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Growth impact of transition from non-renewable to renewable energy in the EU: The role of research and development expenditure

Festus Fatai Adedoyin [a], Festus Victor Bekun [b, c], Andrew Adewale Alola [d, e, *]

[a] Department of Accounting, Economics and Finance, Bournemouth University, United Kingdom
[b] Department of Logistics and Transportation, Istanbul Gelisim University, Istanbul, Turkey
[c] Department of Accounting, Analysis and Audit, School of Economics and Management, South Ural State University, 76, Lenin Aven., Chelyabinsk, 454080, Russia
[d] Department of Economics and Finance, Istanbul Gelisim University, Istanbul, Turkey
[e] Department of Financial Technologies, South Ural State University, Chelyabinsk, Russia

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A B S T R A C T

In recent times, physical-capital investment has been outweighed by research and development expenditure in terms of their growth impact. However, how such expenditure affect economic expansion in the presence of energy consumption is yet to be given thorough attention in the literature. Consequently, this study used data from 1997 to 2015 for 16 EU countries to demonstrate how expenditure on research and development drives growth in the presence of renewable and nonrenewable energy consumption. Empirical results from the Pool Mean Group Autoregressive distributive lag model (PMG-ARDL) revealed that in the short run, investment in research and development adversely affect growth prospect in the EU. However, in the long run, research-led growth is evident alongside energy consumption, although the latter outweighs the former. Additionally, result from Dumitrescu and Hurlin Panel Causality tests showed a feedback causality between energy consumption, research and expenditure and economic growth. The findings of this study make it essential for EU countries to boost spending on renewable energy sources. Additionally, EU countries should pay closer attention to investment in research and development in order to sustain the plan for long term advancement in sustainable power sources for feasible energy and economic development.

1. Introduction

There has been a long-standing debate on the need for successful integration of economic growth and environmental quality [1,2]. In essence, economic growth and energy consumptions positively react to each other, that is, as energy consumption increases, the output level also increase [3,4]; Khan et al., 2019; [5], therefore, with the emissions from energy consumption, poor environmental quality is inevitable. Also, high economic growth rate driven by industrialization, is attributed to increase in greenhouse gas emissions (GHGs) [6–9]. It is noteworthy that industrialization is highly instrumental for economic growth, and it generates environmental pollution, CO_2 emissions, and environmental degradation in general. Moreover, most countries in the early stage of development and those experiencing economic growth easily oversight the potential environmental pollution with economic boom visibly apparent [2,10,11], therefore, the higher the drive for economic growth, the higher the environmental pollution [6]. Waqih et al. [7]; simply put that the concentration of CO_2 was about 280 parts per million (ppm) before the industrial revolution, and has crossed 400 ppm, the highest value ever recorded. Also, CO_2 is found to constitute the major part of GHGs emissions to the atmosphere, with a total of 82% [7,12].

Energy serves as the building block upon which all sectors of modern economies are founded; therefore, it underpins all of our economic activities [13].[1] The importance of energy to growth

* Corresponding author. Department of Economics and Finance, Istanbul Gelisim University, Istanbul, Turkey.
E-mail addresses: fadedoyin@bournemouth.ac.uk (F.F. Adedoyin), fbekun@gelisim.edu.tr (F.V. Bekun), aadewale@gelisim.edu.tr (A.A. Alola).

[1] The energy literature can be divided into four divide namely (i) Growth hypothesis (ii) conservative hypothesis (iii) Feedback hypothesis and (iv) Neutrality. For more insight into the energy literature on the four divide see Ozturk [44]; Bekun and Agboola, [45]; Akadiri et al.(2019).

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cannot be overemphasized; likewise, the growing damage of the GHGs emissions from the traditional nonrenewable energy consumption to the atmosphere calls for a greater attention. Additionally, energy is pivotal for economic development and social well-being, whereas the future of climate change amidst sustainable development lies with renewable energy consumption [14]. As a consequence, nations, regions, communities, and institutions are poised to find alternative energy sources [15–17].

Furthermore, Shahbaz et al. [18] showed that energy security is a modern day challenge that motivates economies to invest diversely in energy portfolio. Energy sources in general are crucial for alleviating poverty and achieving sustainable human development, while renewable forms of energy are specifically essential tools for achieving the Millennium Development Goals (MDGs) [14]. Shahbaz et al. [18] further states that consumption of energy from renewable and traditional nonrenewable sources enhances growth of the economy; however, it is preferable for an economy to increase the consumption of renewable energy against the nonrenewable as the former mitigates CO_2 emissions. More precisely, Zafar et al. [16] stated that environmental there is a surge in global renewable electricity generation, particularly in the advanced countries, the nonrenewable electricity generation source still dominates for most countries degradation still remains the biggest challenge to global sustainable development due to the increasing GHGs emissions.

A growing number of literatures, both empirical and theoretical have underscored the importance of expenditure on research and development (RD) on sustainable economic growth. Freimane and Bāliņa [19] found that to achieve a long-term economic growth, huge investment in RD expenditure is of great importance. Investment in RD expenditure catalyzes economic growth through innovation and total factor productivity [20]. An investment in RD expenditure can be considered as an investment in technology, innovation, and stock of knowledge. According to the OECD (2013, p. 2), RD expenditure is the "creative work undertaken on a systematic basis in order to increase the stock of knowledge (including knowledge of man, culture, and society) and the use of this knowledge to devise new applications". As a matter of fact, countries that invest more in RD expenditure are considered to have better economic performance and a robust value addition [21]. However, RD investment opportunities and appropriability condition differs across sectors, countries, and regions [22].

In terms of RD intensity in the EU, in 2005 it stood at 1.84% compared with those of US (2.68%), Japan (3.18%), and China (1.34%) respectively. Though this shows a fast-paced investment growth in RD expenditure, but the EU still lagged behind US and Japan. The differences in the composition of RD intensity were as a result of the structural differences among these regions. Also, within the EU, Sweden and Finland exceeded the 3% RD intensity target at 3.86% and 3.48% respectively, while the remaining EU member states recorded RD intensity below the 3% benchmark. Worst still, about 21 states had RD intensities below the EU-average of 1.84%. By implication, there is a wide difference, that is, an uneven distribution of RD investment in the region. Also, wide dispersion in both economic growth and RD expenditure investment cascades the global economy. For instance, the overview from the OECD Factbook [23] showed that among the G7 countries, Germany, Japan, Italy, and France total RD expenditure grew in real terms by 3.7%, 1.4%, 1.3%, and 1.2% respectively, while Canada and the United Kingdom experienced decline in RD expenditure by approximately 3%. Also, in terms of RD expenditure intensity in the same period, Estonia, Portugal, and Turkey were the fastest growing countries among the OECD countries.

The way forward to mitigate the growing environmental degradation is to transit from the traditional energy consumption source to renewable energy consumption source. Given that renewable energy reduces carbon emissions, Acheampong et al. [24] emphasized the need for economies to drastically reduce over-reliance on fossil energy and invest substantially in renewable energy. They also affirmed that the only way to mitigate environmental degradation and global warming is through transition from the consumption of nonrenewable to renewable energy. Hanif et al. [25] emphatically stressed that the fossil fuels for renewable energy source trade-off is inevitable if economies want to foster environmental-friendly economic growth. Similarly, Jin and Kim [26] decried the consumption of nuclear energy, they applauded the need to develop and expand renewable energy for the fast-paced global warming to be mitigated. Also, Atems and Hotaling [13] stressed the necessity for swift transition to the renewable, cleaner, or less risky forms of energy without hampering economic growth.

However, transitioning from nonrenewable energy source to renewable energy source cannot be done in isolation; it requires heavy investment in RD and labour, conscious and deliberate government policies, and increased opportunities for foreign investments. The most stressed among them is the investment in RD expenditure. According to Shahbaz et al. [27]; RD activities is the only global solution to the energy crises in the energy sector. Expenditure on RD is very important for economic growth since it helps in the discovery of alternate energy sources for the reduction of nonrenewable energy composition in the energy mix [16].

Moreover, from the endogenous growth model, RD investment is pivotal for long-run economic growth, likewise from existing literatures energy consumption is considered as a strong factor in determining long-term economic growth. For instance, emphasis was made by Al-Mulali et al. [28] on the dire need for increased investment in renewable energy projects for renewable electricity consumption to generate inclusive growth in the economy. RD investment was one of the key factors emphasized by the African Development Bank (AfDB) on the need for transition to green growth as the focal point of its new ten-year strategy to ensure resource efficiency and sustainable development in the continent [29]. As a matter of fact, it will be difficult if not impossible to successfully alternate to renewable energy source without investing hugely in RD activities.

In this study, for effective assessment of the growth impact of energy consumption from nonrenewable and renewable sources, investment in RD was considered as a key explanatory factor. Therefore, the main purpose of this study is to show how research and development expenditure affect economic growth especially in the presence of transition from nonrenewable to renewable energy consumption in the panel of EU countries. Thus, the current study compliment the recent study of Kose, Bekun and Alola [30] and Zafar et al. [16] for the case of EU and APEC respectively. Specifically, the current study employs a more recent Granger causality approach of Dumitrescu and Hurlin [31] in a panel framework while Kose, Bekun and Alola [30] examined considered a country-specific Granger causality approach of Emirmahmutoglu and Kose [32]. The most recent work done in this regard is by Zafar et al. [16] who focused attention on APEC countries. Unlike Zafar et al. [16]; the current study utilize data across 16 European countries by using Panel Pool Mean Group Autoregressive Distributed Lag (PMG-ARDL) methodology. In general, the present study compliment the current body of knowledge on the energy-growth nexus by considering the role of R-D for the case of EU. This study is conducted in a multivariate framework to circumvent for omitted variable bias and by extension render ample policy direction for stakeholders and practitioners in the region. Studies of this sort are arguably timely and worthwhile as most regions and economies are on the trajectory for alternative energy sources and transition from pollutant driven economy to clean energy drivers.

The reminder of this study follows as: section two present data, materials and methods applied to conceptualize the hypothesized claim of the study while section three entails the empirical results and discussion. Finally, section four conclude the study with policy implications.

2. Materials and methods

2.1. Data

The empirical analysis covers the impact of energy consumption transition on economic growth in 16 European Union (EU) countries with the aid of panel data spanning from 1997 to 2015. The study is interested in discovering how economic growth has responded to diversity in energy consumption (renewable and nonrenewable energy sources) and also how expenditure on research and development influence economic growth in the EU. The World Bank development indicators provided all data for this empirical analysis. Real gross domestic product represents (GDP); Research and Development is indicated by (RD); Renewable energy consumption is indicated as (REN) and Nonrenewable energy consumption is indicated as (NREN). The measure of GDP is US$ constant 2010 while Research and Development is a taking in measure of percentage of GDP. Renewable energy consumption is measured in percentage of total final energy consumption (% of total energy consumption) while Nonrenewable energy is measured in oil equivalent on kilogram.In Table 1, the summarized description of the dataset is illustrated.

2.2. Econometric model

This paper examines the impacts of energy consumption (renewable and nonrenewable) and expenditure on research and development on economic growth. The theoretical discussion on the role of research and development in growth models was shown by Romer [33]. Also, how innovations in the energy sector via spending on research and development, contributes to economic growth and development has been shown in the literature [34,35]. Hence, our growth function is set to include research and development expenditure and is given as:

$$GDP_t = f(NREN_t,\ REN_t,\ RD_t) \quad (1)$$

In order to make the data smooth and for interpretation as point elasticities, we log transform the data. Also, the log-linear transformation is given as:

$$LNGDP_{it} = \alpha_0 + \alpha_1 LNNREN_{it} + \alpha_2 LNREN_{it} + \alpha_3 LNRD_{it} + \varepsilon_i \quad (2)$$

where α_0 depicts coefficient of the slope; i depicts the 16 EU countries ranging from 1 to 16; t is the period of analysis ranging from 1997 to 2015; ε depicts the error term; while $\alpha_1,\ \alpha_2,\ and\ \alpha_3$ which are the respective coefficients of nonrenewable energy consumption, renewable energy consumption as well as expenditure on research and development. In what follows, we present a discussion of important tests (unit root and cointegration analysis) results and short and long run estimation results of equation (2).

Table 1
Summary of data under consideration.

Name of Indicator	Symbol	Source
Real Gross domestic product	GDP	World development indicator
Research and development	RD	World development indicator
Renewable energy consumption	REN	World development indicator
Nonrenewable energy consumption	NREN	World development indicator

NB: As earlier mentioned all data were source from world development indicators. Economic growth is measured in (US$ constant 2010), renewable energy consumption in (% of total final energy consumption). Also, nonrenewable energy in oil equivalent in Kg while research and development as percentage of GDP.

3. Empirical results and discussion

3.1. Descriptive analysis

Table 2 shows a descriptive analysis of all variables for this empirical analysis. The average values of variables for this study is 10.43% of GDP being the highest of all variables followed by NREN (8.17%), REN (2.19%) and RD (0.36%). The maximum and minimum values of the variables range from −1.60 to 11.02, while there is a minimal range of dispersion from the mean values with the highest being 0.99% from REN followed by RD with 0.67%, GDP (0.54%) and NREN (0.33%). The distribution of data for RD, REN and NREN is flat relative to normal for each of this variable while GDP has a peaked distribution relative to normal. A further test for normal distribution was carried out, which showed that the series is not normally distributed being 0.01, 0.05, 0.1 level of significance less than the probability values see [Table 2].

Table 3 presents correlation among variables and this shows the relationship among variables. Economic growth and nonrenewable energy have correlation of (r = 0.5618) which implies a significant positive and high-level relationship between these variables. Also, a positive correlation exists between economic growth and renewable energy consumption while economic growth and research and development have a positive and significant correlation with the following correlation coefficients r = 0.0109 and r = 0.6702 respectively. In addition, a positive relationship exists between nonrenewable energy and renewable energy (r = 0.0796), while renewable and nonrenewable energy both hold a positive relationship with research and development at r = 0.3220 and r = 0.8104, respectively. A significant positive correlation exists between renewable energy consumption and research and development expenditure.

3.2. Unit root tests

Data series in an empirical analysis could be spurious, to validate that data series for analysis is predictable and stable the data must be tested for unit root. The data series for this study is taken to have no data interlink with each other. First-generation unit root is valid to check for spurious trends among series. Augmented Dickey Fuller (ADF) and Im, Pasaran and Shin (IPS) unit root test is utilized by this study to observe stability, predictability and shock response of the data series. As shown in Table 4, both tests at first difference

Table 2
Descriptive statistics for EU for the underlined variables.

	LNGDP	LNNREN	LNREN	LNRD
Mean	10.42632	8.170192	2.187772	0.361007
Median	10.57687	8.185317	2.190248	0.519103
Maximum	11.02149	8.872747	3.910993	1.363760
Minimum	8.229643	7.431173	−0.15915	−1.60321
Std. Dev.	0.542913	0.329282	0.988787	0.672158
Skewness	−2.402941	0.151677	−0.29627	−0.72888
Kurtosis	9.012253	2.145880	2.354254	2.720371
Jarque-Bera	710.9241	9.858541	9.217198	26.43901
Probability	0.000000	0.007232	0.009966	0.000002
Sum	3002.779	2353.015	630.0782	103.9700
Sum Sq. Dev.	84.59456	31.11844	280.5997	129.6657
Observations	288	288	288	288

Table 3
Correlation coefficient matrix results.

	LNGDP	LNNREN	LNREN	LNRD
LNGDP	1			
T-Stat	–			
P-Value	–			
LNNREN	0.56158	1		
T-Stat	11.4779***	–		
P-Value	0.0000	–		
LNREN	0.01092	0.079695	1	
T-Stat	0.18473	1.35207	–	
P-Value	0.8536	0.1774	–	
LNRD	0.67023	0.810466	0.32206	1
T-Stat	15.2727	23.39803	5.753053	–
P-Value	0.0000***	0.0000***	0.0000***	–

Note: the superscript *** represents 0.01 statistical rejection level.

Table 4
Unit root results.

	ADF-Fisher		Im, Pesaran Shin	
	Level	Δ	Level	Δ
LNRGDP	25.3499	72.6194***	0.7507	–4.2593***
LNNREN	15.2683	94.5382***	3.7769	–6.2409***
LNREN	26.2639	67.1698***	0.5725	–3.5928***
LNRD	23.3028	72.8326***	1.6536***	–4.2069***

Note: The superscripts *** indicates 0.01 statistical rejection while Δ represents first difference. The fitted model for the unit root accounts for both individual intercept and trend.

concludes that there is stability among the variables. ADF and IPS at levels indicates stability for expenditure on research and development.

3.3. Cointegration tests

All variables are integrated at varying order of integration, cointegration test is to determine if a long-run equilibrium exits among variables in the model. The test helps to validate how variables in an empirical model will adjust to short-term shocks in the long-term. According to Sadorsky [36]; evidence of cointegration shows that there is structural stability among data series. The study did put into consider information of structural breaks which Rafindadi [37] observed as the weakness of the unit root test adopted by this study. We also applied the Pedroni and Johansen multivariate cointegration tests to determine the possibility of a long-run stability among data variables as the latter detects the robustness in after short-run relationship. Similar to Sadorsky [38] this study utilizes the tests of Pedroni [39] to verify long run relationship with alternate hypothesis which states there is cointegration in heterogeneous panels.

Panel cointegration test by Pedroni is based on the regression residual from hypothesized cointegration regression which are in two forms namely; the panel (within-dimension) and group (between-dimension) statistics. These two forms have a the general null hypothesis but a slight disparity on the alternate hypothesis; Panel (within-dimension) statistics has an alternate hypothesis that the autoregressive coefficient is set to fixed value while group (between-dimension) statistics has an alternate hypothesis that the autoregressive coefficient is not set to fixed value. Pedroni test has a sum of seven statistics, in which panel (within-dimension) statistics are four and group (between-dimension) statistics are three. Hence, cointegration results are a mix with five of the seven test result stating cointegration at 10% statistical significance. This is sufficient to justify an evidence of cointegration between economic growth, renewable energy, nonrenewable energy and research and development (Table 5).

Johansen multivariate cointegration approach is to explain the robustness of the long-run relation identified using Pedroni cointegration tests. The null hypothesis to Johansen test is no cointegration, the Trace and Maximum Eigenvalue statistics results are statistically significant. This implies there is cointegration because the null hypothesis was rejected (Table 6).

3.4. Long-run and short-run analysis

Details of the long-run results are shown on Table 7, the summary of findings from this analysis shows that GDP is positively and statistically significant to renewable energy consumption, nonrenewable energy consumption in the long-run. As way of further details, the empirical analysis observed that 1% increase in nonrenewable energy consumption will lead to a corresponding increase of 0.60% in GDP of EU countries. In line with Wesseh and Lin [29] on the use of alternate energy sources such as renewable energy, our analysis shows that 1% increase in renewable energy utilization for economic activities leads to 0.13% increase in economic growth. This further reveal that economic growth in European Union countries are more influenced by alterations in the non-renewable options compared to that of the renewable options. The study found that research and development significantly and positively influence economic growth. Empirical observation implies that 1% increase in expenditure on research and development will lead to an increase of in economic growth by 0.05% in the long run. This matters for sustainable development in the presence of ever-changing global energy sector.

The analysis for short-term effects of shocks are also reported is stated "short-run" in Table 7. This developments deviates from the long-run findings. Short-run results shows nonrenewable energy has an insignificant negative relationship with economic growth. This implies that a 1% change in nonrenewable energy consumption will yield decrease in economic growth by 0.083% in the short run. Similarly, this analysis further discovers that renewable energy has a negative insignificant relationship with economic growth. The result reveals that 1% increase in renewable energy consumption will lead to 0.013% in GDP. More importantly, we find a significant but negative influence of research and development to economic growth in the short run. Specifically, increasing spending on research and development by 1% reduces economic growth by 0.13% in the EU. The Error correction trend has a negative and statistically significant value of 0.3146. This suggests that short-run deviations toward long-run preposition would be adjusted by 0.3146% in the long-run.

3.5. Dumitrescu and Hurlin causality analysis

Observations has been made for cointegration among the dependent and independent variables for the empirical analysis. This study like other similar literature [16], adopt the Dumitrescu and Hurlin [31] heterogeneous panel causality test to discover the causal associations among the model variables. Table 8 show the results of Dumitrescu and Hurlin causality tests for this analysis. The results indicate bidirectional causality otherwise known as feedback effect between GDP, renewable energy, and nonrenewable energy. This finding is in line with the findings of Zafar et al. [16]; whose studies reveal a feedback effect among renewable energy, non-renewable energy and GDP growth. However, this is contrary to Omri [40] who identifies that low-income countries have a growth-led relationship from GDP to energy consumed while high-income countries and averagely financially strong countries have a feedback effect between GDP and energy

Table 5
Pedroni cointegration test results.

Alternative hypothesis: Common AR coefficients (within-dimension)				
	Stat	Prob.	W.Stat	Prob.
Panel v-Statistic	4.5202***	0.0000	−0.4205	0.6630
Panel rho-Statistic	2.7092***	0.9966	3.7058	0.9999
Panel PP-Statistic	−0.3307	0.3704	−0.7277	0.2334
Panel ADF-Statistic	−1.3539*	0.0879	−5.8398***	0.0000
Alternative hypothesis: individual AR coefficients (between-dimension)				
Group rho-Statistic	4.5232	1.0000		
Group PP-Statistic	−1.5914	0.0558*		
Group ADF-Statistic	−3.2960	0.0005***		

Note: The superscripts ***, **, * indicates 0.01, 0.05 and 0.10 statistical rejection respectively.
Cointegrating vectors established at several statistical threshold.

Table 6
Johansen multivariate cointegration test results.

Hypothesized No. of CE(s)	Fisher Stat. (from trace test)	Prob.	Fisher Stat. (from max-eigen test)	Prob.
r ≤ 0	301.3***	0.0000	200.9***	0.0000
r ≤ 1	138.4***	0.0000	99.23***	0.0000
r ≤ 2	70.75***	0.0001	65.35***	0.0005
r ≤ 3	45.78*	0.0544	45.78*	0.0544

Note: The superscripts ***, **, * indicates 0.01, 0.05 and 0.10 statistical rejection respectively.
Cointegrating vectors established at several statistical threshold.

consumed. Sadorsky [38]; also contradicted our observation of no feedback interaction exists between renewable energy consumed and economic growth. In summary many methods have been used to analyze the causality between GDP, renewable energy and nonrenewable energy consumption observations can be summarized inconclusive as various technique reveals differing causal conclusion [41].

Dumitrescu and Hurlin (DH) panel causality test revealed a bidirectional relationship between research and development to GDP which is consistent with findings of Zafar et al. [16]. Similarly, a feedback effect occurs between renewable energy consumption and non-renewable energy consumption. This finding is similar to Zafar et al. [16]. and Apergis and Payne [42,43] where bidirectional causal relationship occurs among renewable energy and nonrenewable energy. This study also discovers a unidirectional relationship between research, development and nonrenewable energy consumption. As a bidirectional causal relationship occurs between research, development and renewable energy consumption. Zafar et al. [16]. notices unidirectional causal relationship between expenditures on research and development and consumption of energy (renewable and nonrenewable).

4. Conclusion

This study sought to understand policy trend for purpose of economic growth as energy consumption drifts from solely nonrenewable source to inclusion and mix of renewable sources as well as spending on research and development in the EU. From empirical results, renewable and nonrenewable energy consumption both have a bidirectional interaction with economic growth, this further stress why policies can no longer overlook issues of energy consumption. This is because many campaigns and movement have in recent times emphasized on the need for policy makers to pay more attention to energy sources that would improve the environment, sustain the ecosystem, prioritize energy efficiency and alleviate poverty.

These two options to energy consumption both have a positive and significant impact on economic growth, the advantages of the renewable option outwit the nonrenewable option although initial cost of substituting renewable for renewable is high. To benefit

Table 7
Pooled mean group with dynamic autoregressive distributed lag (PMG-ARDL (2, 1, 1, 1).

Model: LNGDP = f (LNNREN, LNREN, LNRD)				
Long run				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNNREN	0.6001***	0.0487	12.3298	0.0000
LNREN	0.1268***	0.0097	13.0005	0.0000
LNRD	0.0522***	0.0123	4.2374	0.0000
Short run				
ECT	−0.3146***	0.0695	−4.5278	0.0000
⊿LNNREN	−0.0837	0.0665	−1.2585	0.2098
⊿LNREN	−0.0127	0.0266	−0.4782	0.6331
⊿LNRD	−0.1249**	0.05252	−2.3777	0.0184
Constant	1.6713***	0.3604	4.6368	0.0000
Kao cointegration test				
		t-Stat		Prob.
ADF		−2.9933***		0.0014
Residual variance		0.000825		
HAC variance		0.001288		

Note: The superscripts ***, **, * indicates 0.01, 0.05 and 0.10 statistical rejection respectively.

Table 8
Dumitrescu and hurlin panel causality tests.

Null Hypothesis:	W-Stat.	Causality direction	Prob.
LNNREN ≠>LNGDP	3.1685***	NREN ↔ GDP	0.0000
LNGDP ≠>LNNREN	6.0753***		0.0000
LNREN ≠>LNGDP	4.7304***	REN ↔ GDP	0.0000
LNGDP ≠>LNREN	4.1167***		0.0000
LNRD ≠>LNGDP	2.2719***	RD ↔ GDP	0.0000
LNGDP ≠>LNRD	4.1796***		0.0000
LNREN ≠>LNNREN	9.6660***	REN ↔ NREN	0.0000
LNNREN ≠>LNREN	3.03782***		0.0000
LNRD ≠>LNNREN	6.2952***	RD → NREN	0.0000
LNNREN ≠>LNRD	1.7175		0.2415
LNRD ≠>LNREN	3.2465***	RD ↔ REN	0.0000
LNREN ≠>LNRD	4.8940***		0.0000

Note: the symbol ≠> denotes null hypothesis that, the variables do not Granger cause one another. The superscripts ***, **, * indicates 0.01, 0.05 and 0.10 statistical rejection respectively.

from a sustainable growth impact between renewable energy consumption and nonrenewable energy consumption there should be a provision of interest free loan for firms who are willing to switch. Also, multiple sources of renewable options should be considered as a fast approach to attain sufficient capacity for public and private organization. The investment in renewable energy options should be encouraged through public-private collaborations to hedge the risks in renewable energy projects. This necessitates the need for even more spending on research and development to for long term sustainability purposes.

Research and development have a bidirectional relationship with renewable energy and unidirectional relationship with nonrenewable energy. This implies that as economic grows by utilization of renewable energy sources, renewable energy sources also lead to economic growth. This can be proven by exportation of renewable energy solution created by GDP expenditure on research and development for further innovation in renewable energy solutions by European countries to other countries will foster economic growth. Policies to encourage engineering develop technological approach to make renewable technologies should be embark upon. Also, scholarships and educational incentives should be given to students and teachers interested in this sector. It is when all of these solutions are employed that the impact of growth in economy based on transition from nonrenewable energy to renewable energy influenced by expenditure on research and development will be measurable at the long run.

CRediT authorship contribution statement

Festus Fatai Adedoyin: Writing - original draft. **Festus Victor Bekun:** Investigation, Methodology, Supervision, Validation, Visualization. **Andrew Adewale Alola:** Data curation, Writing - original draft, Writing - review & editing, Conceptualization, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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List of Abbreviation

PMG-ARDL: Pool Mean Group Autoregressive Distributive Lag Model
D-H: Dumitrescu and Hurlin Panel Causality tests
EU: European Economy
IPCC: Intergovernmental Panel on Climate Change
GHGs: Greenhouse gas emission
RGDP: Real gross domestic product
ECT: Error correction term
EKC: Environmental Kuznets curve
MDGs: Millennium Development Goals
CO_2: Carbon dioxide emissions
VECM: Vector Error correction model
VAR: Vector Auto regressive Model