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Modeling natural gas consumption, capital formation, globalization, CO_2 emissions and economic growth nexus in Malaysia: Fresh evidence from combined cointegration and causality analysis

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A R T I C L E I N F O

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A B S T R A C T

The discovery of natural gas in the 20th century has increased aggregate energy consumption while spurring economic development. However, very little attention has been given in the energy economics literature, especially in Malaysia. As such, this paper primarily revisited the natural gas — economic growth nexus hypothesis in the case of Malaysia. The study was conducted with data from 1980 to 2014 in a multivariate framework with the inclusion of capital formation, globalization, and CO_2 emissions to avoid omitted variable bias. We investigated the stationarity properties with a method that accommodates a single structural break. Subsequently, the novel combined co-integration test in conjunction with several techniques were used to assess the magnitude of the long-run equilibrium relationship. The empirical findings trace the long-run equilibrium relationship among the variables over the sampled period. The Granger causality test analysis confirmed the growth-energy driven hypothesis in Malaysia. The findings call for the adoption of cleaner and environmentally friendly energy sources in the Malaysian energy mix. We highlight the need for pragmatic strides from both private and public energy sector stakeholders to prioritize clean and accessible energy in line with the Sustainable Development Goals.

1. Introduction

Energy is identified as an integral driver of socio-economic development of all forms of economies — developing, transition, and developed economies [1]. The last two decades have experienced a persistent demand for energy sources like natural gas, oil, electricity consumption across the globe [2]. The continuous and persistent pressure for more energy sources puts pressure on the environment. This has been a heated debate among environmental economist, stakeholder and policymakers that design and formulate energy strategies [3–7].

Energy sources could either be from fossil fuel sources like crude oil, coal, and uranium or renewable energy sources like solar, geothermal, biomass, hydro, and wind, which are the alternative cleaner energy sources. However, non-renewable energy sources are known to emit carbon dioxide emissions which translate into environmental deterioration. The environmental and health-related hazards attributed to fossil fuels have raised concern and discourse among nations. Thus, in energy-dependent economies, there is a potential tradeoff between productivity and environmental sustainability [5]. Natural gas (NG hereafter) is somewhat preferred among other fossil fuel energy sources due to its low carbon intensity and limited environmental effects in production and consumption compared to oil and coal [8]. Global energy demand for natural gas rose from 5353 Tcf in 1980 to 113 trillion cubic feet (Tcf) in 2010. This swift increase was experienced across regions in the world. For instance, in the Middle East, NG demand rose from 3.1 Tcf in the 1980s to an overwhelming 51.7 Tcf in 2017. This sharp increase is

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attributed to the rapid economic expansion initiated in the region. A similar trend of increased consumption of NG in North America was observed from 58.5 Tcf in 1980 to 91.2 Tcf in 2017 [9]. Thus, natural gas production and consumption play a pivotal role in economic prosperity across countries [10,11].

Several studies have since emerged after the seminal work on energy-growth nexus [12] documented in the existing literature (see: [13–16]. The studies outlined incorporate other interesting variables, however, there is no consensus in the reported direction of causality. The plausible explanation for the divergent empirical findings could be due to varying sample size selection, estimation techniques (methodology), and selected sample area. Regarding natural gas consumption, there exists a paucity of studies (see [10,11,17]: for the Asian countries, however, Malaysia has received little attention. Malaysia is worthy of investigation, given its energy portfolio with almost 40% share of energy consumption from natural gas (see Fig. 1).

To this end, we assess the nexus between NG consumption and economic growth with a novel perspective in a multivariate framework. This is necessary to avoid the omitted variable bias which earlier studies failed to address. To circumvent the issues of omitted variable bias, we incorporate capital formation, globalization, and CO_2 emissions as additional variables. For the case of Malaysia, few studies [18,19] exist in the literature. Thus, we seek to improve the literature on natural gas energy and limited studies in Malaysia by investigating the theme via new insights that account for useful variables. This is crucial, given the key role of natural gas consumption in the Malaysian economic output. The study further strengthens the quest to achieve the 11th Malaysian Plan and goal 7 of the sustainable development target. In terms of estimation method, a novel combined non-cointegration, Granger causality, and Zivot and Andrews unit root techniques are utilized to examine the cointegration, causal direction, and account for a single structural break.

The subsequent sections of the study are as follows: *Section 2* presents a review of related literature; *Section 3* provides an overview of the Malaysian economy and its energy sector dynamics. *Section 4* focuses on data and econometrics procedures, *Section 5* details the interpretation and discussion of the results, while *Section 6* concludes the studies with policy direction for stakeholders, energy regulators, and government officials.

2. Review of related literature

Over the past decades, energy consumption remains the backbone of socio-economic development across economies. This is validated by the seminal work of Kraft and Kraft [12] for the US, which serves as a gateway to several studies in the energy literature for both, single country, cross countries and panel of countries with diverse and insightful outcomes (*inter alia* [20–22]; Bekun & Agboola,2019; Alola & Alola,2018 [23–29]; Solarin & Shahbaz,2014; Shahbaz & Lean,2012; [30,31]. To date, the energy literature has well-documented studies on the trajectory of the energy revolution. However, these studies have focused on the linkage between NG consumption and its effect on economic output. The literature on NG-economic nexus can be classified into four hypotheses namely (a) growth hypothesis (b) conservative hypothesis (c) feedback hypothesis and (d) neutrality hypothesis. First, the growth hypothesis posits that economic growth drives NG consumption — a one-way causality running from economic growth to NG consumption [32]. The second tier reflects on the unidirectional causality from NG to economic growth, known in the energy literature as NG-induced hypothesis (see [33]: — implying that the consumption of NG is a key determinant of economic growth. Meaning that any attempt to apply the conservative hypothesis will hurt such an economy. Third, the feedback hypothesis entails two-way causality running from both NG and economic growth and vice versa (Shahbaz, 2014). Finally, the neutrality hypothesis occurs when there is no causality in either direction from NG consumption and economic growth and vice versa. This means that both variables do not affect each other [11,34]. The application of the conservative hypothesis can be applied in this situation without an adverse effect on the economy.

There are numerous studies on natural gas — economic growth nexus. For instance, Solarin and Ozturk [28] explored the linkage that exists between NG consumption economic growth for 12 members of the organization of petroleum exporting countries (OPEC) over the period 1980–2012. The study findings for the bloc supports the feedback causality hypothesis. On the contrary, the study for individual countries reported diverse outcomes. For instance, in Nigeria, Kuwait, Iraq, and Saudi Arabia the growth hypothesis was valid while Iran, the United Arab Emirates (UAE), Algeria, and Venezuela join the strands of studies that support the conservative hypothesis. The neutrality hypothesis was confirmed in Angola and Qatar while Ecuador was the only country to supported the bidirectional causality hypothesis (feedback hypothesis).

Zamani [35] investigated the natural-gas induced growth relationship in Iran using disaggregated energy consumption through the vector error correction model (VECM) methodology. The study found a feedback causality between Natural gas consumption and economic growth between 1967 and 2003. Other studies validated the significant role of natural gas on economic growth in Russia, Iran, Qatar, Turkmenistan, and Iran, respectively [36,37]. However, there exists a paucity of studies on the theme for Malaysia — for instance, a study by Solarin and Shahbaz [18]. Our study is in line with Rafindadi and Ozturk [19]; who investigated natural gas-economic growth nexus in a multivariate framework with the inclusion of foreign direct investment (FDI), trade openness and gross capital formation while accounting for a possible structural break. The empirical findings of the study support the feedback hypothesis between the consumption of natural gas and economic development, FDI and economic development, and natural gas consumption and FDI. The line of studies on the theme for selected regions, variables, and hypothesis are reported in Table 1.

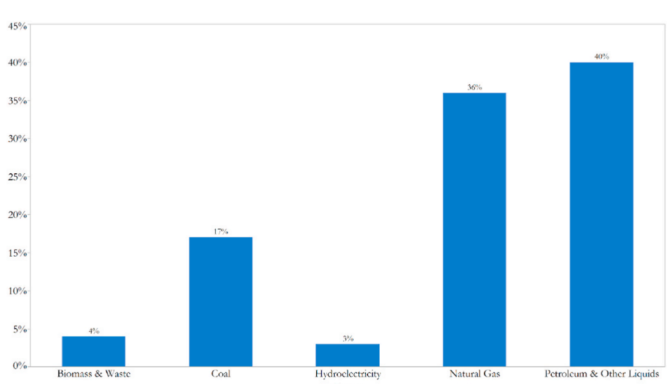

Fig. 1. Malaysian energy mix. Data source: US energy information administration.

3. An overview of the Malaysian economy and its energy dynamics: a brief discourse

Malaysia has a unique geographical feature with a landmass of 329,847 km^2 located in the southern Asia Peninsula. With the current population of 32, 386, 784 as of May 2019. This population is equivalent to 0.42% of the total world population. Malaysia's population density is estimated at 99 per km^2 (256 people per mi^2). Malaysia operates a constitutional monarchy system that holds thirteen states and three federal territories. The country is bordered around countries like Thailand, in the northern by Indonesia, Brunei and in the South China Sea, south of Vietnam. The Malaysian economy is blessed with natural endowment not limited to petroleum, natural gas, bauxite, iron, copper, ore, timber, etc. Malaysia has gradually transformed its economy from agriculture and commodity, being the producer of raw materials to a

Table 1
Summary of selected studies on natural gas economic growth nexus across the globe.

Author & Year	Location	Coverage	Technique	Findings	Decision
Khan and Ahmad [33]	Pakistan	1972–2007	Johansen test	Y → NG	Growth
Apergis and Payne [11]	67 Countries	1992–2005	Pedroni cointegration	NG ↔ Y	Feedback
Yang [38]	Taiwan	1954–1997	ARDL, GC, JJ	NG ↔ Y	Feedback
Adeniran [39]	Nigeria	1980–2006	Sims Causality test	Y → NG	Growth
Zahid [40]	India, Pakistan, Bangladesh	1971–2009	TY	NG → Y; Y x NG	Growth; Neutrality
Farhani et al. [34]	Tunisia	1980–2010	ARDL, GC, JJ	NG ↔ Y	Feedback
Rafindadi and Ozturk [19]	Malaysia	1971–2012	ARDL,BH,GC	NG ↔ Y	Feedback
Shahbaz et al. [10]	Pakistan	1972–2010	ARDL,JML,GC	NG → Y	Conservative
Ighodaro [41]	Nigeria	1970–2005	VECM, JJ	NG → Y	Conservative
Zamani [35]	Iran	1967–2003	JML, VECM	NG ↔ Y	Feedback
Fatai et al. [42]	New Zealand and Australia	1960–1999	ARDL, JML, TY	Y x NG	Neutrality
Solarin and Shahbaz (2014)	Malaysia	1971–2012	BH, ARDL, VECM	NG ↔ Y	Feedback
Hossein et al. [43]	OPEC countries	1980–2009	GC	Y x NG	Neutrality
Kum et al. [44]	G-7 Countries	1970–2008	Bootstrap, TY	NG → Y; Y x NG	Growth; Neutrality
Payne [45]	USA	1949–2006	TY	Y → NG	Growth
Esen and oral (2016)	Iran, Russia, Qatar, Turkmenistan	N/A	Descriptive statistics	NG ↔ Y	Feedback
Bildirici and Bakirtas [46]	Brazil, Russia and Turkey	1980–2011	ARDL, JML,GC	NG ↔ Y	Feedback
Saboori and Sulaiman [47]	Malaysia	1980–2013	ARDL, JML, GC	NG ↔ Y	Feedback
Aqeel and Butt [48]	1955–1996	Pakistan	GC	Y x NG	Neutrality
Hu and Liu [32]	Taiwan	1973–2003	VECM	NG ← Y	Growth
Akadiri and Akadiri [17]	Iran	1980–2013	ARDL, TY	Y x NG	Neutrality
Furuoka [49]	China	1980–2012	ARDL,GC,TY	NG → Y	Conservative
Das et al. [50]	Bangladesh	1980–2010	JML,GC	Y → NG	Growth
Solarin and Ozturk [28]	OPEC member countries	1980–2012	Panel GC	NG ↔ Y	Feedback
Shahiduzzaman and Alam [51]	Australia	1970–2009	ARDL	NG ↔ Y	Feedback
Ozturk and Al-Mulali [52]	Gulf Cooperation Council Countries	1980–2012	Pedroni cointegration test	NG ↔ Y	Feedback
Pirlogea and Cicea [53]	Romania	1990–2010	GC	Y x NG	Neutrality
Balitskiy et al. [54]	EU-26	1997–2011	Panel cointegration	NG↔ Y	Feedback
Dogan [55]	Turkey	1995–2012	VECM, GC	NG ↔ Y	Feedback
Das et al. [50]	Bangladesh	1980–2010	JML,GC	Y → NG	Growth
Solarin and Lean [56]	India and China	1965–2013	Hatemi-J, TYDL GC	NG ↔ Y	Feedback
Muhammad et al. [57]	Pakistan	1972–2010	ARDL	NG → Y	Conservative
Destek [58]	OECD countries	1991–2013	Panel VECM, FMOLS, DOLS	NG ↔ Y	Feedback
Hafeznia et al. [37]	Iran	N/A	Descriptive stats, Graphs	NG ↔ Y	Feedback
[59]	Iran	1990Q1 - 2017Q4	ARDL, GC, BH	NG ↔ Y	Feedback

Notes: The definition of the following abbreviations and notations: ↔ feedback causality; → conservative causality; ← growth causality; x no causality, N/A: Not available; NG: Natural Gas; Y: Economic growth; ARDL: Autoregressive Distributed Lag; VECM: Vector Error Correction Model; GC: Granger Causality; BH: Bayer and Hanck; JML: Johansen's Maximum Likelihood; JJ: Johansen-Joselius Cointegration; TY: Toda and Yamamoto; TYDL: Toda and Yamamoto and Dolado and Luktkepohl.

global player in the manufacturing and services sector, specifically in the exportation of palm oil, electrical appliances, electronics components, and natural gas as outlined by British Petroleum, (2019).

With the recognition of energy sector as the life wire of the Malaysian economy, deliberate measures in terms of energy policies birthed Acts like the National Depletion Policy of 1980 National Energy Policy of 1979, Petroleum Development Act of 1974, National Petroleum Policy of 1975 and more recently the Energy Commission Act 2001 were adopted to explore and develop a framework for producing petroleum resources, as well as look into issues related to ensuring the continuous supply, utilization and environmental concerns of energy without losing focus to ensure and promote private sector involvement in infrastructural facilities development — all in the bid to stimulate the economy and prolong the existence of the country's oil reserves [18].

The energy sector given its central role in the Malaysian economy accounts for more than 20% of its GDP. The upstream activities of the oil and gas sector can be estimated as well above RM87 billion whereas the similar activities from the downstream including refining can be estimated at more than RM 24 billion. This sector single-handedly accounts for the biggest source of revenue to the Malaysian government through dividends and taxes [60].

The principal forms of the energy consumed in Malaysia include natural gas responsible for 36% and oil account for 40% of the total energy mix. Coal also accounts for about 17% of the total energy mix. Fig. 1 gives more insights into the energy mix of Malaysia.[1]

4. Methodology

This section focuses on the econometrics procedures applied, data description, unit of measurement and data source.

4.1. Data

To explore the relationship between NG consumption, gross capital formation, globalization, and CO_2 emissions on economic growth in Malaysia, the study constructed a multivariate framework using five variables. The variables include the real gross domestic product (RGDP) used as a proxy for economic growth, gross capital formation used as a proxy for physical capital, carbon dioxide emission, and globalization index as developed by Dreher (2006) which accounts for economic, social and political dimensions of globalization. The intuition behind the choice of variables can be traced from the United Nations Sustainable Development Goals [(UNSDG) 7, 8, 9, 13, and 17] [61].

Natural gas (NG): intentional efforts made in using renewable energy to provide access to electricity and clean cooking fuels constitute a component of the sustainable goals that will enhance growth and sustain the environment (SDG 7).

Economic Growth (RGDP): A high level of productivity is needed to

[1] For more insight into energy mix in Malaysia, interested reader may visit the following linkshttps://www.st.gov.my/contents/files/download/116/Malaysia_Energy_Statistics_Handbook_2017.pdfhttps://www.st.gov.my/

achieve full employment in the economy. Hence, SDG 8 seeks to empower entrepreneurs who drive the process, create decent jobs for the massive unemployed population who are ready and able to work. These will help in achieving sustained economic development.

Gross Capital Formation (GCF): The investment needed to build infrastructural facilities will depend on capital formation vis-à-vis manufacturing and labor productivity. The sum of these will increase investment which will be useful in developing infrastructure, which will, in turn, boost the industrial share of economic development. Hence, helps to promote inclusive, sustainable industrialization and foster innovation (SDG 9).

Carbon dioxide emissions (CO_2): The negative effect of greenhouse gas (GHG) emissions on human lives and environment calls for urgent attention, especially when CO_2 constitutes a significant portion of GHG. Therefore, SDG 13 is concerned with reducing climate change hazards and its impact.

Globalization index (GI): The benefits that come from interconnectedness and global partnership through massive cooperation and exchange of ideas are needed to foster economic growth and development. To attain these, SDG 17 plays a critical role to ensure and enhance access to knowledge and technology with the sole target of achieving this goal.

These variables were sourced from World Bank Development Indicators (WDI) database and measured in constant 2010 USD for RGDP, GCF, and CO_2 in kt whereas NG consumption was derived from the U.S Energy Information Administration database (EIA). The annual data used for the econometric analysis spans from 1980-2014.[2] Table 2 describes the data, unit of measurement, and their respective sources.

4.2. Test processes

The study used the following empirical sequence: (a) tested for stationarity among the variables of interest via Augmented Dickey-Fuller (ADF, 1981), Philips Perron (PP, 1988), and Zivot-Andrews [62]. (b) Examined the long-run equilibrium relationship between variables using a combined cointegration test by Bayer & Hanck [63]. The Autoregressive Distributed Lag Model (ARDL) method of Pesaran et al. [64] was further explored to test for the robustness of the long-run relationship. (c) Granger causality test was carried out to ascertain the direction of causality among variables of interest.

4.3. Model specification

This study is predicated on the existing study of Solarin and Ozturk [65]. Hence, the functional form adopted in the study is expressed as:

$$RGDP = f\,(NG, GCF, GI, CO_2) \quad (1)$$

Table 2
Data description and unit of measurement.

Series	Unit of Measurement	Source
Carbon dioxide (CO_2) emissions	kt	WDI
Real Gross domestic product (RGDP)	Constant 2010 $ USD	WDI
Gross capital formation (GCF)	Constant 2010 $ USD	WDI
Globalization index (GI)	KOF Index of globalization	KOF index
Natural gas (NG)	Measured in dry NG in billion ft^3	EIA

Author's compilation.

[2] This study coverage span is restricted based on data availability. Also the data for CO_2 is available at WDI till 2014. Thus, for balance data and easy of estimations the study is trim to 2014.

In determining that there is homoscedasticity in the variables, logarithm transformation (*ln*) was applied to equation (1).

$$\ln RGDP_t = \delta + \alpha_1 \ln NG_t + \alpha_2 \ln GCF_t + \alpha_3 \ln GI_t + \alpha_4 \ln CO_{2t} + \epsilon_t \quad (2)$$

Where δ represents intercept or constant and $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are partial slope parameters to be estimated while ϵ_t is the stochastic terms to capture unobserved in the fitted model.

4.4. Test of stationarity

The test of stationarity in time series econometrics literature is essential to ascertain the order of integration of a variable before proceeding to test for cointegration and causality test — to prevent spurious analysis and erroneous policy implications. The basic test of stationarity using Elliot et al. [66]; Philips and Perron (1988), and Augment Dickey-Fuller [67] have become inadequate in some sense by lacking the capability to capture structural breaks which are present in most time-series data. This weakens the power of these traditional unit root test to reject the null hypothesis of unit root stationary test. Consequently, we introduced a unit root test with structural breaks to complement the deficiencies of the traditional unit root test and provide reliable and consistent estimates. Zivot-Andrews [62] was used for this purpose and it is computed as follows:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \gamma DU_t + \sum_{i=0}^{r} \Phi_i \Delta Y_{t-i} + \varepsilon_t \quad (3)$$

$$\Delta Y_t = \beta_1 + \beta_2 t + \lambda Y_{t-1} + \varphi DT_t + \sum_{i=0}^{r} \Phi_i \Delta Y_{t-i} + \varepsilon_t \quad (4)$$

$$\Delta Y_t = \beta_1 + \beta_2 t + \lambda Y_{t-1} + \gamma DU_t + \varphi DT_t + \sum_{i=0}^{r} \Phi_i \Delta Y_{t-i} + \varepsilon_t \quad (5)$$

From equations (3)–(5), Y_t refers to the time series examined, Y_{t-1} denotes the first lag of the time series under consideration and ΔY_{t-i} is lagged first differences to accommodate the serial correlation in the errors. The "t sig" represents the lag length which is useful in producing the test statistics given some information-based criteria. The DU_t denotes the dummy variable for the mean shift occurring at each possible structural break date, whereas DT_t refers to the dummy variable indicator for the trend shift occurring at each possible break date. Equation (3) allows for a unit root test which permits a one time change in the series level. Equation (4) permits the unit root test that allows a one-time change in the slope of the trend function, and finally equation (5) which allows for unit root test by combining one-time changes in the level as well as the slope of the trend function of the series.

The null hypothesis of Zivot-Andrews unit root applies to equations (3)–(5) and it is denoted as $\theta = 0$. Hence, the null hypothesis $H_0 : \theta > 0$ is tested against the alternative of stationarity $H_1 : \theta < 0$. The null hypothesis implies that the series (Y_t) contains a unit root with a drift that excludes any structural break, whereas the alternative hypothesis implies that the series is a trend-stationary process with a one-time break occurring at a point in time that is unknown. Therefore, in a case where we fail to reject H_0 then there is the presence of unit root whereas rejection validates stationarity.

4.5. Measurement of cointegration relationships

The pioneering approach to testing the equilibrium association between variables was advanced by Engle and Granger [68]. The test of cointegration simply requires that variables possess a unique order of integration. Econometric literature reveals that there is a lower integration order especially when the time series are integrated at *I(0)* or *I(1)*. However, the Engle-Granger cointegration test is puzzled with the challenge of a biased empirical outcome as a result of low explanatory power properties. The Johansen [69] cointegration test is a better option of a cointegration test relative to the aforementioned as it allows more than one cointegrating relationship between the variables. The recently advanced Bayer and Hanck [63] cointegration test blend various test statistics ranging from Engle-Granger [68]; Johansen [69]; Boswijk [70] and Banerjee et al. [71] in the bid to have a robust result from a single framework and arrive at a more robust and comprehensive conclusion. The current study used the combined cointegration of Bayer-Hanck cointegration test to assess possible cointegration between NG consumption and economic growth in Malaysia. Combining the estimated significance level of the individual cointegration test in line with Fishers' formula is given as:

$$EG - JOH = -2\{\log(P_{.EG}) + (P_{.JOH})\} \tag{6}$$

$$EG - JOH - BO - BDM = -2\{\log((P_{.EG}) + (P_{.JOH}) + (P_{.BO}) + (P_{.BDM}))\} \tag{7}$$

Meaning that, $P_{.EG}, P_{.JOH}, P_{.BO}$ and $P_{.BDM}$ are the individual probabilities of each test statistic. That is, p-values of cointegration tests such as Engle-Granger [68]; Johansen (JOH, 1988); Boswijik (BO, 1994) and, Banerjee et al. (BDM, 1998) as represented by $P_{.EG}, P_{.JOH}, P_{.BO}$ and $P_{.BDM}$ respectively. The decision rule holds that where the calculated Fisher statistics is greater than the critical values provided by the Bayer and Hanck [63]; the null hypothesis of no cointegration can be rejected.

4.6. Autoregressive Distributed Lag (ARDL) approach

The ARDL bounds test approach can be used to revalidate the robustness of the cointegration relationship between NG consumption and economic growth and other variables such as gross capital formation, globalization, and CO_2 emissions. This approach guarantees efficient estimates especially when the sample size is relatively small compared to other traditional cointegration tests. The ability of this method to report simultaneously the long and short-run dynamics of fitted regression together with error correction model term (ECT) is laudable. Besides the outlined merits, it is also known for its usefulness in the case of an unknown order of stationarity — be it either ~ I(0) or I(1) but certainly not I(2). It is usually estimated within the framework of unrestricted error correction where all the variables are assumed to be endogenous. This estimate is carried as follows:

$$\Delta Y_t = \delta_0 + \delta_1 t + \beta_1 y_{t-1} + \sum_{k=1}^{Z} \gamma_1 v_{kt-1} + \sum_{n=1}^{X} \phi_n \Delta Y_{t-n} + \sum_{k=1}^{Z}\sum_{n=1}^{X} \mu_{kn} \Delta V_{kt-n} + \theta D_t + \varepsilon_t \tag{8}$$

The exogenous variable that accommodates the structural breaks in the framework is denoted as D_t whereas the vector is represented by V_k. Where there is no cointegration, the F-statistics computed from the bounds test is used to confirm the null hypothesis. The decision can be made from the following scenarios: (a) a situation where the F-statistics computed is greater than the upper limit of the critical values reported, the null hypothesis of no cointegration is rejected. (b) a case where the F values are within lower and upper bounds, the decision will be inconclusive, and (c) a situation where the F-statistics is found below the upper limits, the decision, in this case, will be no cointegration.

The bounds test specification is expressed as:

H_0: $\beta_1 = \beta_2 = \ldots \ldots = \beta_{k+2} = 0$

H_1: $\beta_1 \neq \beta_2 \neq \ldots \ldots \neq \beta_{k+2} \neq 0$

Different forms of long-run relationship tests exist in the existing literature that can be employed after validating the presence of cointegration among variables. For instance, the among the long run estimators includes the Dynamic ordinary least squares, (DOLS), advanced by Ref. [72]; Fully Modified Ordinary Least Squares (FMOLS) proposed by Philips and Hansen (1990) and Park [73] proposed Canonical Cointegration Regression (CCR).

4.7. Granger Causality approach

Since the traditional regression does not imply causal interaction or association among the variables, it was needful to assess the direction of causality given the marginal benefits for policy formulation. This study used the Granger causality technique to detect the predictability power that exists among the variables of interest.

5. Results interpretations and discussions

The visual plot of the variables depicted in Fig. 2 is essential to understand the trend/patterns of the dataset used in the estimation analysis. Fig. 2 reveals the trend of each series, natural gas, and gross capital formation series exhibit obvious structural breaks relative to gross domestic product, globalization index, and CO_2 emissions. This study has a provision to capture these structural breaks in subsequent estimation. Table 3 reports basic descriptive statistics such as averages, variance, minimum, maximum, normality, skewness, and kurtosis. Table 3 shows that economic growth has the highest average followed by real gross fixed capital formation with NG with the lowest mean. Coincidentally over the sampled period, RGDP has maximum with NG minimum. All the series shows significant deviation from their means as revealed by the standard deviation.

Table 4 reports the ADF and PP unit root tests to validate the unit root properties of the series in the study. The results reveal that the series are non-stationary at levels in the presence of structural breaks. However, all the variables are stationary at first difference. Implying that the variables are integrated of *I(1)* at a 1% level of significance. Further confirmation of ADF is validated by the PP unit root test implying that the order of the integration of the variable is I(1). The fundamental issue with the traditional ADF and PP unit root tests is the inability to capture structural breaks in series thereby resulting in ambiguous and misleading results. However, Zivot and Andrews [62] unit root test can accommodate single unknown structural breaks in the series as observed in Table 5. The Zivot and Andrews unit root test is usually selected in favor of the null hypothesis when considering the break date selection using the t-statistics and it uses the critical values of the ADF unit root test. The identified break dates tally with landmark political and economic episodes in Malaysian history.

The maximum lag length selection criteria are presented in Table 6, which afford the best model to be selected. The results from Table 6 reveal that the most appropriate criteria for lag length selection are AIC with a lag length of 1 which is capable to accommodate small sample size which is suitable for this nature of the study.

The ARDL short and long-run results to validate the long-run equilibrium relationship are presented in Table 7. The results reveal a slightly above average speed of adjustment of approximately 59% in collaboration with the explanatory variables. In the short run, the empirical results show that a 1% increase in NG consumption leads to an increase in economic output by 0.02% holding other things constant. This implies that energy (NG) adds to the growth of the Malaysian economy in contrast to a study by Rafindadi and Ozturk [19]. The study reveals a positive and statistically significant relationship with economic output stemming from the increase in energy (NG) consumption. Meaning that an expansion in NG consumption in Malaysia directly stimulates economic growth. This trend is also found positive and statistically significant in the long run. A positive relationship is observed between gross capital formation and RGDP. An increase in gross capital formation by 1% will increase RGDP by 0.09% — leading to economic expansion. Globalization and CO_2 emissions follow a similar positive trend with RGDP. The results in Table 7 further affirm convergence between NG consumption, gross capital formation, globalization, CO_2, and RGDP. The long-run for all the variables is aligned with the trend of the short run. The positive relationship observed between CO_2 and

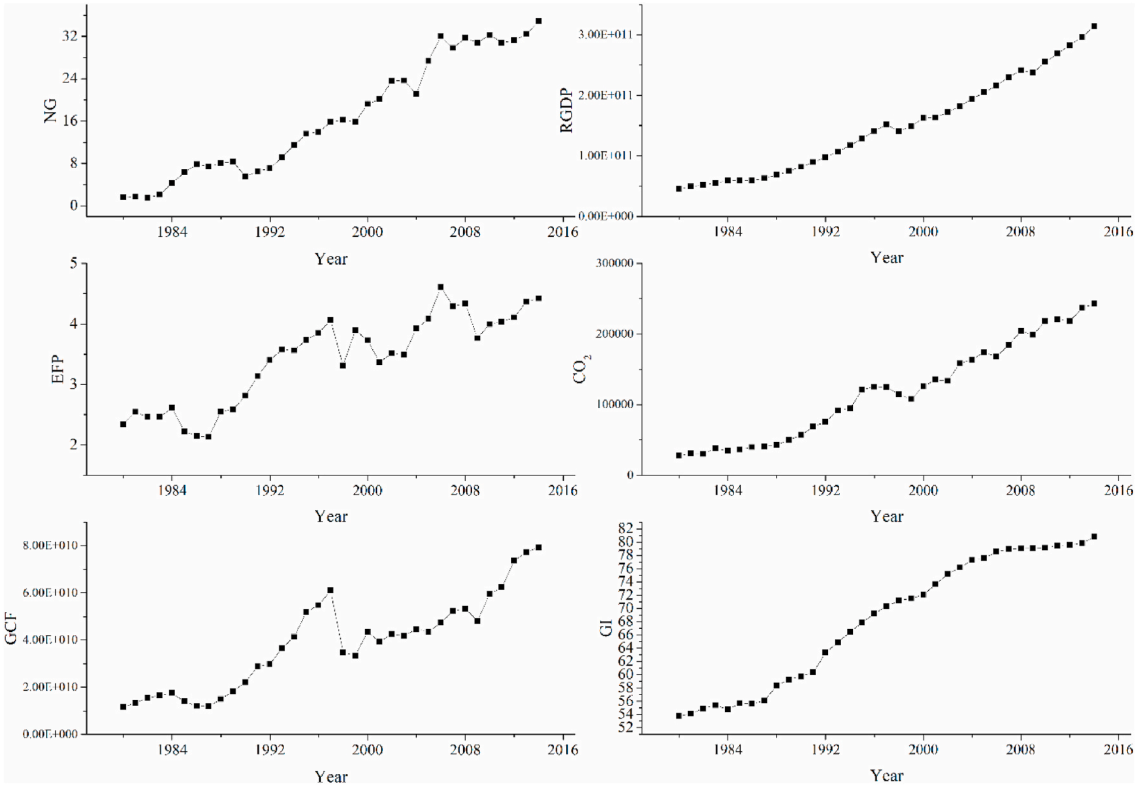

Fig. 2. Trend plot of the relationship between Carbon dioxide, economic output, gross capital formation, globalization and natural gas (1981–2014).

Table 3
Descriptive statistics.

	$lnCO_2$	lnRGDP	lnGCF	lnGI	lnNG
Mean	11.4673	25.5641	24.2202	4.2131	2.4924
Median	11.7046	25.6754	24.4431	4.2535	2.7601
Maximum	12.4001	26.4737	25.0963	4.3917	3.5493
Minimum	10.2399	24.5469	23.1660	3.9844	0.3947
Std. Dev.	0.7069	0.6008	0.5992	0.1462	0.9381
Skewness	−0.3836	−0.2090	−0.4468	−0.3039	−0.8335
Kurtosis	1.7143	1.7109	1.8794	1.5198	2.7706

Author's compilation.

Table 4
Unit root result.

Variables	ADF	PP
Panel A: Level		
$lnCO_2$	−1.3187	−1.3755
lnRGDP	−1.0392	−0.9949
lnGCF	−1.1139	−1.1448
lnGI	−1.3294	−1.1624
lnNG	−2.2940	−2.5450
Panel B: Difference		
$lnCO_2$	−6.3518*	−6.3227*
lnRGDP	−4.7161*	−4.7246*
lnGCF	−4.9737*	−4.9522*
lnGI	−4.2584*	−4.2586*
lnNG	−4.1843*	−4.1740*

Notes:*denotes a rejection of the null at 1% significance level.

economic growth both in the short and long-run has useful policy implications. This increment allows for a tradeoff between environmental quality and economic development. Hence, modernized and environmentally friendly energy sources are encouraged especially in the face of a global shift to cleaner energy sources advanced by other nations [74]; Emir & Bekun, 2018). The non-cointegration test results via Bayer and Hanck are reported in Table 8. The null hypothesis of no cointegration is rejected at a 1% significance level, thus, the results confirm a cointegration between the variable under consideration. A further step of checking the robustness was considered using the ARDL bounds testing which validated cointegration among variables showed in Table 8.

The FMOLS and CCR estimators were used to investigate the long-run equilibrium elasticities and determine the magnitude of the cointegration. This is usually carried out after confirming the existence of cointegration between the variables. Table 9 reveals a positive relationship between NG, GCF, GI, CO_2 and RGDP for the two estimators. This implies that NG, GCF, GI and CO_2 are positively related to the dependent variable (RGDP). Both estimation techniques reveal a positive and significant relationship between NG consumption and economic growth. Hence, our estimates validate the growth-induced NG consumption hypothesis, as a positive relationship running from RGDP to NG consumption in Malaysia. Besides, a 1% increase in NG consumption will result in a corresponding increase in economic output by 0.028% and 0.027% for FMOLS and CCR respectively. In the same vein, a positive and statistically significant trend association is observed for gross capital formation, globalization, and CO_2 emissions. The positive relationship between globalization, CO_2 emissions, and economic growth suggest simultaneous and proper management of the economy and environment. The positive empirical evidence between economic growth and CO_2 emissions implies the need for more action to disentangle economic growth from environmental pollution, especially from fossil fuel sources. A similar study by Leah and Smith (2009) observed unidirectional causality from energy use to carbon emissions for Iran.

This study further reveals a positive collaboration between gross capital formation and economic growth. This is a clarion call for the Malaysian economy to harness and strengthen institutions on the path of accumulation capital to grow the economy both in the short and long run. This capital accumulation can guarantee sustained economic growth. The results of fitted model residual diagnostic tests reported in

Table 5
Unit root test for single structural break.

	Statistics (Level)			Statistics (Difference)			Conclusion
	ZA_I	ZA_T	ZA_B	ZA_I	ZA_T	ZA_B	
$\ln CO_2$	−3.7763	−3.3067	−3.8550	−7.8608*	−6.9301*	−8.1548*	I (1)
Time Break	1991	1996	1991	1997	1992	1997	
Lag Length	1	1	1	1	1	1	
lnRGDP	−3.1738	−2.8636	−3.0479	−6.2209*	−5.0245*	−6.2069*	I (1)
Time Break	1991	1996	1991	1998	1991	1998	
Lag Length	1	1	1	1	1	1	
lnGCF	−3.0868	−2.3875	−3.2702	−5.9633*	−4.9199*	−5.8819*	I (1)
Time Break	1990	1994	1998	1998	1991	1998	
Lag Length	1	1	1	1	1	1	
lnGI	−3.3536	−3.0439	−3.2544	−6.7284*	−6.0440*	−6.6015*	I (1)
Time Break	1992	2003	1992	1988	1993	1988	
Lag Length	1	1	1	1	1	1	
lnNG	−3.2556	−2.1477	−3.5229	−6.4074*	−5.7804*	−6.8542*	I (1)
Time Break	2007	2008	1989	1987	1990	1991	1990
Lag Length	1	1	1	1	1	1	1

Notes: * represents a 1% significance level. Variables used are in their natural logarithms. ZA_B denotes the model with a break in both the trend and intercept; Whereas ZA_T and ZA_I are for models with a break in trend and intercepts respectively.

Table 6
Lag selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	110.8500	NA	1.13e-09	−6.4151	−6.1884	−6.3388
1	285.8914	286.4314*	1.29e-13*	−15.5085*	−14.1481*	−15.0508*
2	305.8952	26.6717	1.96e-13	−15.2057	−12.7116	−14.3665

Notes: (*) denotes lag order selected by the criterion. HQ stands for Hannan Quinn, AIC represents Akaike information criterion, SC denotes Schwarz information criteria, FPE means Final prediction error and lastly LR signifying sequential modified LR statistic.

Table 7
ARDL Long and Short-run result.

$\ln RGDP = f(\ln NG, \ln GCF, \ln GI, \ln CO_2)$				
Variable	Coefficient	Std error	t-Statistics	Probability
Short-run result				
ECT (−1)	−0.5853*	0.0905	−6.0348	0.0000
ΔlnNG	0.0164***	0.0087	1.8796	0.0719
ΔlnGCF	0.0945*	0.0315	3.0027	0.0060
ΔlnGI	0.4910*	0.2010	2.4424	0.0220
$\Delta\ln CO_2$	0.0766	0.0531	1.4422	0.1616
Constant	9.4603*	1.4562	6.4964	0.0000
Long run result				
lnNG	0.0280*	0.0111	2.5198	0.0185
lnGCF	0.1615*	0.0378	4.2701	0.0002
lnGI	0.8389*	0.2608	3.2165	0.0036
$\ln CO_2$	0.1340	0.1050	1.2472	0.2239
Constant	9.4449*	2.2188	4.2567	0.0003

Notes: Asterisk (,***) denotes 1%, and 10% significant level, respectively.*

Table 8
Bayer and hanck results of non-cointegration.

Fitted Model		EG-JOH	EG-JOH-BO-BDM	Cointegration Remark
lnRGDP *f*(lnNGC, lnRGCF, $\ln CO_2$, lnGI)		55.2799***	56.2988***	Yes
ARDL bounds testing to cointegration				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.2791	10%	3.03	4.06
k	4	5%	3.47	4.57
		2.5%	3.89	5.07
		1%	4.4	5.72

Notes: The asterisks (***) signifies 1% level of statistical significance. The Critical values of EG-JOH and EG-JOH-BO-BDM are 15.845 and 30.774, respectively.

Table 9
Results of Long run regression (FMOLS and CCR).

Dependent variable: lnRGDP		
Variable	FMOLS	CCR
lnNG	0.0280*	0.0271*
	3.5595	3.3272
	0.0013	0.0025
lnGCF	0.1900*	0.1837*
	11.4843	8.3296
	0.0000	0.0000
lnGI	1.1221*	1.0999*
	10.2060	8.2938
	0.0000	0.0000
lnCO2	0.0061*	0.0226*
	3.1334	0.4214
	0.0039	0.6767
R^2	0.9994	0.9994
Adjusted R^2	0.9994	0.9993
S.E. of regression	0.0142	0.0143
Long-run variance	0.0001	0.0001
Mean dependent var	25.5940	25.9540
S.D. dependent var	0.5828	0.5828
Sum squared resid	0.0056	0.0057

Notes: * denotes 1% significance level. Values in bracket denote P-values and [] represents t-statistics.

Table 10 validate the adequacy of the model for policy direction and guidance. The fitted model is void of violation of any assumption of the classical linear regression model (CLRM) namely serial correlation, heteroscedasticity, and misspecification bias.

Fig. 3 reports the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMsq) stability diagnostic test of the fitted model. CUSUM and CUSUMsq tests are essential for examining the stability of short and long-run parameters of NG consumption function. The plots depicted in Fig. 3 are observed within the 95% threshold limit, signifying statistical significance at 5%. The implication is that the NG

Table 10
Residual diagnostic tests for the fitted model.

Test	Coefficient	p-Value
Heteroscedasticity (ARCH)	0.1211	0.9412
Normality	2.2100	0.1325
Autocorrelation	0.1441	0.7069
Functional form (Ramsey RESET)	0.2316	0.6347

Author's compilation.

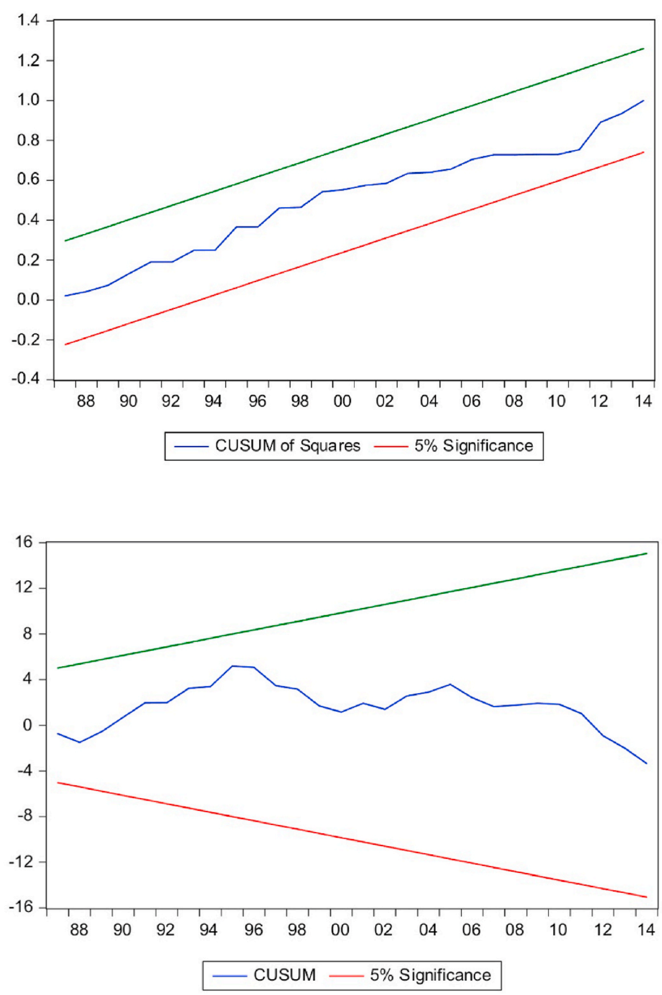

Fig. 3. CUSUM and CUSUMsq graphical plot.

consumption function reveals the efficiency and consistency of the parameters used in the short and long run as validated by CUSUM and CUSUMsq.

The Granger causality was applied to test the direction of causality among the variables of the model. Such knowledge helps craft appropriate energy policies for sustainable economic growth. The results presented in Table 11 outline the direction of causality among variables under consideration. The Granger causality helps to detect the predictability power of variables by considering the contemporaneous term and its past realization between the underlined variables namely economic growth to NG consumption, gross capital formation, globalization, and CO_2 emissions. Table 11 reveals a unidirectional causality stemming from economic growth (RGDP) to NG consumption. This outcome is similar and corroborates the findings of Rafindadi and Ozturk [19]. A similar trend of unidirectional causality is observed running from RGDP to gross capital formation, from globalization to NG consumption and from CO_2 to NG consumption. This study gives credence to economic growth induced NG consumption hypothesis in Malaysia — as causality is observed from RGDP to NG consumption. Also, Globalization and CO_2 have no causality on RGDP, whereas a bidirectional causality exists between gross capital formation and NG consumption and CO_2 versus gross capital formation. Malaysian economic growth drives NG consumption and gross capital formation. This means that energy consumption (natural gas) and gross capital formation does not granger cause economic growth in Malaysia. Similarly, the study reveals that globalization and CO_2 emissions drive natural gas consumption and not the opposite. This means that globalization and CO_2 emissions stimulate an economy that is dependent on natural gas consumption. Thus, deepening diversification of the energy portfolio and capital accumulation strategies are essential to enhance sustainable economic growth and ensure a feedback effect on the economy.

Table 11
Causality test result.

Null Hypothesis	Causality	F- Statistic	Probability
lnNG $\neq>$ LNRGDP	lnRGDP → lnNG	1.4993	0.2390
lnRGDP $\neq>$ LNNG		6.1350*	0.0028
lnGCF $\neq>$ lnRGDP	lnRGDP → lnGCF	1.1671	0.3420
lnRGDP $\neq>$ lnGCF		2.8061***	0.0603
lnGI $\neq>$ lnRGDP	lnGI ≠ lnRGDP	1.9525	0.1470
lnRGDP $\neq>$ lnGI		1.1241	0.3582
lnCO2 $\neq>$ lnRGDP	$\ln CO_2$ ≠ lnRGDP	1.6271	0.2083
lnRGDP $\neq>$ $\ln CO_2$		1.9834	0.1422
lnGCF $\neq>$ lnNG	lnGCF ↔ lnNG	3.2213**	0.0397
lnNG $\neq>$ lnGCF		2.5962***	0.0748
lnGI $\neq>$ lnNG	lnGI → lnNG	8.3079*	0.0005
lnNG $\neq>$ lnGI		2.0136	0.1377
lnCO2 $\neq>$ lnNG	$\ln CO_2$ → lnNG	5.5028*	0.0048
lnNG $\neq>$ $\ln CO_2$		1.4096	0.2633
lnGI $\neq>$ lnGCF	lnGI ≠ lnGCF	2.0740	0.1292
lnGCF $\neq>$ lnGI		0.7652	0.5242
$\ln CO_2$ $\neq>$ lnGCF	$\ln CO_2$ ↔ lnGCF	2.5725***	0.0767
lnGCF $\neq>$ $\ln CO_2$		2.3289***	0.0988
$\ln CO_2$ $\neq>$ lnGI	lnGI ≠ lnNG	2.0413	0.1337
lnGI $\neq>$ $\ln CO_2$		1.9694	0.1444

Notes: Asterisk(s) *,**,*** denote(s) the rejection of the null hypothesis at 1%, 5% and 10% significance levels. The symbol → represents unidirectional causality, ↔ denotes bidirectional causality and ≠ means neutrality while $\neq>$ means does not Granger cause.

Subsequently, we proceeded to explore the impact of one standard deviation shocks on each other through the Impulse response function (IRF). The impulse response function shows the reaction of the dependent variable to external impulses from its explanatory variables. It is observed in Fig. 4 that NG consumption is sensitive to economic output, positive and persistent over the entire time horizon. For the response of GDP to gross capital, an inverse and persistent trend are observed over the entire period. The impact of globalization on NG consumption is initially negative from the first 1–3 periods after which turns positive. This implies that external shocks as a result of changes in the global market have a significant impact on NG consumption in Malaysia. CO_2 has a negative impact on NG consumption for the first 2 periods, after which a noticeable persistent impact is observed on NG consumption. This entails depletion of the environment as such the need to shift to cleaner and friendlier environmental sources like renewables. A feedback causality is confirmed between NG consumption and real capital formation. We observe that NG consumption is sensitive to positive shocks in real capital formation and vice versa in the long run with persistent impact over the time horizon. Human activities in capital terms contribute to CO_2 emissions positively but turn negative and persistent over the time horizon, with a similar pattern in terms of CO_2 emissions to gross capital formation.

6. Concluding remarks and policy direction

Due to its lowest carbon intensity, natural gas appears to have the

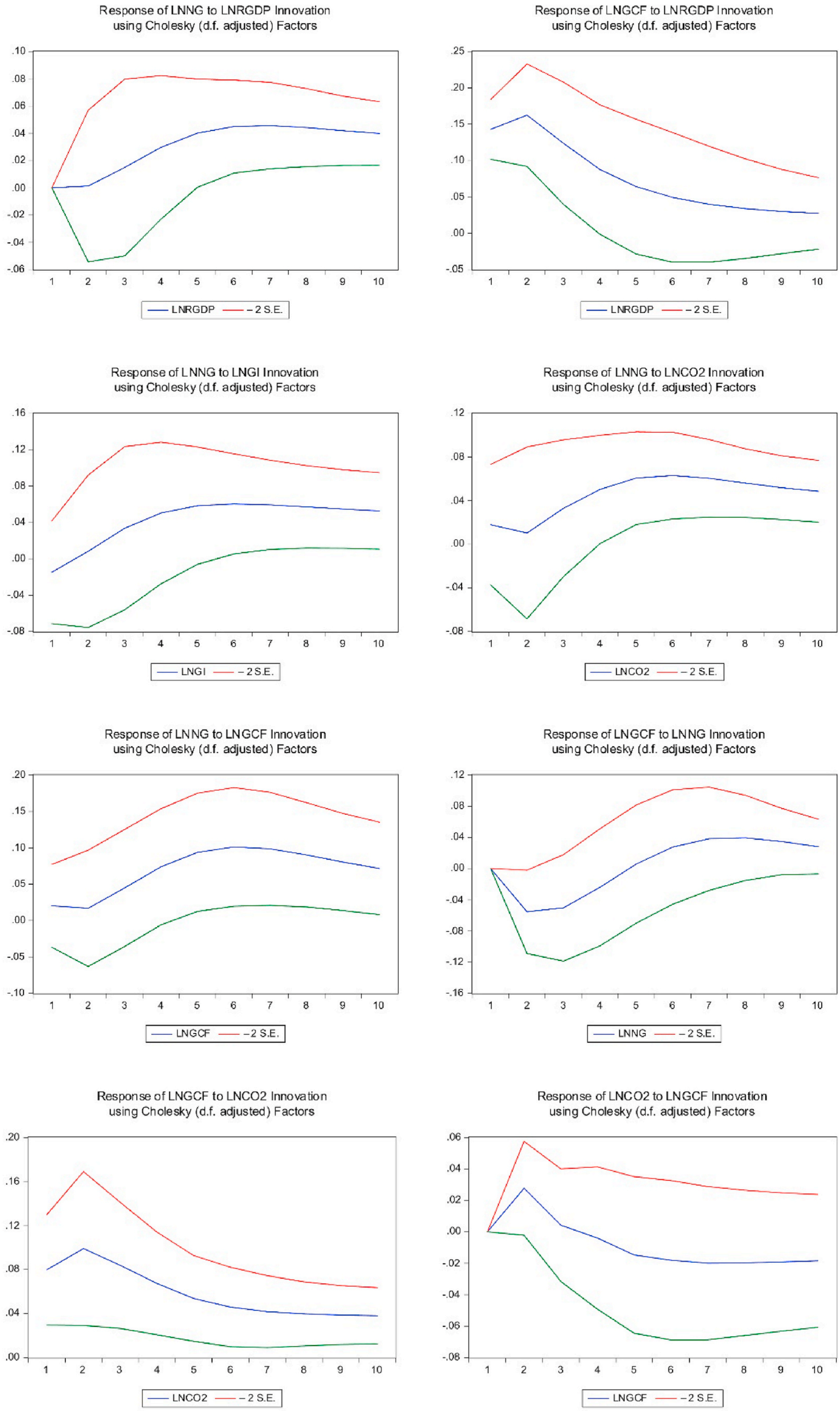

Fig. 4. Impulse response graphical plot of shocks among variables.

least environmental effect compared to oil and coal. The discovery has improved Malaysia's economic development by increasing the total energy consumption. However, studies that examine the natural gas-driven economy is limited, especially in Malaysia. Motivated by the 11th Malaysian Plan and goal 7 of sustainable development target, we investigated the nexus between the consumption of natural gas and economic development for Malaysia from 1980 to 2014 — by integrating globalization index, gross capital formation, and CO_2 emissions in a multivariate framework. The empirical results showed that a 1% increase in energy consumption (natural gas) consumption increases economic growth by 0.03% in the long-run and 0.02% in the short-run in Malaysia. This implies that energy consumption (natural gas) consumption can help achieve the 11th Malaysian Plan as envisaged. The study further found a short-run gross capital formation-led economic growth by 0.09 and 0.16% in the long-run. Globalization was observed to influence economic development positively by 0.84% with a 1% increase in economic growth. Implying that, globalization can significantly influence economic development in Malaysia. These findings suggest that an increase in the levels of CO_2 emissions emanate from human activities such as industrial production, urbanization, transportation, and other activities that translate into higher economic output both in the short- and long-run. The dual findings of natural gas consumption and gross capital formation influencing economic output have policy implications. Based on the empirical revelations, the following policy directions are made:

(i) The study confirmed the growth-induced natural gas consumption hypothesis as highlighted by the Granger causality analysis. Such causality insights help craft appropriate energy policies for sustainable economic growth.
(ii) The role of capital in economic growth is significant to the Malaysian economic prosperity, hence, promote inclusive, sustainable industrialization and foster innovation (SDG 9) as suggested in the causality result. As such, policymakers are enjoined to intensify efforts to increase both physical and human capital accumulation in the country to achieve the 7th Sustainable Development Goal (SDG) and the agenda 2020 of the 11th Malaysian Plan.
(iii) The need for the Malaysian government to strengthen its institutions on environmental treaties and regulations like the Kyoto Protocol and Paris Agreement is a requirement to check its emission level, thereby contributing to the reduction of the global average temperature of below 1.5 °C.

This study serves as a beacon to other Asian countries in their quest to improve economic growth without tradeoff for environmental quality and achieving SDGs 7 and 8 and the 11th Malaysian Plan. Future research needs to revisit the theme by considering other growth drivers like population, democratic regime, and good governance in terms of asymmetry, given the paucity of studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Mfonobong Udom Etokakpan: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing - review & editing. **Sakiru Adebola Solarin:** Writing - original draft. **Vedat Yorucu:** Writing - original draft. **Festus Victor Bekun:** Writing - original draft. **Samuel Asumadu Sarkodie:** Writing - original draft, Writing - review & editing, Funding acquisition.

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Appendix A. Supplementary data

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