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Article

The Relationship between Natural Gas Consumption and Economic Growth in Egypt

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Abstract: Given the increasing reliance on natural gas as a primary energy source in Egypt and its pivotal role in supporting industrial production and electricity generation, understanding the relationship between natural gas consumption and economic growth is of great importance. This is particularly crucial in the context of energy policy formulation, sustainable development, and efficient resource allocation. This study investigates the causal nexus between natural gas consumption and economic growth in Egypt during the period from 1988 to 2018. The primary aim is to determine whether economic growth drives gas consumption or vice versa, which carries significant implications for energy policy and sustainable development planning. The research adopts the Auto Regressive Distributed Lag (ARDL) approach to analyze long-term relationships, while the Vector Error Correction Model (VECM) Granger causality test is employed to explore short-run and long-run causal dynamics between the variables. The empirical findings reveal a unidirectional causality running from economic growth to natural gas consumption in the short run, supporting the conservation hypothesis. This suggests that economic expansion leads to increased gas consumption, but not the other way around. In contrast, no causality is detected in the long run, aligning with the neutrality hypothesis, which implies that natural gas consumption does not significantly influence long-term economic growth.

Keywords: Natural Gas Consumption; Economic Growth; ARDL; VECM; Granger Causality

1. Introduction

Energy is fundamental to all sectors of economic activity, yet its central role in driving long-term economic growth was underappreciated until the 1973 oil crisis. This event exposed the structural vulnerabilities of industrial economies to energy shocks and firmly established the link between energy security and macroeconomic performance [1]. Since then, energy policy has become an integral part of national development strategies, as the consumption of energy is now widely recognized as both a driver and a consequence of economic growth.

From 1988 to 2018, global real GDP increased by 132.11%, rising from USD 35.525 trillion to USD 82.458 trillion [2]. Over the same period, global primary energy consumption rose by 76.22%, while natural gas consumption grew substantially, with a notable 5% annual increase in 2018 alone [3]. Natural gas has become a vital part of the global energy mix due to its efficiency and relatively lower environmental impact. In Africa, natural gas consumption rose from 30.8 million tonnes of oil equivalent (Mtoe) in 1988 to 129 Mtoe in 2018—an increase of 318.8%—with Egypt accounting for 33% of the continent's usage in 2018 [3]. Domestically, Egypt consumed 59.6

billion cubic meters of natural gas in 2018, making it the dominant energy source in the country. Recent discoveries, favorable geographic positioning, and substantial infrastructure investments have further strengthened Egypt's ambition to become a regional energy hub [4].

Despite this strategic importance, the literature reveals a critical gap in country-specific studies examining the causal relationship between natural gas consumption and economic growth in Egypt. Most prior research either aggregates various energy sources or includes Egypt only as part of broader regional panels, which fail to capture its unique structural, policy, and market dynamics. Furthermore, many existing studies rely on bivariate models or overlook the short- and long-run causal directions that are crucial for policy formulation.

This paper addresses these shortcomings by making three key contributions:

1. Empirical Contribution: It isolates natural gas—Egypt's most consumed energy source—as a distinct variable, and analyzes its relationship with GDP using a multivariate ARDL and VECM framework that includes capital and labor. This allows for a more accurate and policy-relevant estimation of both short- and long-run effects.
2. Theoretical Contribution: It offers an integrated review of economic thought on energy and growth, from classical physiocracy to modern biophysical and ecological economics, thereby situating the empirical analysis within a broader conceptual framework.
3. Policy Contribution: The paper links its empirical findings directly to Egypt's ongoing energy transition—specifically, the shift away from subsidies and the promotion of renewable energy—providing actionable insights into how energy policy can support sustainable growth without compromising efficiency.

By bridging theoretical foundations with rigorous empirical analysis and current policy relevance, this study offers novel insights into the energy-growth nexus in Egypt and helps inform strategic decisions on energy conservation, investment, and development planning.

2. Literature Review

This section aims to investigate the relationship between natural resources, particularly energy resources, and economic growth from the perspective of economic theory and empirical evidence. This section is divided into two parts. Part One focuses on tracing and contrasting the different views of economic theories starting from the physiocracy economic theory to the modern biophysical economics theories concerning the role of natural resources, particularly energy resources in achieving economic growth. In addition, Part Two presents the empirical literature concerning the nexus between energy consumption and economic growth.

2.1. Theoretical Background

This section reviews the evolution of economic thought concerning the role of natural resources—especially energy—in shaping economic growth. The analysis is structured chronologically, tracing the theoretical progression from early classical theories to modern ecological and biophysical frameworks. Understanding this evolution provides essential context for interpreting the empirical relationship between energy use and economic performance, particularly in resource-dependent countries like Egypt.

2.1.1. Classical and Early Views on Natural Resources

Early economic theories placed natural resources, especially land, at the center of wealth creation. The Physiocrats in the 18th century, led by Quesnay, Mirabeau, and Dupont, considered land-based agriculture as the only productive economic activity, producing surplus beyond capital and labor inputs [5]. They viewed land as a renewable natural asset essential for national prosperity.

Following the Physiocrats, Classical economists such as Adam Smith, Malthus, Ricardo, and Mill refined the resource-growth nexus. Smith emphasized the productive surplus of agriculture but assumed nature's bounty was limitless and therefore did not treat scarcity as a constraint [5]. Malthus and Ricardo, in contrast, introduced the concept of diminishing returns to land and emphasized resource scarcity as a potential limit to economic expansion [6]. Mill expanded this view by incorporating exhaustible resources, stressing that knowledge and technological progress could partially offset resource limitations.

2.1.2. The Conservationist Perspective

By the mid-19th to early 20th centuries, the conservationist doctrine emerged, framing natural resources as finite and essential to human welfare. Conservationists emphasized the biological and ecological constraints of the economic process and called for resource-saving strategies, such as preserving renewable capacities, substituting minerals with renewables, and recycling exhaustible inputs [6]. This laid the groundwork for the idea that managing natural resources wisely is not optional, but central to sustainable economic growth.

Neoclassical Economics and the Rise of Substitution Thinking

Early neoclassical economists, including Jevons, Marshall, and Solow, shifted focus from nature to capital, labor, and technology as the primary factors of production. Jevons, however, warned about the limits of substitution, particularly in the case of coal scarcity [6]. Marshall recognized diminishing returns on land but believed institutional reforms and knowledge diffusion could counteract these effects [7].

Solow's (1956) neoclassical growth model largely treated natural resources as intermediate inputs, downplaying their strategic role [8]. This model assumed that technological progress could indefinitely substitute for natural capital, a view that came under increasing scrutiny during the energy and environmental crises of the 1970s.

In response, economists like Dasgupta, Heal, Solow (1974), and Stiglitz introduced modified growth models that explicitly incorporated exhaustible resources as inputs [9–13]. These models—collectively known as the DHSS framework—argued that sustainability could be maintained if societies reinvested resource rents into other forms of productive capital (as per the Hartwick Rule [14]). These ideas formed the foundation of "weak sustainability", which assumes substitutability between natural and man-made capital.

Yet, critiques emerged. Scholars noted that manufactured capital itself relies on natural resources, and that assuming perfect substitutability overlooks thermodynamic constraints and resource quality decline [9].

2.1.3. Biophysical and Ecological Economic Critiques

The late 20th century saw a paradigm shift toward biophysical and ecological economics, which challenged neoclassical assumptions. Drawing from thermodynamics, Nicholas Georgescu-Roegen (1979) argued that increasing capital (K) inevitably requires increasing resource (R) inputs, refuting the neoclassical notion that natural capital can be diminished to near-zero without affecting output [15]. His critique targeted the oversimplified Cobb-Douglas production function and its unrealistic substitution assumptions.

Building on these ideas, Daly, Costanza, and others institutionalized ecological economics, which treats the economy as a subsystem embedded in the finite biosphere [16]. This school introduced the concepts of:

- Strong Sustainability, which insists that some forms of natural capital are non-substitutable.
- Critical Natural Capital (CNC), whose loss would be irreversible and extremely harmful to human well-being [17].

These frameworks emphasize that economic growth must respect planetary boundaries, especially when relying on non-renewable resources like fossil fuels and natural gas.

2.1.4. Synthesis and Relevance to This Study

Across these theoretical strands, a key insight emerges: natural resources, particularly energy, are not merely auxiliary inputs but potentially binding constraints or enablers of economic growth, depending on how they are managed. While classical and neoclassical models offer mechanisms for overcoming resource limits through capital deepening and technological innovation, ecological economics urges caution, especially where exhaustible resources like natural gas dominate.

This theoretical foundation supports the need to empirically assess whether Egypt's heavy reliance on natural gas is a driver, a consequence, or independent of economic growth. The next section turns to empirical literature to explore how these theoretical views manifest in real-world data.

2.2. Empirical Literature

Before the 1980s, the dominant belief was that natural resource abundance was beneficial for economic growth, as resource wealth could support various sectors of the economy and enhance overall production. However, this assumption was increasingly questioned after the 1980s, as emerging studies began to highlight a negative relationship between natural resource abundance and economic performance. This phenomenon, known as the "resource curse" hypothesis, has become a well-established concept in the literature [18].

There are several explanations for this negative relationship. One is based on the Dutch Disease theory, which refers to the economic challenges faced by the Netherlands following the discovery of significant natural gas reserves in the 1950s. The boom in the resource sector led to a decline in manufacturing, demonstrating how resource wealth can distort economic structure [19]. Another explanation emphasizes institutional quality. In cases where natural resources are exploited by rent-seeking elites, poor governance and mismanagement tend to follow, leading to negative consequences for long-term economic growth [18]. Because the link between natural resources and growth varies across countries, it is essential to investigate this relationship to inform effective energy policy design.

In the literature, the economic relevance of different energy sources is typically assessed through the causal relationship between energy consumption and national income. Researchers use either a bivariate or multivariate methodological approach to analyze this relationship. The multivariate approach is generally preferred, as it helps to address the omitted variable bias inherent in the bivariate model [20].

The multivariate method consists of two main analytical perspectives. The supply-side approach examines how energy consumption contributes to economic output within traditional production functions, particularly the Cobb-Douglas framework. The demand-side approach, on the other hand, explores the relationship between energy consumption, economic growth, and energy prices [21–23].

Empirical studies have identified various types of relationships between energy consumption and economic growth as showed in **Table 1**. The growth hypothesis posits that energy consumption plays a direct role in driving economic growth or complements other inputs like labor and capital. In such cases, energy conservation policies may hinder growth, especially if the causality runs from energy use to economic expansion. This hypothesis has been supported by researchers such as Lee (2005), Oh and Lee (2004), Chang (2010), Isik (2010), Yang (2000), and Narayan and Popp (2012) [24–29].

The conservation hypothesis suggests a unidirectional causality from economic growth to energy consumption, indicating that implementing energy-saving measures would not negatively impact growth. Studies by Lee (2005), Yang (2000), Narayan and Popp (2012), and Sharaf (2016) support this perspective [24,28–30].

The neutrality hypothesis asserts that there is no significant causal link between energy consumption and economic growth, implying that changes in energy use have little or no effect on GDP. This view is reflected in the findings of Narayan and Popp (2012) and Sharaf (2016) [29,30].

The feedback hypothesis proposes a bidirectional relationship between energy consumption and economic growth, meaning the two variables influence each other. This conclusion is supported by studies such as those by Apergis and Payne (2010), Erdal et al. (2008), Oh and Lee (2004), Chang (2010), Yang (2000), and Zhang and Yang (2013) [20,25,26,31,32].

Lastly, some studies found a negative causal link from energy consumption to economic growth. This has been attributed to factors such as structural shifts towards less energy-intensive sectors, inefficient energy use in low-productivity industries, poor institutional quality, or the adverse spillover effects of resource booms on other economic sectors. Such conclusions were drawn by Narayan and Popp (2012) and Zhang and Yang (2013) [29,32].

Table 1. Results of the previous studies on the causality between energy consumption and economic growth.

Author	Countries	Period	Methodology	Variables	Causality
Yang (2000) [28]	Taiwan	1954–1997	Standard granger causality test	GDP, aggregate energy, Coal, oil, gas and electricity	EC ←→ Y NC → Y OC ← Y
Oha and Leeb (2004) [25]	Korea	1970–1999	Cointegration, VECM and Granger causality	GDP, capital, labour and energy consumption	EC ←→ Y in the long run EC → Y in the short run
Lee (2005) [24]	18 developing countries	1975–2001	(FMOLS) and VECM	GDP, energy consumption and capital	EC → Y except for Hungary
Erdal et al (2008) [31]	Turkey	1970–2006	Johnson cointegration and Granger causality	GNP and energy consumption	EC ←→ Y

Table 1. *Cont.*

Author	Countries	Period	Methodology	Variables	Causality
Apergis and Payne (2010) [20]	67 countries	1992–2005	FMOLS and VECM	Real GDP, capital, labour force and natural gas consumption	EC ←→ Y
Chang (2010) [26]	China	1981–2006	Cointegration, VECM and Granger causality	GDP, CO2, oil, NG, Coal Electricity consumption	OC ← Y Coal.C ← Y Elec.C → Y NC → Y
Isik (2010) [27]	Turkey	1977–2008	ARDL	economic growth rate and Natural gas consumption	NC → Y
Narayan and Popp (2012) [29]	93 countries	1980–2006	Panel cointegration, VECM and granger causality test	real GDP and energy consumption	The study found mixed results regarding the impact of energy consumption on real GDP, though the evidence at the individual country level more strongly supports a negative causal relationship between energy use and economic growth
Zhang and Yang (2013) [32]	China	1978–2009	VAR and Toda Yamamoto granger causality test	Real GDP, gross fixed capital formation, employed labour force, energy consumption, Coal, oil and gas consumption	EC ←→Y and Coal.c ←→Y (negative) OC←→Y NC←→Y
Apergis & Payne (2009) [22]	6 Central American countries	1980–2004	Panel cointegration and Error Correction Model	GDP, energy consumption, labor force, gross fixed capital formation	EC → Y (in both short and long run)
Apergis and Payne (2009) [23]	11countries of the Common-wealth of Independent States	1991–2005	FMOLS and VECM	GDP, energy consumption, real gross fixed capital formation and labour force	EC → Y
Sharaf (2016) [30]	Egypt	1980–2012	Var analysis, today yamamoto granger causality test	GDP, capital, labour and energy consumption	EC— Y.

EC, OC, NC, Elec.C, coal.C, Nuclear.c and Y refer to energy consumption, oil consumption, natural gas consumption, electricity consumption, coal consumption, nuclear energy consumption and real GDP. EC→ Y indicates a unidirectional causality from energy consumption to economic growth, while EC ← Y indicates that causality runs from economic growth to energy consumption. EC ←→ Y indicates a two-way causality, and EC— Y indicates no causality. VECM refers to Error Correction Model, ARDL refers to Auto Regressive Distributed Lag model, FMOLS refers to fully modified ordinary least squares, DOLS refers to dynamic ordinary least squares.

These different results are mainly due to different econometric approaches, different time periods and different countries.

Conceptual Framework

This study adopts a conceptual framework that integrates key economic theories with a practical empirical model to investigate the relationship between natural gas consumption and economic growth in Egypt. The framework is grounded in four theoretical schools—classical, neoclassical, conservationist, and ecological/biophysical economics—which collectively inform the roles of natural resources, capital, labor, and technology in the growth process.

Economic growth (Y) is conceptualized as a function of capital (K), labor (L), technology (T), and natural gas consumption (E). These core variables are selected based on both theoretical justification and data availability. Capital and labor are standard in growth models, technology is proxied by a time trend reflecting the influence of innovation, and natural gas is isolated as a distinct energy input due to its central role in Egypt's energy mix and its environmental and economic policy relevance. Unlike many prior studies that rely on total energy use, this study focuses on natural gas specifically to reflect Egypt's structural reliance and policy context.

While the conceptual model also recognizes the importance of mediating factors—such as institutional frameworks, substitutability, and environmental constraints—these are not explicitly included in the empirical analysis due to data limitations and methodological considerations. Many of these factors are either qualitative (e.g., regulatory quality) or conceptual (e.g., elasticity of substitution), making them difficult to quantify reliably over the 1988–2018 period. Moreover, adding imprecise proxies could compromise the integrity of the time-series analysis. Instead, their influence is accounted for indirectly through interpretation of the results within the theoretical and policy context.

This theoretical foundation guided the empirical strategy, which employs an ARDL bounds testing approach and VECM Granger causality analysis to explore both short-run dynamics and long-run equilibrium relationships. This dual structure allows the study to determine whether gas consumption acts as a driver of growth, a consequence of it, or is neutral—thereby contributing to the ongoing debate in the energy-growth literature.

Finally, the limitations in incorporating mediating variables present a clear avenue for future research. Upcoming studies could seek to integrate policy indices, institutional quality metrics, or environmental performance indicators into the empirical model. Techniques such as structural equation modelling (SEM) or extended ARDL models with interaction terms could allow for deeper analysis of how institutional and environmental factors condition the energy-growth relationship in Egypt and similar economies.

All of these relationships are illustrated in **Figure 1**, which maps out how theory, core inputs, and contextual factors come together to shape the energy-growth relationship examined in this study.

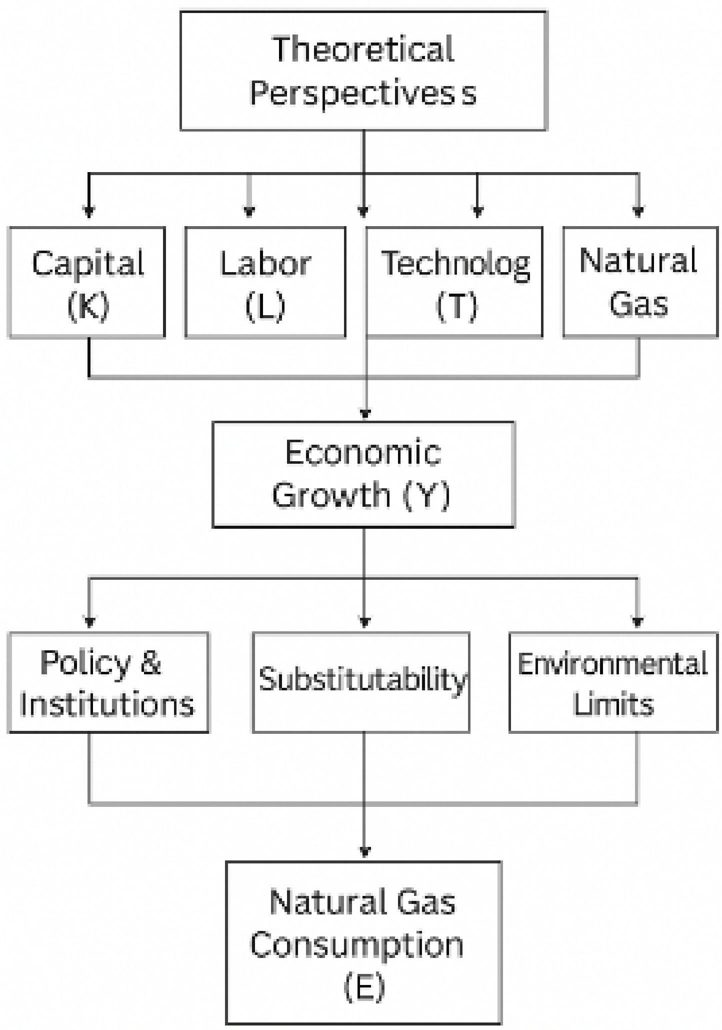

Figure 1. Conceptual framework.

3. Data, Model and Estimation Procedures

To support the empirical analysis conducted in this study, it is essential to first understand the trends in natural gas consumption in Egypt over the past three decades. Egypt is the largest consumer of natural gas in Africa, with domestic consumption reaching 59.6 billion cubic meters (BCM) in 2018. This represents a substantial increase from 6.66 BCM in 1988—an overall growth of approximately 795% over 30 years.

As shown in **Figure 2**, consumption rose steadily between 1988 and 1998, growing by 98% to reach 13.19 BCM. A more pronounced increase occurred from 1998 to 2012, with consumption surging to 50.64 BCM, marking a growth of over 280%. Between 2013 and 2015, a slight decline was observed, largely due to political instability and economic uncertainty. However, consumption rebounded in the following years, reaching 59.6 BCM in 2018.

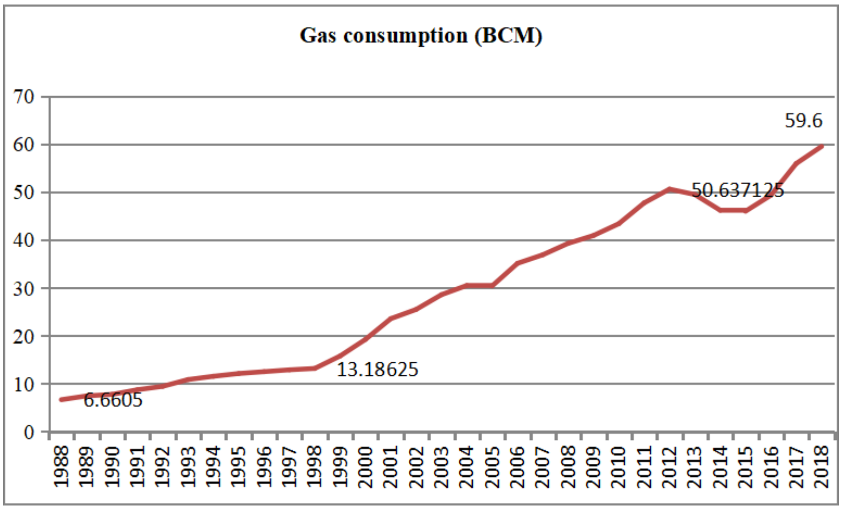

Figure 2. Consumption of natural gas in Egypt (1988–2018).
Source: constructed by the author based on data from British Petroleum Statistical Review of World Energy, 2019 [3].

Natural gas plays a vital role in Egypt's energy landscape. It is the primary source of energy used across four key sectors: electricity generation, industry, petroleum, and residential use. According to **Figure 3**, in FY 2018/2019, the electricity sector was the dominant consumer, accounting for 62% of total gas use, followed by the industrial sector (23%), while the petroleum and residential sectors made up the remaining 15% [4]. Gas is favored in power generation due to its efficiency and lower emissions, while in industry, it is used both as a fuel and as a feedstock for producing chemicals, fertilizers, plastics, and steel. In the residential sector, it serves heating and cooking purposes.

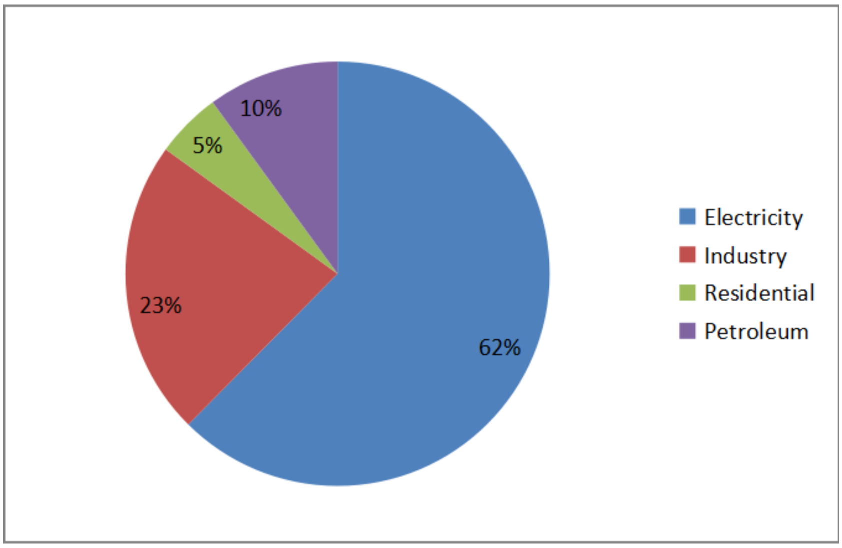

Figure 3. Natural gas consumption by four sectors in the economy in the FY 2018/2019.
Source: Constructed by the author based on data from EGAS annual 2018/2019 report [3].

The consistent rise in gas consumption can be attributed to several factors: government policies in the 1990s promoting gas as a substitute for petroleum products; mandated domestic sales at subsidized prices; increasing economic activity; population growth; and energy subsidies. Conversely, the temporary decline in consumption during 2013–2015 can be linked to the aftermath of the 2011 revolution and subsequent reductions in government energy subsidies.

To further explore the connection between energy use and economic activity, **Figure 4** presents a scatter plot showing the relationship between natural gas consumption and real GDP in Egypt from 1988 to 2018. The observed positive correlation suggests the relevance of testing for causality between these variables, forming the basis for the methodological approach adopted in this study.

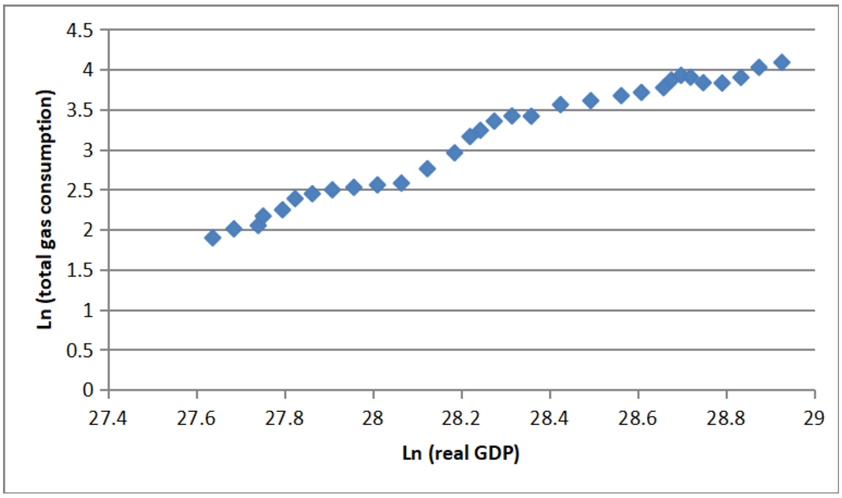

Figure 4. The relationship between the domestic gas consumption and real GDP in Egypt (1988–2018).
Source: Constructed by the author based on data from British Petroleum Statistical Review of World Energy, 2019 and World Bank, 2019 [4].

3.1. Data

It is apparent from the previous tracing of economic growth theories by classical, biophysical and ecological economists in Section One that the most important variables affecting growth are capital, labour, knowledge and natural resources. Hence, the Cobb-Douglas production function is used for assessing the relationship between the two concerned variables by adding labour and capital to the conventional natural gas growth nexus bivariate frame work perspective.

Gas consumption data were obtained from BP statistical review of world energy, 2019. The values are expressed in billion cubic meters. Gross domestic product, Gross fixed capital formation and labour data are obtained from the World Bank noting that Labour force data for 1988 and 1989 were obtained from Radwan (2002) and the IMF, respectively [33]. The Gross domestic product and Gross fixed capital formation are expressed in constant LCU. Labour is expressed in persons.

3.2. The Basic Supply Side Model

The gas and economic growth nexus will be examined using the supply side model. The cobb-Douglas production function is utilized for assessing the relationship between the two concerned variables by adding labour and capital to the conventional natural gas growth nexus bivariate frame work perspective [34]. The multivariate production function can be expressed in the following form:

$$Y = AE^{\propto 1}K^{\propto 2}L^{\propto 3}e^{u} \tag{1}$$

In this model, Y represents real GDP, while E, K, and L correspond to energy consumption, real capital, and labor, respectively. The technological factor is denoted by A, and eee stands for the normally distributed error term. The parameters α1, α2, and α3 reflect the output elasticities associated with energy, capital, and labor. For empirical analysis, the non-linear Cobb-Douglas production function is transformed into a linear form by applying logarithms, as this log-linear transformation yields consistent and efficient estimators. The model transformation is as follows:

$$\ln Y_t = \ln A + \alpha_1 \ln E_t + \alpha_2 \ln K_t + \alpha_3 \ln L_t + U_t \quad (2)$$

$$\ln Y_t = a + \alpha_1 \ln E_t + \alpha_2 \ln K_t + \alpha_3 \ln L_t + U_t \quad (3)$$

Where $\ln Y_t$, $\ln E_t$, $\ln K_t$ and $\ln L_t$ are the natural logarithms of real gross domestic product, Gas consumption, real gross capital formation and labour force, respectively. u_t is the error term.

In the literature, Heidari, Katircioglu et al. (2013), Oh and Lee (2004), Apergis and Payne (2009), Zhi-Guo, Cheng et al. (2018) used Equation 3 in their studies to investigate the relationship between natural gas consumption and economic growth [22,25,35,36]. Accordingly, we have adopted Equation 3.

3.3. Estimation Procedures

In our attempt to investigate the impact of the natural gas on economic growth, stationarity of each variable in the model is investigated to assess the order of integration for each one. If the variables are stationary, the usual OLS regression may be suitable in this case. But if the variables are not stationary, the usual regression will not be suitable since the regression of a non-stationary variable on another non-stationary one may result in a spurious regression. This gives incorrect estimation results. One way of solving this problem is to differ each series consecutively to be stationary. Although the problem is resolved, the model in this case reflects only the short run relationship between the variables and can no longer provide a unique long run equilibrium solution [37].

The concept of cointegration allows for meaningful regression analysis using non-stationary time series data. When individual variables are non-stationary, a stationary linear combination of them may still exist, indicating that the variables are cointegrated. In such cases, standard econometric practice involves estimating the model using either a Vector Autoregressive (VAR) model or a Vector Error Correction Model (VECM), depending on whether cointegration is present, to analyze short-run dynamics [34].

In this context, the Johansen cointegration technique (1988) requires all variables to be integrated of the same order, typically I(1). However, this assumption can be restrictive when variables have mixed orders of integration. To address this limitation, Pesaran et al. introduced the Autoregressive Distributed Lag (ARDL) model for cointegration testing, which does not require prior classification of variables as I(0) or I(1) [27].

This study adopts the ARDL bounds testing approach for several reasons. First, unlike other multivariate cointegration methods such as the Engle-Granger and Johansen techniques, the ARDL bounds test is more straightforward, as it allows the estimation of cointegrating relationships using Ordinary Least Squares (OLS) once the appropriate lag length is determined [27]. Second, it yields consistent and asymptotically normal estimates of long-run coefficients, regardless of whether the variables are stationary, non-stationary, or fractionally integrated. This feature removes the uncertainty related to pre-testing for the order of integration. Additionally, the method generates unbiased long-run coefficient estimates and reliable t-statistics, even in the presence of endogenous regressors. Third, the ARDL method is particularly effective in small or limited sample sizes [35].

Therefore, the ARDL bounds testing method is employed in this study to explore both the long-run relationships and short-run dynamics among the selected variables.

A two variable ARDL model of order (p) can be represented by equation 4:

$$\Delta y_t = \mu + \sum_{j=1}^{p} c_j \Delta y_{t-j} + \sum_{j=1}^{p} d_j \Delta x_{t-j} + \alpha_1 y_{t-1} + \alpha_2 x_{t-1} + \xi t \quad (4)$$

Where μ is the intercept and ξ t is the white noise error term. The long run effects are inferred by the sign and significance of α_1 and α_2, whereas the short run dynamics are captured by c_j and d_j. p is the number of lags selected to minimize some known information criteria.

The ARDL bound testing approach involves two steps. First, the existence of a long run relationship is tested by estimating equation (4) using ordinary least squares (OLS) method where each variable is taken as a dependent variable once to investigate the cointegration between the underlying variables in the model. A Wald test is conducted for the joint significance of the coefficients of the lagged levels in included variables, with the null hypothesis of the absence of cointegration, defined by ho: $\alpha_1 = \alpha_2 = 0$, which indicates the absence of a long run relationship between the variables against the alternative of the presence of cointegration.

Pesaran et al. (2001) provided the critical values for the F-statistic used in the bounds testing procedure, tailored to various numbers of independent variables and model specifications. The ARDL framework includes five model forms, each differing based on the inclusion of deterministic elements like the intercept and trend: (i) a model with no intercept and no trend, (ii) a model with a restricted intercept but no trend, (iii) a model with an unrestricted intercept and no trend, (iv) a model with an unrestricted intercept and a restricted trend, and (v) a model with both an unrestricted intercept and trend. Among these, the last three configurations are considered more suitable for economic modelling and real-world data characteristics [38].

For each model specification, two critical bounds are presented: the upper bound assumes that all variables are integrated of order one (I(1)), while the lower bound assumes they are stationary (I(0)). If the computed F-statistic exceeds the upper bound, it indicates that a long-run relationship exists, leading to the rejection of the null hypothesis of no cointegration. If the F-statistic is below the lower bound, the null hypothesis cannot be rejected. However, if the F-statistic falls between the two bounds, the result is considered inconclusive [39].

However, Narayan (2005) noted that the critical values provided by Pesaran et al. are based on large samples and may not be appropriate for small samples. To address this, Narayan developed alternative critical values specifically for smaller samples, ranging from 30 to 80 observations [40].

To compute the F-statistics in the ARDL bounds testing procedure, each variable is alternately treated as the dependent variable using the formulation presented in Equation 4.

If the variables turn out to be cointegrated, the next step is to estimate an error correction representation of the ARDL model so as to determine the speed of adjustment for restoring the long run equilibrium.

The ECM version of the ARDL model can be written as follows:

$$\Delta y_t = \mu + \sum_{j=1}^{p} c_j \Delta y_{t-j} + \sum_{j=1}^{p} d_j \Delta x_{t-j} + \alpha_1 y_{t-1} + \beta e\hat{}t - 1 + \xi t \tag{5}$$

where the c_j and d_j are the short run coefficients, e_{t-1} is the lagged error term that is computed using the coefficient estimates obtained from the ARDL model by estimating Equation (6).

$$e\hat{}_{t-1} = y_{t-1} - \mu\hat{} - \alpha_2\hat{}x_{t-1} \tag{6}$$

And β is the coefficient of the error correction term that shows the speed of adjustment toward the long run equilibrium. A significant negative value for this coefficient indicates that the variables actually converge to equilibrium and reinforce the presence of a long run relationship among the variables [41]. If the variables are not cointegrated, the VAR model is chosen as it is considered a means for dealing with non-stationary time-series, in the absence of cointegration.

When the variables are found to be non-stationary but exhibit a long-run relationship, the next step is to assess causality using the Vector Error Correction Model (VECM) based Granger causality approach. Unlike the traditional Granger causality test, this method incorporates the lagged error correction term derived from the cointegration equation. Including this term reintroduces the long-term dynamics that are otherwise lost when the data are differenced, and does so in a statistically valid manner. Causality is determined by examining the significance of the coefficient on the lagged error correction term (which indicates long-run causality) and the joint significance of the lagged differences of the explanatory variables using the Wald test [39].

However, if no cointegration exists among the variables, a standard Vector Autoregressive (VAR) model is used instead. In this case, causality is assessed solely through the joint significance of the lagged differences of the independent variables in each equation of the VAR model, also using the Wald test [39,42].

In addition, the forecast error variance decomposition allows for the assessment of how much of the variation in a specific time series is attributable to its own past disturbances compared to shocks originating from other variables [43]. Causality methods can only test causality within sample period, but variance decomposition analysis can be considered an out of sample causality test [44]. In addition, the Granger-causality tests presented above refer only to the existence of causality between the dependent variable and the concerned independent variable. They do not offer any insight into the magnitude or significance of the causal effect that the independent variable exerts on the dependent variable. Hence, the generalized forecast error variance decomposition analysis is applied to provide an indication of how important the causal relationship between the dependent variable and the concerned independent variable is and to assess how each variable responds to innovations in other variables [45].

4. Empirical Results

4.1. Stationarity Tests

Stationarity refers to a condition where a time series maintains a constant mean and variance over time, and its auto-covariance remains stable and does not vary with time. Testing for stationarity is essential in order to correctly specify and estimate the appropriate econometric model, as an incorrect model selection can result in biased outcomes and misleading interpretations [27]. In this study, two unit root tests—the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests—are employed to assess the stationarity of the variables.

Table 2 displays the results of the ADF test for the sample (1988–2018). Schwartz information criterion was applied to determine the lag length of the ADF regressions. Under the results of the ADF test, the results indicate that only the time series of KS and LS are stationary at level. However, all the time series have become stationary at the first difference.

Table 2. ADF results.

Variable	Level Series			First Difference Series			Decision
	Deterministic term	p-value	Lag	Deterministic term	p-value	lag	
Ln Y_t	Trend and intercept	0.1860	1	Intercept	0.0118	2	I(1)*
Ln K_t	Trend and intercept	0.1478	0	None	0.0001	0	I(1)*
Ln L_t	Trend and intercept	0.4971	0	Intercept	0.0017	0	I(1)*
Ln GC_t	None	0.9861	1	Intercept	0.0202	0	I(1)*

Note: *denotes significance at 5 percent level.

The Phillips Perron test is also applied to confirm the results of the ADF test. The results of the PP test are reported in **Table 3**. According to the PP test, not all the variables are stationary (integrated of order one).

Table 3. PP results.

Variable	Level Series		First Difference Series		Decision
	Deterministic term	p-value	Deterministic term	P value	
Ln Y_t	None	1.000	Intercept	0.0368	I(1)*
Ln K_t	Trend and intercept	0.1270	None	0.0005	I(1)*
Ln L_t	Trend and intercept	0.3932	Intercept	0.0017	I(1)*
Ln GC_t	Intercept	0.5187	Intercept	0.0248	I(1)*

Note: *denotes significance at 5 percent level.

4.2. Cointegration Analysis

Based on the results of the unit root tests, there is evidence that none of the series has been integrated of order 2. Hence, the ARDL bounds test can be applied to test the cointegration relationship between the four variables.

The first step is to run the unrestricted error correction model (UECM) in order to test the cointegration. Hence, the UECMs represented in Equations 7, 8, 9 and 10 which are estimated by Ordinary Least Squares method where each variable in the model works as a dependent variable once to investigate the existence of a long run relationship between the variables. The equations are compressed as follows: F(Y/x1,x2,x3); where Y is the dependent variable, and x1, x2 and x3 are the explanatory variables, respectively.

$$\Delta Lny_t = \mu + bT + \sum_{j=1}^{p} a_j \Delta Lny_{t-j} + \sum_{j=1}^{p} b_j \Delta LnK_{t-j} + \sum_{j=1}^{p} c_j \Delta LnL_{t-j} + \sum_{j=1}^{p} d_j \Delta LnGC_{t-j} + \alpha_1 Lny_{t-1} + \alpha_2 LnK_{t-1} + \alpha_3 LnL_{t-1} + \alpha_4 LnGC_{t-1} + \xi t \quad (7)$$

$$\Delta LnK_t = \mu + bT + \sum_{j=1}^{p} e_j \Delta Lny_{t-j} + \sum_{j=1}^{p} f_j \Delta LnK_{t-j} + \sum_{j=1}^{p} g_j \Delta LnL_{t-j} + \sum_{j=1}^{p} h_j \Delta LnGC_{t-j} + \alpha_1 Lny_{t-1} + \alpha_2 LnK_{t-1} + \alpha_3 LnL_{t-1} + \alpha_4 LnGC_{t-1} + \xi t \quad (8)$$

$$\Delta LnL_t = \mu + bT + \sum_{j=1}^{p} I_j \Delta Lny_{t-j} + \sum_{j=1}^{p} J_j \Delta LnK_{t-j} + \sum_{j=1}^{p} K_j \Delta LnL_{t-j} + \sum_{j=1}^{p} L_j \Delta LnGC_{t-j} + \alpha_1 Lny_{t-1} + \alpha_2 LnK_{t-1} + \alpha_3 LnL_{t-1} + \alpha_4 LnGC_{t-1} + \xi t \tag{9}$$

$$\Delta LnGC_t = \mu + bT + \sum_{j=1}^{p} M_j \Delta Lny_{t-j} + \sum_{j=1}^{p} N_j \Delta LnK_{t-j} + \sum_{j=1}^{p} O_j \Delta LnL_{t-j} + \sum_{j=1}^{p} P_j \Delta LnGC_{t-j} + \alpha_1 Lny_{t-1} + \alpha_2 LnK_{t-1} + \alpha_3 LnL_{t-1} + \alpha_4 LnGC_{t-1} + \xi t \tag{10}$$

Table 4 shows the results of examining the cointegration relationship between the four variables included in this study in Egypt. The null hypothesis of no cointegration is rejected when the UECM is normalized on Y,K and L, but it is rejected when the UECM is normalized on GC.

Table 4. Results of bounds testing for cointegration.

Equation	F-Statistic Calculated	Decision
F(Y/K,L,GC)	5.331207**	Cointegration
F(K/Y,L,GC)	5.337122**	Cointegration
F(L/Y,K,GC)	5.297445**	Cointegration
F(GC/Y,K,L)	3.432676*	No cointegration
Lower critical values:	Upper critical values:	
At 1%: 5.333	At 1%: 7.063	
At 5%: 3.71	At 5%: 5.018	
At 10%: 3.008	At 10%: 4.15	

Note: *denotes significance at 1 percent level and ** denotes significance at 5 percent level.

The ARDL bounds testing approach confirms the presence of a long-run cointegrating relationship among real GDP, capital, labor, and natural gas consumption in Egypt. This implies that, over time, these variables tend to move together, indicating a stable long-run association. However, cointegration was not established for all model specifications. Specifically, for equation (9), the null hypothesis of no cointegration could not be rejected. Therefore, an unrestricted Vector Autoregressive (VAR) model is employed for that specification, enabling the examination of short-run causal relationships through Granger causality testing, rather than including an error-correction term.

Table 5 presents the estimated long-run coefficients based on the ARDL model when real GDP is used as the dependent variable. The results indicate that capital is the only variable with a statistically significant long-run impact on economic growth at the 5% level. A 1% increase in capital stock is associated with a 0.08% increase in GDP, consistent with theoretical expectations and the growth literature. In contrast, both natural gas consumption and labor are statistically insignificant in explaining long-term variations in GDP. This outcome may reflect Egypt's increasing reliance on renewable energy sources, such as solar, wind, hydro, and biomass, which are gradually displacing fossil fuels like natural gas. Moreover, recent energy reforms and subsidy restructuring may have weakened the direct growth dependence on gas consumption.

When capital is the dependent variable, the ARDL model reveals that economic growth exerts a significant and positive long-run effect. A 1% rise in GDP leads to a 4.6% increase in capital accumulation, suggesting that rising economic activity stimulates investment and capital formation. However, natural gas consumption remains insignificant in this equation, implying that capital availability does not directly influence gas use. This may reflect the sector-specific nature of energy consumption, where capital investments are not necessarily directed toward gas-intensive production.

In contrast, the model where labor is the dependent variable yields a noteworthy result: natural gas consumption has a statistically significant and positive effect on labor. Specifically, a 1% increase in gas consumption leads to a 0.05% increase in labor input. This finding suggests that gas expansion may be associated with increased labor demand, possibly due to job creation in gas-intensive sectors such as manufacturing, petrochemicals, and power generation. It also reflects the labor-absorbing nature of energy infrastructure development in Egypt.

Overall, the results reveal a nuanced relationship: while capital plays a central role in long-run economic growth, natural gas consumption does not exert a direct effect on output growth in the long term—possibly due to ongoing energy transition strategies. However, its influence on labor suggests that energy policy still holds implications for employment, particularly in the short-to-medium term. These findings underscore the importance of aligning energy investment with broader development goals, including labor market participation and green growth.

Table 5. Long run coefficients using the ARDL-bounds model.

Dependent Variable	Regressors	Coefficient	ARDLlag (AIC)	Standard Error	T-Ratio (Prob)
Ln Y	Ln K Ln L Ln GC	0.081566 0.127855 0.011398	(1, 0,0,0)	0.018142 0.109439 0.018432	4.495899(0.0001) 1.168273(0.2537) 0.618399(0.5419)
Ln K	Ln Y Ln L Ln GC	4.684781 −0.446595 −0.040516	(1, 1, 0, 0)	1.108464 0.812402 0.135069	4.226371(0.0003) −0.549722(0.5876) −0.299963(0.7668)
Ln L	Ln Y Ln K Ln GC	0.134706 −0.023366 0.050626	(1, 0, 0, 0)	0.090653 0.022630 0.020425	1.485961(0.1498) −1.032518(0.3117) 2.478640(0.0203)

4.3. Error Correction Model

Table 6 presents the short-run coefficient estimates obtained through the Error Correction Model (ECM) derived from the ARDL approach. These estimates provide important insights into the short-term dynamics among real GDP, capital, labor, and natural gas consumption in the Egyptian economy, while also shedding light on the system's adjustment behavior toward its long-run equilibrium.

When real GDP is specified as the dependent variable, natural gas consumption is found to be statistically insignificant at the 5% level. This result suggests that, in the short run, gas consumption does not make a measurable contribution to Egypt's economic growth. One potential explanation lies in the government's active pursuit of energy diversification, particularly its substantial investment in renewable energy sources such as solar, wind, and hydropower. These structural changes in the country's energy strategy may have reduced the short-term dependence on natural gas in the production process. Furthermore, the error correction term carries the expected negative sign, indicating a theoretically correct adjustment direction, but it is not statistically significant. This suggests that any deviations of GDP from its long-run path are not quickly corrected in the short term, possibly due to institutional lags or inertia in energy reallocation.

In the ECM model where capital is treated as the dependent variable, real GDP exhibits a statistically significant and positive short-run effect, consistent with economic theory which posits that economic expansion stimulates capital accumulation. In contrast, both labor and natural gas consumption remain statistically insignificant in explaining short-term variations in capital. The error correction term in this model is correctly signed and statistically significant, indicating that the model exhibits a meaningful speed of adjustment. This implies that short-term shocks to capital tend to converge back to their long-run path, reinforcing the validity of the long-run cointegration relationship previously established.

When labor is the dependent variable, the short-run dynamics reveal a statistically significant and negative relationship between capital and labor. This inverse relationship implies that increases in capital may be associated with short-term reductions in labor demand, possibly due to capital-labor substitution effects in response to investment in automation or more efficient technologies. However, both real GDP and gas consumption do not exhibit significant short-run effects on labor. The error correction term in this model is again negative and statistically significant, confirming the existence of a stable adjustment process in which the labor market gradually returns to its long-run equilibrium following short-term disturbances. The magnitude of this term also reflects the speed of correction, with a smaller coefficient indicating a slower adjustment toward equilibrium [46,47].

Overall, these short-run results highlight important structural features of Egypt's economy. The lack of significance of natural gas consumption in the short-term equations for GDP, capital, and labor suggests that the influence of gas may be more medium- to long-term in nature, or is currently being moderated by policy shifts favoring renewable energy sources. At the same time, the short-run responsiveness of capital to GDP, and the negative capital–labor relationship, underscore the dynamic nature of internal factor allocation and investment. The significance of the error correction terms in two of the three models supports the validity of the long-run relationships and confirms the robustness of the error correction mechanism in re-aligning the variables after shocks.

Table 6. The short run estimates using the ECM model.

Dependent Variable	Regressors	Coefficients	Standard Error	T-Ratio (Prob)
Ln Y	Constant	0.017450	0.012906	1.352142(0.1895)
	D(LN_CAPITAL(-1))	0.008219	0.025355	0.324176 (0.7487)
	D(LN_GDP(-1))	0.483238	0.288381	1.675694(0.1073)
	D(LN_LABOUR(-1))	0.308642	0.162190	1.902966(0.0696)
	D(LGC_BCM_(-1))	−0.037530	0.042531	−0.882427(0.3867)
	CointEq(-1)	−0.075728	0.356119	−0.212647(0.8335)
Ln K	Constant	0.114125	0.067308	1.695564(0.1072)
	D(LN_CAPITAL(-1))	1.539688	0.334547	4.602304(0.0002)
	D(LN_CAPITAL(-2))	0.227429	0.176824	1.286189(0.2147)
	D(LN_GDP(-1))	−6.849652	2.006831	−3.413169(0.0031)
	D(LN_GDP(-2))	4.167912	1.633086	2.552169(0.0200)
	D(LN_LABOUR(-1))	1.282055	1.173924	1.092110(0.2892)
	D(LN_LABOUR(-2))	−1.584767	1.243316	−1.274629(0.2186)
	D(LGC_BCM_(-1))	−0.338040	0.334198	−1.011496(0.3252)
	D(LGC_BCM_(-2))	−0.084299	0.326952	−0.257832(0.7995)
	CointEq(-1)	−2.354682	0.456451	5.158677(0.0001)
Ln L	C	−0.005016	0.008255	−0.607630(0.5494)
	D(LN_LABOUR(-1))	0.992566	0.218636	4.539814(0.0001)
	D(LN_CAPITAL(-1))	−0.051530	0.020424	−2.522970(0.0190)
	D(LGC_BCM_(-1))	−0.050299	0.039419	−1.276013(0.2147)
	D(LN_GDP(-1))	0.275858	0.160938	1.714066(0.1000)
	CointEq(-1)	−1.333184	0.292179	−4.562895(0.0001)

The robustness of the previous models has been examined by the diagnostic tests such as Breush–Godfrey serial correlation LM test, Breusch-Pagan-Godfrey heteroskedasticity Test and the cumulative sum of recursive residuals (CUSUM) stability test. The results of these tests are reported in **Table A1** in the appendix, while the stability of the models based on the CUSUM test is also visually reflected in **Figures A1, A2** and **A3**.

4.4. Granger Causality Test

According to the results of the cointegration analysis, a stable long-run relationship exists among the variables in equations (6), (7), and (8), thereby justifying the use of the Vector Error Correction Model (VECM) Granger causality framework to assess the direction of causality between the variables involved. In contrast, equation (9), where gas consumption is specified as the dependent variable, does not exhibit evidence of cointegration, as the null hypothesis of no cointegration cannot be rejected. Consequently, an unrestricted Vector Autoregressive (VAR) model is applied in this case to test for short-run Granger causality between gas consumption and real gross domestic product.

The short-run causality results presented in **Table 7** indicate that economic growth Granger-causes gas consumption, providing empirical support for the conservation hypothesis in the short run. This implies that policies aimed at conserving or restricting natural gas use are unlikely to hinder economic growth, at least in the short run. In contrast, capital does not Granger-cause either GDP or gas consumption, suggesting that short-term changes in capital stock are not significant drivers of economic performance or energy demand. On the other hand, labor Granger-causes economic activity, reflecting its vital role in the productive capacity of the economy, but it does not Granger-cause gas consumption in the short run.

Regarding long-run causality, the coefficient of the lagged error correction term (ECT $_{t-1}$) in the VECM carries the correct negative sign, indicating the expected convergence behavior. However, the term is statistically insignificant, implying the absence of long-run causality between GDP and gas consumption in either direction. This finding supports the neutrality hypothesis in the long run, suggesting that economic growth and natural gas consumption evolve independently over time, without exerting significant long-term influence on one another.

These findings offer important policy implications. While economic growth appears to drive gas consumption in the short term, its long-run disconnection suggests that structural energy policies, such as transitioning to renewables or reforming subsidies, can proceed without threatening macroeconomic stability. Furthermore, the short-run causality from labor to GDP highlights the importance of labor market dynamics in driving output, underscoring the need for integrated energy and employment strategies.

Table 7. Granger causality test results.

Dependent Variable	Causal Flow	Coefficients	t-Statistic (prob)	ECM Coefficient	T-test on ECM (Prob)
D(Ln Y)	Ln K→ Ln Y Ln L→ Ln Y Ln GC→ Ln Y	0.007408 0.305048 −0.027532	0.302437(0.7650) 1.898594(0.0702) −0.595954(0.5570)	−0.048939	−0.542591(0.5926)
D(Ln K)	Ln Y→ Ln K Ln L→ Ln K Ln GC→ Ln K	0.690951 0.895690 −0.286195	0.397328(0.6948) 0.609389(0.5482) −0.677183(0.5050)	0.932840	1.130579(0.2699)
D(Ln L)	Ln Y→ Ln L Ln K→ Ln L Ln GC→ Ln L	0.273129 −0.037025 −0.037630	1.527294(0.1403) −1.606701(0.1218) −0.865822(0.3955)	0.301042	3.547934(0.0017)
D(Ln GC)	Ln Y→ Ln GC Ln K→ Ln GC Ln L→ Ln GC	1.618641 −0.083640 −0.130293	2.051007(0.0513) −0.830481(0.4145) −0.193982(0.8478)		

The robustness of the previous models have been examined by the diagnostic tests such as the normality test of Jarque-Bera, residual serial correlation LM test, Breusch-Pagan-Godfrey, Heteroskedasticity Test and the cumulative sum of recursive residuals stability test. It can be found that all models passed successfully the tests of normality, serial correlation, heteroskedasticity and stability as shown in **Table A2** and **Table A3** in the Appendix, while the stability of the models based on the CUSUM test is also visually reflected in **Figures A4, A5, A6** and **A7**.

5. Conclusions

This study represents one of the earliest comprehensive attempts to examine the causal relationship between natural gas consumption and economic growth in Egypt over the period 1988–2018, both in the short run and the long run. In addition to identifying the direction of causality, the study aimed to offer practical policy recommendations to ensure alignment between Egypt's energy strategy and its economic development goals.

To support this objective, a theoretical exploration of economic thought was undertaken to understand how different schools—ranging from physiocracy and classical economics to ecological and biophysical approaches—have viewed the role of natural resources in production and growth. While early classical thinkers emphasized the centrality of land and resource scarcity as constraints on growth, later neoclassical models introduced the idea of capital accumulation and technological progress as mechanisms for overcoming resource limitations. Conservationists and ecological economists, however, have challenged this substitution logic, arguing that the depletion of non-renewable energy resources, such as fossil fuels, poses fundamental long-term risks to sustainability. These theoretical debates informed the conceptual framework of the study and helped guide the selection of variables in the empirical analysis.

Using time-series econometric tools, the study tested for both long-run cointegration and short-run causal dynamics between real GDP, natural gas consumption, capital, and labor. The results indicated no significant long-run causality between natural gas consumption and economic growth, thereby supporting the neutrality hypothesis. This implies that, over the long term, changes in gas consumption do not drive GDP growth, nor does economic activity stimulate gas usage. In contrast, short-run analysis found unidirectional causality running from GDP to gas consumption, consistent with the conservation hypothesis. This suggests that increases in economic activity may trigger a temporary rise in gas consumption, but not vice versa.

Furthermore, the analysis confirmed that natural gas consumption and capital are not substitutes in either the short or long term. This finding is especially relevant in light of Egypt's ongoing energy transition, which involves reducing dependence on fossil fuels and increasing investment in renewable energy. The sectoral distribution of gas usage—particularly its concentration in electricity generation and industry—highlights the importance of considering sector-specific dynamics when formulating energy policy.

Policy Implications

The findings from this study carry several important implications for policymakers. The long-run neutrality between gas consumption and economic growth implies that energy conservation policies can be implemented without compromising economic performance. In the short run, where growth leads gas demand, conservation policies can still be pursued without harming output, suggesting a strategic window to implement energy-efficiency reforms.

Notably, given that natural gas consumption is heavily concentrated in the electricity (62%) and industrial (23%) sectors, targeted efficiency measures in these areas can deliver meaningful reductions in overall gas demand without negatively affecting productivity. Policies that improve thermal efficiency in power plants, encourage fuel-switching in heavy industries, and promote technology upgrades in energy-intensive sectors can help decouple gas use from output growth. In the residential and commercial sectors, behavioral awareness and appliance efficiency standards remain key levers. These sector-specific interventions can complement macro-level reforms to ensure energy security and economic resilience.

Accordingly, a comprehensive national energy conservation strategy should consider the following:

- Accelerate the implementation of government-led energy efficiency programs and promote public awareness of energy-saving behaviors.
- Incentivize private sector engagement through revised tax and pricing policies, and provide dedicated financing tools—such as grants or low-interest loans—for small and medium-sized enterprises adopting energy-efficient technologies.
- Establish clear institutional frameworks for managing, evaluating, and reporting national energy efficiency indicators (e.g., energy intensity metrics).
- Gradually phase out outdated, energy-intensive production technologies while promoting innovation, digitization, and high-efficiency industrial alternatives.
- Expand public investment in research and development of alternative fuels and clean energy technologies.
- Integrate energy education into public and vocational training systems by offering workshops, seminars, and awareness materials to a wide audience.
- Launch targeted national campaigns to promote energy conservation as a public responsibility.
- Reform the natural gas pricing system to reflect market conditions, reduce subsidies, and promote energy efficiency across all consuming sectors. Liberalizing the gas market would help curb overconsumption and attract new investments into more sustainable and efficient energy systems.

Future Research Directions

This study opens the door to several promising avenues for further investigation. Future research should explore the relationship between natural gas consumption and economic growth at the sectoral level, particularly in high-demand sectors such as electricity, industry, and transportation. Utilizing higher-frequency data (e.g., quarterly or monthly) would also allow for more detailed and responsive analysis of short-run dynamics. In addition, employing alternative methodological approaches—such as sector-specific demand-side models—could provide more precise insights for designing gas pricing regulations and sector-targeted energy policies. Such extensions would not only enrich the academic literature but also offer more actionable recommendations for policymakers navigating Egypt's evolving energy landscape.

Future research should also incorporate mediating variables that may influence the relationship between natural gas consumption and economic growth, such as energy pricing policies, subsidy structures, institutional quality, technological efficiency, and environmental regulations. While this study acknowledged their theoretical importance, limited data availability prevented their inclusion. However, future studies could adopt methods such as interaction terms, structural equation modelling, or panel data approaches to examine how these factors shape or condition the energy–growth nexus. Including such variables would enhance explanatory power and provide more nuanced insights for sector-specific and policy-relevant energy planning.

Author Contributions

Conceptualization, M.M. and D.M.I.; methodology, M.M.; software, M.M.; validation, M.M., O.H., and D.M.I.; formal analysis, M.M.; investigation, M.M.; resources, M.M.; data curation, M.M.; writing—original draft preparation, M.M.; writing—review and editing, M.M., O.H., and D.M.I.; visualization, M.M.; supervision, O.H. and D.M.I.; project administration, M.M. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. However, the data are not publicly shared due to privacy and confidentiality considerations.

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Not applicable.

Conflicts of Interest

The author declares no conflict of interest.

Appendix A

Table A1. Diagnostic tests of the ARDL-error correction models.

Dependent Variable	Diagnostic Test	Test Statistic	H0	Prob. Values/ Graph	Decision
Ln Y	Breusch Godfrey LM test for serial correlation	0.769079	H0: no serial correlation	0.3900	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	0.815874	H0: Constant variance	0.5507	There is no heteroscedasticity
	Normality test	2.576637	H0: residuals are normally distributed	0.275734	Residuals are normally distributed
	CUSUM test			CUSUM 1	
Ln K	Breusch Godfrey LM test for serial correlation	0.351222	H0: no serial correlation	0.5612	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	4.066400	H0: Constant variance	0.0055	There is heteroscedasticity
	Normality test	0.334403	H0: residuals are normally distributed	0.846029	Residuals are normally distributed
	CUSUM test			CUSUM 2	
Ln L	Breusch Godfrey LM test for serial correlation	1.779523	H0: no serial correlation	0.1959	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	0.871272	H0: Constant variance	0.5154	There is no heteroscedasticity
	Normality test	2.351819	H0: residuals are normally distributed	0.308538	Residuals are normally distributed
	CUSUM test			CUSUM 3	

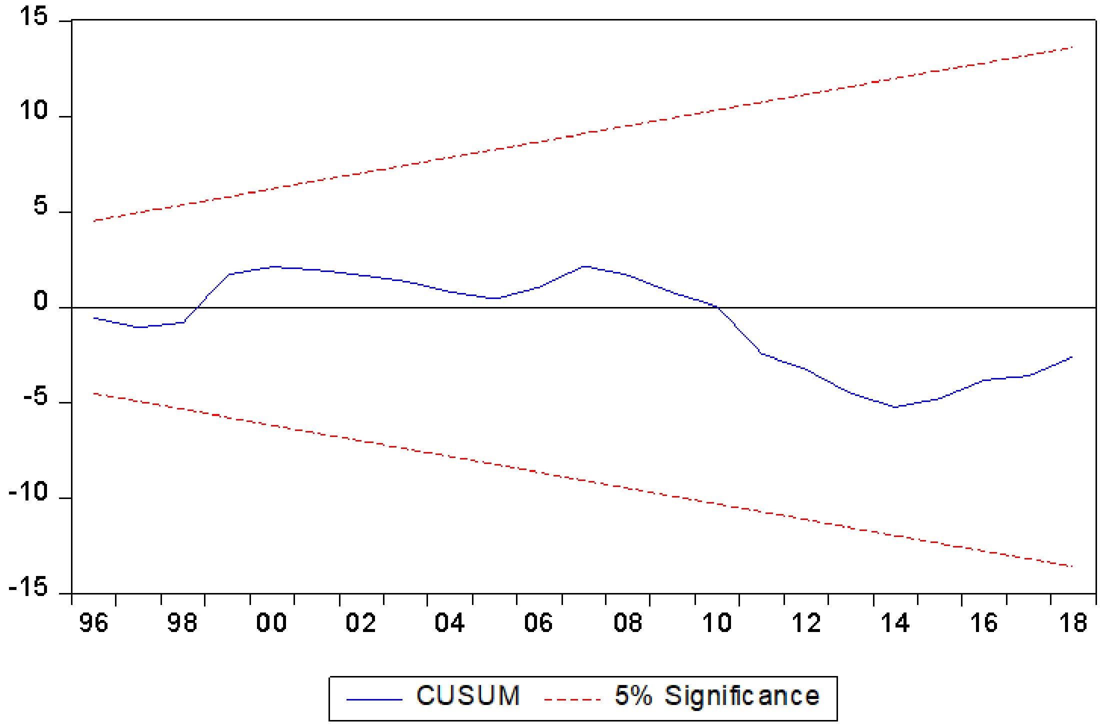

Figure A1. CUSUM 1 Plot.

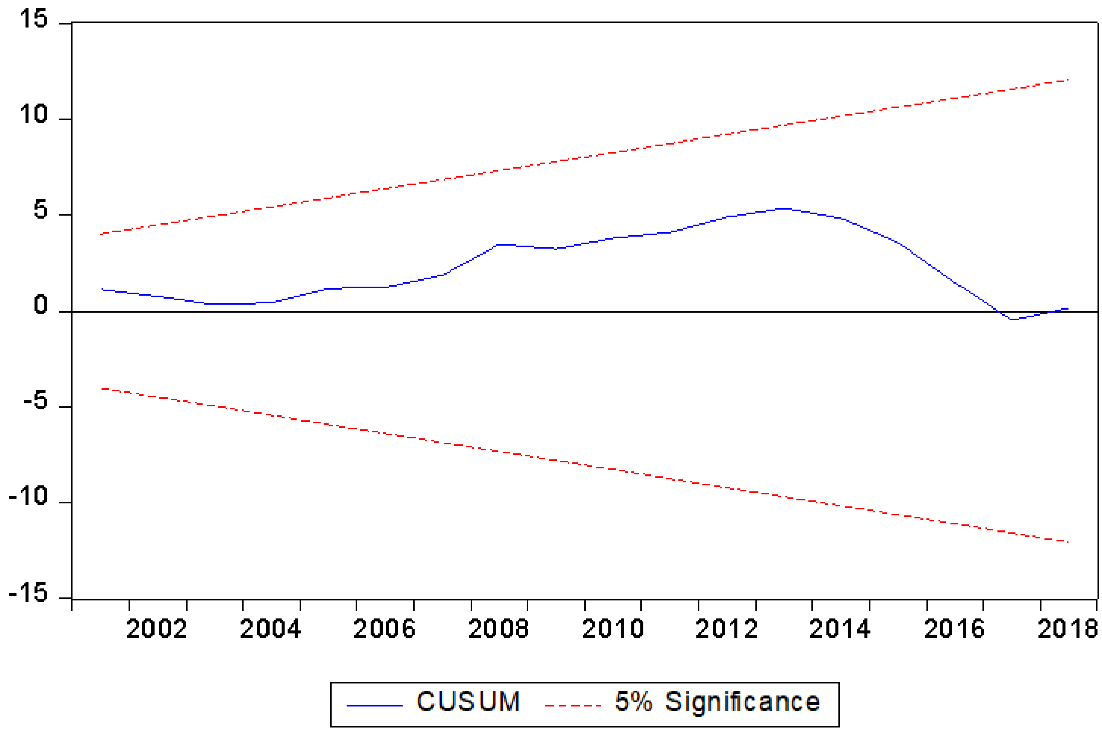

Figure A2. CUSUM 2 Plot.

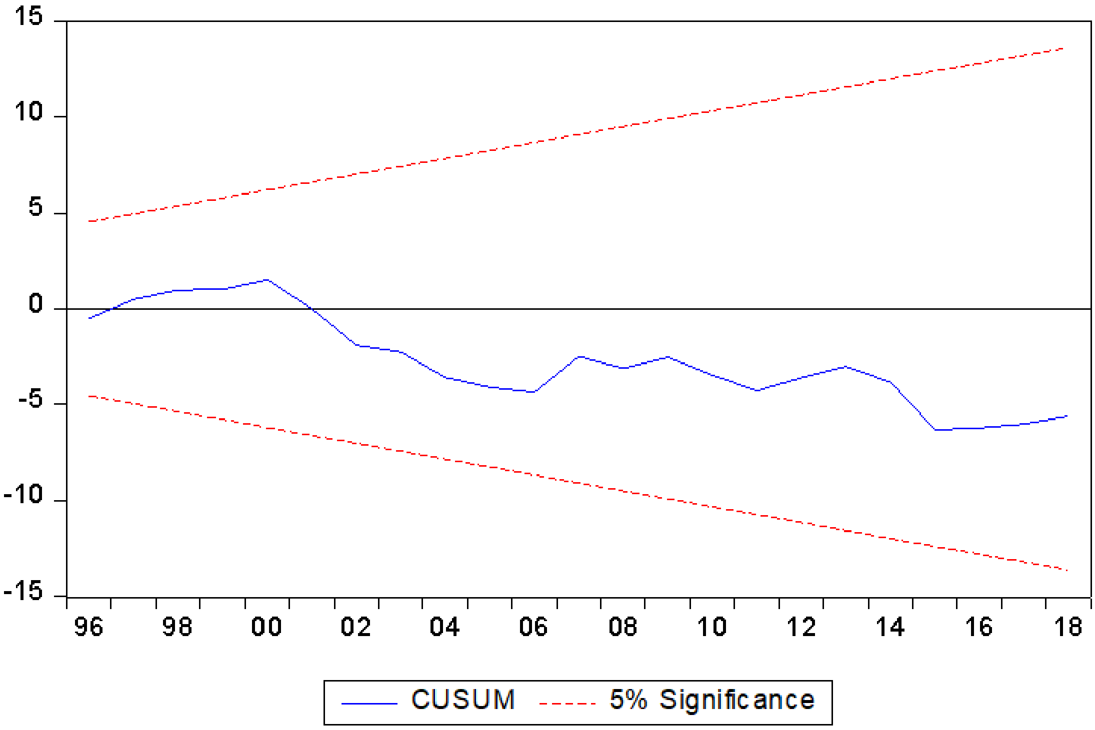

Figure A3. CUSUM 3 Plot.

Table A2. Diagnostic tests of the VECM.

Dependent Variable	Diagnostic Test	Test Statistic	H0	Prob. Values/Graph	Decision
D(Ln Y)	Breusch Godfrey LM test for serial correlation	0.271136	H0: no serial correlation	0.6078	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	0.380867	H0: constant variance	0.9183	There is no heteroscedasticity
	Normality test	3.018319	H0: residuals are normally distributed	0.22109	Residuals are normally distributed
	CUSUM test				CUSUM 4
D(Ln K)	Breusch Godfrey LM test for serial correlation	1.057641	H0: no serial correlation	0.3149	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	1.701363	H0: constant variance	0.1596	There is no heteroscedasticity
	Normality test	2.750376	H0: residuals are normally distributed	0.252792	Residuals are normally distributed
	CUSUM test				CUSUM 5
D(Ln L)	Breusch Godfrey LM test for serial correlation	4.160882	H0: no serial correlation	0.0536	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	0.568995	H0: constant variance	0.7908	There is no heteroscedasticity
	Normality test	1.433560	H0: residuals are normally distributed	0.488322	Residuals are normally distributed
	CUSUM test				CUSUM 6

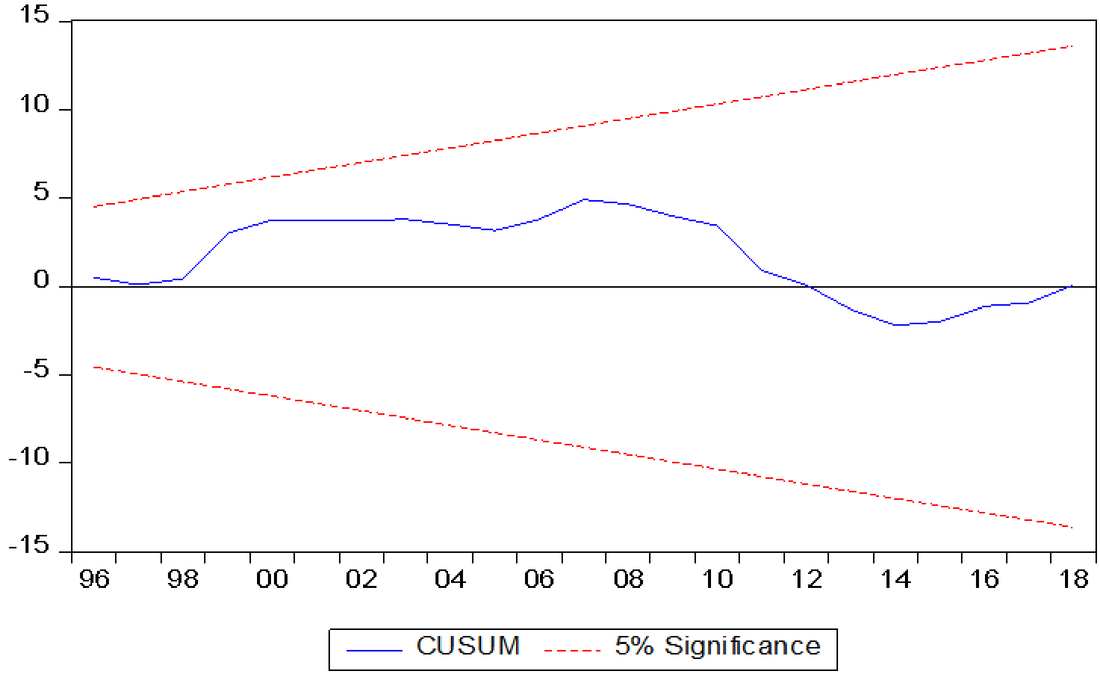

Figure A4. CUSUM 4 Plot.

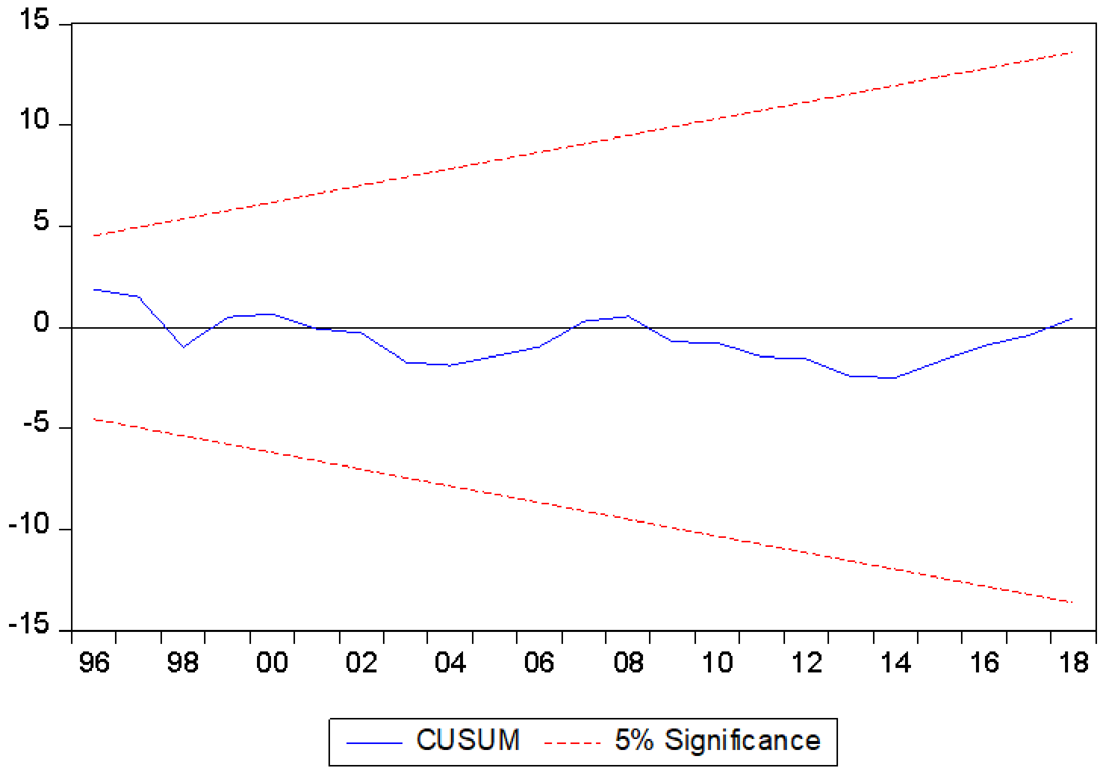

Figure A5. CUSUM 5 Plot.

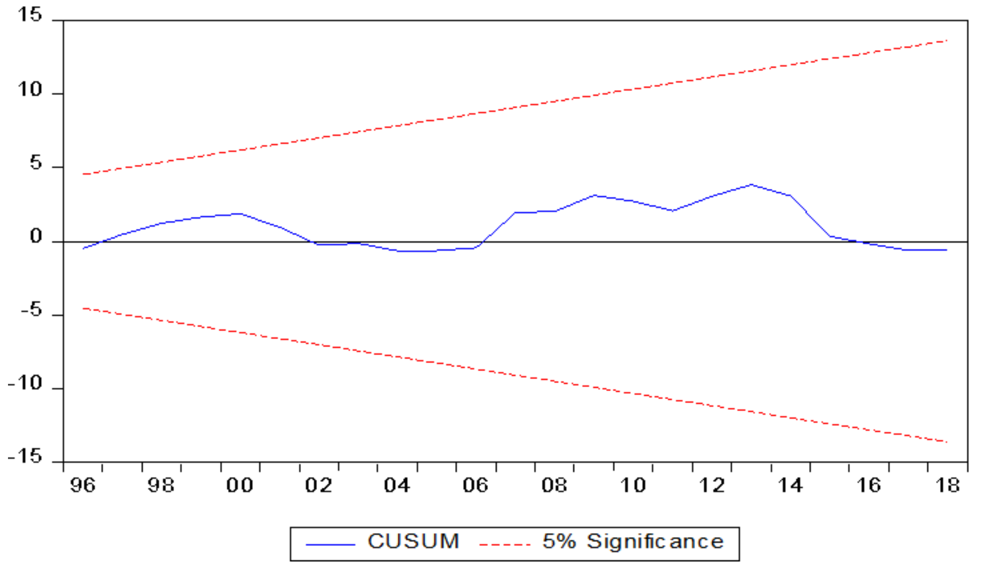

Figure A6. CUSUM 6 Plot.

Table A3. Diagnostic tests of the VAR.

Dependent Variable	Diagnostic Test	Test Statistic	H0	Prob.Values/Graph	Decision
D(Ln GC)	Breusch Godfrey LM test for serial correlation	0.10844	H0: no serial correlation	0.7449	The model has no serial correlation
	Breusch Pagan Heteroscedasticity test	0.37293	H0: Constant variance	0.9227	There is no heteroscedasticity
	Normality test	1.50964	H0: residuals are normally distributed	0.470095	There is normality
	CUSUM graph				CUSUM 7

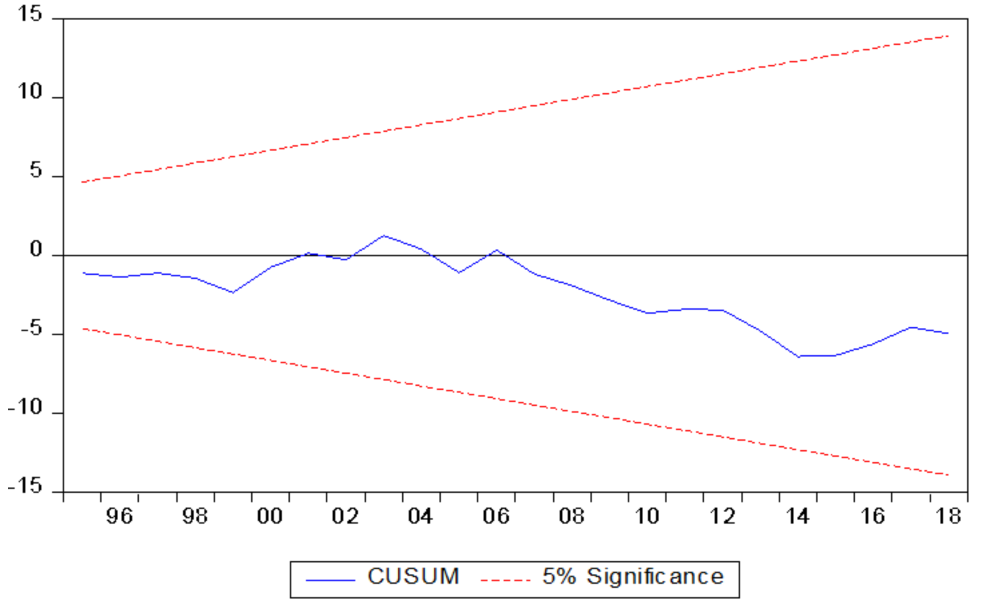

Figure A7. CUSUM 7 plot.

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