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Modeling the environmental implications of car ownership and energy consumption in the UK: Evidence from NARDL model

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ABSTRACT

We investigated the asymmetric effects of energy consumption, car ownership and tourism activities on CO_2 emissions in the UK. Empirical results from the Non-Linear Autoregressive Distributed Lag (NARDL) model reveal that in the UK, only car ownership has asymmetric effects on emissions with a magnitude of −1.428% (positive) and 10.108% (negative) shocks that highlight the impact of car ownership on emission level in UK while rising energy consumption and GDP have symmetric positive impacts on emissions, and tourism has a negative impact on emissions. Furthermore, on causality analysis, we found a unidirectional causality runs from GDP per capita to car ownership, and that car ownership and tourism both causes energy consumption in a one-way relationship. Apart from encouraging environmentally friendly energy sources to reduce carbon emission in the UK, the short and long-run analyses disclose that economic expansion and energy consumption increase carbon emission. Empirical results also offer a new perspective on the ascending relevance of electric cars in UK. Hence, only policies that discourage the use of carbon emission inputs in the process of production should be encouraged. Electric vehicles seem to be more efficient when compared to combustion engines because most energy put in the battery is used to drive the cars and wastes less energy when they are driven in cities. This can be achieved by increasing tariffs and decreasing quotas on internal combustion-powered cars. Subsequently, promote and increase usage of electric vehicles that reduce greenhouses

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1. Introduction

Over the decades, the world is increasingly experiencing climate change which has been proven as a phenomenon caused by human activities (Abdouli & Hammami, 2016; Álvarez-Herranz et al., 2017; Sebri & Ben-Salha, 2014). Continental, regional, and countries studies on the nexus between environmental pollution and macroeconomic variables are not scarce in the empirical literature, with the Environmental Kuznets curve (EKC) provide a solid theoretical threshold for analyzing and comparing CO_2 emission among countries and regions (Verbič et al.,2021). There is a convergence consensus on the pending hazard that GHGs poses on the planet if sustainable palliative measures are not put in place to check human mate activities that cause it.

Before addressing the issue of CO_2 emission and its anticipated consequences on the existence of lives, it becomes imperative to identify the core causes. The casual factors of CO_2 emission have remained an important issue among countries, sub-regional governments, and international communities. Ascending urbanization processes and human behaviors exert a pivotal and leading role in producing CO_2 emissions globally (Bakirtas & Akpola, 2018; Belloumi & Alshehry, 2016). As a necessary factor for economic development, urbanization has suddenly become a nightmare for urban development agencies due to its threat to the environment (Liddle & Lung, 2014). Zhang and Lin (2012) suggested that virtually all socioeconomic predictors of CO_2 emission have direct and indirect connections with urbanization processes. For instance, Shahbaz et al. (2017) and Lin and Liu (2016) found a positive linkage between urbanization and electricity consumption. Prieto and Caemmerer (2013) showed a positive connection between urbanization and rise in car ownership. Unavoidably, it implies a mounting pressure on transport infrastructure and rise in energy consumption.

Variations in the dimension of emissions across regions, countries and sectors as found by empirical studies have a significant bearing on the nature of policies geared toward regulations (Liu et al., 2017; Oney et al., 2016; Vardag et al., 2015). Taking cognizance of these discrepancies and their peculiarities informs respective regions and countries of the imperativeness of regulatory policy domestication. In their study on emission variation in Europe, Liu et al. (2017) found fossil fuel burning to be a core determinant of CO_2

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variation in the region. This, of course, is different from Sub-Saharan Africa, where deforestation is the lead contributor. The finding showed that power plant, road transportation, residential and industrial sector accounted for 31.8 percent, 22 percent, 18 percent and 17.4 percent, respectively of total fossil-fuel CO_2 in Europe. On account of sectorial and sub-regional discrepancies in Europe, predominantly, the transportation sector was found to have produced the highest fossil fuel-CO_2 in Southern and Western Europe, while Northern and Central Europe led the energy sector fossil fuel-CO_2 emission.

It is therefore imperative to ascertain the subsector of the transportation sector that dominate fossil fuel CO_2 emission. More importantly, as 90% of global energy consumption by transport sector is derived from oil, while fossil fuel combustion contributes 90% of total global CO_2 emissions (Oliver et al., 2012). On a global view, as reported by International Energy Agency, 81% of world energy are derived from fossil fuels-oil (31 percent), natural gas (21 percent) and coal (29 percent) (Cherni & Essaber, 2017). The end-product comprises water vapor, Methane (CH_4), Co_2 and Chlorofluorocarbons (EIA, 2017). Thus, the spillover effect of these inimical gases on the earth is termed "climate change".

At post-millennium, the deterioration of global climate has triggered concerns across countries. Thus, tackling it from the largest source have been identified as a long-term measure. Invariably, the rise in the GHG emission from the transportation sector has been largely attributed to a significant rise in the volume of personal car ownership (PCs) and mileage/weight of the vehicle in Europe (Transport & Environment, 2018). The transportation sector remains Europe biggest contributor to carbon emissions (Frondel et al., 2011). Invariably, the sector's emissions account for 27% of overall CO_2 emissions in the past two decades, as cars and vans contribute around two-thirds of it. The European transportation sector consumes about 66 percent of total fossil fuel, while passenger cars ownership alone accounts for 41percent and 11 percent of the transportation emissions and overall emission, respectively. Thus, the transportation emission rate as a percentage of total emission increased significantly from 21.7 percent in 1990 to 28 percent in 2015. European transportation remains the only sector whose emission growth rate has increased during the period 1990–2015 (WDI, 2020). By implication, without sustainable palliative measures to enforce decarbonized policy, attaining climate goals as sub-objective of sustainable Development Goals will be a mirage.

Additionally, in the UK, the Climate Change Act (AoP 2008) assigned a duty to the country to ensure that net carbon account for the year 2050 is at least 80% lower than the 1990 baseline. The Act aims to enhance carbon management and help the UK's transition toward a low carbon economy. Whilst the country's total GHG emissions were 29% lower in 2013 compared to 1990 levels, the emissions from the transportation sector remained nearly constant in 2013 compared to 1990 levels. 58% of the GHG emissions from the transportation sector are attributed to cars and taxis, 12% to light vans and 21% to other road vehicles such as buses and Heavy Good Vehicles (HGVs) (Department for Transportation, 2013). In 2011, the DfT committed £400 million for the development, supply and use of ultra-low emission vehicles. This package included over £300 million funding for the Plug-in car grant which reduces the upfront cost of purchasing Electric Vehicles (EVs) and qualifying Plug-in Hybrid Electric Vehicles (PHEV) plus £30 million for recharging infrastructure provision through the Plugged in Places Programme (DFT, 2013).

Premised on Kuznets hypothesis, urbanization remains a constant medium of interaction between economic growth and CO2 emissions. Using 2017 GDP as a base year for economic growth, Kompas et al. (2018) forecast an approximate US$9,593.71 billion global potential loss, equivalent to 3% of the 2050 world GDP for an average 3°C global warming. According to the suggestion of IPCC (2014), if sustainable control measure is not firmly executed, climate change impact would inevitably reduce annual GDP growth in developing countries by 3% in 2050, and 10% in 2100. The projection will align with and against the theoretical framework that underpins N-shape and Kuznets theories, respectively.

Both governmental and non-government bodies had advocated a pro-active control measure and workable solutions. Shifting to the renewable and innovative energy mix, among others, have been suggested to control environmental degradation (Balsalobre-Lorente & Álvarez-Herranz, 2016; Álvarez-Herránz et al., 2017). Boarnet (2010), Tayarani et al. (2018) and Stanley et al. (2011) equally found that the government's effective implementation of regulatory policies is an efficacious measure. Also, Moro and Lonza (2017) and Laberteaux and Hamza (2018) suggested that electric vehicles replace conventional vehicles. However, international communities need to compliment sanctions with diplomacy to implement more environmentally friendly energy policies without jeopardizing the economic progress of developing countries.

Thus, on the premise of the above highlights, the present study tends to examine the nexus between car ownership, economic growth, urbanization, tourism and per capita CO_2 emission in the UK. To the best of the authors' knowledge, no studies of this sort has been conducted for the case of UK with the blend of macroeconomic indicators to the carbon-income function framework. Additionally, our study leverages on Nonlinear version of ARDL, which has desirable merits over the conventional ARDL. Specifically, modeling estimates on short and long run simultaneously on car ownership, energy consumption, tourism on CO_2 emission in UK. The NARDL aids in capturing asymmetric of the relationship, which is not accounted for in the liner ARDL. Also worthy of mention, macroeconomic indicators like those employed in this study are plagued with nonlinear traits, making NARDL the most appropriate tool to apply. Thus, providing ample and viable estimates for policy blueprint. The empirical outcome of this study seeks to serves as policy guide to the concerned stakeholders and government officials at all levels for adequate and prompt policy direction. Thus, studies of this sort are timely and worthwhile to the energy-environment and tourism industry.

The rest of this paper is sectioned as follows: Section two highlights the literature review on car ownership, tourism, urbanization and CO_2 emissions. The third section provides data, modeling and methodology. Section four presents a discussion of the analysis and result. Finally, the last section presents the conclusion and policy implications of the findings.

2. Literature review

Environmental Kuznets hypothesis bedrocks studies on environmental economics. The theory demonstrates a U-shape (nonlinear) relationship between environmental degradation and income. Kuznets hypothesis believes that at the initial take-off of the economy, growth is recorded to a certain threshold, corresponding to fast deterioration in environmental quality. But subsequently improves steadily to a level where marginal productivity of inputs begins to reduce, which coincident with the rise in the welfare of the citizens. Then, environmental deterioration plays out again, which is an indication that corrective measure is either obsolete or exhausted

Following the Environmental Kuznets Curve (EKC) hypothesis, several studies either validate or refute the theory, while others remain on the fence. These studies examined the relationship between CO2 and several macroeconomic variables such as GDP (Sinha & Shahbaz, 2018); foreign direct investment (Shahbaz et al., 2015, 2018); car ownership (González et al., 2019; Liu et al., 2017); and energy consumption (Liu et al., 2017). Some studies examined it from the perspective of institutions and governance, such as corruption (Aparicio et al., 2016; Biswas et al., 2012; Choi, 2015; Ozturk & Al-Mulali, 2015). At the same time, others equally suggested sustainable corrective measures to curb anticipated socioeconomic hazards.

Some studies found an N-shape relationship between income and CO2 emissions. According to this submission, initially, both environmental degradation and income show a positive relationship. At higher income, the economy exhibits a self-adjustment-correcting mechanism to suppress ecological maladies. Poor technologies give way to more sophisticated ones, thereby reduces CO_2 emission growth rate. This process is known as the "technical effect". Subsequently, as controlled-measure technologies become obsolete, the ecological status becomes worsen. The hypothesis depicts three different scenarios of the relationship between economic prosperity and environmental pollution: Phase-one (positive), phase-two (negative) and Phase-three (negative). The invention of new technology allows the first phase to metamorphose into the second phase. Increased in economic prosperity promotes Research and Development, leading to better and more cleaned energy consumption. However, according to Balsalobre and Alvarez, Alvarez-Herrranz et al. (2017), Shahbaz, Balsalobre-Lorente, et al. (2019) and Balsalobre-Lorente et al. (2018), the third phase will inevitably emerge when the existing technologies become outdated.

In a nutshell, the world is faced with two challenges: economic development and ecological balance. In recent decades, developed countries thrived toward more development and at worse sustained previous growth when there are shocks. In the same vein, many developing countries have emerged while the developing ones continue to intensify more developmental plans and policies to pull out of poverty and keep up the jones with developed economies. The East Asian miracles epitomize this dimension of economic emancipation. Thus, over the decades, the world has experienced a fast-growing population, industrialization, and transportation, partly attributed to globalization and technological domestication (Baloch et al., 2021). For instance, during the period 1960–2018, the World and Europe recorded an annual average GDP growth rate of 3.5 percent and 2.8 percent. Correspondingly to these decades, gaseous emission grew annually at 18 percent and 24 percent in the World and Europe respectively. Europe's manufacturing and construction emissions scaled by percentage of fuel consumption and transportation emission scaled by total emission were estimated at 15 percent and 24.3 percent, respectively, during the period 1990–2018.

Consequently, the world is facing severe challenges of CO_2 emission emanating from industrial, transportation and services. The socioeconomic cost of environmental degradation poses a serious threat to human health, rainfalls, agricultural output and wildlife (Hafeez et al., 2019). Therefore, environmental dynamics, climate changes, and global warming have enthralled the attention of researchers around the globe (Yuelan et al., 2019). Furthermore, over the years, especially since the inception of the European Environmental Agency (EEA, 2017), empirical studies have addressed CO_2 and suggested an effective mechanism for tackling man-made phenomena. However, there were variations in their findings, benchmarked by Kuznets inverted U-shape theory.

Panel studies by Jamel and Maktouf (2017) and Uddin et al. (2017) found a bidirectional linkage between GDP and pollution. The former validated the environmental Kuznets hypothesis, while the latter found evidence of a positive relationship between ecological footprint (EF) and real income. Similarly, Abdouli et al., Mori et al. and Zturk and Acaravc found evidence of a bidirectional causal relationship between economic growth and CO2 emissions. A unidirectional relationship was found by Ajmi et al. (2015); Farhani and Ozturk (2015); Seker et al. (2015) and Saboori et al.; flowing from economic growth to environmental degradation. Alam et al. (2012) used the Johansen cointegration model and autoregressive distributed lag to examine the dynamic link between economic growth, energy consumption and environmental pollutions in Bangladesh. They found strong unidirectional causality running from CO_2 emissions to economic growth. A Similar study in France and Switzerland by Zanin and Marra (2012) and Al-Mulali et al. (2015), respectively, agreed with Alam et al. (2012) on causality test and conformed to Kuznets' hypothesis. From both studies, per capita GDP showed a positive impact on per capita emissions in the short and long run. Using Panel Pooled Mean Group-Autoregressive distributive lag model (PMG-ARDL) for 16 European countries, Bekun et al. (2019) found a long-run positive relationship between European countries' natural resources rent and CO_2 emissions.

Other studies across countries and regions that validated Kuznets hypothesis are Zambrano-Monserrate and Fernandez (2017) in Brazil; Saboori et al. in Malaysia; Shahbaz et al. (2013) in Romania; Yavuz (2014) in Turkey; Esteve and Tamarit in Spain; Shahbaz et al. and Farhani et al. (2014) in Tunisia; Osabuohien et al. (2014) Africa; Jamel and Derbali (2016) in Asia. Country and regional studies that opposed Kuznets hypothesis are Ozcan (2013) in the Middle East; Chandran and Tang in ASEAN; for Vietnam, Al-Mulali et al. (2015). However, empirical works on the direction and causality link between growth and CO_2 emission failed to account for sector-specific. There are different findings on the sector-specific dimension of CO_2 emission. Among these sectors are tourism, energy, transportation, industrial and construction, among others. However, the energy sector plays an intermediary role between other sectors and CO_2 emissions.

Many recent studies found an inverse relationship between the quality of energy consumed and the quality environment (Cetin & Ecevit, 2017; Dogan & Turkekul, 2016; Hafeez et al., 2019). Jamel et al. found a strong bidirectional link in Asian countries. Shahbaz, Khraief, et al. (2014; Shahbaz, Sbia, et al. 2014) aligned with Kuznets' hypothesis and showed a positive relationship between energy consumption and CO_2 emission. Like Balsalobre-Lorente and Shahbaz (2016), findings by Álvarez-Herránz et al. (2017) validated and justified the efficacy of renewable energy technologies on the environment. They found evidence of an inverse relationship between renewable energy and CO_2 emission in 17 OECD countries. This, of course, suggests strict adherent to the use of renewable energy as efficacious means in tackling CO_2 emission. The outcome for a paradigm shift to renewable energy consumption is also promoted in the empirical study documented by Ozcan and Ozturk (2019). They attributed much importance of renewable as a pathway to green economic growth and environmental sustainability.

Furthermore, Balsalobre-Lorente et al. (2018) validated the N-shaped hypothesis in the EU-5 countries. They found evidence of a negative relationship between clean energy and CO_2 emissions, but was positive when trade openness and natural resources were added to the model. Al-Mulali et al. (2015) found a direct relationship between fossil fuel energy consumption and CO2 emission. However, contrary to Balsalobre-Lorente et al. and Álvarez-Herránz et al. (2017), as found in Al-Mulali et al. (2015), renewable energy consumption showed no efficacy in reducing pollution.

As suggested by Kuznets hypothesis, countries record a high growth rate of emission before they hit a certain threshold. Energy is one of the crucial channels that link up economic growth and CO2 emission. Therefore, the CO2 emissions growth rate in emerging and developing economies is critical to global regulatory policy. In lieu of this, taking into cognizance the mega project "Belt and Road Initiative" (BRI) across Asian countries is not out of place in the context of CO_2 literature. On account of the impact of energy inequalities on environmental degradation among the Belt and Road Initiative (BRI) member states, Hafeez et al. (2019) found positive relationships in Southeast Asia, Central Asia, East Asia, and the Middle East North African region. But negative in the South Asia region. A similar study by Hafeez et al. (2018) for 52 member states of "One Belt and One Road Initiative" aligned with the EKC hypothesis.

Furthermore, Considering that renewable energy is critical to cleaning the environment, Dogan and Seker (2016) showed that renewable energy mitigates CO_2 emissions in Europe. They also found bidirectional causality between renewable energy and carbon emissions. In the same vein, Sharif et al. (2019) explored the dynamic relationship between renewable and nonrenewable energy consumption with carbon emission for a panel of 74 economies using panel estimators that addresses the issues of cross-sectional dependency and heterogeneity issues. The study affirms the presence of possible long-run relationship over sampled period. Furthermore, the study's findings validate the detrimental role of nonrenewable energy on environmental quality. This further highlights the role of Environmental Kuznets Curve (EKC) hypothesis, where emphasis is on economic growth relative to quality of the environment. As a policy suggestion, Sharif et al. (2019) recommends conservative energy policies taking into consideration environmental growth, economic growth and renewable energy options as alternative to fossil fuel-based energy.

In a similar study conducted by Sharif et al. (2020) outlined the pertinent contribution of energy portfolio diversification for the case of Turkey using novel Quantile ARDL approach, where the study validated the EKC phenomenon for Turkey. Additionally, renewable energy decreases ecological footprint in long-run across the characterization of each quantile. In conclusion, renewable was perceived as panacea for sustainable economic growth and environmental sustainability.

Transportation as a derived demand service is a wheel of every economy, and of course requires energy to function. An indication of positive relationship between demand for transportation service and energy consumed. Therefore, the direction of causality and relationship between transportation and CO2 emission has generated several debate and inconclusive submissions. However, the point of convergence indicates that clean energy reduces CO2 emission. For instance, Saboori et al. found a bidirectional and long-run positive relationship between CO_2 emissions and road transportation sector in all the 27 OECD countries. Projection made by Gambhir et al. (2015) and Liu et al. (2017) found passenger cars and heavy-duty trucks as major contributors of future CO_2 emissions. The former estimated a projected annual mitigation cost $64 billion by 2050, while the latter found fossil fuel CO_2 to be predominant in European countries. Similarly, evidences by Nordic Council of Ministers (NCM, 2018) and Liu and Santos (2015) attributed explosive environmental degradation to rise in fossil fuel-powered automobile vehicles. Their findings aligned with Liu et al. (2017). However, the latter found it as the cheapest source of transportation energy.

Different submissions on transportation-CO2 emission nexus is time and sub-sector variant across countries and regions. For instance, in 1990s, emission from air transportation was infinitesimal when scaled by total global emission, but in recent years it has accelerated, enhanced by economic prosperity, especially in emerging economies. As found by Graver et al. (2019), aviation sector accounted for 2.4 percent of global CO_2 emission in 2018. In US, the sector accounted for 12 percent and 3 percent of transportation sector and national emission respectively (Overton, 2019). Taking 2013 as a base year, Overton (2019) found evidence of increment in aviation emissions by 21 percent and 5 percent in 2017 and 2018 respectively. In 2015, as found by Air Transportation Action Group (ATAG, 2019), the sector became the sixth- largest source of global energy emissions. The submission of International Civil Aviation Organization (ICAO, 2019) expects aviation emissions to triple by 2050, and to account for 25% share of global carbon budget.

On the account of European railroad as found by International Union of Railway (2016), it carries 8.5 percent of European overall transportation activities but constitutes less than 1.5 percent of the transportation sector's CO_2 emission. This was in contrast with road (71.9 percent), aviation (12.4 percent) and shipping (14.4 percent). And this justifies the fact that rail remains the most emission-efficient major mode of transportation system in the continent. The comparative emissions advantage of train over other modes of transportation is significant. Compared with road transportation, evidence by Merchan et al. found electric and diesel powered-train to have reduced environmental pollution by 32 percent and 3 percent respectively.

Over the decades it remains crystal clear in literature that urbanization takes prominent interface between economic growth and CO_2 emission. Against this back drop Wang et al. (2018) found bidirectional causality between urbanization and CO_2 emissions in low-income countries. Similar study by McGee and York (2018) found evidence of Asymmetric relationship between urbanization and CO_2 emission. It is an indication that urbanization control policy had a greater impact in reducing CO_2 emission than the reversed scenario. Using a panel threshold regression, as found by Cui et al. (2019), residential electricity consumption constituted an interface in a positive relationship between urban population size and CO_2 emission in China. The empirical evidences provided by Cui et al. (2019), Zhou and Wang (2018), Asumadu-Sarkodie and Owusu and Ahmad et al. (2019) showed that urbanization affected CO_2 emission directly. The findings of Cui et al. (2019) found household energy consumption as interface between the two. However, Raggad (2018), Zheng et al. and Tong et al. found inverse relationship, while Zhou and Liu and Zhu and Peng (2012) showed a negligible and zero impact respectively.

Furthermore, many empirical studies provided evidences of contribution of tourism to emission (Dubois et al., 2011; Katircioglu et al., 2014; Solarin, 2013). In Southeast region, Sherafatian-Jahromr et al. found evidence of U-shape relationship. On the contrary, Lee and Brahmasrene (2013) found negative relationship. However, as suggested by Sherafatian et al., tourism-CO_2 emission nexus could not always be positive in all cases. This was premised on the fact that most countries use tourism to cushion hazardous impact of CO_2. Therefore, empirical findings produced mixed outcomes. Some aligned with Kuznets theory while other totally refute it. Shahbaz et al. (2017) found mixed results in ten selected countries on time-varying causal nexus between tourism development and economic growth. They found weakest causal link in China, Germany and France, while the UK, Italy and Mexico had the strongest causal links.

Many studies refuted EKC hypothesis as it underscores some exceptional scenarios. However, these scenarios do not justify nor render EKC hypothesis totally irrelevant in this present global economic dispensation. The scenario that played out in "Asian Miracle" shows that, at the early stage of economic development most countries vehemently embraced cleaned energy while some resort to modern technologies. In another dimension, clean technologies can be internalized to neutralize hazardous activities that emanate from human and mechanical activities (Vishal, 2011). The findings of Schwanen et al. (2011) lent credence to technological-driven solution, but not without effective government policy. And unlike the developing countries in Africa and Asia, the rich and developed countries in Europe have the resource and policy thrust to tackle environmental degradation, however, it is imperative to define the relationship that exist between the concerned variables and CO_2 emission as to provide definite direction for these policies.

In summary, the empirical studies reviewed in this study provided evidences of dynamism and strong link between CO_2 emission and predictors like urbanization, car ownership, infrastructure, energy-consumed, tourism and deforestation, among other. However, debate on the nexus between CO_2 and its predictors remains inconclusive in the literature (see Katircioglu et al., 2014; Lee & Brahmasrene, 2013) and has not received much attention in European countries at both individual country level and comparatively.

Additionally, a sizeable number of empirical studies on the EKC hypothesis exists on developed countries and emerging economies (Chen et al., 2016). However, given the variation and heterogeneous nature of macroeconomic performance among the sub-regions in Europe, to the best knowledge of the researchers there is yet a study on variation of CO_2 emission using car ownership as a measure in the model for a developed country like the UK. The present study contributes to the existing literature on CO_2 emission globally.

3. Data and methodology

This study adopted the model by Salahuddin and Gow and introduced car ownership, tourism, urbanization and energy

Table 1. Descriptive statistics.

	$LNCO_2$	LNCO	LNGDPPC	LNEC	LNTA
Mean	2.198	10.205	10.366	7.798	9.982
Median	2.222	10.203	10.388	7.833	10.102
Maximum	2.331	10.481	10.627	7.878	10.445
Minimum	1.872	9.863	9.979	7.632	9.346
Std. Dev.	0.114	0.198	0.214	0.074	0.344
Skewness	−1.297	−0.199	−0.374	−0.757	−0.423
Kurtosis	3.899	1.745	1.818	2.178	1.868
Jarque-Bera	10.989	2.527	2.852	4.331	2.915
Probability	0.004	0.283	0.240	0.115	0.233
Sum	76.930	357.160	362.813	272.935	349.363
Sum Sq. Dev.	0.443	1.334	1.552	0.188	4.031
Observations	35	35	35	35	35

Note. Ln represents the natural logarithm of the outlined variables to achieve homoscedasticity.

consumption. Thus, we empirically investigate the following model based on variables in natural logarithms:

$$LNCO2_t = \beta_0 + \beta_1 LNCO_t + \beta_2 LNGDPPC_t + \beta_3 LNEC_t + \beta_4 LNTA_t + \varepsilon_t \quad (1)$$

Where $LNCO_2$ represents the logarithm of CO_2 emissions in the UK; LNCO is the logarithm of the total number of vehicles including Private and light goods, Goods vehicles, Motorcycles, scooters and mopeds, Buses, Special machines, and Crown and exempt vehicles sourced from the Vehicle Licensing Statistics Unit of the Department for Transportation Statistics; LNGDPPC is the logarithm of GDP per capita, sourced from the World Bank Database; LNEC represent log of energy consumption and it is the sum up of Gasoline production (thousand barrels per day), Jet fuel production (thousand barrels per day), Liquefied petroleum gas production (thousand barrels per day), and Oil production (thousand barrels per day), and is sourced from the Office of National Statistics. LNTA repsents total number of tourist arrival in UK sourced from World Bank database.

The coefficients, β_1 … β_4 are elasticity estimates of the variables. We expected that $\beta_1 > 0$; $\beta_2 < 0$ since the UK is a developed economy and the EKC hypothesis suggests this apriori expectation for such economies; $\beta_1 > 0$ and $\beta_4 > 0$. This study is synthesized from economic growth and CO_2 emissions literature. However, the inclusion of tourism, and the use of car ownership variable in this present study distinguishes it from previous studies. Annual data of UK covering the period of 1980 to 2014 were used. We carry out pre-estimation, estimation and post-estimation diagnostics to ensure robustness of the results and overcoming potential limitations in time series analysis. These includes ADF and Phillip Perron unit root tests, bound tests, Pairwise Granger Causality Test, NARDL short and long run estimates, autocorrelation, Heteroskedasticity Test provided by Breusch-Pagan-Godfrey as well as the normality test. Dicks and Pachenko causality test was employed to test the flow of directional relationship.

4. Results and discussion

4.1. Descriptive Analysis

The descriptive statistics of the natural logarithm of carbon emissions ($LNCO_2$), car ownership (LNCO), economic expansion (LNGDPPC), energy consumption (LNEC) and tourist arrival (LNTA) are reported in Table 1. It can be seen from the results that LNGDPPC has the highest average value while $LNCO_2$ has the lowest average values. In terms of volatility (i.e. the degree of the dispersion of the variables from their mean), the values of the standard deviation suggest that the variables are not volatile. A close look at the results reveal that LNGDPPC has the highest volatility while LNEC has the lowest volatility.

Further, all the variables are negatively skewed as indicated by the negative values of the skewness. It is evidently clear from the results of the Jargue-Bera statistic that all the variables except $LNCO_2$ are normally distributed at 5 percent significance level. This finding also agrees with Shahbaz

Table 2. ADF and PP results.

	ADF		PP		
Variables	Levels	First difference	Levels	First difference	Decision
LNCO	−1.967	−3.758**	−1.119	−3.790**	I(1)
$LNCO_2$	0.466	−8.873***	−8.925	−3.874**	I(1)
LNEC	−0.514	−9.410***	0.361	−10.926***	I(1)
LNGDPPC	−1.988	−3.822**	−0.757	−3.827**	I(1)
LNTA	−2.782	−5.238***	−1.660	−5.238***	I(1)

Note. ***, **, and * denote significance at 1%, 5% and 10% level of significance respectively.

Table 3. Bound test results.

ARDL bounds test		
Null hypothesis: No long-run relationships exist		
Test statistic	Value	K
F-statistic	4.471**	4
Critical value bounds		
Significance	I0 Bound	I1 Bound
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Note. ***, **, and * denote significance at 1%, 5% and 10% level of significance respectively.

Table 4. Dicks and Pachenko causality test.

Null hypothesis	F-statistic	Prob.
LNCO ≠>LNCO2*	1.412*	(0.07902)
LNCO2 ≠>LNCO	0.870	(0.19225)
LNGDPPC ≠>LNCO2*	1.535*	(0.06242)
LNCO2 ≠>LNGDPPC	0.775**	(0.21929)
LNEC ≠>LNCO2*	1.564	(0.05891)
LNCO2 ≠>LNEC	0.929	(0.17650)
LNTA ≠>LNCO2***	1.986**	(0.02352)
LNCO2 ≠>LNTA	0.468	(0.32004
LNGDPPC ≠>LNCO*	1.430*	(0.07643)
LNCO ≠>LNGDPPC	−0.675	(0.75014)
LNEC ≠>LNCO	0.773	(0.2198)
LNCO ≠> LNEC	0.350	(0.36322)
LNTA ≠>LNCO***	1.501*	(0.06662)
LNCO ≠>LNTA	1.124	(0.13042)
LNEC ≠>LNGDPPC	0.747	(0.22746)
LNGDPPC ≠>LNEC	1.023	(0.15326)
LNTA ≠>LNGDPPC	0.798	(0.21240)
LNGDPPC ≠>LNTA*	1.300*	(0.09672)
LNTA ≠>LNEC*	1.331*	(0.09165)
LNEC ≠>LNTA	0.360	(0.35929)

Note. ***, **, and * denote significance at 1%, 5% and 10% level of significance respectively, while the symbol ≠> indicate "does not Granger cause".

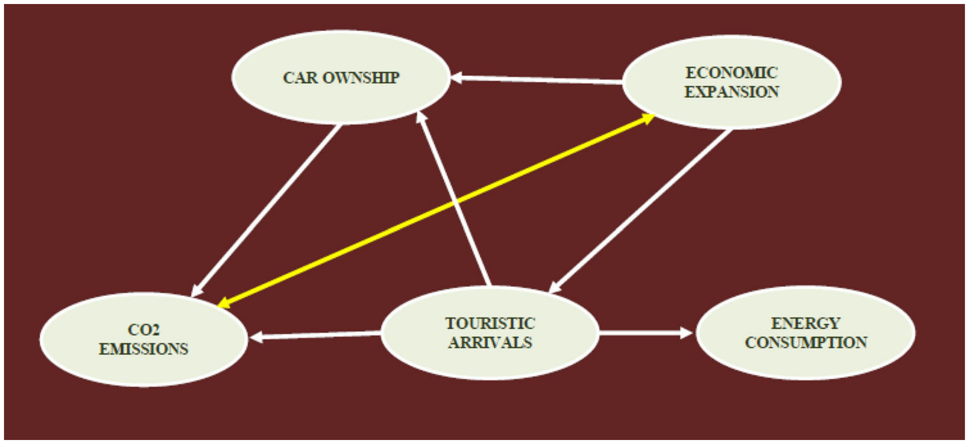

Figure 1. Dicks and Pachenko causality test scheme.

Table 5. NARDL-ESTIMATION (ARDL (2, 1, 3, 3, 3, 3)).

Dependant variable: $LNCO_2$				
	Coefficient	Std. error	t-Statistic	Prob.*
LNCO2(-1)***	−0.924729***	0.186344	−4.962473	(0.0006)
LNCO2(-2)**	−0.381686**	0.150237	−2.540566	(0.0293)
LNCO_POS**	−1.428223**	0.520677	−2.743015	(0.0207)
LNCO_POS(-1)**	−1.654807***	0.529886	−3.122946	(0.0108)
LNCO_NEG***	10.10829***	3.552012	2.845793	(0.0174)
LNCO_NEG(-1)	0.580036	3.915365	0.148144	(0.8852)
LNCO_NEG(-2)	2.713450	3.512875	0.772430	(0.4577)
LNCO_NEG(-3)**	9.307794***	3.101215	3.001337	(0.0133)
LNGDPPC***	1.510803***	0.228388	6.615061	(0.0001)
LNGDPPC(-1)***	0.114085	0.409413	0.278655	(0.7862)
LNGDPPC(-2)	1.182040***	0.357946	3.302289	(0.0080)
LNGDPPC(-3)***	0.244025	0.284297	0.858345	(0.4108)
LNEC	0.573703***	0.154418	3.715268	(0.0040)
LNEC(-1)***	0.351871***	0.122652	2.868852	(0.0167)
LNEC(-2)***	0.493729***	0.143956	3.429721	(0.0064)
LNEC(-3)***	0.400884***	0.194259	2.063656	(0.0660)
LNTA*	−0.195893*	0.096450	−2.031030	(0.0697)
LNTA(-1)	−0.034719	0.107677	−0.322432	(0.7538)
LNTA(-2)	0.042589	0.094647	0.449980	(0.6623)
LNTA(-3)***	−0.398806***	0.080543	−4.951469	(0.0006)
C	−14.64724***	2.473658	−5.921289	(0.0001)
R-squared	0.995689	Mean dependent var		0.949186
Adjusted R-squared	0.987066	S.D. dependent var		0.050057
S.E. of regression	0.005693	Akaike info criterion		−7.275732
Sum squared resid	0.000324	Schwarz criterion		−6.304321
Log likelihood	133.7738	Hannan-Quinn criter.		−6.959076
F-statistic	115.4710	Durbin-Watson stat		2.569400
Prob(F-statistic)	0.000000			

Notes. *p*-values and any subsequent tests do not account for model selection. ***, **, and * denote significance at 1%, 5% and 10% level of significance respectively.

et al. who submitted that carbon emission is not normally distributed at 5% level of significance.

4.2. Unit root test

According to Granger and Newbold (1974), estimated model with non-stationary variables yields spurious results. To avoid this problem, the study employs Philip Perron (PP) and Augmented Dickey-Fuller (ADF) tests to investigate the stationary property of the variables used in the analysis (Phillips & Perron, 1988). Table 2 details the order at which all the variables become stationary. With the exception of the $LNCO_2$ which is stationary at level as indicated by the results of PP and first difference as indicated by ADF, the two tests of stationarity disclose that all the other variables (i.e. LNCO, LNEC, LNGDPPC, and LNTA) are integrated at order one.

4.3. ARDL bound test

Results of the ADF and PP (Phillips & Perron, 1988) tests indicate that the variables are integrated of order zero I(0) and order one I(1). The most suitable test of the long-run relationship in this case is ARDL bound. A close look at Table 3 show that the value of the critical values of the lower (I0) and upper (I1) bounds at 5 percent level is less than the values of the F-statistic. What this implies is that there is more than enough evidence to reject the null hypothesis of no long-run relationship among the variables at 5 percent level of significance. In other words, LNCO2, LNCO, LNGDPPC, LNEC, and LNTA have long-run relationship.

4.4. Granger causality

The paper uses the pairwise Granger causality approach to investigate whether the past value of the variables in the model can be used to predict the future value of the other or not. The pairwise Granger causality results in Table 4 reject the null hypothesis of no Granger causality between carbon emission ($LNCO_2$) and car ownership (LNCO), economic expansion (LNGDPPC) and carbon emission ($LNCO_2$), tourist arrival (LNTA) and carbon emission ($lnCO_2$), tourist arrival (LNTA) and car ownership (LNCO), as well as tourist arrival (LNTA) and economic expansion (LNGDPPC). In other words, the study finds no evidence of directional causality between carbon emission and car ownership, economic expansion and carbon emission, tourist arrival and carbon emission, tourist arrival and car ownership, as well as tourist arrival and economic expansion in the United Kingdom. The findings imply that the past value of the variables cannot be used to predict the future value of the other. Specifically, the finding of non-causality between carbon emission and economic expansion contradict Sinha et al. who reported a bidirectional causality between energy use and growth for the Next 11 countries as well as Huang and Huang (2019) who

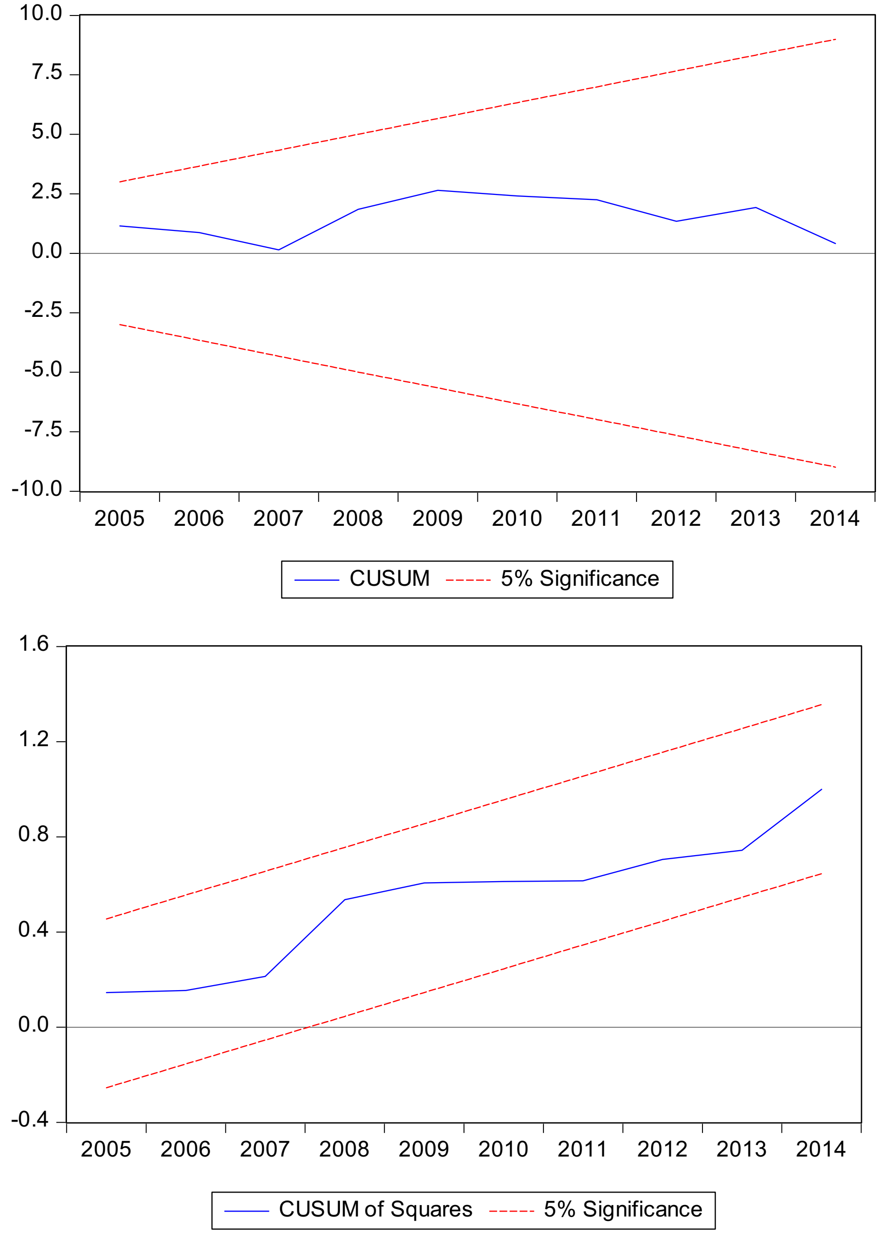

Figure 2. CUSUM and CUSUM-Q.

reported that energy consumption Granger causes economic growth in China.

At 1% significance level, it can be seen that $LNCO_2$ Granger causes LNEC. By implication, the future value of the United Kingdom energy consumption can be predicted using the past value of the carbon emission. This finding is contrary to the work of Rafindadi and Usman, which discloses that energy consumption Granger causes carbon emission in South Africa, and Shahbaz et al. (2018), who reported a bidirectional relationship between carbon emission and energy consumption for France.

There is a one-way causality flowing from LNGDPPC to LNCO at 5 percent. That is, changes in car ownership is preceded by the changes in economic expansion in the United Kingdom as outlined in Figure 1. In a similar manner, the results of the pairwise Granger causality show a unidirectional causality from LNGDPPC to LNEC at 1 percent significance level. This result lends credence to the work of Shahbaz, Sbia, et al. (2019) and the prediction of the growth-led hypothesis, which argue that changes in economic expansion lead to changes in energy consumption. Finally, there is enough evidence that LNTA Granger causes LNEC at 1 percent significance level. This means the past value of tourist arrival influences the future value of energy consumption in the United Kingdom.

This finding directly supports Sherafatian-Jahromr et al. who found evidence of a U-shape relationship between tourism and CO2 emission in the Southeast Asia region. Also, Overton (2019) found evidence of increment in global CO2 emission contributed by the aviation sector, which is a major means of tourist's arrival to be 21 percent and 5 percent in 2017 and 2018 respectively. The finding opposes Lee and Brahmasrene (2013), who found a negative relationship between tourism and CO2 emissions. However, the

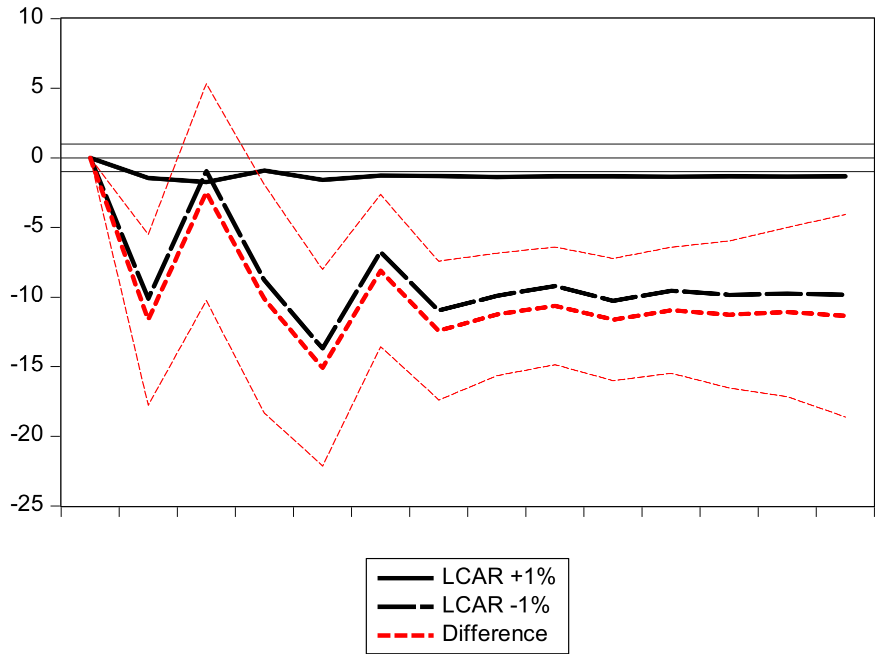

Figure 3. NARDL multiplier.

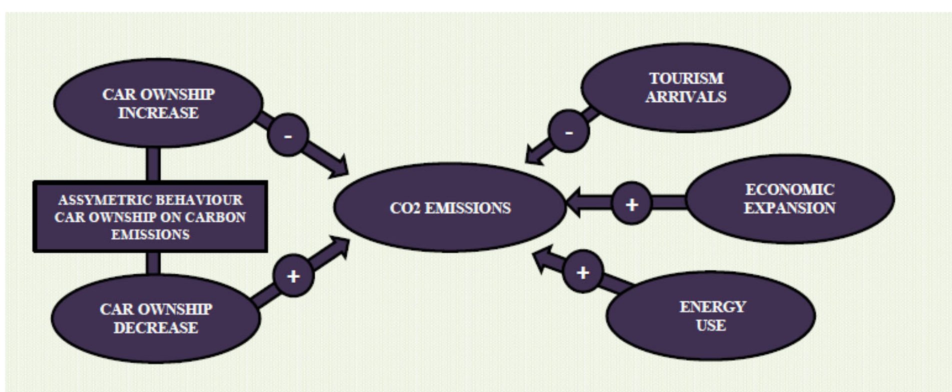

Figure 4. Empirical results graphical abstract.

suggestion by Sherafatian et al. shows that tourism-CO2 emission could not always be positive in all cases, as most countries use tourism to cushion the hazardous side of CO2.

4.5. NARDL estimation

Table 5 presents results for the NARDL estimation. From the results, car ownership has a significant asymmetric impact on CO2 emissions in the United Kingdom while the other variables in the model do not. Previous values of CO2 emissions (LNCO2 (-1)) and LNCO2 (-2)) have a significant negative impact on carbon emission in the United Kingdom. In order words, a 1% increase in (LNCO2 (-1)) and LNCO2 (-2)) leads to 0.92% and 0.38% decrease in the current value of carbon emission in the United Kingdom, respectively, ceteris paribus. Car ownership has an asymmetric relationship with carbon emissions, as earlier stated. This signifies that a negative and positive change in car ownership will have a negative and positive impact respectively on emissions in the UK, ceteris paribus. Specifically, a 1% increase (decrease) in car ownership will lead to a decrease of 1.4% (10.1%) in emissions. Also, the lag value for car ownership has an asymmetric effect on emissions. A positive change in car ownership will lead to a 1.4% reduction in emissions (in the current period), while a negative change in LNCO (-1) will lead to a 0.58% increase in emissions. However, the latter effect is not significant. Also, a negative change in LNCO (-2) will raise emissions by 2.7% but this effect is also not significant. A negative change in LNCO (-3) will lead to 9.3% increase in the level of emissions.

GDP per capita and its lag values have an adverse impact on emissions in the United Kingdom. A 1% rise in LNGDPPC will bring about a rise in emissions by 1.51%. This process implies that as economic expansion occurs in the UK, production activities use a significant amount of combustible energy resources that release emissions into the environment. Though this finding is in line with the submission of Rahmana and Kashemb for Bangladesh as well as Waqih et al. (2019) and Khan et al. for the SAARC region and Pakistan, respectively, it contradicts the finding of BelaIda and Zrellib for Mediterranean countries. Similarly, the lag values of GDP per capita (LNGDPPC (-1), LNGDPPC (-3)) also contribute significantly to high emissions in the United Kingdom.

For Energy consumption, the result is as expected. As can be seen in Table 5, high energy consumption escalates the level of emissions in the UK by an average of 0.57%. This outcome could be due to a rise in nonrenewable energy, especially C02 emitting energy resources such as petroleum, jet fuel in the country, which consequently contribute to high emissions levels. This finding agrees with that of Rahmana and Kashemb for Bangladesh as well as Waqih et al. (2019) and Khan et al. for the SAARC region and Pakistan, respectively. In the same vein, energy consumption in previous years (LNEC (-1), LNEC (-2), LNEC (-3)) also contribute to high levels of emissions in the current period.

On the other hand, as tourism activities go up emissions experience a fall by an average of 0.19%. The emphasis on environmentally friendly tourism in the United Kingdom could be the reason behind the negative relationship between tourism and emissions in the country. Similarly, this result shows that the UK government's efforts in pursuing a clean environment are paying off. Among the previous values of tourism activities in the result, we find that LNTA (-3) contributes to a fall in emissions as well.

4.6. NARDL post-estimation diagnostics

Figure 2 depicts CUSUM and CUSUMSQ tests. Both represent the cumulative sum of recursive residuals and cumulative sum of square of recursive residuals respectively. They are within the critical bounds at 5% significance level. Thus, it implies that our model is stable and reliable to estimate both the short-run and long-run coefficients. The NARDL multiplier in Figure 3 signifies the response of emissions to asymmetric impacts from car ownership (been the only variable with asymmetric characteristics in the model). We can interpret the multiplier thus; a 1% increase in car ownership will increase the emissions of carbon dioxide (CO_2) while a 1% decrease in car ownership leads to a decrease in CO_2 emissions (Figure 4).

5. Concluding remark and policy implications

The causal relationship between economic expansion, tourist arrivals and carbon emission has attracted enormous attention in the empirical literature. This paper, therefore, advances the body of knowledge by investigating the direction of causality between car ownership, economic expansion, tourist arrivals and carbon emission in the United Kingdom using time series data spanning from 1980 to 2014. For the analysis, the paper employed Philip Perron test, Augmented Dickey-Fuller test, Nonlinear Autoregressive Distributive Lag, and pairwise causality test.

The bounds test and the error correction term indicate that the variables are co-integrated. The results of the pairwise Granger causality only suggest a unidirectional causality from carbon emission to energy consumption, economic expansion to car ownership, economic expansion to energy consumption and tourist arrival to energy consumption. The directional causal relationship from economic expansion to car ownership, in particular, suggest that improvement in the performance of the United Kingdom economy will go a long way in driving the purchase of cars in the country.

Further, the short and long-run results show that car ownership has a negative impact on carbon emission. Based on this finding, it is reasonable for the United Kingdom to encourage the use of environmentally friendly cars as this will reduce the carbon emission in the country. The short and long-run analysis discloses that Economic expansion and energy consumption increase carbon emission in the country.

In consequence, our study confirms the validation of the car ownership climate change policies in the UK. For instance, Transportation measures proposed are wide-ranging from providing green travel plan for its staff, introducing flexible working hours and low carbon vehicle fleet to developing a specific project such as the Bristol Rapid Transit Project.

Finally, the short-run and long-run estimates reveal that tourist arrival reduces carbon emissions. So, policies that promote tourism should be encourage as such policies will enhance the use of eco-friendly technologies that will reduce carbon emission in the United Kingdom.

Consequently, our study assumes that the promotion of electric vehicles (EVs) would be seen as the main factor in reducing emissions. So, in order to increase the proportion of EVs in UK urban areas, it will be necessary to implement policies that are "car-friendly" in general rather than being seen as EV friendly specifically. Hence, from empirical results, we recommend that due to the failure of current policies to increase acceptance, the UK government must consider the local characteristic to tailor suitable policies to increase EV uptake.

Abbreviations/Nomenclature

EKC	environmental Kuznets curve
$\beta 1$, $\beta 2$, $\beta 3$, $\beta 4$, and $\beta 5$	are coefficients of parameters to be estimated
ε and t	represents the stochastic term of the fitted model Superscript t time
ADF	augmented Dickey-Fuller
PP	Phillips–Perron
ARDL	autoregressive distributive lag
EIA	US Energy information Agency
NARDL	non-linear Autoregressive distributive lag
GDP	gross domestic product
GHG	greenhouse gas
CO	carbon monoxide
CO_2	carbon dioxide
GDP	gross domestic product
PC	personal car ownership

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