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Research Article

The role of economic complexity in shaping the energy-growth nexus: Evidence from cross-country panel data

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Abstract. The study investigated the interplay between energy consumption (EN), economic growth (EG), and economic complexity across 59 countries from 2000 to 2018. Employing panel data methods, the research examined various models to estimate long-term effects while addressing unobserved heterogeneity and potential biases. Results indicate significant relationships between EG, EN, and economic complexity. Notably, the economic complexity index (ECI) displayed a positive effect on economic development, while trade openness and foreign direct investment showed varying impacts. The study identified a positive association between EG and EN, suggesting that increased energy consumption accompanies economic growth. However, a higher capital-to-labor ratio was associated with lower EN, indicating a substitution effect. Of particular note is the significant positive impact of the interaction between ECI and EN on GDP across various models. In the Country Fixed Effects Model, a one-unit increase in the interaction correlated with a 0.026 unit increase in GDP ($p < 0.001$). Similarly, significant positive relationships were observed in the Panel EGLS and FMOLS models, with coefficients of 0.055 and 0.031, respectively ($p < 0.001$ and $p = 0.011$). Conversely, all models consistently demonstrated a negative relationship between economic complexity and GDP, with coefficients ranging from -0.062 to -0.089 ($p < 0.001$). These findings underscore the importance of considering economic complexity and energy consumption in policy interventions aimed at promoting sustainable economic growth. Policymakers are encouraged to adopt comprehensive approaches that account for the complex interplay of various factors influencing economic development and energy consumption to formulate effective strategies.

Keywords: Energy consumption, Economic development, Economic complexity, Panel data methods

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1. Introduction

Climate change presents a critical challenge in today's world, threatening both environmental sustainability and global socio-economic stability. The escalating temperatures, intensifying weather extremes, and melting glaciers underscore the urgent need for immediate mitigation and adaptation efforts (Kyriakopoulos & Sebos, 2023). In response to this challenge, the United Nations (UN) endorsed 17 Sustainable Development Goals (SDGs) in 2015, with SDG7 and SDG13 specifically targeting energy access and climate change mitigation. Achieving these goals and effectively addressing climate change requires empowering communities to actively participate in the transition to sustainable energy systems (Losada-Puente *et al.*, 2023).

Moreover, the role of economic complexity in the discourse on climate change has grown in recognition in recent years. Economic complexity refers to the structural changes within production processes, shifting towards more technology- and knowledge-based methods. Climate change experts widely acknowledge that environmental degradation is a primary driver of climate change (Romero & Gramkow, 2021).

Furthermore, since the energy crises of the 1970s, the relationship between economic growth (EG) and energy consumption (EN) has been a central concern for economists and policymakers. The debate surrounding whether energy drives economic expansion or if EG increases EN has been extensively explored in the literature. Scholars have investigated this link using various econometric methodologies, time frames, levels of analysis, and variables (Arouri *et al.*, 2012; Fei *et al.*, 2011; Lin & Moubarak, 2014; Mahadevan & Asafu-Adjaye, 2007; Soytas & Sari, 2009).

A country's economic development is impossible without adequate energy supplies. For EG to be sustained over time, there must be a continuous supply of inputs, including energy. Existing studies on the nexus between EN and EG have explored the connection from various perspectives. The empirical literature identifies four distinct hypotheses regarding the relationship between EN and EG: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. The growth hypothesis suggests that EN contributes to EG, indicating that an increase in EN would lead to higher EG (Tiwari *et al.*, 2021). Despite the increasing body of research on the relationship between EN and EG, there is no consensus on the nature of this relationship. The lack of theoretical agreement in experimental literature may explain why more comprehensive research is needed. One factor that could be considered in understanding these differences is the economic structure of the sample countries.

Traditionally, economic success is explained by structural changes and breakthroughs in knowledge and technology,

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resulting in a wide range of goods and services and increased economic complexity (Hidalgo *et al.*, 2007). Economic complexity is a relatively new concept introduced by Hidalgo and Hausmann (2009) to provide a comprehensive assessment of a country's industrial structure and productive capabilities. Economic complexity helps to comprehend not only countries' productive systems but also differences in income levels and growth patterns across countries. Economic complexity emphasizes the dual nature of economic inputs and outputs. However, unlike traditional approaches that aggregate output or make assumptions about the nature of inputs, economic complexity techniques employ fine-grained data on thousands of economic activities to learn about both abstract factors of production and how they combine to produce thousands of outputs (Hidalgo, 2021). Recently, economic complexity has been identified as a significant predictor of EG in the literature. In this regard, Hoeriyah *et al.* (2022) investigated how economic complexity impacts EG in 86 developing countries. Their findings suggest that economic complexity promotes EG in developing countries. Economic complexity increases the likelihood of structural change by facilitating the emergence of high-value-added economic sectors capable of producing more complex goods and generating a higher income.

On the other hand, the relationship between economic complexity and EN has not been extensively studied. However, recent research has shed light on this nexus. Liu *et al.* (2020) explored the link between EN and economic complexity among Lancang-Mekong Cooperation countries and found a one-way relationship between EN and the economic complexity index. Similarly, Can *et al.* (2022) found that economic complexity increases EN in developing countries while decreasing it in developed countries. These studies suggest that differences in EN across nations can be explained by their economic complexity, which is measured by a country's variety of skills and their interconnections.

This research contributes to the field in two significant ways. First, it investigates the impact of a country's economic structure on EN and economic development using the Economic Complexity Index (ECI), which is a widely regarded measure of economic change established by Harvard University. Second, this study aims to close gaps in the experimental literature and achieve agreement on the link between EN and economic development by exploring the economic structures of countries in relation to these effects.

The article's second section reviews the research literature on the relationship between EN and economic development, while the third section presents descriptive data and models. The fourth section examines the results, and the fifth section concludes the research by discussing its policy implications.

2. Literature review

There is a growing interest among scholars in investigating the relationship between EN and EG (Belke *et al.*, 2011; Chica-Olmo *et al.*, 2020; S. Narayan & Doytch, 2017; Ouyang & Li, 2018; Shahbaz *et al.*, 2018; Song *et al.*, 2021). Although various factors that affect a country's economic growth have been explored in the literature, energy has not always been included as a potential resource for enhancing economic growth. However, recent research has sought to fill this gap by examining the complex relationship between economic growth (EG) and energy (EN) using different methods such as Granger causality (Apergis & Payne, 2011; Chang *et al.*, 2015; Chiou-Wei *et al.*, 2008; Jiang & Chen, 2020; Long *et al.*, 2015) and panel data analysis (Charfeddine & Kahia, 2019; Shojaee & Seyedin, 2021). Some studies have explored this relationship in different contexts and by using different periods of data (Acaravci & Ozturk, 2010; Huang *et al.*, 2008; Mahadevan & Asafu-Adjaye, 2007). Other researchers have discussed this relationship in more detail by dividing energy into renewable and non-renewable energy (Chica-Olmo *et al.*, 2020; Ivanovski & Hailemariam, 2021) or differentiating between residential and industrial users of energy (S. Narayan & Doytch, 2017). Some studies have even added more variables, such as carbon emissions, to explore the relationships among multiple variables (Chen *et al.*, 2019). Additionally, researchers have explored the influence of time on the relationship between EN and EG by observing different time intervals (Magazzino *et al.*, 2021). Several studies have provided a comprehensive review of past research on the energy-growth link. These studies include Magazzino (2014), Narayan and Doytch (2017), Yang and Kim (2020), and Mutumba *et al.* (2021). Other studies have examined the link between economic complexity and EN among countries such as Liu *et al.* (2020) and Can *et al.* (2022).

According to the literature, four distinct hypotheses attempt to elucidate the connection between EN and EG. These hypotheses are growth, conservation, feedback, and neutrality. A recent literature review conducted by Mutumba *et al.* (2021) indicated that the ongoing discussion regarding the relationship between EN and EG remains inconclusive. However, the growth hypothesis was found to be the most prevalent, accounting for 43.8% of country-specific studies. The conservation hypothesis accounted for 27.2%, while feedback and neutrality accounted for 18.5% and 10.5%, respectively.

The growth hypothesis posits that relaxing regulations on EN would have a negative impact on EG due to the unidirectional causation from EN to EG. This hypothesis has been substantiated in numerous countries, including the United States (Bowden & Payne, 2010; Payne, 2011; Stern, 1993, 2010), Turkey (Soytas *et al.*, 2001), Italy, France, Canada, Germany, and United Kingdom (P. K. Narayan & Smyth, 2008), Japan (Lee & Chien, 2010; P. K. Narayan & Smyth, 2008), Canada (Lee & Chien, 2010), Ghana, Cote d'Ivoire, Brazil and Uruguay (N. M. Odhiambo, 2014), Greece (Tsani, 2010), Algeria, Benin and South Africa (Wolde-Rufael, 2009), Argentina, Indonesia, Kuwait, Malaysia, Nigeria, Saudi Arabia and Venezuela (Mahadevan & Asafu-Adjaye, 2007), Guatemala, Honduras, Costa Rica, Nicaragua, Panama and Salvador (Apergis & Payne, 2009), Tanzania (N. Odhiambo, 2009), Bangladesh, India and Pakistan (Imran & Siddiqui, 2010), Croatia (Borozan, 2013), Sweden (Piłatowska & Geise, 2021), Nigeria (Okoye *et al.*, 2020), Botswana (N. Odhiambo, 2021), Czech, Hungary, Slovakia (Krkošková, 2021), Saudi Arabia (Kahia *et al.*, 2021), India (Jayasinghe & Selvanathan, 2021), Pakistan (Fazal *et al.*, 2021).

In contrast to the growth hypothesis, the conservation hypothesis proposes that there is no causal link between an increase in EN and economic expansion. This hypothesis suggests that economic development can occur without relying on increased EN and that energy conservation programs can be implemented without negatively impacting EG. The conservation hypothesis has been found to hold in several countries, including the United States (Kraft & Kraft, 1978; Salari *et al.*, 2021) and Taiwan (Cheng & Lai, 1997). Japan (Ho Thi Hong *et al.*, 2021), Bulgaria, Croatia, Czech, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia (Shojaee & Seyedin, 2021), The conservation hypothesis has also been supported by MENA countries, such as Algeria, Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Kuwait, Morocco, Oman, Saudi Arabia, Sudan, Syria, Tunisia, Turkey, and the UAE (Nagmi & Serkan, 2021).

The third hypothesis explaining the relationship between EN and EG is the feedback hypothesis, which posits that there is a bi-directional causality between EN and EG in certain countries. Empirical evidence has supported the feedback hypothesis in various countries, such as South Korea (Glasure & Lee, 1998), Portugal, Italy, Greece, and Spain (Fuinhas & Marques, 2012), Canada (Ghali and El-Sakka, 2004), Korea (Oh and Lee, 2004), Turkey (Erdal *et al.*, 2008; Fuinhas & Marques, 2012; Yıldırım *et al.*, 2019), Tunisia (Belloumi, 2009), India (Kumar Mandal & Madheswaran, 2010; Sebri & Ben-Salha, 2014; Yıldırım *et al.*, 2019), China (Sebri & Ben-Salha, 2014; Wang *et al.*, 2011; Yıldırım *et al.*, 2019), Brazil, Russia, and South Africa (Sebri & Ben-Salha, 2014; Yıldırım *et al.*, 2019), Poland (Gurgul & Lach, 2012; Kasperowicz, 2014), and Liberia (Wesseh & Zoumara, 2012). Additionally, some studies found evidence of bi-directional causality between EN and EG in Australia, Norway, the United Kingdom, Japan, Sweden, and the United States (Mahadevan & Asafu-Adjaye, 2007).

As per the neutrality hypothesis, there is no causal relationship between EN and EG. Hence, both conservative and expansive energy policies do not impact EG. This hypothesis has been observed in various countries such as the United States and the United Kingdom (Tugcu & Topcu, 2018), Turkey (Halicioglu, 2009), China, Indonesia, South Korea, Taiwan, Thailand (Ho Thi Hong *et al.*, 2021), Albania, Romania, Bulgaria (Ozturk & Acaravci, 2010), Hungary (Marinas, Dinu, and Cristian Socol, 2018), Poland (Krkošková, 2021), Mozambique, South Africa, Zambia, Zimbabwe (Sunde, 2020), India (Singh & Vashishtha, 2020), Germany, Canada, United States (Shahbaz *et al.*, 2020), Turkmenistan (Orhan *et al.*, 2020), Nepal (Nepal & Paija, 2019), and Oman (Gorus & Aydin, 2019).

3. Model and Data Description

The objective of this study is to investigate the relationship between EN and EG in 59 countries from 2000 to 2018. The countries included in the sample were selected based on the period covered and data availability. The empirical model utilized in this research is an extended version of the Cobb-Douglas production function developed by Kahouli (2018). This model builds on the standard Cobb-Douglas production function with constant returns and the aggregate output function with time t, which is in line with Shahbaz *et al.* (2013). The model considers capital stocks (K), the labour force (L), and technical progress (A) as determinants of economic growth (EG). In addition to these factors, the extended model includes energy consumption (EN) as a determinant of EG, reflecting the potential importance of energy in economic growth. This extended version of the Cobb-Douglas production function allows for a more comprehensive analysis of the factors driving EG, providing insights into the potential role of energy in economic growth.

$$Y_t = A_t K_t^{\alpha_1} L_t^{\alpha_2} EN_t^{\alpha_3} e^u \quad (1)$$

Where Y is the gross domestic product (GDP), EN denote energy consumption and e the error term. α_1, α_2, and α_3 are the output elasticities respectively concerning domestic capital (K), and the labour force (L). The model also allows for endogenous determination of technology, which is influenced by foreign direct investment (FDI), economic complexity index (ECI), and trade openness (OPE) (Omri & Kahouli, 2014; Shahbaz & Lean, 2012). FDI inflows foster spillover knowledge and technology transfer, while the ECI enables and promotes technical developments and their dissemination. Trade openness, through labour mobility and capital transfer, can also promote technological development.

In this study, technology is considered to be endogenously determined by foreign direct investment (FDI), economic complexity index (ECI)*, and trade openness (OPE) within an augmented Cobb–Douglas production function (Omri & Kahouli, 2014; Shahbaz & Lean, 2012). FDI inflows are seen to promote knowledge and technology transfer, while the ECI facilitates technical developments and their dissemination. Additionally, trade openness, through labour mobility and capital transfer, is identified as a factor that can promote technological development.

$$A_t = \theta FDI_t^{\alpha_4} ECI_t^{\alpha_5} OPE_t^{\alpha_6} \quad (2)$$

Where θ is a time-invariant constant. Therefore, by substituting Eq. (2) into Eq. (1), the production function can be represented by the equation:

$$GDP_t = \theta K_t^{\alpha_1} L_t^{\alpha_2} EN_t^{\alpha_3} FDI_t^{\alpha_4} ECI_t^{\alpha_5} OPE_t^{\alpha_6} e^u \quad (3)$$

By taking the log, the linearized production function can be given as follows:

$$lnGDP_t = \alpha_0 + \alpha_1 lnK_t + \alpha_2 lnL_t + \alpha_3 lnEN_t + \alpha_4 lnFDI_t + \alpha_5 lnECI_t + \alpha_6 lnOPE_t + \varepsilon_t \quad (4)$$

Another determinant of GDP is the inflation rate (INF). Accelerated inflation and a decrease in household welfare, as well as shortages and negative effects on economic activity. In terms of commerce, capital stock, and urbanization, it is believed that both capital and labour are employed as potential inputs in the process of creating real economic output and that these inputs also assist producers of an economy in meeting their energy demand (Kahouli, 2017). Given that the research utilizes panel data, Equation (4) can be expressed in panel data form as follows:

$$lnGDP_{it} = \alpha_0 + \alpha_1 lnK_{it} + \alpha_2 lnL_{it} + \alpha_3 lnEN_{it} + \alpha_4 FDI_{it} + \alpha_5 ECI_{it} + \alpha_6 lnOPE_{it} + \alpha_7 INF_{it} + \varepsilon_{it} \quad (5)$$

$$lnGDP_{it} = \alpha_0 + \alpha_1 lnK_{it} + \alpha_2 lnL_{it} + \alpha_3 lnEN_{it} + \alpha_4 FDI_{it} + \alpha_5 ECI_{it} + \alpha_6 lnOPE_{it} + \alpha_7 INF_{it} + \alpha_8 (ECI_{it} \times lnEN_{it}) + \varepsilon_{it} \quad (6)$$

Where $i = 1, 2, \ldots, N$ and $t = 1, 2, \ldots, T$ denote the member country and year, respectively. The natural logarithm ln is applied to all variables except FDI, ECI, and INF, rendering the estimated coefficients are elasticities. Several energy economists, including Shahbaz *et al.* (2013), Salahuddin *et al.* (2015), Saidi and Hammami (2015), and Kahouli (2017, 2018), included EG, openness to trade, capital stock, labour force, and total population variables in their empirical models to investigate the impact of these variables on EN. The degree of industrialization of a country is indicated by the capital-labour ratio (K/L), which is one of the research's independent variables. The greater the capital (K) to labor (L) ratio, the more capital-intensive the country's economic structure. If a rise in the labor force's per capita capital raises the energy intensity,

* The Economic Complexity Index (ECI) is a measure of a country's level of economic development and potential for growth based on the diversity and complexity of its export basket. It assesses a country's productive capabilities and expertise, considering the range, pervasiveness, and intricacy of the goods it exports. Countries with a high level of complexity in their exports, indicating a diversity of productive know-how and specialized skills, can produce a wide range of sophisticated products. The ECI is found to highly predict a country's current income levels, and where complexity exceeds expectations for a country's income level, it is predicted to experience more rapid growth in the future.

this indicates that energy and capital have a supportive connection. If raising this ratio results in a decrease in energy intensity, substitution has occurred. Hence, the proposed model, which aligns with the broader body of research on the determinants of energy consumption (EN) as described earlier, includes the following factors:

$$lnEN_{it} = \alpha_0 + \alpha_1 lnGDP_{it} + \alpha_2 \frac{lnK_{it}}{lnL_{it}} + \alpha_3 INF_{it} + \alpha_4 lnOPE_{it} + \alpha_5 FDI_{it} + \alpha_6 ECI_{it} + \varepsilon_{it} \quad (7)$$

$$lnEN_{it} = \alpha_0 + \alpha_1 lnGDP_{it} + \alpha_2 \frac{lnK_{it}}{lnL_{it}} + \alpha_3 INF_{it} + \alpha_4 lnOPE_{it} + \alpha_5 FDI_{it} + \alpha_6 ECI_{it} + \alpha_7 (ECI_{it} \times lnGDP_{it}) + \varepsilon_{it} \quad (8)$$

Models 6 and 8 include the interaction term of economic complexity and energy $(ECI_{it} \times lnEN_{it})$ and the interaction term of economic complexity and GDP $(ECI_{it} \times lnGDP_{it})$, respectively. To appreciate the consequences of such interactions when evaluating the results, one can calculate the derivatives of Equation (6) to EN and Equation (8) to GDP to discover how two variables interact. The following equations (9) and (10) provide the outcome of the derivations:

$$\frac{d(lnGDP_{it})}{d(lnEN_{it})} = \alpha_3 + \alpha_8 ECI_{it} \quad (9)$$

$$\frac{d(lnEN_{it})}{d(lnGDP_{it})} = \alpha_1 + \alpha_7 ECI_{it} \quad (10)$$

Equations (9) and (10) allow us to explore the spillover effects of economic complexity on the relationship between EN and GDP. While some impacts of GDP and EN are direct (direct effects), the remainder is contingent on the economic structure and degree of complexity of individual countries (spillover effects). This research employs an empirical model to investigate the impact of economic systems on the interdependence of model variables, which is the primary objective of this study. The definition of the variables and data resources used to collect study data is provided in Table 1.

The proposed approach enables us to gain crucial insights into the complex relationships between EN, GDP, and economic systems, which can aid policymakers in designing effective policies to address energy and economic challenges. The statistics in Table 2 are summarized from 2000 to 2018. The standard deviations for the majority of variables are much less than their means, showing the lack of outliers and a low amount of temporal volatility in the model's variables despite the

Table 1
Variable definitions

Variable	Source	Variable constructed
$lnGDP$	WDI	$lnGDP_{it} = log(GDP_{it})$ $GDP_{it} = GDP\ (constant\ 2015\ US\$)$
$lnEN$	BP	$lnEN_{it} = log(EN_{it})$ $EN_{it} = Primary\ energy\ consumption\ (TWh)$
lnK	WDI	$lnK_{it} = log(K_{it})$ $K_{it} = Gross\ capital\ formation\ (constant\ 2015\ US\$)$
lnL	WDI	$lnL_{it} = log(L_{it})$ $L_{it} = Labor\ force, total$
$lnOPE$	WDI	$lnOPE_{it} = log(OPE_{it})$ $OPE_{it} = Trade\ Openness\ (\%\ of\ GDP)$
FDI	WDI	$lnFDI_{it} = log(FDI_{it})$ $FDI_{it} = Foreign\ direct\ investment, net\ inflows\ (\%\ of\ GDP)$
INF	WDI	$INF_{it} = Inflation, consumer\ prices\ (annual\ \%)$
ECI	Harvard's Growth Lab	$ECI_{it} = Economic\ Complexity\ Index$

Notes: WDI: World Development Indicator; Harvard's Growth Lab; Statistical Review of World Energy (BP).

Table 2
Summary statistics (54 countries observed between 2000 and 2018

Variables	Mean	Maximum	Minimum	Std. Dev.	Observations
GDP	26.328	6.454	1.955	2.40	1121
EN	2024.237	37714.1	27.752	4918.75	1121
K	2.370	5.820	1.120	6.270	1121
L	405000	7.870	445198	1.140	1121
OPE	80.643	227.402	19.56	38.88	1121
FDI	5.201	280.132	-40.330	16.697	1121
INF	4.657	168.620	-4.478	8.407	1121
ECI	0.636	2.824	-1.855	0.890	1121
$lnGDP$	26.328	30.604	22.588	1.536	1121
$lnEN$	6.377	10.538	3.323	1.505	1121
lnK	24.860	29.393	20.835	1.564	1121
lnL	16.184	20.484	13.006	1.525	1121
$lnOPE$	4.277	5.427	2.973	0.482	1121

Source: Authors' estimations.

Table 3
Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) $lnGDP$	1.000							
(2) $lnEN$	0.917*	1.000						
	(0.000)							
(3) lnK	0.987*	0.919*	1.000					
	(0.000)	(0.000)						
(4) lnL	0.753*	0.837*	0.755*	1.000				
	(0.000)	(0.000)	(0.000)					
(5) $lnOPE$	-0.489*	-0.485*	-0.464*	-0.626*	1.000			
	(0.000)	(0.000)	(0.000)	(0.000)				
(6) FDI	-0.147*	-0.179*	-0.156*	-0.205*	0.209*	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
(7) INF	-0.125*	0.014	-0.114*	0.091*	-0.036	-0.053	1.000	
	(0.000)	(0.629)	(0.000)	(0.002)	(0.232)	(0.076)		
(8) ECI	0.451*	0.279*	0.432*	-0.011	0.209*	0.041	-0.202*	1.000
	(0.000)	(0.000)	(0.000)	(0.719)	(0.000)	(0.167)	(0.000)	

Note: p-values in parentheses, ***, **, and * show significance at the 1%, 5%, and 10% level respectively
Source: Authors' estimations.

relatively long duration. Table 3 presents the pairwise correlations among the variables examined in the analysis, providing correlation coefficients for each variable pair along with the associated p-values enclosed in parentheses.

4. Estimation and Analysis of the Results

4-1 Unit Root Tests

The findings from the stationarity tests in Table 4 offer crucial information about the integration order of the variables being investigated. By employing four distinct panel unit root test techniques - Im, Pesaran, and Shin (IPS) (2003), Levin, Lin, and Chu (LLC) (2002), Phillips-Perron Fisher (PP-Fisher) (1988), and Augmented Dickey-Fuller Fisher (ADF-Fisher) (1981), it becomes clear that numerous variables are integrated of order I(1) at a 1% significance level.

The analysis shows a consistent pattern is observed across various panel unit root test methods, as most test statistics display significance at the 1% level for their first differences. This indicates that the variables are non-stationary at levels but become stationary after accounting for the first differences. The uniformity of the test results across different methods bolsters the reliability of these conclusions. Additionally, the stationarity of the variables in their first differences implies they share a common stochastic trend, a vital condition for performing further assessments like cointegration tests and panel vector autoregression models.

4.2 Estimation Results

To provide a more comprehensive estimation of the model's long-run effects, various panel models were employed, including a time-period fixed effects model, a country fixed effects model, a two-way country and time-period fixed effects model, and a Panel EGLS model. These panel models enabled the researchers to account for the effects of unobserved heterogeneity across countries and over time and to control for the potential biases resulting from omitted variables that vary over time or across countries.

However, since the model's variables are integrated on one scale, it was necessary to use a specific method that accounts for cointegration, such as the panel fully modified OLS (FMOLS) model. The FMOLS estimator is a well-known approach that is widely used in applied econometric research for estimating long-run relationships between variables. It allows for the presence of a common stochastic trend among variables and provides consistent parameter estimates in small samples, see Table 5.

Table 4
The panel unit root tests

		Level		First Difference	
Variable	Method	Statistic	p-value	Statistic	p-value
$lnGDP$	Levin, Lin & Chu t*	-4.359	(0.000)	-10.161	(0.000)
	Im, Pesaran and Shin W-stat	2.510	(0.994)	-8.546	(0.000)
	ADF - Fisher Chi-square	95.087	(0.940)	273.513	(0.000)
	PP - Fisher Chi-square*	195.873	(0.000)	376.625	(0.000)
$lnEN$	Levin, Lin & Chu t*	-4.754	(0.000)	-11.076	(0.000)
	Im, Pesaran and Shin W-stat	2.377	(0.991)	-13.050	(0.000)
	ADF - Fisher Chi-square	89.290	(0.977)	395.891	(0.000)
	PP - Fisher Chi-square	126.650	(0.277)	1103.680	(0.000)

Table 4 (continued). The panel unit root tests

		Level		First Difference	
Variable	Method	Statistic	p-value	Statistic	p-value
lnK	Levin, Lin & Chu t*	-3.138	(0.001)	-11.332	(0.000)
	Im, Pesaran and Shin W-stat	-0.419	(0.338)	-10.847	(0.000)
	ADF - Fisher Chi-square	122.986	(0.358)	337.123	(0.000)
	PP - Fisher Chi-square*	148.174	(0.031)	624.758	(0.000)
lnL	Levin, Lin & Chu t*	-11.121	(0.000)	-3.590	(0.000)
	Im, Pesaran and Shin W-stat	-0.255	(0.400)	-5.882	(0.000)
	ADF - Fisher Chi-square	165.415	(0.003)	225.364	(0.000)
	PP - Fisher Chi-square*	311.902	(0.000)	415.306	(0.000)
$lnOPE$	Levin, Lin & Chu t*	-3.496	(0.000)	-14.900	(0.000)
	Im, Pesaran and Shin W-stat	-0.372	(0.355)	-13.374	(0.000)
	ADF - Fisher Chi-square	116.635	(0.518)	399.455	(0.000)
	PP - Fisher Chi-square	108.088	(0.733)	762.143	(0.000)
FDI	Levin, Lin & Chu t*	-5.402	(0.000)	-16.577	(0.000)
	Im, Pesaran and Shin W-stat*	-7.686	(0.000)	-18.789	(0.000)
	ADF - Fisher Chi-square*	259.463	(0.000)	551.614	(0.000)
	PP - Fisher Chi-square*	439.668	(0.000)	1742.760	(0.000)
INF	Levin, Lin & Chu t*	-9.042	(0.000)	-20.723	(0.000)
	Im, Pesaran and Shin W-stat*	-8.946	(0.000)	-21.065	(0.000)
	ADF - Fisher Chi-square*	284.638	(0.000)	615.412	(0.000)
	PP - Fisher Chi-square*	667.500	(0.000)	2482.080	(0.000)
ECI	Levin, Lin & Chu t*	-5.442	(0.000)	-11.704	(0.000)
	Im, Pesaran and Shin W-stat	-1.929	(0.027)	-14.543	(0.000)
	ADF - Fisher Chi-square	137.647	(0.104)	429.626	(0.000)
	PP - Fisher Chi-square*	184.479	(0.000)	1366.480	(0.000)

Note: p-values in parentheses, ***, **, and * show significance at the 1%, 5%, and 10% level respectively
Source: Authors' estimations.

To estimate the long-run effects of the variables, Phillips and Moon's (1999) panel cointegrating estimators for the PFMOLS model were employed. These estimators utilize a two-step procedure, initially estimating the cointegrating vector, a linear combination of variables forming a stationary process, followed by estimating the short-run dynamics of the variables around this long-run relationship. This approach facilitates obtaining unbiased and efficient estimates of the long-run coefficients, even in the presence of endogeneity and serial correlation in the residuals.

To ensure the validity and robustness of the results, several diagnostic tests were conducted, including the Hausman test and Kao's cointegration test. These tests are essential for assessing the reliability of the findings and confirming the consistency of the estimated parameters. The Hausman test is commonly used to assess the adequacy of the fixed effects specification of the panel models. It compares the estimated coefficients of the fixed effects model with those of the random effects model and tests the null hypothesis that the difference between them is not systematic. If the null hypothesis is rejected, it suggests that the fixed effects model is a better specification. Kao's cointegration test, on the other hand, tests the null hypothesis that the variables are not cointegrated. If the null hypothesis is rejected, it implies that there is a long-run relationship among the variables, and therefore, the typical pooled least-squares approach may provide erroneous results.

The analysis was initiated by examining the factors impacting economic growth. Diagnostic tests were utilized, and estimations were conducted using country and time-period fixed effects as well as FMOLS. However, significant differences were observed in the outcomes of the two models for several variables. For example, while the FMOLS model indicated a positive effect of trade openness on economic development, the country and time-period fixed effects model revealed a negative effect. Similar patterns were observed for the logarithm of the labour force.

To understand the reasons for these differing findings, the fixed-time effects model and the country-fixed effects model were examined separately. The former eliminates cross-period heterogeneity, explaining the differences between variables across countries, while the latter captures cross-country heterogeneity, demonstrating the impacts of variables across time. It was found that while both variables had a positive impact in the country fixed effects model, the impact of the first variable was insignificant, and the impact of the second variable was negative in the time-period fixed effects model.

From Table 5, several factors emerge when discussing the negative relationship between $\boldsymbol{lnGDP}$ and $\boldsymbol{lnOPE}$. Initially, trade openness can intensify competition among domestic

Table 5
The estimation results for Model 1 (Equation 5)

	Country fixed effects	Time-period fixed effects	Country and time-period fixed effects	Panel EGLS	FMOLS
$lnEN$	0.163	0.104	0.321	0.301	0.140
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
lnL	0.225	0.008	-0.323	0.036	0.162
	(0.000)	(0.386)	(0.000)	(0.024)	(0.004)
lnK	0.434	0.805	0.274	0.296	0.475
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
INF	-0.002	-0.004	-0.0001	-0.001	-0.004
	(0.000)	(0.000)	(0.278)	(0.003)	(0.000)
$lnOPE$	0.111	-0.235	-0.104	-0.078	0.136
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
FDI	0.000	0.001	0.000	0.000	0.000
	(0.639)	(0.002)	(0.146)	(0.919)	(0.646)
ECI	0.018	0.136	0.058	0.078	0.024
	(0.221)	(0.000)	(0.000)	(0.000)	(0.283)
$LogL$	1222.491	121.527	1859.213		
$LR\ test$	1273.444	3475.371			
	(0.000)	(0.000)			
$Hausman\ Test$				1032.593	
				(0.000)	
$Kao\ Test$					-2.954
					(0.002)
R^2	0.997	0.980	0.999	0.912	0.997

Source: Authors' estimations.

industries, making it difficult for them to compete with imports. As a result, this can lead to a decline in economic growth as domestic industries dwindle or go out of business. Additionally, trade openness can foster specialization in specific sectors, which can have both positive and negative impacts on economic growth. Although specialization can improve efficiency and productivity in certain sectors, it can also limit diversification and increase countries' vulnerability to changes in global demand or supply chain disruptions. Furthermore, the negative relationship between lnGDP and lnOPE may also be attributable to the unique contexts of the countries under examination. For example, countries that are highly reliant on natural resource exports may experience a negative effect of trade openness on economic growth because they become excessively dependent on a single commodity or market.

On the other hand, countries with more diversified economies may encounter a positive effect of trade openness on economic growth because they can leverage new markets and access a broader range of goods and services. Therefore, time-period effects are more important in country and time-period fixed effects models, while country effects are more prominent in FMOLS.

The analysis of variables affecting economic growth was further extended by conducting diagnostic tests and estimating results for different models, including country and time-period fixed effects as well as FMOLS. The results of these models showed that the positive impact of the economic complexity index was insignificant in FMOLS, while the negative effect of inflation on economic growth was also insignificant in the country and time-period fixed-effects models. However, the analysis indicated that economic complexity had a positive impact on economic development, with each per cent increase in ECI leading to a 0.321 to 0.14 per cent increase in EG, while fixed capital creation resulted in a 0.274 to 0.475 per cent increase.

Table 6 includes an interaction term between ECI and EN, which represents the combined influence of these two variables on a country's GDP or economic growth. The interaction term has a positive coefficient, indicating that countries with higher values of ECI and energy consumption tend to have even higher GDP levels. This could be because a higher ECI implies a more diverse and complex economy, which can take advantage of increased energy consumption to achieve higher productivity and output.

Furthermore, the model that combines country and time-period fixed effects reveals a significant positive impact of FDI on economic development. Although economic complexity has a negative direct influence on economic development, its spillover effects are significant and require further analysis. Therefore, Equation (9) is introduced to examine these spillover effects more closely.

$$\frac{d(lnGDP_{it})}{d(lnEC_{it})} = 0.299 + 0.036ECI_{it} \tag{11}$$

$$\frac{d(lnGDP_{it})}{d(lnEC_{it})} = 0.119 + 0.031ECI_{it} \tag{12}$$

Therefore, the economic complexity index increases the positive effects of EN on EG. Next, the variables influencing energy consumption (EN) were examined (refer to Table 7). Utilizing country and time-period fixed-effect models alongside the FMOLS model, the investigation revealed generally consistent results across the fixed-effects and FMOLS models, except for trade openness, which displayed conflicting effects. The fixed-effects model indicated that increasing trade openness over time led to reduced EN, while countries with higher trade openness tended to consume more energy. Time-period effects were more evident in the country and time-period fixed-effects models, while country effects were observed in the FMOLS model. Additionally, a positive association between economic growth (EG) and EN was found, suggesting that as economies expand, energy consumption increases. However, higher capital-to-labour ratios were linked to lower EN, indicating a substitution effect between capital and energy. Notably, the economic complexity index exhibited a positive and statistically significant impact solely in the FMOLS model.

Table 6
The estimation results for Model 2 (Equation 6)

	Country fixed effects	Time-period fixed effects	Country and time-period fixed effects	Panel EGLS	FMOLS
$lnEC$	0.146	0.103	0.299	0.274	0.119
	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)
lnL	0.249	0.007	-0.292	0.035	0.184
	(0.000)	(0.431)	(0.000)	(0.029)	(0.001)
lnK	0.438	0.804	0.276	0.297	0.481
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
INF	-0.002	-0.004	0.000	-0.001	-0.004
	(0.000)	(0.000)	(0.241)	(0.004)	(0.000)
$lnOPE$	0.120	-0.233	-0.095	-0.067	0.149
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
FDI	0.000	0.001	0.000	0.000	0.000
	(0.431)	(0.002)	(0.032)	(0.222)	(0.692)
ECI	-0.156	0.113	-0.183	-0.290	-0.185
	(0.003)	(0.005)	(0.000)	(0.000)	(0.028)
$ECI \times lnEN$	0.026	0.003	0.036	0.055	0.031
	(0.001)	(0.558)	(0.000)	(0.000)	(0.011)
$LogL$	1228.290	121.700	1894.355		
$LR\ test$	1332.129	3545.309			
	(0.000)	(0.000)			
$Hausman\ Test$				953.501	
				(0.000)	
$Kao\ Test$					-2.686
					(0.004)
R^2	0.997	0.980	0.999	0.912	0.997

Source: Authors' estimations.

Table 7
The estimation results for Model 3 (Equation 7)

	Country fixed effects	Time-period fixed effects	Country and time-period fixed effects	Panel EGLS	FMOLS
$lnGDP$	0.718	0.996	1.373	1.135	0.734
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\frac{lnK}{lnL}$	-0.729	-2.962	-3.627	-2.352	-1.011
	(0.010)	(0.000)	(0.000)	(0.000)	(0.030)
INF	0.003	0.013	0.002	0.002	0.004
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
$lnOPE$	-0.149	0.427	0.039	0.008	-0.194
	(0.000)	(0.000)	(0.106)	(0.732)	(0.000)
FDI	0.000	-0.002	0.000	0.000	0.000
	(0.450)	(0.056)	(0.177)	(0.363)	(0.470)
ECI	0.108	-0.184	0.011	0.023	0.122
	(0.000)	(0.000)	(0.490)	(0.170)	(0.000)
$LogL$	929.447	-754.070	1099.694		
$LR\ test$	340.493	3707.527			
	(0.000)	(0.000)			
$Hausman\ T$				99.789	
				(0.000)	
$Kao\ Test$					-2.333
					(0.010)
R^2	0.995	0.901	0.996	0.726	0.995

Source: Authors' estimations.

To gain deeper insights into the spillover effects of economic complexity on economic growth, an interaction term between EG and ECI ($ECI \times lnGDP$) was incorporated into the analysis (refer to Table 8). The examination revealed that the coefficients for the economic complexity index became significant, indicating that increasing economic complexity not only positively influences EG but also has a positive and substantial impact on EN. Subsequently, the spillover effects were assessed using Equation (10).

$$\frac{d(lnEN_{it})}{d(lnGDP_{it})} = 1.45 - 0.088 \times ECI_{it} \quad (13)$$

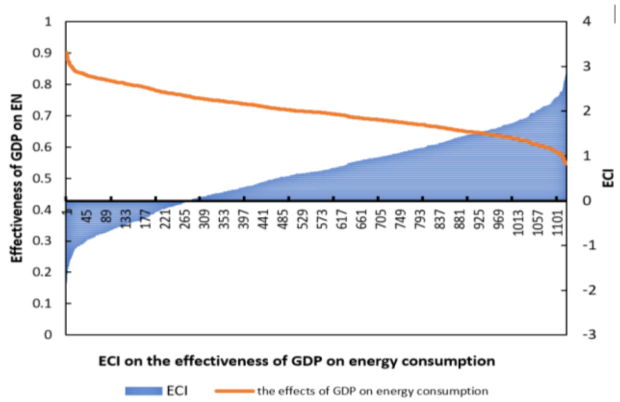
$$\frac{d(lnEN_{it})}{d(lnGDP_{it})} = 0.761 - 0.076 \times ECI_{it} \quad (14)$$

In Figure 1, a visual representation is provided to illustrate the evolving influence of EG and EN on each other, with consideration of the economic complexity index and the FMOLS coefficient. The analysis reveals a consistent positive relationship between economic growth (EG) and energy consumption (EN), while an increase in the economic complexity index (ECI) correlates with a decline in energy consumption. The findings suggest that EN generally contributes positively to GDP, except in cases where the economic complexity index falls below -0.388. In countries with low economic complexity, negative consequences of EG on EN may be observed, whereas in nations with high economic complexity, EN consistently has a positive impact on economic development.

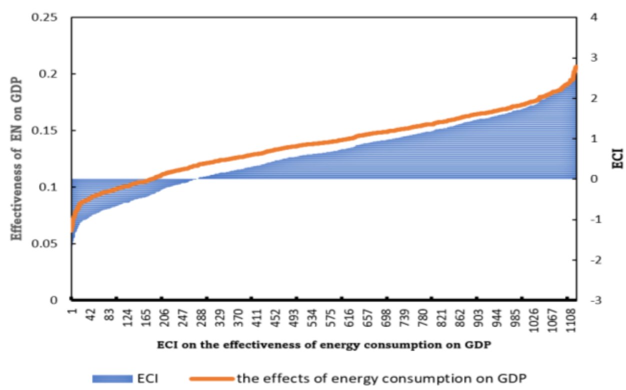
Table 8.
The estimation results for Model 4 (Equation 8)

	Country fixed effects	Time-period fixed effects	Country and time-period fixed effects	Panel EGLS	FMOLS
$lnGDP$	0.736	1.045	1.450	1.223	0.761
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ln\frac{K}{L}$	-0.788	-2.944	-3.863	-2.622	-1.103
	(0.005)	(0.000)	(0.000)	(0.000)	(0.016)
INF	0.003	0.012	0.001	0.002	0.004
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
$lnOPE$	-0.164	0.384	0.039	0.010	-0.217
	(0.000)	(0.000)	(0.086)	(0.682)	(0.000)
FDI	0.000	-0.002	0.000	0.000	0.000
	(0.166)	(0.052)	(0.023)	(0.072)	(0.311)
ECI	1.747	1.493	2.341	2.378	2.153
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$ECI \times lnGDP$	-0.062	-0.063	-0.088	-0.089	-0.076
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$LogL$	948.616	-741.220	1151.088		
$LR\ test$	404.945	3784.617			
	(0.000)	(0.000)			
$Hausman\ Test$				97.451	
				(0.000)	
$Kao\ Test$					-2.285
					(0.011)
R^2	0.995	0.903	0.997	0.728	0.995

Source: Authors' estimations.



(a). The economic complexity index on the effectiveness of GDP on energy consumption



(b). The economic complexity index on the effectiveness of energy consumption on GDP

Fig 1. The Impact of Economic Complexity Index on the Relationship between GDP and Energy Consumption

5. Discussion

This research examines the relationship between EN and economic development in 59 countries from 2000 to 2018, using a suitable panel model chosen through diagnostic tests. The findings suggest that an increase in the labour force contributes to a country's economic development over time. Furthermore, the development of fixed capital is a crucial aspect of countries' EG and can help explain the variation in growth rates across countries, as demonstrated by earlier studies (Omri, 2013; Omri & Kahouli, 2014). Additionally, the data indicate that an improvement in the capital-labour ratio leads to a decrease in EN. While foreign direct investment (FDI) has a positive effect on economic development, its significance has been confirmed in some panel models but dismissed in others. In contrast, FDI has no impact on EN. According to Kahouli *et al.* (2019), Ren *et al.* (2014), and Sbia *et al.* (2014), FDI inflows contribute to job creation and EG. On the other hand, inflation limits economic development and leads to increased EN due to lower relative energy costs, consistent with economic theory (Kahouli & Kadhraoui, 2012; Kahouli & Maktouf, 2015; Omri & Kahouli, 2014). Thus, the results indicate that policy interventions targeting reduced inflation rates, increased FDI inflows, and the promotion of fixed capital formation could effectively enhance EG while simultaneously reducing EN.

In addition to implementing new technologies and enhancing energy efficiency, promoting business openness is also a key factor in contributing to economic development while reducing EN. According to Ghani (2012), reducing trade barriers leads to a decline in transportation costs, which ultimately leads to decreased EN. However, in countries with higher trade openness, the benefits of trade openness on efficiency are more limited, leading to weaker EG and higher levels of EN.

Furthermore, the findings of the study suggest a positive relationship between economic development and increased energy consumption, which is consistent with the previous studies conducted by Saboori *et al.* (2014), Kasman and Duman (2015), and Kahouli *et al.* (2019) that reported a positive and substantial association between EN and EG. Ajmi *et al.* (2015) also found that an increase in GDP per capita leads to an increase in EN, which is directly linked to EG. The results support the feedback concept's validity, which was suggested by (2009) and Omri (2013), that growth and energy are interdependent.

The relationship between EG and EN is typically positive and significant, but the extent of this relationship is influenced by the economic complexity of countries. In countries with a higher degree of economic complexity, EG has a less pronounced impact on EN. Conversely, the influence of EN on EG is more severe in countries with greater economic complexity. This study confirms the hypothesis of growth for countries with high economic complexity, which has already been proven for various countries, such as the United States (Bowden & Payne, 2010; Payne, 2011; Stern, 1993, 2010), Italy, France, Canada, Germany, and United Kingdom (P. K. Narayan & Smyth, 2008), Japan (Lee & Chien, 2010; P. K. Narayan & Smyth, 2008), Canada (Lee & Chien, 2010), Sweden (Piłatowska & Geise, 2021), Czech, Hungary, Slovakia (Krkošková, 2021), India (Jayasinghe & Selvanathan, 2021), and Indonesia, Malaysia (Mahadevan & Asafu-Adjaye, 2007). Additionally, the hypothesis is also validated for countries with minimal economic complexity, as demonstrated by earlier studies conducted in Algeria, Benin, South Africa, Argentina, Kuwait, Nigeria, Saudi Arabia, Venezuela, Guatemala, Honduras, Costa Rica, Nicaragua, Panama, Salvador, Tanzania, Bangladesh, Pakistan, Croatia, Nigeria, Botswana, Saudi Arabia, and Pakistan.

The interplay between energy consumption (EN) and economic growth (EG) is generally positive and substantial. However, the strength of this relationship is influenced by a nation's economic complexity. In countries with higher economic complexity, the advantageous impact of EG on EN is less apparent, whereas the repercussions of economic complexity in moderating EN's influence on EG are more pronounced. Specifically, EN exerts a positive effect on EG in economically complex nations, while the opposite is true for countries with lower economic complexity (Arouri *et al.*, 2012).

Empirical evidence supports the growth hypothesis for countries with high economic complexity, including the United States (Bowden & Payne, 2010; Payne, 2011; Stern, 1993, 2010), Italy, France, Canada, Germany, and the United Kingdom (P. K. Narayan & Smyth, 2008), Japan (Lee & Chien, 2010; P. K. Narayan & Smyth, 2008), Canada (Lee & Chien, 2010), Sweden (Piłatowska & Geise, 2021), Czech, Hungary, Slovakia (Krkošková, 2021), India (Jayasinghe & Selvanathan, 2021), and Indonesia, Malaysia (Mahadevan & Asafu-Adjaye, 2007)

This hypothesis also holds for countries with low economic complexity, as demonstrated by previous research on Algeria, Benin, and South Africa (Wolde-Rufael, 2009), Argentina, Kuwait, Nigeria, Saudi Arabia and Venezuela (Mahadevan & Asafu-Adjaye, 2007), Guatemala, Honduras, Costa Rica, Nicaragua, Panama and Salvador (Apergis & Payne, 2009), Tanzania (N. Odhiambo, 2009), Bangladesh, and Pakistan (Imran & Siddiqui, 2010), Croatia (Borozan, 2013), Nigeria (Okoye *et al.*, 2020), Botswana (N. Odhiambo, 2021), Saudi Arabia (Kahia *et al.*, 2021), and Pakistan (Fazal *et al.*, 2021).

The outcomes of this analysis provide a fresh perspective on the influence of various factors and highlight the vital role of economic structure as a moderating force in understanding the effects of these variables. As such, it is advised that future research consider incorporating additional elements that could contribute to a more accurate comprehension of the causal relationship between EN and economic growth. Potential factors to explore include demographic aspects, technological innovations, governmental policies, and cultural distinctions. By integrating these elements into future research, scholars can deepen their understanding of the intricate connections between EN and economic development, ultimately offering valuable guidance for policymakers in devising effective energy and economic strategies.

Finally, the article acknowledges the limitations of the traditional Cobb-Douglas production function and presents an updated model that incorporates human capital as a key factor in economic growth. It also addresses the assumption that labour and capital are exogenous to the growth process and discusses the potential influence of demand-side factors on the availability of capital and labour. The paper explores how changes in GDP growth may impact the demand for labour and capital and how this, in turn, could affect their supply.

In summary, this research explores the intricate relationship between energy consumption (EN) and economic growth (EG) across 59 countries from 2000 to 2018. It underscores the significant contributions of the labour force and fixed capital development to economic growth, while also highlighting the ambiguous impact of foreign direct investment (FDI) on both economic development and energy consumption. Moreover, the study identifies inflationary pressures as a hindrance to economic development, leading to increased energy consumption. It also emphasizes the role of trade openness in fostering economic development, albeit with varying effects based on a country's economic complexity. Additionally, the study confirms a positive relationship between energy consumption and economic growth, moderated by a nation's economic complexity. It concludes with recommendations for policy interventions aimed at reducing inflation rates, increasing FDI inflows, promoting fixed capital formation, and enhancing energy efficiency to foster economic growth while curbing energy consumption. Finally, it calls for further research to explore additional factors such as demographic aspects, technological innovations, governmental policies, and cultural distinctions to deepen understanding of the causal relationship between EN and EG.

6. Policy Implications

In order to foster sustainable economic growth while minimizing energy consumption, several key strategies should be considered by policymakers. These approaches, outlined below, emphasize the importance of a holistic approach that takes into account the complex interplay of various factors that influence both economic development and energy consumption.

First and foremost, policymakers need to promote fixed capital formation to boost economic development and decrease energy usage. By offering tax incentives and subsidies, they can stimulate investments in infrastructure and productive assets. Attracting foreign direct investment is another important strategy for fostering job creation and accelerating economic growth. Secondly, addressing inflation rates is crucial for policymakers, as high inflation hampers economic development and leads to greater energy consumption. Implementing measures such as sound monetary policy can help maintain low and stable inflation rates. Thirdly, encouraging business openness and lowering trade barriers can help decrease transportation costs and, consequently, reduce energy consumption. In countries with high trade openness, however, policymakers should be cautious of potential efficiency limitations that could negatively impact economic growth and increase energy consumption. Fourthly, understanding the significance of economic complexity in shaping the relationship between energy consumption and economic growth is vital for policymakers. As such, policies should be customized to each country's unique economic context, taking into account their level of economic complexity and specific factors driving development.

In conclusion, policymakers must adopt a comprehensive approach to energy and economic policies, considering the interconnected nature of various elements and their influence on both economic development and energy consumption. This will enable them to formulate effective strategies that foster sustainable economic growth while reducing energy consumption.

7. Conclusion

This study illuminates the intricate relationship between energy consumption (EN) and economic growth (EG) across 59 countries from 2000 to 2018. The findings underscore the pivotal role of various factors in shaping economic development and energy usage patterns.

Key insights reveal the nuanced causative relationship between EN and EG, influenced by factors such as labour force dynamics, fixed capital development, and foreign direct investment. Moreover, the impact of inflation rates underscores the importance of macroeconomic stability in fostering sustainable development.

Policymakers are urged to adopt a holistic approach, prioritizing strategies that promote fixed capital formation, attract foreign direct investment, and ensure price stability. Tailored interventions, taking into account each country's economic complexity, are essential for addressing specific challenges and leveraging opportunities.

In essence, this study underscores the urgency of collaborative action to steer nations towards sustainable economic growth while safeguarding environmental sustainability. By heeding these insights, policymakers can navigate the complex landscape of energy and economic development, paving the way for a prosperous future.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statements

The generated during and/or analysed during the current study are available in the:

- World Development Indicator, (World Development Indicator; https://datacatalog.worldbank.org/dataset/world-development-indicators.
- Harvard's Growth Lab, (https://atlas.cid.harvard.edu/rankings).
- Statistical Review of World Energy (https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html).

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