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RESEARCH ARTICLE

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New insights into economic expansion in the United Kingdom: Does energy mix specificity matter?

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Summary

This paper sheds light on the causality linkages between economic growth and energy production, that is, natural gas, bioenergy and waste, coal, nuclear, petroleum, wind, solar and hydro for the United Kingdom over the period 1998Q1 to 2017Q4. To this end, we apply time-domain causality tests—Toda-Yamamoto causality test and gradual shift causality test, and frequency domain causality (FDC) test for empirical analysis to sort out the causality among the outlined variables under consideration. Empirical findings from the spectral BC causality test reveal that (a) changes in energy production from natural gas and petroleum spur significant changes in economic growth in the United Kingdom; (b) economic growth causes energy production from natural gas, petroleum, wind, solar, hydro and nuclear and (c) it is worthy of mentioning that time and FDC tests provide consistent outcomes at different significance and frequency levels. On the causality analysis, the hypothesis that natural gas triggers economic growth is valid, while the result also reveals a feedback causality the variables of concern. Similarly, economic growth drives nuclear energy production one-way as well as total energy drives economic growth. These results provide policy implications for energy and environmental sustainability in the United Kingdom where renewable energy sources drive economic growth. Thus, necessitates the need to maintain the current trajectory for more renewable energy promotion in energy mix relative to fossil-fuel energy sources.

Highlights

- Economic impact is revisited for the United Kingdom over the period 1998Q1 to 2017Q4.
- Toda-Yamamoto, gradual shift and frequency domain causality tests were employed.
- Distinct roles of natural gas, fossil, nuclear and mix of renewables were explored.
- Changes in natural gas and petroleum significantly spur economic growth.
- Frequency domain causality tests offer consistent time and frequency changes.

KEYWORDS

economic expansion, energy cocktail conservation, frequency and domain causality, United Kingdom

1 | INTRODUCTION

While fostering economic growth, the governments and other economic sector stakeholders have increasingly looked out for the underpinnings of economic expansion as instigated by energy production. This, among other reasons, necessitated the modification of the economic growth model, such as the Solow model.[1–3] The neoclassical growth theory, as outlined and expanded in the literature has provided a theoretical background to relevant growth-related studies. Consequently, the incorporation of the energy factor in economic growth further illustrates the innovative properties of the growth model.[4] Additionally, technological change and a shift toward the consumption of cleaner energy sources in developed and various developing countries are now being traced to significant energy efficiency. Moreover, the nexus of energy and economic growth has continued to be investigated for different cases through the conceptual frameworks demonstrated in the recent literature but providing ambiguous empirical findings.[5–8] Despite the environmental consequences of energy utilization (especially from the conventional sources), the economic impact of energy utilization amidst the drive for global economic prosperity has continued to dominate the narratives in the extant studies.[9–12] Importantly, Adedoyin and Zakari[13] and Shahbaz et al[14] observed the role of economic growth and energy utilization in environmental quality, especially for the United Kingdom.

Moreover, the energy dynamics and economic composition of the United Kingdom (a developed country) is a reflection of the country's energy mix and economic diversification. For instance, the Guardian reported that energy efficiency due to diversification and changing economy is responsible for a 1% decline in electricity generation in 2018.[15] Being the largest oil producer after Norway and the third-largest producer of natural gas after Norway and Netherland among the Organization for Economic Co-operation and Development countries, United Kingdom has remained the fifth-largest economy by gross domestic product (GDP).[16] Importantly, EIA noted that the spike in oil and natural gas prices in 2014 is significantly responsible for high investment levels during the period mentioned above, thus causing increased production. Since prices and investment have declined considerably compared to 2014, productions are expected to experience a trend of a long-run decline.[16] Additionally, the UK's energy sector reportedly created £ 83.7 billion in economic activity, supported about 682 000 jobs in the country, and now produces about 53% of power generation from low carbon sources in 2017.[17] However, the share of the clean energy mix in total energy use in the United Kingdom has doubled in the last 10 years, thus implying a significant decline in the share of coal in total energy consumption for many years[16] (inference is captured in Figure 1). Interestingly, Kirikkaleli et al[18] outlined the changes in the United Kingdom's energy utilization in relation to the country's economic dimension. Notably, as illustrated in Figure 2, the United Kingdom's economic progression has not been without undesirable fluctuations which could be explained by energy market dynamics and other related factors.

Given the motivations, especially with a lack of evidence suggesting the impact of the UK's energy

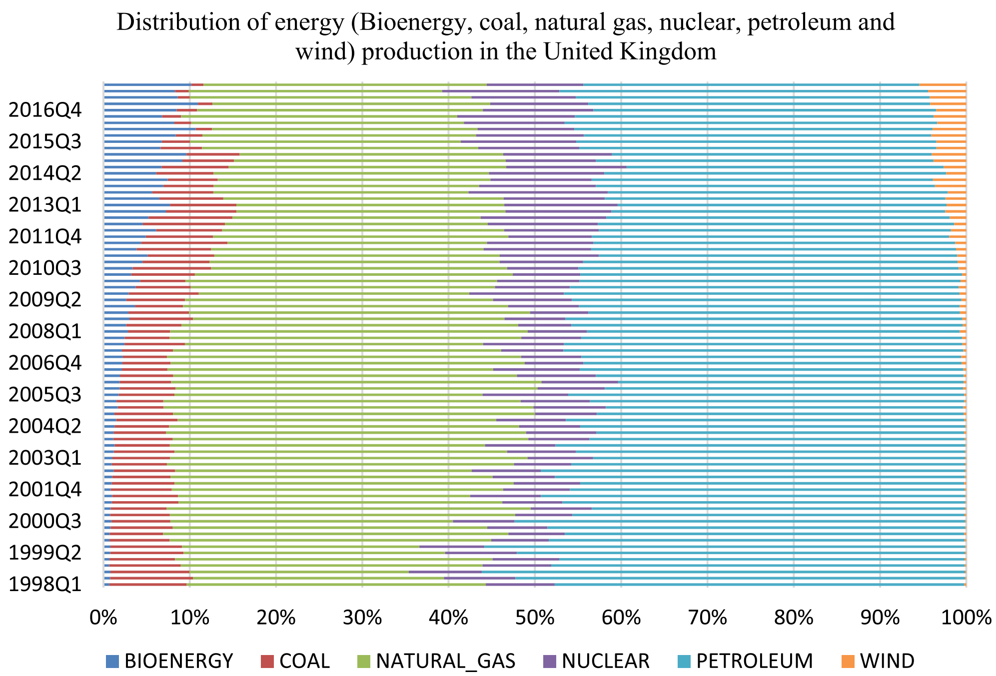

FIGURE 1 The distribution of energy production in the United Kingdom

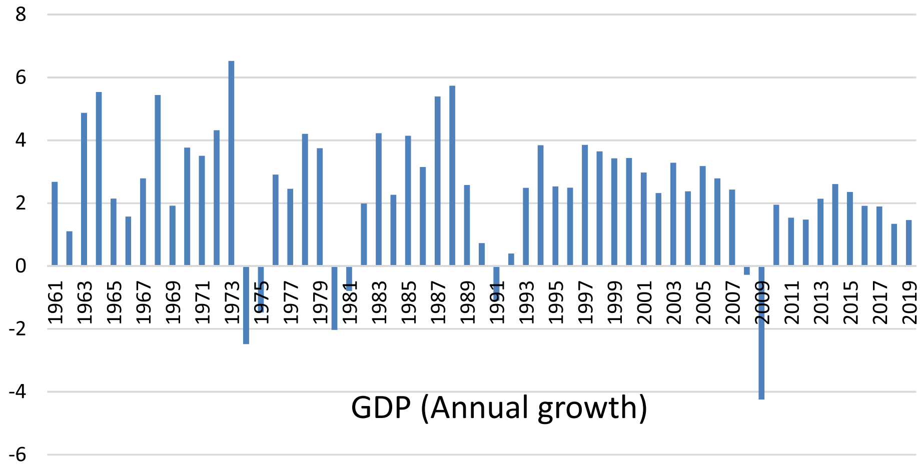

FIGURE 2 Illustration of the annual economic growth of the United Kingdom
Source: The World Bank Development

components on the country's economy, the current study further advances the investigation of the energy sources-economic growth nexus of the world's fifth-largest economy by GDP. Hence, the current study employs six components of the UK's energy mix (coal, petroleum, natural gas, bioenergy and waste, nuclear, wind, solar and hydro) over the period 1998Q1 to 2017Q4 to model economic growth. Giving that this study put forward the United Kingdom's disaggregated energy sources from a rare perspective, this current study provides a novel concept to the existing literature. Given that the aforementioned relationship (between energy utilization and economic growth) exists, the primary objective of the study is geared at examining the magnitude of the influence of each energy production mix on the economic growth of the United Kingdom. In doing so, the potential of the current investigation relies on providing novel contributions to extant literature. Consequently, the foremost contribution is that the current study is one of the first studies that provide empirical and significant evidence that the economic growth of the United Kingdom is a function of the country's energy mix production. Additionally, the current study uniquely provides more robust evidence of gradual shift causality through the novel and recent approach of Nazlioglu, Gormus,[19] and Soytas (2016). The relevance of this approach is that it complements the conventional evidence of gradual causality by Toda and Yamamoto.[20] Studies of this sort are valuable and timely for policy framework construction given the holistic investigation of the energy sector (energy cocktail) in the United Kingdom. Thus, outcomes from this study will serve as a blueprint for government officials, and stakeholders that design and implement energy regulations and strategies in the country and region at large.

The following structure has been employed in the remaining part of this study. An overview of the existing and related literature on the relationship between energy production and economic growth is discussed in Section 2. In Section 3, there are data and the description of the empirical method, while the investigation results are detailed in Section 4. In Section 5, the concluding remarks with relevant policy implications and recommendations for future study are presented.

2 | LITERATURE REVIEW

This section highlights two important aspects. In the first case, we present an additional theoretical perspective that establishes the connection between the nexus of economic growth and energy development. In the second part, related studies were carefully discussed.

2.1 | Theoretical perspective

Globally the world is at a crossroad where energy production and consumption is been blamed for global warming issues. Thus, there is a need for sustainable and responsible energy consumption (SDG-11). This implied the need for innovative ways for energy production and consumption. The present study draws strength for the tradeoff between energy production or consumption and environmental quality fondly known in the energy and environment literature (especially the environmental Kuznets curve of[21]) as further expanded by Grossman and Krueger.[22] Additionally, the channel through which energy drives economic growth is hind on four divides in the energy literature namely (a) growth-induced energy consumption where energy drives energy production and consumption, (b) conservative hypothesis, (c) feedback causality hypothesis and (d) neutrality hypothesis more insight in the channel and connection on energy production and economic growth.[23,24]

2.2 | Economic growth-energy production nexus at global level

The novel study of Kraft and Kraft[23] that examines the nexus of energy and Gross National Product (GNP) has been a pioneering framework between energy production (consumption) and economic growth. The aforementioned study notes that there is either a constant or an unchanging relationship between energy production (consumption) and economic growth by investigating the energy-GNP causal nexus. Despite the observation of a declining impact of energy on the economy, especially in developed countries,[4] the related studies from the last decades have continued to reveal the importance of studying the energy-growth nexus. The importance of energy to most world economies is not unconnected with the dynamics of global energy prices and other socio-economic and environmental indicators.[25] For instance, while considering the panel of Asian developing countries (India, Indonesia, the Philippines, and Thailand), Asafu-Adjaye[26] investigated the nexus of energy consumption, energy prices and economic growth. The empirical results found a unidirectional Granger causality (in the short-run) running from energy consumption to economic growth for India and Indonesia; the evidence of bidirectional Granger causality was found for both Thailand and the Philippines. Indicatively, Asafu-Adjaye[26] validated the energy-income nexus hypothesis as expanded in existing literature.[27–31] However, the specific role of energy production in economic growth is as important as the energy consumption-economic growth nexus.

In respect to energy production, insight from extant literature has further provided varying evidence of energy production and economic growth relationship, most likely due to the country's energy mix's peculiarity. For instance, Wada[32] associates the high personal income with a higher production level per capita. The study further found significant evidence of Granger causality (unidirectional) from economic growth to total energy production for the case of Saudi Arabia. Additionally, Bento and Moutinho[33] disaggregate energy production into conventional (dirty) energy sources and renewable (cleaner) electricity production. The impacts of these forms of electricity production on economic growth are observed over the period 1960 to 2011 in Italy. In the presence of structural breaks, the study of Bento and Moutinho[33] validates a unidirectional Granger causality between income per person and clean electricity production per capita. Their empirical evidence of renewable electricity production and GDP per capita nexus is further validated by York and McGee[34] while further indicating that the experience of economic growth is susceptible to CO_2 emissions. In Brazil, hydropower has since been the primary energy source. Notwithstanding, the growing influence of hybrid power generation from hydro- and solar energy resources has remained the current energy-mix policy.[35–37]

Besides, by employing the empirical (cointegration) approach by Maki,[38] which complement other empirical methods in a three different case (Nigeria, Pakistan, and Zimbabwe) investigation, evidence found a nexus of energy use and economic growth nexus over the period 1971 to 2014. In the first case, Bekun and Agboola[39] found long-run and positive statistical evidence of electricity utilization and economic growth nexus for Nigeria, thus affirming the electricity-induced growth hypothesis. They applied the Granger causality approach of Toda and Yamamoto[20] and reported one-way causality between electricity consumption and economic growth. Similarly, by employing the Maki cointegration approach accounting for multiple structural breaks in Zimbabwe, Samu et al[40] further revealed a long-run relationship between electricity utilization and GDP per capita. They also noted the impact of electricity consumption on GDP per capita, which significantly validates the electricity-led growth hypothesis. Balcilar et al[28] found a cointegration between electricity usage, economic growth, and CO_2 emissions. They further noted the presence of a conservative hypothesis, that is, causality running from electricity consumption to CO_2 emissions. In the literature, the growth model has been expanded from the perspective of energy consumption using different estimation techniques or approaches and for varying cases across the globe.[41–43]

3 | INDICATORS AND METHODS

The current section presents the description of the dataset and the sequence of the methodology.

3.1 | Description of the indicators

This paper adopts a secondary quarter frequency dataset for the period of 1998Q1 to 2017Q4 to conceptualize the dynamic interaction between the highlighted variables under consideration for the UK's case. The data for the study comprises of energy production which includes natural gas, bioenergy and waste, coal, nuclear, petroleum, wind, solar and hydro where retrieved from the UK Energy Statistics available at (https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes). At the same time, economic growth measured by

TABLE 1 Descriptive statistics

Variable	Bioenergy	Coal	Natural gas	Nuclear	Petroleum	Wind, solar and hydro	Economic growth
Mean	1.357	3.205	17.501	4.264	21.744	0.440	5.768
Median	1.150	2.854	17.740	4.069	20.231	0.240	5.797
Maximum	3.158	6.909	27.852	6.133	38.137	1.603	5.903
Minimum	0.507	0.434	8.662	2.780	10.059	0.082	5.599
Std. Dev.	0.749	1.600	6.836	0.815	8.931	0.417	0.096
Skewness	0.796	0.249	0.040	0.369	0.410	1.256	−0.634
Kurtosis	2.565	2.449	1.415	2.320	1.795	3.338	1.989
Jarque-Bera	9.085	1.838	8.388	3.359	7.080	21.445	8.771
Probability	0.010	0.398	0.015	0.186	0.029	0.000	0.012
Observations	80	80	80	80	80	80	80

real GDP per capita (constant US$) is gathered from World Development Indicators (DUKES, 2019).[44] All interest variables have been converted to natural-log form. This helps to achieve the growth of all outlined variables and eliminate heteroscedasticity in the variables. Table 1 reports the descriptive statistics of energy production (natural gas, bioenergy and waste, coal, nuclear, petroleum, wind, solar, and hydro) and economic growth in the United Kingdom.

3.2 | Methods

This study's empirical path to explore the causality relationship between energy variables and economic expansion over 1998Q1 to 2017Q4 is constructed in three ways. First, preliminary analysis of basic summary statistics of the variables under review. Second, an investigation of the stationarity properties of the employed variables is undertaken in the subsequent subsection. The stationarity test is pertinent to avoid spurious estimation and, by extension, wrong inferences.

3.2.1 | Unit root testing

In examining the stationarity behavior of the dataset, we employ the Zivot and Andrews (ZA) unit root test. The ZA stationarity vis-à-vis unit root test that accommodates a single unknown structural break in the time series (TS) data is employed. Further, the ZA unit root test is used instead of traditional unit root test such as Phillips and Ouliaris,[45] Phillips and Perron,[46] and Augmented Dickey-Fuller[47] that are plague with size and power problem. Thus, the ZA unit root test ameliorates for issues that provide a more robust estimate. The empirical equation for ZA unit root test is modeled as follows:

$$\Delta Y_t = \alpha_1 + \alpha_2 t + \theta Y_{t-1} + \gamma \mathrm{DU}_t + \sum_{i=0}^{k} \xi_i \Delta Y_{t-i} + \varepsilon_t, \quad (1)$$

$$\Delta Y_t = \alpha_1 + \alpha_2 t + \theta Y_{t-1} + \phi \mathrm{DT}_t + \sum_{i=0}^{k} \xi_i \Delta Y_{t-i} + \varepsilon_t, \quad (2)$$

$$\Delta Y_t = \alpha_1 + \alpha_2 t + \theta Y_{t-1} + \gamma \mathrm{DU}_t + \phi \mathrm{DT}_t + \sum_{i=0}^{k} \xi_i \Delta Y_{t-i} + \varepsilon_t, \quad (3)$$

where dummy represents by $\mathrm{DU_t}$ indicates a possible shift in either the intercept model or intercept and trend model. The ZA unit root test has a null hypothesis of non-stationarity, that is, $H0: \theta > 0$, against an alternative of stationarity, $H1: \theta < 0$.

3.2.2 | The causality analysis

A series of causality estimators that are applied to investigate the direction of causality include the use of the Toda-Yamamoto (hereafter T-Y), causality test,[20] frequency domain causality (FDC) test—Spectral BC causality test proposed by Breitung and Candelon (2006),[48] and more recently, gradual shift causality (GSC) test proposed by Nazlioglu, Gormus, and Soytas (2016). Previous studies in the related literature detected the direction (uni- or bi-directional) of causality flow by the conventional Granger causality test between the variables in the short run. For instance, say variable X and Y. The Granger causality test has the null hypothesis of non-Granger causality: variable

X does not Granger cause Y, that is, if only the contemporaneous and past realization of X variable does not have explanatory power to explain variable Y. Equation (4) presents the idea in statistical form.

$$X_t = \alpha_0 + \alpha_1 Y_{t-1} + \ldots + \alpha_z X_{t-z}, \tag{4}$$

$$Y_t = \beta_0 + \beta_1 X_{t-1} + \ldots + \beta_z Y_{t-z}. \tag{5}$$

Here, X_t represents the different energy forms as outlined in the data section while Y indicates economic growth while α's β's are slope and coefficient parameters to be estimated. Finally, the lag order is represented by symbol z.

This study further conducts the FDC test advanced by Breitung and Candelon (2006), which is an extension of the previous work of Geweke (1982)[49] and Hosoya (1991)[50] called the "spectral BC causality method." The core distinction between the common time-domain causality and frequency causality techniques is "the time-domain" techniques display all variations in TS. On the other hand, frequency domain techniques capture the degree of specific variation in TS. In short series study cases where there may be a seasonal pattern of importance, the frequency domain ameliorates for such variations. Furthermore, the frequency domain accounts for non-linearity and possible causality cycles in the series of interest, that is, causality at either high or low frequencies.[51–53] To achieve the main objective of this study, we need to explore the causality between different energy forms and economic growth for the case of the United Kingdom. The present study adopts the use of Breitung and Candelon (2006), especially using a simplified approach. We let $Z_t = [X_t, Y_t]'$, such that X_t (a stable and two-dimensional vector of endogenous variables over the period t = 1, ..., T) is presented in the following expression.

$$\Theta(L) X_t = \varepsilon_t. \tag{6}$$

In addition, the $\Theta(L)$ (which is a 2 × 2 lag polynomial of order p) is further computed using the technique of Cholesky decomposition such that the moving average (MA) is composed as:

$$Z_t = \begin{pmatrix} X_t \\ Y_t \end{pmatrix} = \Phi(L)\varepsilon_t = \begin{bmatrix} \Phi_{11}(L) & \Phi_{12}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}, \tag{7}$$

$$= \begin{pmatrix} X_t \\ Y_t \end{pmatrix} = \Psi(L)\eta_t = \begin{bmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \end{bmatrix} \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \end{bmatrix}. \tag{8}$$

Given that $\Phi(L) = \Theta(L)^{-1}$ and $\Psi(L) = \Phi(L)G^{-1}$, the spectral density of FS_t becomes

$$f_X(\omega) = \frac{1}{2\pi}\left\{ \left|\Psi_{11}\left(e^{-i\omega}\right)\right|^2 + \left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2 \right\}. \tag{9}$$

Given Equations (7) and (8), respectively, presents the MA sum of the uncorrelated process of saying variable X and Y. Intuitively, we say the past and the present component of variable X has predictive power over Y. The predictive power of each variable at a different frequency can be computed by ω which is estimated by comparing the predictive components of the spectrum and intrinsic components at the frequency. Thus, the computation is demonstrated from the following expression:

$$M_{X\to Y}(\omega) = \log\left[\frac{2\pi f_X(\omega)}{\left|\Psi_{11}\left(e^{-i\omega}\right)\right|^2}\right], \tag{10}$$

$$= \log\left[1 + \frac{\left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2}{\left|\Psi_{11}\left(e^{-i\omega}\right)\right|^2}\right], \tag{11}$$

when $\left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2 = 0$, the Geweke's measure becomes zero. That is, as already establish, variable X does not cause Y frequency (ω). A simple version of the above equation is presented as advance by Breitung and Candelon (2006) by imposing a linear restriction on the coefficient of the VAR model and the subsequent expressions are detailed in the aforementioned literature (Breitung and Candelon 2006).

This paper also applied the time-domain causality of Toda-Yamamoto[20] and recently developed and advanced by Nazlioglu et al (2016) to explore the nexus between the different energy forms and economic growth for the United Kingdom. The criticism of the traditional Granger causality test that is constructed on the asymptotic distribution is viewed to present bias results in cases where the variables have a unit root (Granger & Newbold, 1974).[54] The T-Y causality a modified version of the Wald test distributed by chi-square does not require any pretest and integration order of outlined variables neither cointegration among variables investigated. The abovementioned traits of T-Y causality pace it at an advantage over conventional Granger causality. The T-Y causality is built on vector autoregressive (VAR) (with K dmax); where the optimal order of the VAR is represented as K while the dmax means maximum integration order of the outlined variables under investigation. To further substantiate the causality analysis, the recently novel Fourier causality test includes a smooth, gradual shift that is robust for a structural shift in detecting the causality flow direction. The Fourier T-Y accommodates for breaks by the use of Fourier approximation in the analysis of Granger causality.[55–57]

TABLE 2 The stationarity verification

	Constant model		Constant and trend model	
	T-stat	Breaks	T-stat	Breaks
Series in levels				
Natural gas	−3.512	2009Q2**	−3.806	2010Q4
Bioenergy	−2.910	2014Q4**	−2.609	2011Q4
Coal	−4.704*	2008Q2**	−4.642	2010Q2**
Nuclear	−3.469	2009Q3**	−5.150**	2006Q4**
Petroleum	−3.967	2014Q4**	−4.126	2012Q2
Wind, solar and hydro	−1.135	2013Q2*	−3.840	2010Q1**
Economic growth	−3.446	2003Q4**	−4.696	2008Q3**
Series in first differences				
Natural gas	−5.953**	2013Q1**	−5.806**	2005Q3*
Bioenergy	−8.746**	2014Q4**	−9.144**	2014Q4**
Coal	−6.799**	2012Q3**	−6.810**	2008Q1
Nuclear	−8.374**	2008Q4**	−8.301**	2008Q4
Petroleum	−5.195**	2014Q4**	−5.305**	2014Q4**
Wind, solar and hydro	−7.907**	2011Q2**	−7.807**	2011Q2**
Economic growth	−7.480**	2008Q1**	−7.432**	2008Q1**

Note: ** and * denote statistically significant at 5% and 10% levels, respectively.

4 | RESULTS AND DISCUSSION

In TS analysis econometrics literature, it is usually a tradition to explore the primary summary statistic of outlined interest variables for indicating the nature of the variables to aid adequate modeling. Table 1 presents the summary statistics that report both central tendency measures (mean, median, maximum and minimum) and measurement of dispersion like SD. In Table 1, among energy cocktail, petroleum energy ranks with the highest average and same time possess highest maximum and minimum followed by natural gas and while wind, solar and hydro possessing lowest mean. All the outlined variables exhibit significant departure from their means as reported by the SD. The three indicators of symmetry, kurtosis, skewness and Jarque Bera test shows that all variables are positively skewed, except economic expansion. Coal and nuclear energy sources show normality properties. Subsequently, the stationarity is rendered in Table 2. Two models were conducted, both models of only constant term and constant and trend were reported. Both models submit the interest variables are first difference stationary. At level form, the variables were nonstationary but after the first difference, all series were stationary as reported by the Zivot and Andrews[58] unit root estimates that accounts for a single structural break (see Table 1).

4.1 | Causality results

In econometric inference, regression analysis expectedly presents a different inference from causality, thus necessitates the need for a causality test in the current endeavor. This study adopts a battery of causality tests to reinforce the causality results for more robust and insightful inferences for policy direction. This approach has been utilized.[18,59,60] Table 3 presents the modified Wald test results. We observe a feedback causality relationship between natural gas and economic growth. This outcome is insightful for government officials as energy (natural gas) drives economic growth. This result is consistent with Wesseh and Lin[61] for the case of Egypt. Akadiri et al[62] for Saudi Arabia's case found contrary results where natural gas and economic growth do not drive each other. Although Ozcan and Ozturk[63] and other studies found a neutrality hypothesis between energy utilization and economic growth, there are consistent revelations that support either a one-way or two-way Granger causality between the variables of concern (economic-energy dynamics).

Similarly, a one-way causal relationship is seen from total energy to economic expansion, while unidirectional causality is seen from economic growth to nuclear energy consumption. This implies that the diverse energy sources of the United Kingdom are pertinent to economic growth. The concern observed in her energy

TABLE 3 Causality tests

	Direction of causality	Lag	MWALT	Prob.
Toda Yamamoto causality	BIO → EG	2	3.246	0.197
	EG → BIO	2	2.175	0.336
	COAL → EG	2	0.524	0.769
	EG → COAL	2	1.822	0.402
	NATGAS → EG	7	18.821	0.012**
	EG → NATGAS	7	16.288	0.022**
	NUCL → EG	3	0.802	0.848
	EG → NUCL	3	9.739	0.020**
	PET → EG	2	0.298	0.861
	EG → PET	2	6.837	0.057*
	WIND → EG	3	4.132	0.247
	EG → WIND	3	3.065	0.381
	TOTAL → EG	7	13.463	0.061*
	EG → TOTAL	7	13.475	0.061*
		Lag	**F-stat.**	**Prob.**
Gradual shift causality	BIO → EG	2	2.376	0.304
	EG → BIO	2	3.071	0.215
	COAL → EG	2	0.219	0.895
	EG → COAL	2	1.453	0.483
	NATGAS → EG	7	17.456	0.013**
	EG → NATGAS	7	17.796	0.012**
	NUCL → EG	3	0.243	0.970
	EG → NUCL	3	22.371	0.000**
	PET → EG	2	0.256	0.879
	EG → PET	2	7.793	0.047*
	WIND → EG	3	4.182	0.242
	EG → WIND	3	2.905	0.406
	TOTAL → EG	7	15.964	0.025**
	EG → TOTAL	7	14.449	0.043**

Note: → indicates the direction of causality. The optimal lag is selected using AIC. ** and * denote statistically significant at 5% and 10% levels, respectively.

mix is that the economy is driven by non-renewable energy sources even though renewables are in her energy mix. There is a need for government administrators to intensify the diversification of the UK energy mix to cleaner energy sources like renewables that are more eco-friendly.[64] The spectral BC causality graphical plots are presents in Figures 3 to 16. Figures show the spectral BC causality running from economic growth to natural gas, which indicates an ongoing strong long-run one-way causality relationship running from economic growth to natural gas and nuclear energy productions in the long run.

Moreover, economic growth changes significantly lead to petroleum energy production changes in the short run at a 10% significance level. The present study also reveals that natural gas production is an important factor influencing predicting economic growth in the United Kingdom. Besides, Figures 14 and 15 show that while in the United Kingdom the economic growth significantly causes total energy production in the short term and medium term, total energy production significantly causes economic growth in the long term. In other words, there is feedback causality between total energy production and economic growth in the United Kingdom at different frequencies. As a robust causality test, we also employed a time-domain causality test, namely T-Y causality and GSC estimation approaches. The outcomes from these tests are reported in Table 3. It is noteworthy to mention that the findings from the spectral BC

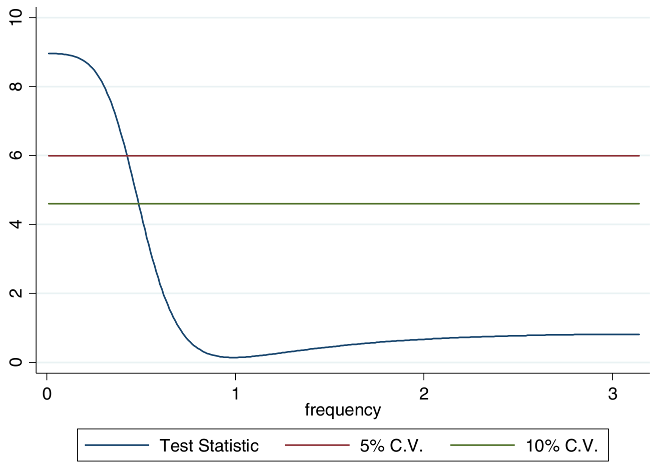

FIGURE 3 The SBC causality from economic growth to natural gas

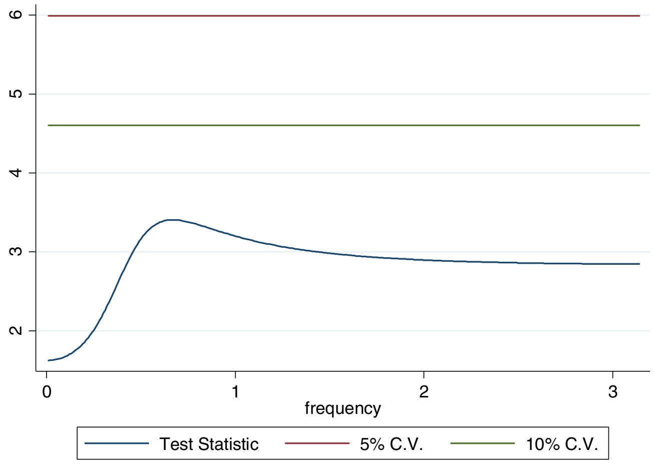

FIGURE 4 The SBC causality from economic growth to bioenergy

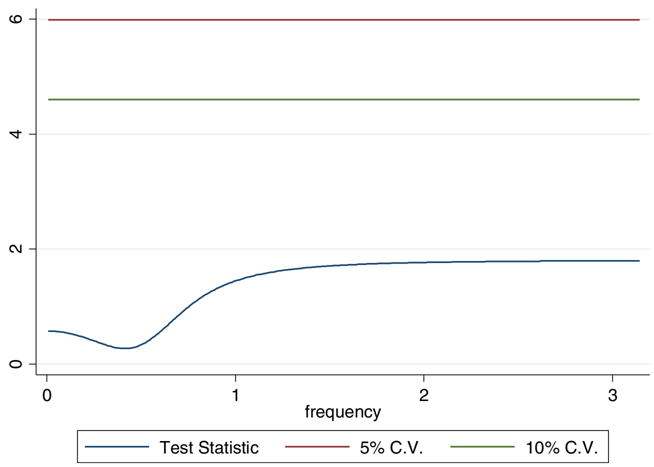

FIGURE 5 The SBC causality from economic growth to coal

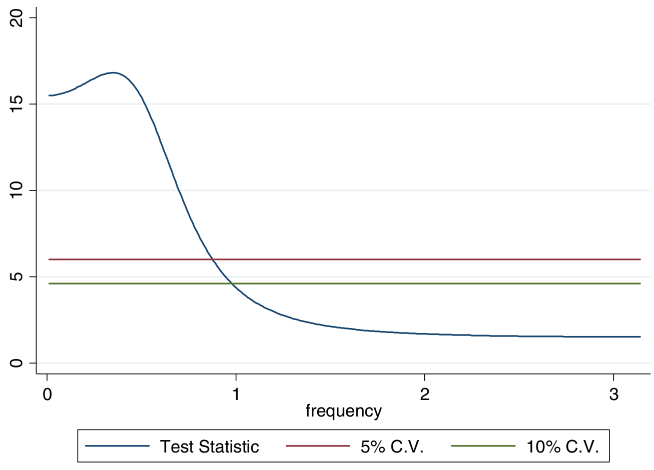

FIGURE 6 The SBC causality from economic growth to nuclear

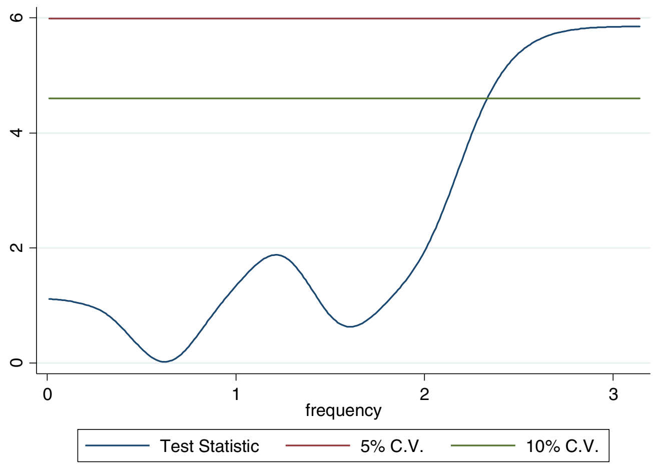

FIGURE 7 The SBC causality from economic growth to petroleum

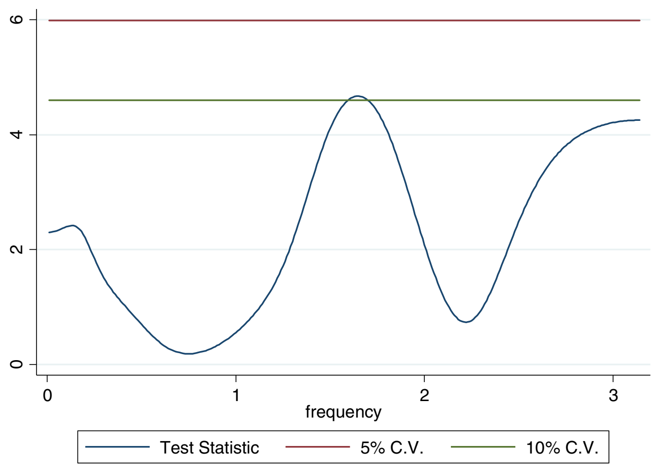

FIGURE 8 The SBC causality from economic growth to wind, solar and hydro

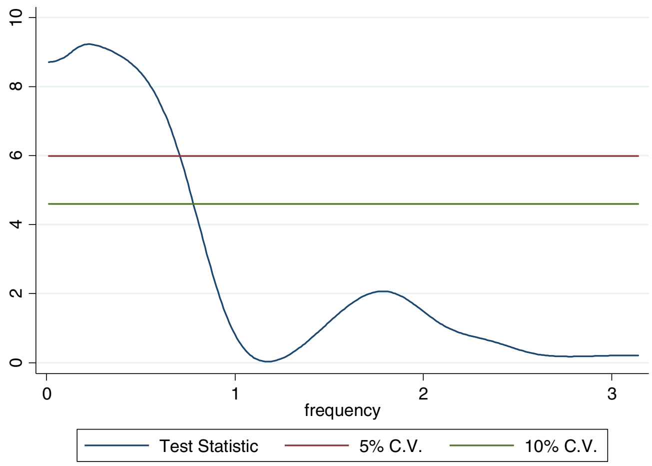

FIGURE 9 The SBC causality from natural gas to economic growth

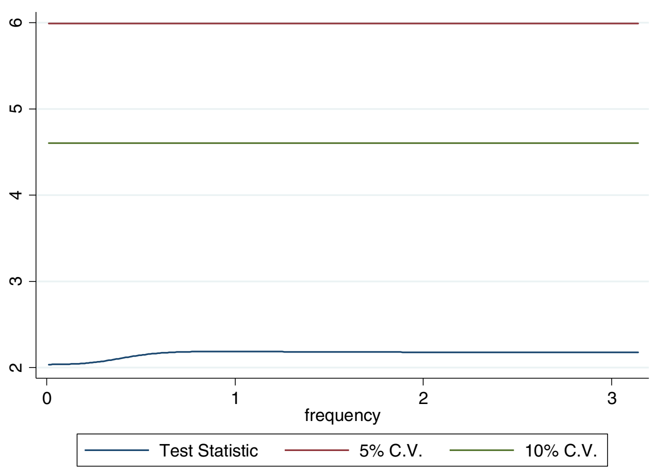

FIGURE 10 The SBC causality from bioenergy to economic growth

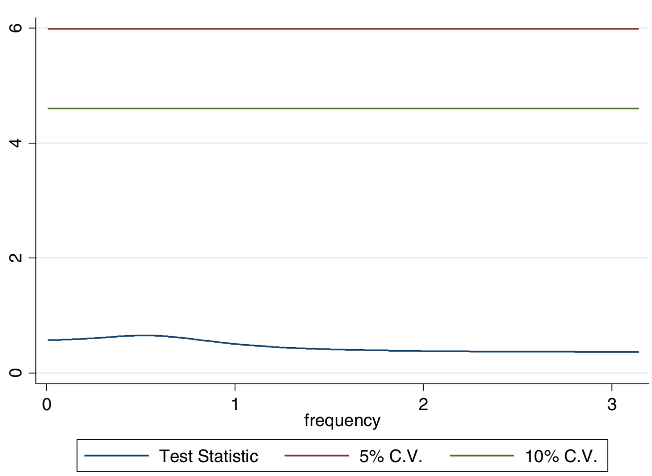

FIGURE 11 The SBC causality from coal to economic growth

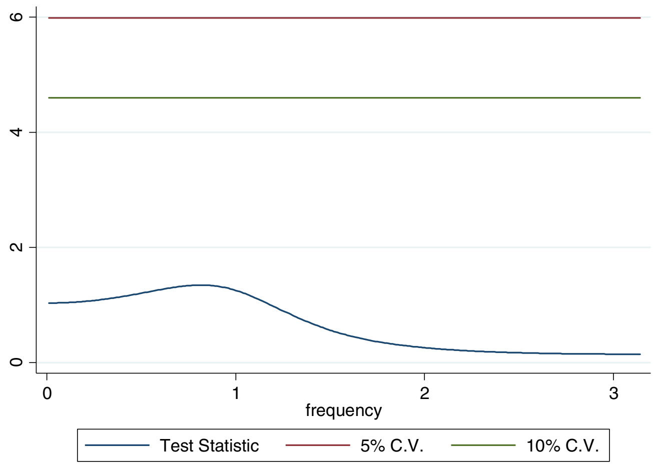

FIGURE 12 The SBC causality from nuclear to economic growth

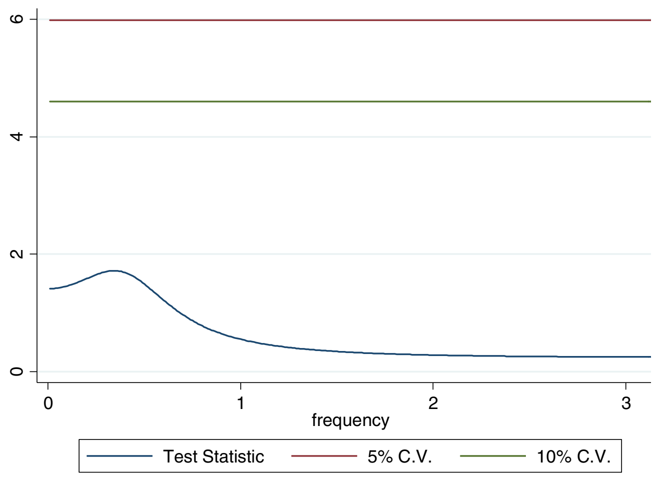

FIGURE 13 The SBC causality from petroleum to economic growth

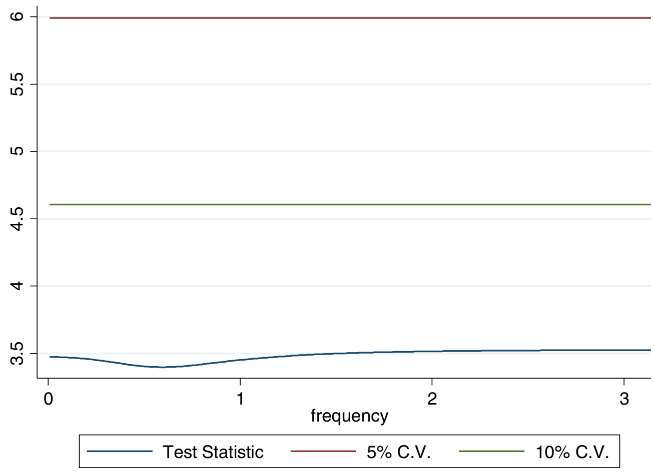

FIGURE 14 The SBC causality from wind, solar and hydro to economic growth

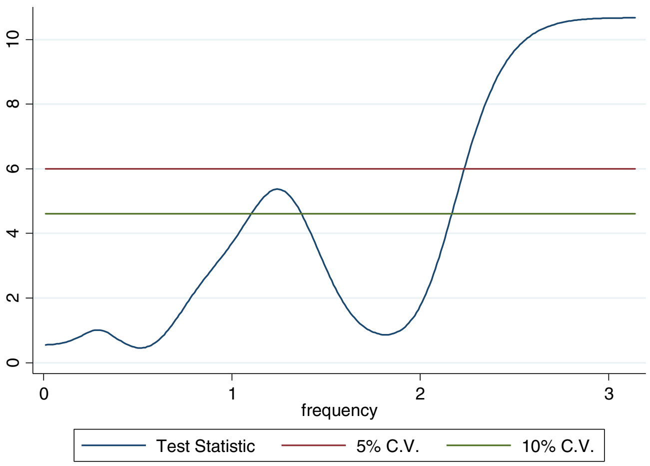

FIGURE 15 The SBC causality from economic growth to total energy

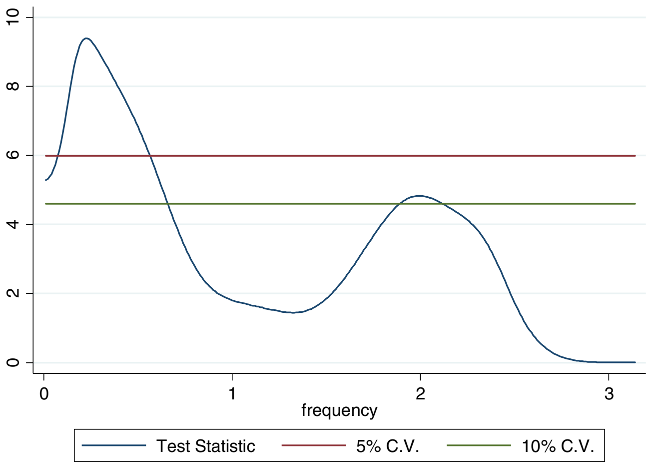

FIGURE 16 The SBC causality from total energy to economic growth

causality tests are in line with the results from Toda Yamamoto Causality and GSC.

5 | CONCLUSION AND POLICY IMPLICATIONS

The path to sustainable economic growth and clean energy is part of the core of sustainable development goals (SDGs). This has left most government of nations on the trajectory for economic expansion, especially the wave of energy intensification and global warming issues. Since the emergence of the study of Kraft and Kraft[23] that relates the role of energy utilization economic expansion, several studies have followed the approach to present different cases.[65–68] However, energy economics literature has well-documented studies on the theme under review for several regions. This study distinct from the bulk of studies in the extant literature in terms of scope as the focus is on the United Kingdom and holistically investigated an array of energy sources and economic growth ignored in existing literature or has received less documentation. Simply put that, the current study examined the energy cocktail on the economic growth of the United Kingdom.

Empirical results from the battery of the causality test show different outcomes. For instance, the feedback causality seen from economic growth to natural gas is indicative for the United Kingdom. The results from the spectral BC causality test show the following (a) changes in energy production from natural gas and petroleum significantly lead to changes in economic growth in the United Kingdom; (b) economic growth causes energy production from the sources of natural gas, petroleum, wind, solar, hydro and nuclear; and (c) it is worthy of mentioning that time and FDC tests provide consistent outcomes at the different significance and frequency levels.

These findings show the pivotal role of economic growth in predicting energy production, especially the feedback causality observed between natural gas and economic growth over the UK's sampled period. In addition, worthy of note is the one-way causal linkage from nuclear energy to economic growth, validating the growth-induced energy hypothesis. This outcome resonates with the study of Lean and Smyth[69] for the case of Malaysia. This suggests that the more significant the UK economy's expansion, the more demand for energy production and consumption by industrial and private sectors. This current energy disposition for the United Kingdom is instructive, to energy specialists, and insightful to government administrators on her energy mix to circumvent the advert effect for fossil fuel energy-driven economy. This, in turn, will align with the attainment of the SDGs-11 that focuses on cleaner energy access. In summary, this study reveals that renewable energy production increases economic growth as nuclear energy, natural gas and total energy spur economic growth in the United Kingdom. The plausible explanation to this success story could be tied to the commitment of each EU country to a cleaner environment and decarbonization of the economy by focusing on renewable energy in the energy portfolio. Furthermore, being a signatory to the Kyoto Protocol and Paris agreement and national environment treaties will perpetually leave the United Kingdom economy on green development.

Conclusively the current study explored energy production across varying renewable sources namely natural gas, bioenergy and waste, coal, nuclear, petroleum, wind, solar and hydro. In the context of this study, further studies can be conducted in other developed countries to determine the determinant of renewable energy production on economic growth using disaggregated data.

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