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# Causal Examination of Energy Consumption and Economic Indicators in Organization of Petroleum Exporting Countries (OPEC)

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**ABSTRACT: -** The aim of this study is to examine the causality between energy consumption and economic indicators in organization of petroleum exporting countries (OPEC). Secondary data sourced from IEA, OPEC and WDI databases for period between 2010 and 2022 was utilized in this study. The ADF unit root test showed that the variables were $I(0)$ and $I(1)$, integrated at level and order 1 respectively. The energy consumption was proxied by Herfindahl-Hirschman Index (HHI), Non-renewable energy (NRE) consumption and renewable energy (RE) consumption. On the other hand, economic indicators were proxied by Real GDP, Gross Domestic Product (GDP) per capita (GDPPC), and real sectors (proxied by manufacturing sector and agriculture sector). The study utilized panel cointegration test and panel causality instruments. Firstly, the paper found that energy consumption and economic indicators have a long-run relationship. Secondly, there exist a unidirectional causality between renewable energy (RE) consumption and real GDP (RGDP) and there is absence of a bi-directional causality between energy consumption indicator (proxy by HHI) and RGDP in OPEC. Thirdly, the paper found that manufacturing value added (proxy for real sector) granger causes non-renewable energy (NRE) consumption and RE consumption in OPEC, while there is absence of directional causality existing between manufacturing added value and other energy consumption indicators. Fourth, the paper found that RE consumption and NRE consumption granger cause Agriculture Value Added in OPEC. However, there is no causality between agricultural sector value added and other energy consumption indicators in OPEC. In conclusion the paper asserted that there is mix causality between economic indicators and energy consumption in OPEC. Thus, this paper recommended that OPEC should consider energy diversification policy that would not disrupt its productive capacity and its ability to produce competitively.

**Keywords:-** Panel Causality, Panel cointegration, Energy Consumption, Economic Indicators, Real Sectors, and Energy diversification

## I. INTRODUCTION

Several theoretical models have shown the inevitable relevance of energy input. For example, Georgescu-Roegen's (1976) fund-flow model described production as a transformation process in which a flow of materials, energy, and information as inputs is transformed into output by human labour and manufactured capital. Also, the laws of thermodynamics and the conservation of matter described the immutable constraints within which the economic system must operate in concert with energy consumption. Furthermore, the second law of thermodynamics (the efficiency law) asserts that a minimum quantity of energy is required in the input-output relationship. Essentially, energy consumption or utilization (energy consumption whether in the form of sectoral production, household consumption, exchange, and distribution) alongside other factors of production provides an indispensable input for economic growth and development (Stern, 2011; Stern, 2003). However, energy consumption and the corresponding energy crises, environmental, economic, and health effects concretize the policy choice on energy diversification amongst non-renewable energy (NRE) consumption, transition energy (TE) consumption (e.g., gas and nuclear power), and renewable energy (RE) consumption.

Over time, as global energy consumption (GEC) grows, the global community tends to contend with the associated energy crises. Global energy crises impede economic and financial development, for which the key variables are the gross domestic product per capita (GDPPC) and financial development (Lee & Chang, 2008; Apergis & Payne 2009; Ouedraogo, 2013; Khan, Teng, Khan & Khan, 2019; Tsemekidi, Bertoldi, Diluiso, Castellazzi, Economidou, Labanca & Zangheri, 2019; Lianos, Kristjanpoller, Michell, & Minutolo, 2022). At the same time, the excessive use of existing natural resources (oil, gas, and coal) that occur in limited capacities exacerbates the energy crises. The usage of renewable energy (RE) sources can reduce the dependence on fossil fuels and help reduce greenhouse gas emissions (Wu & Broadstock, 2015; Anton & Nucu, 2020). Another cause for the energy crisis as identified in the literature is due to the ever-increasing global population and its demand for fuel and products. None of the types of food or products used are produced or transported without the significant depletion of energy resources. The proxy of this variable is population growth (Zaman, Shahbaz, Loganathan & Raza, 2016).

The causality literature is built around four basic hypotheses that premise the question of whether energy consumption causes economic growth or economic growth causes energy consumption. The literature on the nexus between energy consumption and transition is rooted in the linkage that economic growth requires energy input, and high energy input to the industrial sector stimulates greenhouse gases (GHG). On the other hand, a cutback in energy use therefore may disrupt economic growth and development. The four hypotheses are, firstly, the energy-led growth hypothesis which contends that economic indicators are stimulated by energy consumption, since energy is a major input, together with other conventional inputs (labour and capital) in the growth process (Apergis and Payne 2009; Bhattacharya, *et al*. 2016, 2017; Paramati *et al*. 2017e; Ozturk 2010; Payne 2010a, 2010b). The substitution of energy types with other inputs occurs with changes in the stages of development of a particular country. The second hypothesis which is the conservation hypothesis implies that the energy transition policy would optimally stimulate economic growth. The third hypothesis known as the feedback hypothesis represents the existence of a bi-directional causality between energy consumption and economic growth variables. In order to achieve a favourable green economy, policy changes in energy consumption and economic growth should be complementary with a view to achieving viable economy and renewable energy targets. The fourth hypothesis, the neutrality hypothesis relies on the absence of causality between energy consumption and economic growth (Ocal & Aslan, 2013; Dogan, 2015; Menegaki, 2011).

In the literature, the findings from the environmental Kuznets curve (EKC) established by Grossman and Krueger (1995) connote that GDP per capita (income) and pollution have an inverted U and non-linear relationship (Panayotou, 1993). This relationship in EKC has incontrovertibly ignited debate on economic growth and emissions nexus. For example, EKC typifies two stages of economic developments and corresponding impacts on environmental degradation (inverted-U shape) (Grossman & Krueger, 1991) the stages are represented as: the rising pollution stage level (emissions) due to economic activities' and reliance on non-renewable energy (e.g., fossil fuel)(first stage), and the pollution declining stage characterized by emissions (pollution) reduction stage due to innovation, adoption, and installation of clean technology and investments in technologies that control pollution (second stage). Since, emissions are inevitable, in both energy consumption and energy supply value chain, countries are realizing the urgency to invest some amount of their income in pollution abatement technology and also in their capacity to cope with the adoption of energy-efficient technology to reduce pollution and to conserve energy by using energy diversification policy.

Smyth and Narayan (2015) and Yildirim *et al.* (2014) reviewed the earlier mentioned four hypotheses linking energy consumption (EC) and economic growth (EG) and concluded that the outcome of the nexus between the key parameters, i.e., EC and EG, varies due to the stages of development, time period considered, and econometric techniques used in the empirical literature. According to the environmental Kuznets curve (EKC) hypothesis the initial stage of energy consumption that can lead to economic growth cause environmental degradation (Kumar, Kumar & Bhatia, 2021). The later stages of EKC incentivize efficiency in the use of energy to perfect energy transition or shift to renewable energy (RE) consumption. However, in developing countries with an insufficient energy infrastructure for electricity and sectoral production, a swift energy transition (ET) from NRE consumption to RE consumption could be detrimental to economic growth. Some characteristics of such economies include overreliance on external economies for the energy infrastructure supply as well as the usage of energy-inefficient devices, and frequent unannounced power cuts (Samuel, Manu & Wereko, 2013).

Thus, given the indispensable character of energy consumption (use or utilization) and energy as an input, the international government and global policy agencies are increasingly adopting policies to promote energy diversification because of its indispensable direct effect on the environmental commons e.g. greenhouse gas (GHG) emissions, global warming, and climate change and indirect health and price effects on the economy (Sovacool & Brown, 2010). In this process less and less amount of one source of energy is increased to multiple sources of energy, so fossil-fuel-dependent countries could have interplay of both renewable (RE) and non-renewable (NRE) sources of energy in their energy mix.

As a way of diversifying the reliance on a single source of energy type, especially, the Non-renewable Energy (fossil fuels), the global community is striving to meet Goals 7 and 13 (energy-related targets) and Goals

1 and 8 (economic growth-related targets) of the sustainable development goals (SDGs) by decreasing the carbon footprint of global fossil-fuel consumption (FFC) (National Academies, 2021), shrinking greenhouse gas (GHG) emissions through adaptation and mitigation (net-zero emission target), and adopting energy transition policy target towards cleaner and more diverse energy sources.

It is based on the inconclusive nature of GDP per capita and emissions (pollution) that this study seeks to examine the causal relationship between energy consumption and economic growth in selected OPEC between 2010 and 2020.

The motivating question becomes what optimal policy best explains economic growth and energy-environment trade-off in OPEC? The contribution of this paper is to document recent evidence on which hypotheses best explain the nature of the relationship between energy consumption and economic indicators in selected OPEC between 2010 and 2022.

The remaining parts of this paper include, literature review, methodology, discussion of findings, and conclusion and recommendations.

## II. LITERATURE REVIEW

### a. Theoretical Framework

**Energy Ladder Theory**

One of the early works associated with the concept of the energy ladder is the study by Harold D. Rosen in 1984, titled Traditional fuels for cookers, where he discussed the shift from traditional biomass to modern fuels. However, it's important to note that Rosen did not explicitly propose the energy ladder theory as a comprehensive framework; rather, his work contributed to the understanding of energy transitions.

Debates around the energy ladder theory often revolve around its simplicity and the assumption of a linear progression. Critics argue that the theory oversimplifies the complexity of energy transitions and overlooks various contextual factors that influence the choices made by individuals and communities in adopting new energy sources. Social, economic, cultural, and political factors play a significant role in shaping energy use patterns, and these are not always captured by a linear ladder model (Rosen, 1984; Barnes, 1994; Barnes & Khandker 1991).

The energy ladder theory is a conceptual framework that describes the transition of societies from traditional, biomass-based energy sources to modern, high-density energy sources. It highlights the progression of energy use and the associated socio-economic development that occurs as societies move up the "ladder" of energy sources. This theory is particularly relevant when examining the evolution of energy consumption patterns in developing countries. The basic idea behind the energy ladder theory is that societies tend to go through a series of stages in terms of energy use, starting with traditional biomass fuels like wood, dung, and crop residues, and progressing towards more advanced and efficient sources such as fossil fuels and electricity. The transition is often driven by factors such as economic development, urbanization, and technological advancements.

**Stages of Energy Ladder Theory**

**Stage 1: Traditional Biomass Fuels**

In the initial stage, societies primarily rely on traditional biomass fuels for cooking, heating, and lighting. This includes wood, crop residues, dung, and other organic materials (Smith, & Haigler, 2008)

**Stage 2: Transition to Improved Biomass**

As societies develop, there is a shift towards using improved biomass technologies such as efficient stoves and cleaner fuels to reduce indoor air pollution and improve health (Barnes, Openshaw, Smith, & van der, 1994).

**Stage 3: Introduction of Modern Fuels**

Further development leads to the adoption of modern fuels like kerosene, liquefied petroleum gas (LPG), and natural gas. These fuels offer higher energy density and convenience (Barnes & Floor, 1996)

**Stage 4: Electrification**

The highest rung of the energy ladder involves widespread access to electricity. Electrification enables a broad range of applications, from lighting and cooking to powering appliances and machinery (Barnes & Khandker, 1991).

**Stage 5: High-Efficiency Technologies**

In the advanced stages, there is a focus on high-efficiency technologies, renewable energy sources, and sustainable practices to mitigate environmental impacts and address energy security (IEA, 2021).

**Assumptions Underlying the Energy Ladder Theory (ELT)**

**Linear Progression**: One of the fundamental assumptions of the energy ladder theory is that societies progress through a linear sequence of energy sources, moving from traditional, and low-efficiency sources to modern, high-efficiency sources as they undergo economic development.

**Income and Development Correlation**: The theory assumes a positive correlation between income levels and the transition along the energy ladder. As income increases, it is expected that communities will have the financial means to adopt more advanced and efficient energy sources.
Technological Readiness: The Energy Ladder Theory assumes that there is a ready supply of more advanced energy technologies available and that these technologies are accessible to communities as they climb the ladder. This assumes a certain level of technological infrastructure and dissemination.
**Behavioural Rationality**: The theory assumes that households and communities make rational decisions based on economic considerations. It presupposes that people will choose the most economically viable energy source available to them at each stage of development.

Homogeneity of Transition Patterns: The Energy Ladder Theory assumes that transition patterns are relatively homogeneous across different communities and regions. It implies that the factors influencing energy transitions are consistent and universally applicable.

Environmental Awareness: There is often an assumption that as communities climb the energy ladder, they become more environmentally conscious. This assumption suggests that with increased income and access to cleaner energy sources, there is a growing emphasis on environmental considerations.
**Energy Source Substitution**: The theory assumes that as communities move up the energy ladder, there is a substitution effect, meaning that they replace traditional biomass fuels with more advanced and cleaner energy sources. This assumes a willingness and ability to replace existing practices with new technologies.
**Availability of Alternatives**: The Energy Ladder Theory presupposes the availability of viable alternatives at each stage of the ladder. It assumes that there are feasible options for communities to transition to as they seek more efficient and modern energy sources.
**Policy Influence**: There is an assumption that policy interventions can accelerate or facilitate the transition along the energy ladder. Effective policies are believed to encourage the adoption of cleaner technologies and promote sustainable energy practices.
**Cultural Relevance**: While economic factors are emphasized, the theory recognizes that cultural factors may influence energy choices. However, it assumes that cultural factors align with economic considerations in the decision-making process.

Critics of the energy ladder theory have raised several important points and criticisms. They are issues of non-linearity of transitions: According to Sovacool and Dworkin (2015) energy transitions are not always linear, and the assumption of a clear progression up the energy ladder oversimplifies the complexities involved. Transitions may be influenced by a variety of factors, including cultural practices, economic conditions, and technological advancements. Additionally, Sovacool and Linnér (2016) contend that the energy ladder theory often neglects the influence of social and cultural factors in shaping energy use patterns. Social norms, cultural practices, and gender dynamics play a significant role in determining which energy sources are adopted and accepted by communities. Concerns that the energy ladder theory tends to focus more on rural energy transitions and may not adequately capture the dynamics of urban energy use was raised by Mohr and Raman (2013). This is because urbanization introduces different challenges and opportunities for energy transitions that may deviate from the linear progression suggested by the energy ladder. Furthermore, the energy ladder theory is sometimes criticized for its technological determinism, assuming that the adoption of higher-level energy sources is inevitable with development. Reddy and Goldemberg (1990) argued that socio-political factors and institutional arrangements play a crucial role in determining energy pathways. In terms of the sustainability of the theory, scholars argued that the energy ladder theory, by emphasizing the transition to higher energy density sources, may overlook sustainability concerns and environmental impacts associated with certain modern energy sources. This includes concerns related to deforestation, air pollution, and greenhouse gas emissions (Sovacool, 2011).

The Energy Ladder Theory serves as a valuable framework for understanding the dynamics of energy transitions, while energy diversification strategies provide a roadmap for achieving a more resilient, sustainable, and secure energy future. Integrating these concepts in policy and planning can contribute to balanced and context-specific approaches to meet the energy needs of diverse populations. In terms of policy formulation**:** The Energy Ladder Theory helps policymakers understand the current energy consumption patterns in a region and predict potential future trends. This information is crucial for formulating effective energy policies tailored to the specific needs and stage of development of a community or country (Barnes & Floor, 1996). Barnes et al. (1994) argued that by recognizing the different stages on the energy ladder, policymakers can design targeted interventions to address specific challenges at each level. For instance, promoting cleaner and more efficient cook stoves in areas where biomass is still the dominant fuel, or facilitating the transition to modern fuels where feasible. Similarly, Sovacool and Brown (2010) argued that energy diversification involves moving away from a heavy reliance on a single energy source. The energy ladder theory, when coupled with the concept of energy diversification, encourages a balanced approach by promoting the use of multiple energy sources. UN (2017) stated that energy diversification enhances energy security by reducing vulnerability to supply disruptions. By incorporating a mix of energy sources, countries can better withstand shocks in the global energy market or geopolitical events affecting a specific energy resource. Energy ladder theory helps to ignite consciousness of renewable energy (IEA, 2021), and accelerate technological innovation (Grubler, 2012).

**b. Empirical Review**

| **Author and Date** | **Method, Region** | **Conclusion** |
|---|---|---|
| **Paramati *et al.* (2018)** | fully modified ordinary least square (FMOLS) 1980 to 2012 | Unidirectional effect |
| **Adams *et al.* (2018)** | 30 SSA countries (1980–2012) Electricity from RE and NRE FMOLS and DOLS | Positive effect of NRE |
| **Kahia *et al.* (2017)** | 11 MENA Net Oil Importing Countries (1980–2012) Electricity from RE and NRE FMOLS and Panel granger causality | Feedback causality between NRE and growth |
| **Destek and Aslan (2017)** | 17 emerging nations (1980–2012) Electricity from RE and NRE Panel granger-causality | Mixed results across countries |
| **Rafindadi and Ozturk (2017)** | combined cointegration test | Unidirectional effect |
| **Shahbaz *et al.* (2016)** | BRICS countries 1991Q1–2015Q4. Panel cointegration, fixed effect and panel VEC | feedback |
| **Ozturk and Bilgili (2015)** | 51 SSA nations (1980–2009) Biomass Dynamic panel OLS | Positive |
| **Caraiani *et al.* (2015)** | Emerging European nations (1980–2013) Coal, natural gas, oil, and renewables VECM | Positive |
| **Dogan (2015)** | Turkey 1990–2012 Cointegration and VEC | Neutrality |
| **Shahbaz *et al.* (2015)** | Pakistan 1972Q1– 2011Q4 Cointegration and VEC | Feedback |
| **Al-mulali *et al.* (2014)** | 18 Latin American countries 1980–2010 Panel cointegration, panel DOLS, panel VEC | Feedback |
| **Lin and Moubarak (2014)** | China 1977–2011 Cointegration and VEC | Feedback |
| **Al-mulali *et al.* (2013)** | High, upper-middle, lower middle- and low-income countries Different periods FMOLS | Feedback (79% of the countries) Neutrality (19% of the countries) Conservation (2% of the countries) |
| **Ocal and Aslan (2013)** | Turkey 1990–2010 Cointegration and Toda-Yamamoto | Neutrality |
| **Apergis and Payne (2012)** | 80 countries 1990–2007 Panel cointegration, panel FMOLS, panel VEC | Feedback |
| **Pao and Fu (2013)** | Brazil 1980–2010 cointegration and VEC | Feedback |
| **Salim and Rafiq (2012)** | 6 major emerging 1980–2006 Panel cointegration, panel DOLS, panel FMOLS, Granger causality | Feedback |
| **Tugcu *et al.* (2012)** | G7 countries 1980–2009 Cointegration and Hatemi-J causality | Mix Results |
| **Tiwari (2011)** | India 1960–2009 Structural VAR | Conservation |
| **Apergis and Payne (2011b)** | 6 Central American nations (1980– | Feedback |

| | | |
|---|---|---|
| | 2006) Electricity from renewable. The heterogeneous panel cointegration and FMOLS | Positive |
| **Apergis and Payne (2011a)** | 16 emerging economies (1990–2007) Electricity from RE and NRE Panel Granger causality | Feedback causality between NRE and growth |
| **Pao and Tsai (2011)** | BRIC (1980–2007) Aggregate energy Gray prediction and VECM | Positive |
| **Menegaki (2011)** | 27 European countries 1997–2007 random effect | Neutrality |
| **Fuinhas and Marques (2011)** | Italy, Greece, Portugal, Spain, Turkey Aggregate energy Autoregressive distributed lag (ARDL) | Feedback |
| **Apergis and Payne (2010)** | 15 emerging market economies (1980–2006) Coal FMOLS and Panel causality | Negative |
| **Apergis and Payne (2010)** | 20 OECD countries 1985–2005 Panel cointegration, panel FMOLS, panel VEC | Feedback |
| **Payne (2009)** | USA 1949–2006 Toda-Yamamoto | Neutrality |
| **Sadorsky (2009)** | 18 emerging countries 1994–2003 Panel cointegration, panel DOLS, panel FMOLS, panel VEC | Conservation |
| **Lee and Chang (2008)** | 16 Asian nations (1971–2002) Aggregate energy Panel-based error correction models (FMOLS and causality) | Positive |
| **Sadorsky (2009)** | 18 emerging nations Renewable energy Panel cointegration and fully modified ordinary least squares | Conservation |

**Source: Compiled by the Author**

## III. METHODOLOGY

### 3.1 Panel Causality

Panel causality refers to the analysis of causal relationships between variables in panel data, which involves both cross-sectional and time-series dimensions. In a panel dataset, observations are collected on multiple entities over multiple time periods, allowing researchers to examine how changes in one variable may cause changes in another across both dimensions. It is important to note that specific formulations may vary based on the econometric methodology employed (such as fixed effects, random effects, or other panel data techniques) and the characteristics of the data being analyzed. The concept of panel causality builds on the foundations of causality testing in time series and cross-sectional settings. While there isn't a specific founder for panel causality, the methodology has been developed by various researchers over time. Notable contributors include Hsiao (1986) and Granger (1969).

**Assumptions:**

The assumptions for panel causality analysis are often extensions of the assumptions made in time series or cross-sectional causality testing. Common assumptions include stationarity of variables, exogeneity of regressors, and the absence of spurious correlation.

**Criticisms:**

**Endogeneity Issues:** Panel causality tests may be sensitive to endogeneity issues, and controlling for endogeneity is crucial for accurate results.

**Heterogeneity:** Panel datasets often exhibit heterogeneity across entities, and assuming homogeneous causal relationships may oversimplify the analysis.

**Sample Size:** The power of panel causality tests can be influenced by the sample size, and small sample sizes may lead to unreliable results.

A cross-sectional causality test examines causal relationships between variables at a single point in time across different entities or individuals. Unlike time-series causality tests that explore temporal relationships, cross-sectional causality tests focus on determining whether changes in one variable can be considered a cause of changes in another variable across different entities at a specific moment. The mathematical representation of a basic cross-sectional causality test involves examining the relationship between an independent variable ($X$) and a dependent variable ($Y$) across different entities or observations ($i$) in a single time period.

The test typically involves estimating a regression equation of the form:

$$Yi=\alpha i+\beta Xi+\epsilon i \quad (1)$$

In this equation:

$Yi$ is the dependent variable for entity $i$.
$Xi$ is the independent variable for entity $i$.
$\alpha i$ represents entity-specific effects or intercepts.
$\beta$ is the coefficient that measures the impact of $X$ on $Y$.
$\epsilon i$ is the error term.

The null hypothesis in a cross-sectional causality test often states that changes in $X$ do not cause changes in $Y$ across entities. The alternative hypothesis posits that changes in $X$ cause changes in $Y$ across entities. The test involves assessing the statistical significance of the estimated coefficient $\beta$. A statistically significant and positive $\beta$ suggests evidence in favor of the alternative hypothesis, indicating a cross-sectional causal relationship from $X$ to $Y$. It is important to note that cross-sectional causality tests are specific to a given point in time and may not capture dynamic relationships or causality over time. Different econometric techniques, such as fixed-effects or random-effects models, may be employed depending on the characteristics of the data and the assumptions made in the analysis (Hsiao, 1986; Granger, 1969).

Consider a panel dataset with entities indexed by $i$ and time periods by $t$. Let $Yit$ and $Xit$ represent two variables of interest, and $Zit$ be a vector of additional control variables. The panel causality test can be expressed using the following equations:

**Null Hypothesis:**

$H_0$:$X$ does not Granger cause $Y$ (2)

**Alternative Hypothesis:**

$H_1$:$X$ Granger causes $Y$ (3)

The basic panel causality model often follows the framework of a lag-augmented Vector Autoregression (VAR). The equation representing the relationship between $Xit$ and $Yit$ is as follows:

$$Yit=\alpha i+\beta 1Yi,t-1+\beta 2Xi,t-1+\gamma 1Zi,t-1+\epsilon it \quad (4)$$

In this equation:

- $\alpha i$ represents entity-specific fixed effects.
- $\beta 1$ and $\beta 2$ capture the lagged effects of $Y$ and $X$, respectively.
- $\gamma 1$ represents the effect of the vector $Z$.
- $\epsilon it$ is the error term.

The Granger causality hypothesis is typically tested by examining the significance of the coefficients associated with the lagged values of $X$ in explaining variations in $Y$. If $\beta 2$ is found to be statistically significant, it provides evidence in favor of the alternative hypothesis that $X$ Granger causes $Y$ in the panel data context.

Many empirical studies that use Granger causality test have examined the causal relationship in a two-variable context, but Granger has stated that ignoring other related variables may cause spurious causality. Besides, neglected variables in a bi-variate system can result in non-causality, as indicated by Lütkepohl (1982). To remedy the omitted variable bias, this study follows Payne (2009); Apergis and Payne (2010), and Ozcan and Ozturk (2019), and test the causality between RE, NRE, CE, and economic growth (GDP- real gross domestic product) by including measures of capital and labor. Both data on the RE, CE, and NRE are defined in billion kWh while GDP, and real gross fixed capital formation (K) in constant 2010 US$, and labor force (L) in millions. We take logarithms of all variables and use population data to convert them into per capita. The study used annual data from 2007 to 2022 that was retrieved from WDI database of the World Bank and Energy Information Administration for 13 OPEC members. The baseline model is the Dumistrescu and Hurlin (2012) Granger non-causality test. Following the Dumistrescu and Hurlin (2012) supported by the Byesian information

Criterion (BIC), Akaike information criterion (AIC) and the Hannan-Quinn information criterion (HQIC) was developed as an extension of Granger (1969) methodology for analyzing causal relationship between time series. Thus, Dumitrescu and Hurlin (2012) offered an augmented model to detect causality in panel data.
The underlying regression model becomes:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{k} \gamma_{ik}\, y_{i,t-k} + \sum_{k=1}^{k} \beta_{ik}\, x_{i,t-k} + \epsilon_{i,k} \qquad (5)$$

Where $x_{i,t}$and $y_{i,k}$ are the observations of two stationary variables for individual *i* in period *t*, Coefficients are allowed to differ across countries but assumed to be time invariant. The lag order *K* is assumed to be identical for all countries, and the panel must be balanced. Dumitrescu and Hurlin (2012) proposed the following *K* selection must be based on corresponding to AIC/BIC/HQIC and the bootstrap procedure must follow the p-values and critical value. Thus the corresponding models are:

$$RGDP_{i,t} = \alpha_i + \sum_{k=1}^{k} \gamma_{ik}\, RGDP_{i,t-k} + \sum_{k=1}^{k} \beta_{ik}\, HHI_{i,t-k} + \epsilon_{i,k} \qquad (6)$$

$$GDPPC_{i,t} = \alpha_i + \sum_{k=1}^{k} \gamma_{ik}\, RGDP_{i,t-k} + \sum_{k=1}^{k} \beta_{ik}\, REC_{i,t-k} + \epsilon_{i,k} \qquad (7)$$

$$RealSector_{i,t} = \alpha_i + \sum_{k=1}^{k} \gamma_{ik}\, RGDP_{i,t-k} + \sum_{k=1}^{k} \beta_{ik}\, NREC_{i,t-k} + \epsilon_{i,k} \qquad (8)$$

*i*=shows the number of countries (i = 1,.2,. . .,n), *t* shows time-period and l indicates the optimal lag length selected using Akaike information criteria (Becker *et al.*, 2006). Where RGDP = Real Gross Domestic Product, GDPPC = GDP per capita, Real Sectors= Manufacturing and Agricultural value Added, REC = Renewable Energy Consumption, NREC = Non-Renewable Consumption, HHI = Herfindahl-Hirschman Index (proxy for energy diversification index).

## IV. DISCUSSION OF FINDINGS

**Trend Data Analyses**

The data utilized in this study show an upward and downward trend with no negative trend. The upward and downward movement in data connotes the presence of demand and supply disequilibrium and price shocks within the energy sector as well as the presence of economic recession and recovery on the economy performance variables in OPEC. Most OPEC member countries are fossil-fuel dependent hence any perceptible geo-political heterogeneity issues affect the movement and state of energy demand and supply. Three OPEC economies stand out in terms of agricultural value-added contribution to GDP which are Nigeria, Iran, and Angola. The data trends within the period under review show that Nigeria, Iran, and Angola have robust agricultural productivity reflected in the data. Data movement in the agricultural sector's value-added within OPEC shows that agricultural productivity is influenced by several such as government policies, arable land, techniques, and the effect of climate change which causes climate variability, etc. Data from the ease of doing business shows unstable and relatively low ease of doing business which is reflected in business expectation and re-investment policy in the OPEC. The trend shows an erratic ease of doing business behaviour, especially for Iran, Libya, Algeria, Venezuela, and Congo. In terms of the global competitiveness index (GCI), the data used shows decreasing (2010-2019) and increasing (2020-2022) dimensions. The increasing dimension in the GCI within OPEC is reflected in the region's target to improve the export capacity and economic resilience. From the data, Saudi Arabia, Kuwait, and UAE are the best-performing OPEC member countries in terms of their global competitiveness structure. Data from GDP per capita which is a broad measure of economic growth shows relatively low GDP per capita within OPEC countries. Low GDP per capita shows a low distributional coefficient of GDP and implies that GDP per capita is less inclusive. Data from energy diversification represented by HHI is erratic in nature only Saudi, Iran, and Kuwait present an upward energy diversified economy. The graphical display of HHI shows that OPEC's energy diversification is relatively skewed to a few countries in the region e.g., Venezuela, although the display connotes that there has been a series of government policy directions to expanding energy diversification in the region. A high energy diversification is necessary to achieve energy security and environmental stability in the region. Data from OPEC manufacturing sector's value added showed that Nigeria, Saudi, Iran, Kuwait, UAE, Algeria, and Congo have secured and thriving manufacturing sectors' value-added growth albeit with fluctuations. For other instances countries such as Libya, Iraq, and Venezuela, data showed that its manufacturing sectors value added are relatively low. This implies that OPEC should design regional manufacturing sectors value added to comparatively expand its frontiers to meet the targets of industrialized nations.

Data obtained for fossil fuel consumption (called non-renewable energy consumption) in OPEC showed both a rising and a declining trend in NRE consumption. On the country-specific front, Saudi, Iran, Kuwait, UAE, Venezuela, and Nigeria have an increasing cut-back on the NRE consumption. This could be due to several factors such as insecurity, instability, OPEC's supply cut, and other geopolitical influences. Conversely, data from RE (renewable energy) consumption in OPEC countries such as Nigeria, Venezuela, and Congo have improved their energy mix by diversifying to biofuel. A case study of low biofuel use is shown in Saudi, Iran, Libya, Iraq, Kuwait, UAE, and Algeria. In aggregate, OPEC's use of biofuel is low save for some selected countries. The Real GDP which is the growth coefficient after adjusting for prices displays the pattern of economic growth in OPEC. The graphical representation of the Real GDP within OPEC member countries showed a very high trend for Iran and a very low trend for the selected OPEC member countries. Real GDP on the average in OPEC is low. Transition energy consumption in this study is called Gas. Gas is referred to as clean energy but could be classified into non-renewable energy hence this study used gas as one of the energy diversification varieties available for fossil fuel-dependent countries such as OPEC. The data used showed rising trends viz-a-viz gas consumption in Nigeria, Saudi, Iran, Algeria, and UAE. Conversely, the data also showed minimal gas consumption in countries such as Libya, Iraq, Venezuela, and Congo. This may largely be due to infrastructure challenges, low investment in the sector, low gas deposits, etc.

**Presentation of Result**

Table 1 provides information on the ADF Fisher Chi-square unit root test for panel data. The Unit Root Test is sued to ascertain the stationarity of the data used in this study. The result outcome showed that the data are both *I*(0) at levels and were stationary to order 1 *I*(1) at first difference. The purpose of this test is to avoid spurious and misleading result, hence the imperative of this test. Fulfilling these preconditions, the econometric test is predicated on the unit root test.

**Table 1: ADF Fisher Chi-square Unit Root Test**

| Variables | At levels | First Differencing | Conclusion |
|---|---|---|---|
| **AGRICADD** | 33.7821 (0.0276) | - | *I*(0) |
| **EODB** | 28.4903 (0.0983) | 44.0811 (0.0015) | *I*(1) |
| **GCI** | 11.4250 ( 0.9344) | 28.8622 (0.0405) | *I*(1) |
| **GDPPC** | 22.7872 (0.2994) | 46.6044 (0.0007) | *I*(1) |
| **HHI** | 38.4350 ( 0.0078) | - | *I*(0) |
| **MANUADD** | 31.9474 ( 0.0439) | - | *I*(0) |
| **NREC__FF** | 26.0831 (0.1631) | 47.1305 (0.0006) | *I*(1) |
| **REC__BF_** | 12.5213 (0.8970) | 30.2485 (0.0351) | *I*(1) |
| **RGDP** | 16.5619 (0.6812) | 35.7828 (0.0163) | *I*(1) |
| **TEC__GS_** | 19.2851 (0.5034) | 30.0088 ( 0.0397) | *I*(1) |

**Source: Author's computations from EViews 10**

**Pesaran CD Cross-Section Dependence Test**

In panel study, cross-section dependence test is required to determine the existence of correlation within OPEC. Additionally, over and above the unit root test, before utilizing these variables, it is pertinent to determine whether the variables in OPEC are correlated. This condition is necessary for panel data. Using the Pesaran CD the results in Table 2 connotes that $H_1$ is accepted. Thus, therefore accepting $H_1$ implies that there is cross sectional dependence amongst the variables which meets the conditions for panel study.

**Table 2: Pesaran CD Cross section dependence Test**

| Variables | Cross Section dependence test | Conclusion |
|---|---|---|
| **AGRICADD** | 8.157777 (0.0000) | Reject $H_0$ Accept $H_1$: There is cross Section |
| **EODB** | 6.211458 (0.0000) | Reject $H_0$ Accept $H_1$: There is cross Section |
| **GCI** | 14.03812 (0.0000) | Reject $H_0$ Accept $H_1$: There is cross Section |

| | | |
|---|---|---|
| **GDPPC** | 0.817718<br>(0.0135) | Reject $H_0$<br>Accept $H_1$: There is cross Section |
| **HHI** | 1.421626<br>(0.0033) | Reject $H_0$<br>Accept $H_1$: There is cross Section |
| **MANUADD** | 3.557980<br>(0.0004) | Reject $H_0$<br>Accept $H_1$: There is cross Section |
| **NREC__FF_** | 1.382103<br>(0.0069) | Reject $H_0$<br>Accept $H_1$: There is cross Section |
| **REC__BF_** | 12.12521<br>(0.0000) | Reject $H_0$<br>Accept $H_1$: There is cross Section |
| **RGDP** | 8.607318<br>(0.0000) | Reject $H_0$<br>Accept $H_1$: There is cross Section |
| **TEC__GS_** | 7.502305<br>(0.0000) | Reject $H_0$<br>Accept $H_1$: There is cross Section |

**Source: Author's computations from EViews 10**

**Pedroni Residual Panel Cointegration Test**

Pedroni residual panel cointegration test show that there is long-run relationship between the hypothesized variables. From Table 3, the study captured the long-run or equilibrium relationship energy diversification indicators and economic growth indicators within OPEC. In Table 3 panel PP-statistic shows that RGDP (proxy for economic indicator) and NREC, REC, TEC and HHI (energy consumption) in OPEC have a long-run relationship. These results (see Table 3) imply that policy changes in any of the energy consumption indicators could affect economic indicators in the long-run. This is because reforms in energy mixes and diversification (proxy by HHI) have the portent force to affect Real GDP in the long-run and vice-versa.

**Table 3 Panel PP-statistic**

| Models | Pedroni Residual Cointegration Test | Coefficient | P-values | Conclusion |
|---|---|---|---|---|
| **RGDP** | Panel PP-Statistic | -6.107087 | 0.0000 | Long-run Relationship |
| **GDP per capita** | Panel PP-Statistic | -5.793812 | 0.0000 | Long-run Relationship |
| **ManuAdded** | Panel PP-Statistic | -4.449551 | 0.0436 | Long-run Relationship |
| **Agric.Added** | Panel PP-Statistic | -4.559897 | 0.0000 | Long-run Relationship |

**Source: Author's computations from EViews 10**

**Table 4: Correlated Random Effects - Hausman Test**

| Models | **Chi-Sq. Statistic** | **Chi-Sq. d.f.** | **Prob.** | **Conclusion** |
|---|---|---|---|---|
| **RGDP** | 2.582268 | 5 | 0.7641 | Accept $H_0$: Random Effect Model Appropriate |
| **GDP per capita** | 2.913466 | 5 | 0.7133 | Accept $H_0$: Random Effect Model Appropriate |
| **ManuAdded** | 2.634748 | 5 | 0.7561 | Accept $H_0$: Random Effect Model Appropriate |
| **Agric.Added** | 7.499225 | 5 | 0.1861 | Accept $H_0$: Random Effect Model Appropriate |

**Source: Author's computations from EViews 10**

**Table 5: Panel Causality**

Pairwise Dumitrescu Hurlin Panel Causality Tests
Date: 03/15/24 Time: 17:20
Sample: 2010 2022
Lags: 1

| Null Hypothesis: | W-Stat. | Zbar-Stat. | Prob. |
|---|---|---|---|
| HHI does not homogeneously cause RGDP | 2.03621 | 1.00128 | 0.3167 |
| RGDP does not homogeneously cause HHI | 2.37214 | 1.45524 | 0.1456 |
| NREC__FF_ does not homogeneously cause RGDP | 1.88881 | 0.82921 | 0.4070 |
| RGDP does not homogeneously cause NREC__FF_ | 1.66185 | 0.51716 | 0.6050 |
| REC__BF_ does not homogeneously cause RGDP | 4.54994 | 4.15090 | 3.E-05 |
| RGDP does not homogeneously cause REC__BF_ | 1.54056 | 0.28344 | 0.7768 |
| TEC__GS_ does not homogeneously cause RGDP | 1.59681 | 0.42773 | 0.6688 |
| RGDP does not homogeneously cause TEC__GS_ | 1.81138 | 0.72276 | 0.4698 |

**Source: EViews 10**

In table 5, the study measured the granger causality between RGDP and the energy diversification indicators conceptualized in this study. The p-value is the criterion used to decipher the existence of causality between RGDP and energy diversification in OPEC. From the result outcome in table 4.12, there exist no feedback relationships between RGDP and energy diversification indicators in OPEC except for unidirectional feedback between RE (biofuel) consumption causes RGDP. Hence, the p-values were more than 5 percent; save for RE consumption causes RGDP which has p-value less than 5percent in the table 4.12 above.

**Table 6**

Pairwise Dumitrescu Hurlin Panel Causality Tests
Date: 03/15/24 Time: 17:21
Sample: 2010 2022
Lags: 1

| Null Hypothesis: | W-Stat. | Zbar-Stat. | Prob. |
|---|---|---|---|
| HHI does not homogeneously cause GDPPC | 1.71514 | 0.56741 | 0.5704 |
| GDPPC does not homogeneously cause HHI | 3.37713 | 2.81330 | 0.0049 |
| NREC__FF_ does not homogeneously cause GDPPC | 3.95686 | 3.67264 | 0.0002 |
| GDPPC does not homogeneously cause NREC__FF_ | 2.86896 | 2.17685 | 0.0295 |
| REC__BF_ does not homogeneously cause GDPPC | 3.57518 | 2.89821 | 0.0038 |
| GDPPC does not homogeneously cause REC__BF_ | 3.21265 | 2.43230 | 0.0150 |
| TEC__GS_ does not homogeneously cause GDPPC | 1.49933 | 0.29371 | 0.7690 |
| GDPPC does not homogeneously cause TEC__GS_ | 2.05588 | 1.05892 | 0.2896 |

**Source: EViews 10**

From Table 6, there is unidirectional feedback between GDP per capita and energy diversification indicators in OPEC. The flow of causality emanates from GDPPC on HHI. The result showed that GDP per capita provide a leverage for HHI (p-value = 0.0049). From the result non-renewable energy consumption (fossil fuel) and renewable energy consumption (biofuel) shows a feedback and bi-directional causality with corresponding p-values less than 5 percent. Also, the result showed no feedback relationship between GDP per capita and transition energy (gas) (p-value is more than 5 percent).

**Table 7**

Pairwise Dumitrescu Hurlin Panel Causality Tests
Date: 03/15/24 Time: 17:22
Sample: 2010 2022
Lags: 1

| Null Hypothesis: | W-Stat. | Zbar-Stat. | Prob. |
|---|---|---|---|
| HHI does not homogeneously cause MANUADD | 1.37906 | 0.08007 | 0.9362 |
| MANUADD does not homogeneously cause HHI | 1.52067 | 0.26180 | 0.7935 |
| NREC__FF_ does not homogeneously cause MANUADD | 1.43603 | 0.16800 | 0.8666 |
| MANUADD does not homogeneously cause NREC__FF_ | 3.27210 | 2.56123 | 0.0104 |
| REC__BF_ does not homogeneously cause MANUADD | 2.30426 | 1.21822 | 0.2231 |
| MANUADD does not homogeneously cause REC__BF_ | 2.98220 | 2.06591 | 0.0388 |
| TEC__GS_ does not homogeneously cause MANUADD | 0.74372 | -0.73440 | 0.4627 |
| MANUADD does not homogeneously cause TEC__GS_ | 2.48020 | 1.52903 | 0.1263 |

**Source: EViews 10**

In table 7, the result produced unidirectional feedback between manufacturing value added and non-renewable energy (fossil fuel) and renewable energy (biofuel) because the corresponding p-values are 0.010 and 0.0388 respectively which are less than 5 percent. Conversely, there is no directional feedback relationship between manufacturing sector's value added and HHI and transition energy consumption (gas) in OPEC.

**Table 8**

Pairwise Dumitrescu Hurlin Panel Causality Tests
Date: 03/15/24 Time: 17:18
Sample: 2010 2022
Lags: 1

| Null Hypothesis: | W-Stat. | Zbar-Stat. | Prob. |
|---|---|---|---|
| HHI does not homogeneously cause AGRICADD | 1.91466 | 0.83704 | 0.4026 |
| AGRICADD does not homogeneously cause HHI | 1.86321 | 0.76751 | 0.4428 |
| NREC__FF_ does not homogeneously cause AGRICADD | 2.71551 | 1.96587 | 0.0493 |
| AGRICADD does not homogeneously cause NREC__FF_ | 1.25083 | -0.04796 | 0.9617 |
| REC__BF_ does not homogeneously cause AGRICADD | 4.83753 | 4.52050 | 6.E-06 |
| AGRICADD does not homogeneously cause REC__BF_ | 2.37070 | 1.35029 | 0.1769 |
| TEC__GS_ does not homogeneously cause AGRICADD | 1.06849 | -0.29866 | 0.7652 |
| AGRICADD does not homogeneously cause TEC__GS_ | 2.46046 | 1.61519 | 0.1063 |

**Source: EViews 10**

Based on the result on table 8 above, there is unidirectional feedback relationship between energy consumption in OPEC and agricultural sector's value added. The result shows that NRE consumption (fossil fuel) and RE consumption (biofuel) causes agricultural value added. The corresponding p-values are less than 5 percent. Also, the table 8 indicates that there is absence of causality between agricultural sector's value added and HHI and TE (gas) consumption within OPEC.

## V. CONCLUSION AND RECOMMENDATIONS

Hence, this study concluded that there is a mixed causality between HHI (energy consumption) and economic indicators in OPEC. The study established that:

1) Energy consumption and HHI does not granger cause RGDP. Hence, there is no causality.

2) HHI, NRE consumption, REC granger cause GDP per capita, hence there is uni-directional causality. Also, TE consumption does not granger cause GDP per capita. This implies the existence of ELG hypothesis.
3) HHI, energy consumption does not granger cause manuAdded sector, and manuAdded value granger cause NRE consumption and RE consumption. Hence, there is no causality.
4) HHI and energy consumption does not granger cause AgricAdded sector. Hence, there is no causality.

Thus, pin-pointedly, neutrality hypothesis can be used to explain the nexus between energy consumption and Real GDP. Secondly, ELG hypothesis applies in the energy consumption and GDP per capita nexus. Third, ELG hypothesis and Neutrality hypothesis can be utilized to explain the policy linkage between energy consumption and manufacturing and agriculture (real) sector in OPEC. This paper recommends that sound energy transition policy that takes into consideration the future economic pattern and social needs of the members states must be carefully analyzed before embarking on energy diversification in order for OPEC to accurately transit without compromising its capacity to achieve development.

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