Technological Forecasting & Social Change 161 (2020) 120255

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

UK's net-zero carbon emissions target: Investigating the potential role of economic growth, financial development, and R&D expenditures based on historical data (1870–2017)

Muhammad Shahbaz[a,b], Muhammad Ali Nasir[c], Erik Hille[d,*], Mantu Kumar Mahalik[e]

[a] Beijing Institute of Technology, Beijing, China
[b] University of Cambridge, Cambridge, UK
[c] University of Huddersfield, Huddersfield, UK
[d] HHL Leipzig Graduate School of Management, Leipzig, Germany
[e] Department of Humanities and Social Sciences, Indian Institute of Technology, Kharagpur, West Bengal, India

ARTICLE INFO

Keywords:
CO_2 Emissions
Economic Growth
Financial Development
R&D Expenditures
Net-zero Emissions

JEL Classifications:
C22
O44
Q54
Q55

ABSTRACT

The 4th industrial revolution and global decarbonisation are frequently referred to as two interrelated megatrends. Particularly, where the 4th industrial revolution is expected to fundamentally change the economy, society, and financial systems, it may also create opportunities for a zero-carbon future. Therefore, in the context of UK's legally binding commitment to achieve a net-zero emissions target by 2050, we analyse the role of economic growth, R&D expenditures, financial development, and energy consumption in causing carbon dioxide (CO_2) emissions. Employing the bootstrapping bounds testing approach to examine short- and long-run relationships, our analysis is based on historical data from 1870 to 2017. The results suggest the existence of cointegration between CO_2 emissions and its determinants. Financial development and energy consumption lead to environmental degradation, but R&D expenditures help to reduce CO_2 emissions. The estimated environmental effects of economic growth support the EKC hypothesis. While a U-shaped relationship is found between financial development and CO_2 emissions, the nexus between R&D expenditures and CO_2 emissions is analogues to the EKC. In the context of the efforts to tackle climate change, our findings suggest policy prescriptions by using financial development and R&D expenditures as the key tools to meet the emissions target.

1. Introduction

The 4th industrial revolution and climate change are often seen as two interconnected megatrends (BlackRock, 2020). On the one hand, the 4th industrial revolution is expected to deeply transform the way that the global economy, society and financial system work. Primarily, through disruptive technological advances, such as artificial intelligence, the Internet of Things, and machine learning. At the moment, the direction of this transformation is unclear, but if steered effectively, it may benefit human civilisation as well as the environment (Herweijer et al. 2018). For instance, Corfe (2020) has listed several opportunities on how the 4th industrial revolution may help to clean the environment. To decarbonize the industry, his list includes ideas such as green commercial vehicle fleets, 3D printing, and cloud-based computing. Nonetheless, there is also an increasing realisation that the technological revolution could exacerbate economic problems, for example in the form of unemployment or reduced wages (Acemoglu and Restrepo, 2018).

On the other hand, due to growing anthropogenic greenhouse gas emissions, there has been a continuous increase in the possibility of a catastrophic climate change (Committee on Climate Change, 2019). The climate is rapidly changing and planet Earth is warming, potentially more than the targeted increase to a maximum of 2 °C above pre-industrial levels (Shahbaz et al. 2020). Climate change is not only an existential threat to humankind in the developing world but also an important challenge for advanced countries including the UK.[1] Already today, the UK is suffering from climate change, manifested in a rising number of extreme weather events, warmer winters and hotter summers, rising sea levels of around 3mm a year, and changing rainfall patterns (Gov.uk, 2017). The health consequences of extreme weather events are comparatively large in the UK. The heatwave in 2003 has taken the life of two thousand people. Similarly, the 2007 disastrous

---

* Corresponding author.

E-mail addresses: ms2609@cam.ac.uk (M. Shahbaz), m.a.nasir@hud.ac.uk (M.A. Nasir), erik.hille@hhl.de (E. Hille), mkm@hss.iitkgp.ac.in (M.K. Mahalik).

[1] In their recent study, Chaudhry et al. (2020) found that climate change increases sovereign risk for G7 countries.

https://doi.org/10.1016/j.techfore.2020.120255
Received 26 April 2020; Received in revised form 11 August 2020; Accepted 12 August 2020

flooding is regarded as a sign of climate change, which has not only adversely affected 55,000 homes and killed 13 people but also amounted for economic losses of about £3.2 billion. Subsequently, the UK government has faced an average flooding loss of about £1.5 billion per year in the last two decades. These extreme events are economically and socially detrimental and pose multifaceted challenges to the UK. Given the amount of damages caused to the UK economy, a climate emergency with a set of serious actions is required to lower the rising carbon emissions that can protect the UK economy and environmental quality (Committee on Climate Change, 2019).

The Climate Change Act of 2008 had provided a legally binding framework to the UK government to regularly assess the risk arising from climate change, mitigate national greenhouse gas emissions, and prepare a climate change adaptation strategy (Gov.uk, 2019a). This important legislation established the world's first climate change target that is binding by law. Specifically, as compared to the 1990 baseline, the UK was expected to reduce carbon emissions by 80% till 2050 (Gov.uk, 2015).[2] Furthermore, the UK has joined hands with the other 194 countries ratifying the Paris Agreement of 2015. The Paris Agreement was drafted in line with the United Nations Framework Convention on Climate Change (UNFCC), which calls upon the international community to tackle rising carbon emissions through greater regulatory efforts and financial capacities. It is quite likely that, if the UK among the other international partners fails to achieve its nationally determined reduction targets, then it has to face more flooding, greater pressure on scarce water resources, damage to natural or wildlife habitats, and occupational health risks from heatwaves (Committee on Climate Change, 2019). Considering the severity of climate change and the UK Climate Change and Risk Assessment, stating that the right time is now for the UK government to act on these challenges (Gov.uk, 2017), the UK government decided to speed up its efforts. Hence, instead of the 80% reduction goal, the UK became the first major economy to pass a net-zero emissions law, targeting a 100% reduction of carbon dioxide (CO_2) emissions by 2050 (Gov.uk, 2019b). However, without appropriate actions, based on thorough empirical evidence about the factors causing CO_2 emissions in the long run, the facts on the ground will not change.

Economic activity is often considered as the main driver of CO_2 emissions. Indeed, economic growth is essential to improve the lives of the people. The notion of the Environmental Kuznets Curve (EKC) suggests that in the long run, people with better income and environmental education will demand better environmental quality. Better environmental quality is beneficial both for higher economic growth as well as for the quality of life of the human. This is the key environmental protection mechanism of the EKC hypothesis. The evidence on the EKC hypothesis can be best described as mixed (Onafowora and Owoye, 2014; Apergis, 2016; Özokcu and Özdemir, 2017; Nasir et al., 2019; Pham et al, 2020). This contrast suggests that we shall see the growth-emissions nexus in a broader context and account for country-level differences as well as other factors. Putting this together with the environmental ambitions of the UK government, it is important to see how the economic growth-emissions nexus prevails in the UK. In addition to economic growth, financial development is also considered to play a vital role in the dynamics of greenhouse gas emissions (Charfeddine and Ben Khediri, 2016; Bekhet et al., 2017; Nasir et al., 2019; Shahbaz et al., 2013a, b, 2016a, 2018a). Resource allocation by the financial sector has the potential to influence emission levels (Tamazian and Rao, 2010; Jalil and Feridun, 2011; Zhang, 2011; Shahbaz et al., 2013a, 2016). For instance, financial development can help firms in developed countries to adopt better technologies, which can enable them to realize economies of scale in the production process, creating lower pollution levels. The financial sector is of particular importance for the UK, which has one of the largest and well-developed financial sectors in the world. By its size, the UK is the 5th largest economy in the world, whereas its financial sector tops the list of the Global Financial Centre Index (Yeandle and Wardle, 2019). This raises the question of how financial development in the UK impacts the quality of the natural environment. Last but not least, innovation and technological improvements through research and development (R&D) expenditures are not only an important driver of economic growth (Freimane and Bāliņa, 2016; Minniti and Venturini, 2017) but also considered as another important determinant of carbon emissions for developed and developing countries (Churchill et al., 2019). For instance, it may be argued that developed countries, such as the UK, with their higher income levels, can expect greater technological progress resulting from higher investments on R&D. These expenditures may enable them to adopt energy-saving and carbon-reducing efficient technologies (Churchill et al., 2019). The adoption of efficient technologies may help the UK economy to reduce the usage of earth's natural resources and reduce environmental pollution (Dinda, 2004) through proper waste management and the internalization of pollution (Arora and Cason, 1996). Therefore, R&D expenditures are crucial to meet ecological challenges, such as biodiversity loss, frequent flooding, and temperature increases.

This study contributes to the literature in four aspects: (i) It empirically examines the effects of economic growth, financial development, R&D expenditures, and energy consumption on environmental quality in a carbon emissions modelling framework for the UK, covering the historical period from 1870–2017. (ii) The single unknown structural break unit root test is applied to decide on the order of integration of variables. (iii) The bootstrapped auto-regressive distributive lag model (BARDL) is applied to examine the long-run relationship between the variables. As robustness tests, we use ARDL bounds testing and Johansen and Juselius (1990) cointegration approaches. (iv) Both variance decomposition analysis and impulse response function as part of the innovative accounting approach are employed to gauge the direction of causality in the carbon emissions model. Our study also differs from some of the existing studies on the subject (e.g. Charfeddine and Ben Khediri, 2016; Bekhet et al., 2017; Nasir et al., 2019; Shahbaz et al., 2013a, b; 2016a, 2018a) by employing long-run historical data for modelling the carbon emissions function. The use of historical data is equally important for research scholars and policymakers, because it captures the lag effect of past information on environmental quality.[3] The empirical results confirm the presence of cointegration between carbon emissions and its determinants for the UK economy. Furthermore, financial development and energy consumption impede environmental quality by increasing carbon emissions, whereas R&D expenditures enhance environmental quality. The inverted U-shaped EKC hypothesis between carbon emissions and economic growth is validated for the UK. Inverted U-shaped relationships are also detected between carbon emissions and other determinants. These results help to draw interferences and policy recommendation on how the UK may achieve its commitment to net-zero emissions.

The remaining sections of the study include the following: Section 2 critically discusses the existing evidence on the subject. In Section 3,

---

[2] Prior to this legislation, the UK had a climate policy stringency that was comparable to other Western European countries. For instance, between 1995 and 2009, on average the UK had the 11th strictest climate regulation out of 28 OECD countries, placing after countries like Denmark, Sweden, and Germany, but ahead of Finland, France, and Greece (Althammer and Hille, 2016).

[3] Nonetheless, this study is not the first one examining the determinants of CO_2 emissions for the UK. The recent study by Churchill et al. (2019) used panel data for G7 countries and also highlighted the importance of considering long-run historical data. However, our study is different from Churchill et al. (2019). It used the bootstrapping ARDL bounds testing approach within a time series framework to examine both the short-run and long-run effects. Furthermore, we employed additional determinants of CO_2 emissions, i.e. financial development and energy consumption.

both the empirical approach and dataset are discussed. In Section 4, the empirical results are presented and discussed. Section 5 provides robustness tests. Section 6 concludes with policy implications.

2. Literature Review

2.1. Economic Growth & Carbon Emissions Nexus

Economic growth, that is often measured in the form of gross domestic product (GDP) and is a sign of economic development, has been one of the core economic policy objectives. Undoubtedly, economic progress is essential for countries to mitigate poverty and build up infrastructure in the long run. Yet, higher growth resulting from greater economic activities, requires a higher usage of energy. Greater use of non-renewable energy sources, such as coal, crude oil, and natural gas, rather than renewable energy in economic activities may result in environmental degradation through the increase of carbon emissions. In this context, the question is: at what cost of ecological or environmental health is higher economic growth desirable? This has become a matter of concern for policymakers, governments, and ecologists with ever-increasing globalization, rapid climate change, and global warming. Therefore, researchers have aimed to empirically understand the linkage between economic growth and carbon emissions.

Rooted in the EKC hypothesis, many studies have investigated the role of economic growth not only in the EKC modelling framework but also its wider consideration in the policymaking for climate change and sustainability. The studies based on the EKC hypothesis have produced inconclusive findings. For instance, inconclusive results are reported in the study by Apergis (2016) on a panel sample of 15 countries. Onafowora and Owoye's (2014) analysis, using time series data for 8 countries, i.e. China, Brazil, Japan, Egypt, Nigeria, Mexico, South Africa, and South Korea, also found mixed results. Inverted U-shaped EKCs were found in the case of South Korea and Japan, whereas N-shaped EKCs were reported for the remaining six countries. Such mixed findings may be associated with the differences in the development level as well as in the energy mix (renewable vs non-renewable) in each country. In another study on 43 developing economies, Narayan and Narayan (2010) reported that improved environmental quality is only found in the Middle Eastern and South Asian countries. A study by Shahbaz et al. (2015) using a time series framework for India, found a significant role of economic growth for environmental quality. In contrast, Shahbaz et al. (2018b) found that economic growth deteriorates environmental quality in Japan. Similarly, in a study on 27 developed economies, Al-Mulali and Ozturk (2016) found that environmental quality is improved with high levels of economic growth only in the long term, not in the short term. By using a comprehensive panel dataset for 26 OECD and 52 emerging economies, Özokcu and Özdemir (2017) found evidence of an N-shaped (inverted N-shaped) relationship between growth and environmental degradation for OECD (emerging) countries. As the EKC hypothesis was not supported, these findings led them to argue that economic growth alone may not be sufficient to enhance environmental quality. Drawing on Spanish data, Esteve and Tamarit (2012) revealed that the income elasticity between carbon emissions and income is less than one, which indicates a decreasing path in their relationship. Fosten et al. (2012) found that economic growth benefits the UK economy while improving environmental quality in the long run. Both Baek and Kim (2013) for Korea and Tiwari et al. (2013) for India supported the EKC hypothesis, while the studies of Song et al. (2013) on Chinese provinces, and Apergis et al. (2017) and Atasoy (2017) on the US economy revealed mixed results.[4] Ang (2007) found that growth is not beneficial for long-run environmental quality in France due to its harmful carbon effect on the atmosphere. Nasir et al. (2019) on ASEAN reported very weak evidence of the EKC hypothesis, whereas the study by Pham et al. (2020) on European economies and Shahbaz et al. (2020) on the US reported strong evidence of the EKC hypothesis, suggesting crucial differences among countries.

2.2. Financial Development & Carbon Emissions Nexus

The financial sector plays an essential role in economic growth and development (Nasir et al., 2015). Finance coming from financial and non-financial institutions enables countries to grow, eradicate poverty, and utilize limited financial resources (Redmond and Nasir, 2020). Similarly, energy financing is important for a country to engage in promoting environmental sustainability. The issue of climate change becomes difficult to handle by governments if energy financing is not utilized efficiently or not considered by the policymakers in the formulation of climate policy. Given the growth and ecological implications of financial development, most of the studies in the field of energy economics argue that increased growth due to financial depth and development is the key driver of rising energy consumption (Sadorsky, 2010, 2011; Islam et al., 2013; Shahbaz et al., 2013b, 2017). From a theoretical point of view, financial development has dual effects on the pollution level. On the one hand, the finance possessing wealth effect may degrade environmental quality (Frankel and Romer, 1999; Dasgupta et al., 2001; Sadorsky, 2010, 2011; Shahbaz et al., 2015). For instance, low cost of capital may motivate firms to produce more, which leads to rising energy consumption (Mahalik et al., 2017). The higher consumption of energy pollutes the atmosphere (Dasgupta et al., 2001; Sadorsky, 2011). Furthermore, less costly banking loans can increase CO_2 emissions by enabling consumers to excessively use energy (Sadorsky, 2010; Zhang, 2011; Mahalik et al., 2017). On the other hand, financing helps economies to improve environmental quality by using imported pollution abatement technology (Claessens and Feijen, 2007; Tamazian et al., 2009; Tamazian and Rao, 2010). That is, business enterprises with easier access to banking loans import green technologies and reduce CO_2 emissions by internalizing the negative externality (e.g. the pollution level). In so doing, the business enterprises not only protect the environment by implementing better pollution control mechanisms but also enable countries to build up green economies by advancing low-carbon business activities (Tamazian et al., 2009; Claessens and Feijen, 2007).

There are three strands of literature on the linkage between financial development and pollution. The *first* strand detected negative effects of financial development on the pollution level. For instance, Tamazian et al. (2009) found a beneficial effect of financial development on the environment in *BRICS* countries and Jalil and Feridun (2011) in China. In their studies, Shahbaz et al. (2013a, b, 2018a) found a pollution level dampening effect of financial development for the Malaysian, South African, and French economies. Abbasi and Riaz (2016) and Katircioğlu and Taşpinar (2017) detected similar effects for Pakistan and Turkey, respectively. Dogan and Seker (2016) using panel data for a sample of top countries listed in the renewable attractiveness index, found that financial development reduced the level of pollution discharged into the atmosphere. Moreover, Xiong and Qi (2018) using panel data on 30 Chinese provinces, found that development in the banking sector and the stock market is effective in curbing the pollution level. They further argued that the Chinese government should strengthen the green finance policy by developing inter-provincial coordination and interaction.

The *second* strand of the literature suggests a positive relationship between financial development and the pollution level. For instance, Shahbaz et al. (2016a, b) using the comprehensive financial index for Pakistan and Portugal, found that development in the banking sector matters more for environmental degradation. Subsequently, the studies by Javid and Sharif (2016) on Pakistan and Salahuddin et al. (2018) on Kuwait found that development in the financial system is harmful to the

---

[4] The study by Ghosh (2010) for India reports no causality while linking the relationship between growth and pollution.

natural environment. Nasir et al. (2019) further reported that development in the financial sector weighs on environmental quality in the ASEAN region. The *third* strand of literature draws an insignificant relationship between development in the financial sector and the pollution level. For instance, Ozturk and Acaravci (2013) on Turkey and Omri et al. (2015) on 12 MENA countries found an insignificant effect of financial development. In another study on 27 European countries, the neutral effect is noted between development in the financial sector and pollution by Coban and Topcu (2013).

2.3. Research & Development (R&D) Expenditures & Carbon Emissions Nexus

Schumpeter (1942) argued that ‘change in technology’ enters the production process in the forms of inventions and innovations. Research and development (R&D) expenditures are required to make the innovation process successful. Furthermore, the diffusion process is likely to happen when both invention and innovation are adopted by individuals, business firms, and governments. Subsequently, Romer (1990) in his endogenous growth theory argued that the role of technological change is also essential in the process of economic growth. Technological change as an endogenous variable enters in the production process to grow at a larger scale and helps the market to function smoothly. In this context, Weitzman (1997) argued that technological change also plays a vital role in curbing environmental pollution. Environmental quality improvement is possible if the producers use energy-efficient technology in the production process (Bruyn and Sander, 1997). Thus, while dealing with climate change and global warming, it is advisable for policymakers and governments to consider not only economic growth and financial development but also energy innovation in the production process to reduce energy usage pollution (Jordaan et al., 2017). One reason is that financial investments required in energy innovation have been increasingly important, because of their capacity in the reduction of carbon emissions. A low carbon economy supported by energy innovations may also enable a green and sustainable future (Anadon et al., 2011; Gallagher et al., 2012). Fernández et al. (2018) identified the role of energy innovation as a ‘pollution internalizing strategy’ in combating climate change, global warming, and promoting sustainable development in the long run.

Energy innovation not only decreases the usage of energy required for economic activity but also reduces the intensity of the pollution level (Garrone and Grilli, 2010; Ellabban et al., 2014). Governmental subsidies enable corporate firms to focus on energy innovation, which is beneficial for promoting sustainable quality of the natural environment (Ockwell et al., 2010; Chen and Xu, 2010). For instance, renewable energy consumption helps firms to increase their business activity without hampering the quality of the natural environment (Hall and Bain, 2008; Luo et al., 2015). By looking into environmental issues, many researchers have used technological innovations as one of the control variables in environmental degradation modelling with the usage of different econometric methods. For instance, Yeh et al. (2011) analysed the nexus between climate change and rates of technological change. Jones (2002) argued that R&D investments in energy innovation can lead to a reduction in carbon emissions. Moreover, the climate change challenge may be handled at lower costs, if energy-saving technology is utilized in economic activities (Newell and Pizer, 2008). Sohag et al. (2015) also indicated that technological innovations reduce energy consumption by improving energy efficiency, and thus help to reduce carbon emissions. Similarly, Smulders and De Nooij (2003) identified energy-saving technology as one of the effective instruments to lower the pollution level. In contrast, Parry (2003) argued that environmental quality gains from optimal pollution control are more important than the role of technology

Jordaan et al. (2017) focusing on the Canadian economy investigated the role of energy innovation as a pollution-reducing strategy. To achieve the international greenhouse gas emissions targets, they suggest that the government and industry need to advance clean energy through fiscal investments in energy innovation. Jin et al. (2017) explored the relationship between energy technology innovation and environmental quality in China and found that energy innovation reduces carbon emissions. On the policy side, they argued that the Chinese government should invest more in innovations in the energy industry to increase energy efficiency and reduce the burden on the usage of natural resources. Ganda (2019) using panel data on OECD countries reported that renewable energy consumption and spending on R&D contributes to a cleaner environment, whereas other R&D variables, such as triadic patent families and the number of researchers also positively influence it. In a study on G-6 countries that employed firm-level data, Alam et al. (2019) found that R&D investment helps firms to protect the quality of the natural environment. Their findings also supported the fundamental argument of the natural resource-based view, indicating that the employment of firm's resources and capabilities on environment-friendly activities enables a firm to achieve sustainable competitiveness by improving energy efficiency and reducing carbon intensities. In a contemporary study on 19 high-income OECD countries, Koçak and Ulucak (2019) found that fossil fuel energy R&D investment contributes to the pollution level, whereas renewable energy R&D investment does not have any effect. On the policy side, Álvarez-Herránz et al. (2017) argued that energy innovation should be given a priority in sustainable environmental policymaking.

3. Theoretical Construction, Methodology and Data

3.1. Theoretical Construction and Data

Numerous studies have investigated the EKC framework and reported inconclusive empirical results (Shahbaz and Sinha, 2019). Besides economic growth, factors influencing the pollution level include, among others, institutional quality and democracy (Tamazain and Rao, 2010; You et al., 2015), financial development (Nasir et al., 2019, Pham et al. 2020), trade measures such as trade openness and FDI (Hille and Shahbaz, 2019; Hille et al., 2019), urbanization (Pham et al., 2020), transportation (Nassani et al., 2017), general as well as energy innovations (Shahbaz et al., 2018a; Yang et al., 2014), and government environmental expenditures (Hille and Lambernd, 2020). Although existing studies also treated financial development as an important determinant in pollution modelling, ambiguous results are reported (Zaidi et al., 2019). In search of the potential determinant of environmental quality, Churchill et al. (2019) added the R&D intensity to the carbon emissions function and found an uncertain effect of R&D intensity on carbon emissions.[5] This further warrants for empirical investigation of the EKC hypothesis by considering development in the financial system, R&D expenditures, economic growth, and energy consumption as determinants of emissions, while employing time-series approaches on a country-specific dataset.

This study employs an EKC framework to empirically analyze the environmental consequences of economic growth, development in the financial system, and R&D expenditures for the UK. There are environmental health consequences of development in the financial system (Shahbaz et al., 2016a). The development in financial markets may affect the pollution level by not only reducing financial cost but also allocating financial resources to fund projects for purchasing clean and energy-efficient technology, which in result, may benefit economies in protecting the natural environment (Tamazian et al., 2009). The

---

[5] Churchill et al. (2019) used panel data on G7 economies while examining the linkage between R&D intensity and pollution level. Their empirical evidence is less helpful to policymakers while designing environmental policy to R&D expenditures as key tool to improve environmental quality especially at the country-level.

development in the financial system with strong institutional quality enables the government of an economy to direct local and foreign investors for using clean and energy-saving technology. This is a sign of stringent environmental regulation, which not only increases productivity in the production process but also adds to the sustainability of the natural environment. Furthermore, growth in the financial system stimulates business opportunities by providing cheaper loans for productive ventures that also stimulates economic activity and increases energy demand, which degrades the quality of the natural environment. The growth in the financial system via financial intermediation encourages the people to buy household items, such as motorbikes, cars, air-conditioners, refrigerators, and washing machines etc. This is another source of energy demand that increases carbon emissions via financial development (Sadorsky, 2010; Zhang, 2011). Last but not least, financial development also contributes to carbon emissions by assisting pubic companies in lessening financial and operational cost (risk), spreading financial linkages, and allocating financial resources to new and productive ventures that stimulate energy demand and hence, increase environmental degradation through rising CO_2 emissions.

Frankel and Romer (1999) cited that growth in the financial system encourages firms to increase R&D expenditures such that energy-efficient and environmental-friendly technologies are introduced. Similarly, endogenous growth theory also indicates the pivotal role of technological advancement, through which firm's investments in R&D not only bring efficiency in the production process but also enhance a better usage of natural resources. This reveals that growth in income is accompanied with the affordability of investments in R&D and a better adoption of efficient technologies, which, as a result, may improve environmental quality as well (Komen et al., 1997; Dinda, 2004). Moreover, Arora and Cason (1996) unveiled that investments in R&D improve environmental quality if the environmental management system is strong enough to ensure proper waste management. An increase in R&D expenditures stimulates economic activity, entailing increased domestic output, and hence trade that may increase carbon emissions via a scale effect. It is noted that the adoption of new technology has the potential to improve efficiency, incentivising firms to increase domestic output, which may require more usage of energy resources (or natural resources) and may harm environmental quality (Churchill et al., 2019). Moreover, energy consumption can be detrimental to the natural environment when the massive use of energy resources pollutes the environment by discharging emissions into the atmosphere (Shahbaz et al., 2015). On the other hand, energy consumption can contribute to the betterment of the natural environment if clean energy is used extensively in economic activities.

Based on the theoretical and empirical discussions, we model the general carbon emissions function, considering economic growth, financial development, energy consumption, and R&D expenditures as determinants of environmental quality using historical data for the UK economy spanning well over 147 years from 1870 to 2017. The general form of the extended pollution function is modelled as follows:

$$C_t = f\,(Y_t,\ Y_t^2,\ R_t,\ F_t,\ E_t) \tag{1}$$

The logarithmic transformation is performed on all variables by taking the natural-log. Moreover, we converted the data into per capita units. The empirical equation of the extended carbon emissions function can be specified as:

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln Y_t^2 + \beta_3 \ln R_t + \beta_4 \ln F_t + \beta_5 \ln E_t + \mu_i \tag{2}$$

where, ln C_t, Y_t, Y_t^2, R_t, F_t, E_t and μ_i are natural log of carbon emissions, real GDP, squared of real GDP, R&D expenditures, broad money as a proxy for financial development, energy consumption, and the residual term with the assumption of normality. The relationship between economic growth and the pollution level has an inverted U-shape in case $\beta_1 > 0$ and $\beta_2 < 0$. R&D expenditures are environmentally friendly if $\beta_3 < 0$, otherwise it will increase carbon emissions. Financial development improves environmental quality if $\beta_4 < 0$. We further extend the carbon emissions function by considering square terms of financial development and R&D expenditures to examine whether the relationships between development in the financial system, R&D expenditures, and the pollution level is inverted U-shaped or not. It may be noted that the pollution level is positively associated with development in the financial system, and beyond a threshold level, it is also negatively linked with development in the financial system. This reflects the improved quality of the natural environment due to a better financial system in long run. When the countries wish to grow, they need to use services of financial institutions but at the cost of environmental health in short run. When the countries further wish to grow, they need to take care of environmental health in the long run with increased finance. The increased finance makes it possible to have better environmental health by helping economies to use more imported energy-saving technology in production.

We further extend the carbon emissions function by considering squared terms of financial development and R&D expenditures to examine whether the relationship between these variables and carbon emissions follows an inverted U-shape. It is argued that carbon emissions are accompanied by financial development and after reaching a threshold level of financial development, further development improves environmental quality and lowers carbon emissions. This implies that initially, the focus of the financial sector remains on the allocation of resources to investment projects to boost economic activity (the scale effect), which increases energy demand and hence environmental degradation. After reaching the threshold level of income per capita, the financial sector starts distributing resources to firms who adopt energy-efficient technology (the technique effect) for domestic production following environmental regulations implemented by the government (on public demand). This in result raises energy efficiency, which improves environmental quality by reducing carbon emissions. Similarly, with regard to R&D expenditures, it is crucial to account for the non-linearity in its association with carbon emissions. Intuitively, we postulate that R&D expenditures involve economic activity, which increase carbon emissions initially. This implies that in the short run, there would be a positive impact of R&D expenditures on carbon emissions. However, long terms net gains are expected, as R&D investments stimulate the development of innovation and sustainable solutions for increasing domestic production. Concomitantly, we would expect that in the long run, there is a negative impact of R&D expenditures on carbon emissions leading to an improvement of environmental quality. Therefore, we expect a quadratic relationship between R&D expenditures and carbon emissions that is inverted U-shaped. Thus, the carbon emissions function is extended by including squared terms of financial development (F_t) and R&D expenditures (R_t) in equation-2, and equation-3 is modelled as follows:

$$\ln C_t = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln Y_t^2 + \alpha_3 \ln F_t + \alpha_4 \ln F_t^2 + \alpha_5 \ln R_t + \alpha_6 \ln R_t^2 + \alpha_7 \ln E_t + \mu_i \tag{3}$$

Association between emissions and financial development is supposed to be inverted U-shape if $\alpha_3 > 0$ and $\alpha_4 < 0$, and U-shaped if $\alpha_3 < 0$ and $\alpha_4 > 0$. Similarly, $\alpha_5 > 0, \alpha_6 < 0$ would imply an inverted U-shaped relationship between emissions and R&D, and $\alpha_5 < 0$ and $\alpha_6 > 0$ would confirm the presence of a U-shaped association.

This study drew on a very long historical data set on the United Kingdom, spanning over 147 years from 1870–2017. The data on R&D expenditures are obtained from Madsen and Ang (2016). The GDP data is collected from Maddison (2007). The data on emissions is collected from the Carbon Dioxide Information and Analysis Center (CDIAC) database (Marland et al. 2006). For energy consumption, the data is obtained from Paul (2007). Broad money (M2) is used as a measure of financial development and data is collected from the Global Financial Data database. All the data series are converted into per capita units using population data obtained from Maddison (2007).[6]

3.2. Bootstrapping-ARDL Approach

For the analysis of cointegration, this study draws on the seminal work by McNown et al. (2018) and employs a bootstrapping ARDL cointegration framework. The novelty of this framework is that it accounts for the limitations, such as weak size and power properties, which the traditional ARDL approach suggested by Pesaran et al. (1996, 2001) ignores. Furthermore, capitalizing on the traditional ARDL bounds testing framework, the bootstrapping ADRL incorporates advanced testing of the F-test to the increased power. Specifically, we go a lot further than the conventional ARDL bounds testing approach (Pesaran et al., 2001) and in so doing, we employ three tests to determine cointegration between the variables. In a traditional ARDL, conditions of statistical significance of the error correction term and lagged variables help to conclude on the presence or absence of cointegration (Pesaran et al., 2001). In case the lagged dependent variable is statistically significant in the error correction term, we conclude that the first condition holds. If the lagged explanatory variables are shown to be significant, it suggests that the second condition holds. The critical (upper and lower) bounds testing devised by Pesaran et al. (2001) is only applicable in the second case. Under the first case condition where we have a statistically significant error correction term coefficient, we can proceed with the estimation of the order of integration $I(1)$ of both the response and the explanatory variables. However, an important factor at this juncture is that the conventional approach to unit root testing might not be the appropriate methods of testing for the order of integration, as they have low power and explanatory properties (Goh et al. 2017). The bootstrapping ARDL framework proposed by McNown et al. (2018), can address this issue as their Monte Carlo simulations of the test statistics show that the critical values through bootstrapping yield greater power and size properties. The benefit of this approach is that it is particularly effective even when we have a small sample size and dynamic time-series models. Nonetheless, the order of integration of variables does not cast doubts on the applicability of the approach (Goh et al., 2017). Concomitantly, with these advantages, the bootstrapping ARDL approach can easily address several issues, which may arise in the traditional ADRL bound testing framework, such as the problem of inconclusive cases (area) in the results (McNown et al. 2018)[7]. To reiterate, the conventional ARDL approach focuses on the bounds based on the data generating process where the order of integration of the underlying series is either I(0) or I(1). This led Narayan (2005) to argue that critical bounds, which were put forward by Pesaran et al. (2001), can lead to inconclusive results and are suitable only for long-span data samples. However, the bootstrapping approach eliminates the likelihood of indecisiveness, which may happen in the traditional approach to cointegration. Another novel feature of the bootstrapping ARDL bounds testing approach is its effectiveness for dynamic models with multiple independent variables. It may appear an unimportant issue but is crucial to account for as the strict exogeneity of explanatory variables is required for the critical values bounds proposed by Pesaran et al. (2001). However, in reality, the relationship among macroeconomic time series does not often support the assumption of strict exogeneity. The traditional, as well as bootstrapping, can be expressed in mathematical terms. Let's consider an ADRL with three variables (p, q, r). Following Goh et al. (2017), it can be specified as:

$$y_t = \sum_{i=1}^{p} \alpha'_i y_{t-1} + \sum_{j=0}^{q} \beta'_j x_{t-1} + \sum_{k=0}^{r} \gamma'_k z_{t-k} + \sum_{l=0}^{s} \tau'_{t,l} D_{t,l} + \mu_t \tag{4}$$

whereas in equation-3, l, k, j and i are lag order ($l = 0, 1, 2, \ldots s$; $k = 0, 1, 2, \ldots r$; $j = 0, 1, 2, \ldots, q$; and $i = 1, 2 \ldots p$; t denotes time, y_t is the dependent, x_t and z_t are independent, and $D_{t,\ l}$ represents a dummy variable with τ as its coefficient. The $\beta's$ and $\gamma's$ are the coefficients of the lagged independent variables. Lastly, μ_t represents the error-term with the finite variance and zero means. Equation-4 can be specified in an error correction form as follows:

$$\Delta y_t = \varphi y_{t-1} + \gamma x_{t-1} + \psi z_{t-1} + \sum_{i=1}^{p-1} \lambda'_i \Delta y_{t-1} + \sum_{j=1}^{q-1} \delta'_j \Delta x_{t-1} + \sum_{k=1}^{r-1} \pi'_k \Delta z_{t-k} + \sum_{l=1}^{s-1} \omega'_l \Delta D_{t,l} + \varepsilon_t \tag{5}$$

whereas $\varphi = \sum_{i=1}^{p} \alpha_i$, $\gamma = \sum_{j=0}^{q} \beta_j$, and $\psi = \sum_{k=0}^{r} \gamma_k$in equation-4. The related functions in equation-3 are captured by λ_i, δ_J, π_k and ω_l. By transforming the vector auto-regression (at levels) specified in the error correction form, we can derive equation-5 from equation-4 along with a constant term $(\tilde{c})$. Equation-5 can be estimated and then the conditional model can be specified as:

$$\Delta y_t = \tilde{c} + \tilde{\varphi} y_{t-1} + \tilde{\gamma} x_{t-1} + \tilde{\psi} z_{t-1} + \sum_{i=1}^{p-1} \lambda'_i \Delta y_{t-1} + \sum_{j=1}^{q-1} \lambda'_j \Delta x_{t-1} + \sum_{k=1}^{r-1} \lambda'_k \Delta z_{t-1} + \sum_{l=1}^{s} \tilde{\omega}'_l D_{t,l} + \varepsilon_t \tag{6}$$

It will require us to unanimously reject all three null hypotheses to conclude on the presence of cointegration among y_t, x_t and z_t. These can be stated as:

i) The F_1 test is employed based on associated error-correction terms where the null hypothesis is H_0: $\phi = \gamma = \psi = 0$ against the alternative H_1: any of ϕ, γ, ψ are different from 0.
ii) Based on the explanatory variables, the F_2 test is employed, where the null hypothesis is H_0: $\gamma = \psi = 0$ against the alternative H_1: either γ or ψ is different from 0.
iii) The t-test is constructed on the lagged values of the response variable where the null hypothesis is H_0: $\phi = 0$ against the alternative H_1: ϕ is different from 0.

The approach proposed by Pesaran et al (2001) has often been used to generate the critical values for the F_1 and t-tests, however, it does not account for the test statistic for the F_2 test on the lagged explanatory variables. This limitation is addressed by a more recent study by McNown et al. (2018), which by employing the bootstrapping approach provides critical values for all three sets of tests. Considering these benefits, we follow the approach and use the critical values of McNown et al. (2018) that provides us with robust empirical estimates.

4. Analysis Findings

4.1. Correlation Analysis

The descriptive statistics reported in Table A1 (in Appendix) suggest the presence of high volatility in R&D expenditures compared to economic growth. Energy consumption is less volatile compared to carbon emissions. Volatility in economic growth is higher than volatility stems in financial development. The normality test based on Jarque-Bera stats shows that the underlying variables are normally distributed. The correlation analysis shows the existence of a positive correlation of growth, financial development and energy consumption with emissions. However, R&D expenditures show a negative correlation with carbon emissions. All other variables show a positive correlation with each other, except the R&D expenditures and energy consumption which are found to be negatively correlated.

---

[6] We have updated the data for all variables using the World Development Indicators (CD-ROM 2019) for the years 1870-2017.

[7] The traditional ARDL approach to cointegration is applicable if we have a mixed order of integration among variables.

4.2. Unit Root Analysis

The ADF unit root test is applied to examine the stationarity properties in the underlying dataset containing intercept and trend. The results presented in Table A2 suggest that all the variables were found to have unit root at the level, however at the first difference they were found to be stationary. In other words, our variables are integrated of order I (1). Considering that the traditional ADF (Dickey and Fuller, 1979) unit root test does not account for the structural breaks in the data series, we compliment the unit root testing with the approach proposed by Kim and Perron (2009). The results in Table A2 show the presence of a structural break in the series which were non-stationary at level with intercept and trend. The breaks are 2008, 1916, 1985, 1918 and 1887 in the series of carbon emissions, economic growth, financial development, energy consumption and, R&D expenditures. These correspond to major events, such as the Global Financial Crisis of 2008–09 which led to a significant reduction in carbon emissions due to sharp decrease in economic activity. Similarly, the year of 1916 corresponds to the severity of WWI and its implications for the economy and per capita income. The break in financial development as measured by the monetary aggregates in 1985 reflects the impact of the suspension of the policy of targeting broad money in 1985[8]. The break in energy consumption around 1918 corresponds to the end of WWI which led to sudden changes in energy usage. We found that carbon emissions, economic growth, financial development, energy consumption and R&D expenditures are stationary at first difference containing information of single unknown structural break in each series. This confirms that all the variables are stationary at first difference i.e. I (1).

4.3. ARDL Bounds Testing Analysis

The unique integration among underlying variables implies that we can proceed with the application of the bounds testing approach and finding long-run association among variables. We can only apply the cointegration test if we have variables integrated of I (0), I (1) or I (0) / I (1). To start with, we also need an information criterion for appropriate lag length selection. The ARDL-F statistic is also affected by the number of lags. The Akaike Information Criteria (AIC) is used to decide on the optimal lag length and the results are presented in Table A3 (second column 2) and with the ARDL F-stats. It shows that as the ARDL F-Stats are greater than upper critical bounds, hence the null of no cointegration has been rejected while carbon emissions, financial development, energy consumption and, R&D expenditures are treated as dependent variables. We accept the null hypothesis of no cointegration as ARDL F-statistic is less than lower critical bound when we used economic growth as the dependent variable. Overall results show the existence of four cointegrating vectors. We may conclude that the emissions of CO_2, growth of the economy, financial development, energy consumption and, R&D expenditures have cointegration in the case of the UK from 1870 to 2017.

4.4. Bootstrap ARDL Cointegration Analysis

The bootstrapping ARDL bounds testing approach to cointegration is applied and the results are presented in Table A4. We noticed the rejection of the null hypothesis of no cointegration while treating carbon emissions as dependent and all other variables as explanatory variables. The alternative hypothesis was also accepted in the light of t-test on lagged explanatory variables. At the 1% and 5% levels of statistical significance, all three testes indicate four cointegrating vectors.

The evidence of cointegration in carbon emissions function was further strengthened by the existence of four cointegrating vectors. It implies that there is a long-run association between growth, financial development, energy consumption, R&D expenditures, and carbon emissions in the UK between 1870 and 2017. This confirms the established cointegration by ARDL bounds testing approach between carbon emissions and its determinants for the UK. Diagnostic testing results reported in the 9th column of Table A4, suggest that there is no issue of serial correlation. The Jarque-Bera test statistics show the normal distribution of all the variables, whereas the difference between $Q - stat$ is the studentized range distribution statistic which fails to reject the null hypothesis confirming the normal distribution of data and residual(s).

4.5. Long & Short-Run Analysis

The results of the long-run analysis of carbon emissions function reported in Table 1 suggest that there is a positive impact of GDP growth per capita in linear terms whereas the squared terms suggest negative impact at 1% level of statistical significance. Specifically, a 1% increase in real GDP per capita is supposed to increases the emissions of carbon by about 6.1789% (4.9426%). The negative coefficient for real GDP squared term shows its decarbonising effects at a higher income level in the United Kingdom. It also confirmed the EKC for the British economy, as the relationship between income (real GDP per capita) and emissions is found to be an inverted U-shaped. In the light of the EKC hypothesis, it implies that in the beginning, the growth of income (GDP) per capita will lead to increased emissions, however after reaching a threshold, further growth will lead to a reduction in carbon emissions. In a policy context, this would employ that the growth policies in Britain should be cautious of environmental consequences which are evident in the British signing up to the Paris-Agreement, legally binding herself with zero-emissions by 2050 and most recently emphasis on other countries to raise climate ambitions in G-20 summit on June 2019 in Osaka, Japan. These findings are in line with Sephton and Mann (2016) and Shahbaz et al. (2017) as they also found that between economic growth and carbon emissions there is an inverted-U association in the UK, contrary to Balcilar et al. (2018) who argued that EKC hypothesis is not valid in the UK. Intuitively, increasing consumption of energy, significantly adds to emissions. Specifically, a 1% increase leads to increasing emissions by about 0.4534-1.9525%. Financial development also shows a positive relationship with carbon emissions, which is statistically significant as well at 1% level. It implies that financial development is not environment-friendly i.e. financial activity leads to increased emissions, impeding environment. This would suggest that the policy of curbing net emissions to zero needs to focus on financial development and its environmental consequences. Keeping other things constant, carbon emissions are expected to increase by 0.0428% as a result of 1% increase in financial development. This finding is similar to the study by Zhang (2011) on China and Sehrawat et al. (2015) on India as both of these studies reported a positive impact of financial development on carbon emissions.

By contrast, the results are different to the findings of Tamazian et al. (2009) on BRIC countries, Jalil and Feridun (2011) and Zaidi et al. (2019) on China, Shahbaz et al. (2013a) on Malaysia, Álvarez-Herránz et al. (2017) on OECD countries and Shahbaz et al. (2018a) on the French economy, who reported that financial development lowers emissions and improves the environmental quality. The results on the impact of R&D expenditures were more promising as it shows a negative impact on emissions. Specifically, ceteris paribus, a 1% increase in the expenditure on R&D was to have a -0.0454% impact on emissions. The negative impact of R&D on emission is in line with the existing evidence, for instance, the studies by Tamazian et al. (2009) on BRIC countries, Lee and Min (2015) on Japan, Xiong and Qi (2018) on China, Álvarez-Herránz et al. (2017) on OECD countries, Balsalobre-Lorente et al. (2018) on EU-5 countries, Cho and Sohn (2018) and Shahbaz et al. (2018a) on the French economy, and Fernández et al. (2018) on the United States that also

---

[8] Then the Chancellor of Exchequer Nigel Lawson suspended targeting broad money in 1985 giving the reason that the monetary aggregates were being distorted by financial liberalisation.

Table 1
Long-Run Analysis

	Coeff.	T-Stat.	Coeff.	T-Stat.
Constant	-21.9627	-12.206	-15.3684*	-7.3762
$\ln Y_t$	6.1789*	17.7008	4.9426*	8.1725
$\ln Y_t^2$	-0.3289*	-18.114	-0.2818*	-8.3648
$\ln E_t$	0.4534***	1.8023	1.9525*	5.9478
$\ln F_t$	0.0428***	1.7397	-1.3815*	-3.8725
$\ln F_t^2$	....	....	0.1868*	4.1678
$\ln R_t$	-0.0545*	-3.4083	0.4079*	2.7505
$\ln R_t^2$	....	....	-0.0721*	-3.4294
D_{2008}	-0.1990*	-6.2538	-0.3191*	-12.3424
R^2	0.7780		0.9239	
$Adj - R^2$	0.7684		0.9195	
Durbin-Watson	1.8863		1.5793	
Stability Analysis				
	F-stat.	Sig.	F-stat.	Sig.
χ^2_{NORMAL}	0.4052	0.2314	0.4512	0.2204
χ^2_{SERIAL}	0.1854	0.8765	0.2052	0.8675
χ^2_{ARCH}	0.4885	0.2409	0.4808	0.2429
χ^2_{Hetero}	0.1951	0.8705	0.3053	0.8665
χ^2_{RESET}	1.0987	0.1234	1.9080	0.1114
CUSUM	Stable		Stable	
CUSUMsq	Stable		Stable	

Note: *, **, and *** show significance at 1%, 5%% and 10% levels, respectively.

showed that R&D expenditures lower carbon emissions and resultantly, the environmental quality is improved. Surprisingly, Koçak and Ulucak (2019) reported that emissions are positively affected by the R&D expenditures in the OECD countries. On the contrary, Churchill et al. (2019) noted that the intensity of R&D has an uncertain impact on carbon emissions. In specific to the UK, the role of R&D in meeting climate challenges and policy objectives is benign. However, as advised by the Committee on Climate Change (CCC), Britain must invest more in low-carbon innovations to hit the 2050 net-zero emissions target. Our empirical findings provide support to this notion. The dummy variable also improves environmental quality by lowering carbon emissions. This relates to the financial crisis i.e. 2007–08 and UK manufacturing industry increased her efficiency and economy shifted from heavy industry towards more advanced industry and services which reduced energy usage in the industrial sector. Similarly, the UK Department for Business, Energy and Industrial Strategy (2018) reported that the financial crisis is one of the factors that pushed business and industrial sectors towards energy efficiency and switching economy to lower carbon fuels, which reduced carbon emissions. The changes in the quantity of aggregate demand due to the financial crisis as well as its composition are prima facie evident in the negative impact of the crisis on carbon emissions. Conceivably, there is a positive side to it and should be seen in conjunction with the increasing importance and awareness of climate change.

In order to account for the non-linear effects of financial

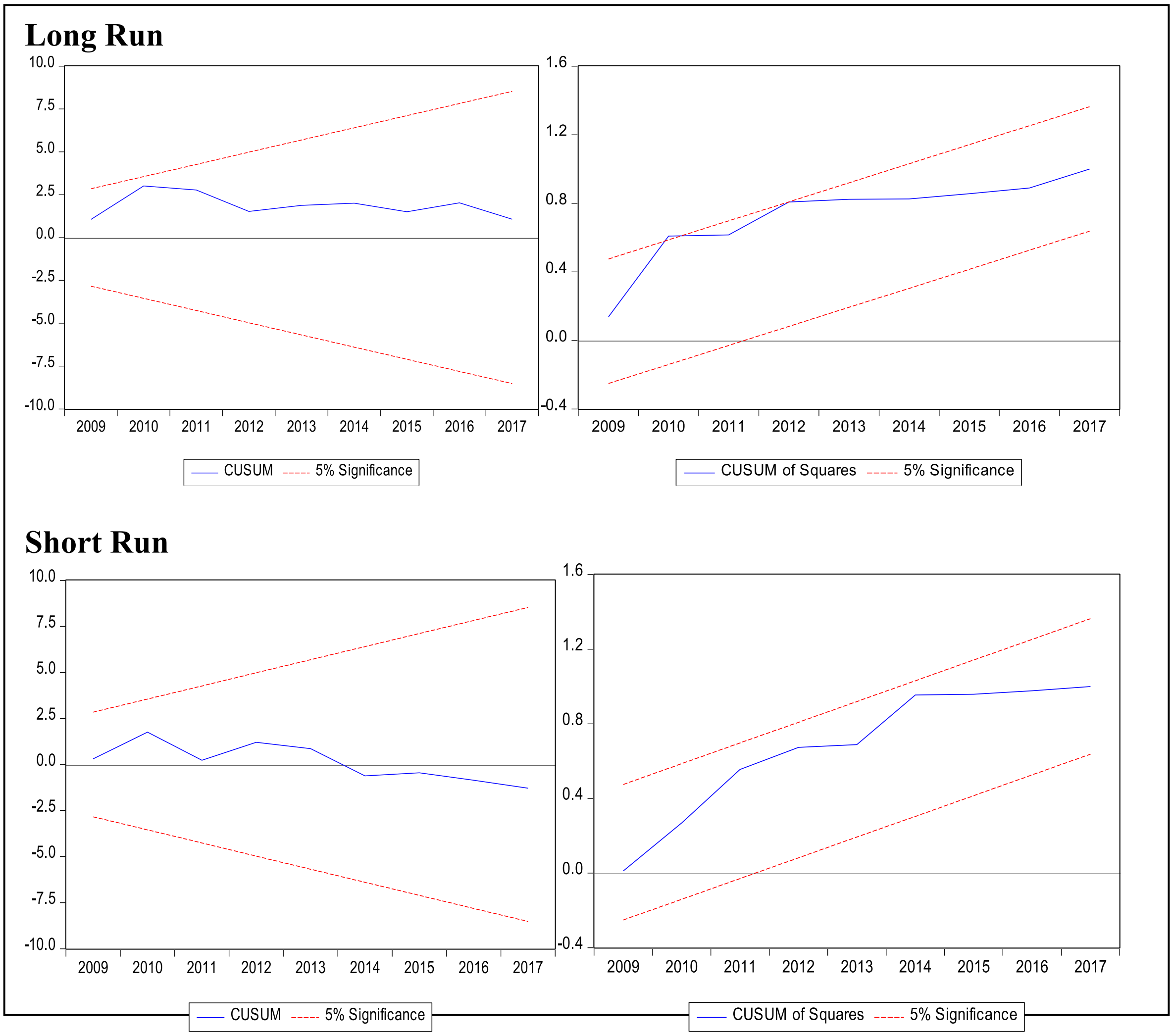

Fig. 1. CUSUM and CUSUMsq

development as well as R&D, their squared terms have been included in carbon emissions function. The empirical results presented in Table 1 show that the linear term of financial development has positive while the quadratic term has a negative impact on carbon emissions. This suggests that the relationship between financial development and emissions is also U-shaped. The result is in line with the study by Shahbaz et al. (2013a) on Malaysia but it is insignificant statistically. On contrary, in a study on France, Shahbaz et al. (2018a) reported that between financial development and carbon emissions there is inverted U-shaped relationship which made them argue that financial development initially increases emission, but after a threshold, it contributes to reducing CO_2 emissions. In policy setting this finding has profound implications for the UK as it implies that the increasing financialization would hamper the environment through increased CO_2 emissions. Hence, the financial policy should be focused on the allocation of finance to more efficient and environmentfriendly sectors of the economy. Green monetary and financial policies are very much required.

The results on R&D expenditure show that the linear term has a positive while the squared term has a negative impact on the emissions suggesting inverted U-shaped relationship between R&D expenditure and carbon emissions at 1% level of statistical significance. We may conclude that the EKC hypothesis is validated between R&D expenditures and carbon emissions. Empirical results are in line with Mensah et al. (2018) for OECD countries who reported the validation of R&D EKC in OECD countries. In specific to the UK it implies that R&D investment in innovation can help to cut emission to the net-zero target in the long term. Furthermore, the results do not show the autocorrelation between carbon emissions and the error term, whereas they reveal that the errors follow a normal distribution. Empirical results also indicate no issue of autocorrelation, white heteroscedasticity and auto-conditional heteroscedasticity. In terms of specification, the Ramsey RESET test confirmed the correctness of specification. Finally, model stability at 5% level of significance is confirmed by the CUSUM and the CUSUMsq tests (see Figure 1).

The results of the short-run analysis reported in Table 2 show that the relationship between economic growth and emissions is inverted U-shaped, validating the EKC. Carbon emissions are positively associated with energy consumption, which also turned out to be the dominant factor to impede environment by increasing emissions. The relationship between financial development and emissions is also positive and significant at 5% level, suggesting that financial sector development is not environment-friendly. The expenditures on R&D also show positive while dummy variable show negative and statistically significant (10% level) impact on emissions in the short run. In the case of financial development, both linear and squared terms showed a positive impact, though results were only significant for the former. However, both linear and squared terms of R&D expenditures show a positive but statistically insignificant impact on emissions. It shows that in the short run, we do not have a U-shaped or inverted U-shaped association between R&D expenditures and financial development and emissions.

Table 2
Short Run Analysis

	Coef.	T-Stat.	Coef.	T-Stat.
Constant	-0.0030	-0.9088	-0.0035	-1.0499
$\Delta\ln Y_t$	3.5741***	1.9256	3.9343*	2.9299
$\Delta\ln Y_t^2$	-0.1996***	-1.9646	-0.2174*	-2.9502
$\Delta\ln E_t$	2.6062*	7.9433	2.5640*	22.8381
$\Delta\ln F_t$	0.0860**	2.0634	0.0993*	2.9172
$\Delta\ln F_t^2$	....	....	0.0403	0.4262
$\Delta\ln R_t$	0.0403***	1.6937	0.0236	0.7267
$\Delta\ln R_t^2$	....	....	0.0569	0.5839
D_{2008}	-0.0374*	-2.9422	-0.0411*	-4.1954
ECM_{t-1}	-0.3820*	-4.0580	-0.5605*	-7.7816
R^2	0.8748		0.8913	
$Adj-R^2$	0.8685		0.8873	
Durbin-Watson	2.1421		2.0725	
Stability Analysis				
	F-statistic	P. value	F-statistic	P. value
χ^2_{NORMAL}	0.2207	0.2020	0.2007	0.1970
χ^2_{SERIAL}	0.8287	0.4338	0.8080	0.4408
χ^2_{ARCH}	2.1515	0.1123	2.1010	0.1129
χ^2_{ARCH}	0.1045	0.9817	1.1141	0.8107
χ^2_{RESET}	1.3596	0.1762	1.3060	0.1802

Note: CUSUM and CUSUMsq suggested parameter stability.

The error correction term ECM_{t-1}shows a negative coefficient (-0.3820) which is also statically significant at 1% level indicating the validity of long-run relationship as well the speed of adjustment. The coefficients of ECM_{t-1} are -0.3820 and-0.5605 for linear and nonlinear models, indicating that the correction from short-run disequilibrium to a long-run equilibrium is about 38.20% and 56.05% respectively. The overall value of R^2 i.e. 0.8748 shows that the dynamics of carbon emissions are explained by the underlying explanatory variables to the extent of 87.48% out of 100% and the remaining variance of the dependent variable is done by the residual term. There was no issue of serial correlation, white heteroscedasticity and auto-conditional heteroscedasticity in the estimation of carbon emissions function. The Ramsey RESET test suggested that the model was well specified. The model stability at 5% level of significance is also validated by CUSUM and CUSUMsq tests in short-run and long-run estimated (see Figure 1).

4.6. *Results of the Variance Decomposition Analysis and Impulse Response Functions*

The VECM Granger causality is one of the most widely used approaches to examine the direction of a causal relationship, but this approach does not provide the sign of relation, i.e. whether there is a negative or positive relationship. In this context, Shan (2005) proposed an innovative accounting approach (IAA) which report the sign of the causal relationship between the variables. To account for the magnitude of the causal impact of innovation from the explanatory variables, this approach entails impulse response functions and variance decomposition and can go beyond the time horizon of response variables data series (see Pesaran and Shin (1999), Engle and Granger (1987), and Ibrahim (2005) for discussion on generalized forecast error variance decomposition and vector auto-regression (VAR) system). The results of variance decomposition analysis presented in Table 3 suggest that the emissions are significantly affected i.e. 75.97% by their own innovations. Among other factors, growth of the economy (5.20%), the financial sector (9.48%), energy consumption (71.3%) and R&D expenditures (2.18%) also play their role. R&D expenditures contribute to economic growth by 22.33%. The contribution by innovative shocks stemming in carbon emissions, financial development and energy consumption is minimal. A 73.58% of economic growth is contributed by its own innovations in carbon emissions contribute to financial development by 18.66%. A 9.87%, 2.13% and 0.61% is contributed to financial development by economic growth, energy consumption and R&D expenditures. There is about 68.70% variance contributed by its own innovation in financial development.

There is some contribution of economic growth and financial development to the consumption of energy i.e. 8.89% and 5.35% respectively. The contribution of emissions to energy consumption is about 39.14%. R&D expenditures contribute to energy consumption by 4.27%. A 42.33% of contribution to energy consumption is by innovative shocks stem in energy consumption. The innovations in emissions contribute to R&D expenditures by about 3.33%, whereas the contribution by financial development and energy consumption to R&D expenditures is about 14.34% and 15.42%. The contribution of economic growth to R&D expenditures is minimal i.e. 2.93%. A 63.96% is contributed to R&D expenditures by its own innovative shocks. Overall,

Table 3
Variance Decomposition (VDC) Analysis

VDC $\ln C_t$ Period	$\ln C_t$	$\ln Y_t$	$\ln F_t$	$\ln E_t$	$\ln R_t$
1	100.0000	0.0000	0.0000	0.0000	0.0000
2	95.7645	1.5313	0.0001	0.1224	2.5814
3	94.5986	2.3302	0.1608	0.1449	2.7653
4	93.6059	2.6688	0.5840	0.2517	2.8894
5	92.8157	2.6080	1.2630	0.5275	2.7855
6	91.8202	2.4889	2.0987	0.9262	2.6658
7	90.5233	2.4619	3.0105	1.4460	2.5581
8	88.9473	2.5784	3.9418	2.0544	2.4777
9	87.1664	2.8247	4.8592	2.7291	2.4205
10	85.2678	3.1637	5.7446	3.4458	2.3779
11	83.3256	3.5574	6.5887	4.1858	2.3423
12	81.3952	3.9755	7.3867	4.9344	2.3079
13	79.5134	4.3975	8.1365	5.6808	2.2715
14	77.7021	4.8111	8.8374	6.4176	2.2316
15	75.9727	5.2098	9.4897	7.1399	2.1877
VDC $\ln Y_t$					
	$\ln C_t$	$\ln Y_t$	$\ln F_t$	$\ln E_t$	$\ln R_t$
1	14.724	85.2753	0.0000	0.0000	0.0000
2	8.3712	91.3994	0.0317	0.1349	0.0626
3	7.0209	92.6236	0.0620	0.2263	0.0669
4	6.2338	93.0802	0.0652	0.3062	0.3144
5	5.7509	92.8571	0.0582	0.3479	0.9857
6	5.3492	92.1021	0.0517	0.3590	2.1377
7	4.9953	90.8484	0.0472	0.3485	3.7604
8	4.6781	89.1794	0.0441	0.3284	5.7698
9	4.3986	87.1960	0.0444	0.3084	8.0524
10	4.1549	85.0058	0.0541	0.2947	10.4902
11	3.9419	82.7044	0.0806	0.2901	12.9828
12	3.7528	80.3670	0.1302	0.2952	15.4545
13	3.5813	78.0472	0.2070	0.3092	17.8550
14	3.4224	75.7790	0.3125	0.3312	20.1545
15	3.2732	73.5817	0.4461	0.3603	22.3384
VDCln F_t					
	$\ln C_t$	$\ln Y_t$	$\ln F_t$	$\ln E_t$	$\ln R_t$
1	5.4696	2.3627	92.1676	0.0000	0.0000
2	5.4825	1.7967	91.6808	0.6828	0.3569
3	7.7609	1.2939	89.0298	1.3596	0.5556
4	10.1273	0.9604	86.3235	1.9649	0.6237
5	12.4001	0.8830	83.7351	2.3874	0.5943
6	14.2889	1.1322	81.4176	2.6271	0.5339
7	15.7431	1.7154	79.3459	2.7107	0.4846
8	16.7836	2.5779	77.4887	2.6851	0.4644
9	17.4875	3.6297	75.8135	2.5964	0.4727
10	17.9417	4.7750	74.3015	2.4822	0.4994
11	18.2258	5.9332	72.9391	2.3685	0.5330
12	18.4024	7.0474	71.7141	2.2711	0.5647
13	18.5165	8.0842	70.6120	2.1979	0.5891
14	18.5986	9.0284	69.6162	2.1522	0.6043
15	18.6678	9.8777	68.7095	2.1343	0.6105
VDC $\ln E_t$					
	$\ln C_t$	$\ln Y_t$	$\ln F_t$	$\ln E_t$	$\ln R_t$
1	77.5497	0.5351	1.3637	20.5512	0.0000
2	61.7152	5.7454	2.0280	26.5448	3.9663
3	55.3572	8.6381	2.8727	28.7774	4.3544
4	50.6951	10.1110	3.6143	31.0922	4.4871
5	47.9399	10.4718	4.2012	33.0762	4.3106
6	45.9827	10.3625	4.6254	34.9171	4.1121
7	44.5276	10.0942	4.9189	36.5011	3.9579
8	43.3593	9.8245	5.1154	37.8265	3.8741
9	42.3923	9.6037	5.2435	38.9041	3.8563
10	41.5815	9.4337	5.3236	39.7732	3.8876
11	40.9021	9.3000	5.3698	40.4777	3.9502
12	40.3350	9.1869	5.3910	41.0581	4.0288
13	39.8628	9.0839	5.3932	41.5470	4.1128
14	39.4696	8.9856	5.3807	41.9681	4.1957
15	39.1409	8.8905	5.3569	42.3377	4.2739
VDC of $\ln R_t$					
	$\ln C_t$	$\ln Y_t$	$\ln F_t$	$\ln E_t$	$\ln R_t$
1	0.420	3.3084	0.0283	2.3916	93.8512
2	0.2040	5.8388	0.0916	6.8716	86.9938
3	0.2903	6.5823	0.5374	8.7221	83.8676
4	0.2716	6.2375	1.4066	10.2778	81.8063
5	0.2265	5.4893	2.6324	11.4909	80.1607
6	0.2020	4.7283	4.0817	12.4428	78.5451
7	0.2513	4.1233	5.6111	13.1638	76.8502
8	0.4036	3.7067	7.1078	13.7011	75.0806
9	0.6607	3.4467	8.5027	14.1014	73.2882
10	1.0074	3.2929	9.7661	14.4072	71.5261
11	1.4208	3.1994	10.8946	14.6524	69.8326
12	1.8773	3.1328	11.8998	14.8619	68.2280
13	2.3571	3.0723	12.7988	15.0532	66.7184
14	2.8453	3.0071	13.6097	15.2376	65.3001
15	3.3319	2.9325	14.3487	15.4220	63.9646

we find that carbon emissions and economic growth are independent i.e. neutral effect. There was a unidirectional causal association from R&D expenditures to the growth of the economy. Financial development is also caused by but similar is not true from the opposite side. No causal relationship exists between economic growth and energy consumption. Energy consumption is the cause of carbon emissions. Financial development causes R&D expenditures, and R&D expenditures also cause energy consumption.

5. Robustness Checks

Results of conventional ADF unit root testing has shown that all the series were first differenced stationary. However, it is vital to test for the robustness of these results using the Kim and Perron (2009) approach which accounts for the structural break. The results of the ADF test with structural breaks supported the findings of conventional ADF test. All the series were found to be first differenced stationary in the presence of structural break (see Table A2) suggesting the robustness of our estimates. We also employed the Johansen and Juselius (1990) cointegration approach (see Table 4) which provided further support to findings on cointegration. Specifically, Max-Eigen statistic and Trace test statistic suggest rejection of the null hypothesis of no cointegration at 1% and 5% levels of statistical significance. This reveals that carbon function entails two cointegrating vectors. It can be argued that the confirmation of cointegration vectors in carbon emissions function shows the possibility of long-run association. There is an argument that when there is long-run equilibrium, there must be a short-run disequilibrium, it is important to check whether the cointegrating vectors are present in carbon emissions function. In such a case, the findings reveal that our cointegration analysis is robust and is reliable.

We have divided our sample into two sub-samples following Kim and Perron (2009) empirical results which indicated the presence of structural break for the year of 2008. The break in carbon emissions series relates to the global financial crisis that hit the UK economy. It is argued by Shahbaz et al. (2018a) that existence of structural breaks in the data may affect the empirical results, therefore we should re-estimate empirical results by dividing the whole sample into sub-samples based on the indication of the structural break(s) to test the robustness

Table 4
Johansen Cointegration Analysis

Hypothesized No. of CE(s)	Trace Stat.	Sig.	Max-Eigen Stat.	Sig.
$R \le 0$	127.1424*	0.0013	47.6519**	0.0164
$R \le 1$	79.4904**	0.0487	30.3477	0.2459
$R \le 2$	49.1427	0.1546	24.6089	0.2371
$R \le 3$	24.5332	0.4116	12.9728	0.6805
$R \le 4$	11.5605	0.3428	10.9365	0.3167
$R \le 5$	0.6244	0.4294	0.6244	0.4294

Notes: * and ** depict statistical significance at 1%, and 5% levels. MacKinnon et al. (1999) p-values are employed.

Table 5
Long-Run Analysis Robustness Check

Response Variable: $\ln C_t$

Variables	FMOLS		CCR		OLS (1870-2008)		OLS (2009-2017)	
	Coef.	T-Stat.	Coef.	T-Stat.	Coef.	T-Stat.	Coef.	T-Stat.
Constant	-24.3260*	-12.1321	-24.2741*	-12.2479	-23.6571*	-15.6840	2.3459	0.0158
$\ln Y_t$	6.3621*	15.5431	6.3661*	15.7871	6.1345*	19.8561	-3.5441***	-1.9221
$\ln Y_t^2$	-0.3531*	-15.9852	-0.3531*	-16.1821	-0.3427*	-20.5874	0.1833***	1.7980
$\ln E_t$	1.5143*	9.6224	1.4745*	8.5460	1.7476*	14.7322	8.0505*	9.0845
$\ln F_t$	0.1133*	4.7078	0.1124*	4.7021	0.1176*	6.4546	1.7905*	12.2351
$\ln R_t$	-0.0999*	-2.9016	-0.0105**	-1.9598	-0.0387**	-2.4609	-0.7495*	-5.2601
D_{2008}	-0.2124*	-8.7142	-0.2139*	-8.4627	….	….	….	….
R^2	0.8843		0.8833		0.8739		0.9985	
$Adj - R^2$	0.8793		0.8783		0.8691		0.9970	

Notes: *, **, and *** depict statistical significance at 1%, 5%% and 10% levels.

of empirical findings. Due to the global financial crisis, UK manufacturing industry efficiency and productivity have been affected and the economy shifted from heavy industry towards advance industry and services which reduced electricity usage in the industrial sector. Similarly, Business, Energy and Industrial Strategy (2018) reported that financial crisis is one of the factors pushed business and industrial sectors for energy efficiency and switching economy to lower carbon fuels which reduced carbon emissions. The empirical results of FMOLS, CCR and OLS with sub-samples are reported in Table 5. We found that empirical results provided by FMOLS and CCR are similar to long-run empirical analysis. This validates the robustness of long-run empirical results. The empirical analysis of sub-samples also shows the presence of EKC for the period of 1870–2008. On the contrary, over the period of 2009–2017, we found no significant evidence of an inverted U-shaped relationship between the growth of economy and emissions. The empirical analysis confirms the presence of U-shaped relationship between economic growth and carbon emissions i.e. economic growth is negatively linked with carbon emissions initially, but economic growth increases carbon emissions are the higher level of GDP per capita. This is a crucial finding which implies that in contemporary Britain, the notion of the long-term negative impact of economic growth on emissions does not prevail in the Post-global crisis period. Concomitantly, it requires more emphasis and being more cautious about the implication of economic growth for the environment. Consumption of energy seems to have a dominant positive impact on emission in the pre (1870–2008) and post (2009–2017) break periods. The empirical results are also statistically very significant suggesting that an increase in energy consumption leads to higher consumption regardless of the period. Similarly, financial development also showed a very significant positive impact on emissions in both periods. The coefficients are positive and statistically significant suggesting that financial development in the UK has severe ecological implications which as important in the post and pre-global financial crisis periods. Lastly, R&D expenditures have a negative and statistically very significant effect on carbon emissions. The empirical results are consistent with the earlier estimations using FMOLS and CCR approaches, which reflects the robustness of our results but is most importantly the prima facie evidence of the importance of R&D in tackling emissions.

6. Conclusion and Policy Implications

In the context of the 4th industrial revolution, global decarbonisation and UK's legally binding commitment to a net-zero emission target, we investigated the historical determinants of CO_2 emissions. Specifically, we focused on the potential role of economic growth, R&D expenditures, financial development, and energy consumption in determining the dynamics of CO_2 emissions. This exercise was important for two reasons. First, the 4th industrial revolution through its disruptive technological advances is not only fundamentally changing socio-economic and financial systems, but also creates opportunities for a zero-carbon future. Second, as a signatory of the Paris Agreement, the United Kingdom is the first developed economy and G-7 member that has committed to achieving a net-zero carbon emissions target by 2050.

Our empirical results lead us to conclude on the presence of long-run association among the underlying variables. Specifically, the EKC hypothesis is validated for the UK, which implies that in the short run economic growth damages the environment, and beyond the threshold level it improves environmental quality. The post-global financial crisis period, however, showed less support to this notion. It implies that in the current climate, the ecological consequences of economic growth should be given an utmost priority in the policy-making to achieve a sustainable natural environment. Economic growth in the United Kingdom has been buoyant after the Brexit referendum, although the rate of growth has been modest by historical averages. Considering the recent and future events, the impact of COVID-19 and British membership of the European Union, as well as the effects on its economic growth and probable policy response, pose a whole set of economic and ecological challenges. In the policy setting, it implies that to achieve the target of a carbon-free economy by 2050, Britain needs to develop the right attitude of building a clean environment while enhancing the economic activities. Concomitantly, emphasis should be given to investments in projects, which are more sustainable, as well as the facilitation of sustainable consumption. Our empirical results suggest that excessive energy consumption hits the environment of the UK very severely. This reflects the significance of energy usage not merely in the facilitation of economic activity but its ecological consequences. It is quite alarming and indicates a climate urgency for the UK government to revisit its energy policy. There is prima facie evidence that the energy mix adopted so far has been leading to significant environmental degradation. Therefore, it is important that the energy policy and energy mix are revisited. More emphasis should be given on renewable energy usage if the target of a carbon-free economy is to be met by 2050.

The British financial sector is one of the largest financial sectors in the world and it is multiple folds larger than some of the other sectors of the economy. This size and significance are also evident in its environmental footprint. Our finding leads us to conclude on the significant role of financial development in environmental degradation. In a policy setting, it implies that where the financial sector is important for the real economy, it has crucial implications for environmental stability. Therefore, financial activities and development should be focused on improving environmental quality, and such forms of financialization should be encouraged, which are more sustainable. Green and sustainable finance are to be the focus of public and macroeconomic policymaking. Allocation of financial resources to environmentally less efficient sectors should be discouraged, while at the same time resources should be allocated to more sustainable sectors. Our empirical results on R&D expenditures lead us to conclude that R&D expenditures are beneficial for the natural environment. The statistics showed very strong and empirically robust results, which give us strong confidence to infer that R&D is key to tackling environmental challenges. Therefore, in policy setting and particularly to curb carbon emissions, it is vital to focus the public policy and allocation of resources to research and development. This will facilitate the efforts to cut carbon emissions to a net of zero.

The nonlinear association between development in the financial system and environmental pollution was found to be U-shaped. This is a quite alarming finding, implying that the increase in financial development causes environmental degradation, which does not diminish with increasing financialization. Given that the British financial sector is developed and still growing with its gigantic size and global significance, it is vital to take into account its environmental consequences. In a policy setting, the allocation of financial resources should be channelled to environment-friendly and sustainable sectors. The policy of facilitation of financial development without its environmental consequences could have a drastic impact on the environment. The results of linear and squared terms of R&D expenditures showed positive and negative effects on environmental pollution, respectively, i.e. an inverted U-shaped relationship. This suggests that increasing innovation expenditures adds to the improvement of environmental health, and hence in policy setting, more expenditures on innovation may result in a better environment. Our findings have profound implication for tackling the environmental challenges and the ambitions of the British government to meet its Paris Agreement commitments, as it has committed to cut net emissions to zero by 2050.

Author statement

Muhammad Shahbaz: Methodology, Data curation, Formal analysis, Writing - original draft, Supervision.

Muhammad Ali Nasir: Investigation, Writing - original draft, Writing - review & editing.

Erik Hille: Investigation, Writing - original draft, Writing - review & editing.

Mantu Kumar Mahalik: Writing - original draft, Writing - review & editing.

Appendix

Table A1, Table A2, Table A3, Table A4

Table A1
Correlation Analysis and Descriptive Statistics

	$\ln C_t$	$\ln Y_t$	$\ln F_t$	$\ln E_t$	$\ln R_t$
Mean	7.8710	8.9570	4.0059	2.1577	2.2166
Median	7.9040	8.8389	3.8738	2.1698	2.0613
Maximum	8.0647	10.189	5.1839	2.2390	6.2353
Minimum	7.3667	8.0681	3.4557	1.9513	-1.5315
Std. Dev.	0.1365	0.6393	0.4167	0.0501	2.5898
Skewness	-1.3195	0.4647	1.3761	-0.9298	0.1511
Kurtosis	4.8544	1.9278	4.0860	4.2909	1.5582
Jarque-Bera	0.6415	0.1240	0.5398	0.3160	0.1338
Probability	0.5050	0.8202	0.5243	0.7989	0.8120
Sum	1164.90	1325.64	592.88	319.33	328.07
Sum Sq. Dev.	2.7394	60.0905	25.5341	0.3702	986.0106
$\ln C_t$	1				
$\ln Y_t$	0.1174	1			
$\ln F_t$	0.5989	0.6166	1		
$\ln E_t$	0.1976	0.6497	0.2104	1	
$\ln R_t$	-0.0576	0.9764	0.5474	-0.5583	1

Table A2
Unit-Root Test

	ADF Test		ADF Test with Break		
	T-Stat.	Sig.	T-Stat.	Sig.	Date of Break
$\ln C_t$	0.8370	0.9989	-1.7585	0.9919	2008
$\ln Y_t$	-2.1360	0.5211	-4.0296	0.3537	1916
$\ln F_t$	-2.0019	0.5951	-4.0234	0.3547	1985
$\ln E_t$	-1.5544	0.6253	-1.7006	0.9928	1918
$\ln R_t$	-2.2469	0.4598	-3.0686	0.8904	1887
$\Delta\ln C_t$	-11.5919*	0.0000	-13.2126*	0.0001	1921
$\Delta\ln Y_t$	-8.7985*	0.0000	-9.4611*	0.0001	1919
$\Delta\ln F_t$	-8.0542*	0.0000	-9.0763*	0.0001	1987
$\Delta\ln E_t$	-10.3711*	0.0000	-10.8070*	0.0000	1933
$\Delta\ln R_t$	-9.1651*	0.0000	-10.7298*	0.0000	1920

Note: * shows significance at 1%.

Table A3
The Bounds Cointegration Analysis

Bounds Testing Approach to Cointegration Model	Lags	Break Year	F-statistic	Diagnostics χ^2_{NORMAL}	χ^2_{ARCH}	χ^2_{RESET}	χ^2_{SERIAL}	CUSUM	$CUSUM_{SQ}$
$C_t = f(Y_t, Y_t^2, E_t, F_t, R_t)$	6, 6, 5, 6, 5, 6	2008	13.349*	0.1822	1.7477	2.3562	0.0244	Stable	Stable
$Y_t = f(C_t, Y_t^2, E_t, F_t, R_t)$	6, 6, 6, 5, 6, 6	1916	2.1612	0.4013	2.1012	0.1305	1.0017	Unstable	Stable
$Y_t^2 = f(C_t, Y_t, E_t, F_t, R_t)$	6, 6, 6, 5, 6, 6	1916	2.6102	0.1191	1.0102	1.1003	2.0052	Unstable	Unstable
$E_t = f(C_t, Y_t, Y_t^2, F_t, R_t)$	6, 5, 5, 5, 5, 6	1918	11.7128*	2.0302	2.1001	0.30705	0.1500	Stable	Stable
$F_t = f(C_t, Y_t, Y_t^2, E_t, R_t)$	6, 6, 6, 5, 5, 5	1985	21.1722*	1.3003	2.1021	2.1005	0.3035	Stable	Stable
$R_t = f(C_t, Y_t, Y_t^2, E_t, F_t)$	6, 6, 5, 6, 5, 6	1887	14.8301*	1.2208	2.2021	2.1153	0.3112	Stable	Stable
Statistical Significance	Critical values (T = 52)								
	L.B $I(0)$	U.B $I(1)$							
1 %	7.317	8.70							
5 %	5.360	6.373							
10 %	4.437	5.377							

Note: * represents 1% statistical significance level. The AIC is used for optimal lag length section.

Table A4
Bootstrapped ARDL Analysis

Bootstrapped ARDL Estimation Models	Lags	Break date	F_{PSS}	T_{DV}	T_{IV}	Diagnostic testing $\bar{R}^2$	$Q-stat$	$LM(2)$	JB
$C_t = f(Y_t, Y_t^2, E_t, F_t, R_t)$	6, 6, 5, 6, 5, 6	2008	10.105*	-3.2209**	-4.2704***	0.7609	5.8088	2.7050	0.9015
$Y_t = f(C_t, Y_t^2, E_t, F_t, R_t)$	6, 6, 6, 5, 6, 6	1916	2.908	-1.8058	0.8065	0.6316	6.1607	0.4060	0.7777
$Y_t^2 = f(C_t, Y_t, E_t, F_t, R_t)$	6, 6, 6, 5, 6, 6	1916	3.161	-1.8290	1.0505	0.7592	5.6043	1.2005	0.7002
$E_t = f(C_t, Y_t, Y_t^2, F_t, R_t)$	6, 5, 5, 5, 5, 6	1918	12.615*	-7.1511*	-5.6191***	0.6038	4.2702	0.3050	0.8202
$F_t = f(C_t, Y_t, Y_t^2, E_t, R_t)$	6, 6, 6, 5, 5, 5	1985	13.159*	-7.9809*	-4.0901*	0.7154	5.8020	2.1035	0.6657
$R_t = f(C_t, Y_t, Y_t^2, E_t, F_t)$	6, 6, 5, 6, 5, 6	1887	12.206*	-8.4945*	-4.8065*	0.2222	6.2002	2.1051	0.9205

Note: *, ** and *** are 1%, 5% and 10% levels of statistical significance. For optimal lag length selection, the Akaike Information Criterion (AIC) is used. Using asymptotic critical bounds generated by bootstrapping, the F-statistic F_{PSS} (Pesaran et al. 2001) is calculated. T_{DV} and T_{IV} are t-statistics for dependent and independent variables, JB is Jarque-Bera and LM is the Langrage Multiplier test.

References

Abbasi, F., Riaz, K., 2016. CO_2 emissions and financial development in an emerging economy: An augmented VAR approach. Energy Policy 90, 102–114.

Acemoglu, D., Restrepo, P., 2018. The race between man and machine: Implications of technology for growth, factor shares, and employment. Am. Econ. Rev. 108 (6), 1488–1542.

Alam, M.S., Atif, M., Chien-Chi, C., Soytaş, U., 2019. Does corporate R&D investment affect firm environmental performance? Evidence from G-6 countries. Energy Econ. 78, 401–411.

Al-Mulali, U., Ozturk, I., 2016. The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices. Renew. Sustain. Energy Rev. 54, 1622–1631.

Althammer, W., Hille, E., 2016. Measuring climate policy stringency: a shadow price approach. Int. Tax Public Financ. 23 (4), 607–639.

Álvarez-Herránz, A., Balsalobre, D., Cantos, J.M., Shahbaz, M., 2017. Energy Innovations-GHG Emissions Nexus: Fresh Empirical Evidence from OECD Countries. Energy Policy 101, 90–100.

Anadon, L.D., Bunn, M., Chan, G., Chan, M., Jones, C., Kempener, R., Lee, A., Logar, N., Narayanamurti, V., 2011. Transforming U.S. Energy Innovation, a report of the findings of the Energy Technology Innovation Policy (ETIP) research group, Belfercenter for science and international affairs. Harvard Kennedy School November 2011.

Ang, J.B., 2007. CO_2 emissions, energy consumption, and output in France. Energy Policy 35, 4772–4778.

Apergis, N., 2016. Environmental Kuznets curves: New evidence on both panel and country-level CO_2 emissions. Energy Econ. 54, 263–271.

Apergis, N., Christou, C., Gupta, R., 2017. Are there Environmental Kuznets Curves for US state-level CO_2 emissions? Renew. Sustain. Energy Rev. 69, 551–558.

Arora, S., Cason, T.N., 1996. Why do firms volunteer to exceed environmental regulations? Understanding participation in EPA's 33/50 program. Land Econ. 72, 413–432.

Atasoy, B.S., 2017. Testing the environmental Kuznets curve hypothesis across the US: Evidence from panel mean group estimators. Renew. Sustain. Energy Rev. 77, 731–747.

Baek, J., Kim, H.S., 2013. Is economic growth good or bad for the environment? empirical evidence from Korea. Energy Econ. 36, 744–749.

Balcilar, M., Ozdemir, Z.A., Ozdemir, H., Shahbaz, M., 2018. Carbon dioxide emissions, energy consumption and economic growth: The historical decomposition evidence from G-7 countries. In: Discussion Paper 15-41, Department of Economics Discussion Paper Series. Eastern Mediterranean University, North Cyprus, Turkey.

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., Farhani, S., 2018. How economic growth, renewable electricity and natural resources contribute to CO_2 emissions? Energy Policy 113, 356–367.

Bekhet, H.A., Matar, A., Yasmin, T., 2017. CO_2 emissions, energy consumption, economic growth, and financial development in GCC countries: Dynamic simultaneous equation models. Renew. Sustain. Energy Rev. 70, 117–132.

Black Rock, 2020. What are megatrends? Accessed April 26, 2020. https://www.blackrock.com/sg/en/investment-ideas/themes/megatrends.

Bruyn, D., Sander, M., 1997. Explaining the environmental Kuznets curve: Structural change and international agreements in reducing sulphur emissions. Environ. Dev. Econ. 2, 485–503.

Charfeddine, L., Khediri, K.B., 2016. Financial development and environmental quality in UAE: Cointegration with structural breaks. Renew. Sustain. Energy Rev. 55, 1322–1335.

Chaudhry, S.M., Ahmed, R., Shafiullah, M., Huynh, T.L.D., 2020. The impact of carbon emissions on country risk: Evidence from the G7 economies. J. Environ. Manage. 265, 110533.

Chen, W., Xu, R., 2010. Clean coal technology development in China. Energy Policy 38 (5), 2123–2130.

Cho, J.H., Sohn, S.Y., 2018. A novel decomposition analysis of green patent applications for the evaluation of R&D efforts to reduce CO_2 emissions from fossil fuel energy consumption. J. Cleaner Prod. 193, 290–299.

Churchill, S.A., Inekwe, J., Smyth, R., Zhang, X., 2019. R&D intensity and carbon emissions in the G7: 1870–2014. Energy Econ. 80, 30–37.

Claessens, S., & Feijen, E. (2007). Financial sector development and the millennium development goals. World Bank Working Paper, No. 89.

Çoban, S., Topcu, M., 2013. The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. Energy Econ. 39, 81–88.

Committee on Climate Change, 2019. Independent advice to government on building a low-carbon economy and preparing for climate change. Accessed November 10, 2019. https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/.

Corfe, S., 2020. 4IR and the environment: How the fourth industrial revolution can curb air pollution and decarbonise the economy. In: Social Market Foundation, January 2020.

Dasgupta, S., Laplante, B., Mamingi, N., 2001. Pollution and capital markets in developing countries. J. Environ. Econ. Manage. 42 (3), 310–335.

Dickey, D.A., Fuller, W.A., 1979. Distribution of the Estimators for autoregressive time series with a unit root. J. Am. Assoc. 74, 427–431.

Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. Ecol. Econ. 49 (4), 431–455.

Dogan, E., Seker, F., 2016. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew. Sustain. Energy Rev. 60, 1074–1085.

Ellabban, O., Abu-Rub, H., Blaabjerg, F., 2014. Renewable energy resources: Current status, future prospects and their enabling technology. Renew. Sustain. Energy Rev. 39, 748–764.

Engle, R.F., Granger, C.W., 1987. Co-integration and error correction: representation, estimation, and testing. Econometrica 55, 251–276.

Esteve, V., Tamarit, C., 2012. Is there an environmental Kuznets curve for Spain? Fresh evidence from old data. Econ. Model. 29 (6), 2696–2703.

Fernández, Y., Fernández López, M.A., Olmedillas, B., 2018. Innovation for sustainability: The impact of R&D spending on CO_2 emissions. J. Cleaner Prod. 172, 3459–3467.

Fosten, J., Morley, B., Taylor, T., 2012. Dynamic misspecification in the environmental Kuznets curve: evidence from CO_2 and SO_2 emissions in the United Kingdom. Ecol. Econ. 76, 25–33.

Frankel, J.A., Romer, D.H., 1999. Does trade cause growth. Am. Econ. Rev. 89, 379–399.

Freimane, R., Bāliņa, S., 2016. Research and development expenditures and economic growth in the EU: A panel data analysis. Econ. Bus. 29 (1), 5–11.

Gallagher, K.S., Grübler, A., Kuhl, L., Nemet, G., Wilson, C., 2012. The energy technology innovation system. Annu. Rev. Environ. Resour. 37, 137–162.

Ganda, F., 2019. The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. J. Cleaner Prod. 217, 469–483.

Garrone, P., Grilli, L., 2010. Is there a relationship between public expenditures in energy R&D and carbon emissions per GDP? an empirical investigation. Energy Policy 38 (10), 5600–5613.

Ghosh, S., 2010. Examining carbon emissions economic growth nexus for India: a multivariate cointegration approach. Energy Policy 38, 3008–3014.

Goh, S.K., Sam, C.Y., McNown, R., 2017. Re-examining foreign direct investment, exports, and economic growth in asian economies using a bootstrap ARDL test for cointegration. J. Asian Econ. 51, 12–22.

Gov.uk, 2015. 2010 to 2015 government policy: Greenhouse gas emissions. Policy paper. Accessed July 16, 2020. https://www.gov.uk/government/publications/2010-to-2015-government-policy-greenhouse-gas-emissions/2010-to-2015-government-policy-greenhouse-gas-emissions.

Gov.uk, 2017. UK climate change risk assessment 2017: Presented to Parliament pursuant to Section 56 of the Climate Change Act 2008. Accessed November 10, 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/584281/uk-climate-change-risk-assess-2017.pdf.

Gov.uk, 2019. Climate Change Act 2008. Accessed November 10, 2019. http://www.legislation.gov.uk/ukpga/2008/27/contents.

Gov.uk, 2019. UK becomes first major economy to pass net zero emissions law. Accessed November 10, 2019. https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law.

Hall, P.J., Bain, E.J., 2008. Energy-storage technologies and electricity generation. Energy Policy 36 (12), 4352–4355.

Herweijer, C., Combes, B., Johnson, L., McCargow, R., Bhardwaj, S., & Jackson, B. (2018). Enabling a sustainable Fourth Industrial Revolution: how G20 countries can create the conditions for emerging technologies to benefit people and the planet. Economics E-Journal Discussion Paper, No. 2018-32.

Hille, E., Lambernd, B., 2020. The role of innovation in reducing South Korea's energy intensity: Regional-data evidence on various energy carriers. J. Environ. Manage. 262 (1), 110293.

Hille, E., Shahbaz, M., 2019. Sources of emission reductions: market and policy-stringency effects. Energy Econ. 78 (1), 29–43.

Hille, E., Shahbaz, M., Moosa, I., 2019. The impact of FDI on regional air pollution in the Republic of Korea: A way ahead to achieve the green growth strategy? Energy Econ. 81 (1), 308–326.

Ibrahim, M.H., 2005. Sectoral effects of monetary policy: Evidence from Malaysia. Asian Econ. J. 19, 83–102.

Islam, F., Shahbaz, M., Ahmed, A.U., Alam, M.M., 2013. Financial development and energy consumption nexus in Malaysia: a multivariate time series analysis. Econ. Model. 30, 435–441.

Jalil, A., Feridun, M., 2011. The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Econ. 33 (2), 284–291.

Javid, M., Sharif, F., 2016. Environmental Kuznets curve and financial development in Pakistan. Renew. Sustain. Energy Rev. 54, 406–414.

Jin, L., Duan, K., Shi, C., Ju, X., 2017. The impact of technological progress in the energy sector on carbon emissions: An empirical analysis from China. Int. J. Environ. Re. Public Health 14 (12), 1505.

Johansen, S., Juselius, K., 1990. Maximum likelihood estimation and inference on cointegration with applications to the demand for money. Oxf. Bull. Econ. Stat. 52, 169–210.

Jones, CI., 2002. Introduction to Economic Growth, 2nd ed. WW. Norton, New York.

Jordaan, S.M., Romo-Rabago, E., McLeary, R., Reidy, L., Nazari, J., Herremans, I.M., 2017. The role of energy technology innovation in reducing greenhouse gas emissions: A case study of Canada. Renew. Sustain. Energy Rev. 78, 1397–1409.

Katircioğlu, S.T., Taşpinar, N., 2017. Testing the moderating role of financial development in an environmental Kuznets curve: empirical evidence from Turkey. Renew. Sustain. Energy Rev. 68, 572–586.

Kim, D., Perron, P., 2009. Unit root tests allowing for a break in the trend function at an unknown time under both the null and alternative hypotheses. J. Econometrics 148, 1–13.

Koçak, E., Ulucak, Z.S., 2019. The effect of energy R&D expenditures on CO_2 emission reduction: estimation of the STIRPAT model for OECD countries. Environ. Sci. Pollut. Res. 26, 14328–14338.

Komen, M.H., Gerking, S., Folmer, H., 1997. Income and environmental R&D: empirical evidence from OECD countries. Environ. Dev. Econ. 2, 505–515.

Lee, K.H., Min, B., 2015. Green R&D for eco-innovation and its impact on carbon emissions and firm performance. J. Cleaner Prod. 108, 534–542.

Luo, X., Wang, J., Dooner, M., Clarke, J., 2015. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Appl. Energy 137, 511–536.

Maddison, A., 2007. The World Economy. OECD Publishing, Paris.

Madsen, J.B., Ang, J.B., 2016. Finance-led growth in the OECD since the nineteenth century: how does financial development transmit to growth. Rev. Econ. Stat. 98, 552–572.

Mahalik, M.K., Babu, M.S., Loganathan, N., Shahbaz, M., 2017. Does financial development intensify energy consumption in Saudi Arabia? Renew. Sustain. Energy Rev. 75, 1022–1034.

Marland, G., Boden, T., Andres, R., 2006. Global, Regional, and National Annual CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 17512003. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN.

McNown, R., Sam, C.Y., Goh, S.K., 2018. Bootstrapping the autoregressive distributed lag test for cointegration. Appl. Econ. 50, 1509–1521.

Mensah, C.N., Long, X., Boamah, K.B., Bediako, I.A., Dauda, L., Salman, M., 2018. The effect of innovation on CO_2 emissions of OCED countries from 1990 to 2014. Environ. Sci. Pollut. Res. 25, 29678–29698.

Minniti, A., Venturini, F., 2017. The long-run growth effects of R&D policy. Res. Policy 46 (1), 316–326.

Narayan, P.K., 2005. The saving and investment nexus for China: evidence from cointegration tests. Appl. Econ. 17, 1979–1990.

Narayan, P.K., Narayan, S., 2010. Carbon dioxide emissions and economic growth: Panel data evidence from developing countries. Energy Policy 38, 661–666.

Nasir, M.A., Ahmad, M., Ahmad, F., Wu, J., 2015. "Financial and economic stability as 'two sides of a coin': Non-crisis regime evidence from the UK based on VECM. J. Financ. Econ. Policy 7, 327–353.

Nasir, M.A., Huynh, T.L.D., Tram, H.T.X., 2019. Role of financial development, economic growth & foreign direct investment in driving climate change: A case of emerging ASEAN. J. Environ. Manage. 242 (1), 131–141.

Nassani, A.A., Aldakhil, A.M., Abro, M.M.Q., Zaman, K., 2017. Environmental Kuznets curve among BRICS countries: spot lightening finance, transport, energy and growth factors. J. Cleaner Prod. 154, 474–487.

Newell, R.G., Pizer, W.A., 2008. Indexed regulation. J. Environ. Econ. Manage. 56 (3), 221–233.

Ockwell, D.G., Haum, R., Mallett, A., Watson, J., 2010. Intellectual property rights and low carbon technology transfer: Conflicting discourses of diffusion and development. Global Environ. Change 20 (4), 729–738.

Omri, A., Daly, S., Rault, C., Chaibi, A., 2015. Financial development, environmental quality, trade and economic growth: What causes what in MENA countries? Energy Econ. 48, 242–252.

Onafowora, O.A., Owoye, O., 2014. Bounds testing approach to analysis of the environment Kuznets curve hypothesis. Energy Econ. 44, 47–62.

Özokcu, S., Özdemir, Ö, 2017. Economic growth, energy, and environmental Kuznets curve. Renew. Sustain. Energy Rev. 72, 639–647.

Ozturk, I., Acaravci, A., 2013. The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Econ. 36, 262–267.

Parry, I.W., 2003. On the implications of technological innovation for environmental policy. Environ. Dev. Econ. 8 (1), 57–76.

Paul, W. (2007). Energy Consumption in England & Wales, 1560-2004 (Naples: CNR, 2007).

Pesaran, H.M., Shin, Y., Smith, R.J., 1996. Testing for the 'Existence of a Long-Run Relationship.' Department of Applied Economics Working Paper no. 9622. University of Cambridge, Cambridge, UK.

Pesaran, M.H., Shin, Y., 1999. An autoregressive distributed lag modeling approach to cointegration analysis. In: Strom, S (Ed.), Chapter 11 in Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium, 1999. Cambridge University Press, CambridgeUK.

Pesaran, H.M., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. 16, 289–326.

Pham, N.M., Huynh, T.L.D., Nasir, M.A., 2020. Environmental consequences of population, affluence and technological progress for European countries: A Malthusian view. J. Environ. Manage. 260 (1), 110143.

Redmond, T, Nasir, M.A., 2020. Role of natural resource abundance, international trade and financial development in the economic development of selected countries. Resour. Policy 66, 101591.

Romer, P.M., 1990. Endogenous technological change. J. Polit. Econ. 98, 71–102.

Sadorsky, P., 2010. The impact of financial development on energy consumption in emerging economies. Energy Policy 38 (5), 2528–2535.

Sadorsky, P., 2011. Financial development and energy consumption in Central and Eastern European frontier economies. Energy Policy 39 (2), 999–1006.

Salahuddin, M., Alam, K., Ozturk, I., Sohag, K., 2018. The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO_2 emissions in Kuwait. Renew. Sustain. Energy Rev. 81, 2002–2010.

Schumpeter, J.A., 1942. Capitalism, socialism and democracy. Routledge, London, pp. 82–83.

Sehrawat, M., Giri, A.K., Mohapatra, G., 2015. The impact of financial development, economic growth and energy consumption on environmental degradation. Manage. Environ. Qual.: Int J 26, 666–682.

Sephton, P.&, Mann, J., 2016. Compelling Evidence of an Environmental Kuznets Curve in the United Kingdom. Environ. Resour. Econ. 64, 301–315.

Shahbaz, M., Solarin, S.A., Mahmood, H., Arouri, M., 2013a. Does financial development reduce CO_2 emissions in Malaysian economy? A time series analysis. Econ. Model. 35, 145–152.

Shahbaz, M., Tiwari, A.K., Nasir, M., 2013b. The effects of financial development, economic growth, coal consumption and trade openness on CO_2 emissions in South Africa. Energy Policy 61, 1452–1459.

Shahbaz, M., Mallick, H., Mahalik, M.K., Loganathan, N., 2015. Does globalization impede environmental quality in India? Ecol. Indic. 52, 379–393.

Shahbaz, M., Shahzad, S.J.H., Ahmad, N., Alam, S., 2016a. Financial development and environmental quality: The way forward. Energy Policy 98, 353–364.

Shahbaz, M., Jam, F.A., Bibi, S., Loganathan, N., 2016b. Multivariate granger causality between CO_2 emissions, energy intensity and economic growth in Portugal: Evidence from cointegration and causality analysis. Technol. Econ. Dev. Econ. 22, 47–74.

Shahbaz, M., Shafiullah, M., Papavassiliou, V.G., Hammoudeh, S., 2017. The CO_2-Growth nexus revisited: A nonparametric analysis for G7 economies over nearly two centuries. Energy Econ. 65, 183–193.

Shahbaz, M., Nasir, M.A., Roubaud, D., 2018a. Environmental Degradation in France: The Effects of FDI, Financial Development, and Energy Innovations. Energy Econ. 74, 843–857.

Shahbaz, M., Shahzad, S.J.H., Mahalik, M.K., 2018b. Is globalization detrimental to CO 2 emissions in Japan? New threshold analysis. Environ. Model. Assess. 23 (5), 557–568.

Shahbaz, M., Sinha, A., 2019. Environmental Kuznets curve for CO_2 emissions: A literature survey. J. Econ. Stud. 46, 106–168.

Shahbaz, M., Kablan, S., Hammoudeh, S., Nasir, M.A., Kontoleon, A., 2020. Environmental implications of increased US oil production and liberal growth agenda in post -Paris Agreement era. J. Environ. Manage. 271, 110785.

Shan, J., 2005. Does financial development 'lead' economic growth? a vector autoregression appraisal? Appl. Econ. 37, 1353–1367.

Smulders, S., De Nooij, M., 2003. The impact of energy conservation on technology and economic growth. Resour. Energy Econ. 25 (1), 59–79.

Sohag, K., Begum, R.A., Abdullah, S.M.S., Jaafar, M., 2015. Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. Energy 90, 1497–1507.

Song, M.L., Zhang, W., Wang, S.H., 2013. Inflection point of environmental Kuznets curve in Mainland China. Energy Policy 57, 14–20.

Tamazian, A., Rao, B., 2010. Do economic, financial and institutional developments matter for environmental degradation? evidence from transitional economies. Energy Econ. 32, 137–145.

Tamazian, A., Chousa, J.P., Vadlamannati, K.C., 2009. Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. Energy Policy 37, 246–253.

Tiwari, A.K., Shahbaz, M., Hye, Q.M.A., 2013. The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. Renew. Sustain. Energy Rev. 18, 519–527.

UK Department for Business, Energy and Industrial Strategy, 2018. Organisation. Accessed December 20, 2018. https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy.

Weitzman, M.L., 1997. Sustainability and technical progress. Scandinavian J. Econ. 99 (1), 1–13.

Xiong, L., Qi, S., 2018. Financial development and carbon emissions in Chinese provinces: a spatial panel data analysis. Singap. Econ. Rev. 63 (02), 447–464.

Yang, Y., Cai, W., Wang, C., 2014. Industrial CO_2 intensity, indigenous innovation and R&D spillovers in China's provinces. Appl. Energy 131 (1), 117–127.

Yeandle, M., Wardle, M., 2019. The global financial centres index 25. Long Finance and Financial Centres Futures, March 2019. Accessed November 10, 2019. https://www.longfinance.net/publications/long-finance-reports/the-global-financial-centres-index-25/.

Yeh, S., Rubin, E., Hounshell, D.A., Taylor, M.R., 2011. Uncertainties in technology experience curves for energy-economic models. Model. Econ., Greenh. Gas Mitig.: Summ. Workshop 91 (9), 36. Available from: http://www.ourenergypolicy.

You, W-H., Zhu, H-M., Yu, K., Peng, C., 2015. Democracy, financial openness, and global carbon dioxide emissions: heterogeneity across existing emission levels. World Dev. 66, 189–207.

Zaidi, S.A.H., Zafar, M.W., Shahbaz, M., Hou, F., 2019. Dynamic linkages between globalization, financial development and carbon emissions: evidence from Asia Pacific Economic Cooperation countries. J. Cleaner Prod. 88, 533–543.

Zhang, Y-J., 2011. The impact of financial development on carbon emissions: an empirical analysis in China. Energy Policy 39, 2197–2203.

Dr. Muhammad Shahbaz is Professor of Economics at the Beijing Institute of Technology, China and Visiting Research Fellow at the University of Cambridge, UK. He received his PhD in Economics from the National College of Business Administration and Economics, Lahore, Pakistan. His research focuses on the development, energy, environmental, and tourism economics. He has widely published in peer-reviewed international journals, such as Energy Economics, Energy Policy, Journal of Banking & Finance, Economic Modeling, and Applied Economics. Dr. Shahbaz is among the world's top 10 authors in the Economics category as compiled by IDEAS, and among top 5 active researchers from developing countries as declared by David McKenzie (Chief Economist), World Bank.

Dr. Muhammad Ali Nasir is an Associate Professor in Economics at the University of Huddersfield, UK. His main areas of research interest are macro and monetary economics, financial economics, econometrics, energy and environmental economics. He has published a number of high-quality research outputs in reputable journals. Dr. Nasir also has a great interest in the socioeconomic issues, financial and ecological stability. His recent publications are in the Journal of Environmental Management, Energy Economics, Resources Policy, New Political Economy and Journal of Economics Studies. Dr. Nasir is guest editor of very reputable journals such as the Journal of Environmental Management, Resources Policy, and Technological Forecasting and Social Change.

Dr. Erik Hille is an Assistant Professor in Economics at HHL, Germany. He studied economics and management at the Martin Luther University Halle-Wittenberg and HHL. During his studies, he spent semesters abroad at Harvard University, Vietnam National University, and KDI School of Public Policy and Management. His research is focused on the effects of environmental policies on different dimensions of industrial competitiveness as well as the trade, growth, and environment relationship. His recent articles have been published in reputable journals, such as the Journal of Environmental Economics and Management, Energy Economics, and Environmental and Resource Economics. He has taken active roles in various research and consulting projects, funded, among others, by the European Commission and the German Federal Ministry of Education and Research.

Dr. Mantu Kumar Mahalik is now an Assistant Professor of Economics in the Department of Humanities and Social Sciences at the Indian Institute of Technology (IIT), Kharagpur, West Bengal, India. He works in the areas of open empirical macroeconomics, housing economics, energy economics and financial markets. He has published many papers in international journals, mainly in the areas of macroeconomics, housing economics, and energy economics, such as Empirical Economics, Journal of Economic Policy Reforms, Applied Economics, Australian Economic Papers, Applied Economics Letters, International Journal of Real Estate Finance and Economics, Journal of Property Research, Energy Economics, Energy Policy, and Resources Policy.