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

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 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 enegy 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 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. In specific, 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 pollutant 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.

Keywords: Renewable energy; environmental sustainability; Trade; income; Pollutant emissions; European Union

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- Organisation for Economic Co-operation and Development

ARDL-Autoregressive distributive lag

GH- Greenhouse gas

CO-Carbon monoxide

CO_2-Carbon dioxide

GDP-Gross domestic product

OLS-Ordinary Least Square

WDI- World Bank Development Indicators

UN-United Nations

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, the use of 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 (Atabani et al,2012). However, the example of financial development and vitality utilization contributes greatly to the enhancement of countries environmental performance levels (Ozcan et al., 2019). 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 (Ozcan et al., 2019).

Correspondingly, considering the importance of globalization and the rapid increase in industrial activities associated with it, it is 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 (Etokakpan et al., 2020). 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_2). 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 (Kais and Sami, 2016). 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 1999-2010 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 (Halicioglu and Ketenci, 2018).

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 is study is supported by the EKC phenomena (liner version) on the inverse nexus between income level and environmental quality (Stern, 2004). 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_2), others considered the pollutant emissions in relation with trade (Adedoyin et al., 2020; Etokakpan et al., 2020; Pao & Tsai, 2010; Kahia et al., 2017; Alola et al., 2019; Saint Akadiri et al., 2019). 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. (Adedoyin et al., 2020a; Adedoyin et al., 2020b; Adedoyin et al., 2020c; Adedoyin and Zakari, 2020; Etokakpan et al., 2020; Kirikkaleli et al., 2020; Udi et al., 2020). 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 (Pao and Tsai, 2010). 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 (Etokakpan et al., 2020). 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 (Yuan et al., 2008).

Furthermore, there exists a significant connection between gross domestic product (GDP), renewable energy (RE), non-renewable energy (NRE), natural resource rents and CO_2 emissions. Natural resource rent and NRE generation have tendencies of increasing emissions (Adedoyin et al., 2020a). 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 (Adedoyin et al., 2020a). Also, there exists a solid positive and measurably noteworthy connection between inexhaustible and sustainable energy and development (Atems and Hotaling, 2018). 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, (Ito, 2017). 1% increase in the share of non-fossil fuels power generation decreases CO_2 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 CO2 emission from electricity generation (Liddle and Sadorsky, 2017). 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 (Marques et al., 2014). 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 (Owusu and Asumadu-Sarkodie, 2016). 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 (Fatai et al., 2004). 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 (Kahia et al., 2017). Additionally, a bi-directional causal relationship exists between monetary development and CO_2 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_2 discharges, however, attempts to reduce the emissions of carbon reduces economic growth (Saboori and Sulaiman, 2013).

Although, the pattern of economic growth and the amount of energy consumed contributes greatly to the enhancement of countries environmental performance levels (Ozcan et al., 2019). 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 (Pao and Tsai, 2010). 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 (Ding et al., 2020), innovation shocks in OECD countries (Ahmad et al., 2020, 2021), monetary policy in Asian economies (Qingquan et al., 2020), commercial policy in Australia (Qingquan et al., 2021), and higher education in China (Li et al., 2021) and many other.

According to Ahmad et al. (2021), 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. Fernández et al. (2018) used the OLS method to investigate the impact of innovation activities on CO_2 emission in developing countries. The results, which is consistent with the study of Awaworyi et al. (2019) and Su and Moaniba (2017), showed an adverse relationship between the emission and innovation activities. In research conducted in China by Jin et al. (2017) and Shahbaz et al. (2018), nexus between pollutant emission, R&D spending, financial development, energy use and urbanization. Their outcomes revealed that a reduction in CO_2 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 (CO2). Energy consumption and population density will increase in the long run and further increase environmental degradation, (Ahmed et al., 2017). Also, CO2, 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, (Ertugrul et al., 2016).

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, (Gorus and Aydin, 2019). 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, (Destek and Aslan, 2017).

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 thecae 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.

Table 1: Description of indicators

Indicators	Description	Code
CO_2 emissions (CEM)	Quantified in million tonnes of CO_2 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

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:

$$CEM = f(INCOME, RENE, TRADE) \quad (1)$$

$$CEM = \alpha_0 + \beta_1 INCOME_{it} + \beta_2 RENE_{it} + \beta_3 TRADE_{it} + \varepsilon_{it} \quad (2)$$

Where CEM, INCOME, RENE and TRADE are all variables in the model and ε_{it} , α is error term and intercept respectively. In addition, the partial slope coefficient is represented by β'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 Khoshnevis Yazdi & Shakouri, 2017;Inglesi-Lotz & Dogan, 2018). 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 (United Nations, 2015). 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 (Phillips & Sul, 2003; Pesaran, 2004; Breitung, 2005). 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 (Breusch and Pagan,1980) and the panel unit root tests following Pesaran (2007) including CIPS.

To examine the long-run relationships among these indicators, we carry out the Westerlund (2007) second-generation cointegration test. After which we conducted the AMG estimations estimator proposed by Eberhardt and Bond (2009), CCEMG (Pesaran, 2006) and MG estimations (Pesaran and Smith, 1995) to analyze the model. Finally, we apply Dumitrescu and Hurlin tests (Dumitrescu and Hurlin, 2012) to establish dynamic linkages among the variables.

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 anayysis 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.

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.

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 Breusch and Pagan (1980) Lagrange Multiplier CD test. The results as presented in Table 4 revealed the evidence of interdependence among, 10 % significance level, across the EU countries

Table 4. Test of a dependency across the sections

Indicators	LM Test	CD_{LM} 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.

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).

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.

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.

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 (Eberhardt and Bond, 2009), CCEMG (Pesaran, 2006) and MG estimations (Pesaran and Smith, 1995) 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. 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 Zhou et al (2019) for BRICS and G7 countries and Gövdeli (2019) for OECD countries. Specifically, a 1 million dollars increase in income is associated with an increase in emissions between 0.004 to 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 to 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 to 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 Jayanthakumaran et al (2012) for India and China and Jalil and Mahmud (2009) 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 CCMGG estimates provide evidence in support of the robustness of the model as most of the variables were significant.

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

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.

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 Yoo (2006) 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 Apergis and Payne (2014) that established a bi-directional causal relationship between renewable energy and emissions for 7 central American countries. There is still evidence of feedback causality energy from renewable sources and income, similar to the findings of Apergis and Payne (2010) for 20 OECD countries. Trade, on the other hand, has a feedback causality with income which is in line with the case in Aïssa et al (2014) for 11 countries. Similarly, there is a two-way causal relationship between renewable energy and trade as was found by Jebli and Youssef (2015) for 69 countries. One case of unidirectional causality is observed from trade to emissions, which is contrary to the findings of Sebri and Ben-Salha (2014) who found a one-way causal relationship from emissions to trade for BRICS countries.

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	

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 actives 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 .

References

Adedoyin, F., Abubakar, I., Victor, F., Asumadu, S. (2020a). Generation of energy and environmental-economic growth consequences: Is there any difference across transition economies? Energy Reports 6, 1418–1427. https://doi.org/10.1016/j.egyr.2020.05.026

Adedoyin, F., Ozturk, I., Abubakar, I., Kumeka, T., Folarin, O. (2020b). Structural breaks in CO 2 emissions: Are they caused by climate change protests or other factors ? J. Environ. Manage. 266, 110628. https://doi.org/10.1016/j.jenvman.2020.110628

Adedoyin, F.F., Alola, A.A., Bekun, F.V. (2020a). An assessment of environmental sustainability corridor: The role of economic expansion and research and development in EU countries. Sci. Total Environ. 713, 136726. https://doi.org/10.1016/j.scitotenv.2020.136726

Adedoyin, F.F., Bekun, F.V., Alola, A.A. (2020b). Growth Impact of Transition from Non-renewable to Renewable Energy in the EU: The role of Research and Development Expenditure. Renew. Energy.

Adedoyin, F.F., Gumede, I.M., Bekun, V.F., Etokakpan, U.M., Balsalobre-lorente, D. (2020c). Modelling coal rent, economic growth and CO2 emissions: Does regulatory quality matter in BRICS economies? Sci. Total Environ. 710, 136284. https://doi.org/10.1016/j.scitotenv.2019.136284

Adedoyin, F.F., Zakari, A. (2020). Energy Consumption, Economic Expansion, and CO2 Emission in the UK: The Role of Economic Policy Uncertainty. Sci. Total Environ.

Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H. H., & Mekhilef, S. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. Renewable and sustainable energy reviews, 16(4), 2070-2093.

Ahmad, Manzoor & Khattak, Shoukat & Khan, Anwar & Rahman, Zia. (2020). Innovation, foreign direct investment (FDI), and the energy–pollution–growth nexus in OECD region: a simultaneous equation modeling approach. Environmental and Ecological Statistics. 10.1007/s10651-020-00442-8.

Ahmad, Manzoor & Khan, Zeeshan & Rahman, Zia & Khattak, Shoukat & Ullah Khan, Zia. (2021). Can innovation shocks determine CO2 emissions (CO2e) in the OECD economies? A new perspective. Economics of Innovation and New Technology. 30. 89-109. 10.1080/10438599.2019.1684643.

Ahmed, K., Rehman, M.U., Ozturk, I. (2017). What drives carbon dioxide emissions in the long-run? Evidence from selected South Asian Countries. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2016.12.018

Aïssa, M. S. B., Jebli, M. B., & Youssef, S. B. (2014). Output, renewable energy consumption and trade in Africa. *Energy Policy*, *66*, 11-18.

Alola, A. A., Yalçiner, K., Alola, U. V., & Saint Akadiri, S. (2019). The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe largest states. Science of The Total Environment, 674, 307-315.

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: evidence from a panel of OECD countries. *Energy policy*, *38*(1), 656-660.

Apergis, N., & Payne, J. E. (2014). Renewable energy, output, CO2 emissions, and fossil fuel prices in Central America: Evidence from a nonlinear panel smooth transition vector error correction model. *Energy Economics*, *42*, 226-232.

Atems, B., Hotaling, C. (2018). The effect of renewable and nonrenewable electricity generation on economic growth. Energy Policy 112, 111–118. https://doi.org/10.1016/j.enpol.2017.10.015

Awaworyi Churchill, S., J. Inekwe, R. Smyth, and X. Zhang. (2019).“R&D Intensity and Carbon Emissions in the G7: 1870–2014.”Energy Economics 80: 30–37. doi:10.1016/J.ENECO.2018.12.020.

Bélaïd, F., Youssef, M. (2017). Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: Assessing the evidence from Algeria. Energy Policy 102, 277–287. https://doi.org/10.1016/j.enpol.2016.12.012

Bello, M.O., Solarin, S.A., Yen, Y.Y. (2018). The impact of electricity consumption on CO2 emission, carbon footprint, water footprint and ecological footprint: The role of hydropower in an emerging economy. J. Environ. Manage. 219, 218–230. https://doi.org/10.1016/j.jenvman.2018.04.101

Breitung, J. (2005). *The local power of some unit root tests for panel data*. Humboldt-Universität zu Berlin, Wirtschaftswissenschaftliche Fakultät.

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The review of economic studies*, *47*(1), 239-253.

Destek, M.A., Aslan, A. (2017). Renewable and non-renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality. Renew. Energy 111, 757–763. https://doi.org/10.1016/j.renene.2017.05.008

Ding, Qing & Khattak, Shoukat & Ahmad, Manzoor. (2021). Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations. Sustainable Production and Consumption. 27. 254-268. 10.1016/j.spc.2020.11.004.

Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic modelling*, *29*(4), 1450-1460.

Eberhardt, M., & Bond, S. (2009). Cross-section dependence in nonstationary panel models: a novel estimator.

Ertugrul, H.M., Cetin, M., Seker, F., Dogan, E. (2016). The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries. Ecol. Indic. 67, 543–555. https://doi.org/10.1016/j.ecolind.2016.03.027

Etokakpan, M.U., Adedoyin, F.F., Vedat, Y., Bekun, F.V. (2020). Does globalization in Turkey induce increased energy consumption : insights into its environmental pros and cons. Environ. Sci. Pollut. Res.

Fatai, K., Oxley, L., Scrimgeour, F.G. (2004). Modelling the causal relationship between energy consumption and GDP in New Zealand, Australia, India, Indonesia, The Philippines and Thailand, in: Mathematics and Computers in Simulation. pp. 431–445. https://doi.org/10.1016/S0378-4754(03)00109-5

Fernández Fernández, Y., M. A. Fernández López, and B. Olmedillas Blanco. (2018).“Innovation for Sustainability: TheImpact of R&D Spending on CO2 Emissions.”Journal of Cleaner Production 172: 3459–3467. doi:10.1016/J.JCLEPRO.2017.11.001

Gorus, M.S., Aydin, M. (2019). The relationship between energy consumption, economic growth, and CO2 emission in MENA countries: Causality analysis in the frequency domain. Energy 168, 815–822. https://doi.org/10.1016/j.energy.2018.11.139

Gövdeli, T. (2019). Health Expenditure, Economic Growth, and CO2 Emissons: Evidence from the OECD Countries. *Adıyaman Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, (31), 488-516.

Halicioglu, F., Ketenci, N. (2018). Output, renewable and non-renewable energy production, and international trade: Evidence from EU-15 countries. Energy 159, 995–1002. https://doi.org/10.1016/j.energy.2018.06.197

Ito, K. (2017). CO2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. Int. Econ. 151, 1–6. https://doi.org/10.1016/j.inteco.2017.02.001

Jalil, A., & Mahmud, S. F. (2009). Environment Kuznets curve for CO2 emissions: a cointegration analysis for China. *Energy policy*, *37*(12), 5167-5172.

Inglesi-Lotz, R., & Dogan, E. (2018). The role of renewable versus non-renewable energy to the level of CO2 emissions a panel analysis of sub-Saharan Africa's Big 10 electricity generators. Renewable Energy, 123, 36-43.

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO2 emissions, energy consumption, trade and income: a comparative analysis of China and India. *Energy Policy*, *42*, 450-460.

Jebli, M. B., & Youssef, S. B. (2015). Output, renewable and non-renewable energy consumption and international trade: Evidence from a panel of 69 countries. *Renewable Energy*, *83*, 799-808.

Jiang, Qingquan & Khattak, Shoukat & Ahmad, Manzoor & Ping, Lin. (2020). A new approach to environmental sustainability: Assessing the impact of monetary policy on CO2 emissions in Asian economies. Sustainable Development. 10.1002/sd.2087.

Jin, L., K. Duan, C. Shi, X. Ju, L. Jin, K. Duan, C. Shi, and X. Ju. (2017). "The Impact of Technological Progress in the EnergySector on Carbon Emissions: An Empirical Analysis from China."International Journal of Environmental Research andPublic Health 14: 1505. doi:10.3390/ijerph14121505

Khoshnevis Yazdi, S., & Shakouri, B. (2017). Renewable energy, nonrenewable energy consumption, and economic growth. Energy Sources, Part B: Economics, Planning, and Policy, 12(12), 1038-1045.

Kahia, M., Aïssa, M.S. Ben, Lanouar, C. (2017). Renewable and non-renewable energy use - economic growth nexus: The case of MENA Net Oil Importing Countries. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2017.01.010

Kais, S., Sami, H. (2016). An econometric study of the impact of economic growth and energy use on carbon emissions: Panel data evidence from fifty eight countries. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2016.01.054

Kirikkaleli, D., Adedoyin, F.F., Bekun, F.V. (2020). Nuclear energy consumption and economic growth in the UK : Evidence from wavelet coherence approach. J. Public Aff. 1–11. https://doi.org/10.1002/pa.2130

Li, H., Khattak, S.I. & Ahmad, M. Measuring the impact of higher education on environmental pollution: new evidence from thirty provinces in China. Environ Ecol Stat 28, 187–217 (2021). https://doi.org/10.1007/s10651-020-00480-2

Liddle, B., Sadorsky, P. (2017). How much does increasing non-fossil fuels in electricity generation reduce carbon dioxide emissions? Appl. Energy 197, 212–221. https://doi.org/10.1016/j.apenergy.2017.04.025

Mahalik, M.K., Babu, M.S., Loganathan, N., Shahbaz, M. (2017). Does financial development intensify energy consumption in Saudi Arabia? Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2016.11.081

Marques, A.C., Fuinhas, J.A., Menegaki, A.N. (2014). Interactions between electricity generation sources and economic activity in Greece: A VECM approach. Appl. Energy 132, 34–46. https://doi.org/10.1016/j.apenergy.2014.06.073

Owusu, P.A., Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng. https://doi.org/10.1080/23311916.2016.1167990

Ozcan, B., Tzeremes, P.G., Tzeremes, N.G. (2019). Energy consumption, economic growth and environmental degradation in OECD countries. Econ. Model. https://doi.org/10.1016/j.econmod.2019.04.010

United Nations, (2015) United Nations Sustainable development goals Retrieved fromhttps://sustainabledevelopment.un.org/?menu=1300

Pao, H.T., Tsai, C.M. (2010). CO 2 emissions, energy consumption and economic growth in BRIC countries. Energy Policy 38, 7850–7860. https://doi.org/10.1016/j.enpol.2010.08.045

Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels.

Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, *74*(4), 967-1012.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, *22*(2), 265-312.

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of econometrics*, *68*(1), 79-113.

Phillips, P. C., & Sul, D. (2003). Dynamic panel estimation and homogeneity testing under cross section dependence. *The Econometrics Journal*, *6*(1), 217-259.

Qingquan Jiang, Shoukat Iqbal Khattak, Manzoor Ahmad, Ping Lin. (2021). Mitigation pathways to sustainable production and consumption: Examining the impact of commercial policy on carbon dioxide emissions in Australia, Sustainable Production and Consumption, Volume 25, Pages 390-403, ISSN 2352-5509, https://doi.org/10.1016/j.spc.2020.11.016.

Saboori, B., Sulaiman, J. (2013). Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. Energy Policy 60, 892–905. https://doi.org/10.1016/j.enpol.2013.05.099.

Saint Akadiri, S., Alola, A. A., Akadiri, A. C., & Alola, U. V. (2019). Renewable energy consumption in EU-28 countries: Policy toward pollution mitigation and economic sustainability. Energy Policy, 132, 803-810.

Sebri, M., & Ben-Salha, O. (2014). On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries. *Renewable and Sustainable Energy Reviews*, *39*, 14-23.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. World development, 32(8), 1419-1439.

Shahbaz, M., M. Ali, and D. Roubaud. 2018."Environmental Degradation in France: The Effects of FDI, Financial Development, and Energy Innovations." Energy Economics 74: 843–857. doi:10.1016/j.eneco.2018.07.020.

Su, H.-N., and I. M. Moaniba. (2017). "Does Innovation Respond to Climate Change? Empirical Evidence from Patents andGreenhouse Gas Emissions."Technological Forecasting and Social Change 122: 49–62. doi:10.1016/J.TECHFORE.2017.04.017

Udi, J., Bekun, F.V., Adedoyin, F.F. (2020). Modeling the nexus between coal consumption, FDI inflow and economic expansion: does industrialization matter in South Africa? Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-020-07691-x

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and statistics*, *69*(6), 709-748.

Yoo, S. H. (2006). Causal relationship between coal consumption and economic growth in Korea. *Applied Energy*, *83*(11), 1181-1189.

Yuan, J.H., Kang, J.G., Zhao, C.H., Hu, Z.G. (2008). Energy consumption and economic growth: Evidence from China at both aggregated and disaggregated levels. Energy Econ. 30, 3077–3094. https://doi.org/10.1016/j.eneco.2008.03.007

Zamani, M. (2007). Energy consumption and economic activities in Iran. Energy Econ. 29, 1135–1140. https://doi.org/10.1016/j.eneco.2006.04.008

Zhou, Y., Sirisrisakulchai, J., Liu, J., & Sriboonchitta, S. (2019). Factors Affecting Carbon Emissons in the G7 and BRICS Countries: Evidence from Quantile Regression. In *International Symposium on Integrated Uncertainty in Knowledge Modelling and Decision Making* (pp. 406-417). Springer, Cham.