



# The alternative energy utilization and common regional trade outlook in EU-27: Evidence from common correlated effects

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## ABSTRACT

The role of low-carbon energy and trade on the environment has drawn several studies that have looked at issues from different perspectives, thus yielding differing conclusions. Considering the current emphasis on the COP25 conference and the commitment to cut down carbon emissions level, this study also draws strength from the United Nations Sustainable development Goals (UNSDGs) that comprises of positive strides for access to clean and responsible energy consumption (SDGs 7, 12) and climate change mitigation issues (SDG-13). To this end, this study is a timely outlook that underpins the case of the European Union (EU) countries as well as the root cause of anthropogenic activities on clean trajectory of global environment. Hence, we investigate the connection between alternative and sustainable energy source, trade, income and emissions in 27 selected European Union economies by utilizing data covering the period 1990–2017 on an annual frequency. We used second-generation panel model estimators to analyze the relationship between the variables in the long-run. Specifically, the long run results from the MG (Mean Group), AMG (Augmented Mean Group), and CCEMG (Common Correlated Effects Mean Group) estimators reveal that sustainable and alternative energy sources have a negative significant impact on pollutant emissions while trade and income have a positive impact on carbon emissions except that the impact of trade is insignificant. Although the positive impact of openness in trade on carbon emission is insignificant, the positive impact suggests that the free-trade policy that is currently in place in the EU should further incorporate sustainable development goals (SDGs) to avoid the outsourcing of carbon emissions among the member countries. Causality tests reveal a feedback hypothesis between renewable energy, income, trade, and carbon emanations. The investigation proposes expanded utilization of sustainable power source to mitigate carbon emissions in the European Union.

## 1. Introduction

The drive for economic and social growth has led to interrelationship amongst nations and increased economic activities. These activities which are mostly industrial involve the emission of greenhouse gases that are detrimental to the environment and leads to environmental degradation which results from energy consumption with fossil fuels. Developed and developing countries focus on economic activities and policies towards enhancing economic growth and this quest for economic development is joined by the consumption of energy irrespective of the source of energy. However, fossil fuels energy is widely used and possess a threat to environmental quality as already outlined in the

energy literature. Thus, the need for an alternative energy sources like renewables is timely to fulfill the current energy demand mostly driven by industrial sector globally [1]. However, the example of financial development and vitality utilization contributes greatly to the enhancement of countries environmental performance levels [2]. This means that the policies for monetary development and utilization of energy policies determine the performance of the environment in terms of degradation and climate change. Also, it is important to ensure tradeoffs is avoided between energy usage, economic activities and environmental degradation but rather the interdependence between the variables should be encouraged to ensure sustainable development [2].

Correspondingly, considering the importance of globalization and the rapid increase in industrial activities associated with it, it is

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**List of abbreviations/nomenclature**

UNSDG	United Nations Sustainable Development Goals
EKC	environmental Kuznets curve
MG	Mean Group
AMG	Augmented Mean Group
CCEMG	Common Correlated Effects Mean Group
EU	European Union
WTO	World Trade Organization
GHGs	Greenhouse gas
PPP	Polluters pay principles
RE	Renewable energy consumption
NRE	Non-renewable energy consumption
OECD	Organization for Economic Co-operation and Development
ARDL	Autoregressive distributive lag
GH	Greenhouse gas
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
GDP	Gross domestic product
OLS	Ordinary Least Square
WDI	World Bank Development Indicators
UN	United Nations

important for the government to adequately manage the current pace of economic development in such a way that it does not tamper with the environment [3]. Energy utilizations positively affect the carbon dioxide outflows, that is, increased consumption of energy in the country contributed to the increasing emission of carbon dioxide (CO<sub>2</sub>). Also, the effect of economic activities on nature has gotten expanded consideration as a dangerous atmospheric deviation and other ecological issues arise and become more serious. The purpose of countries activities and policies geared towards economic growth is therefore important to ensure that economic growth is sustained. Meanwhile, the impact of per capita GDP on carbon dioxide emissions is positive and statistically significant. An inverted U-shaped curve was found between the emissions of carbon dioxide and GDP per capita which validates the environmental Kuznets curve hypothesis (EKC) [4]. The EKC hypotheses established that the early stages of economic development come with ecological corruption which increases until it arrives at a specific level of income and then environmental improvement will occur. Therefore, a relationship that exists between environmental degradation and real GDP is inverted and U-shaped.

The EU-27 is a political and economic union that consists of 27 member states that are located primarily in Europe. The EU is one of the world's biggest single market zones as a component of its establishing standards has focused on guaranteeing an open-world exchange. About 30% of the EU's GDP between 1999 and 2010 are responsible for ensuring reasonable trade policies among member countries and negotiating agreements since they carry more weight in international trade negotiations than individual members. The EU alongside the World Trade Organization (WTO) upholds policies that promote trade among the member countries. The economic growth of the nations is associated with their level of international trade and energy consumption is likely to increase with increased carbon emission. Given the foregoing, the inputs of renewable and nonrenewable energies as well as international trade is relatively important and determines the nations' output. Also, the EU is committed to achieving the reduction of GHGs by ensuring that the production and consumption of renewable energies are promoted. The EU is prepared towards helping creating countries in handling the expense of environmental change as they have limited resources to adapt to sustainable power sources. In this way, the EU ought to give further universal exchange motivators to these nations [5].

Hence, this study attempts to have an Outlook into EU-27 Renewable/alternative Energy utilization in the face of common regional trade using evidence from the second-generation panel analysis. This study is important because it addresses the relevance of energy utilization from renewable sources in reducing carbon emissions while considering regional trade in EU 27. The present study draws strength from the income-emission induced environmental degradation hypothesis anchored on the linear trade-off between carbon dioxide emission and income level fondly know in the energy literature as Environmental Kuznets Curve. Energy consumption and trade flow have been identified as drivers of pollution emission. This study is supported by the EKC phenomena (liner version) on the inverse nexus between income level and environmental quality [6]. Global energy demand contributes to environment quality (fossil fuel base) most accessible form of energy globally which translates into environmental pollutant. Hence, the present study advances the liner trade off-between emission and income level by using an augmented carbon-income function to capture trade flow, energy consumption and economic growth trajectory. The current study is posed to contribute to the existing literature in the following parts: (1) In addition to using an updated dataset, the current study also applied a more robust (second-generation panel estimation) methods of MG (Mean group), the Augmented version (AMG), and the Common Correlated Effects (CCEMG) to account for possible country-specific factors. (2) By investigating the environmental impact of trade aspects in the context of the EU-27, the study further posits the implication of free-trade policy from the perspective of environmental sustainability while previous studies have looked at environmental degradation, energy consumption, economic growth about emissions of carbon (CO<sub>2</sub>), others considered the pollutant emissions in relation with trade [3, 7–12]. However, this study expands the focus of previous studies by taking a look at EU-27 consumption of sustainable energy – renewable in the face of Common Regional Trade.

The next section presents a rich discussion on the arguments in the literature as it relates to the utilization of energy from renewable and nonrenewable sources; trade; economic growth and their linkage with pollutant emissions. Also, in section three we present the data used for the empirical exercise, while the main findings of this study are discussed in section four with comparison and contrast with the previous study. Section five concludes the study with vital policy implications.

## 2. Literature review

### 2.1. Energy consumption, economic growth and pollutant emissions

Carbon dioxide does not just emit into the environment without industrial or household activities geared toward economic growth, and such emissions are caused by the consumption of energy which involves burning fossil fuel and a large amount of coal utilization. However, these emissions have been assessed in connection to several determinants including conventional energy sources and alternative sources like solar, wind, and geothermal energy, etc. [3,13–18]. Since economic growth is a concern to countries, it is important to look at the relationship that exists between renewable energy consumption, carbon emission, and economic growth. Over the long run, energy utilization has a positive and factually huge effect on carbon emission. A bi-directional causal relationship exists between energy consumption and emission and between energy consumption and output in the long run [9]. Increased energy consumption reduces environmental pollution in the short run and reduction is more in the long run. Meanwhile, as the economy expands, it dampens the quality of the environment in the short and long run. This is because the country is energy conscious and efficient and they put in place energy conservation policies. Also, growth-induced energy consumption hypotheses are established [3]. The real GDP which is a great indicator of economic growth and electricity consumption are co-coordinated and a one-way Granger causality runs from the consumption of energy to real GDP i.e. with an increase in the

economic activities and rise in GDP, energy consumption increase is attained [19].

Furthermore, there exists a significant connection between gross domestic product (GDP), renewable energy (RE), non-renewable energy (NRE), natural resource rents and CO<sub>2</sub> emissions. Natural resource rent and NRE generation have tendencies of increasing emissions [7]. Due to its lack of involvement in carbon dioxide emissions and also to achieve both economic and environmental sustainability goals, renewable energies may be adopted [7]. Also, there exists a solid positive and measurably noteworthy connection between inexhaustible and sustainable energy and development [20]. Non-sustainable source of power utilization prompts a negative effect on financial development though energy consumption from sustainable sources emphatically adds to monetary development over the long run, [21]. 1% increase in the share of non-fossil fuels power generation decreases CO<sub>2</sub> emanations per capita from power generation by about 0.82%. This shows that the fast increase in the share of non-fossil fuel such as renewable energies used in electricity generation is needed to have a meaningful impact on per capita CO<sub>2</sub> emission from electricity generation [22]. Contrarily in the short run, a causal relationship exists from customary fossil sources to monetary development and no causal relationship exists running from supportable force source to money related turn of events in the short and long run. Just monetary development offers to ascend to sustainable power [23]. This implies that a shift from fossil fuel sources to energy may not guarantee economic growth but rather with the growth of the economy, the use of renewable energy sources will increase.

Even though renewable energy is an appropriate way of mitigating climate change and meeting demand for future energy demand [24]. Energy conservative arrangements might not impact or affect genuine GDP development in industrialized nations, for example, New Zealand and Australia when contrasted with other Asian economies [25]. Also, despite the relevance of renewable energy in ensuring environmental performance factors like failures of the nation's market, absence of relevant information, access to crude materials for future endless resource sending and systematic carbon impression hinders sustainability of renewable energy. In the long run, a balanced relationship exists between real GDP, renewable energy, non-renewable energy, real gross fixed capital arrangement and energy power. However, two-way causal relationships exist between the utilization of energies from low-carbon sources and the expansion of the economy and the same relationship exists between the utilization of conventional energy and economic expansion. This implies that irrespective of the source of energy, consumption of energy affects the growth of the economy and vice-versa. Also, in the short and long run, a two-way causal relationship exists between REN and NREN which shows substitutability and interdependence of both energy types [10]. Additionally, a bi-directional causal relationship exists between monetary development and CO<sub>2</sub> emanations with coal, gas, and power and oil utilization. This means diminishing energy utilization, for example, coal, gas power and oil seems, by all accounts, to be a successful method of controlling CO<sub>2</sub> discharges, however, attempts to reduce the emissions of carbon reduces economic growth [26].

Although, the pattern of economic growth and the amount of energy consumed contributes greatly to the enhancement of countries environmental performance levels [2]. Yet, attempts should be made towards the reduction of the emissions of carbon dioxide and not negatively affect the growth of the economy by increasing the supply of energy investments and energy efficiency as well as stepping up policies that tend to contribute to energy conservation may be adopted in reducing wastage for energy-dependent countries [9]. Likewise, the impact of financial developments on the earth has gotten expanded consideration as a dangerous atmospheric deviation and other ecological issues emerge and turn out to be increasingly genuine.

## 2.2. Other factors mitigating pollutant emissions

Climate change as a result of atmospheric pollution, such as carbon and sulphur that influences the atmosphere to form climate influencing aerosols. Aside from economic growth and energy consumption, several other factors hamper environmental quality. For instance, the level of globalization, urbanization, trade openness, and population increase environmental degradation. Furthermore, recent and most recent researches incorporate new factors, while adding previous factors as control variables, to highlight new evidence for policy directions to attain sustainable development for environmental growth. Such factors are eco-innovation and energy productivity in G7 nations [27], innovation shocks in OECD countries [28,29], monetary policy in Asian economies [30], commercial policy in Australia [31], and higher education in China [32] and many other.

According to Ref. [29]; mitigating carbon dioxide emission is the major priority of government agencies and industries, this is why a lot of effort are put into R&D investment for growing clean energy solution for the proper conservation of energy. From a different perspective, researchers offer a plethora of studies that investigate the link between innovation and pollutant emission [33]. used the OLS method to investigate the impact of innovation activities on CO<sub>2</sub> emission in developing countries. The results, which is consistent with the study of [34,35]; showed an adverse relationship between the emission and innovation activities. In research conducted in China by Refs. [36,37]; nexus between pollutant emission, R&D spending, financial development, energy use and urbanization. Their outcomes revealed that a reduction in CO<sub>2</sub> emission is backed by R&D spending.

EKC exists between income and emissions. Between the utilization of Energy and exchange receptiveness exists a two-way causal relationship. Also, a unidirectional causal relationship runs from the consumption of energy, the openness of trade and population to the emissions of carbon dioxide (CO<sub>2</sub>). Energy consumption and population density will increase in the long run and further increase environmental degradation, [38]. Also, CO<sub>2</sub>, exchange receptiveness, genuine pay and vitality utilization are co-coordinated. Energy utilization and exchange transparency are the primary determinants of carbon emanations over the long run, [39].

Energy preservation arrangements don't adversely affect monetary development both in the short and intermediate run while their belongings are negative over the long run. As for interactions between the development of the economy and the emissions of carbon, no causal nexus of the growth of the economy and emissions level. Also, for energy utilization and financial development, a unidirectional causality runs from the former to the latter, [40]. The consumption of energy and economic-growth nexus differs from countries. The growth hypothesis is only valid or Peru, For energy consumption from non-renewable sources, the hypotheses of growth is found for China, Colombia, Mexico and the Philippines, the conservation hypotheses are confirmed for Egypt Peru and Portugal the feedback hypotheses is supported only or turkey and the neutrality hypotheses is valid for the other 9 emerging economies, [41].

Reviewing several kinds of literature indicates that studies are available on the connection between the utilization of energy, growth of the economy, and degradation experienced by the environment as well as the relevance of the consumption of energy from renewable sources in mitigating environmental degradation. This paper however adopts the second-generation panel analysis to provide evidence for the EU-27 renewable energy consumption in theca of common regional trade.

## 3. Indicators and methodology

### 3.1. Indicators

The data utilized for this study has been collected from two sources, namely British Petroleum (BP) and World Bank Development Indicators

(WDI) and covers the period 1990–2017. We have also collected data to represent the variables. For Carbon emissions, we use carbon emissions, (million tonnes) from British Petroleum. For Income, we use Gross Domestic Product per capita from the World Bank Development Indicators. For renewable energy, we use total energy consumption from the World Bank Development Indicators, while we use trade as a percentage of Gross Domestic Product per capita as a proxy for trade. Further information about the data, especially the description and sources are presented in [Table 1](#).

### 3.2. Model and methods

In an attempt to examine the relationship that exists between trade, energy from renewable sources and emissions for the focus countries, we specify the following model:

$$CEM = f(INCOME, RENE, TRADE) \tag{1}$$

$$CEM = \alpha_0 + \beta_1 INCOME_{it} + \beta_2 RENE_{it} + \beta_3 TRADE_{it} + \epsilon_{it} \tag{2}$$

where CEM, INCOME, RENE and TRADE are all variables in the model and  $\epsilon_{it}$ ,  $\alpha$  is error term and intercept respectively. In addition, the partial slope coefficient is represented by  $\beta$ 's.

While there exist a few studies on the nexus between income-emission. There been no consensus between the relationship. The present study leverage and improves on the study of [\[42,43\]](#). Our Study is constructed on a carbon-income setting to explore the determinant of emission for EU countries as well as account for the role renewable energy consumption as an additional variable in the wave of global trade flows among member countries.

Our study model variables construction draws strength from the United Nations Sustainable Development Goals (SDGs) 7,8,12 and 13 [\[44\]](#). For instance, energy access and consumption play a vital role in economic growth and development (SDGs-7and 8) though with focus on SDG on renewable and responsible energy consumption (SGD 11 and 12). Carbon emission-which advocate for climate change mitigation (SDG-13) is top priority on the world to reduce the global emission level. Thus, a comprehensive study of these highlighted variables is timely in the wave of global trade (SDG-17).

The econometric techniques used to estimate the model are second-generation panel models namely Panel Mean Group, Augmented Mean Group and Common Correlated Effects Mean Group Estimations [\[45–47\]](#). A particular advantage of these estimators over other panel estimators is their ability to accommodate variables with cross-sectional dependence and heterogeneous properties. Very often Cross-sectional dependence comes about as a result of some strongly or weakly unobserved factors in panel units. A certain procedure is followed in the estimation of the model. Firstly, we carried out the cross-sectional reliance test [\[48\]](#) and the panel unit root tests following [\[49\]](#) including CIPS.

To examine the long-run relationships among these indicators, we carry out the [\[50\]](#) second-generation cointegration test. After which we conducted the AMG estimations estimator proposed by Ref. [\[51\]](#); CCEMG [\[52\]](#) and MG estimations [\[53\]](#) to analyze the model. Finally, we apply Dumitrescu and Hurlin tests [\[54\]](#) to establish dynamic linkages among the variables.

**Table 1**

Description of indicators.

Indicators	Description	Code
CO <sub>2</sub> emissions (CEM)	Quantified in million tonnes of CO <sub>2</sub> emissions	BP
Income (INCOME)	Quantified as the gross domestic product per capita	WDI
Renewables energy (RENE)	is measured as the share of renewable energy in Total energy consumption	WDI
Trade (TRADE)	Quantified as % of Gross Domestic Product per capita	WDI

## 4. Results and discussions

### 4.1. Statistical properties and correlation evidence

[Table 2](#) presents the summary statistics for the variables in the model. As it was observed, the mean of carbon emission is 128.224 million tonnes with minimum and maximum values of 1.36 and 1003.2 million tonnes and a standard deviation of 181.4 million tonnes. The deviation indicates that the dispersion among the variables is wide. As for income, it has an average value of 28917.97 (million US dollars) and a maximum value of 111968.3 (million US dollars) and experiences the greatest dispersion, with values of 19982.30, among all variable observations. On average, renewable energy has a mean of 13.94 with a good measure of the standard deviation of 0.931 meaning that the deviation among the observation is very low. Finally, in [Table 2](#), the trade (measured as %GDP) has a mean value of 106.74; the minimum value of 33.878; the maximum value of 408.362; and a standard deviation of 59.771 which denotes a high disparity among the observation.

[Table 3](#) shows the correlation matrix. According to the results, income is positively related to carbon emanations while renewable energy and trade have a negative linear association with the dependent variable-carbon emissions. Furthermore, there is no existence of multicollinearity among the predictor variables. Thus, the variables can be selected for the analysis as reported by the correlation analysis in [Table 3](#), where there is no one to one perfect collinearity that violate the classical linear regression axioms of perfect collinearity. Additionally, the variance inflation factor estimate as shown in [Table](#) further provided evidence that there is no multicollinearity problem in the model.

#### 4.1.1. Panel cross-sectional dependence

Before going further with the estimation of the model, it is necessary to establish cross-sectional dependence (CD) among the variables. The confirmations of CD is a condition for the use of the intended second generation panel models in the study. We use the [\[48\]](#) Lagrange Multiplier CD test. The results as presented in [Table 4](#) revealed the evidence of interdependence among, 10% significance level, across the EU countries.

#### 4.1.2. Panel unit root

Since cross-sectional dependence exists among the countries, the second-order generation of unit root test is employed. The result is presented in [Table 5](#). It revealed the variables are not stationary at the level. However, the significance value, at a 10% level, at first difference implies that the variables are stationary after differencing once and hence they are integrated of order 1 I (1).

#### 4.1.3. Panel cointegration

After testing for CD and unit root test, we go-ahead to test for the presence of cointegrating nexus among the variables in the model using the Westerlund Cointegration test. The results of the test are presented in [Table 6B](#). According to the p-values, the null hypothesis of no cointegration among the variables is rejected. Hence, confirming the presence of cointegration among the studied variables.

**Table 2**

Statistical properties.

Properties	CEM	INCOME	RENE	TRADE
Mean	128.224	28917.97	13.944	106.736
Median	57.356	23700.16	10.001	90.802
Maximum	1003.197	111968.3	53.248	408.362
Minimum	1.354	3582.856	0.000	33.878
Std. Dev.	181.368	19982.30	11.353	59.771
Skewness	2.517	1.397	0.931	1.912
Kurtosis	9.803	5.854	3.065	7.892
Observations	756	756	756	756

**Table 3**  
Evidence of correlation.

Indicators	CEM	INCOME	RENE	TRADE	Variance Inflation Factor (VIF)
CEM	1.000				
INCOME	0.106*	1.000			1.497892
RENE	-0.262*	-0.043*	1.000000		1.333361
TRADE	-0.382*	0.375*	-0.257*	1.000000	1.823210

Note: The \* is the 1% statistical significant level. In addition, the VIF values are all less than 10, thus indicating that there is no multicollinearity in the model.

**Table 4**  
Test of a dependency across the sections.

Indicators	LM Test	CDLM Test	LM Test	CD Test
CEM	3076.290*	24.591*	101.840*	24.59*
INCOME	6018.450*	64.504*	212.885*	64.50*
RENE	6353.697*	77.105*	225.538*	77.10*
TRADE	5708.629*	66.811*	201.192*	66.81*

Note: The \* is the 1% statistical significant level. In addition, the LM, CD, CEM, INCOME, RENE, and TRADE are respectively Lagrange Multiplier, Cross-sectional Dependence, carbon emissions, the gross domestic product per capita, renewable energy consumption, and trade.

**Table 5**  
Evidence of stationarity.

Panel CIPS	Natural level		First Difference	
	Constant	Trend	Constant	Trend
CEM	-2.90*	-3.02*	-4.78*	-5.25*
INCOME	-1.70	-2.30	-3.81*	-4.06*
RENE	-2.25	-2.49	-4.94*	-5.09*
TRADE	-1.97	-1.97	-4.04*	-4.16*

  

IPS	Natural level		First Difference	
	Constant	Trend	Constant	Trend
CEM	-6.79*	-5.00*	-13.18*	-10.74*
INCOME	3.34	-0.14	-9.63*	-6.54*
RENE	2.82	-2.49	-4.94*	-5.09*
TRADE	-1.62	-4.97*	-15.84*	-13.5*

Note: The \* is the 1% statistical significant level.

**Table 6A**  
The MG, AMG, CCEMG estimations.

Variables	MG Test	AMG Test	CCEMG Test
INCOME	0.005*	0.004*	0.004*
RENE	-1.714*	-1.177*	-1.663*
TRADE	-0.099	-0.183	-0.174
C	66.403**	85.996*	-76.691**
T	-1.576**	-1.253	-1.443
Wald	26.45*	18.74*	11.03*
RMSE	5.889	5.301	4.312
No. T	13	15	12

4.2. Results of panel MG, AMG and the CCEMG estimations

The results of diagnostics tests such as the cross-dependency test, panel unit root test and cointegration tests have confirmed the presence of heterogeneity and cross dependency, stationarity relationships as well as long-run respectively among the variables in the model. This qualifies the use of second-generation estimators. Accordingly, we utilize the AMG estimator [51], CCEMG [52] and MG estimations [53] to analyze the models. Our choice of three estimators is to ensure that we obtain robust results for the model.

Table 6A presents the results for the model carried out by the MG, AMG and CCMEG estimators. The model estimates obtained in the CCMEG is more robust considering that it has the least RMSE value.

**Table 6B**  
Cointegration evidence by Westerlund.

Statistic	Value	Z-value	P-value
Gt	-2.237	-2.677	0.004*
Ga	-5.109	2.247	0.988
Pt	-10.727	-2.963	0.002*
Pa	-7.442	-2.610	0.005*

Note: The CEM, INCOME, RENE, and TRADE are respectively the carbon emissions, gross domestic product per capita, renewable energy consumption, and trade. Also, \* indicates the 1% statistical significance level. The RMES, C, T, and No.T are respectively the root mean squared error, intercept group-specific linear trend, and the share of group-specific trends at a 5% significant level. MG, AMG, and CCEMG are respectively the Mean Group, Augmented Mean Group and Common Correlated Effects Mean Group. In addition, the average AIC selected lag and lead length is 1.56 and 0.63 respectively for the Westerlund cointegration.

Overall, the results are significant and consistent with previous findings. Accordingly, income has influences carbon emissions positively across all estimators at a 10% significance level. The evidence in this study coincides with that of [55] for BRICS and G7 countries and [56] for OECD countries. Specifically, a 1 million dollars increase in income is associated with an increase in emissions between 0.004 and 0.005 million tonnes. This result implies that as income grows in the EU countries, it triggers an increase in emissions which contributes to worsening the quality of the environment. This is because economic activities (represented by income) involve the conventional energy utilization that is responsible for pollutant emissions and consequently causes degradation in the quality of the environment. Such economic activities involve production activities in industries, transportation activities among many others.

On the other hand, the low carbon energy sources have a negative effect on carbon emissions at a 10% level of significance. This finding is similar to that of Dong et al. (2017) for BRICS countries and Bilgil et al. (2018) for 17 OECD countries. On average, a 1 unit increase in renewable energy consumption will lead to a fall in emissions by 1.177–1.714 million tonnes. This implies that the continuous use of renewable energy is capable of reducing the levels of emissions in the European Union and thus, improving the quality of the natural environment. Renewable energy by its nature comprises non-carbon emitting forms hence, its negative effects on carbon emissions in the environment.

Additionally, trade exerts a negative impact on carbon emissions in the EU 27 economies, howbeit the impact is insignificant. Going further, a 1 million dollar increase in trade activities among the European Union countries will lead to a statistically insignificant fall in emissions by 0.099–0.183 million dollars. This implies that an increase in trade activities is capable of reducing emissions, but this is not possible as it is statistically insignificant. This finding is similar to that of [57] for India and China and [58] for China.

In summary, the results have proved that renewable energy and income have a significant impact on pollutant emissions in the European Union, while the impact of trade on emissions is insignificant in the region. Also, AMG and CCEMG estimates provide evidence in support of the robustness of the model as most of the variables were significant.

4.3. Dumitrescu-hurlin causality test

Table 7 presents the causality evidence which shows which variables are causative agents to others. Overall, there is impressive causality evidence found among all variables in the model which in most cases is bidirectional. For instance, there is causality feedback between income and carbon emissions which is similar to the findings of [59] who also found feedback causality between income and emissions in South Korea.

There is also feedback causality between sustainable power source utilization and emissions as is the case in Ref. [60] that established a bi-directional causal relationship between renewable energy and

**Table 7**  
DH causality evidence.

Relationship	W-Stat.	Zbar-Stat.	Prob.	Direction of causality
INCOME→CEM	4.950*	5.7925	7.00E-09	Bi-directional
CEM→INCOME	3.294*	2.29157	0.022	
RENE→CEM	5.986*	7.9841	1.00E-15	Bi-directional
CEM→RENE	3.805*	3.37124	0.0007	
TRADE→CEM	3.391**	2.49628	0.0126	Uni-directional
CEM→TRADE	1.81295	-0.84085	0.4004	
RENE→INCOME	3.054**	1.78284	0.0746	Bi-directional
INCOME→RENE	6.374*	8.80458	0	
TRADE→INCOME	3.093***	1.86596	0.062	Bi-directional
INCOME→TRADE	5.230*	6.38692	2.00E-10	
TRADE→RENE	4.047*	3.88396	0.0001	Bi-directional
RENE→TRADE	4.123*	4.04466	5.00E-05	

emissions for 7 central American countries. There is still evidence of feedback causality energy from renewable sources and income, similar to the findings of [61] for 20 OECD countries. Trade, on the other hand, has a feedback causality with income which is in line with the case in Ref. [62] for 11 countries. Similarly, there is a two-way causal relationship between renewable energy and trade as was found by Ref. [63] for 69 countries. One case of unidirectional causality is observed from trade to emissions, which is contrary to the findings of [64] who found a one-way causal relationship from emissions to trade for BRICS countries.

## 5. Conclusion and policy recommendations

Considering the current global emphasis to cut down emissions as was discussed at the COP25 in December 2019, this study investigates the link between energy from renewable sources, trade, income and emissions for a panel of 27 European Union Countries utilizing data covering the period 1990–2017. The study employs the use of second-generation panel model estimators to analyze the long-run relationship among the variables. According to the findings of the study, renewable energy has a long-run negative and significant impact on emissions while trade and income have a positive impact on emissions except that the impact of trade is insignificant. Furthermore, causality analysis reveals a feedback hypothesis between renewable energy, income, trade, and carbon emissions.

The study makes some recommendations for policy consideration. Firstly, owing to the tradeoff between income and environmental quality established in the study, it gets important to search for economical methods of conducting economic (income) activities in a way that lowers emissions level and consequently improves the quality of the environment. To achieve this outcome, the study provides suggestions that the increased use of renewable energy in the European Union bloc. This can be achieved by increased investments in the production of various forms of renewable energy in the region which will increase the share of energy from renewable sources in the energy mix for the EU countries and will make renewable energy available and accessible for economic activities. On the other hand, the governments in the region could also encourage the consumption of Renewable energy in the region by providing incentives for the use of such energy, for example, price subsidy for renewable energy forms. This will also go a long way to stimulate an increased adoption of renewable energy in EU countries.

Thirdly, to curb the effect of economic activities on emissions, the introduction of a penalty for high carbon-emitting activities such as crude oil exploration and aviation is desirable. The detrimental effect anthropogenic human activities that comprise of trade flows channels and energy demand. Thus, there is need for more pragmatic action step that is deliberate on policy direction for climate change mitigation on pollution determinants in the context of EU countries. From a policy lens, there is need to have a more paradigm shift to renewables like hydro energy sources, wind energy and photovoltaic energy alongside adoption of new technologies. While re-invigorating such policy measure, there is need to further regulate trade flows that harm the

environmental quality of the region. Thus, there is need for more enforcement of the polluters pay principles (PPP), a concept that emphasizes the need to enforce regulation(s) on those who pollute the environment subject to cost of damage on the environment. This measure popularly known as the carbon tax will aid to reduce emissions as a result of economic expansion.

Though the study from our findings is useful for an environmental improvement road map in the EU countries, it may not be suitable for policy use in individual countries out of the region. For this reason, we suggest that future studies be carried out for various countries and regions to serve their environmental policy needs. Secondly, future studies could also consider the use of Ecological Footprints as a representation of the environment, given that it is capable of accounting for a wide range of environmental resources using disaggregated data.

## Credit author statement

Festus Victor ADEDOYIN: Writing – review & editing; Conceptualization; Formal analysis. Festus Victor BEKUN: Writing – original draft; Writing, Validation; Visualization; Andrew Adewale ALOLA: Data curation; Writing – original draft; Investigation; Methodology; Supervision, and Corresponding.

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## 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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