Energy Consumption, Economic Expansion, and CO2 Emission in the UK: The Role of Economic Policy Uncertainty.

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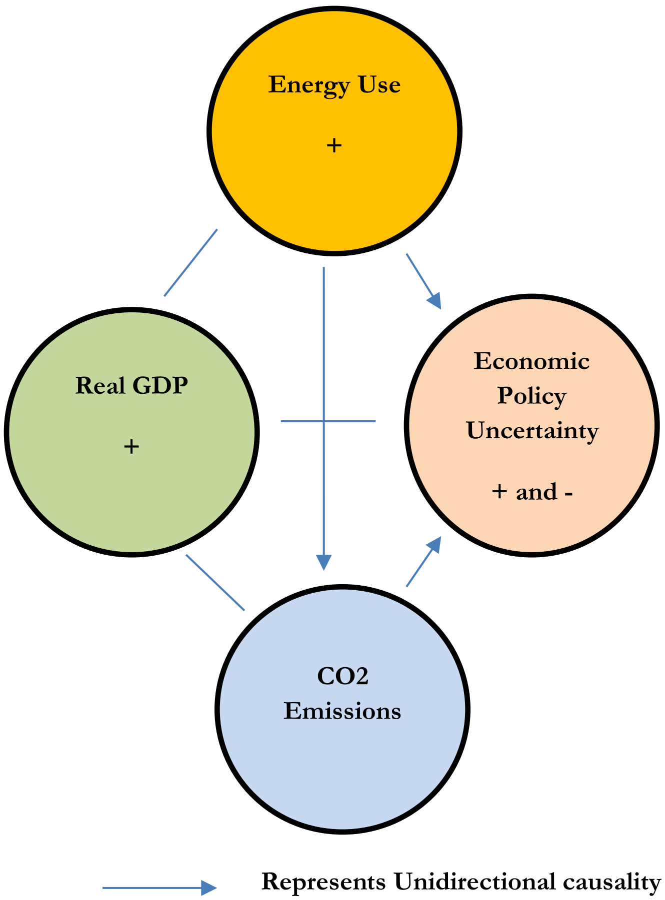
Graphical Abstract



Highlights

- The role of Economic Policy Uncertainty in the Energy Consumption - Emission nexus in the UK is assessed
- A one-way causality is found which runs from CO_2 emissions to economic policy uncertainty, and also from energy use to economic policy uncertainty
- The impact of energy use on CO_2 emissions is significantly moderated by EPU in both the short and long run

Abstract

On the 23rd of June 2016, the United Kingdom voted to leave the EU, leading to months and years of economic policy uncertainties. Such uncertainties have not only characterized the UK but have become a center point for energy debate in recent times. Given the foregoing, this paper progresses to provide evidence on the role of Economic Policy Uncertainty in the Energy Consumption - Emission nexus in the UK. We use annual data spanning the period of 1985–2017 for the UK for CO_2 emissions in tons per capita (CO_2), real GDP (RGDP), energy use (EU), and economic policy uncertainty (EPU). The Autoregressive distributed lag model (ARDL) bound test is used to test the fitness of the model in the short and long term. Our model shows that EPU matters most in the short run, as it reduces the growth of CO2 emissions, while prolonged use of EPU in the UK, exhibit controversial influence, where CO2 emissions continue to rise. In addition, pairwise Granger causality shows a one-way causality running from energy use to CO2 emissions, CO2 emissions to economic policy uncertainty, and also from energy use to economic policy uncertainty. However, two-ways causality is found between real GDP and real GDP per capita. Overall, our results imply that EPU is likely to yield a positive effect on climate change for a short time, but continue dependent will, in the long run, create an unhealthy environment. We suggest that the UK government should consider implementing an additional long-run policy that will supplement the effort of EPU.

Keywords: Economic Policy Uncertainties; Energy Consumption; CO2 Emission; Economic Growth

1. Introduction

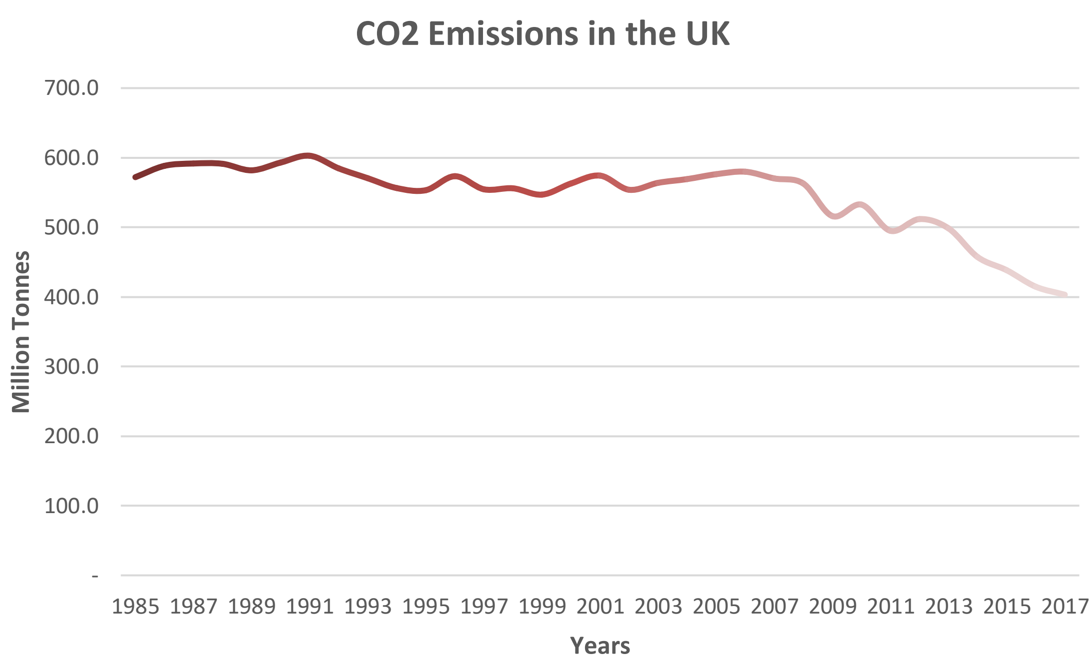
The global economy has witnessed rapid turn out events in the past few years, giving rise to concerns on climate change, political and policy uncertainty. As a result, past and existing studies have tried to examine these topical issues for the welfare and sustenance of the world economy. According to Antonakakis et al. (2017), climate change concerns associated with the nexus of energy consumption and emission are related to all human and energy activities geared towards economic growth, inducing detrimental effects to global welfare and its environs. Interestingly, the literature reveals that the Environmental Kuznets Curve theory (EKC) has been simultaneously used in this nexus. The EKC hypothesizes that as a country embarks on the process of income growth, there is an increase in energy consumption, thus raising the level of pollution and environmental degradation. Once a certain level of wealth is reached, environmental degradation reduces with the use of cleaner energy sources (Cowan, 2014). Studies have indicated this to be true; that is, an increase in income (GDP) induces a similar decrease in energy consumption and pollution(carbon emission). In contrast, for others, it appeared that pollution (carbon emission) increased with a similar increase in income (GDP) and energy consumption (Antonakakis et al., 2017; Zakarya, 2015).

While examining the trends of real GDP per capita, primary energy consumption per capita and carbon emission for an industrialized country such as the United Kingdom. (Fig.2.) It can be observed that the real GDP per capita for the economy increased rapidly between 1985-2000, recording an increase of about 44% in this period. It appears that the rise in real GDP per capita induced a noticeable upward trend for energy consumption from 151.4 to 161.3 in 1985 to 2000, respectively, which is about a 6% increase in primary energy consumption. However, the

UK's carbon emission reduced by 2% over the 1985 and 2000 values. Thus, the changes in real GDP per capita had a positive effect on energy consumption, but the impact was negative for carbon emission within this period.

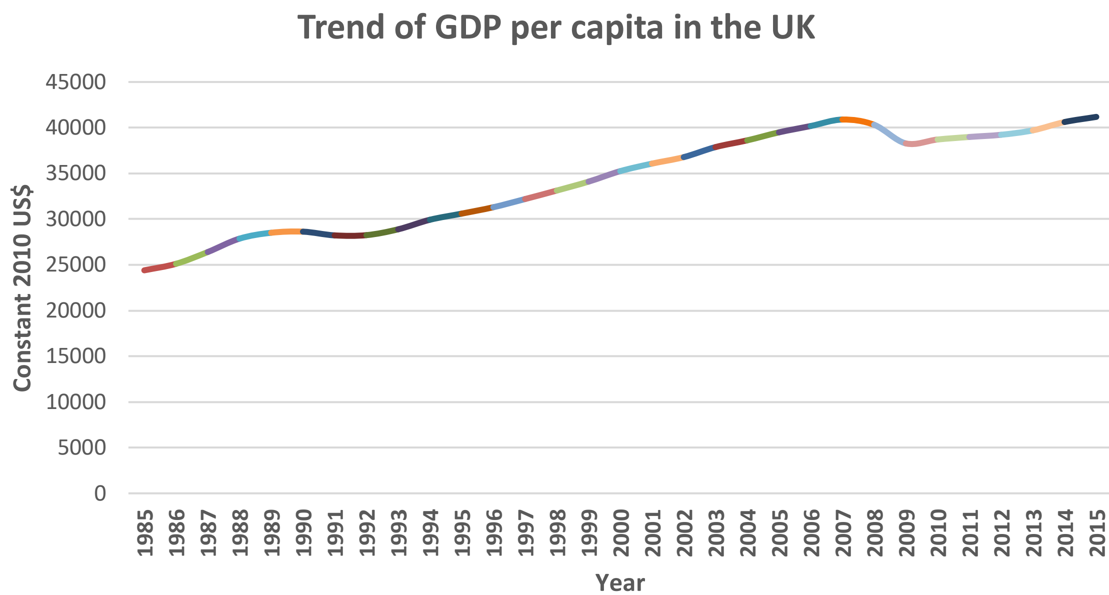
Furthermore, while real GDP per capita, energy consumption, and carbon emission rose consistently in other countries from the early 2000s up till 2015. The UK witnessed a fall in real GDP per capita, energy consumption, and carbon emission during the period 2008-2009, which was marked by the Global Financial Crisis. Primary energy consumption fell from 152.3 to 139.8 in 2007 and 2009, respectively, leading to a reduction in carbon emission of about 8% during the period.

Fig.1. CO2 emissions (Million Tonnes)



Source: Author, underlying data from British Petroleum Review

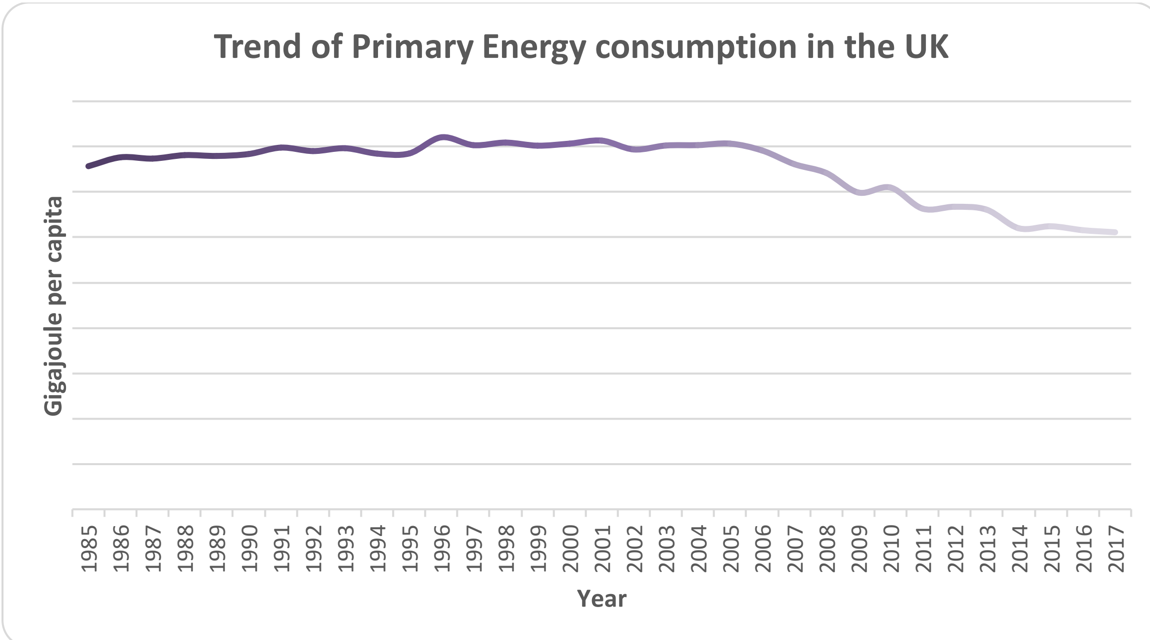
Fig.2. GDP per capita (constant 2010 US$)



Source: Author, underlying data from World Bank, World Development Indicators

The same downward trend was observed for 2010-2015. It appeared that the uncertainty of Brexit and other public and institutional policy reforms caused decreasing energy consumption and carbon emission. Nevertheless, real GDP per capita still increased during this period. More recently, energy consumption in the UK has remained unstable, with a corresponding decline in carbon emission. On the other hand, a rise in the share of total global emissions has been observed for similar globalized countries like China, the USA, and India with values of 30%, 14.6%, and 6.8%, respectively (IEA, 2019).

Fig.3. Primary Energy consumption (Gigajoule per capita)



Source: Author, underlying data from British Petroleum Review

The reason for these mixed results, as implied by other studies are largely due to the rapid growth of population and industries, increasing dependence on carbon-related energy sources, and heightened policy uncertainties. In an attempt to define uncertainties existing literature points to two most common measures of uncertainties; Geopolitical risk (GPR) and Economic Policy Uncertainty (EPU), stating that they influence the behavior of economic agents and lead to delays in their consumption and investment decisions. GPR is associated with events such as political tensions, disagreements, warlike events, while EPU is concerned with uncertainties relating to monetary, fiscal, trade, and other interrelated policies (Aviral, 2019). The global financial challenges associated with the 2007-2009 Global financial crisis, US and European taxation, European Debt crisis, US-China trade war, Brexit, and other events have made EPU earn more considerations (Saud and Barrack, 2019).

Following Jin et al. (2020), EPU is described as the uncertainty associated with spikes in government regulatory, monetary, and fiscal policies that alter the environment in which individuals and institutions operate. It is clear from empirical evidence that higher economic policy uncertainty affects macroeconomic indicators, innovation, financial development, capital investment at the firm level, firm's earnings and cash flow, tourism and economic growth (GDP) (Adams, 2016; Badar and Shen, 2019; Jin et al. 2020; Sagi et al., 2020; Zhaoxia, 2020). These results suggest that examining EPU is also critical in energy consumption nexus. Expectedly, higher EPU affects energy consumption, carbon emission, and economic growth with implications on environmental sustainability and development.

In this wise, our study provides direct evidence on the role of Economic Policy Uncertainty in the Energy Consumption Emission nexus in the UK. We focus on this topic for three reasons. First, the literature on EPU is limited in the aspect of environmental sustainability, and this study is one of the contributors to the growing debate. Secondly, the rising concerns on Brexit affected the real and financial sectors of the UK, which may have also extended to macroeconomic indicators, consumption, and capital investments in the energy sector. Lastly, the impacts of the second may likely affect the future of environmental sustainability in the UK, and therefore this study will assist the design of her government policy. Similarly, lessons from this study will apply to countries with a similar commitment to maintain a steep trend in environmental pollution. In particular, such experiences will highlight the role of policy uncertainty in the energy-emissions nexus and the necessary policy implications.

The aftereffects of the pairwise Granger causality shows a one-way causality running from energy use to CO2 emissions, CO2 emissions to economic policy uncertainty and energy use, and economic policy uncertainty. However, two-ways causality is found between real GDP and real GDP per capita. Further, the short and long-run result shows that EPU matters both in the short and long run and has a negative impact on carbon emissions in the short term but if prolonged it contributes significantly to CO2 emissions. The effect of energy use on CO2 emissions is moderated substantially by EPU in both the short and long run. The rest of the paper is structured such that section 2.0 contains the literature review. Section 3.0 discusses the theory and methodology of the study. Section 4 presents and discusses the empirical results, and section 5 summarizes the paper with policy implications.

2. Literature Review

The literature captures the link between energy consumption emission nexus and economic growth by using specific countries, region-specific countries, or groups of countries, different methodologies including control variables, and covering different periods. Table 1 summarizes this literature into three strands: First, the energy consumption emission nexus; second, energy consumption and economic growth; and lastly, the energy consumption emission nexus and economic growth.

2.1 Energy consumption emission nexus

In the literature, the energy consumption emission nexus simply focuses on the relationship between energy consumption and environmental pollution (Carbon emission). Rahman (2020), using an FMOLS estimator, found that electricity consumption has a detrimental impact on the environment for the panel of G7 countries andthe UK as a country. Using data on total energy consumption and carbon emission, Jalil and Feridun (2011) employed the Autoregressive Distributed Lag bounds test for China from 1953-2016. They found out that total energy consumption had a positive effect on environmental pollution. Hossain (2011), who employed the Vector Error Correction Mechanism and Generalized Method of Moments on 9 newly industrialized economies from 1971-2007, equally had similar findings. Studies by Jayanthakumaran et al. (2012), Ozturk and Acaravci, (2013) and Shahbaz et al. (2013) using the Autoregressive Distributed and Error Correction Model for China(and India), Turkey and Indonesia data respectively indicated that total energy consumption has a positive effect on carbon emission in the short run and long run. In addition, Dong et al. (2017) used the Granger causality and Augmented Mean Group estimator to examine the effect of natural gas and renewable energy consumption on CO2 emission in BRICS countries during 1985-2016. Their result indicated a negative impact and bi-directional causality flowing from the energy consumption to carbon emission for the countries.

In the case of renewable and non-renewable energy, Bellaid and Youssef (2017) employed the ARDL and VECM Granger Causality on total renewable energy and non-renewable energy in Algeria during 1980-2012. Their findings indicated that NRE has a positive effect on environmental pollution (CO2). Furthermore, using ARDL Pata (2018) revealed that these energy types had a positive and negative impact, respectively, on carbon emission. Also, PMG-ARDL, Chen et al. (2019) discovered that coal and non-fossil fuel energy had a positive effect on carbon emission in China during 1995-2012. More noticeable is that as important as energy consumption emission nexus is to economic growth, these studies did not emphasize the role of economic growth in the link.

Table 1: Summary of the reviewed literature

S/N	Authors &Year	Country/Territory (s)	Scope	Energy Variable	Methodology	Impact on Economic Growth or Carbon Emission
			Energy consumption and Carbon Emission			
1	Dong et al. (2017)	BRICS countries	1985-2016	Natural gas and renewable energy	Granger Causality and Augmented Mean Group (AMG) estimator	Adverse effect and bidirectional causality (consumption and CO2)
2	Jalili and Feridun (2011)	China	1953-2006	Total energy	ARDL	Positive effect in the long run
3	Jayanthakumaram et al. (2012)	China and India	1971-2007	Total energy	ARDL and ECM	Positive effect in the short run
4	Ugur Korkut Pata (2018)	Turkey	1971-2014	Coal and noncarbohydrate	ARDL	The positive and negative effect
5	Oztur Acarvci (2013)	Turkey	1960-2007	Total energy	ARDL and ECM	Positive effect in the
6	Hossain (2011)	Nine industrialized economies	1971-2007	Total energy	VECM and GMM	Positive effect
7	Chen et al. (2019)	China	1995-2012	Coal and non-fossil fuel energy	PMG-ARDL	Positive effect
8	Shabaz et al. (2013)	Indonesia	1975-2011	Total energy	ARDL and VECM Granger causality	Positive effect
9	Bellaid and Youssef (2017)	Algeria	1980-2012	Renewable and Nonrenewable energy	ARDL and VECM Granger causality	The positive effect of NRE on CO2

10	Bilgil et al. (2018)	17 OECD countries	1977-2010	Renewable energy	FMOLS and Panel DOLS	Negative effect
11	Carfora et al. (2019)	4 Asian countries	1971-2015	Oil	Vector of Co-integration and Granger-causality	Mixed Results across countries
12	Barreto (2018)			Oil and alternative energy	Growth model	Positive effect
13	Atems and Hostaling (2018)	174 countries	1980-2012	Renewable and Nren electricity	System GMM	A positive and significant relationship
14	Alam and Murad (2020)	25 OECD countries	1970-2012	Renewable energy	ARDL, PMG, MG, and DFE	Positive and significant effect in the long term
15	Aspergis and Payne (2010)	15 emerging market	198-2006	Coal	FMOLS and Panel causality	Negative effect

		economies				
16	Eggoh et al. (2011)	21 African countries	1970-2006	Total energy	Panel co-integration and causality tests	Positive effect
17	Aydin (2019)	BRICS countries	1992-2013	Biomass	CIPS, bootstrap panel cointegration and causality test	Mixed results across countries
18	Bao and Xu (2019)	China	1997-2015	RE	Bootstrap panel causality test	No causality effect
19	Bhattacharya et al. (2016)	38 countries	1991-2012	RE	Panel estimation techniques	Positive significant effect
20	Akinlo (2008)	11 Sub Sahara countries	1980-2003	Total energy	ARDL bounds test and VECM	Positive effect: mixed results on causality
21	Apergis and Payne (2011)	16 emerging market economies	1990-2007	Total RE and NRE electricity	Panel Granger causality	Bidirectional causality (NRE and growth)

22	Carainani et al. (2015)	Emerging European countries	1980-2013	Coal, gas, oil, and renewable	VECM	Positive
23	Lei et al. (2014)	Biggest coal consuming countries	2000-2010	Coal	Panel Causality	Mixed results
24	Kahia et al. (2017)	11 MENA Net oil-importing countries	1980-2012	Total RE AND NRE	FMOLS and Panel Granger causality	Bidirectional causality (NRE and growth)

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25	Saidi and Hammami (2015)	58 Global panel countries and sub-panel regions	1990-2012	Total Energy	Dynamic Panel Data Model	Positive effect

26	Adewuyi and Awodumi (2017)	11 ECOWAS countries	1995-2010	Biomass	Three Stage Least Square	Mixed results across countries (growth and carbon emission)
27	Antonakakis et al. (2017)	Different income groups of 106 countries	1971-2011	Total energy	PVAR	No significant effect and Bi-directional causality (growth and consumption)
28	Chakamera and Alagidede (2018)	18 SSA countries	1990-2013	Electricity	Two-stage least square	Positive effect
29	Chen et al. (2016)	188 countries	1993-2010	Total Energy	Panel co-integration and VECM	The mixed result across countries
30	Cowan et al. (2014)	BRICS countries	1990-2010	Electricity	Panel Causality Analysis	Mixed results across

						countries(growth and consumption)
31	Sebri and Ben-Salha (2014)	BRIC countries	1971-2010	Renewable Energy	ARDL, VECM Granger Causality	Positive effect and bi-direction causality
32	Wang et al. (2018)	Balanced dataset for 170 countries	1980-2011	Primary energy	Panel Co-integration, VECM Granger causality	Positive in the long run. Short-run and long-run bidirectional causality co2
33	Katsuya Ito	42 developed countries	2002-2011	Renewable energy		Positive effect
34	Zaman and Moemen (2017)	90 selected income level countries	1975-2015		Non-linear regression, GMM, and DFE regression	Evidence of EKC

35	Riti et al. (2019	China	1970-2015	Total energy	ARDL, FMOLS, DOLS, and IRVD	Evidence of EKC
36	Belsalobre-lorente et al. (2018)	EU-5	1985-2016	Renewable electricity consumption	Econometrical model based on empirical EKC model	N-shaped relationship between growth and emission
37	Rahman (2020)	G7	1961-2013	Electricity consumption	FMOLS	Positive effect
38	Fosten, Morley and Taylor (2012)	UK	1830 - 2003	Total energy	Non-linear threshold cointegration	Evidence of EKC
39	Sephton and Mann (2016)	UK	1830 - 2003	Total energy	the multivariate adaptive regression spline model	Evidence of EKC

40	Altunbas and Kapusuzoglub (2011)	UK	1987 - 2007	Total energy	Granger causality	Uni-directional Short-run causality from

2.2 Energy Consumption and Economic Growth

The literature on the relationship between energy consumption and economic growth is quite vast owing to the awareness of the effects of energy consumption on economic growth in developing and developed economies (F. Adedoyin, Abubakar, Victor, & Asumadu, 2020; F. F. Adedoyin, Alola, & Bekun, 2020; F. F. Adedoyin, Bekun, & Alola, 2020; F. F. Adedoyin, Gumede, Bekun, Etokakpan, & Balsalobre-lorente, 2020; F. Adedoyin, Ozturk, Abubakar, Kumeka, & Folarin, 2020; Etokakpan, Adedoyin, Vedat, & Bekun, 2020; Kirikkaleli, Adedoyin, & Bekun, 2020; Udi, Bekun, & Adedoyin, 2020). Akinlo (2008) and Eggoh et al. (2011), while focusing on total energy consumption in their panel data studies on African and sub-Saharan Africa, revealed a positive effect of energy consumption on economic growth that is the higher the energy consumption, the more growth economies experience. Considering biomass and coal consumption; Aydin, (2019) produced mixed results for biomass consumption across BRICS countries while using the CIPS, Bootstrap panel cointegration, and causality test. Aspergis and Payne (2010) employed the FMOLS and panel causality in 15 emerging market economies and found a negative effect of coal consumption on economic growth.

On the contrary, Lie et al. (2014), while using the panel causality estimation technique, found the relationship to be mixed across the biggest coal consuming countries. Carainani et al. (2015) looked at emerging European countries using gas, oil, renewable, coal consumption in emerging European countries during the period 1980-2013. They revealed a positive effect of the energy mix on economic growth. A more recent study by Barreto (2018) using oil and alternative renewable energy, findings indicated a positive effect of oil on economic growth. In contrast, Carfora et al. (2019) results in 17 OECD countries revealed that there were mixed results across countries on oil consumption and economic growth. Taking into consideration renewable and non-renewable energy, Bhattacharya et al. (2016), using the panel estimation technique, found renewable energy consumption positively related to economic growth. The result for OECD countries is negative for renewable energy consumption by Bilgil et al. (2018) using FMOLS and panel DOLS but was confirmed positive by Alam and Murad (2020) using ARDL, PMG, MG, and DFE. In another study, Atems and Hostaling (2018) found out that a positive and significant relationship exists between renewable and nonrenewable electricity consumption and economic growth. Bao and Xu (2019) found no causality effect of renewable energy and economic growth in China using the Bootstrap panel causality test. Aspergis and Payne (2011) and Kahia et al. (2017) showed that a bi-directional causality exists between non-renewable energy consumption and economic growth while using Panel granger causality and FMOLS with panel granger causality analysis respectively. In the reviewed literature, there is no agreement on the effects of specific energy or energy mix on economic growth.

2.3 Energy consumption emission nexus and economic growth

This strand of literature describes the relationship between energy consumption, carbon emission, and economic growth. In the literature, on the type of energy, Altunbas and Kapusuzoglub (2011) could not find long-run causality between total energy consumption and economic growth in the United Kingdom. However, the study which utilized the granger causality test and data between the period between 1987 and 2007 found a short run unidirectional causality from GDP to energy consumption in the UK. Also, non-renewable energy consumption was found to have a negative impact on economic growth, while renewable energy had a positive impact (Sebril and Ben-Salha, 2014; Ito, 2017). Primary energy had a positive effect on C02 and economic growth (Wang et al., 2018), Electricity was found to have a positive effect in the growth consumption emission nexus for 18 SSA countries (Chakamera and Alagidede, 2018) whereas, the effect of biomass consumption was mixed across 11 ECOWAS countries (Adewuyi and Awodumi, 2017). Total energy consumption revealed a mixed impact across 188 countries (Chen et al., 2016) but no significant effect on 106 countries of different income groups (Antonakakis et al., 2017).

Considering BRICS countries, Cowan et al. (2014) employed the Panel Causality Analysis while investigating economic growth and the nexus of energy consumption and CO_2 emission during the period 1990-2010. The results indicated mixed results on the causality across countries. Sebril and Ben-Salha (2014) found out a positive and bi-directional causality between these variables when they employed ARDL, VECM, and Granger causality. In the same vein, bidirectional causality finding was revealed for different income level countries when tested with Panel Cointegration and VECM Granger causality (Wang et al., 2018). On the EKC hypothesis in the United Kingdom, Fosten, Morley, and Taylor (2012) used a non-linear threshold cointegration and error correction methodology and an extended dataset beginning in 1830 to 2003 to investigate disequilibrium from the EKC in the United Kingdom. The study found that the inverted U shaped relationship between growth and emissions holds for the UK and that technological change could account for asymmetric adjustments in the emissions growth long-run relationship. The study by Sephton and Mann (2016) confirmed the findings of Fosten, Morley, and Taylor (2012). The study used data spanning 1830 to 2003, and a multivariate adaptive regression spline model established a non- linear cointegrating relationship between emissions and income. Also, the study found the presence of the EKC in the UK with turning points around 1966 and 1967 for C02 and S02, respectively. The turning points were associated with the introduction of the clean air Act in the UK and also the reduced use of coal to meet energy needs. Upon investigating the temporal behavior of the EKC, they found that emissions restore the system to equilibrium in the case of a deviation from long-run relationship (between income and emissions).

In a global context, Zaman and Moemen (2017) examined the interrelationship of energy consumption, C02 emissions, and economic development and indicated that the results support the EKC hypothesis. Similarly, Riti et al. (2019) findings also support the EKC hypothesis in a study on the consistency of the EKC results on the CO2 emission and economic growth in China using the ARDL, FMOLS, DOLS and IRVD techniques. However, when the EKC turning points of China were compared with different countries, inconsistencies were discovered. On the contrary, Balsalobre-Lorente et al. (2018) results did not support the EKC; instead, it confirmed an N-shaped relationship between the subject variables.

Followingthe above, it is evident that there is no consensus on the direction of causality and effect as the results are mixed with or without considering the EKC hypothesis. This suggests that there might be inconsistencies due to macroeconomic institutional policies and poorly managed energy consumption, emission, and economic growth relationship existing in the different countries and regions (Adams et al., 2016). Thus, the rising concern of policy uncertainty is looked at in the next strand of studies.

2.4 Energy consumption and Economic policy uncertainty

In the literature, Economic Policy Uncertainty (EPU) is described as the uncertainty associated with impaled government regulatory, monetary, and fiscal policies that alter economic outcomes and the environment in which economic agents operate. As EPU rises, firms revise and delay their investment decisions such that with this disclosure, other economic units hesitate in their consumption, investment, and savings decisions. Since the public and financial sector policies are weaker during high economic uncertainty (Harkos and Tzemeres, 2013; Aastveit, 2017), it is expected that environmental concerns (carbon emission) deteriorate as a result of decreased pressure from consumption. Expectedly industries will employ cheap energy for production to make up for the low turnover due to EPU. Therefore, as the net income of such industries increases, they might use high energy production methods that are cleaner, and which invariably reduces carbon emissions.

Thus, the EKC hypothesis might be true for the impact of EPU in the energy consumption emission nexus. More noticeable is that investment might be slightly or negatively affected during this period (Aastveit et al., 2017; Akron et al., 2020). A considerable number of studies have investigated the EPU for its impact in investment (Akron et al., 2020) equity (Raza, 2013) financial policy (Astaveit et al. 2017; Albulescu, 2019; Ulusory, 2019) industrial and bank returns (Jin et al., 2019, Rehman, 2020), tourism (Tiwari et al., 2019) Stock market and commodity pricing (Raza, 2018; Rehma, 2019) liquidity management (Li, 2019) energy (Halkos et al.; 2013, Jiang et al., 2019; Adams, 2016) and environmental pollution (Jiang et al. 2019).

These studies have considered a specific country, region, or group of countries together using varying theories, measures, control variables, periods, and estimation techniques. Considering the impact of EPU on the energy consumption nexus, Adams et al. (2016) employed the Panel Vector Autoregressive (PVAR) and Generalized Method of Moments (GMM) to investigate the effect of economic and political reforms on energy consumption in 16 SSA countries. Their findings revealed that there is a positive effect between the two variables.

Charfeddine and Kahia (2019), while also using the PVAR but with Impulse Response Function (IRF) to analyze the impact of renewable energy consumption and financial development in 24 MENA countries indicated that a slight influence of renewable energy and financial development elucidate CO2 emissions. Rehma (2019) examined the predictability of energy prices (oil) to EPU and found out that there is an asymmetric long-run relationship between oil shocks and EPU. Jiang et al. (2019) used the Novel Parametric test of Granger causality to ascertain the effect of economic policy uncertainty on carbon emission. Their results showed that in the US sector, EPU granger causes carbon emission when the growth of carbon emission is in a lower or higher growth period.

Since the existing literature find that the effect of EPU is significant in economic and financial activities, it is expected that leading from these activities, EPU may have an impact on energy consumption, which is reflected in the carbon emission decision for a country. It also appears that the studies on the EPU have increased in recent years; nevertheless, there is still dearth on the impact of EPU on the growth of energy consumption and carbon emission. Based on the studies reviewed, there was no study on the impact of EPU in the energy consumption emission nexus in the UK; neither was there any application of the EKC hypothesis on the subject matter. It is in this vein that this study tends to fill the knowledge gap.

3. Data and Methods

3.1 Models and Method

Most of the previous panel analyses have used the Panel Vector Autoregressive (PVAR) and Generalized Method of Moments (GMM). Panel vector autoregressive (PVAR) is known to pose restrictions on the coefficients of the contemporaneous variables (Sims 1980). Others impose restrictions on the covariance of the structural innovations (Hausman, Newey, and Taylor 1987), or the long-run multipliers (Blanchard and Quah 1989). While Generalized Method of Moments (GMM) estimation can only hold on transformed data, which often time does not hold. Hence, we employed ARDL estimation, which takes into cognizant the limitations posed by the above models.

There are numerous advantages of using the ARDL framework instead of the Panel Vector Autoregressive (PVAR) and Generalized Method of Moments (GMM), as noted by Adams et al. (2016). The conventional cointegration method estimates the long-run relationships within a context of a system of equations; the ARDL method employs only a single reduced form equation (Pesaran & Shin, 1995). The ARDL method yields consistent and robust results both for the long-run and short-run relationships among variables. The ARDL approach does not involve pre-testing variables, which means that the test for the existence of the relationship between variables in levels is applicable irrespective of whether the underlying regressors are purely I(0), purely I(1) or a mixture of both. This feature alone, given the characteristics of the cyclical components of the data, makes the standard of cointegration technique unsuitable, and even the existing unit root tests to identify the order of integration are still highly questionable.

Following the literature, we adopt a single equation model to analyze the link that exists between energy use, economic policy uncertainty, and CO2 emission. The estimable equation is modeled as follows:

$$In\, CO_{2t} = \alpha_0 + \alpha_1 InEU_t + \alpha_2 InRGDP_t + \alpha_3 InRGDP2_t + e_t \qquad (1)$$

$$In\, CO_{2t} = \alpha_0 + \alpha_1 InEU_t + \alpha_2 InRGDP_t + \alpha_3 InRGDP2_t + \alpha_4\, InEPU_{it} + e_{it} \qquad (2)$$

$$In\, CO_{2t} = \alpha_0 + \alpha_1 InEU_t + \alpha_2 InRGDP_t + \alpha_3 InRGDP2_t + \alpha_4\, InEPU_t + \alpha_5\, InEPU * EU_t + e_t \quad (3)$$

Where *CO2* represents *CO2* emission; *EU* measures the energy use; RGDP is real GDP; R*GDP2* measures real GDP per capita, and *EPU* is economic policy uncertainty, while subscripts t is the period.

To test for the impact of energy use and economic policy uncertainty on CO_2 emissions on a country basis, we introduced the ARDL bound test to enable us to test the fitness of the model in the short and long term. The ARDL bound test is widely used because of its essential predictive techniques for differentiating long-run and short-run models irrespective of the level of data stationarity.[1] First, we estimated if the series would meet the long-run criteria; if so, then the error correction model (ECM) test would be conducted to determine the short-run relationship among the series. However, if the bound test failed to meet the criteria, then VAR estimation would be used to test the connection of selected variables. This model was chosen because it can check the past value of variables. Therefore, this approach can improve our estimation because a country maybe not have economic policy uncertainty at a point in time but can regain it after some time. Such disparities in periods can be tested with the ARDL bound test.

3.2 Data

We used annual data spanning the period of 1985–2017 for the UK. For time-series analyses of the determinants of CO_2 emissions, we utilized CO_2 emissions in tons per capita (CO_2), real GDP (RGDP) is proxied by gross domestic product (billions of 2010 U.S. dollars),

[1] Enable the estimation of data series at both levels and the first different value

real GDP per capita (RGDP2) is proxied by gross domestic product per capita (billions of 2010 U.S. dollars), energy use (EU) is proxied by primary energy consumption (Million tonnes oil equivalent) and economic policy uncertainty (EPU). The descriptive statistics of the data are provided in Tables 1.

Table 1 report that CO2 emission, energy use, real GDP, real GDP per capita, and economic policy uncertainty is positively trending on average of 545.4054, 215.5784, 2116.942, 34987.08 and 0.0706, respectively. While the standard deviation shows that real GDP per capita have the highest values, showing that real GDP per capita have the highest value. The skewness value shows negatively skewed for all the variables except economic policy uncertainty, while kurtosis value indicates that all the variables are positively leptokurtic.

Table 1: Description of data and measurement units

	CO2	EPU	EU	RGDP	RGDP2
Mean	545.4054	0.0706	215.5784	2116.942	34987.08
Median	562.9870	0.0557	217.3056	2163.400	36592.81
Maximum	602.8413	0.3021	232.3125	2841.200	43010.71
Minimum	403.2094	0.0016	192.5221	1369.300	24214.04
Std. Dev	51.7386	0.0616	11.8271	452.6043	5976.425
Skewness	-1.4742	1.8261	-0.5053	-0.0873	-0.3157
Kurtosis	4.2455	7.1988	2.2254	1.6198	1.6133
Jarque-Bera	14.0850	42.5816	2.2293	2.6612	3.1924
Observation	33	33	33	33	33

Author's calculation

4. Results and Discussion

Table 2 shows the unit-root results, and this is imperative to enable us to confirm the series of the data and its fitness ARDL analysis. Both ADF and PP tests the findings on the level data series across the variables, and economies suggest the evidence of a unit root. However, the estimates on the first-order difference data series confirmed the rejection of the null hypothesis at a 1% level of significance for all samples and accepted alternative hypotheses. This evidence implies that the selected variables are not stationary at the level, but stationary at their first-order difference. This is suitable for ARDL bound test.

Table 2: Unit root results

Variable	ADF	PP
	T-statistic	T-statistic
Panel A: Level		
CO2	1.8435	2.0674
EPU	-1.9436	-1.7544
EU	-0.6043	-0.7534
RGDP	-0.4236	-0.4384
RGDP2	-1.2719	-1.3998
Panel A: Difference		
CO2	-6.2261***	-6.1859***
EPU	-5.1906***	-7.4337***
EU	-7.1846***	-6.9208***

RGDP	-3.4562***	-3.4269***
RGDP2	-3.1701***	-3.1459***

Note: *** indicates that the variable coefficient is at the 1% significance level, respectively.

Table 3 shows the bound test, and the results indicate that long-term equilibrium exists among the variables for the three models. The bound of the F-statistic is higher than the upper bound of the T-statistic (upper and lower bound) at all levels (i.e., 10%, 5%, and 1%), confirming that the series are co-integrated in the long run.

Table 3: Bound test

CO_2 = f (EU, RGDP,RGDP2)									
	K=2	10%		5%		1%		p-value	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	4.9002	2.72	3.77	3.23	4.35	4.29	5.61	0.0000	0.0000
T	2.5011	-2.57	-3.46	-2.86	-3.78	-3.43	-4.37	0.0000	0.0000
CO_2 = f (EU, RGDP,RGDP2,EPU)									
	K=2	10%		5%		1%		p-value	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	6.9439	1.9	3.01	2.26	3.48	3.07	4.44	0.0000	0.0000
T	3.0931	-1.62	-3.26	-1.95	-3.6	-2.58	-4.23	0.0000	0.0000
*CO_2 = f (EU, RGDP,RGDP2,EPU, EPU*EU)*									
	K=2	10%		5%		1%		p-value	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	4.4731	2.26	3.35	2.62	3.79	3.41	4.68	0.0000	0.0000

T	-1.8524	-2.57	-3.86	-2.86	-4.19	-3.43	-4.79	-	-

Source: Authors Calculation

Table 4 long runs ARDL results for the first model. The long-run estimation confirmed that energy use has a negative relationship with CO_2 emission at the 5% significance level. This relationship means that energy use can lead to a reduced CO_2 emission with an average value of 3.8899%. This could be as a result of using cleaner energy use. Similarly, 1% increments in real GDP per capita adversely lead to increases of 0.0541% in CO_2 emissions. However, real GDP shows no relationship with CO_2 emission in the UK. This finding means that real GDP is never a determinant of CO_2 emissions in the UK. This finding is in line with the work of Jalili and Feridun (2011), who reported a positive effect of energy consumption on CO2 emissions in China.

As for the short-run, the coefficient of ECM is negative as expected and low (-0.3944) at the 1% significance level. The short-run estimation indicated that the past values of CO_2 emissions have a positive influence on CO_2 emissions because they reduce this variable by 0.5092%. By contrast, the present values of energy use have a strong influence on CO_2 emission because they increase the growth of CO_2 emissions by 2.8185%. The finding is contrary to the work of Jayanthakumaram et al. (2012) in China and India. Overall, energy use has both positive and negative impacts on CO_2 emissions in the UK.

Table 4: ARDL results

$CO_2 = f\,(EU, RGDP, RGDP2)$			
Variable	Coefficient	Std. error	T.stat.
Long-run results			

EU	-3.8899***	1.5869	2.4512
RGDP	-0.6483	0.3407	1.9029
RGDP2	0.0541***	0.0253	-2.1360
Short-run results			
ECT	-0.3944***	0.0825	4.7820
D(CO2(-1))	-0.178079	0.197202	-0.903028
D(CO2(-2))	-0.5092***	0.1832	-2.7794
D(EU)	2.8185***	0.2741	10.2815
D(EU(-1))	0.4301	0.6144	0.7001
D(EU(-2))	1.2816***	0.5611	2.2839

Note: *** indicates that the variable coefficient is at the 1% significance level.

Table 5 shows the ARDL results for model 2, and the long-run estimation shows that energy use and real GDP have a great impact on CO_2 emissions because they reduce the growth of CO_2 emissions in the UK by 6.0713% and 1.2344% yearly, respectively. This may be possible because the UK has adopted the policy of clean energy use, and for that reason, productions are also suggested from low emissions or clean energy sources. By contrast, real GDP per capita shows an adverse effect on CO2 emissions, as CO2 emissions continue to grow yearly by 0.0950 % due to an increase in the level of real GDP per capita. The findings are not different from the work of Saidi and Hammami (2015) and Chakamera and Alagidede (2018).

The short-run estimation shows that the model is stable as it has the ECT negative value of -0.3439 at 1% significance levels. Further, the estimation proved that the past value of CO2 emission impacted on the CO2 emission, because it reduces its growth by 0.1166% yearly. Similarly, real GDP also positively impacted the growth of CO2 emissions. That means CO2 emissions decreased yearly with an average of 0.3697% due to an increase in real GDP. However, energy use shows a significant influence in increasing the growth of CO2 emissions yearly, with an average of 2.2486%. Poor implementation could be a factor in this negative impact on CO_2 emissions. Surprisingly, economic policy uncertainty shows no connection with CO2 emission in the UK.

Table 5: ARDL results

CO_2 = f (EU, RGDP,RGDP2,EPU)			
Variable	Coefficient	Std. error	T.stat.
Long-run results			
EU	-6.0713***	0.7695	7.8896
RGDP	-1.2344***	0.3177	3.8858
RGDP2	0.0950***	0.0236	-4.0291
EPU	285.0788	156.9562	-1.8163
Short-run results			
ECT	-0.3439***	0.05281	6.5142
D(CO2(-1))	-0.1166*	0.0813	-1.4342
D(EU)	2.2486***	0.2709	8.2982
D(RGDP)	-0.3697***	0.0574	-6.4441

D(EPU)	-0.3204	26.0732	-0.0123

Note: ***, * indicates that the variable coefficient is at 1% and 10% significance levels, respectively.

The table 6 shows the ARDL results for the model three and the long-run estimation show that energy use, real GDP, economic policy uncertainty and the interaction between economic policy uncertainty and energy use have a positive relationship with CO2 emissions by 4.8002%, 1.2942%, 10244.68%, and 48.8308%, respectively while an increase in the level of real GDP per capita shows that CO2 emissions are reducing by 0.0822% yearly.

The short-run estimation, the results show that past value of CO2 emissions and real GDP strongly increase the growth of CO2 emissions by 0.3585% and 2.6493%, respectively, while real GDP per capita shows an improving effect on CO2 emissions with an average of 0.1591% reductions yearly. Similarly, economic policy uncertainty shows significant power in reducing the level of CO2 emissions by 1603.593% yearly. By contrast, energy use and interaction between economic policy uncertainties adversely affect the growth of CO2 emission, with an average growth rate of 1.3915% and 7.6510% yearly. Poor implementation could be a factor in this negative impact on CO_2 emissions.

Table 6: ARDL results

$CO_2 = f(EU, RGDP, RGDP2, EPU, EPU*EU)$

Variable	Coefficient	Std. error	T.stat.
Long-run results			
EU	4.8002*	3.0292	-1.5847
RGDP	1.2942**	0.7296	-1.7738

RGDP2	-0.0822*	0.0509	1.6141
EPU	10244.68**	5324.590	-1.924031
EPU*EU	48.8308**	25.8516	1.8889
Short-run results			
ECM	-0.3898***	0.0646	-6.0352
D(CO2(-1))	0.3585***	0.1179	3.0393
D(EU)	1.3915***	0.4036	3.4476
D(RGDP)	0.1589	0.8041	0.1976
D(RGDP(-1))	2.6493***	1.0969	2.4151
D(RGDP2)	-0.0015	0.0497	-0.0309
D(RGDP2(-1))	-0.1591***	0.0658	-2.4182
D(EPU)	-1603.593***	577.3962	-2.7773
D(EPU*EU)	7.6510***	2.8338	2.6999

Note: ***, ** and * indicate that the variable coefficient is at 1%, 5%, and 10% significance levels, respectively.

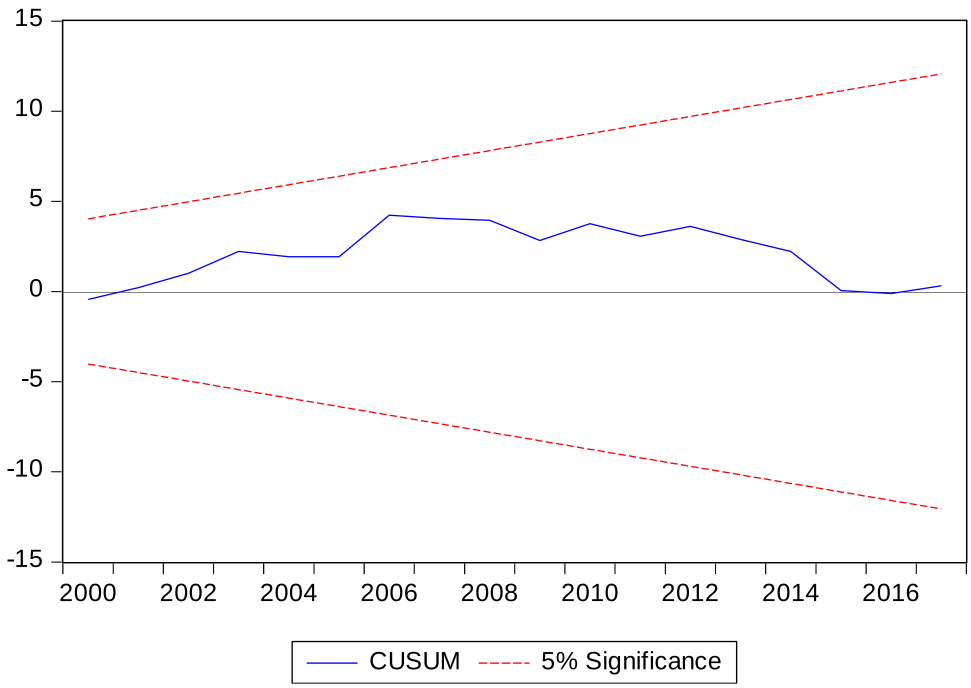
Table 7 shows Granger causality results, and the estimation shows one-way causality running from energy use to CO_2 emissions. This is now new to the literature and has been heavily documented in the literature. Furthermore, there is a one-way causality that runs from CO_2 emissions to economic policy uncertainty on the one hand as well as from energy use to economic policy uncertainty on the other hand. This is an addition to the literature. Economic policy uncertainty is Granger caused by both CO_2 emissions and energy use.

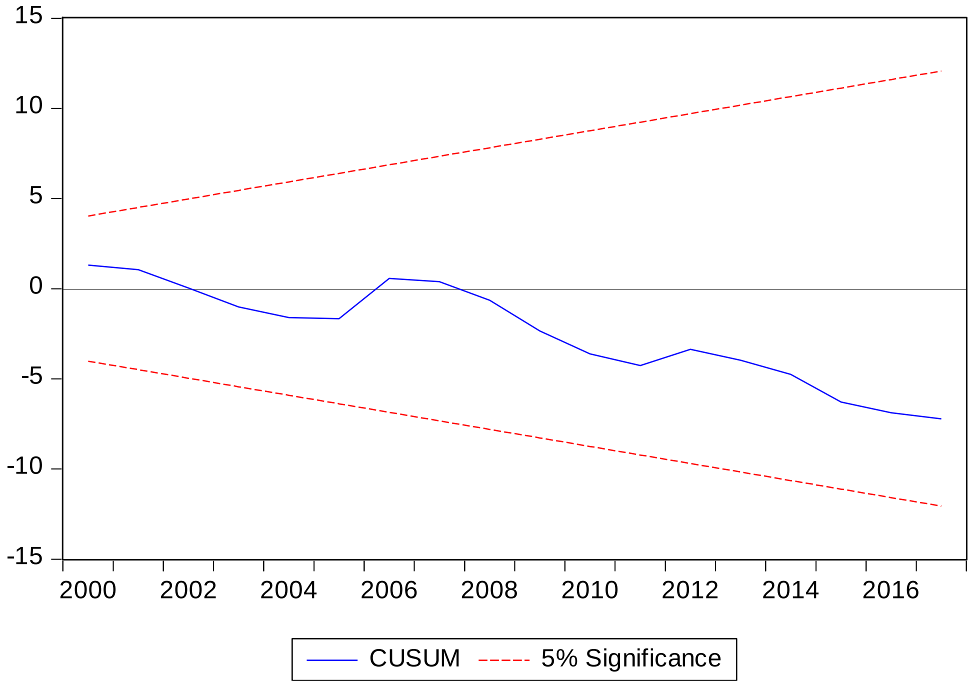
Table 7: Granger causality results

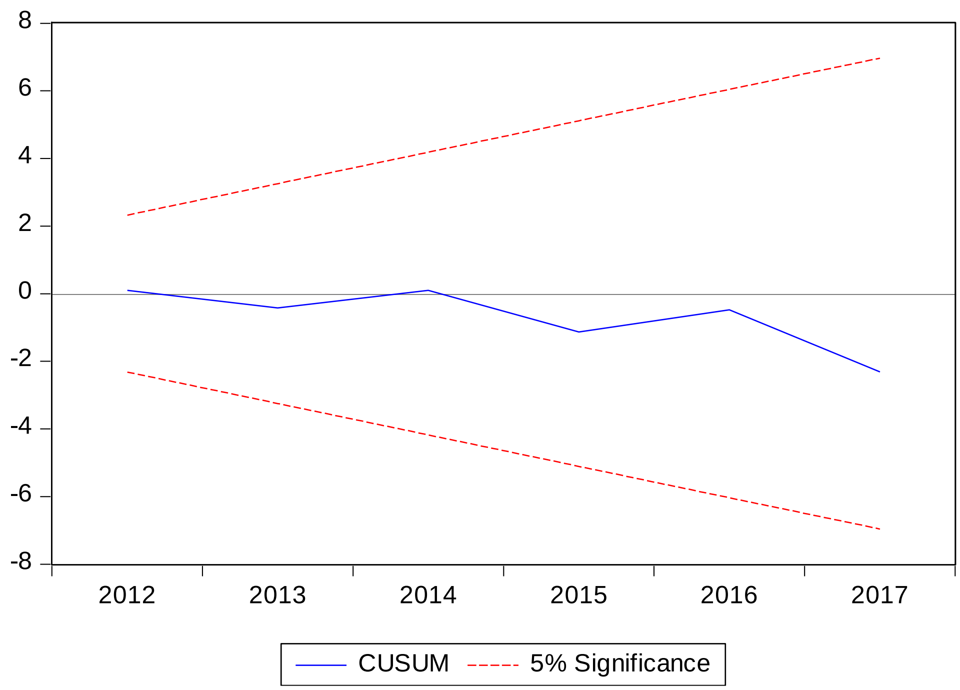
Variable	F-Statistics	Direction of Causality
EU – CO2	2.1819*	Unidirectional
CO2 –EU	1.3664	
EPU – CO2	1.5184	Unidirectional
CO2 – EPU	2.0762*	
EPU – EU	1.3079	Unidirectional
EU – EPU	2.4531**	

Note: ***, ** and * indicate that the variable coefficient is at 1%, 5%, and 10% significance levels, respectively.

The post analysis for the stability of the models shows that the recursive estimates are obtained at a 5% significance level.







5. Conclusion and Policy Implications

5.1 Summary and Conclusion

An assessment of the causal connection between economic policy uncertainty, energy consumption, and CO2 emissions in the UK is not only timely but offers fresh insight into an environmental policy for developed economies. This paper, along these lines, progresses the assortment of information by examining the evidence on the role of Economic Policy Uncertainty in the Energy Consumption - Emission nexus in the UK. We use annual data spanning the period of 1985–2017 for the UK for CO_2 emissions in tons per capita (CO_2), real GDP (RGDP), energy use (EU), and economic policy uncertainty (EPU). The Autoregressive distributed lag model (ARDL) bound test is used to test the fitness of the model in the short and long term. Additionally, the error correction model (ECM) analysis was conducted to determine the short-run relationship among the series. The aftereffects of the pairwise Granger causality shows a one-way causality running from energy use to CO2 emissions, CO2 emissions to economic policy uncertainty and energy use, and economic policy uncertainty. However, two-ways causality is found between real GDP and real GDP per capita.

This study finds that EPU plays an important role in the effort to mitigate pollution, particularly CO_2 emissions in the UK. Firstly it shows that EPU reduces the level of CO_2 emissions of the UK in the short-run, while the CO_2 emissions increase due to EPU in the long-run. The study further shows that economic growth and energy use primarily increases the level of CO_2 emissions. Overall, this indicates that EPU plays a relevant role in curbing the rise in CO_2 emissions. Consequently, pertinent policies that discourages the rise in CO_2 emissions are necessary.

5.2 Policy Implication

Following the findings of this study, first, it is noteworthy that EPU matters in curtailing emissions in the UK as empirical results show that EPU have negative impacts on CO_2 emissions in the short-run while the reverse is the case in the long-run as EPU shows positive impacts on CO_2 emissions. This suggests that at the beginning, the role of EPU on the energy consumption-emissions seems to require some attention because it act as a deterrent to emissions. However, in the longrun, given that clean energy sources are often used to curtail a rise in CO_2 emissions as it has low or zero emissions, it becomes imperative to control the level of uncertainties that affect clean energy sources. This will help foster creativity in the industry. Furthermore, extracting power from such a source minimizes the level of CO_2 emissions. Therefore, the government and relevant policymakers alike must explore workable policies that foster the use of clean energy sources for energy consumption. The moderating role of the impact of uncertainties can then be potentially achieved by deploying additional funds for the purchase of clean energy sources including through other means, such as domestic and foreign investments, loans, and fiscal benefits. This will not only enaure stability in the industry but also bring about some level of resilience, which can be achieved during times of shocks to the economy. Also, local investors can be motivated to venture into clean energy by offering funds and relaxing part of the taxes that discourage investments in energy.

Second, this study finds that the level of economic expansion and energy use exerts a negative impact on mitigating CO_2 emissions. For this reason, policymakers must prioritize their goals for a clean and healthy environment alongside economic growth and energy use. A high level of economic growth is likely to translate into CO_2 emissions through production maximization. Firms often produce goods and services through the maximization of resources, such as energy use. Thus, the government must provide a prevailing environment and guideline for the operation of firms to discourage firms from emitting CO_2 emissions, while maintaining the growth of the overall economy. This way, the UK will be in line with the Sustainable Development Goal 12 by 2030 and on track to attaining her domestic target of zero-emission by 2050.

In a nutshell, the findings of this study presents us with a two-face policy - one that considers a short-term i.e. the pre-phase and another that considers a long term period i.e. main phase. Considering the sensitivity of pollution and its effects, it demands holistic policies that will act fast to reduce emissions. Findings presented in both the short-run and long-run would be an eye-opener for the policymakers to develop policies, first, in the short-time period to minimise the challenges posed by pollution but complemented by other sustainainable policies that will last for an extended period. However, despite the findings presented in this study, we recommend further studies that can take into account several panel of countries. In addition, a similar study on the UK economy can further consider specific impacts of Brexit and its uncertainty on energy-environment mix in both former and current European Union member clusters i.e. the EU with and without the UK.

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