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RESEARCH ARTICLE

The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27

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Abstract
Considering the prevailing wave of global warming and other environmental challenges, which can be attributed to increasing environmental pollution as a result of economic activity, thus, it is essential to understand the effect of economic progress on the environment. More importantly, this endeavor is especially suited for the European Union (EU) member states, which account for a sizable portion of the world economy. However, by considering the open border or trade policy approach of the bloc, this study applies a battery of econometrics analysis that consists of mean group, augmented mean group, common correlated effect mean group estimators, and Dumitrescu and Hurlin causality analysis for direction of causality. These techniques are superior to first-generation methods to substantiate the relationship between real income, energy intensity, and carbon emission between annual frequency data from 1990 to 2017. Empirical results from series of cointegration tests reveal the long-run equilibrium relationship between the highlighted variables in the EU. Our study validates the existence of EKC phenomenon where emphasis is based on GDP growth at the expense of environmental quality. This implies that EU growth trajectory comes with an environmental trade-off and consequences. However, few countries in the region have made substantial strides of carbon reduction but not as a bloc. This position is resonated by the regression from all estimators in harmony where energy intensity dampens environmental quality in the blocs investigated. On the direction of causality, feedback Granger causality is observed running from GDP growth and carbon emission. A similar direction of causality is seen between energy intensity and carbon emission. These outcomes have far-reaching consequences on the environment. This study recommends the need for energy transition to cleaner and friendlier energy technologies by EU officials. That is, the need for a paradigm shift from conventional energy based on fossil fuel to renewable energy should be pursued in the region. More policy directions are outlined in the concluding section.

Keywords Energy intensity · EKC hypothesis · Carbon mitigation · Environmental sustainability · The EU

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Introduction

Effective competition on industrial production of its final products and ecosystem services is linked to recent concerns on global pollution, climate change, socioeconomic inequalities, and economic losses. In reaction, increased awareness and push for sustainable change in the areas of ecological preservation (sustainability) have persisted a global issue for environmentalists and economists. Increased human development, either positively and negatively (Alola 2019; Bekun et al. 2019a), increased consideration that has been devoted to demographic trends, oil consumption, productivity expansion, and so many other significant reviews (Shahbaz and Sinha 2019; Wang and Dong 2019). In relation to the use of greenhouse gases (primarily utilizing CO_2) to compensate for ecological sustainability, pollutant pollution accounting and biodiversity have indeed been embraced and provide diverse views. Considering the value of the Intergovernmental Panel on Climate Change (IPCC) study on "global warming, deforestation, soil loss, green infrastructure use, food protection and pollutant pollutions in biogeochemical cycles" (Intergovernmental Panel on Climate Change (IPCC) 2017), it is clear that concerted attempts are being made to reduce stress on the environment ecological ability. Overall, despite the rapid development of broad markets such as the United States, China, and specific European communities, the influences, as mentioned earlier, pose a significant challenge to governments, activists, and decision-makers of the nations as mentioned above.

In terms of the European Union's (EU) move for sustainability growth and ecological sustainability, appropriate strategies are being enforced by the Commission to direct their member states in achieving the Sustainable Development Goals (SDGs). For instance, the edited deed of the EU's 2030 global warming instructional techniques includes a suggestion to reduce global warming GHG pollutants by at least 40% when compared to 1990 pollution. To achieving the milestone, driving toward a minimum of 27% of the overall electricity demand from green power sources as well as a rise of 27% in clean power is essential (European Commission 2019). Thus, the EU has set a goal of reducing emissions by an average of 11.8% by the end of the Kyoto protocol's first commitment term. Additionally, the EU's Doha Amendment targets a reduction in emissions of an average of 20% below 1990 levels by 2020. Additionally, the EU has expected a 40% reduction in emissions by 2030 compared to 1990 levels. As a result of these commitments and forecasts, it is critical to consider the determinants of pollution in European countries and the significance of the environmental Kuznets curve (EKC) hypothesis. Designing renewable energy networks and identifying energy markets where the application of new technologies (e.g., artificial intelligence and industrial ecology) may have the most significant impact, and the underlying factors motivating improvements in energy intensity will now be explored.

In this regard, the British Petroleum (BP) (2018) report indicated that emissions of greenhouse gases rose from 29,714.2 million tons in 2009 to 33,444.0 million tons in 2017. Given the Paris Agreement of 2015 and the clear push by participating states to curb greenhouse gases, the BP study reveals that greenhouse gas pollutions have risen by 1.6% among 2006 and 2017. Pertinently, among those time frames, the advancement of greenhouse gas pollutions within the European continent is second to anything other than the Middle East which is around 2.5% (British Petroleum 2018). The continent has always been at the center of the fight toward environmental changes. However, after experiencing the fulfillment of its willingness from the first time frame (2008–2012) of the Kyoto Protocol, consequent objectives have been set to fulfill a transition in the decay of pollutant pollution considerations in the continent. The complexities that have affected effect on the level of energy-related pollutant pollution are already recognized in the existing studies. Several of the key drivers listed above include economic development (Apergis et al. 2010; Sarkodie and Owusu 2016a); fossil or non-renewable power efficiency technology (Khoshnevis Yazdi and Shakouri 2017; Nguyen and Kakinaka 2019); sustainable power components (Inglesi-Lotz and Dogan 2018), and other important variables (Sarkodie and Owusu 2016b).

Nevertheless, sustainable progress and energy intensity can be necessarily synonymously ascertained, while the affirmation of the effect regarding other variables in the study is impatient. Biesiot and Noorman (1999) concluded that economic output and energy intensity were associated before the dawn of the industrial era. In other words, growth and speed accelerated simultaneously with industrialization. This partnership has raised a threat to rising environmental degradation by increasing carbon dioxide pollution as an outcome of expanded industrial activity using fossil fuels to support economic growth. However, from Halicioglu's (2009) perspective, the road to economic growth requires more than increasing power use or productivity to raise actual output rates. Sustainable degradation is expected to decline as commercial production rises. Several other investigations have concentrated on pollutant pollution, while a few have concentrated on energy intensity (Sadorsky 2013, 2014). Alternative techniques of breakdown were used for energy systems in Asia and Europe. Xu et al. (2014) analyzed power utilization in China utilizing the logarithmic mean Divisia index decomposition (LMDI) approach as well as Sun et al. (2014) using the mean exchange rate index (MRCI) approach. Wang et al. (2014) provide a simplified LMDI approach in which spending on fixed assets and labor has been considered in the analysis of China's energy use. LMDI, as well as Kaya identification, has been used by Ren et al. (2014) to investigate developments in carbon emissions and energy intensity in the Chinese manufacturing sector. Choi and Oh (2014) analyses in South Korea were carried out for the industry sector, including utilizing Choi and Ang (2012) expanded decomposition index Divisia. Jeong and Kim (2013) utilized the LMDI study to note that emissions of greenhouse gases shifted under the policy of the International Monetary Fund in Korea. Voigt et al. (2014) analyzed energy intensity in 40 central Eurozone peripheries (for the period 1995–2007) and confirmed that technical advances are primary drivers of energy intensity management. Gonzalez et al. (2013) have carried out an overview of European nations, although this work did not provide a case report on all the 28 EU nations.

Due to the doubt which still arises regarding income, income square, and energy intensity in reducing carbon pollutions, nevertheless, the nature of the considerations due to the different economic systems and ecological policy between nations makes it extremely challenging to create an agreement on environmental predictor changes in various nations. However, the empirical observation provided in this report is, therefore, helpful in formulating policies relevant to global warming for the EU nations. The suggestions of all the above reasons are the driving force behind the goal of evaluating the competitive effect of income (GDPC), income square (GDPCsq), and energy intensity (EINTENSITY) on carbon emissions (CEM) for the 27 EU Member States. A handful of conventional econometric approaches were employed for these variables over the experimental period of 1990–2017. The selection of these nations depends on the essential variables needed for the analysis, particularly carbon emissions, income, and energy intensity.

We used Pesaran (2006) cross-section dependence techniques to determine the panel's cross-section dependency of the variables. Additionally, Pesaran (2007) and Im et al. (2003) panel unit root tests were used to determine the variables' characteristics due to the existence of second-generation cross-section dependency; the Kao (1999) cointegration test was used to analyze the variables' long-run equilibrium. Again, novelty estimation techniques, namely mean group (MG test), augmented mean group (AMG test), and common mean group (CCEMG test), were used in this analysis to access the impact of the control variables, which is income, square of income, and energy intensity on carbon emission in the 27 EU states and to establish if EKC can be identified from the outcomes of three estimate techniques within the region. Moreover, a cross-section dependency test was carried out to check multi-correlation among the variables, and the DH Granger causality technique was employed to assess the causal relationship between the variables of income, energy intensity, and carbon emissions within the 27 EU communities. Lastly, a great deal has been recorded in energy economic literature for years in both the advanced and the emerging states. Therefore, this analysis will add up to the existing literature of energy-income analysis, and filling the gap of using a new technique is accessing the relationship of the variables.

This paper is structured as follows: "Review of related literature" provides a review of related literature. "Material and methodology" focuses on data and methodological procedures employed. "Empirical results" concentrates on the interpretation of empirical findings. Finally, "Conclusion remark" concludes the study with policy prescriptions accordingly.

Review of related literature

This portion of the review is divided into two subsections. The first segment addresses the study's theoretical basis of the EKC hypothesis, while the empirical analysis section discusses prior research on the effect of income, income squared, and energy intensity on CO_2 emissions.

Theoretical framework of EKC hypothesis

Numerous studies in the energy economic theory check the effectiveness of the EKC hypothesis, as environmental problems have grown in prominence over the last few decades. The traditional EKC theory suggests that environmental pollution should be quantified in terms of CO_2 pollution which is largely determined by real income. Given that real income is measured by output and energy consumption is the primary mode of sustenance, energy is suggested as the next important aspect of carbon emission that should be considered (Kirikkaleli and Kalmaz 2020).

Grossman and Krueger (1991) developed the EKC to explain the inverted U-shaped relationship between sustainable growth and environmental devastation. As a result, several experiments have attempted to empirically test the theory (Gyamfi et al. 2020a, b, 2021c, d, e, f; Kirikkaleli et al. 2021; Sarpong et al. 2020). Following Grossman and Krueger's (1991) discovery of an inverted U-shaped relationship between pollution and income, extensive research into the EKC hypothesis has been conducted (Ekins 1997; Acaravci et al. 2009). Both of these assessments used the EKC conceptual approach to examine the relationship between income and environmental degradation, implying a connection between economic advancement and environmental conservation, while ecological deterioration is an increasing feature of economic growth until a critical threshold is reached, after which higher earnings rates contribute.

Empirical review

Over the decades, power intake has been reported to cause productivity expansion. Currently, there are excellently documented literature on the relationship among the gross domestic product (GDP) as well as many macro-economic factors to various estimation methodologies. The evidence can be grouped into four categories in spite of their course of causal relationships. Notably, there are (a) growth-led assumption, (b) cautious assumption, (c) feedback assumption, and (d) neutral theory. The subsequent work of Kraft and Kraft (1978) was the very first recorded work in the analysis on the subject regarding the gross national product (GNP) as well as power. In the analysis, unidirectional relationship among GNP and power was established, whereas correlation among power and GNP was noted. Analysis on Kraft and Kraft (1978) was the foundation of many other field surveys (Gyamfi et al. 2020a, b; Alola 2019; Alola et al. 2019a, b, c, d; Bekun et al. 2019a, b; Balsalobre-Lorente et al. 2019; Adedoyin et al. 2020; Adedoyin et al. 2021b; Sarkodie

2021). A significant volume of analyses is based on the topic under study, the EKC phenomenon. The EKC theory explores that there is an opposite association regarding sustainable economic prosperity and environmental pollution (Kuznets 1955; Stern 1998, 2004a, b; Ozturk 2010).

In addition, studies have increased the revenue-carbon relationship with so many other macro-economic measures such as international funding, industrialization, digital media technologies, financial progress, and, further significantly, survey and energy usage such as increasing community, energy intensity, and many others. For example, Balsalobre-Lorente and Shahbaz et al. (2016) investigated the correlation regarding carbon revenue with regard to research and development (R&D), power creativity, and financial development. The outcomes of the report reflect the inverse relationship involving work, growth, and ecological deterioration over the duration under review. The Balsalobre-Lorente et al. (2019) report also supports this status for the European Union 5 (EU-5) nations. In addition, Sinha et al. (2017) analyzed the panel of the Next Eleven (N-11) states and reported the inverse correlation regarding pollutant emissions as well as market accessibility. Even so, there are other research like Akadiri et al. (2019a, b) that verified the favorable association regarding economic activity and pollutant pollution utilizing the ARDL approach. For a one nation on the concept, Bekun and Agboola (2019) analyze the connection regarding energy (electric power), pollutant pollutions, and socioeconomic development utilizing the Maki (2012) cointegration method and create a long-term balance among the corresponding variables. The long-term downturn of the report indicates that sustainable development has a negative ecological effect on industrial development as found for the Nigerian market. Balcilar et al. (2019) obtained similar observational results from research performed in Zimbabwe with Samu et al. (2019) including Pakistan. The two reports affirm the results of Bekun and Agboola (2019).

From Malaysia's perspective, Shahbaz et al. (2016) studied the linkage involving pollutant pollution, urban growth, and power use over the period 1970–2011. The research utilizes the cause and effect vector error correction model (VECM) as well as Bayer and Hanck integrated cointegration approaches to investigate the interaction regarding the variables illustrated. Investigation of Shahbaz et al. (2016) affirms the connection of balance among variables. The evidence-based discovery results suggest that environmental development and power intake boost pollutant pollution. Nevertheless, there is an inverse link among urban development and pollutant pollutions over the recorded time frame. This final result was acknowledged by the outcomes of the VECM-Granger Causality technique. In the scenario of the United States (USA), Shahbaz et al. (2018) utilized a combination of cointegration approaches to identify the path of causality for economic growth, learning, and asset lease. The empirical data of the 1960–2016 survey reflects a possible and empirical connection regarding resource rent and economic deepening. A similar trend is repeated among employment and public growth, with a favorable effect on employment.

Kirikkaleli and Adebayo (2021) aimed to investigate the long-term and causal effects of financial development and renewable energy use on ecological responsibility while balancing technological innovation and economic expansion within a global context. Their empirical evidence established the long-run relationship between the variables. The study's findings revealed that while global financial advancement and clean energy use have a long-run favorable impact on green protection, economic activity increases global carbon pollution swelling. Within a global context, the study proposes that global stakeholders should recognize the positions of clean energy and financial growth in order to improve climate sustainability by reforming energy policies in both industrialized and developing economies. Ajmi and Inglesi-Lotz (2020) tested the validity of the EKC hypothesis for Tunisia from 1965 to 2013 using carbon pollution and ecological footprint as indicators of ecological deterioration. The approximation results indicate a U-shaped relationship among CO_2 pollution as well as income, indicating that the EKC assumption is invalid for Tunisia during this time. Nevertheless, when the EF was used as a reference for environmental damage, the EKC assumption was found to be true for Tunisia.

For the carbon-income nexus study, Hanif (2018) added even more fossil fuel usage, industrialization; sustainable energy usage, and its impact on ecological performance about two decades for developing African nations. The outcomes of the analysis confirm the EKC theory over the quoted time frame, given that intake of fossil fuel energy as well as industrialization relates noticeably to the rise of pollutant emissions. Lastly, the study argues that the use of sustainable power enhances the health of the air in Africa. While the definition of EKC was not included in the latest research by Alola et al. (2019b), the study did, nevertheless, include the lease of ecosystem services and other ecological factors in the context of the euro zone. The Wang and Dong report (2019) also looked at the interaction among the benefits and ecological (i.e., a more holistic metric for the ecosystem Erosion), industrialization, and sustainable growth for African regions for the period 1990–2014. The analysis implemented the Enhanced Mean Community Estimator, and the resulting results indicate that urban development and non-renewable power use are core predictors of resource depletion in SSA nations. In a related analysis undertaken for the case of European Union states (Alola et al. 2019a, b, c, d; Bekun et al. 2019a, b; Aydin and Turan 2020; Zhang et al. 2021; Etokakpan et al. 2020; Kirikkaleli and Adebayo 2021), leasing of environmental assets as well as clean power intake leads to increasing the sustainability of the ecosystem.

In light of the increasing findings trend following the foundational work of economic growth and environmental quality nexus, the analyses have put less focus on the parameters illustrated in the current research, specifically in the context of EU nations. EU nations have complex power complexities. All of the above variables have significant results, with some experiments supporting the EKC phenomenon (Saint Akadiri et al. 2019a, b; Gokmenoglu and Taspinar 2018), while several others struggled to validate the EKC phenomenon (Mukhopadhyay 2008; Dietzenbacher and Mukhopadhyay 2007; Cheikh et al. 2021; He and Lin 2019). Dogan and Inglesi-Lotz (2020) analyzed the position of European nations' economic structures in evaluating the EKC concept for the duration 1980–2014. The study's central hypothesis was that income activity in general is the element where the CO_2 emissions show an inverted U-shaped association in the nation group examined. On the other hand, when nations' industrial contribution is used as a proxy for their economic system, the EKC concept is not supported — but a U-shaped association is. The industrial sector reduces pollution through the production and adoption of energy-efficient and environmentally friendly innovations. When total GDP expansion is observed, the EKC theorem is verified, despite the economic framework or function of industrialization. Nevertheless, the findings of the research are inconsistent with conflicting evidence-based nexuses. As a consequence, hence, the desire to re-investigate the problem in EU members where much has been achieved yet not certain about the appropriate and crucial documentation in the power economic framework for stakeholders as well as decision-makers by integrating energy intensity and other macroeconomic metrics in the sense of EU countries.

Material and methodology

The European economy as with many other economies is a victim of increased fossil fuels and other primary energy source costs. This has made it necessary for the EU to expand its energy consumption base in order to be more efficient in energy usage in the past two decades. It has become very important for many countries all over the world to move from unclean energy source to a cleaner energy source in the fight against climate change due to pollution. Among numerous steps taken by the EU includes the 2001/77EC (European Union 2001) and the 2003/30/EC (European Union 2003) resolutions which were framework that were architecture and accented by member countries toward efficient and clean energy consumption. This was associated with the agreement clean energy agenda for the year 2020 (the Directive 2009/406/EC). The cost-effectiveness and efficiency of renewable energy have encouraged the region to lead to the reduction of fossil fuel importation by over sixteen billion Euros. These are all efforts in ensuring a sustainable environment considering the economic outlook of the region by relying on a clean, reliable, cost-effective, and efficient energy sources for consumption.

Data

Except the data for carbon emissions that was obtained from the British Petroleum database (BP), while data for income and energy intensity were sourced from the world development indicators (WDI) of the World Bank database. Carbon emissions are a proxy for environmental quality measured in million tons, gross domestic product (GDPC) per capita measured in constant 2010 USD is a proxy for income, and energy intensity (EINTENSITY) is a proxy for energy consumption measures as a percentage of gross domestic product per capita. The energy intensity variable is vital for benchmarking properties in order to estimate usage of energy in respect of buildings for instance. Economic growth is proxied by GDPCsq which is the squared term of the real GDP per capita. This term refers to the growth that is experienced in real incomes over time for all the countries under review. GDP per population is the ideal indicator for income as it is used in measuring the mean well-being of an individual in an economy, and this variable is universally traced in calculating prosperity or growth. A more detailed description of the data that span over 1990–2017 is shown in Table 1.

Although many analyses have examined the relationship between emission growth and energy use (Adedoyin et al. 2020; Adedoyin et al. 2021; Gyamfi et al. 2020a, b, c), the present study uses a broad dataset to examine energy intensity-induced pollution in 27 EU countries. Moreover, in the analysis, our model surprisingly consolidated income, square of income, and energy intensity with the ultimate objective that:

$$CEM_{it} = \alpha_0 + \beta_1 GDPC_{it} + \beta_2 GDPCsq_{it} + \beta_3 EINTENSITY_{it} + \varepsilon_{it} \quad (1)$$

where CEM, GDPC, GDPCsq, and EINTENSITY represent carbon emission, income, square of income, and energy intensity respectively as stated early. ε_{it}, α, and βs represent the stochastic, intercept, and partial slope coefficients respectively. However, logarithmic transformation has been performed to enable the variables in this current study to maintain constant variance across all the series.

Method

We were able to achieve the objectives of this paper by resorting to different estimation techniques. We first established correlations and the statistics of the variable. Descriptive statistical analysis is displayed in Table 3, as a

Table 1 Variable description and respective statistics

Variable	Description	Code
Carbon emission (CEM)	Measure as million tons of carbon dioxide	BP
Income (GDPC)	It is proxied by the gross domestic product per WDI capita (2010 Constant USD)	WDI
Square of income (GDPCsq)	It measures the square of GDP per capita	WDI
Energy intensity (EINTENSITY)	It is measured as the percentage of Gross Domestic WDI Product per capita.	WDI

preliminary analysis. For all variables, the average result is optimistic. The cumulative incomes and carbon dioxide emissions have a negative skewed value, suggesting that the distribution is skewed to the left, with further findings on the right. The three series are highly correlated, since all the coefficients of correlation are statistically significant. In addition, the cross-relations assessment widely confirms those results. To begin the analysis, cross-sectional dependency test was performed through the Pesaran (2006) CD test. This test is robust to ascertain dependency of the variables across sections even in the presence of unit root or structural breaks and also appropriate for small N and T. We proceeded to determine stationarity of the variables by conducting the Panel CIPS (Pesaran 2007) and Im, Pesaran, and Shin (IPS) (2003) unit root test techniques. These tests are powerful to determine whether trending data must necessarily be regressed on the deterministic function of the period so that it could achieve stationarity or at first difference.

The Kao (1999) cointegration test method was executed to ascertain the likelihood of a long-run equilibrium relationship between the variables. This technique is good because problems related to non-reliable standard errors due to serial correlation are solved with the help of the heteroscedasticity and autocorrelation consistent (HAC) computers of the variance-covariance matrix. It also provides stronger and reliable results by advancing the Engle-Granger two-step cointegration context. Three further cointegration tests, mean group (MG) (Pesaran et al. 1999), augmented mean group (AMG), and common mean group (CCEMG) (Pesaran 2006), were conducted to establish the strength of a long-run relationship between the variables. The mean group approach was initiated by Pesaran et al. (1999) to establish a robust degree in terms of the heterogeneous characteristics of variables in regression analysis as compared to other estimation techniques. It is capable of producing coefficients for all cross-sections by estimating each cross-section separately in an equation although coefficients for the entire pane are calculated without weighting the means of the individual coefficients. Lastly, we applied the Dumitrescu and Hurlin (2012) Granger non-causality estimation method to determine the direction of causality between the variables under consideration. This methodology is favorable for a heterogeneous and non-experimental dataset and also assumes a balance data with a lag order (k). The test was appropriate as the error term of cross-sections were found to be dependent on each other.

Results

In this section, the preliminary results and other results from the cointegration and Granger causality estimations are highlighted.

Cross-sectional dependency

The empirical results for this current study are reported in this section alongside all the necessary models estimated. The Pesaran (2006) cross-sectional dependency test results are displayed in Table 2. This test is essential in evaluating the shudders among the cross-sections of the panel data used for the study. The results prove that the alternative hypothesis was unacceptable and that the null hypothesis was accepted given the presence of cross-independency in the panel data. It was therefore adequate to estimate the first generational estimations since it was reliable to confirm the absence of cross-dependency in the panel.

Correlation matrix

Furthermore, we estimated a correlation matrix to establish the association between the variables of interest and presented the results in Table 3. The outcome shows a significant positive relation between income and carbon emissions confirming the

Table 2 Cross-section dependency test

Variables	LM Test	CD_{LM} Test	LM Test	CD Test
CEM	3076.290*	24.591*	101.840*	27.57*
GDPC	6018.450*	64.504*	212.885*	67.54*
GDPCsq	5845.402*	60.583*	206.354*	19.53*
EINTENSITY	7228.673*	83.567*	258.562*	82.89*

Note: The LM, CD, CEM, GDPC, GDPCsq, and EINTENSITY are respectively Lagrange multiplier, cross-sectional dependence, the carbon emissions, income per capita, square of income per capita, and energy intensity by primary source

Table 3 The corre2lation evidence

Correlation Variables	CEM	GDPC	EINTENSITY
CEM	1.000		
GDPC	0.106*	1.000	
EINTENSITY	− 0.131*	− 0.360*	1.000000

Note: Variables are correlated at * which is for 0.01 significant level. In addition, the CIPS and IPS are respectively the cross-sectional dependence

Table 4 Descriptive statistics

Statistics	CEM	GDPC	EINTENSITY
Mean	128.2241	28917.97	5.530939
Median	57.35583	23700.16	4.761434
Maximum	1003.197	111968.3	18.23322
Minimum	1.354078	3582.856	1.808454
Std.Dev.	181.3677	19982.30	2.377245
Skewness	2.516738	1.397491	1.718174
Kurtosis	9.803152	5.854266	6.833006

assertions of the EKC hypothesis. There is a robust negative relationship between income and energy intensity implying the improvement that growth could contribute to energy consumption. The results additionally prove a strong negative association between carbon emissions and energy intensity. The traditional adage that correlations do not necessarily depict causality encouraged the authors to carry out further more investigations to establish more reliable estimation results to back inferential conclusions of this paper.

Descriptive statistics

The next thing was the descriptive statistics of the variables used for the study given the estimation procedure adopted. Results from Table 4 show that the variables moved considerably away from their average values. All variables are positively skewed and Kurtosis. Values of the skewness fall within the normal range of − 2 and +2 and therefore show that the skewness of the data set is not seriously violated. Extremeness of the values or outliers of the data was identified by the Kurtosis and this proved that there were no outliers in the data set. The positive and the Kurtosis of more than 3 in all the variables indicate that the distribution of the data set contains heavy tails as compared to a normal distribution. The average carbon dioxide emission in the EU-27 countries for the period was 128.22 million tons with a minimum of 1.35 million tons and a maximum of 1003.19 million tons. The mean income stood at 28,917.97 USD while the minimum and maximum totaled 3,582.85 and 111,968.30 USD respectively. In addition, the average energy intensity was 5.53% of GDP with a minimum of 1.80% of GDP and the highest energy intensity totaling 4.76% of GDP. The results generally imply a considerable encouraging income generation performance.

Unit root

On this premise, in the first place, we conducted the stationarity test by employing the Panel CIPS (Pesaran 2007) and Im et al. (2003) unit root tests to ensure that all the variables for the study were stationery to avoid spurious results of the regressions. Test results in Table 5 show that at level only carbon dioxide emissions and energy intensity were stationary in respect of the CIPS test and for IPS only CO_2 emissions were stationary. But all the variables were stationary at the first difference for both unit root test techniques.

Long-run cointegration analysis

After confirming the stationarity of the indicators, we proceeded to ascertain the possibility of equilibrium long-run relationships between them by resorting to the Kao residual cointegration test technique. From Table 6, it was observed that there is a long-run cointegration at 5% significant level between the variables.

Table 5 Panel unit root test

	Level		First Difference	
	Constant	Trend	Constant	Trend
Panel CIPS				
CEM	− 2.90*	− 3.02*	− 4.78*	− 5.25*
GDPC	− 1.70	− 2.30	− 3.81*	− 4.06*
GDPCsq	− 1.36	− 1.73	− 3.60*	− 4.02*
EINTENSITY	− 2.62***	− 2.65***	− 5.27*	− 5.49*
IPS				
CEM	− 6.79*	− 5.00*	− 13.18*	− 10.74*
GDPC	3.34	0.20	− 9.95*	− 7.06*
GDPCsq	5.14	1.26	− 9.13*	− 7.43*
EINTENSITY	1.05	− 0.75	− 13.20*	− 11.41*

Note: Variables are stationary at * which is for 0.01 significant level and *** represents 0.10 significant level. The CEM, GDPC, GDPCsq, and EINTENSITY are respectively the carbon emissions, income per capita, square of income per capita, and energy intensity by primary source. In addition, the CIPS and IPS are respectively the cross-sectional dependence

Table 6 Kao cointegration

	t-statistic	Prob.
ADF	− 2.014124**	0.0220
Residual variance	59.15983	
HAC variance	68.78333	

Note: Variables are stationary at * *which is for 0.05 significant level

Empirical result

The results from Table 7 prove the possibility of equilibrium long-run connectedness of carbon emission, energy intensity, and income at 5% significance level. We additionally executed three different common correlated effect mean group unit root tests namely MG test, AMG test, and CCEMG test to assist us to establish strength of the relationship in the long run by estimating carbon emissions as the dependent variable. The results show a robust positive relationship between carbon emissions and income. This implies that a percentage change in income will significantly increase carbon dioxide pollution by 0.009% and 0.008% in respect of MG and AMG estimations respectively. The results mean that high levels of environmental dilapidation are the consequences of increased economic activities. This finding supports the Environmental Kuznets Curve theory which proposes that as the economy grows and activities rise, this has a direct relationship with a degraded environment (Shahbaz et al. 2017).

Besides, the table proves that income squared has a strong negative relationship with carbon pollution in the long. This confirms the debate of an inverted U-shaped income-environment nexus (Saint Akadiri et al. 2019a, b; Gokmenoglu and Taspinar 2018; Katircioğlu and Katircioğlu 2018). The implication is that the quality of the environment is meant to improve with increased economic growth and development. Until the average income per capita acquires certain levels over the period of development, indicators of environmental degradation will birth poor healthy environment. Furthermore, there is a significant positive relationship between pollutants and energy intensity. A percent increase in the intensity of energy utilization in the EU-27 economies will result in an increased pollution of over 25.4% and 23.4% respectively for MG and AMG. This observation makes important revelations referring from previous studies of Alola and Alola (2018); Emir and Bekun (2019) who advocate that renewable energy utilization reduces carbon dioxide emissions but non-renewable energy use is not favorable to fight pollution in the EU context. The finding means that the non-renewable share of energy consumption is greater than the renewable share resulting in detrimental consequences of carbon pollution. A quick response to this is the all-important Kyoto Protocol resolution which could be a safe haven for policy makers of these economies to adhere strictly toward a healthy environment.

Table 7 common correlated effect mean group tests

Variables	MG Test	AMG Test	CCEMG Test
INCOME	0.009**	0.008**	0.003
INCOMEsq	− 2.42e-07**	− 1.92e-07***	− 1.18e-07
EINTENSITY	25.406*	23.467*	26.011
C	− 132.332**	− 88.951**	− 20.526
T	− 1.048*	− 0.609**	− 0.949
Wald	18.90*	18.74*	15.92*
RMSE	3.803	3.495	2.867
No. T	15	11	8

Note: The CEM, GDPC, GDPCsq, and EINTENSITY are respectively the carbon emissions, income per capita, square of income per capita, and energy intensity by primary source. In addition, * 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 5% significant level. MG, AMG, and CCEMG are respectively the mean group, augmented mean group, and common correlated effect mean group

Granger causality test

Finally, we present the Dumitrescu and Hurlin panel causality test results in Table 8. Following Dumitrescu and Hurlin (2012), we establish the Granger non-causality from the independent variables to the predictor variable considering the heterogeneous nature of the panel data. We found a bi-directional causality relationship between income and carbon dioxide emissions consistent with (Bekun et al. 2019a; Bekun and Gyamfi 2020). The implication of this outcome is that industrialization is a precondition for high economic activities which will ensure growth and development. The sectoral frameworks are also factors that encourage economic activities which could increase pollution. In this sense, the result implies a two-way bi-directional poor environment-economic

Table 8 The DH Granger causality evidence

Null Hypothesis	W-Stat.	Zbar-Stat.	P-value
GDPC→CEM	4.949*	5.793	7.E-09
CEM→GDPC	3.294**	2.292	0.0219
EIP→CEM	3.791*	3.343	0.0008
CEM→EIP	5.565*	7.094	1.E-12
EIP→GDPC	2.950	1.564	0.1177
GDPC→EIP	4.776*	5.425	6.E-08

Note: The * is the 1% statistically significant level.

development nexus in the EU context. This is supportive of the assertion that environmental outlook through economic development could be discouraging. As a result, a move toward a clean energy mix is a precursor for clean environment to ensure an economy with quality air devoid of pollutants that could be inimical to health (Sarkodie and Strezov 2019).

Additionally, we found a bi-directional causal relationship between energy intensity and carbon emissions. The implication of this observation is that the economies in the EU rely greatly on a mixture of energy consumption (fossil fuel) that is not clean enough for primary use. These in the end have had ramifications on the environment in increasing carbon dioxide pollution. In situations where there are increased levels of unclean energy consumption, it leads to a rise in renewable energy use which is a panacea for high climate change connected issues (Bekun et al. 2019a). This goes also to suggest that the countries used for this study are carbon intensity economies with increased dependency on fossil fuel energy for primary consumption. As recommended by Sarkodie and Strezov (2018), a combination of both renewable and non-renewable energy technologies is ideal to confront issues of clean environment and universality in accessing energy products and facilities at inexpensive prices. Income has proved to play a very important role in the primary source of energy consumption. The results also show a unidirectional causality from income to energy intensity by primary source. This implies that improvement in economic growth determines the intensity of the primary energy source of consumption. Dynamics of incomes in the economy is a precondition to predict the degree to which primary energy sources will be used. Energy governance should involve quality institutions that would maintain environmental policies that will be able to absorb changes that are associated with economic growth and development considering the environmental complications with increased economic activities.

Conclusion remark

Globally, the energy mix has been proven to determine environmental health and that the role of energy consumption is associated with cost implications, both socially and economically. Many economies all over the world have made strides toward the reduction of the devastation that energy consumption causes on environmental health even as they experience economic growth and development. From this background, this study expands the scope of the existing literature on the subject of environmental sustainability through the income-energy nexus in the EU-27 context. The study examined the income-energy intensity trade-off for a sustainable environment in respect of the EU-27 countries over the period 1990-2017. The Kao and common correlated effects of mean group cointegration test techniques prove that the variables for the study were cointegrated proving the possibility of long-run relationships between them. The overall result was that there is a statistically positive relationship between income and carbon dioxide emissions. The general impression here is that while economic activities increase as a result of increased incomes, it encourages carbon emissions which is detrimental to the environment. This will continue until income levels or economic growth and development reach a certain threshold; otherwise, predictors of environmental degradation will continue to be worsened. This finding is in support of the inverted U-shaped phenomenon that exists between income and the environment. There was also a strong positive relationship between carbon emission and energy intensity by primary sources which shows that the primary source of energy consumption in the EU-27 economies is not clean enough to guarantee freedom from pollutants. The energy-directed growth theory is held for the EU countries affirming the successes of the Romania (Emir and Bekun 2019).

As policy implications, this current study has revealed the need for the countries under review to adopt renewable energy and non-renewable energy know-hows that will promote steps favorable for climate change interrelated matters. In addition, the positive income-emission nexus means that these EU countries are in the early stages of their growth path. This indicates that the focus on economic growth compared to environmental sustainability is at the early phase of their development course. The above is valid for the countries studied, as the emphasis is on rising real output.

Policy insight

This empirical study is implicitly demonstrating to relevant parties, policy makers, and public officials who devise and architecture power blueprinting. This calls for much more progressive strides on the aspect of EU governments to step up their dedication to far more energy and climate change agreements such as the Kyoto Paris Accord as well as submit to the Kyoto Protocol. Even in an attempt to lower carbon pollution in the European sphere. As has already been noted above, protocols such as the 2001/77EC (European Union 2001) and the 2003/30/EC (European Union 20030) all very critical trajectory worth of receiving the most attention by governments in the EU toward clean the attainment of the sustainable development goal 17. The stance was echoed in the Romanian economy's Emir and Bekun (2019) study, as the country has reached its target for renewable energy use for a sustainable clean environment. Therefore, the need to shift to numerous different clean and efficient and ecologically responsible sources of energy such as solar, biomass, and hydro-energy is encouraged in Europe. For instance, the consumption of electricity will be the end product of economic growth and development, and therefore, a constant supply of electricity, for example, will be an area of energy policy direction for stakeholders in this part of the world. In doing so, renewable energy sources such as wind, sun, tides, and nuclear fuels, thus uranium that will assist in powering hydroelectricity power will be ideal in the quest to ensure a climate devoid of pollutants. Policy directions should be focused on a trajectory of reducing the impact of economic growth on the environment as a result of increased agricultural activities which leads to all manner of human events against ecological and aquatic sustainability. This is because findings of this paper have proven that economic growth and development would have a positive impact on energy intensity that are primary sources, and this means that the proportion of renewable energy source should be greater in the energy mix to take off the negative effects of unclean energy source (fossil fuels, coal, and oils).

While this study used CO_2 emissions as a proxy for environmental sustainability, future research might suggest using ecological footprints or carbon footprints as proxies for environmental sustainability. Additionally, individual research on a similar subject may be conducted in order to produce a more tailored document for environmental policy in particular EU member states. This study's findings can also be applied to other developed economies.

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Author contribution Andrew Adewale ALOLA: Formal analysis, Methodology, and Corresponding. Festus Victor BEKUN: Conceptualization draft, Investigation, and Data curation. Bright Akwasi Gyamfi: Writing — original draft. Sarpong Steve Yaw: Writing.

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