Energy Economics Letters
ISSN(e): 2308-2925
DOI: 10.18488/5049.v9i1.4396
Vol. 9, No. 1, 1-19.

URL: www.aessweb.com

TIME SERIES ANALYSIS OF GLOBAL ENERGY INDICES: LOGARITHMIC AND NORMALIZED TECHNIQUES FOR DEVELOPMENTAL STUDIES

S. N. Nnamchi[1+]
Z. O. Jagun[2]
M. A. Ijomah[3]
O. A. Nnamchi[4]
J. D. Busingye[5]

[1]*Department of Mechanical Engineering, Kampala International University, Kansanga, Kampala, Uganda.*
Email: stephen.nnamchi@kiu.ac.ug Tel: +256701966149
[2]*Department of Computer Engineering, Olabisi Onabanjo University, Ibogun, Nigeria.*
Email: jagun.zaid@oouagoiwoye.edu.ng Tel: +2438069096257
[3]*Department of Mathematics and Statistics, Faculty of Sciences, University of Port Harcourt, Choba Port Harcourt, Nigeria.*
Email: maxwell.ijomah@uniport.edu.ng Tel: +2348037789700
[4]*Department of Agricultural Engineering and Bio Resources, Michael Okpara University of Agriculture, Umudike, Umuahia, Nigeria.*
Email: onyxhoni@yahoo.com Tel: +2438063816885
[5]*Kampala International University, Kansanga, Kampala, Uganda.*
Email: dvcfa@kiu.ac.ug Tel: +256772629973

(+ Corresponding author)

Article History
Received: 15 November 2021
Revised: 17 December 2021
Accepted: 30 December 2021
Published: 7 January 2022

Keywords
Energy
Indices (EC, GDP, CDE, HDI, OP)
Time series analysis
Logarithmic
Normalized techniques
Causality
Development.

JEL Classification:
C59, O29, Q40.

ABSTRACT

Diverse opinions exist in the time series analysis of energy and related indices, difference in methodology, sample size, and time variation. This paper will make a conscious effort to converge the divergent outlooks. To accomplish this essential task, five energy indices consisting of energy consumption (EC), gross domestic product (GDP), carbon dioxide emission (CDE), the human development index (HDI), and oil price (OP) were selected. Two analytical methods were adopted, namely logarithmic and normalized techniques, which are designed to complement each other in drawing unfalsified statistical inference concerning the causality between the energy indices. The methods were subjected to four statistical tests and analyses: the augmented Dickey-Fuller, cointegration, pairwise Granger causality, and vector error correction model (VECM). Irrespective of prevailing challenges, both logarithmic and normalized techniques unanimously filtered out causalities. This consisted of neural flow between oil price and energy consumption, gross domestic product and carbon dioxide emission, and energy consumption and the human development index, unidirectional flow between energy consumption and the human development index, oil price and energy consumption, gross domestic product and carbon dioxide emission, and the human development index and oil price, whereas a normalized technique established bidirectional flow between gross domestic product and the human development index, and the human development index and oil price. Pertinently, the research suggests appropriate policies that will generate sustainable development in all the causal directions. Assiduously, the overwhelming agreement between both techniques at the 0.05 level is recommended for further validation with more modern econometric tests.

Contribution/ Originality: This study originates a new normalized technique for analyzing time series. The normalized technique can complement the logarithmic technique to establish causality among econometric variables with econometric tests, but it has demonstrated greater sensitivity than the logarithmic technique by identifying bidirectional causality. The results are policy drivers for development.

1. INTRODUCTION

Knowledge of causality is significant in formulating policies that will engender sustainable development (economic, environmental, and social); otherwise, the promulgation of policies are likely to hamper or skew the trade-off between the facets of sustainable development. Thus, Hossain (2012) advocates that policies should be administered without restriction in the non-causal direction but should be amenable in the unidirectional causality such that instability or disequilibrium in development is not promoted. However, policymaking becomes more critical or stringent in bidirectional causality since ill-posed policies will suppress the growth of the energy indices involved. Moreover, the threat of policies to development facets could be unveiled through short and long run causal relationships between the energy indices via time series analysis. According to Almozaini (2019), there are four possible outcomes of causal relationships between energy consumption indicators, namely zero, forward unidirectional, backward unidirectional, and bidirectional, which could be analyzed with neutrality, growth, conservation, and feedback hypotheses, respectively.

Substantial quantities of literature exist on the modern econometric examination of dependence, interdependence, causality, integration, cointegration, unidirectional, and bidirectional flows between energy and the related index yield results that are significant in making sound policies to promote sustainable development. In the past, time series analysis of an expanse of economic data at national, regional, continental, and international levels was carried out by several authors. At a national level, the causality between energy consumption and economic growth has been studied with diverse techniques by the following authors: Yang (2000); Asafu-Adjaye (2000); Aqeel and Butt (2001); Ghosh (2002); Morimoto and Hope (2004); Jumbe (2004); Altinay and Karagol (2005); Yoo (2006); Wolde-Rufael (2006); Lee and Chang (2007); Halicioglu (2007); Narayan and Singh (2007), for Taiwan (1954-1997), Thailand (1971-1995), Pakistan (1955-1996), India (1950-1997), Sri Lanka (1960-1998), Malawi (1970-1999), Turkey (1950-2000), South Korea (1970-2002), Nigeria (1971-2001), Taiwan (1954-2003), Turkey (1968-2005) and Fiji (1971-2002), respectively. These studies were marked with heterogeneous results ranging from unidirectional to bidirectional flow between energy consumption and economic growth, which according to Asafu-Adjaye (2000) could be attributed to differences in methodology and sample size. In addition, the variation in the results could be due to the prevailing policies in the sampled countries.

At a continental level, Chontanawata, Hunta, and Pierseb (2007) and Chen, Kuo, and Chen (2007) employed the same technique in studying time series data for the Asian continent (1960-2003 and 1971-2002, respectively). Despite the difference in the time periods, both studies agreed that energy consumption causes economic growth but Chontanawata et al. (2007) further established a bidirectional flow between the two indices investigated.

Also, at both regional and international levels, Chontanawata et al. (2007) carried out time series analyses of data from the Organization for the Economic Cooperation and Development (OECD) (1971-2003). They established bidirectional flow between energy consumption and economic growth based on modern econometric methodology. Moreover, Squalli (2007) analyzed time series data from the Organization of Petroleum Exporting Countries (OPEC) (1980-2003) using the bounds testing approach (Toda-Yamamoto test) and affirmed that there is a unidirectional flow from economic growth to energy consumption and energy consumption to economic growth, and bidirectional flow between energy consumption and economic growth for the member countries.

Today, multiple connectivities between energy indices are of paramount interest among both researchers and developers in a bid to understand the intricacies between the indices and to make appropriate policies that will sustain development. In retrospect, Khobai and Le Roux (2017) presented the cointegration and causality results for energy consumption, carbon dioxide emission, economic growth, trade openness, and urbanization in South Africa (1971 - 2013) which support long run relationships between the indices and bidirectional causality between energy consumption and carbon dioxide emission. They advocated for energy policies that would entrench the application of renewable energy resources to sustain both the environment and economic growth in South Africa. Furthermore, Khobai (2017) aligned with the Khobai and Le Roux (2017) by unveiling a unidirectional causality flowing from economic growth to electricity consumption long run in the BRICS countries (Brazil, Russia, India, China, and South Africa) (1990 – 2014).

Pertinently, Boţa-Avram, Grosanu, Răchişan, and Gavriletea (2018) carried out bidirectional causality between country-level governance, economic growth, and sustainable development for a large panel of worldwide countries for a period of ten years (2006–2015). They established Granger causality from country-level governance to economic growth, but from economic growth to country-level governance, the causality is not evident. Furthermore, they opined that good governance characterized with minimum bureaucracy, accountability and transparency, and high-quality regulatory frameworks would foster a bidirectional causality between good governance and economic growth.

Subsequently, Almozaini (2019) investigated causality between economic growth (GDP) and energy, gas, and oil consumption for the world's five top energy consumers (1968 - 2016). The study revealed a unidirectional Granger causality from GDP to gas consumption, a bidirectional Granger causality between oil consumption and energy consumption, and a unidirectional Granger causality from gas consumption to oil consumption. He advocated that adequate energy supplies and energy policies should be in place to ensure economic development in various countries (China, India, the USA, Japan, and Saudi Arabia).

The foregoing literature review and analysis of causality between indicators (indices) is solely based on the logarithmic technique, which is prone to differences in methodology, data period, and sample size, which is the cause of a divergence in the results. However, the present work is aimed at establishing causality between the energy indices, namely energy consumption (EC), gross domestic product (GDP), carbon dioxide emission (CDE), the human development index (HDI), and oil price (OP) which reflect economic development, environmental development, social development, and economic crisis (a reflection of a fluctuation in oil price), respectively by utilizing both logarithmic and normalized global data (1982 - 2017). The logarithmic and normalized global data will be subjected to modern econometrics tests consisting of integration, cointegration, causality, and vector error correction model (VECM) analysis to draw out a statistical inference from both techniques. The normalized technique is to be carried out in two ways, viz a normalization of indices via both average and minimum indices. The normalized data technique is expected to be resistant to the pitfalls in the logarithmic technique and thus will provide unified (convergent) results. Subsequently, the introduction is accompanied by materials and method, results and discussion, and conclusions. Also, the present work will compare a statistical inference sequel to logarithmic and normalized analyses of energy indices.

2. MATERIALS AND METHOD

2.1. Physical Model

The physical model is a formulation of a multivariable power-law model for the different energy indices:

The energy consumption model in Equation 1 is represented in Hossain (2012) as follows:

$$EC = f\left(GDP, CDE, HDI, OP\right);\ EC = \alpha_{ec}\, GDP^{\alpha_{gdp}}\, CDE^{\alpha_{cde}}\, HDI^{\alpha_{hdi}}\, OP^{\alpha_{op}} \tag{1}$$

The gross domestic product model in Equation 2 is given in Hossain (2012) as follows:

$$GDP = f\left(EC, CDE, HDI, OP\right);\ GDP = \beta_{gdp}\, EC^{\beta_{ec}}\, CDE^{\beta_{cde}}\, HDI^{\beta_{hdi}}\, OP^{\beta_{op}} \tag{2}$$

The carbon dioxide emission model in Equation 3 is expressed in Hossain (2012) as follows:

$$CDE = f\left(EC, GDP, HDI, OP\right);\ CDE = \delta_{cde}\, EC^{\delta_{ec}}\, GDP^{\delta_{gdp}}\, HDI^{\delta_{hdi}}\, OP^{\delta_{op}} \tag{3}$$

The human development index model in Equation 4 is written in Hossain (2012) as follows:

$$HDI = f\left(EC, GDP, CDE, OP\right);\ HDI = \varepsilon_{hdi}\, EC^{\varepsilon_{ec}}\, GDP^{\varepsilon_{gdp}}\, CDE^{\varepsilon_{cde}}\, OP^{\varepsilon_{op}} \tag{4}$$

The oil price model in Equation 5 is proposed in Hossain (2012) as follows:

$$OP = f\left(EC, GDP, CDE, HDI\right);\ OP = \phi_{op}\, EC^{\phi_{ec}}\, GDP^{\phi_{gdp}}\, CDE^{\phi_{cde}}\, HDI^{\phi_{hdi}} \tag{5}$$

where EC, ec = energy consumption (*Mtoe*), GDP, gdp = gross domestic product (*US$ Billion*), CDE, cde = carbon dioxide emission (*Mtoe of* CO_2), HDI, hdi = human development index (%), OP, op = oil price (*US$ Billion/Mtoe*).

The logarithmic ($ln \to L$) representation of Equations 1 - 5 is as follows:

The energy consumption logarithmic model in Equation 6 is represented in Khobai and Le Roux (2017) as follows:

$$LEC = \alpha_{ec}^{*} + \alpha_{gdp} LGDP + \alpha_{ec} LCDE + \alpha_{hdi} LHDI + \alpha_{op} LOP + \cdots;\ \alpha_{ec}^{*} = L\alpha_{ec} \quad (6)$$

The gross domestic product logarithmic model in Equation 7 is given in Khobai and Le Roux (2017) as follows:

$$LGDP = \beta_{gdp}^{*} + \beta_{ec} LEC + \beta_{cde} LCDE + \beta_{hdi} LHDI + \beta_{op} LOP + \cdots;\ \beta_{gdp}^{*} = L\beta_{gdp} \quad (7)$$

The carbon dioxide emission logarithmic model in Equation 8 is expressed in Khobai and Le Roux (2017) as follows:

$$LCDE = \delta_{cde}^{*} + \delta_{ec} LEC + \delta_{gdp} LGDP + \delta_{hdi} LHDI + \delta_{op} LOP + \cdots;\ \delta_{cde}^{*} = L\delta_{cde} \quad (8)$$

The human development index logarithmic model in Equation 9 is written in Khobai and Le Roux (2017) as follows:

$$LHDI = \varepsilon_{hdi}^{*} + \varepsilon_{ec} LEC + \varepsilon_{gdp} LGDP + \varepsilon_{cde} LCDE + \varepsilon_{op} LOP + \cdots;\ \varepsilon_{hdi}^{*} = L\varepsilon_{hdi} \quad (9)$$

The oil price logarithmic model in Equation 10 is proposed in Khobai and Le Roux (2017) as follows:

$$LOP = \phi_{op}^{*} + \phi_{ec} LEC + \phi_{gdp} LGDP + \phi_{cde} LCDE + \phi_{hdi} LHDI + \cdots;\ \phi_{op}^{*} = L\phi_{op} \quad (10)$$

where α's, β's, δ's, ε's and ϕ's are regression coefficients.

2.2. Time Series Models

A comprehensive time series or an econometric representation of the global energy indices comprises the short and long run terms, which unveil the causality and dynamics of the perturbation of the indices, respectively. The general vector error correction model (GVECM) for the different indices is as follows:

The GVECM for energy consumption in Equation 11 is given in Mahmood and Zamil (2019) as

$$\begin{aligned}\Delta LEC_t &= \psi_{ec} + \varphi_{ec} LEC_{t-1} + \lambda_{ec,gdp} LGDP_{t-1} + \lambda_{ec,cde} LCDE_{t-1} + \lambda_{ec,hdi} LHDI_{t-1} + \lambda_{ec,op} LOP_{t-1} + \sum_{j=1}^{q} \rho_{ec,gdp,j} \Delta LGDP_{t-j} \\ &+ \sum_{j=1}^{r} \rho_{ec,cde,j} \Delta LCDE_{t-j} + \sum_{j=1}^{s} \rho_{ec,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{t} \rho_{ec,op,j} \Delta LOP_{t-j} + \mu_{ec,ect} ECT_{t-1} + \vartheta_{ec}\end{aligned} \quad (11)$$

The GVECM for gross domestic product in Equation 12 is *expressed* in Mahmood and Zamil (2019) as

$$\begin{aligned}\Delta LGDP_t &= \psi_{gdp} + \varphi_{gdp} LGDP_{t-1} + \lambda_{gdp,ec} LEC_{t-1} + \lambda_{gdp,cde} LCDE_{t-1} + \lambda_{gdp,hdi} LHDI_{t-1} + \lambda_{gdp,op} LOP_{t-1} + \sum_{j=1}^{q} \rho_{gdp,ec,j} \Delta LEC_{t-j} \\ &+ \sum_{j=1}^{r} \rho_{gdp,cde,j} \Delta LCDE_{t-j} + \sum_{j=1}^{s} \rho_{gdp,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{t} \rho_{gdp,op,j} \Delta LOP_{t-j} + \mu_{gdp,ect} ECT_{t-1} + \vartheta_{gdp}\end{aligned} \quad (12)$$

The GVECM for carbon dioxide emission in Equation 13 is derived in Mahmood and Zamil (2019) as

$$\begin{aligned}\Delta LCDE_t &= \psi_{cde} + \varphi_{cde} LCDE_{t-1} + \lambda_{cde,ec} LEC_{t-1} + \lambda_{cde,gdp} LGDP_{t-1} + \lambda_{cde,hdi} LHDI_{t-1} + \lambda_{cde,op} LOP_{t-1} + \sum_{j=1}^{q} \rho_{cde,gdp,j} \Delta LGDP_{t-j} \\ &+ \sum_{j=1}^{r} \rho_{cde,ec,j} \Delta LEC_{t-j} + \sum_{j=1}^{s} \rho_{cde,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{t} \rho_{cde,op,j} \Delta LOP_{t-j} + \mu_{cde,ect} ECT_{t-1} + \vartheta_{cde}\end{aligned} \quad (13)$$

The GVECM for human development index in Equation 14 is written in Mahmood and Zamil (2019) as

$$\begin{aligned}\Delta LHDI_t &= \psi_{hdi} + \varphi_{hdi} LHDI_{t-1} + \lambda_{hdi,ec} EC_{t-1} + \lambda_{hdi,gdp} LGDP_{t-1} + \lambda_{hdi,cde} LCDE_{t-1} + \lambda_{hdi,op} LOP_{t-1} + \sum_{j=1}^{q} \rho_{hdi,gdp,j} \Delta LGDP_{t-j} \\ &+ \sum_{j=1}^{r} \rho_{hdi,ec,j} \Delta LCDE_{t-j} + \sum_{j=1}^{s} \rho_{hdi,ec,j} \Delta LEC_{t-j} + \sum_{j=1}^{t} \rho_{hdi,op,j} \Delta LOP_{t-j} + \mu_{hdi,ect} ECT_{t-1} + \vartheta_{hdi}\end{aligned} \quad (14)$$

The GVECM for energy consumption in Equation 15 is articulated in Mahmood and Zamil (2019) as

$$\begin{aligned}\Delta LOP_t &= \psi_{op} + \varphi_{op} LOP_{t-1} + \lambda_{op,ec} EC_{t-1} + \lambda_{op,gdp} LGDP_{t-1} + \lambda_{op,cde} LCDE_{t-1} + \lambda_{op,hdi} LHDI_{t-1} + \sum_{j=1}^{q} \rho_{op,gdp,j} \Delta LGDP_{t-j} \\ &+ \sum_{j=1}^{r} \rho_{op,cde,j} \Delta LCDE_{t-j} + \sum_{j=1}^{s} \rho_{op,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{t} \rho_{op,ec,j} \Delta LEC_{t-j} + \mu_{op,ect} ECT_{t-1} + \vartheta_{op}\end{aligned} \quad (15)$$

where ψ's, φ's, λ's, and ρ's are the elasticity of the independent variables, whereas μ's is the elasticity of error correction terms and ϑ's are truncation error terms.

Decomposing of GVECM into a long run model (LRM):

The LRM for Energy consumption in Equation 16 is given in Abokyi, Appiah-Konadu, Sikayena, and Oteng-Abayie (2018); Baimaganbetov, Kelesbayev, Yermankulova, Izzatullaeva, and Almukhambetova (2019) as

$$LEC_t = \psi^*_{ec} + \varphi_{ec} LEC_{t-1} + \lambda_{ec,gdp} LGDP_{t-1} + \lambda_{ec,cde} LCDE_{t-1} + \lambda_{ec,hdi} LHDI_{t-1} + \lambda_{ec,op} LOP_{t-1} + \kappa_{ec} \quad (16)$$

The LRM for gross domestic product in Equation 17 is specified in Abokyi et al. (2018); Baimaganbetov et al. (2019) as

$$LGDP_t = \psi^*_{gdp} + \varphi_{gdp} LGDP_{t-1} + \lambda_{gdp,ec} LEC_{t-1} + \lambda_{gdp,cde} LCDE_{t-1} + \lambda_{gdp,hdi} LHDI_{t-1} + \lambda_{gdp,op} LOP_{t-1} + \kappa_{gdp} \quad (17)$$

The LRM for carbon dioxide emission in Equation 18 is derived in Abokyi et al. (2018); Baimaganbetov et al. (2019) as

$$LCDE_t = \psi^*_{cde} + \varphi_{cde} LCDE_{t-1} + \lambda_{cde,ec} LEC_{t-1} + \lambda_{cde,gdp} LGDP_{t-1} + \lambda_{cde,hdi} HDI_{t-1} + \lambda_{cde,op} LOP_{t-1} + \kappa_{cde} \quad (18)$$

The LRM for human development index in Equation 19 is expressed in Abokyi et al. (2018); Baimaganbetov et al. (2019) as

$$LHDI_t = \psi^*_{hdi} + \varphi_{hdi} LHDI_{t-1} + \lambda_{hdi,ec} EC_{t-1} + \lambda_{hdi,gdp} LGDP_{t-1} + \lambda_{hdi,cde} LCDE_{t-1} + \lambda_{hdi,op} LOP_{t-1} + \kappa_{hdi} \quad (19)$$

The LRM for energy consumption in Equation 20 is presented in Abokyi et al. (2018) as

$$LOP_t = \psi^*_{op} + \varphi_{op} LOP_{t-1} + \lambda_{op,ec} EC_{t-1} + \lambda_{op,gdp} LGDP_{t-1} + \lambda_{op,cde} LCDE_{t-1} + \lambda_{op,hdi} LHDI_{t-1} + \kappa_{op} \quad (20)$$

where κ's are truncation terms.

Decomposing general VECM into short run model (SRM):

The SRM for Energy consumption in Equation 21 is given in Hossain (2012); Baimaganbetov et al. (2019) as

$$\begin{aligned}\Delta LEC_t = \psi^{**}_{ec} &+ \sum_{j=1}^{p=1} \rho_{ec,gdp,j} \Delta LGDP_{t-j} + \sum_{j=1}^{q=1} \rho_{ec,cde,j} \Delta LCDE_{t-j} + \sum_{j=1}^{r=1} \rho_{ec,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{s=1} \rho_{ec,op,j} \Delta LOP_{t-j} \\ &+ \mu_{ec,ect} ECT_{t-1} + \eta_{ec}\end{aligned} \quad (21)$$

The SRM for gross domestic product in Equation 22 is stated in Hossain (2012); Baimaganbetov et al. (2019) as

$$\Delta LGDP_t = \psi^{**}_{gdp} + \sum_{j=1}^{p=1} \rho_{gdp,ec,j} \Delta LEC_{t-j} + \sum_{j=1}^{q=1} \rho_{gdp,cde,j} \Delta LCDE_{t-j} + \sum_{j=1}^{r=1} \rho_{gdp,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{s=1} \rho_{gdp,op,j} \Delta LOP_{t-j} + \mu_{gdp,ect} ECT_{t-1} + \eta_{gdp} \quad (22)$$

The SRM for carbon dioxide emission in Equation 23 is defined in Hossain (2012); Baimaganbetov et al. (2019) as

$$\Delta LCDE_t = \psi^{**}_{cde} + \sum_{j=1}^{p=1} \rho_{cde,gdp,j} \Delta LGDP_{t-j} + \sum_{j=1}^{q=1} \rho_{cde,ec,j} \Delta LEC_{t-j} + \sum_{j=1}^{r=1} \rho_{cde,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{s=1} \rho_{cde,op,j} \Delta LOP_{t-j} + \mu_{cde,ect} ECT_{t-1} + \eta_{cde} \quad (23)$$

The SRM for human development index in Equation 24 is well-defined in Hossain (2012); Baimaganbetov et al. (2019) as

$$\Delta LHDI_t = \psi^{**}_{hdi} + \sum_{j=1}^{p=1} \rho_{hdi,gdp,j} \Delta LGDP_{t-j} + \sum_{j=1}^{q} \rho_{hdi,ec,j} \Delta LCDE_{t-j} + \sum_{j=1}^{r} \rho_{hdi,ec,j} \Delta LEC_{t-j} + \sum_{j=1}^{s} \rho_{hdi,op,j} \Delta LOP_{t-j} + \mu_{hdi,ect} ECT_{t-1} + \eta_{hdi} \quad (24)$$

The SRM for oil price in Equation 25 is described in Hossain (2012); Baimaganbetov et al. (2019) as

$$\Delta LOP_t = \psi^{**}_{op} + \sum_{j=1}^{p=1} \rho_{op,gdp,j} \Delta LGDP_{t-j} + \sum_{j=1}^{q=1} \rho_{op,cde,j} \Delta LCDE_{t-j} + \sum_{j=1}^{r=1} \rho_{op,hdi,j} \Delta LHDI_{t-j} + \sum_{j=1}^{s=1} \rho_{op,ec,j} \Delta LEC_{t-j} + \mu_{op,ect} ECT_{t-1} + \eta_{op} \quad (25)$$

where η's are truncation terms.

The error correction term is generated from Equations 1 - 5 as thus:

The error correction term for energy consumption, ECT_{ec} is defined in Equation 26 as

$$\begin{aligned}ECT_{ec,t-1} = &\left(LEC_{t-1} - \alpha^*_{ec} - \alpha_{gdp} LGDP_{t-1} - \alpha_{ec} LCDE_{t-1} - \alpha_{hdi} LHDI_{t-1} - \alpha_{op} LOP_{t-1}\right) \\ &- \left(LEC_{t-2} - \alpha^*_{ec} - \alpha_{gdp} LGDP_{t-2} - \alpha_{ec} LCDE_{t-2} - \alpha_{hdi} LHDI_{t-2} - \alpha_{op} LOP_{t-2}\right)\end{aligned} \quad (26)$$

The error correction term for gross domestic product, ECT_{gdp} is given in Equation 27 as

$$\begin{aligned}ECT_{gdp,t-1} = &\left(LGDP_{t-1} - \beta^*_{gdp} - \beta_{ec} LEC_{t-1} - \beta_{cde} LCDE_{t-1} - \beta_{hdi} LHDI_{t-1} - \beta_{op} LOP_{t-1}\right) \\ &- \left(LGDP_{t-2} - \beta^*_{gdp} - \beta_{ec} LEC_{t-2} - \beta_{cde} LCDE_{t-2} - \beta_{hdi} LHDI_{t-2} - \beta_{op} LOP_{t-2}\right)\end{aligned} \quad (27)$$

The error correction term for carbon dioxide emission, ECT_{cde} is expressed in Equation 28 as

$$ECT_{cde,t-1} = \left(LCDE_{t-1} - \delta^{*}_{cde} - \delta_{ec}LEC_{t-1} - \delta_{gdp}LGDP_{t-1} - \delta_{hdi}LHDI_{t-1} - \delta_{op}LOP_{t-1}\right) - \left(LCDE_{t-2} - \delta^{*}_{cde} - \delta_{ec}LEC_{t-2} - \delta_{gdp}LGDP_{t-2} - \delta_{hdi}LHDI_{t-2} - \delta_{op}LOP_{t-2}\right) \quad (28)$$

The error correction term for human development index, ECT_{hdi} is written in Equation 29 as

$$ECT_{hdi,t-1} = \left(LHDI_{t-1} - \varepsilon^{*}_{hdi} - \varepsilon_{ec}LEC_{t-1} - \varepsilon_{gdp}LGDP_{t-1} - \varepsilon_{cde}LCDE_{t-1} - \varepsilon_{op}LOP_{t-1}\right) - \left(LHDI_{t-2} - \varepsilon^{*}_{hdi} - \varepsilon_{ec}LEC_{t-2} - \varepsilon_{gdp}LGDP_{t-2} - \varepsilon_{cde}LCDE_{t-2} - \varepsilon_{op}LOP_{t-2}\right) \quad (29)$$

The error correction term for oil price, ECT_{op} is defined in Equation 30 as

$$ECT_{op,t-1} = \left(LOP_{t-1} - \phi^{*}_{op} - \phi_{ec}LEC_{t-1} - \phi_{gdp}LGDP_{t-1} - \phi_{cde}LCDE_{t-1} - \phi_{hdi}LHDI_{t-1}\right) - \left(LOP_{t-2} - \phi^{*}_{op} - \phi_{ec}LEC_{t-2} - \phi_{gdp}LGDP_{t-2} - \phi_{cde}LCDE_{t-2} - \phi_{hdi}LHDI_{t-2}\right) \quad (30)$$

Equations 26-30 are error correction term (ECT).

Alternatively, the energy consumption normalized long run model in Equation 31 is represented as follows:

$$EC'_t = \alpha''_{ec} + EC'_{t-1} + \alpha''_{gdp}GDP'_{t-1} + \alpha''_{ec}CDE'_{t-1} + \alpha''_{hdi}HDI'_{t-1} + \alpha''_{op}OP'_{t-1} + \eta''_{ec} \quad (31)$$

where EC′, GDP′, CDE′, HDI′ and OP′ denote normalized energy indices.

The gross domestic product normalized long run model in Equation 32 is given as follows:

$$GDP'_t = \beta''_{gdp} + GDP'_{t-1} + \beta''_{ec}EC'_{t-1} + \beta''_{cde}CDE'_{t-1} + \beta''_{hdi}HDI'_{t-1} + \beta''_{op}OP'_{t-1} + \eta''_{gdp} \quad (32)$$

The carbon dioxide emission normalized long run model in Equation 33 is expressed as follows:

$$CDE'_t = \delta''_{cde} + CDE'_{t-1} + \delta''_{ec}EC'_{t-1} + \delta''_{gdp}GDP'_{t-1} + \delta''_{hdi}HDI'_{t-1} + \delta''_{op}OP'_{t-1} + \eta''_{cde} \quad (33)$$

The human development index normalized long run model in Equation 34 is written as follows:

$$HDI'_t = \varepsilon''_{hdi} + HDI'_{t-1} + \varepsilon''_{ec}EC'_{t-1} + \varepsilon''_{gdp}GDP'_{t-1} + \varepsilon''_{cde}CDE'_{t-1} + \varepsilon''_{op}OP'_{t-1} + \eta''_{hdi} \quad (34)$$

The oil price normalized long run model in Equation 35 is proposed as follows:

$$OP'_t = \phi''_{op} + OP'_{t-1} + \phi''_{ec}EC'_{t-1} + \phi''_{gdp}GDP'_{t-1} + \phi''_{cde}CDE'_{t-1} + \phi''_{hdi}HDI'_{t-1} + \eta''_{op} \quad (35)$$

The energy consumption normalized short run model in Equation 36 is represented as follows:

$$\Delta EC' = \alpha'''_{ec} + \sum_{k=1}^{u=1}\alpha'''_{gdp,k}\Delta GDP'_{t-k} + \sum_{k=1}^{v=1}\alpha'''_{ec,k}\Delta CDE'_{t-k} + \sum_{k=1}^{w=1}\alpha'''_{hdi,k}\Delta HDI'_{t-k} + \sum_{k=1}^{x=1}\alpha'''_{op,k}\Delta OP'_{t-k} + \mu'''_{ec,ect}ECT'_{t-1} + \eta'''_{ec} \quad (36)$$

The gross domestic product normalized short run model in Equation 37 is given as follows:

$$\Delta GDP' = \beta'''_{gdp} + \sum_{k=1}^{u=1}\beta'''_{ec,k}\Delta EC'_{t-k} + \sum_{k=1}^{v=1}\beta'''_{cde,k}\Delta CDE'_{t-k} + \sum_{k=1}^{w=1}\beta'''_{hdi,k}\Delta HDI'_{t-k} + \sum_{k=1}^{w=1}\beta'''_{op,k}\Delta OP'_{t-k} + \mu'''_{gdp,ect}ECT'_{t-1} + \eta'''_{gdp} \quad (37)$$

The carbon dioxide emission normalized short run model in Equation 38 is expressed as follows:

$$\Delta CDE' = \delta'''_{cde} + \sum_{k=1}^{u=1}\delta'''_{ec,k}\Delta EC' + \delta'''_{gdp}\Delta GDP' + \delta'''_{hdi}\Delta HDI' + \delta'''_{op}\Delta OP' + \mu'''_{cde,ect}ECT_{t-1} + \eta'''_{cde} \quad (38)$$

The human development index normalized short run model in Equation 39 is written as follows:

$$\Delta HDI' = \varepsilon'''_{hdi} + \sum_{k=1}^{u=1}\varepsilon'''_{ec,k}\Delta EC'_{t-k} + \sum_{k=1}^{v=1}\varepsilon'''_{gdp,k}\Delta GDP'_{t-k} + \sum_{k=1}^{w=1}\varepsilon'''_{cde,k}\Delta CDE'_{t-k} + \sum_{k=1}^{x=1}\varepsilon'''_{op,k}\Delta OP'_{t-k} + \mu'''_{hdi,ect}ECT'_{t-1} + \eta'''_{hdi} \quad (39)$$

The oil price normalized short run model in Equation 40 is proposed as follows:

$$\Delta OP' = \phi'''_{op} + \sum_{k=1}^{u=1}\phi'''_{ec,k}\Delta EC'_{t-k} + \sum_{k=1}^{v=1}\phi'''_{gdp,k}\Delta GDP'_{t-k} + \sum_{k=1}^{w=1}\phi'''_{cde,k}\Delta CDE'_{t-k} + \sum_{k=1}^{x=1}\phi'''_{hdi,k}\Delta HDI'_{t-k} + \mu'''_{op,ect}ECT'_{t-1} + \eta'''_{op} \quad (40)$$

where:

The normalized energy consumption, EC'(-) in Equation 41 is represented as

$$EC'_t = \frac{EC_t - EC_{\min}}{EC_{\max} - EC_{\min}} \text{ or } EC'_t = \frac{EC_t - EC_{avg}}{EC_{\max} - EC_{avg}};\ EC_{avg} = \frac{1}{n}\sum_{t=1}^{n}EC_t \quad (41)$$

The normalized gross domestic product, GDP'(-) in Equation 42 is given as

$$GDP'_t = \frac{GDP_t - GDP_{\min}}{GDP_{\max} - GDP_{\min}} \text{ or } GDP'_t = \frac{GDP_t - GDP_{avg}}{GDP_{\max} - GDP_{avg}};\ GDP_{avg} = \frac{1}{n}\sum_{t=1}^{n}GDP_t \quad (42)$$

The normalized carbon dioxide emission, CDE'(-) in Equation 43 is expressed as

$$CDE_t' = \frac{CDE_t - CDE_{\min}}{CDE_{\max} - GDP_{\min}} \text{ or } CDE_t' = \frac{CDE_t - CDE_{avg}}{CDE_{\max} - GDP_{avg}};\ CDE_{avg} = \frac{1}{n}\sum_{t=1}^{n} CDE_t \quad (43)$$

The normalized human development index, HDI'(-) in Equation 44 is written as

$$HDI_t' = \frac{HDI_t - HDI_{\min}}{HDI_{\max} - HDI_{\min}} \text{ or } HDI_t' = \frac{HDI_t - HDI_{avg}}{HDI_{\max} - HDI_{avg}};\ HDI_{avg} = \frac{1}{n}\sum_{t=1}^{n} HDI_t \quad (44)$$

The normalized oil price, OP'(-) in Equation 45 is proposed as

$$OP_t' = \frac{OP_t - OP_{\min}}{OP_{\max} - OP_{\min}} \text{ or } OP_t' = \frac{OP_t - OP_{avg}}{OP_{\max} - OP_{avg}};\ OP_{avg} = \frac{1}{n}\sum_{t=1}^{n} OP_t \quad (45)$$

where n is the number of observation and subscripts; *avg*, *max*, and *min* denote average, maximum, and minimum, respectively.

The normalized error correction terms in Equations 41 - 45 are defined as follows:

The normalized error correction term for energy consumption, ECT'_{ec} is defined in Equation 46 as

$$\begin{aligned} ECT'_{ec,t-1} = & \left(EC'_{t-1} - \alpha^{*'}_{ec} - \alpha'_{gdp} GDP'_{t-1} - \alpha'_{ec} CDE'_{t-1} - \alpha'_{hdi} HDI'_{t-1} - \alpha'_{op} OP'_{t-1}\right) \\ & - \left(EC'_{t-2} - \alpha^{*'}_{ec} - \alpha'_{gdp} GDP'_{t-2} - \alpha'_{ec} CDE'_{t-2} - \alpha'_{hdi} HDI'_{t-2} - \alpha_{op} OP'_{t-2}\right) \end{aligned} \quad (46)$$

The normalized error correction term for gross domestic product, ECT'_{gdp} is given in Equation 47 as

$$\begin{aligned} ECT'_{gdp,t-1} = & \left(GDP'_{t-1} - \beta^{*'}_{gdp} - \beta'_{ec} EC'_{t-1} - \beta_{cde} CDE'_{t-1} - \beta'_{hdi} HDI'_{t-1} - \beta'_{op} OP'_{t-1}\right) \\ & - \left(GDP'_{t-2} - \beta^{*'}_{gdp} - \beta'_{ec} EC'_{t-2} - \beta'_{cde} CDE'_{t-2} - \beta'_{hdi} HDI'_{t-2} - \beta'_{op} OP'_{t-2}\right) \end{aligned} \quad (47)$$

The normalized error correction term for carbon dioxide emission, ECT'_{cde} is expressed in Equation 48 as

$$\begin{aligned} ECT'_{cde,t-1} = & \left(CDE'_{t-1} - \delta^{*'}_{cde} - \delta'_{ec} EC'_{t-1} - \delta'_{gdp} GDP'_{t-1} - \delta'_{hdi} HDI'_{t-1} - \delta'_{op} OP'_{t-1}\right) \\ & - \left(CDE'_{t-2} - \delta^{*'}_{cde} - \delta'_{ec} EC'_{t-2} - \delta'_{gdp} GDP'_{t-2} - \delta'_{hdi} HDI'_{t-2} - \delta'_{op} OP'_{t-2}\right) \end{aligned} \quad (48)$$

The normalized error correction term for human development index, ECT'_{hdi} is written in Equation 49 as

$$\begin{aligned} ECT'_{hdi,t-1} = & \left(HDI'_{t-1} - \varepsilon^{*'}_{hdi} - \varepsilon'_{ec} EC'_{t-1} - \varepsilon'_{gdp} GDP'_{t-1} - \varepsilon'_{cde} CDE'_{t-1} - \varepsilon'_{op} OP'_{t-1}\right) \\ & - \left(HDI'_{t-2} - \varepsilon^{*'}_{hdi} - \varepsilon'_{ec} EC'_{t-2} - \varepsilon'_{gdp} GDP'_{t-2} - \varepsilon'_{cde} CDE'_{t-2} - \varepsilon'_{op} OP'_{t-2}\right) \end{aligned} \quad (49)$$

The normalized error correction term for oil price, ECT'_{op} is defined in Equation 50 as

$$\begin{aligned} ECT'_{op,t-1} = & \left(OP'_{t-1} - \phi^{*'}_{op} - \phi'_{ec} EC'_{t-1} - \phi'_{gdp} GDP'_{t-1} - \phi'_{cde} CDE'_{t-1} - \phi'_{hdi} HDI'_{t-1}\right) \\ & - \left(OP'_{t-2} - \phi^{*'}_{op} - \phi'_{ec} EC'_{t-2} - \phi'_{gdp} GDP'_{t-2} - \phi'_{cde} CDE'_{t-2} - \phi'_{hdi} HDI'_{t-2}\right) \end{aligned} \quad (50)$$

2.3. Input data

The five major energy indicators selected for this work are energy consumption (EC), the gross domestic product (GDP), carbon dioxide emission (CDE), the human development index (HDI), and oil price (OP). The data were retrieved from IEA (2019); Amadeo (2019); and Roser (2019) and jointly from Amadeo (2019); Inflationdata (2019); and Macrotrends (2019). Notably, the EC represents utility, GDP primarily denotes economic development, CDE indicates environmental development, HDI designates social development, and OP portrays economic crises or changes in the oil price due to inflation and oil slumps. The raw data is represented in Figure 1.

The logarithmic input data are shown in Figure 2 with the five indicators presented in dimensionless form for logarithmic technique. While the input data for both the normalized average technique and the normalized minimum data are based on Equations 41-45, they are depicted in Figures 3 and 4, respectively.

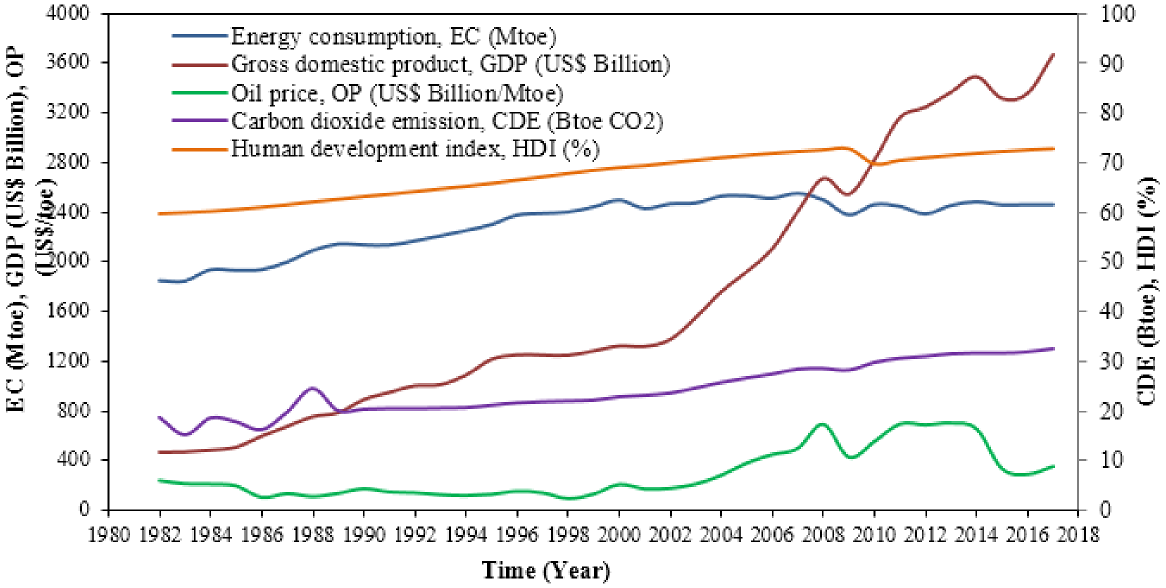

Figure 1. World energy indices.

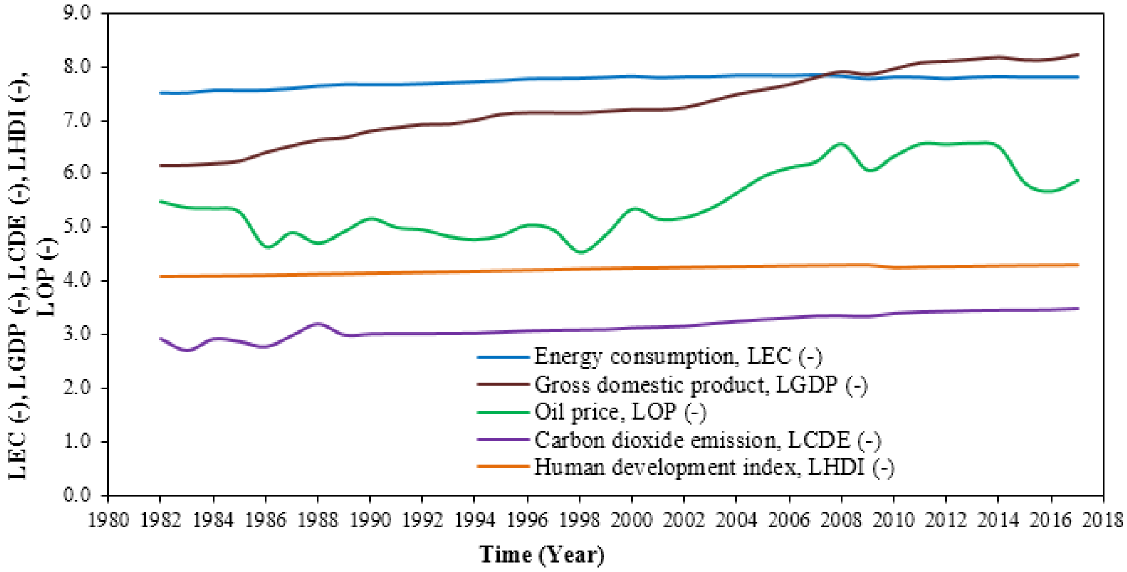

Figure 2. Logarithmic world energy indices.

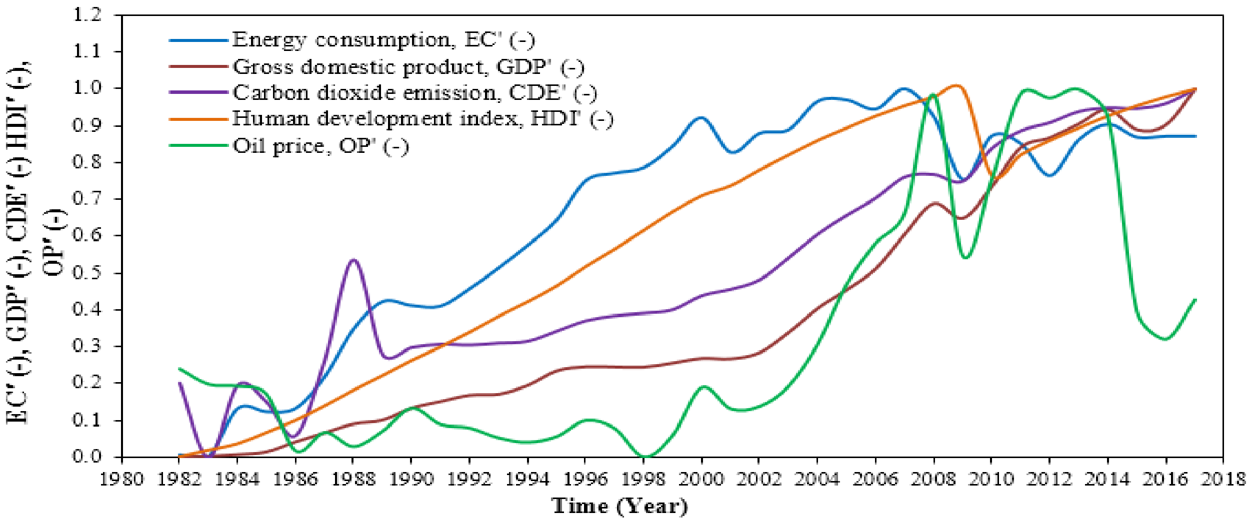

Figure 3. Normalized world energy indices based on minimum index.

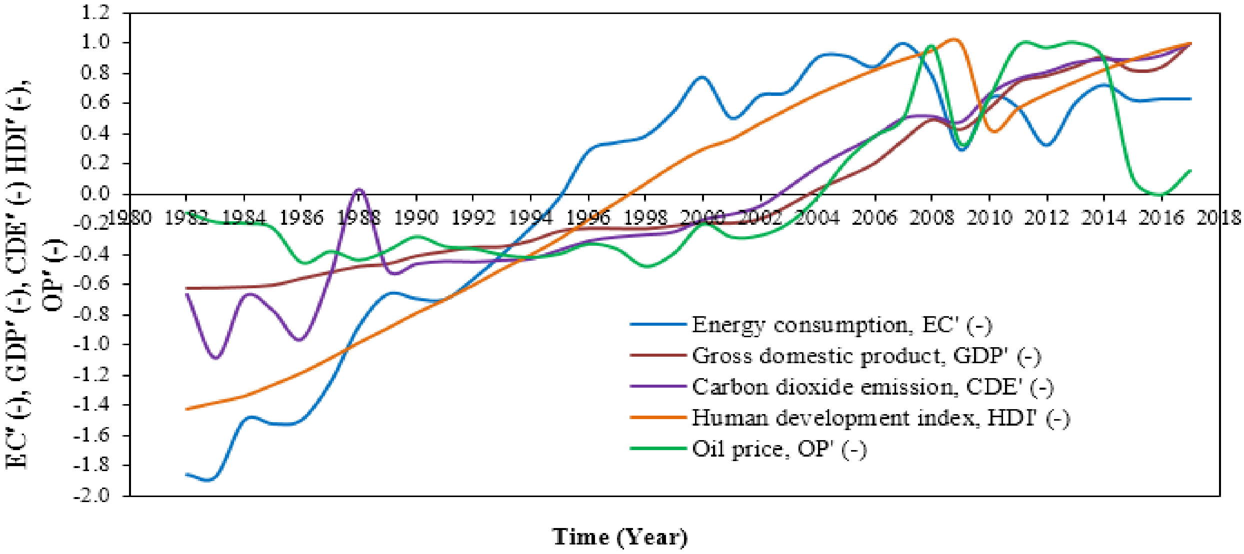

Figure 4. Normalized world energy indices based on average index.

3. RESULTS AND DISCUSSION

The results are presented in Section 3.1 inclusively in Tables 1 – 8 with the accompanying detailed discussion in Section 3.2.

3.1. Results

Table 1 contains the augmented Dickey Fuller unit root test, Table 2a consists of the unrestricted cointegration rank test (trace), Table 2b presents the unrestricted cointegration rank test (maximum eigenvalue), Table 3 holds the pairwise Granger causality test (lag: 2), and Tables 4a-8a contain the logarithmic (normalized) long run analysis of VECM for LEC (EC′), LGDP (GDP′), LCDE (CDE′), LHDI (HDI′), and LOP (OP′), respectively. Tables 4b-8b contain logarithmic (normalized) short run analyses of VECM for ΔLEC (ΔEC′), ΔGDP (ΔGDP′), ΔCDE.

3.2. Discussion

The augmented Dickey Fuller unit root test in Table 1 shows that logarithmic (normalized) results are virtually in accord as most of the indices (LEC (EC′), LGDP (GDP′), LCDE (CDE′), LHDI (HDI′), and LOP (OP′)) recorded an integration order of unity at the 0.05 level, with the exception of normalized LGDP (GDP′) which had an integration order of two at the second difference. This implies that both logarithmic and normalized data are quite stationary, thus, their mean, variance, and autocorrelation structures do not change over time.

Considering the stationarity of the data (LEC (EC′), LGDP (GDP′), LCDE (CDE′), LHDI (HDI′), and LOP (OP′)), cointegration tests were carried out via unrestricted cointegration rank tests comprising trace and maximum eigenvalue for both logarithmic and normalized data. For the trace test, the normalized technique indicated four cointegrations at the 0.05 level, whereas the logarithmic technique indicated only three cointegrations at the 0.05 level, meaning the normalized technique is a more sensitive technique for a time series analysis of energy indices data. Furthermore, the maximum eigenvalue test for both techniques indicated an equal cointegration of two. This parity further buttresses the fact that both techniques are ideal for time series analysis of energy indices. The confirmation of cointegration by both techniques implies that there are obvious long run dynamics between the indices.

The pairwise Granger causality test in Table 3 shows that there is strong agreement between the logarithmic and normalized techniques as both virtually accepted the null hypothesis of non-causality (<>) between the following indicators: LGDP (GDP′) <> LEC (EC′), LCDE (CDE′) <> LEC (EC′), LOP (OP′) <> LGDP (GDP′), LCDE (CDE′) <> LHDI (HDI′), and LOP (OP′) <> LCDE (CDE′) at the global level. Thus, policy regulation becomes immaterial in the absence of causality. Also, the pairwise Granger tests for the logarithmic (normalized) techniques vehemently rejected the null hypothesis of non-causality for certain energy indices and thus established a unidirectional flow (⇒) from LEC (EC′) ⇒ LHDI (HDI′), LOP (OP′) ⇒ LEC (EC′), LGDP (GDP′) ⇒ LCDE (CDE′), and LHDI (HDI′) ⇒ LOP (OP′). Additionally, the normalized technique supports a bidirectional flow (⇔) between GDP′ ⇔ HDI′ and HDI′ ⇔ OP′.

Considering the joint unidirectional causality, there is consequently a need for policies that will regulate LHDI (HDI′) (e.g., social equity, investment in education, urbanization, population structure, political participation, etc.). Of course, these will not affect LEC (LEC′), policies that will regulate LEC (EC′) (e.g., energy efficiency, alternative energy sources, industrialization, etc.) will categorically not disturb LOP (OP′), policies that will regulate LCDE (CDE′) (e.g., greenhouse gas, environmental protection, industrial applications, deforestation, etc.) will not upset LGDP (GDP′), and policies that will regulate LOP (OP′) (e.g., subvention, tariff, supply, import and export, inflation, poverty reduction, etc.) will not change LHDI (HDI′).

The policies above will not be inimical to sustainable development. Moreover, policies that will regulate LHDI (HDI′) (e.g., social equity, investment in education, urbanization, population structure, political participation, etc.) will not alter OP (OP′). Normalized techniques indicate that critical conditions exist in the bidirectional causality as any conservative regulation in one of the indicators GDP′ (via resource exploitation, free economy, free flow of services, goods, consumer benefits, resource allocation, entrepreneurship, etc.), HDI′ (via social equity, investment in education, urbanization, population structure, political participation, etc.), OP′ (via subvention, tariff, supply, import and export, inflation, poverty reduction, etc.), or HDI′ (via social equity, investment in education, urbanization, population structure, political participation, etc.).

Consistently, Tables 4a, 5a, 6a and 7a indicate that the independent indices for logarithmic (normalized) techniques LOP (OP′), LGDP (GDP′), and LEC (EC′) influenced (Grange caused) the dependent indices LEC (EC′), LCDE (CDE′), and LHDI (HDI′), respectively. These results further support that there is an overwhelming agreement between the two techniques. Also, the dependency established in Tables 4a, 5a, 6a and 7a for logarithmic and normalized techniques is in good agreement with the pairwise Granger test for both techniques. It is worth noting that the long run test consolidated with the pairwise Granger test in establishing causality between the indices.

The coefficients of the error correction term for both logarithmic and normalized techniques in Tables 4b-8b are in total agreement. Tables 4b, 5b, and 7b produced positive coefficients for logarithmic (normalized) techniques consisting of 0.1479 (0.09016), 0.40614 (0.444645), and 0.10313 (0.1185) for ΔLEC (ΔEC′), ΔLGDP (ΔGDP′), and ΔLHDI (ΔHDI′) as a dependent variable, respectively. These positive coefficients indicate that short run cannot converge to long run equilibrium. Moreover, the long run coefficients are less than unity, which supports that there are long run cointegration exits. However, Tables 6b and 8b indicated negative coefficients for logarithmic (normalized) techniques consisting of -0.33247 (-0.27899) and -0.16387 (-0.33492) for the dependent variables ΔLCDE (ΔCDE′) and ΔLOP (ΔOP′), respectively. These negative coefficients show that there is a likelihood of short run converging to long run equilibrium and further support that there is two cointegration based on the unrestricted cointegration rank test (maximum eigenvalue) in Table 2b.

Table 1. Augmented Dickey Fuller unit root test.

Hypothesized No. of CE(s)	Logarithmic energy indices				Hypothesized No. of CE(s)	Normalized energy indices (based on average index)			
	ADF Test Statistic	Mackinnon critical value @ 5%	Probability	Order of Integration		ADF Test Statistic	Mackinnon critical value @ 5%	Probability	Order of Integration
LEC	-5.776846	-2.951125	0.0000	I(1)	EC′	-5.962724	-2.951125	0.0000	I(1)
LGDP	-4.195259	-2.951125	0.0024	I(1)	GDP′	-8.632318	-2.951125	0.0024	I(2)
LCDE	-9.084328	-2.951125	0.0000	I(1)	CDE′	-8.480760	-2.951125	0.0000	I(1)
LHDI	-5.592261	-2.951125	0.0000	I(1)	HDI′	-5.719149	-2.951125	0.0000	I(1)
LOP	-5.867349	-2.951125	0.0000	I(1)	OP′	-5.974634	-2.951125	0.0000	I(1)

Table 2a. Unrestricted cointegration rank test (trace).

Hypothesized No. of CE(s)	Logarithmic energy indices				Normalized energy indices (based on average index)			
	Eigenvalue	Trace Statistic	0.05 Critical value	Prob.**	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.834336	118.6567	69.81889	0.0000	0.829512	132.0530	69.81889	0.0000
At most 1 *	0.580779	59.32946	47.85613	0.0029	0.738323	75.44209	47.85613	0.0000
At most 2 *	0.401249	30.64072	29.79707	0.0399	0.404726	32.54143	29.79707	0.0236
At most 3 *	0.263130	13.71471	15.49471	0.0911	0.325463	15.94196	15.49471	0.0428
At most 4	0.104393	3.638360	3.841466	0.0565	0.099187	3.342653	3.841466	0.0675

Note: Trace test indicates 4 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon, Haug, and Michelis (1999) p-values.

Table 2b. Unrestricted cointegration rank test (maximum eigenvalue).

Hypothesized No. of CE(s)	Logarithmic energy indices				Normalized energy indices (based on average index)			
	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.834336	59.32725	33.87687	0.0000	0.829512	56.61088	33.87687	0.0000
At most 1 *	0.580779	28.68874	27.58434	0.0360	0.738323	42.90067	27.58434	0.0003
At most 2 *	0.401249	16.92601	21.13162	0.1755	0.404726	16.59947	21.13162	0.1918
At most 3 *	0.263130	10.07635	14.26460	0.2070	0.325463	12.59931	14.26460	0.0901
At most 4	0.104393	3.638360	3.841466	0.0565	0.099187	3.342653	3.841466	0.0675

Note: Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
*denotes rejection of the hypothesis at the 0.05 level
**MacKinnon et al. (1999) p-values.

Table 3. Pairwise Granger causality test (lag: 2).

Null Hypothesis:	Logarithmic energy indices			Normalized energy indices (based on average index)		Normalized energy indices (based on minimum index)	
	Obs.	f-Value	Prob>|f|	f-Value′	Prob>|f|′	f-Value′	Prob>|f|′
LGDP(GDP′) does not Granger Cause LEC(EC′)	34	0.48131	0.6228	2.37839	0.1105	2.37839	0.1105
LEC(EC′) does not Granger Cause LGDP(GDP′)	34	0.37460	0.6908	0.25402	0.7774	0.25402	0.7774
LHDI(HDI′) does not Granger Cause LEC(EC′)	34	0.11909	0.8882	0.11436	0.8923	0.11436	0.8923
LEC(EC′) does not Granger Cause LHDI(HDI′)	34	8.68729	0.0011	9.32884	0.0007	9.32884	0.0007
LCDE(CDE′) does not Granger Cause LEC(EC′)	34	0.39598	0.6766	0.46244	0.6343	0.46244	0.6343
LEC(EC′) does not Granger Cause LCDE(CDE′)	34	0.32106	0.7279	0.33135	0.7206	0.33135	0.7206
LOP(OP′) does not Granger Cause LEC(EC′)	34	3.34719	0.0492	4.50751	0.0197	4.50751	0.0197
LEC(EC′) does not Granger Cause LOP(OP′)	34	2.14769	0.1350	1.11686	0.3410	1.11686	0.3410
LHDI(HDI′) does not Granger Cause LGDP(GDP′)	34	2.05918	0.1458	4.15586	0.0259	4.15586	0.0259
LGDP(GDP′) does not Granger Cause LHDI(HDI′)	34	2.06149	0.1455	3.42485	0.0462	3.42485	0.0462
LCDE(CDE′)does not Granger Cause LGDP(GDP′)	34	1.24695	0.3023	1.41016	0.2603	1.41016	0.2603
LGDP(GDP′) does not Granger Cause LCDE(CDE′)	34	6.46754	0.0048	4.39686	0.0215	4.39686	0.0215
LOP(OP′) does not Granger Cause LGDP(GDP′)	34	0.43643	0.6505	1.99473	0.1543	1.99473	0.1543
LGDP(GDP′) does not Granger Cause LOP(OP′)	34	2.88508	0.0720	2.95183	0.0681	2.95183	0.0681
LCDE(CDE′) does not Granger Cause LHDI(HDI′)	34	0.17750	0.8383	0.24954	0.7808	0.24954	0.7808
HDI(HDI′) does not Granger Cause LCDE(CDE′)	34	1.92936	0.1634	1.47473	0.2455	1.47473	0.2455
LOP(OP′) does not Granger Cause LHDI(HDI′)	34	2.97679	0.0667	6.54429	0.0045	6.54429	0.0045
LHDI(HDI′) does not Granger Cause LOP(OP′)	34	3.78988	0.0345	3.87234	0.0323	3.87234	0.0323
LOP(OP′) does not Granger Cause LCDE(CDE′)	34	0.72491	0.4929	0.41445	0.6646	0.41445	0.6646
LCDE(CDE′) does not Granger Cause LOP(OP′)	34	1.99360	0.1544	1.20555	0.3141	1.20555	0.3141

Table 4a. Long run analysis of energy consumption with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
EC	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**EC′**	**Value**	**Standard Error**	t-Value	Prob>|t|
Intercept	1.0815	0.47776	2.26367	0.03125	Intercept	0.10746	0.03209	3.34889	0.00226
EC(-1)	0.62319	0.11295	5.51716	6.03311E-6	EC′(-1)	0.72205	0.1249	5.78094	2.90974E-6
GDP(-1)	0.02826	0.02138	1.32176	0.19658	GDP′(-1)	0.07846	0.14966	0.52428	0.60407
CDE(-1)	-0.03434	0.04785	-0.7176	0.47874	CDE′(-1)	-0.04	0.15014	-0.26644	0.79179
HDI(-1)	0.45468	0.22563	2.01512	0.05324	HDI′(-1)	0.2397	0.14829	1.61637	0.11684
OP(-1)	-0.03045	0.00839	-3.6289	0.00108	OP′(-1)	-0.15542	0.05918	-2.62643	0.01364

Table 4b. Short run analysis of energy consumption with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
ΔLEC	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**ΔEC′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	0.00511	0.00611	0.83648	0.40997	Intercept	0.03431	0.02232	1.53719	0.13547
ΔLGDP(-1)	0.01483	0.07539	0.19673	0.84546	ΔLGDP′(-1)	-0.54197	0.56734	-0.95528	0.34761
ΔLCDE(-1)	-0.00599	0.04463	-0.13421	0.8942	ΔCDE′(-1)	0.05429	0.12125	0.44776	0.65777
ΔLHDI(-1)	0.51895	0.54513	0.95197	0.34926	ΔLHDI′(-1)	0.02444	0.24143	0.10123	0.92009
ΔLOP(-1)	-0.04134	0.0178	-2.32177	0.02774	ΔLOP′(-1)	-0.11151	0.11956	-0.93265	0.35898
ECT(-1)	0.1479	0.19316	0.76569	0.45027	ECT′(-1)	0.09016	0.1874	0.48111	0.63418

Table 5a. Long run analysis of gross domestic product with respect to energy indices

Logarithmic energy indices					Normalized energy indices				
GDP	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**GDP′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	-1.0409	1.60958	-0.64669	0.52292	Intercept	0.00348	0.01892	0.1839	0.85537
GDP(-1)	0.92345	0.07203	12.82087	1.78524E-13	GDP′(-1)	0.89583	0.08823	10.15382	4.66269E-11
EC(-1)	-0.34937	0.38054	-0.91809	0.36614	EC′(-1)	-0.11365	0.07363	-1.54345	0.13356
CDE(-1)	0.07247	0.1612	0.44955	0.65638	CDE′(-1)	0.11548	0.08851	1.30466	0.20227
HDI(-1)	1.00183	0.76016	1.31793	0.19784	HDI′(-1)	0.15276	0.08742	1.74732	0.09116
OP(-1)	-0.0158	0.02827	-0.55886	0.58055	OP′(-1)	-0.02999	0.03489	-0.85966	0.39703

Table 5b. Short run analysis of gross domestic product with respect to energy indices

Logarithmic energy indices					Normalized energy indices				
ΔLGDP	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**ΔGDP′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	0.04471	0.01577	2.83452	0.00842	Intercept	0.04392	0.01951	2.25143	0.03239
ΔLEC(-1)	-0.12063	0.50676	-0.23803	0.81359	ΔEC′(-1)	-0.12028	0.07291	-1.64961	0.1102
ΔLCDE(-1)	0.55681	0.31102	1.79028	0.08423	ΔCDE′(-1)	0.30213	0.19827	1.52379	0.13878
ΔLHDI(-1)	0.79465	1.41496	0.56161	0.57885	ΔHDI′(-1)	-0.06063	0.13958	-0.43435	0.66736
ΔLOP(-1)	-0.01799	0.03573	-0.50368	0.61843	ΔOP′(-1)	-0.04158	0.04958	-0.83882	0.40868
ECT(-1)	0.40614	0.194	2.09348	0.04549	ECT′(-1)	0.44645	0.31269	1.42775	0.16442

Table 6a. Long run analysis of carbondioxide emission with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
CDE	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**CDE ′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	1.26942	1.90065	0.66789	0.50949	Intercept	0.0506	0.02728	1.85488	0.07381
CDE(-1)	0.07923	0.19035	0.41625	0.68029	CDE′(-1)	0.19618	0.19957	0.98301	0.33373
EC(-1)	-0.64522	0.44936	-1.43588	0.16174	EC′(-1)	-0.09025	0.12037	-0.74984	0.45939
GDP(-1)	0.28496	0.08505	3.35044	0.00225	GDP′(-1)	0.70908	0.25461	2.78499	0.00933
HDI(-1)	1.10981	0.89762	1.23639	0.22623	HDI′(-1)	0.27068	0.1693	1.59887	0.12069
OP(-1)	-0.01507	0.03338	-0.45153	0.65497	OP′(-1)	-0.06915	0.11083	-0.62387	0.53759

Table 6b. Short run analysis of carbondioxide emission with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
ΔLCDE	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**ΔCDE′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	0.01362	0.02203	0.61816	0.54146	Intercept	0.03525	0.03033	1.16234	0.25491
ΔLEC(-1)	-0.32944	0.69148	-0.47643	0.63747	ΔEC′(-1)	-0.15608	0.24683	-0.63232	0.5323
ΔLGDP(-1)	0.24026	0.26879	0.89386	0.37901	ΔGDP′(-1)	0.09663	0.77486	0.1247	0.90165
ΔLHDI(-1)	-0.34382	1.47227	-0.23353	0.81705	ΔHDI′(-1)	-0.16044	0.33227	-0.48287	0.63294
ΔLOP(-1)	-0.03051	0.05373	-0.56789	0.57463	ΔOP′(-1)	-0.05667	0.17387	-0.32595	0.74689
ECT(-1)	-0.33247	0.16479	-2.01758	0.05331	ECT′(-1)	-0.27899	0.17465	-1.59742	0.1214

Table 7a. Long run analysis of human development index with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
HDI	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**HDI′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	0.13254	0.1985	0.66771	0.5096	Intercept	0.00652	0.01903	0.34275	0.73426
HDI(-1)	0.57705	0.09375	6.1554	1.04085E-6	HDI′(-1)	0.51901	0.08794	5.90165	2.08683E-6
EC(-1)	0.20404	0.04693	4.3478	1.54504E-4	EC′(-1)	0.40483	0.07407	5.46531	6.96553E-6
GDP(-1)	0.00947	0.00888	1.06657	0.29496	GDP′(-1)	0.14908	0.08875	1.67974	0.10375
CDE (-1)	-0.00439	0.01988	-0.22089	0.82673	CDE′(-1)	-0.04206	0.08904	-0.47244	0.64015
OP(-1)	0.00342	0.00349	0.98025	0.33507	OP′(-1)	0.01271	0.03509	0.3623	0.71975

Table 7b. Short run analysis of human development index with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
ΔLHDI	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**ΔHDI′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	0.00126	0.00224	0.56395	0.57728	Intercept	0.01878	0.01353	1.38881	0.17584
ΔLEC(-1)	0.26744	0.09619	2.78032	0.0096	ΔEC′(-1)	0.43113	0.1716	2.5124	0.01803
ΔLGDP(-1)	0.04257	0.02852	1.49286	0.14666	ΔGDP′(-1)	0.00789	0.37175	0.02122	0.98322
ΔLCDE(-1)	-0.02104	0.01696	-1.24028	0.22516	ΔCDE′(-1)	-0.05915	0.07798	-0.7585	0.45449
ΔLOP(-1)	0.00332	0.00575	0.57802	0.56787	ΔOP′(-1)	0.12061	0.07711	1.56418	0.12901
ECT(-1)	0.10313	0.14955	0.68958	0.49613	ECT′(-1)	0.1185	0.14814	0.79991	0.4305

Table 8a. Long run analysis e of oil price with respect to energy indices.

Logarithmic energy indices					Normalized energy indices				
OP	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**OP′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	-9.1935	7.67899	-1.19723	0.24091	Intercept	-0.06791	0.08451	-0.80355	0.4282
OP (-1)	0.74353	0.13487	5.51306	6.10214E-6	OP′(-1)	0.80714	0.15585	5.17905	1.54208E-5
EC(-1)	-1.0515	1.81549	-0.57919	0.56694	EC′(-1)	-0.22978	0.32895	-0.69851	0.49042
GDP(-1)	-0.218	0.34363	-0.63441	0.53078	GDP′(-1)	-0.47685	0.39414	-1.20984	0.23611
CDE (-1)	0.43312	0.76905	0.56318	0.57764	CDE′(-1)	0.43203	0.39541	1.09261	0.28356
HDI (-1)	4.50607	3.62654	1.24252	0.224	HDI′(-1)	0.41736	0.39055	1.06864	0.29405

Table 8b. Short run analysis of oil price with respect to energy indices.

Logarithmic energy indices					Normalized s energy indices				
ΔLHDI	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**	**ΔHDI′**	**Value**	**Standard Error**	**t-Value**	**Prob>|t|**
Intercept	-0.03672	0.08662	-0.4239	0.67488	Intercept	-0.01078	0.05783	-0.18642	0.85346
ΔLEC(-1)	2.51248	3.34253	0.75167	0.45852	ΔEC′(-1)	0.37026	0.5289	0.70006	0.48966
ΔLGDP(-1)	1.01115	1.03854	0.97363	0.33858	ΔGDP′(-1)	0.86723	1.30229	0.66592	0.51091
ΔLCDE(-1)	-0.47633	0.70299	-0.67758	0.5036	ΔCDE′(-1)	-0.03532	0.34487	-0.10242	0.91915
ΔLOP(-1)	-4.4386	6.13544	-0.72344	0.47541	ΔOP′(-1)	-0.69406	0.63038	-1.10101	0.28027
ECT(-1)	-0.16387	0.21002	-0.78025	0.44179	ECT′(-1)	-0.33492	0.33053	-1.01326	0.31961

4. CONCLUSIONS

Time series analysis of energy indices has been successfully carried out via logarithmic and normalized techniques. Five energy indices were considered in the work, namely energy consumption (EC), gross domestic product (GDP), carbon dioxide emission (CDE), the human development index (HDI), and oil price (OP). In the bid to establish favorable policies and sustainable development, four major statistical tests were effectively applied in the analysis, namely the augmented Dickey Fuller, cointegration, pairwise Granger causality, and VECM tests. From an econometric viewpoint, the augmented Dickey Fuller test adduced that the logarithmic and normalized data employed in the study were stationary of the order one at the 0.05 level.

Moreover, the unrestricted cointegration rank test (maximum eigenvalue) for both techniques showed that there was evidence of two cointegrations in the time series analysis. However, the unrestricted cointegration rank test (trace) yielded three and four cointegration results for logarithmic and normalized techniques, respectively. These results support the fact that there is evidence of long run dynamics between the energy indices.

Furthermore, the pairwise Granger test for logarithmic (normalized) techniques unanimously filtered out some energy indices void of causality (<>) consisting of LOP (OP′) <> LEC (EC′), LGDP (GDP′) <> LCDE (CDE′), and LEC (EC′) <> LHDI (HDI′), and those indices with unidirectional causality ($\Rightarrow$) as LEC (EC′) $\Rightarrow$ LHDI (HDI′), LOP (OP′) $\Rightarrow$ LEC (EC′), LGDP (GDP′) $\Rightarrow$ LCDE (CDE′), and LHDI (HDI′) $\Rightarrow$ LOP (OP′). Exclusively, the normalized technique detected bidirectional flow ($\Leftrightarrow$) between GDP′ $\Leftrightarrow$ HDI′ and HDI′ $\Leftrightarrow$ OP′. This proved that the normalized technique is more sensitive in establishing causality between energy indices and equally complements the logarithmic technique in validating causality. Also, the VECM test was in good agreement with the pairwise Granger test for both techniques for the time series analysis. The VECM analysis of short run shows that energy indicesΔLCDE (ΔCDE′) and ΔLOP (ΔOP′) tend to adjust to long run equilibrium due to their negative coefficients.

Thus, the logarithmic and normalized techniques for analysis of time series energy data were in good agreement and complemented each other. However, this research has proved that the normalized technique is more sensitive in establishing causality between energy indices and this study has recommended necessary polices that will create sustainable development based on the time series analysis and the accompanying tests. This work further recommends that more econometric tests be carried out to authenticate the research findings.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: All authors contributed equally to the conception and design of the study.

REFERENCES

Abokyi, E., Appiah-Konadu, P., Sikayena, I., & Oteng-Abayie, E. F. (2018). Consumption of electricity and industrial growth in the case of Ghana. *Journal of Energy, 2018*(8924835). Available at: https://doi.org/10.1155/2018/8924835.

Almozaini, M. S. (2019). The causality relationship between economic growth and energy consumption in the world's top energy consumers. *International Journal of Energy Economics and Policy, 9*(4), 40-53. Available at: https://doi.org/10.32479/ijeep.7657.

Altinay, G., & Karagol, E. (2005). Electricity consumption and economic growth: Evidence from Turkey. *Energy Economics, 27*(6), 849-856.

Amadeo, K. (2019). Oil price history—highs and lows since 1974: What makes oil prices so volatile?. Retrieved from https://www.thebalance.com/oil-price-history-3306200. [Accessed August 05, 2019].

Aqeel, A., & Butt, M. S. (2001). The relationship between energy consumption and economic growth in Pakistan. *Asia-Pacific Development Journal, 8*(2), 101-110.

Asafu-Adjaye, J. (2000). The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. *Energy Economics, 22*(6), 615-625.

Baimaganbetov, S., Kelesbayev, D., Yermankulova, D., Izzatullaeva, B., & Almukhambetova, B. (2019). Effects of oil price changes on regional real income per capita in Kazakhstan: Panel data analysis. *International Journal of Energy Economics and Policy, 9*(4), 356-362.

Boţa-Avram, C., Grosanu, A., Răchişan, P.-R., & Gavriletea, M. D. (2018). The bidirectional causality between country-level governance, economic growth and sustainable development: a cross-country data analysis. *Sustainability, 10*(2), 1-24.

Chen, S.-T., Kuo, H.-I., & Chen, C.-C. (2007). The relationship between GDP and electricity consumption in 10 Asian countries. *Energy Policy, 35*(4), 2611-2621. Available at: https://doi.org/10.1016/j.enpol.2006.10.001.

Chontanawata, J., Hunta, L. C., & Pierseb, R. (2007). *Causality between energy consumption and economic growth in OECD and non-OECD countries: A panel cointegration approach*. Paper presented at the In Energy Markets and Sustainability in a Larger Europe, 9th IAEE European Conference, June 10-31, 2007. International Association for Energy Economics.

Ghosh, S. (2002). Electricity consumption and economic growth in India. *Energy Policy, 30*(2), 125-129. Available at: https://doi.org/10.1016/s0301-4215(01)00078-7.

Halicioglu, F. (2007). Residential electricity demand dynamics in Turkey. *Energy Economics, 29*(2), 199-210.

Hossain, M. S. (2012). Multivariate granger causality between economic growth, electricity consumption, exports and remittance for the panel of three SAARC countries. *Global Journal of Management and Business Research, 12*(4), 41-54.

IEA. (2019). The iea's weo 2011 report - international energy. Retrieved from: https://www.google.com/search?client=firefox-b-d&ei=RsCMXd6DCNCGhbIPyLe4wAE&q=IEA+%282011%29%2C+&oq=IEA+%282011%29%2C+&gs_l=psy-ab.12..0i22i30l9.402419.402419..404419...0.2..0.245.245.2-1......0....2j1..gws-wiz.......0i71.K2-1-dgMWf0&ved=0ahUKEwjevviGz-7kAhVQQ0EAHcgbDhgQ4dUDCAo.

Inflationdata. (2019). Historical crude oil prices (table) oil prices 1946-present. Retrieved rom; https://inflationdata.com/articles/inflation-adjusted-prices/historical-crude-oil-prices-table/.

Jumbe, C. B. (2004). Cointegration and causality between electricity consumption and GDP: Empirical evidence from Malawi. *Energy Economics, 26*(1), 61-68. Available at: https://doi.org/10.1016/s0140-9883(03)00058-6.

Khobai, H. (2017). Electricity consumption and economic growth: A panel data approach to Brics countries, 82460. Retrieved from: https://mpra.ub.uni-muenchen.de/82460/.

Khobai, H., & Le Roux, P. (2017). The relationship between energy consumption, economic growth and carbon dioxide emission: The case of South Africa. *International Journal of Energy Economics and Policy, 7*(3), 102-109.

Lee, C.-C., & Chang, C.-P. (2007). Energy consumption and GDP revisited: A panel analysis of developed and developing countries. *Energy Economics, 29*(6), 1206-1223. Available at: https://doi.org/10.1016/j.eneco.2007.01.001.

MacKinnon, J. G., Haug, A. A., & Michelis, L. (1999). Numerical distribution functions of likelihood ratio tests for cointegration. *Journal of applied Econometrics, 14*(5), 563-577. Available at: https://doi.org/10.1002/(sici)1099-1255(199909/10)14:5%3C563::aid-jae530%3E3.0.co;2-r.

Macrotrends, L. L. C. (2019). Crude oil prices - 70 year historical chart, Retieved from; https://www.macrotrends.net/1369/crude-oil-price-history-chart.

Mahmood, H., & Zamil, A. M. A. (2019). Oil price and slumps effects on personal consumption in Saudi Arab. *International Journal of Energy Economics and Policy, 9*(4), 12-15.

Morimoto, R., & Hope, C. (2004). The impact of electricity supply on economic growth in Sri Lanka. *Energy Economics, 26*(1), 77-85.

Narayan, P. K., & Singh, B. (2007). The electricity consumption and GDP nexus for the Fiji Islands. *Energy Economics, 29*(6), 1141-1150. Available at: https://doi.org/10.1016/j.eneco.2006.05.018.

Roser, M. (2019). Human development index (HDI): Empirical view. Retrieved from: https://ourworldindata.org/.

Squalli, J. (2007). Electricity consumption and economic growth: Bounds and causality analyses of OPEC members. *Energy Economics, 29*(6), 1192-1205. Available at: https://doi.org/10.1016/j.eneco.2006.10.001.

Wolde-Rufael, Y. (2006). Electricity consumption and economic growth: A time series experience for 17 African countries. *Energy Policy*, *34*(10), 1106-1114. Available at: https://doi.org/10.1016/j.enpol.2004.10.008.

Yang, H.-Y. (2000). A note on the causal relationship between energy and GDP in Taiwan. *Energy Economics*, *22*(3), 309-317. Available at: https://doi.org/10.1016/s0140-9883(99)00044-4.

Yoo, S.-H. (2006). The causal relationship between electricity consumption and economic growth in the ASEAN countries. *Energy Policy*, *34*(18), 3573-3582. Available at: https://doi.org/10.1016/j.enpol.2005.07.011.