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Research Article

Policies to reduce pollution and maintain economic sustainability with the use of renewable energy in European Union countries

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Abstract: A major global challenge humanity faces today is how to strike a balance between the mitigation of environmental degradation and the achievement of sustainable economic growth. In this respect, this study applied an autoregressive distributed lag to the panel data of 28 European Union (EU-28) countries from 2000 to 2020. The study's results confirm the existence of a positive and significant long-term nexus between environmental sustainability, renewable energy consumption, and economic growth in EU-28 countries. Furthermore, the empirical results indicate that real capital formation, carbon emissions, and other environmental factors are the principal determinants of long-term growth in the EU. Using Dumitrescu and Hurlin's (2012) research, we found that the non-causality in the heterogeneous panel results showed long-run bidirectional causal relationships among renewable energy consumption, economic growth, and other growth determinants. Therefore, we can say that the consumption of renewable energy sources in the 28 EU countries is a reliable way to mitigate environmental pollution. This indicates that attaining the Sustainable Development Goals by using renewable energy and reducing carbon emission is feasible in EU-28 countries by 2030 and should also be adopted by all countries as an effective global policy.

Keywords: Renewable energy consumption; financial development; financial manageability

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1. Introduction

The critical role of renewable energy in generating jobs and maintaining economic development has been recognized by governments, policymakers, private institutions, and individuals worldwide. For example, by consuming more renewable energy, the European Union has the potential to reduce its reliance on imported fossil fuels, making its energy production and usage more sustainable for its economies and environment. Furthermore, environmentalists and other researchers' interest has led to further inquiry into non-economic environmental factors such as immigration, healthcare, and other related determinants (Saidi and Omri, 2020; Omri, 2013; Zhao and Magoulès, 2012).

The relationship between renewable energy and economic growth, as well other primary growth determinants, has been a topic of discussion among policymakers and researchers in recent years (Yip *et al.,* 2022; Soytas *et al.*, 2022; Mukhtarov, 2022; Apergis and Payne, 2010; Apergis and Pinar, 2021; Ahmadi and Frikha, 2022; Bourcet, 2020; Wolde-Rufael and Weldemeskel, 2020; Arminen, 2019; Dong, 2017; Ur Rahman, 2019; Paramati and Gupta, 2017; Bekun *et al.,* 2018; Emir and Bekun, 2019; Akadiri *et al.,* 2019).

In 2020, the Renewable Energy Directive (RED) targets were adopted by the European Council and the European Union Parliament. This RED initiative established progressive goals for its members. The goals included achieving a 20 % renewable energy share in the final energy consumption mix by 2020. This involved establishing, inter alia, sectorial goals for transportation, temperature control, electricity, planned energy policy initiatives for combining different types of renewable technologies, the use of corporate mechanisms to implement joint support schemes and joint ventures, and statistical transfers among member states. However, in order to achieve these objectives, a thorough understanding of the long-run equilibrium impacts and benefits of renewable energy in fostering and maintaining economic growth is required.

Our current research, which uses EU countries as a case study, aims to contribute to the recent and ongoing debate on the relationship between renewable energy and economic development. Unlike previous research that has only focused on the causal relationship between macroeconomic variables, this study sets out to investigate whether there is an important long-lasting equilibrium relationship between the variables of interest. The study also looks into the implications of that relationship across Europe in the direction of environmental sustainability. We focus on the long-term environmental sustainability of renewable energy and economic development in the EU. Using an autoregressive distributed lag (ARDL) model, we estimate a dynamic panel growth model. We build a panel of European Union member countries from

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2000-2020 and use it to create an error correction model set up within an ARDL system. This model was calculated using three different approaches: pooled mean group (PMG), mean group (MG), and dynamic fixed effect (DFE). These estimation techniques are ideal for dealing with heterogeneous tables. The stationarity and cointegration of the macro panel data in our analysis was assessed. Our findings show that EU countries are convergent on a long-term environmental sustainability direction with renewable energy. It is used in economic growth which is positively associated. Our findings are in line with those of Sadorsky (2009) for G7 countries and those of Ahmadi and Frikha (2022) for Eurasian countries.

This research contributes to the existing literature by investigating the long-term relationships between renewable energy and economic growth on environmental sustainability in Europe. This is achieved using the Combined Medium Group (PMG), the Medium Group (MG), and Dynamic Constant Effect Techniques (DFE). The dynamic team system uses a relatively new and unique method to assess short- and long-term relationships between renewable energy and economic development. The pace of change was also reported, showing how rapidly or slowly EU States are moving towards or away from a long-term environmental sustainability path. (ii) In 2014, Minigaki, while explaining the neutrality hypothesis, argued that renewable energy was used unequally and inadequately by EU states from 1997 to 2007. Our research uses larger and newer dashboard data from 2000 to 2020 in all EU states. Evaluating the long-term relationship between renewable energy and economic growth throughout our revised EU panel dataset shows that the use of renewable energy across Europe is an important means to achieve long-term environmental cleanliness and safety. This suggests that the region is on track to achieve environmental sustainability.

The study aimed to highlight the existence of a significant nexus between environmental sustainability, renewable energy consumption and economic growth in the EU-28 countries. Our findings provided useful information for policymakers in Europe considering renewable energy development.

1.1. Literature review

The Brundtland Report (1987) gave rise to the Sustainable Development (SD) tenets. During its evolution, it shifted away from economic growth and development in general toward the creation of a sustainable economy (Ramcilovic-Suominen and Pülzl, 2018, Agbedahin, 2019). Since both are typically viewed as being inherently incompatible with one another, modern economies have endeavored to reconcile the necessity to protect natural resources and ecosystems with the requirement for economic growth (Kopnina, 2017). Even if one does not take a firm stance, it may be said that a society's sustainability depends on a balance between economic and social sustainability and a between environmental and economic sustainability (Ajmal *et al.*, 2018).

According to a recent article, nuclear energy, hydropower, and wind energy are best for environmental sustainability. The findings showed that emission reduction goals were not met. Indeed, it is necessary to increase the proportion of all zero-emission technologies by 1-2% in order to accomplish this. The article emphasized that the largest renewable energy source (20.28%) is offshore wind. Relevant studies have found a strong correlation between RESs and an efficient, safe, and environmentally friendly future for EU energy.

More recent research has explored and provided insight into the relationship between the environment, renewable energy, and economic development. For example, Sadorsky (2009) used Pedroni's panel cointegration regression techniques to investigate the relationship between renewable energy use, CO2 emissions, and oil prices in G7 countries from 1980 to 2005. Sadorsky concluded that the variables had a long-lasting equilibrium relationship. According to empirical studies, CO2 emissions and real GDP per capita are the most important determinants of renewable energy use, while oil prices have a minor negative impact on renewable energy. Ahmadi and Frikha (2022) investigated the causal relationship between CO2 pollution, GDP, and renewable energy use in the United States from 1960 to 2007. Using the updated Granger causality test, they found unidirectional causality between nuclear energy and CO2 emissions and no causal association between CO2 emissions and renewable energy. They believed that the use of renewable energy is still in its infancy because it had no effect on pollution reduction. Omri and Kahouli (2014) also conducted background studies in Central America for the Organization for Economic Cooperation and Development (OECD) (OECD). Using a multivariate panel data model, researchers focused on the Commonwealth of Independent States (CIS) and, more recently, Eurasian countries from 1992 to 2007. In both the short and long term, they discovered a bidirectional causality between economic development and renewable energy. Furthermore, Marques et al. (2010) used fixed effect vector decomposition panel data methods to examine the motivation for renewable energy adoption in European countries from 1990 to 2006. Their empirical results show that CO2 emissions and existing energy sources obstruct the delivery of renewable energy.

Furthermore, Omri and Nguyen (2014) used a multivariate panel model to analyze the relationship between economic growth and renewable energy in European countries from 1997 to 2007. Additional variables such as job production, GHG emissions, and final energy consumption were included in their model. Since the empirical findings provided no evidence of a causal relationship between renewable energy use and economic development, the authors believed that the neutrality hypothesis held true in the countries studied. They believed that this was due to a skewed and insufficient use of renewable energy sources across Europe. Similarly, Ocal *et al.* (2013) used Autoregressive Distributed Lag (ARDL) and Johansen cointegration techniques to investigate the Granger causality relationship between renewable energy consumption and economic growth for Turkey in both country-specific and multicountry empirical frameworks. The study presented ambiguous results, with no clear relationship between economic development and renewable energy use. Similaly, Lin and Moubarak (2014) investigated the long-term relationship between renewable energy and economic growth in China. Their results indicated that economic growth and the use of renewable energy have a long-run bidirectional causal relationship. This supports the findings of Akpan and Akpan (2012), suggesting that renewable energy, labor, and capital all contribute significantly to Pakistan's economic development.

Furthermore, recent research by Omri *et al.* (2015) sheds light on the effects of immigration on the socio-economic climate of the EU's largest countries. The EU's three most popular countries (France, Germany, and the United Kingdom) have all faced socio-economic problems due to immigrant influxes and migrant classification. Omri *et al.* (2015) also suggested that healthcare and immigration policies in the United States substantially alleviate socio-economic issues. These studies provide not only new evidence of an immigration-environment nexus, but also provide valuable insight into the pressing issue of immigration and the healthcare system. Akadiri *et al* (2019) used the Environmental Kuznets Curve (EKC) hypothesis on states that were popular tourism destinations to investigate the possible effect of globalization from a different viewpoint. Akadiri *et al* (2019) corroborated the globalization-tourism-induced EKC hypothesis by finding that globalization and income had a positive impact on carbon emissions.

1.2. Indications for global environmental sustainability from the EU's renewable energy outlook

Globally, especially among the European Union member states, there has been a concerted effort to reduce CO2 emissions and make a consistent transition from conventional to renewable energy sources. Across Europe, a handful of renewable energy sources (RES) are currently being investigated using cutting-edge technologies (World Energy Resources, 2016). The rapid increase in the consumption of renewable energy among EU member countries has been confirmed by data from the European Environmental Agency (EEA), Eurostat, and the National Renewable Energy Action Plan (NREAP). This is shown in Table 1. In the middle of 2010, the NREAP was submitted by the EU member states and was approved as an indicative supranational route to reach the renewable energy source goal for 2020. The document's guidelines were revised as interim trajectories were noted in REN21 (2016) and the Renewable Energy Directive (EEA, 2017). In the EU, renewable energy is primarily used in three major business sectors: renewable power, renewable temperature control (heating and cooling), and transportation.

The EU has completed the Kyoto Protocol's first commitment cycle of 2008-2012 as a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) (European Commission's Progress Report, 2016). According to the survey, the commission (and its member states) are on track to meet their 2020 GHG emission reduction deadline, which corresponds to the Kyoto Protocol's second commitment duration of 2013-2020. Several initiatives have been adopted by the regional body (EU) and individual constituent nations.

Policies such as 2001/77/EC and 2009/28/EC4 have been put in place to aid the pursuit of the above-mentioned goals and encourage the use of renewable energy sources. This is in line with the French government's recent announcement that it will ban the sales of gasoline and diesel vehicles by 2040 as part of aggressive and far-reaching attempts to wean the country's economy off fossil fuels and, as a result, achieve its Paris climate agreement goals. The World Economic Forum (2017) and the European Environment Agency (2017), published reports that showed the evolution in demands for renewable energy of EU member countries in 2015, as well as projections for 2020. The evidence in these studies, as shown in Table 1, confirms that eleven (11) of the member states (countries with negative point goals in Table-1) met their 2020 targets on time.

The EU has recently developed new sets of renewable energy goals including, GHG emission reduction and energy conservation, and renewable energy goals to be reached by 2030. Policies aimed at achieving these goals are required of all member countries. As a result of a political agreement reached in June 2018 by the European Commission (EC), the Council of Ministers, and the European Parliament, the European Union now has a strong path on its energy and climate priorities for 2030. These goals include, among others; achieving 40 percent mitigation in domestic GHG emissions, with yearly GHG emission mitigation targets for EU member states from 2021-2030, second, an imperative target to improve the proportion of renewable energy sources in the EU member states to about 32 percent of total final energy consumption by 2030, and third, a

Table 1
Share of EU Member States' RES Share of Total RE Usage and Projection for 2020

European Union	Share of total renewable energy		Real GDP per capita growth	
Member states	2015 (%)	2020 (%)	2015 (%)	2020 (%)
Austria	33	34	-0.11	3.93
Belgium	7.8	13	0.9	3.83
Bulgaria	18.2	16	4.27	6.74
Croatia	29	20	2.47	5.93
Cyprus	9.4	13	2.27	4.24
CzechRepublic	15.1	13	4.33	1.58
Denmark	30.8	30	0.89	5.32
Estonia	28.6	25	1.38	8.19
Finland	39.3	38	-0.06	4.68
France	15.2	23	0.62	4.46
Germany	14.6	18	0.84	4.11
Greece	15.4	18	0.44	6.02
Hungary	14.5	13	3.39	4.62
Ireland	9.2	16	24.66	4.55
Italy	17.5	17	0.87	3.64
Latvia	37.6	40	3.55	8.2
Lithuania	25.8	23	2.74	7.17
Luxemburg	5	11	1.58	4.70
Malta	5	10	6.31	6.44
Netherlands	5.8	14	0.60	5.3
Poland	11.8	15	3.91	7.48
Portugal	28	31	2.02	4.2
Romania	24.8	24	4.43	8.14
Slovakia	12.9	14	3.73	6.54
Slovenia	22	25	2.24	5.13
Spain	16.2	20	3.28	5.05
Sweden	53.9	49	2.99	3.16
United Kingdom	8.2	15	1.38	5.83

Sources: Renewable Energy in Europe 2019 by EEA and World Economic Forum 2019

Table 2
Summary statistics of the variables

	Lgdp	Lren	Lco2	Lgfcf	Lfen	Ltr
Mean	10.048	2.176	2.013	24.394	4.290	15.561
Median	10.201	2.242	2.028	24.566	4.378	15.561
Max	11.617	3.91	3.212	27.29	4.603	18.242
Min	8.237	-2.438	0.986	20.811	2.843	13.142
Std. Dev	0.742	1.056	0.393	1.607	0.306	1.251
Skewness	-0.393	0.965	0.217	-0.027	-2.003	0.222
Kurtosis	2.370	4.654	3.340	2.175	7.157	2.225
Jarque-Bera	22.130**	141.133**	6.695**	14.967**	729.011**	17.45**
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Sum	5274.82	1142.95	1056.84	12806.51	2252.99	8170.53
Sum Sq. Dev	288.33	586.52	80.61	1356.27	49.00	819.32

Note: Refer to section 3 for the definition of variables. ** & *** significant at 1% & 5% levels

target increase of about 32.5 percent in energy efficiency by 2030 at EU level (EEA, 2018).

2. Data and Empirical Model

2.1. Data

For the empirical estimates, we used the World Bank database to create a panel dataset of European Union countries (as shown in Tables 1) for the period of 2000-2020 (Online). Due to the lack of longer historical data, the study's scope was limited to this decade. The variables that were used in this study are as follows.

The dependent variable, real GDP (lGDP), is measured in the 2010 value of the US dollar and is used as a proxy for economic growth. Energy obtained from renewable sources such as geothermal heat, waves, rain, tides, and sunlight is referred to as renewable energy consumption (REN). They are replenished naturally on a human timescale and have been shown to emit negligible quantities of greenhouse gases. The consumption of renewable energy is expressed as a percentage of total final energy consumption. We also included two commonly used control variables in the literature on renewable energy and economic growth: carbon emissions (CO2) and actual gross fixed capital creation (GFCF). These variables are important growth determinants (Sadorsky, 2009; Ahmadi & Frikha, 2022). Finally, according to Lee and Brahmasrene (2013), an alternative source of energy—fossil fuel (FEN)—and an alternative determinant of growth—tourism (TR)—are used in conducting robustness tests. Tourist arrivals are seen as a proxy for tourism. This is done to eliminate the possibility of encountering a multicollinearity issue while using tourism receipts. Table 2 shows the descriptive figures for the variables.

2.2. Empirical Models

2.2. ECM-ARDL Cointegration Approach

A multivariate framework is used to examine the long-run relationship between renewable energy consumption and real GDP, building on Menegaki's (2011) work and other existing studies on the causal link between renewable energy and economic growth (e.g. Apergis & Payne, 2010; Omri et al., 2014). What follows is the study's stated model:

$$GDP_{it} = f\,(REN_{it}, CO2_{it}, GFCF_{it}) \quad (1)$$

The natural logarithm in the linear specification of Eq.1 is given below:

$$\ln RGDP_{it} = \beta 0 + \beta 1 \ln REN_{it} + \beta 2 \ln CO2_{it} + \beta\, 3 \ln GFCF_{it} + \varepsilon_{it} \quad (2)$$

The study begins with the following economic growth models within the common Autoregressive Distributed Lag (ARDL: p q,) system that integrates the lagged dependent variable and lagged explanatory variables, as described by Pesaran et al. (1999):

$$\ln RGDP = \alpha i + \sum_{j=1}^{p} \delta\, i,j + \ln RGDP_{i,t-j} + \sum_{j=0}^{q} \gamma\, i,j\ Z_{i,t-j} + \varepsilon_{it} \quad (3)$$

In equation 3, for i N =1,2,....., and t T=1, 2,....., the vector Zi t, is a vector indicating explanatory variables of interest and the control variables that are generally employed in energy-growth empirical analyses. While αi is the country-level fixed effects, δij represents the coefficient of the lagged, ln GDPit and ij,γ represents the coefficients of the lagged independent variables

The ARDL cointegration technique is widely employed among researchers due to its unique econometric merits when compared to other conventional cointegration methods. The approach takes into consideration endogeneity problems and also reports short-run, as well as long-run parameter estimates individually in a single model. The cointegration technique is applicable regardless of the integration order of the variables or model, i.e., whether I(0), I(1) or partly integrated.

Table 3 shows the results of panel unit tests proposed by Choi (2001) and Im et al. (2003). According to the findings, the main variables are non-stationary at speeds, but stationary at the first difference. As a result, it is assumed that the variables are first-order integrated. Our variables' stationarity or integration order necessitates a further cointegration examination based on the regressors' consistency. This is done in addition to the ARDL cointegration exam. Pedroni (2004), proposed the panel cointegration test, which uses the null hypothesis of no cointegration in heterogeneous panels and the long-run coefficients estimate as a sensitivity or robustness check.

Pedroni's Fully Modified Ordinary Least Square (FMOLS) estimation method for heterogeneous cointegrated panels was used to estimate the cointegrating vectors (2001). This method makes it possible to estimate cointegration vectors consistently and efficiently. It also clarifies any issues resulting from the endogenous existence of regressors, as well as the variable's time-series properties in terms of integration and cointegration. At the 1% significance stage, the cointegration test results in Table 4 confirm the existence of a long-run cointegration equilibrium relationship between the variables of interest. It is possible to conduct the selected ARDL specification by rewriting equation 3 into the error correction model (ECM) as follows:

$$\Delta lnlGDP = \phi i lnlGDP_{i,t-1} + \theta i\, Z_{i,t} + \sum_{j=1}^{p-1} \delta\, i,j \Delta \ln lGDP_{i,t-j} + \sum_{j=0}^{q-1} \gamma\, i,j \Delta Z_{I,t-j} + \varepsilon_{it} \quad (4)$$

where

Table 3
Panel Unit Root Test Result

	Im-Pesaran-Shin (IPS) test		Fisher-type (Fisher) test	
Variables	Level	Var	Level	Var
Lgdp	5.03 (1.000)	-7.23* (0.000)	-7.23* (0.000)	146.12* (0.000)
Lren	0.42 (0.661)	-12.72* (0.000)	57.949 (0.403)	244.050* (0.000)
Lco2	2.50 (0.993)	-13.80* (0.000)	54.65 (0.525)	261.29* (0.000)
Lgfcf	2.80 (0.998)	-9.08* (0.000)	46.77 (0.805)	169.65* (0.000)
Lfen	1.82 (0.965)	-13.83* (0.000)	62.38 (0.259)	260.41* (0.000)
Ltr	-4.40 (0.560)	-8.74* (0.000)	60.47 (0.340)	178.89* (0.000)

Note: Variables are in their natural logarithm and stationary at *, 1 % significant level.

Table 4
Cointegration Test

Weighted	Coefficients	Prob.	Coefficients	Prob.
Alternative hypothesis: common AR coefs. (within-dimension)				
Panel rho-Statistic	3.79**	0.999	4.115**	1.000
Panel PP-Statistic	-6.440**	0.000	-5.791**	0.000
Panel ADF-Statistic	-6.082**	0.000	-5.593**	0.000
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group rho-Statistic	5.820**	1.000	-	-
Group PP-Statistic	-9.570**	0.000	-	-
Group ADF-Statistic	-7.114**	0.000	-	-

Note: Refer to section 3 for the definition of variables. ** & *** significant at 1% & 5% levels

$\phi i = -(1 - \sum_{j=1}^{p} \delta\, i, j)$, $\theta i = \frac{\sum_{j=0}^{q} \gamma i,j}{1-\sum_{j=1}^{p} \delta i,j} + \frac{\sum_{j=0'}^{q}}{\phi}$, $\delta i,j = \sum_{d=j+1}^{p} \delta\, i, d$ and $\gamma i,j = - \sum_{d=j+1}^{q} \gamma i, d$

The former part of equation 4, ϕi (In lGDPi,t-1 - θiZi,t) represents the speed of adjustment in the level of growth to deviation from the long-run equilibrium level with the independent variables, while the latter part represents the short-run dynamics of economic growth. The vector parameter θi is the coefficient of the independent variables in estimating the long-run growth, while the parameter coefficient ϕi captures the error-correcting speed of adjustment term. Meanwhile, if the error-correcting speed of the adjustment term is less than zero ($\phi i< 0$), the growth model provides evidence in support of a long-run relationship between, ln GDPi t and the explanatory variables (determinants of dependent variables). The speed of adjustment (ϕi), determines the rate of convergence of the model from the short-run deviation path to the long-run equilibrium path, and vice versa. On the other hand, if the error correcting speed of the adjustment term is greater than or equal to zero ($\phi i \geq 0$), this indicates the absence of a stable linkage between the dependent variable and its determinants in the long-run. Thus, to achieve the study objective, the long-run coefficients(θi) and the speed of the adjustment (ϕi) parameter estimates are the main attractions in our empirical estimation.

In applying ARDL models, p q ==1 is mostly specified. This model specification is mostly used in literature that employs ARDL frameworks to carry out empirical investigations (Bassanini & Scarpetta, 2002; Martínez-Zarzoso & Bengochea-Morancho, 2004; Frank, 2009; Xing, 2012). Our study also suggests a model with p q ==1. Therefore, we derive the equation below by presuming ARDL (1, 1) in equation 4:

$$\ln lGDP_{i,t} = \alpha i + \delta i \ln lGDP_{i,t-1} + \gamma_{i,0} Z_{i,t} + \gamma_{i,1} Z_{i,t-1} + \varepsilon_{it} \quad (5)$$

Thus, we can now reformulate equation 5 in the following error correction model (ECM):

$$\Delta \ln lGDP_{i,t} = \phi i(\ln lGDP_{i,t-1} - \theta_{0,1} - \theta i Z_{i,t}) - \gamma_{i,1} \Delta Z_{i,t} + \varepsilon_{it} \quad (6)$$

Where $\phi = -(1-\delta_i)$, $\theta = -\frac{\gamma i,0 + \gamma i,1}{\phi}$ and $\theta_{0,i} = -\frac{\alpha i}{\theta i}$

The following estimators were used to approximate equation 6: the Mean Group (MG) estimator, the Pooled Mean Group (PMG) estimator, and the Dynamic Fixed-Effect (DFE) estimator. When both N and T are high, the MG estimator remains consistent and does not impose restrictions. It is sensitive to outliers and sample size, especially when the time dimension (T) is small and even when the cross-section (N) is high (Blackburne & Frank, 2007). On the other hand, the DFE estimator assumes homogeneity across cross-sections in both short-run and long-run coefficients, without taking into account the constant term (intercept). Pesaran et al. (1999) proposed the PMG estimator as a comparative estimator between the MG and DFE estimators. Although the PMG estimator indicates that the long-run coefficients I are homogeneous, other slope coefficients will differ across cross-sections. When the long-run slope coefficient's heterogeneity statement is checked, the PMG estimator becomes inconclusive. When the homogeneity assumption is met, the PMG estimator becomes more stable, reliable, and more efficient than the MG estimator. The Pooled Mean Group (PMG) estimator and the Dynamic Fixed Effect (DFE) estimator, according to Pesaran and Smith (1995), have some complementary characteristics. Pesaran et al. (1999), pointed out that the PMG estimator is more robust and accurate when dealing with lag orders and outliers. Hausman tests are used to select the most suitable of these estimators.

2.2.2 Panel Granger Causality Test Approach.

For heterogeneous non-causality, we use the Granger causality test proposed by Dumitrescu and Hurlin (2012). When T is greater than N, and vice versa, this test is applicable. It is based on the Vector Autoregressive Model (VAR) and is robust even when cross-sectional dependency is present. The asymptotic and semi-asymptotic distributions are both present in this test. When T exceeds N, the asymptotic distribution is used, and when N exceeds T, the semi-asymptotic distribution is used. The following equation gives the linear model specification:

$$Y_{it}= \sum_{K=1}^{K} \gamma i(k) y_{i,t-k} + \sum_{K=1}^{K} \beta i\ (k)\ x_{i,t-k} + \varepsilon_{i\ ,t}$$

Where K denotes the lag time, $\gamma i^{(k)}$ I denotes the autoregressive parameter, and $\beta i^{(k)}$ I denotes the regression coefficient that can differ between classes. The causality test is generally distributed and takes heterogeneity into account. For heterogeneous models, the homogenous non-stationary hypothesis (HNC) is used to estimate causal relationships. The following are the null and alternative hypotheses for HNC in the test:

$H_0 : \beta i = 0\ \forall i = 1, \ldots\ldots. N$

$H_1 : \beta i = 0\ \forall i = 1, \ldots\ldots. N_1$

$\beta i \neq 0\ \ \forall i = N_1 + 1\ , N_1 + 2, \ldots\ldots. N$

Where N1 represents the unknown parameter, which satisfies the condition $0 \leq N1\ /\ N < 1$, in any situation, the ratio of $N_1\ /\ N$ should be inevitably less than 1. If N 1 = N, it implies no causality across cross-sections. This indicates a failure to reject the null of HNC. However, if N1= 0, it shows a causal nexus in the macro panel.

3. Results and Discussion

This study continues with empirical estimations because the macro panel data share common integration properties, i.e. I(1), and the presence of a long-run cointegration relationship between the variables has been verified at a 1% level of significance (Table 5). The PMG, MG, and DFE estimation results for equation 6, which are the study's key estimation results, are shown in Table 6. For each process, the long-run coefficients, the speed of adjustment coefficients, and the short-run coefficients are highlighted. The long-run coefficients of renewable energy consumption are positive and statistically significant at 1% and 10% levels in the PMG and DFE estimations, but statistically insignificant in the MG estimate, as shown in the first row of Table 6. Pairwise comparisons are conducted, first between the MG and PMG estimators, and then between the MG and DFE estimators, to assess the most suitable estimation results for the long-run nexus between economic growth and renewable energy consumption estimators MG and DFE. These comparisons, made using Hausman tests, calculate the supplementary homogeneity constraints imposed by the PMG and DFE estimators in relation to the MG estimator.

Under the null hypothesis that homogeneity constraints hold, the PMG and DFE estimators are more effective and more consistent than the MG estimator. When comparing the MG and PMG estimators, the Hausman test statistics are 2.45 with a corresponding probability value of 0.484, and 0.00 with a corresponding probability value of 1.000 when comparing the MG and DFE estimators. Based on the Hausman tests results and its inability to dismiss the null hypothesis in both cases, it is concluded that the PMG and DFE estimators are more effective and suitable than the MG estimator. As a result, the PMG and DFE estimators were chosen as the preferred model specifications. Findings in Table 7 shows that the consumption of renewable energy has a statistically important and positive long-run effect on the economic development of EU countries. The Hausman test results also indicate that, despite the differences in a variety of characteristics among EU countries (for example, environmental resources, climate change, economic policies, developmental levels, GDP per capita, etc.), the proposition of slope homogeneity cannot be statistically rejected. Simply put, long-run relationships between the use of renewable energy, economic development, and other determinants tend to be common across EU countries. The above-mentioned benefits of the PMG and DFE models are evidence that the Autoregressive Distributed Lag (ARDL) model is also relevant. Since it models variables with I (0), I (1), or both, the ARDL is considered acceptable. In addition to the panel long-run and short-run estimates, the 17 models provides state-wide cross-sectional short-run information.

Furthermore, across all estimations, the approximate speed of the adjustment coefficient recorded in Table 7 is negative and statistically significant at the 1% stage. This points to the convergence of renewable energy demand and economic development, as well as the nature of a long-run equilibrium relationship. The DFE adjustment coefficient of -0.105 is the lowest of the three estimates on the short-run speed of adjustment coefficients, followed by the PMG adjustment coefficient of -0.113 and the MG with the highest adjustment coefficient of -0.166. These findings show that a 0.10 percent to 0.12 percent annual deviation from the long-run equilibrium level of real GDP is corrected. Furthermore, the existence of a

Table 5
Regression for FMOLS model

Variables/Models	lGDP = ƒ (lren2. lco2, lrgfcg, lfen, lta)	
Lren	0.042**	(2.720)
Lco2	0.038	(0.582)
Lgfcf	0.486**	(20.297)
Lfen	-0.069	(-0.714)
Lta	0.103**	(3.864)
Long run variance	0.009	-

Note: variables are all significant at 1% level while t-statistics values are in ().

Table 6
PMG, MG and DFE estimates of the ARDL (1, 1) economic growth equation

Regressors	PMG	MG	DFE
		Long-run coefficients	
Lren	0.045* (0.000)	0.208 (0.466)	0.060*** (0.093)
Lco2	0.005 (0.863)	0.730 (0.216)	0.217 (0.141)
Lgfcf	0.348* (0.000)	0.554** (0.016)	0.485* (0.000)
Adjustment coefficient	-0.113* (0.000)	-0.165* (0.000)	-0.103* (0.000)
		Short-run coefficients	
ΔLren	-0.101 (0.517)	-0.012 (0.473)	-0.016* (0.075)
ΔLco2	0.113* (0.000)	0.052***(0.094)	0.111* (0.000)
ΔLgfcf	0.238* (0.000)	0.214*(0.000)	0.151* (0.000)

Note: Refer to section 3 for the definition of variables*, ** & *** significant at 1% , 5% & 10% levels

Table 7
Robustness test with fossil fuel and tourism for PMG and DE estimations of the ARDL (1, 1).

Regressors	**PMG**		**DFE**	
	(a)	(b)	(c)	(d)
Long-run coefficients				
Lren	0.046* (0.000)	0.037** (0.014)	0.058*** (0.093)	0.045*** (0.200)
Lco2	0.005 (0.863)	0.565* (0.000)	0.217 (0.141)	0.208 (0.170)
Lgfcf	0.348*(0.000)	0.222* (0.000)	0.482* (0.000)	0.445* (0.000)
Lfen	-	0.341*(0.000)	-	0.352 (0.140)
Lta	-	0.332* (0.000)	-	0.113** (0.000)
Adjustment coefficient	-0.112*(0.000)	-0.114* (0.000)	-0.105* (0.000)	-0.105* (0.000)
Short-run coefficients				
ΔLren	-0.103 (0.517)	-0.008 (0.654)	-0.016* (0.075)	-0.016* (0.059)
ΔLco2	0.113* (0.000)	0.094* (0.000)	0.111* (0.000)	0.108* (0.000)
ΔLgfcf	0.238* (0.000)	0.216* (0.000)	0.151*(0.000)	0.138* (0.000)
Lfen	-	-0.275 (0.000)	-	-0.381 (0.383)
Lta	-	0.053* (0.000)	-	0.046* (0.000)

Notes: Probability values are shown in brackets. Significance thresholds * (1%), ** (5%), and *** (10%).

stable long-run equilibrium relationship between economic growth and its determinants is confirmed by a significant adjustment coefficient. Indeed, the speed values of the adjustment coefficients from the PMG, MG, and DFE estimators are not significantly different from those reported by Apergis and Payne (2010), which range from 0.12 percent to 0.14 percent. This suggests that the EU countries' rate of change or convergence toward a long-term renewable energy-economic growth partnership is comparable to that of the Eurasian countries.

According to a quantitative analysis of the renewable energy-economic growth relationship using the superior PMG and DFE calculation techniques, a 1% rise in renewable energy demand would increase economic growth by 0.046 percent and 0.058 percent in the long run, respectively, with no noticeable effect in the short run. These are insignificant effects, particularly when compared to Apergis and Payne's 0.195 percent estimate for Eurasia (2010). This form of comparison shows that the relationship between renewable energy and economic growth can vary significantly between countries. The coefficients for real gross fixed capital development, which are positive and statistically significant at the 1% level of significance in both models, are also provided in Table 7 for the long run. This underpins the importance of real gross fixed capital investment in EU countries' development. This is in line with Apergis and Payne's (2010) estimate of the effect of real gross fixed capital creation on Eurasian countries' growth, which yielded a coefficient value of 0.224 percent. In both the PMG and DFE growth models for the EU, real gross fixed capital investment appears to play a larger role in the long run (0.348 percent and 0.482 percent) and short-run (0.238 percent and 0.151 percent) than it does in the models for Eurasian countries. Carbon emissions have a positive but negligible long-run coefficient, but it is positive and statistically important in the short-run in all estimations at 1% and 10% levels, although carbon emissions do not appear to have a significant long-term effect on development in the EU countries.

Both the CUSUM and CUSUM of squares are tests used to examine the constancy of regression coefficients in linear models. These tests do not require detection of possible change points. The results for CUSUM and CUSUMSQ tests indicate the stability of the coefficients because the plots of the CUSUM and CUSUMSQ statistics fall inside the critical bands of the 5 per cent confidence intervals of parameter stability. Therefore, the coefficients are stable over a certain period for the countries under this study.

3.1. Robustness Test

We used an alternative source of energy and incorporate tourism, which is a major contributor to economic growth in the EU countries, to further investigate the importance of renewable

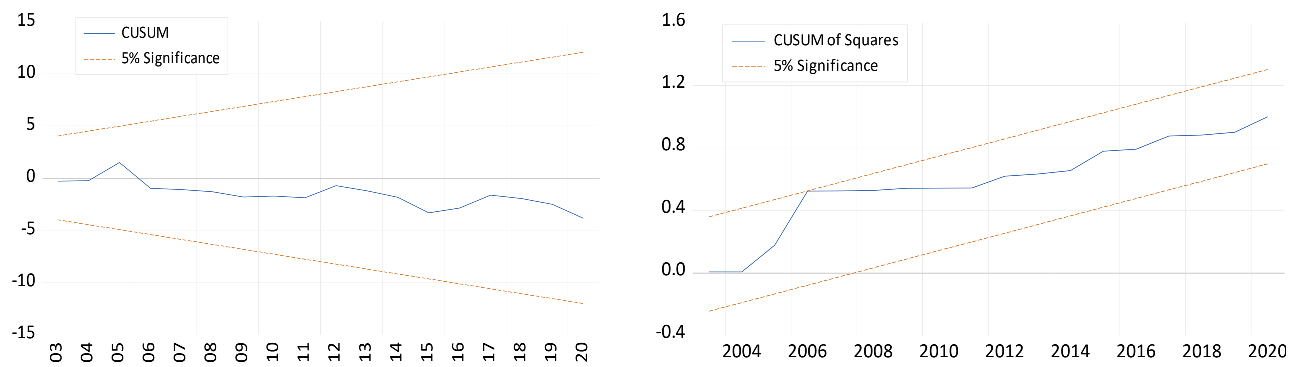

Fig 1. The cusum and cusumsq tests of model one

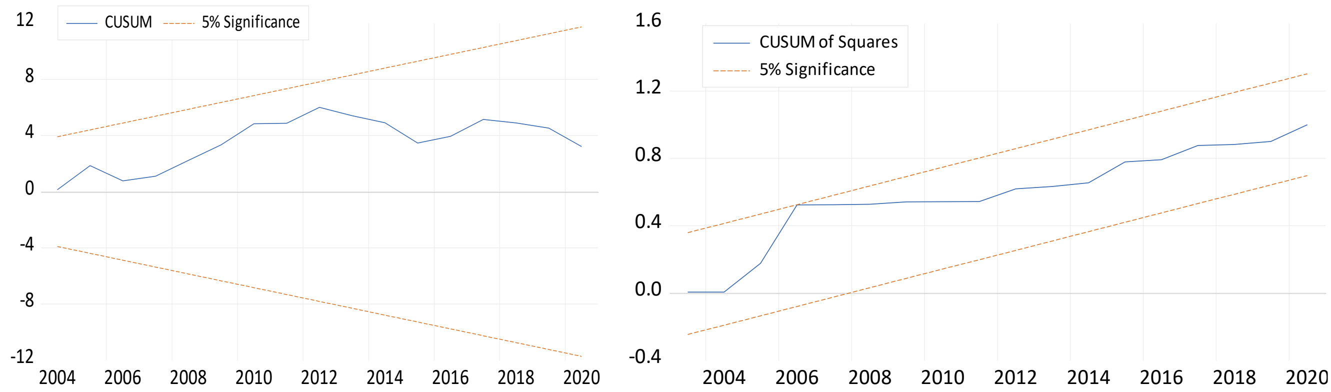

Fig 2. The cusum and cusumsq tests of model two

energy consumption in the EU countries (Lee & Brahmasrene, 2013). We re-estimated equation 6 by simultaneously including the natural logs of fossil fuel ($lnFEN_{i,t}$) and tourism ($lnTR_{i,t}$) in the growth model. Table 8 shows the estimation results for the PMG and DFE estimators. It also shows that the average long-run equilibrium coefficient of renewable energy consumption remains positive and statistically significant at 1%, 5%, and 10% levels for the PMG results in columns (1) – (2) and the DFE result in column (3). Regardless of the usage or non-usage of additional variables, only actual gross fixed capital formation reliably reports large positive coefficients in both the PMG and DFE models. In the long run, carbon emissions become meaningful at 1% for the PMG estimate in column (2), and they continue to have a significant positive effect in the short run at 1% for both the PMG and DFE estimations. The calculated speed of adjustment coefficients, on the other hand, remain quantitatively related and consistent with the Table 7 findings. The estimation results indicate that the substantial positive effect of carbon emissions on growth in the long run, as seen in Table 7, stems primarily from the growth model's inclusion of fossil fuels (though not significant in the short run) and tourism. Tourism has been reported to play a significant role in carbon emissions growth in the EU countries. These results follow the findings of Lee and Brahmasrene (2013).

Table 7 summarizes those findings. Checking the robustness of long-run equilibrium is a possibility. Estimate cointegrating vectors for heterogeneous cointegrated panels using Pedroni's Completely Modified Ordinary Least Square (FMOLS) estimation approach (2001). This method makes it possible to estimate cointegrating vectors consistently and efficiently. It also accounts for the endogeneity of regressors and considers the time-series properties of the variables in terms of integration and cointegration properties, as well as maintaining the continuity of the 20 long-run relations.

Table 8
Panel Granger causality results

Nullhypothesis	W-stat	P-value
GDP → REN	4.942*	0.000
REN → GDP	3.791*	0.000
GDP → CO2	4.706*	0.000
CO2 → GDP	4.306*	0.000
GDP → GFCF	0.208*	0.000
GFCF → GDP	3.172*	0.000
GDP → FEN	5.004*	0.000
FEN → GDP	2.922*	0.000
GDP → TR	2.417*	0.000
TR → GDP	1.803*	0.000
REN → CO2	2.806*	0.000
CO2 → REN	5.968*	0.000
REN → GFCF	0.026*	0.000
GFCF → REN	2.761*	0.000
REN → FEN	3.385*	0.000
FEN → REN	3.525*	0.000
REN → TR	2.708*	0.000
TR → REN	3.038*	0.000
CO2 → FEN	4.965*	0.000
FEN → CO2	2.456*	0.000
CO2 → GFCF	0.076*	0.000
GFCF → CO2	4.115*	0.000
CO2 → TR	4.341*	0.000
TR → CO2	1.351	1.891
FEN→ GFCF	0.047*	0.000
GFCF → FEN	3.038*	0.000
FEN → TR	3.287*	0.000
TR → FEN	2.303*	0.000
GFCF → TR	2.405*	0.000
TR → GFCF	0.001*	0.000

*Notes: Probability values are shown in brackets. Significance thresholds * (1%), ** (5%), and *** (10%).*

3.2. Granger causality results

Granger causality tests are performed using the Dumitrescu and Hurlin (2012) method to supplement the ARDL estimation findings, with the results recorded in Table 8. The Wald statistic's statistical significance of 21 indicates a bidirectional causal relationship between real GDP and renewable energy consumption (Apergis & Payne, 2010), a bidirectional causal relationship between real GDP and real gross fixed capital formation (Apergis & Payne, 2010), and a bidirectional causal relationship between real GDP and carbon emissions (Ang, 2007; Houghton *et al.* 1996). (Katircioglu, Feridun and Kilinc, 2014; Tugcu *et al.* 2012). In the EU countries, the bidirectional causality suggests a long-term interdependence between real GDP and renewable energy consumption, as well as other growth determinants. Menegaki (2011) argues that there is no causal association between renewable energy use and economic growth in Europe, concluding that the neutrality assumption holds in the field. Our results support the idea of a one-way causal relationship between tourism and carbon emissions.

4. Conclusion

This study explores the long-run relationship between renewable energy use and economic growth for a panel of European Union (EU) countries over a 2000-2020 period. The study also investigates the environmental effects of carbon emissions reduction process oriented towards long-term economic development. By testing the error correction model of an autoregressive distributed lag (ARDL) dynamic panel system, the results indicate an important positive long-run equilibrium relationship between renewable energy use and economic growth in the EU countries. In terms of model parameters, estimation methods, and variable selection, this result is consistent and robust. Furthermore, by contrasting our findings with those of Apergis and Payne (2010), the following conclusions can be drawn: first, Eurasian countries are approaching the long-run equilibrium growth path faster than European Union countries in terms of renewable energy. Second, renewable energy has a greater positive effect on economic development in Eurasian countries than in EU countries. Third, EU countries' positive effect on real gross fixed capital formation is greater than that of Eurasian countries. Furthermore, carbon emissions only have a long-term effect on development when fossil fuels and tourism are factored in. This justifies the effect of fossil fuels and tourism on carbon emissions increase. Finally, it was found that tourism has an important and consistent effect on the EU countries' economic development. The hypothesis comes from the bidirectional causal relationship between renewable energy use and economic development. The evidence of a bidirectional causal relationship between renewable energy use and economic growth is consistent with Sadorsky's (2009) research for the G7 countries, and Apergis and Payne's (2009) study for Central America and Eurasia, but differs significantly from Menegaki's (2011) study for Europe. The findings indicated that increasing renewable energy usage will reduce fossil fuel use and therefore reduce carbon emissions. As a result, governments and policymakers in the EU region must implement appropriate economic and energy policies that encourage marketability and the production of renewable energy to ensure the region's environmental sustainability. Subsidies and/or tax incentives on renewable energy output, as well as the implementation of renewable energy portfolio principles, may be useful policy instruments, according to Ahmadi & Frikha (2022). Surprisingly, the current study's findings are consistent with the EU's recently adopted and updated energy transition and efficiency policies (European Commission, 2019). As a result, this study recommends that the Renewable Energy Directive (EU) 2018/2001, the Energy Efficiency Directive (EU) 2018/2002, the Governance Regulation (EU) 2018/1999, and the Energy Performance of Building Directive be implemented constructively. The introduction of the aforementioned regulations across the EU states will not only help to achieve long-term energy efficiency targets, it will also help to create jobs, improve health, and provide platforms for innovation, all of which will contribute to the achievement of the Sustainable Development Goals (SDGs) by 2030. The adoption of corporate mechanisms, especially toward maximizing the use of renewable energy for economic growth stimulus and sustainability, is encouraged from a global perspective. Consequently, the global effort to achieve the SDGs by 2030 will be materialized.

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