration test, panel fully modified ordinary least squares (FMOLS), ARDL model and the Dumitrescu and Hurlin heterogeneous panel causality estimation technique. The causality test results showed a unidirectional causal relationship between economic growth and renewable energy consumption in developed countries, while in developing countries, a bidirectional causal relationship between renewable energy consumption and economic growth was found. Based on these results, the authors emphasised that the conservation hypothesis holds for developed countries, while the feedback hypothesis is valid for developing countries.

Recent studies have analysed the link between renewable energy consumption, economic growth, and international trade. For example, Aïssa et al. (2014) examined the link between renewable energy consumption, output, and trade in 11 African countries for the period from 1980 to 2008 using the panel cointegration test, the panel vector error correction model (VECM), and the Granger causality test. The authors could not find a causal relationship between output, renewable energy consumption, and trade openness in the short and long run. Jebli and Youssef (2015) analysed the link between output, renewable and non-renewable energy consumption, and international trade for a sample of 69 countries from 1980 to 2010 using panel cointegration techniques. The Granger test results yielded a bidirectional causality between output and international trade (exports or imports), as well as between non-renewable energy and trade in the short run, while there was a unidirectional causality flowing from non-renewable energy to trade.

Amri (2017) investigated the link between economic growth, trade, and non-renewable energy consumption in 72 developed and developing countries from 1990 to 2012 using a simultaneous-equation panel data approach. The analysis results yielded a feedback linkage between economic growth and renewable energy consumption, trade and renewable energy consumption, and trade and economic growth. Brini et al. (2017) investigated the link between renewable energy consumption, international trade, oil prices, and economic growth in Tunisia from 1980 to 2011 using the ARDL method and the Granger causality test. The results of the Granger causality test showed a unidirectional causality flowing from economic growth to renewable energy consumption (the conservation hypothesis) and from international trade to renewable energy consumption. Halicioglu and Ketenci (2018) analysed the link between output, renewable and non-renewable energy production, and global trade for 15 EU countries during the period from 1980 to 2015 using the ARDL method and the panel Generalised Method of Moment (GMM). The ARDL test results yielded a cointegration relationship between the variables in seven EU countries. The GMM results showed that international trade and renewable and non-renewable energy inputs are important for the output in 15 EU countries.

Jia et al. (2023) investigated the relationship between renewable energy consumption and economic growth for 90 countries on the Belt and Road with the help of the Kao cointegration test and panel Granger causality test with data from 2000-2019. The panel causality test results showed a bidirectional causality relationship between renewable energy consumption and economic growth. According to these results, the authors concluded that the feedback hypothesis is valid in these countries during the period under review. In addition, the panel causality test results showed a bidirectional causality relationship between economic growth and international trade and labour participation rate. Xie et al. (2023) analysed the relationship between economic growth, renewable energy, trade openness, gross national expenditure, and industry value added with nonparametric panel data and a quantile method of moments regression for N-11 countries from 1990-2020. According to the results of the nonparametric panel data method, it is concluded that the growth hypothesis is valid in the analysed countries and within the analysis period.

Hidayat et al. (2024) examined the relationship between renewable energy, natural resources, foreign direct investment, and economic growth for 9 Southeast Asian countries from 2000 to 2021 using the dynamic panel data method. The analysis results show that renewable energy consumption, foreign direct investment, and natural resources have a statistically significant and positive effect on economic growth. Using the panel data method, Satrianto et al. (2024) analysed the relationship between renewable energy consumption and economic growth for 30 developing countries from 1998-2022. They concluded that renewable energy consumption has a statistically significant effect on economic growth. Moreover, the results suggest that trade openness does not affect economic growth statistically significantly. Shahbaz et al. (2024) analysed the relationship between renewable energy consumption and economic growth with the Dynamic Seemingly Unrelated Regressions (DSUR) model and the Dumitrescu-Hurlin causality test for the period 1995-2015 for 15 energy-importing countries. The causality test results showed a bidirectional causality relationship between economic growth and renewable energy, trade openness, capital, and urbanisation.

As mentioned in the previous section, increasing renewable energy resources is an essential issue for energy-dependent countries in terms of reducing their energy dependence and thus ensuring sustainable economic growth and development. Moreover, to prevent the climate crisis caused by fossil fuels, increasing renewable energy production is essential for energy-dependent countries and the whole world economy. However, there are four hypotheses regarding the relationship between renewable energy and growth: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. This framework does not agree on the relationship between renewable energy and growth. However, many studies in the literature investigate this issue for different countries/countries in different periods and with varying analysis methods. Due to the importance of renewable energy for countries that depend on fossil fuels, the relationship between renewable energy and economic growth in these countries should be re-examined according to the hypotheses in question. In this respect, the issue is still topical. Moreover, trade openness may positively affect economic growth by transferring technology to produce renewable energy. In this respect, trade openness is important in the relationship between renewable energy and growth. Therefore, it is essential to re-examine the relationship between renewable energy, growth, and trade openness, especially in energy-dependent countries.

3. Data and Methodology

The study used annual panel data for 1990-2021 to analyse the relationship between renewable energy consumption, economic growth, and trade openness for energy-dependent EU countries. The variables included in the model are the share of renewable energy consumption in the final energy consumption, GDP per capita representing economic growth (in constant 2015 US dollars), and trade openness. The trade openness variable was calculated as the ratio of exports and imports to GDP ratio based on the study by Brini et al. (2017). The analysis was conducted for 27 EU countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden). The multivariate model used by Brini et al. (2017) was taken as a reference to examine the link between the variables in question.

$$gdppc_{it} = \alpha_i + \beta_1 rec_{it} + \beta_1 to_{it} + u_{it} \tag{1}$$

In the above equation (1), $gdppc_{it,}$ is the GDP per capita of country i in period t, rec_{it} is the renewable energy consumption of country i in period t, and to_{it} is the trade openness of country i in period t. The natural logarithms of all variables in equation (1) were taken and included in the analysis. The World Bank World Development Indicators retrieved all the data in the present study. Descriptive statistics of all data are given in Table 2.

Table: 2
Descriptive Statistics for All Variables

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
lgdppc	864	9.93	0.75	8.17	11.63
lrec	864	0.14	0.1	0.00	0.46
lto	864	0.64	0.3	0.16	1.58

First, the cross-sectional dependence (CD) test was conducted to determine possible cross-sectional dependence among the series. Then, the slope homogeneity test of Pesaran and Yamagata (2008) was used to determine whether the relevant dataset was homogeneous. Panel unit root tests were performed depending on whether the panel dataset is homogeneous and has cross-sectional dependence. The cointegration tests of Westerlund (2007) and Gengenbach, Urbain and Westerlund (2015) were used to find out whether there is a cointegration relationship between the variables. The long-run cointegration coefficients were obtained using the augmented mean group (AMG) estimator, yielding consistent results in cross-sectional dependence. After the long-run coefficients were estimated, the causality between the variables was tested using the causality test developed by Emirmahmutoglu and Kose (2011).

4. Empirical Results and Discussion

4.1. Testing Cross-Sectional Dependence

In panel data analyses, cross-sectional dependence between series should be tested before testing the existence of cointegration. These tests differ according to the homogeneity or heterogeneity of the cross-section. This study used the Breusch-Pagan (1980) Lagrange multiplier (LM) test, the Baltagi, Feng, and Kao (2012) bias-corrected scaled LM test, the Pesaran (2004) scaled LM test, and the Pesaran CD (2004) test for the cross-sectional dependence test. The H_0 hypothesis test of the tests relied on the assumption that *“there is no cross-sectional dependence”*. “N” represents the cross-sectional dimension of the panel data, and “T” means the time dimension. Because T(32) > N(27) was found in the dataset, the Breusch-Pagan (1980) LM test was used.

Table: 3
Results of the Cross-Sectional Dependence Test (CD Test)

Variables	Breusch-Pagan LM (1980)	Pesaran Scaled LM (2004)	Bias-Corrected Scaled LM (2012)	Pesaran CD (2004)
gdppc	8977,67***	325,59***	325,16***	93,58***
rec	7927,39***	285,95***	285,52***	87,61***
to	8916,73***	323,29***	322,86***	92,98***

*Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively.*

According to the Breusch-Pagan (1980) LM test, the relevant dataset had cross-sectional dependence because the H_0 hypothesis test could not be rejected at a 1% significance level (see Table 3).

4.2. Testing the Homogeneity of the Cointegration Coefficients

The slope homogeneity test developed by Pesaran and Yamagata (2008) tests was employed to test whether the slope coefficients between different cross-sections are homogeneous in the models analysed with the panel data, assuming that the regression coefficients of all cross-sectional units are the same.

Table: 4
Results of the Pesaran and Yamagata (2008) Panel Slope Homogeneity Test

	Test Statistics	Prob.
$\tilde{\Delta}$	33,27	0,00***
$\tilde{\Delta}_{adj}$	35,57	0,00***

*Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively.*

As seen in Table 4, the probability values of the slope homogeneity test showed that the H_0 hypothesis, assuming that "*The slope coefficients are homogeneous*", was rejected at the 1% significance level. These results showed that the constant term and the slope coefficients in the cointegration equation are heterogeneous.

4.3. Panel Unit Root Test

Because there was dependence between cross-sections, the panel unit root test called the "cross-sectionally augmented Dickey-Fuller (CADF) test" was used in this study. The cross-sectionally augmented IPS (CIPS) test, which has an asymptotically standard normal distribution, is obtained by taking the arithmetic mean of the test statistics after estimating each horizontal cross-section in the CADF regression. This test was proposed by Pesaran (2007):

$$CIPS=N^{-1}\sum_{i=1}^{N}CADF_i \tag{6}$$

Apart from the CIPS panel unit root test, this study used the second-generation panel unit root test proposed by Bai and Ng (2004), which can be applied under both cross-sectional dependence and the heterogeneity hypothesis. Bai and Ng (2004) divide the time series into common factors and idiosyncratic components and use a unit root test for each related component.

Table: 5
CIPS and Bai-Ng Panel Unit Root Test Results

Variables	Bai and NG		CIPS	
	Constant	Constant and Trend	Constant	Constant and Trend
gdppc	1,83* (0,07)	0,08 (0,94)	-1,88	-1,75
Δ*gdppc*	7,46*** (0,00)	1,88* (0,06)	-2,19**	-8,10***
rec	-0,11 (0,91)	-1,45 (0,15)	-1,59	-1,49
Δ*rec*	15,10*** (0,00)	5,65*** (0,00)	-1,59	-3,44***
to	2,28** (0,02)	3,23*** (0,00)	-1,67	-2,01
Δ*to*	N/A*** (0,00)	6,17*** (0,00)	-2,19**	-1,94
			CIPS Critical Values	
			%10: -2,08 %5: -2,17 %1: -2,32	%10: -2,60 %5: -2,68 %1: -2,83

*Note: "N/A" in the table indicates that the "Eviews-13" software package cannot calculate the statistical value of the related variable, and it only calculates the probability value. The CIPS test is assessed with a maximum lag of 8 and the Akaike info criterion (AIC). ***, ** and * denote significance at 1%, 5% and 10% levels respectively.*
The CIPS and Bai-Ng test null hypothesis is "the series is not stationary."

Based on the data in Table 5, the CIPS and Bai-Ng panel unit root test results indicate that the variables are generally non-stationary at their levels but become stationary at first differences [I(1)]. The Bai-Ng test results show that the gdppc variable is non-stationary in the constant model and remains non-stationary in the constant & trend model, while the

CIPS test results indicate non-stationarity in the constant model but stationarity in the constant & trend model. The Δgdppc variable is stationary [I(1)] in both the constant and constant & trend models in both tests. The rec variable is non-stationary in both models according to the Bai-Ng test, but the CIPS test indicates non-stationarity in the constant model and stationarity in the constant & trend model. The Bai-Ng and CIPS test results confirm that the Δrec variable is stationary [I(1)] in both models. The to variable is stationary [I(1)] in both models according to the Bai-Ng test, while the CIPS test shows non-stationarity in the constant model but stationarity in the constant & trend model. The Δto variable is non-stationary in the constant model but stationary in the constant & trend model, according to both tests. Overall, it is concluded that all variables become stationary at first differences [I(1)], and none of the variables are stationary at second differences [I(2)].

4.4. Panel Cointegration Test

The cointegration relationship between the variables of analysis was tested using the second-generation Westerlund (2007) cointegration test, which can be used in a heterogeneous data set and under horizontal cross-section dependence, and the second-generation Gengenbach, Urbain, and Westerlund (2015) cointegration test, which can also be used in a heterogeneous data set under cross-section dependence.

Table: 6
Westerlund (2007) Cointegration Test Results

	gdppc ~ rec				*gdppc ~ to*		
Statistics	**Value**	**Z-Value**	**Robust Prob.**		**Value**	**Z-Value**	**Robust Prob.**
Gt	-4,86	-17,92	0,00***		-4,03	-13,09	0,00***
Ga	-30,49	-22,33	0,00***		-24,41	-16,50	0,03**
Pt	-22,97	-15,11	0,03**		-19,93	-12,11	0,75
Pa	-23,66	-21,86	0,01**		-20,29	-18,04	0,62

*Note: The Westerlund (2007) test was determined according to the Akaike information criterion (AIC). Robust probability values were estimated through 100 bootstrap cycles. ***, ** and * denote significance at 1%, 5% and 10% levels respectively.*

As seen from the results in Table 6, the Gt and Ga statistics are interpreted for variables whose slope coefficients are heterogeneous. The null hypothesis of the Westerlund (2007) test is established as "*there is no cointegration*". As seen in the left panel of Table 6, the null hypothesis is rejected when the Gt, Ga, Pt and Pa statistics are evaluated for the *rec* variable. There is a cointegration relationship between the relevant variables. As seen in the right panel of Table 6, the null hypothesis is rejected for the *to* variable according to the Gt and Ga statistics. There is also a cointegration relationship between the relevant variables. Apart from the Westerlund (2008) cointegration test, Gengenbach et al. (2015) tests were also used to enhance the robustness of cointegration analysis.

Table: 7
Gengenbach, Urbain and Westerlund (2015) Panel Cointegration Test Results

d.y	**Coefficient**	**T-Bar**	**Prob.**
y(t-1)	−0,71	−3,011	<=0,05

As seen from the results in Table 7, the null hypothesis H_0, which assumes no cointegration relationship, is rejected at a 5% significance level. In other words, the model has a long-run cointegration relationship.

4.5. Estimation of Long-Run Cointegration Coefficients

The augmented mean group (AMG) estimator developed by Eberhart (2009) and Eberhardt and Teal (2010) was used to estimate the long-run cointegration coefficients in the case of cross-sectional dependence and heterogeneity. AMG is a second-generation coefficient estimator that calculates the cointegration coefficients of panel countries when the series is stationary at the first level.

The AMG estimation process starts with pooled regression that expands the equation with year dummies and is estimated using the first difference OLS. Secondly, the group-specific regression model includes an explicit variable or a unit coefficient applied to every group member. Then, the group-specific model parameters are averaged across the panel. The time-invariant fixed effects are captured by an intercept in the regression model (Atasoy, 2017: 737).

Table: 8
Augmented Mean Group (AMG) Estimator Results

Variables	Coefficient	Standard Error	Z-Value	P>Z
rec	−0,43	0,13	−3,45	0,00***
to	0,23	0,07	3,39	0,00***

*Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively.*

The long-run cointegration coefficients in Table 8 show that if renewable energy consumption changes by 1%, per capita income changes by 0.43% in the opposite direction, and if trade openness changes by 1%, per capita income changes by 0.23% in the same direction.

4.6. Panel Causality Test

After the long-run coefficients were estimated, the causality between the variables was tested using the causality test developed by Emirmahmutoglu and Kose (2011), building on the Toda and Yamamoto (1995) causality test. This test is based on a meta-analysis approach that considers cross-sectional dependence and is performed regardless of whether there is a cointegration relationship. Additionally, the test is performed even if the variables are non-stationary at the same level (Emirmahmutoglu & Kose, 2011: 875). To test for Granger non-causality between the variables in heterogeneous mixed panels, Emirmahmutoglu and Kose (2011) expand the lag-augmented vector autoregression (LA-VAR) approach via meta-analysis.

In the first stage of the test, individual Granger causality tests are conducted for each unit separately. The null hypothesis (H_0) tested at this stage is that "*variable (X) does not*

Granger cause variable (Y) in unit (i)". The alternative hypothesis (H_a) is that "*variable (X) Granger-causes variable (Y) in the unit (i)*".

In the second stage, the individual test results are aggregated to perform an overall panel causality test. At the panel level, the null hypothesis (H_0) tested is that "*variable (X) does not Granger cause variable (Y) across the panel as a whole*." The alternative hypothesis (H_a) is that "*variable (X) Granger causes variable (Y) across the panel*."

Table: 9
Emirmahmutoglu and Kose (2011) Causality Test Results-1

H_0: *rec* does not Granger-cause *gdppc*				
Countries	**Lag**	**Wald statistic**	**Probability**	**Decision**
Austria	1	0.01	0.91	Do not reject
Belgium	3	8.87	0.03	Reject
Bulgaria	3	3.30	0.35	Do not reject
Croatia	3	0.96	0.81	Do not reject
Cyprus	1	0.01	0.91	Do not reject
Czechia	2	1.50	0.47	Do not reject
Denmark	1	0.07	0.79	Do not reject
Estonia	3	3.29	0.35	Do not reject
Finland	2	6.38	0.04	Reject
France	1	0.30	0.58	Do not reject
Germany	1	3.49	0.06	Reject
Greece	2	1.23	0.54	Do not reject
Hungary	2	0.02	0.99	Do not reject
Ireland	2	0.10	0.95	Do not reject
Italy	1	2.98	0.08	Reject
Latvia	3	5.95	0.11	Do not reject
Lithuania	2	2.73	0.26	Do not reject
Luxembourg	1	0.05	0.83	Do not reject
Malta	1	2.17	0.14	Do not reject
Netherlands	1	0.92	0.34	Do not reject
Poland	3	3.76	0.29	Do not reject
Portugal	1	0.44	0.51	Do not reject
Romania	3	1.81	0.61	Do not reject
Slovak Republic	2	0.11	0.95	Do not reject
Slovenia	2	1.44	0.49	Do not reject
Spain	1	0.25	0.62	Do not reject
Sweden	1	0.30	0.58	Do not reject
Panel Fisher		**55.17**	**0.43**	**Do not reject**

*Note: The maximum lag length of the test was set as 3, and the appropriate lag length was determined according to the Akaike information criterion (AIC). Critical values were obtained through 10,000 bootstrap cycles. The Fisher bootstrap critical values are 98.31, 84.61, and 77.67 for 1%, 5%, and 10% significance levels, respectively. ***, ** and * denote significance at 1%, 5% and 10% levels respectively.*

According to Table 9, the null hypothesis that "*renewable energy consumption is not the Granger cause of GDP per capita*" is rejected for Belgium, Finland, Germany, and Italy. To put it differently, renewable energy consumption in Belgium, Finland, Germany and Italy is the Granger cause of GDP per capita. The Panel Fisher's test statistic is 55.17 for the entire panel and does not exceed the bootstrap critical values; thus, the null hypothesis cannot be rejected. In other words, renewable energy consumption is not the Granger cause of GDP per capita for the entire panel.

Table: 10
Emirmahmutoglu and Kose (2011) Causality Test Results-2

H_0: *gdppc* does not Granger-cause *rec*				
Countries	**Lag**	**Wald statistic**	**Probability**	**Decision**
Austria	1	1.44	0.23	Do not reject
Belgium	3	1.43	0.70	Do not reject
Bulgaria	3	2.87	0.41	Do not reject
Croatia	3	11.10	0.01	Reject
Cyprus	1	0.27	0.60	Do not reject
Czechia	2	0.12	0.94	Do not reject
Denmark	1	0.23	0.63	Do not reject
Estonia	3	1.28	0.73	Do not reject
Finland	2	2.24	0.33	Do not reject
France	1	0.61	0.43	Do not reject
Germany	1	3.04	0.08	Reject
Greece	2	11.30	0.00	Reject
Hungary	2	0.04	0.98	Do not reject
Ireland	2	6.53	0.04	Reject
Italy	1	2.54	0.11	Do not reject
Latvia	3	6.01	0.11	Do not reject
Lithuania	2	3.13	0.21	Do not reject
Luxembourg	1	0.02	0.90	Do not reject
Malta	1	2.32	0.13	Do not reject
Netherlands	1	4.76	0.03	Reject
Poland	3	2.79	0.43	Do not reject
Portugal	1	3.21	0.07	Reject
Romania	3	7.99	0.05	Reject
Slovak Republic	2	1.00	0.61	Do not reject
Slovenia	2	0.75	0.69	Do not reject
Spain	1	2.91	0.09	Do not reject
Sweden	1	0.81	0.37	Do not reject
Panel Fisher		**88.89**	**0.01**	**Reject**

*Note: The maximum lag length of the test was set as 3, and the appropriate lag length was determined according to the Akaike information criterion (AIC). Critical values were obtained through 10,000 bootstrap cycles. The Fisher bootstrap critical values are 93.64, 81.36, and 76.19 for 1%, 5%, and 10% significance levels, respectively. ***, ** and * denote significance at 1%, 5% and 10% levels respectively.*

According to Table 10, the null hypothesis “*GDP per capita is not the Granger cause of renewable energy consumption*” is rejected for Croatia, Germany, Greece, Ireland, Netherlands, Portugal and Romania at a 10% significance level. In other words, GDP per capita is the Granger cause of renewable energy consumption in Croatia, Germany, Greece, Ireland, Netherlands, Portugal and Romania. The Panel Fisher’s test statistic is 88.89 for the entire panel and exceeds the 5% bootstrap critical value; thus, the null hypothesis is rejected. In other words, GDP per capita is the Granger cause of renewable energy consumption for the entire panel.

Table: 11
Emirmahmutoglu and Kose (2011) Causality Test Results-3

H_0: *to* does not Granger-cause *rec*				
Countries	**Lag**	**Wald Statistic**	**Probability Value**	**H_0**
Austria	1	0.31	0.58	Do not reject
Belgium	2	0.72	0.70	Do not reject
Bulgaria	2	3.06	0.22	Do not reject
Croatia	2	3.10	0.21	Do not reject
Cyprus	3	7.26	0.06	Reject
Czechia	3	0.57	0.90	Do not reject
Denmark	1	0.20	0.66	Do not reject
Estonia	3	7.11	0.07	Reject
Finland	2	1.54	0.46	Do not reject
France	1	0.01	0.93	Do not reject
Germany	1	2.68	0.10	Do not reject
Greece	1	2.07	0.15	Do not reject
Hungary	2	2.15	0.34	Do not reject
Ireland	3	6.85	0.08	Reject
Italy	1	0.41	0.53	Do not reject
Latvia	1	0.05	0.83	Do not reject
Lithuania	3	3.26	0.35	Do not reject
Luxembourg	1	0.00	0.98	Do not reject
Malta	1	0.00	0.99	Do not reject
Netherlands	1	0.11	0.74	Do not reject
Poland	3	0.32	0.96	Do not reject
Portugal	1	0.99	0.32	Do not reject
Romania	1	0.68	0.41	Do not reject
Slovak Republic	3	2.17	0.54	Do not reject
Slovenia	3	5.10	0.17	Do not reject
Spain	3	5.25	0.15	Do not reject
Sweden	1	2.44	0.12	Do not reject
Panel Fisher		**58.61**	**0.31**	**Do not reject**

*Note: The maximum lag length of the test was set as 3, and the appropriate lag length was determined according to the Akaike information criterion (AIC). Critical values were obtained through 10,000 bootstrap cycles. The Fisher bootstrap critical values are 95.22, 82.41, and 76.65 for 1%, 5%, and 10% significance levels, respectively. ***, ** and * denote significance at 1%, 5% and 10% levels respectively.*

According to Table 11, the null hypothesis "*trade openness is not the Granger cause of renewable energy consumption*" cannot be rejected for all countries except Cyprus, Estonia and Ireland. The Panel Fisher's test statistic is 58.61 for the entire panel and does not exceed the bootstrap critical values; thus, the null hypothesis cannot be rejected. In other words, trade openness is not the Granger cause of renewable energy consumption for the entire panel.

Table: 12
Emirmahmutoglu and Kose (2011) Causality Test Results-4

H_0: *rec* does not Granger-cause *to*				
Countries	**Lag**	**Wald Statistic**	**Probability Value**	**H_0**
Austria	1	0.05	0.83	Do not reject
Belgium	2	0.39	0.82	Do not reject
Bulgaria	2	1.03	0.60	Do not reject
Croatia	2	1.41	0.49	Do not reject
Cyprus	3	3.92	0.27	Do not reject
Czechia	3	1.62	0.66	Do not reject
Denmark	1	0.24	0.63	Do not reject
Estonia	3	7.02	0.07	Reject
Finland	2	1.13	0.57	Do not reject
France	1	0.16	0.69	Do not reject
Germany	1	1.78	0.18	Do not reject
Greece	1	0.59	0.44	Do not reject
Hungary	2	1.54	0.46	Do not reject
Ireland	3	4.60	0.20	Do not reject
Italy	1	0.08	0.78	Do not reject
Latvia	1	2.19	0.14	Do not reject
Lithuania	3	40.14	0.00	Reject
Luxembourg	1	0.31	0.58	Do not reject
Malta	1	0.02	0.89	Do not reject
Netherlands	1	0.07	0.80	Do not reject
Poland	3	18.77	0.00	Reject
Portugal	1	1.06	0.30	Do not reject
Romania	1	0.01	0.91	Do not reject
Slovak Republic	3	2.07	0.56	Do not reject
Slovenia	3	3.03	0.39	Do not reject
Spain	3	6.12	0.11	Do not reject
Sweden	1	0.01	0.91	Do not reject
Panel Fisher		**94.11**	**0.01**	**Reject**

*Note: The maximum lag length of the test was set as 3, and the appropriate lag length was determined according to the Akaike information criterion (AIC). Critical values were obtained through 10,000 bootstrap cycles. The Fisher bootstrap critical values are 97.85, 84.12, and 77.90 for 1%, 5%, and 10% significance levels respectively. ***, ** and * denote significance at 1%, 5% and 10% levels respectively.*

According to Table 12, the null hypothesis "*renewable energy consumption is not the Granger cause of trade openness*" cannot be rejected for all countries except Estonia, Lithuania and Poland. The Panel Fisher's test statistic is 94.11 for the entire panel and exceeds the 5% bootstrap critical value; thus, the null hypothesis is rejected. In other words, renewable energy consumption is the Granger cause of trade openness for the entire panel.

5. Conclusion and Policy Recommendations

Although many studies investigate the relationship between renewable energy and growth within the framework of 4 different hypotheses for different countries/countries in different periods/analysis methods, there has yet to be a consensus on the renewable energy-growth relationship. Due to the importance of renewable energy, especially for energy-dependent countries, it is important to re-examine the relationship between renewable energy and economic growth in these countries according to these hypotheses. In addition, trade openness increases economic growth by transferring technology to produce renewable energy. Therefore, trade openness is important in the relationship between renewable energy and growth. The relationship between renewable energy, growth, and trade openness in this framework should be re-examined, especially in energy-dependent countries. In addition, EU countries need to increase renewable energy production to reduce their dependence on fossil fuels and prevent environmental pollution caused by fossil fuels, especially in EU countries that are energy-dependent on Russia. Therefore, in this study, the relationship between renewable energy consumption, economic growth, and trade openness for energy-dependent EU countries is analysed using a panel data method with data for the period 1990-2021. The study contributes to the literature because there is no consensus on this issue in the literature and because there are few studies investigating this issue for energy-dependent EU countries.

The results of the cointegration tests by Westerlund (2007) and Gengenbach, Urbain, and Westerlund (2015) indicate a long-term relationship between renewable energy consumption, economic growth, and trade openness. According to the long-term cointegration coefficients obtained for the panel, renewable energy consumption negatively affects economic growth, while trade openness positively affects growth. Furthermore, the coefficients related to these variables were statistically significant at the 1% significance level.

The causality test results by Emirmahmutoglu and Kose (2011) found that renewable energy consumption is not the cause of economic growth across the panel. Additionally, the causality results indicate that economic growth is the cause of renewable energy consumption across the panel. These findings suggest that the conservation hypothesis is valid for the panel. These results support the studies conducted by Ocal and Aslan (2013), Kahia et al. (2016), Rahman and Velayutham (2020), and Minh and Van (2023) in the literature. When examining the causality test results at the country level, it was observed that renewable energy consumption is not the cause of economic growth in EU countries, except for Belgium, Finland, Germany, and Italy. However, in most EU countries, except for Croatia, Germany, Greece, Ireland, the Netherlands, Portugal, and Romania, economic growth is not the cause of renewable energy consumption. These findings suggest that the growth hypothesis is valid for Belgium, Finland, and Italy; the conservation hypothesis is valid for Croatia, Greece, Ireland, the Netherlands, Portugal, and Romania; and the feedback hypothesis is valid for Germany.

On the other hand, the causality test results by Emirmahmutoglu and Kose (2011) indicate no causality relationship between trade openness and renewable energy consumption across the panel. At the country level, a unidirectional causality relationship between trade openness and renewable energy consumption was found only in Cyprus, Estonia, and Ireland. However, the causality test results reveal a unidirectional causality relationship between renewable energy consumption and trade openness across the panel. A unidirectional causality relationship between renewable energy consumption and trade openness was detected at the country level for all EU countries except Estonia, Lithuania, and Poland.

The panel causality test results indicate that economic growth plays a significant role in renewable energy consumption across the panel. At the country level, renewable energy consumption plays a significant role in economic growth in Belgium, Finland, and Italy, while in Germany, the results show that both variables are mutually causal. In this context, as a policy recommendation, EU countries should continue to support research programs to increase renewable energy production to reduce both their energy dependence and environmental problems caused by fossil fuels. It is also recommended that the relevant policymakers in the EU countries included in the analysis should expand some fiscal incentives, such as tax reduction for renewable energy investments, to increase renewable energy investments.

Additionally, EU countries must increase research development (R&D) expenditures to promote further the production and consumption of renewable energy and enhance investments to develop human capital in these areas. On the other hand, it is recommended that the banking sector in EU countries provide more loans with low interest rates and long-term loans to sectors investing in renewable energy. This approach will encourage investment in renewable energy by enabling these sectors to borrow at lower costs, thereby increasing such investments. Lastly, policymakers in EU countries are advised to collaborate with international companies that are experts/experienced in renewable energy and possess sufficient financial capacity. Nevertheless, the unidirectional causality from renewable energy to trade openness across the panel contradicts what was expected. To put it differently, trade openness facilitates technology transfer for renewable energy and meets the energy demand for sustainable energy, thereby positively affecting economic growth. Taken together, these results showed that renewable energy encourages trade openness. Based on this result, renewable energy helps the integration of the EU countries in international trade.

Due to the importance of renewable energy production/investments not only for energy-dependent countries but for all global economies, it is recommended that research in this field be increased. Future studies are encouraged to explore the relationship between investments in renewable energy sources (solar energy, wind energy, wave energy, geothermal energy, hydropower, biomass energy) and macroeconomic indicators. Furthermore, future research should investigate the effects of renewable energy production on different sectors of the economy and its impact on growth and the trade balance. In this context, policymakers could identify which sectors benefit the most from renewable energy and increase incentives for investments in renewable energy within those sectors.

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