International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(6), 58-68.

Re-Examining Energy-Growth Nexus in 27 Selected South Countries: Heterogeneous Panel Model

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Received: 03 May 2025 **Accepted:** 26 August 2025 **DOI:** https://doi.org/10.32479/ijeep.20474

ABSTRACT

This paper examines the link between energy consumption and economic growth using a panel data sample of 27 Southern countries observed over the period 2002-2020. To capture long-run effects, we used appropriate panel data econometric techniques in the presence of cross-sectional dependence and slope heterogeneity, while Dumitrescu and Hurlin (2012) causality tests examined short-run causal effects. Our results show that (i) in the long run, energy consumption has a negative and significant effect on economic growth in all countries, while other variables have a positive and significant effect, except institutional quality form, which is not significant both in short and long run on economic growth. (ii) in the short run, all variables have a positive and significant effect on economic and, (iii) causality tests confirm the feedback hypothesis between energy consumption and growth. The study concludes by calling on policymakers to strengthen institutional qualities and adopt financial and energy efficiency policies that could sustain economic development in the long run.

Keywords: Growth, Energy Consumption, Financial Development, Pooled Mean Group-Mean Group, Causality
JEL Classifications: C33; O47; Q43; F43; G20

1. INTRODUCTION

Energy is a critical factor in the economic and social development of nations. As a result, access to energy—both in terms of consumption and production—has become a global concern. In recent years, recurring energy crises across various regions, coupled with the ongoing rise in energy prices—particularly oil prices—have prompted numerous studies aiming to understand these phenomena. Notable research includes the works of Erol and Yu (1987), Stern (2000), Morimoto and Hope (2004), Kane (2009), Ozturk (2010), Belke et al. (2011), Magazzino (2015), Grosset and Nguyen (2016), and Shahbaz et al. (2011; 2013; 2017; 2018).

From a theoretical perspective, two primary approaches are commonly employed to analyze the causal relationship between energy consumption and economic growth: the bivariate approach and the multivariate approach. However, findings regarding the causal link between these variables remain mixed, potentially due to differences in country selection, study periods, and economic methodologies (Le and Van, 2020). Since the late 1970s, research has predominantly focused on identifying the directionality of causality between energy consumption and economic growth. The results of these studies can be categorized into four main hypotheses: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis (Apergis and Payne, 2009b; Ozturk, 2010; Apergis and Tang, 2013): (i) The growth hypothesis posits a unidirectional effect of energy consumption on economic growth, suggesting that increased energy use facilitates higher economic activity; (ii) The conservation hypothesis assumes a unidirectional causality from economic growth to energy consumption, indicating that economic activity drives energy use; (iii) The feedback hypothesis proposes bidirectional causality between energy consumption and economic growth; (iv) The neutrality hypothesis asserts that there is no causal relationship between energy use and economic growth.

Recent empirical studies underscore a positive relationship between energy consumption and economic growth. Shahbaz et al. (2013) examining data from 1971 to 2011, incorporated variables such as financial development, international trade, capital, and energy consumption, and found that all variables contributed positively to China's economic growth. Additionally, Granger causality analysis supported the hypothesis that energy consumption drives economic growth. Zafar et al. (2019) examined the impact of non-renewable and renewable energy consumption in conjunction with capital formation, research and development expenditure, and trade openness on economic growth in Asia-Pacific Economic Cooperation (APEC) countries from 1990 to 2015, using the CUP-FMOLS[1] method for long-run panel data estimation. The findings indicate a positive correlation between energy consumption and economic growth, thereby supporting the feedback hypothesis. Le and Bao (2020) expanded the Cobb-Douglas production function using data from 16 Latin American and Caribbean (LAC) countries spanning 1990 to 2014. Their analysis employed a heterogeneous panel model and revealed that factors such as public expenditure, institutional quality, both renewable and non-renewable energy consumption, capital, trade openness, and financial development positively influence economic growth in the selected countries. Additionally, their results affirm the presence of the feedback mechanism between energy consumption and economic growth.

Similarly, Le (2020) examined the relationship between energy use and economic growth by analyzing the roles of institutional quality, public expenditure, financial development, and trade openness across 46 emerging and developing market economies (EMDEs) from 1990 to 2014, utilizing heterogeneous panel econometric methods. The analysis demonstrated that these variables have a positive and statistically significant effect on economic growth, further corroborating the feedback hypothesis within the energy-growth relationship. Therefore, this topic continues to generate debate within the field of energy economics, as the findings remain inconclusive regardless of the study region, time period, variables analyzed, or econometric methodologies employed (Ozturk, 2010; Payne, 2010; Menegaki, 2014; Omrai, 2014; Ahmad et al., 2020).

In 2020, British Petroleum (BP) noted that global primary energy consumption increased by 2.8% in 2019, compared to a 1.3% rise in 2018. Renewable energy sources and natural gas accounted for approximately three-quarters of this growth. Many countries in the Global South are abundant in energy resources. For instance, electricity generation in sub-Saharan Africa primarily depends on fossil fuels, contributing around 19% of global production (BP, 2017, 2020). African populations utilize only 3.2% of the world's primary energy, representing the lowest per capita consumption among continents. Additionally, most African nations continue to rely predominantly on traditional biomass for their basic energy needs. This issue is especially acute in rural areas, where only about 25% of residents have access to electricity (IEA, 2019: 42). On the other hand, Latin America and the Caribbean have made notable progress in expanding electricity access since 2000, with household electrification increasing from 87% in 2001 to 95.1% in 2019. Improvements have been particularly significant in rural regions, where the percentage of households with electricity rose by over 20 points—from 65.3% to 87.5%. Nonetheless, these encouraging figures may conceal substantial disparities in access across subregions, countries, and social groups (United Nations ECLAC Statistical Briefing, May 2022, p. 5). Despite considerable advancements in recent decades, certain vulnerable populations and areas still lack reliable access to electricity.

Based on the information above, the following research question is addressed: What is the impact of energy consumption on economic growth? This study aims to re-examine the relationship between energy use and economic development in 27 Southern countries. Specifically, we will analyze the causality between energy consumption and economic growth within these countries. The research will evaluate both short-term and long-term effects of energy use on economic performance. Additionally, a multivariate approach incorporating multiple variables will be employed to ensure accurate and unbiased estimates (Lütkepoh, 1982; Smyth and Narayan, 2015). To guide our investigation, we propose four hypotheses: (i) the growth hypothesis; (ii) the conservation hypothesis; (iii) the feedback hypothesis; and (iv) the neutrality hypothesis.

This research advances the existing literature through three distinct contributions to the energy-growth nexus scholarship. The primary contribution lies in integrating institutional quality as a fundamental determinant when examining how energy consumption influences economic development outcomes. This analytical approach proves particularly significant given that the selected Southern countries represent economies characterized by extensive global integration through international trade networks and foreign investment flows, yet simultaneously grapple with governance challenges manifested through weak institutional frameworks, underdeveloped financial systems, and inadequate energy security infrastructure alongside environmental protection deficits. Understanding the multifaceted drivers of economic performance in such contexts becomes essential for formulating sustainable development strategies that can navigate these structural constraints. The second contribution addresses a notable gap in the regional literature, where previous empirical investigations of Southern economies have predominantly overlooked the mediating role of institutional governance in energy-growth relationships. By explicitly incorporating institutional quality measures, this study enriches the analytical framework and provides more comprehensive insights into the mechanisms through which energy consumption translates into economic outcomes in institutionally fragile environments. This inclusion is theoretically justified given the extensive literature demonstrating how institutional quality affects resource allocation efficiency, investment climate, and overall economic performance. The methodological contribution constitutes the third advancement, employing sophisticated heterogeneous panel econometric methodologies within a comprehensive multivariate framework derived from an enhanced

1 CUP-FM: Continuously updated fully modified ordinary least square proposed by Bai et al. (2009).

Cobb-Douglas production specification. This technical approach acknowledges the inherent heterogeneity across countries while simultaneously accounting for cross-sectional interdependencies and slope parameter variations, thereby providing more robust and reliable empirical estimates than conventional homogeneous panel techniques commonly employed in earlier studies of similar country groupings.

This paper proceeds as follows: The next section develops the analytical framework and model specification. The third section describes the data collection process and sources. Section 4 explains the econometric methodology employed in the analysis. The fifth section presents and discusses the estimation results, followed by concluding remarks and policy suggestions in the final section.

2. RELATED LITERATURE

The relationship between energy consumption and economic growth continues to be a significant focus within development and environmental economics. Grounded in classical and endogenous growth theories, energy is often viewed as either an exogenous input vital for production or as an endogenously determined factor that can catalyze long-term economic growth. The Solow-Swan model identifies capital and labor as principal production inputs, while subsequent extensions to the Cobb-Douglas production function have integrated energy as a third input, acknowledging its critical role in stimulating economic activities and technological advancements (Solow, 1956; Romer, 1990). Within this context, energy is perceived not merely as a passive contributor but as a potential driver of industrialization, innovation, and productivity growth. Therefore, analyzing the nexus between energy and growth necessitates the inclusion of broader socio-economic variables, such as financial development, institutional quality, trade openness, and infrastructure.

To explore the causality between energy consumption and economic growth, researchers have put forth four primary hypotheses. The growth hypothesis indicates that energy consumption serves as a unidirectional driver of economic output. In contrast, the conservation hypothesis asserts that economic growth dictates the level of energy consumption. The feedback hypothesis suggests a bidirectional causality, while the neutrality hypothesis proposes no causal link between the two (Apergis and Payne, 2009; Ozturk, 2010). These perspectives have directed empirical research globally; however, the findings often diverge due to differences in methodology, country-specific characteristics, and data constraints.

Early empirical investigations, such as the study by Erol and Yu (1987), yielded inconclusive results using bivariate Granger causality tests. Stern (2000) advanced this methodology by employing multivariate cointegration techniques, highlighting the necessity of incorporating additional control variables to reduce omitted variable bias. This evolution has led to more comprehensive models. For instance, Shahbaz et al. (2013) utilized a multivariate framework for China, integrating energy consumption, trade openness, capital formation, and financial development, ultimately confirming the growth hypothesis and emphasizing the robust connection between energy use and GDP growth. Similarly, Zafar et al. (2019) applied panel estimation techniques to APEC countries, establishing a positive and significant impact of both renewable and non-renewable energy on economic outputs, aligning with the feedback hypothesis and illustrating a reciprocal relationship between energy and economic growth.

In Latin America and the Caribbean, Le and Bao (2020) found that energy consumption, along with trade openness and financial development, positively contributed to economic growth from 1990 to 2014. Utilizing a heterogeneous panel model, their findings further supported the feedback hypothesis. Le and Van (2020) examined this relationship in African emerging and developing market economies and emphasized the critical role of institutional quality in mediating the energy-growth connection. Their results indicate that weak institutional frameworks may undermine the developmental benefits of energy investments. This observation highlights that institutional vulnerabilities, such as corruption and ineffective governance, can significantly diminish the efficiency of energy utilization and the success of policy actions.

The evidence in Sub-Saharan Africa presents similar complexity. Kane (2009) conducted an analysis of the West African Economic and Monetary Union (WAEMU) region, concluding that energy demand and GDP were cointegrated, although the direction of causality varied by country and econometric method employed. Grosset and Nguyen (2016) focused on the same region, confirming the diverse energy-growth relationships and identifying both feedback and conservation hypotheses in various country clusters. These studies underscore the necessity for tailored policy responses that take into account specific national contexts.

The case of Sri Lanka, as studied by Morimoto and Hope (2004), illustrates the transformative potential of a reliable electricity supply on economic growth. Their time-series analysis indicated that access to electricity significantly enhances GDP, particularly through improved industrial productivity. A comparable conclusion was reached by Ahmad and Afzal (2020) in Pakistan, where they identified vulnerability in infrastructure as a critical barrier to leveraging energy for economic advancement. These findings underline the fundamental role of infrastructure in influencing the energy-growth relationship.

Beyond infrastructure, the interplay between institutional quality and financial development further complicates the nexus. Le (2020) noted that nations with strong institutions and advanced financial systems are better equipped to capitalize on energy investments. Shahbaz et al. (2017) explored this interaction in India, demonstrating that financial development amplifies the beneficial impact of energy consumption on economic performance. Additionally, Ho and Michaely (1988) suggested that high-quality information systems, supported by robust institutions, improve market efficiency and foster optimal energy resource allocation.

Another critical dimension in the empirical literature involves the composition of energy sources. Omrai (2014) conducted an extensive review differentiating between renewable and non-renewable energy, concluding that while non-renewables provide short-term growth advantages, renewables offer more sustainable, long-term benefits. Zafar et al. (2019) supported this assertion in their investigation of APEC countries, highlighting that research and development investment significantly enhances the growth effects of renewable energy. These insights are essential for developing nations weighing green energy transitions amidst increasing environmental challenges.

Theoretical contributions by Bretschger (2008) further contextualize these discussions by introducing the concept of energy-induced innovation. He argued that rising energy prices can stimulate technological advancements, thereby reducing energy intensity and fostering economic growth, rooted in Hicks' (1932) theory of induced innovation, which asserts that input scarcity or rising costs propel technological progress. Empirical evidence from both developed and developing nations indicates that enhancing energy efficiency may serve as a viable growth strategy, particularly when aligned with institutional and policy reforms.

Methodological advancements have also influenced recent research findings. Conventional time series and pooled panel regressions have gradually been superseded by more sophisticated techniques such as the Mean Group (MG) estimator (Pesaran and Smith, 1995) and the Pooled Mean Group (PMG) estimator (Pesaran et al., 1999). These methodologies accommodate country-specific variations and facilitate comparative short-run and long-run analyses. Complementary techniques, including the Common Correlated Effects Mean Group (CCEMG) estimator (Pesaran, 2006) and the Augmented Mean Group (AMG) estimator (Eberhardt and Teal, 2010), account for cross-sectional dependencies and multifactor error structures commonly found in global datasets.

Moreover, advancements in cointegration testing have emerged. Westerlund (2007) proposed innovative tests addressing cross-sectional dependence and allowing for heterogeneous error correction dynamics. Dumitrescu and Hurlin (2012) introduced a causality test tailored for heterogeneous panels, yielding more precise inferences. These methodological innovations have significantly enhanced the robustness of empirical findings and underscored the necessity of employing advanced econometric techniques in energy-growth research.

Despite these advancements, several gaps persist within the literature. Firstly, while a multitude of studies affirm a significant relationship between energy consumption and economic growth, the strength and direction of this association display considerable variability. Secondly, institutional quality is often insufficiently examined or overlooked, despite evidence pointing to its moderating role. Furthermore, many studies fail to clearly differentiate between types of energy, obscuring the distinct effects of fossil fuels compared to renewables. Lastly, numerous analyses remain geographically limited or dependent on outdated data, diminishing their relevance in contemporary policy discussions.

To address these gaps, the present study makes a valuable contribution by investigating the energy-growth nexus in 27 Southern countries from 2002 to 2020. Utilizing a heterogeneous panel model that incorporates institutional quality, trade openness, and financial development, the study provides nuanced insights into both short-run and long-run dynamics. The application of PMG-MG estimators, along with robustness checks through FMOLS, AMG, and CCEMG methods, ensures methodological rigor. Additionally, advanced diagnostic assessments are employed to evaluate cross-sectional dependence and slope heterogeneity, complemented by second-generation unit root and cointegration tests. This methodological sophistication enhances the validity of the findings and aligns the study with best practices in the field.

The results reveal that while energy consumption positively influences economic growth in the short term, its long-term impact may be negative. This may stem from inefficiencies, environmental degradation, or an overreliance on non-renewable sources. In contrast, public expenditure, gross fixed capital formation, trade openness, and financial development all exhibit positive and significant effects on economic growth across both time frames. However, institutional quality remains statistically insignificant, signaling ongoing governance challenges in the South. Causality tests confirm the feedback hypothesis for most variables, indicating a bidirectional relationship between energy consumption and economic performance.

These findings carry critical implications for policy. They suggest that energy consumption alone is insufficient to sustain long-term growth without accompanying reforms. Strengthening institutional frameworks, promoting energy efficiency, and diversifying energy sources—particularly toward renewable options—are essential for achieving sustainable development. Additionally, integrating financial and trade policies with energy planning can enhance growth benefits and foster economic resilience. As global energy landscapes evolve, particularly in light of climate change and transitioning energy discussions, such integrated approaches will become increasingly vital.

In summary, the literature on the energy-growth nexus has significantly advanced over recent decades, evolving from simplistic causality models to complex, multifaceted analyses. While empirical findings remain mixed, a developing consensus emphasizes the need for context-specific, policy-oriented solutions. This study contributes to the discourse by providing new evidence from the Global South and demonstrating the importance of incorporating institutional and structural considerations into energy-growth models, thereby offering both academic insights and practical guidance for policymakers aiming to balance growth targets with energy and environmental sustainability.

3. MODEL SPECIFICATION

Our methodological approach is based on heterogeneous panel modelling based on the work of Phong (2020) who used an extended Cobb-Douglas production function, which is presented below:

$$Y = AK^{\beta_1} L^{\beta_2} EC^{\beta_3} e^{\mu} \quad (1)$$

Y is domestic production, *A* is the technological factor, *K* capital, *L* is labour, *EC* represents energy consumption, and e^{μ} is error. In fact, β_1, β_2, and β_3 are the elasticities of output, capital, labour and energy respectively. Similarly, returns to scale are constant when the augmented Cobb-Douglas function is constrained by the condition $\beta_1 + \beta_2 + \beta_2 = 1$. According to Le and Bao (2020), the technology factor can be determined endogenously by the level of financial development, international trade and energy consumption. Therefore, the technology factor can be written as:

$$A_t = \tau FD_t^{\lambda_1} TO_t^{\lambda_2} EC_t^{\lambda_3} \quad (2)$$

Where τ a time-invariant is constant, *FD* is financial development, *TO* denotes trade openness and *EC* is illustrated by energy consumption. Replacing the technology factor by its expression in equation (1) gives the following equation (3).

$$Y_t = \tau FD_t^{\lambda_1} TO_t^{\lambda_2} EC_t^{\lambda_3} K_t^{\alpha_1} L_t^{1-\alpha_1} \quad (3)$$

If we divide both factors of equation (3) by labour term, we obtain equation (4) as follow:

$$\frac{Y_t}{L_t} = \tau FD_t^{\lambda_1} TO_t^{\lambda_2} EC_t^{\lambda_3} \left(\frac{K_t}{L_t}\right)^{\alpha_1} \quad (4)$$

If we suppose that $\frac{Y_t}{L_t} = GDP_t$ is growth and $\left(\frac{Y_t}{L_t}\right)^{\alpha_1} = k_t^{\alpha_1}$ the per the capita GDP then, equation (3) can be written as:

$$Y_t = \tau FD_t^{\lambda_1} TO_t^{\lambda_2} EC_t^{\lambda_3} k_t^{\alpha_1} \quad (5)$$

If add the role of government in term of government expenditure ($GC_t + GCF_t$) and institutional quality, (IQ_t) we have:

$$k_t^{\alpha_1} = (GC_t + GCF_t + \mathrm{IQ})^{\alpha} \quad (6)$$

$$k_t^{\alpha_1} \sim GC_t^{\beta_1} . GCF_t^{\beta_1} . \mathrm{IQ}_t^{\beta_3} \quad (7)$$

And we consider that all capital factors are determined endogenously by the country, we get equation (8).

$$Y_t = \tau FD_t^{\lambda_1} TO_t^{\lambda_2} EC_t^{\lambda_3} GC_t^{\lambda_1} GC_t^{\lambda_2}\ \mathrm{IQ}_t^{\lambda_3} \quad (8)$$

If the labour effect remains unchanged[2], we add the role of government in terms of public spending and institutional quality as control variables. Then, considering the log-linear form, we obtain equation (4) after transformation into the following form.

$$lnY_{it} = \gamma_{it} + \lambda_1 \ln FD_{it} + \lambda_2 \ln \mathrm{TO}_{it} + \lambda_3 \ln \mathrm{EC}_{it} + \beta_1 \ln \mathrm{G}\, C_{it} + \beta_2 \ln GCF_{it} + \beta_3 \ln IQ_{it} + \varepsilon_{it} \quad (9)$$

2 Balanced growth means that all parts of the economy are growing together, i.e. when supply and demand are balanced across all markets. Such growth would have far-reaching consequences, as it would imply the absence of economic imbalances such as unemployment and inflation. The factors labour and capital remain constant, as demonstrated by Solow (1956; 1957).

Where *Y*; *FD*; *TO*; *EC*; *GC*; *GFC* and *IQ* are respectively real GDP per capita, financial development, trade openness, energy consumption, government expenditure, gross fixed capital formation, institutional quality, and ε_{it} is the error term.

4. DATA SOURCES AND DESCRIPTIVE STATISTICS

Real GDP per capita, gross fixed capital formation, government expenditure, energy consumption, and trade openness are sourced from the World Bank's World Development Indicators database (World Bank, 2023a). These variables are expressed in current US dollars. The institutional variable selected is scaled between 0 and 1, where values closer to 1 indicate higher levels of corruption, and values nearer to 0 reflect lower levels of corruption. This measure is obtained from the World Governance Indicators database (World Bank, 2023b). The financial development index is derived from the International Monetary Fund (IMF) database and also ranges from 0 to 1, as illustrated in Table 1 below.

Descriptive statistics for all variables are provided in Table 2. The average growth rate in the Southern countries listed in annex (Table A1) is modest, approximately 3.313 points over the period 2002-2020, with a maximum value of 4.229. Additionally, the energy consumption rate remains relatively low, around 2.719 points. The averages for financial development and political stability are negative, at −0.773 and −0.753, respectively. Conversely, the trade openness index is higher, indicating a high level of economic integration across all countries studied.

The multicollinearity between variables is verified by the correlation matrix presented in Table 3. It can be observed that energy consumption, capital, public expenditure, financial development and trade openness are positively correlated with

Table 1: Variable description

Variables	Description	Sources
Y_{it}	Real GDP per capita (in current US dollars)	WDI
GFC_{it}	gross fixed capital formation (% of GDP)	WDI
FD_{it}	The financial development index (IMF) database	IMF
GE_{it}	government expenditure (% of GDP)	WDI
IQ_{it}	Institutional Quality World Governance Indicators	(WGI)
TO_{it}	Trade openness (% of GDP)	WDI
KC_{it}	Energy Consumption Kg of oil equivalent to per capita	WDI

Source: Author's compilation

Table 2: Descriptive statistics

Variables	Mean	Min	Max	SD
lny_{it}	3.313	2.341	4.229	0.474
$lnEC_{it}$	2.719	1.648	3.686	0.572
$lnGE_{it}$	2.419	0.624	3.393	0.547
$lnTO_{it}$	17.050	15.397	19.807	1.031
$lnGFC_{it}$	2.618	1.534	3.594	0.512
$lnFD_{it}$	−0.773	−1.480	−0.208	0.269
$lnIQ_{it}$	−0.753	−0.898	−0.468	0.088

Source: Author calculation based on data used in the regression

GDP per capita, apart from institutional quality, which is negatively correlated with real GDP.

Therefore, to assess the multicollinearity problem, we use multicollinearity tests based on the VIF (variance inflation factor). A common cut-off value for the VIF is 10 (Hair et al., 1995; Wooldridge, 2013). The results in Table 4 indicate that the VIF values are below this threshold.

5. ESTIMATION TECHNIQUE

5.1. Cross-Dependency Test

In panel data analysis, interactions such as exports, imports, and economic integration among countries within the same geographical region can induce cross-sectional dependence. Additionally, common shocks or model misspecification may also contribute to this dependence (Chudik and Pesaran, 2013). It is essential to test for cross-sectional dependence to ensure the validity and robustness of estimators, as outlined by Breusch and Pagan (1980), Pesaran (2004), and Phillips and Sul (2003). Breusch and Pagan (1980) introduced the Lagrange multiplier (LM) test specifically to assess for cross-dependence in panel data models. The following outlines a general specification of a panel data regression:

$$Y_{it}\ \alpha_i + \beta_{it} X_{it} + \varphi_{it} \tag{10}$$

Where X_{it} depicts $k\times 1$ vector of regressor, t represents the temporal dimension ($t = 1, 2,\ldots T$) and each country in panel is indicated by i ($i = 1,2,\ldots N$). Thus the LM test is specified in equation (6) bellow.

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij} \tag{11}$$

Where the null hypothesis is that: H_0: $Cov(\varphi_{it}, \varphi_{jt}) = 0$ exhibits no cross-sectional dependence and H_1: $Cov(\varphi_{it}, \varphi_{jt}) \neq 0$, the alternative hypothesis when the cross-sectional dependence occurs. To adjust bias, Pesaran (2004) proposed the LM test modification expressed by the equation (7).

$$CD = \sqrt{\frac{2T}{N-1}\sum_{i=i}^{N}\sum_{j=1+i}^{N}\frac{(T-k)\hat{p}_{ij}^2 - [(T-k)\hat{p}_{ij}^2]}{\text{var}[(T-k)\hat{p}_{ij}^2]}} \tag{12}$$

Table 3: Correlation matrix

	lnY	lnE	lnGE	lnTO	lnFC	lnFD	lnST
lny_{it}	1.0000						
$lnEC_{it}$	0.8656	1.0000					
$lnGE_{it}$	0.9497	0.8693	1.0000				
$lnTO_{it}$	0.3072	0.2918	0.2300	1.0000			
$lnGFC_{it}$	0.9729	0.8079	0.9144	0.2757	1.0000		
$lnFD_{it}$	0.5302	0.6320	0.4972	0.2997	0.4915	1.0000	
$lnIQ_{it}$	−0.4470	−0.3498	−0.4293	−0.5414	−0.4453	−0.3382	1.0000

Source: Author calculation based on data used in the regression

Table 4: Multicollinearity test of variables

Variables	VIF	1/VIF
lny_{it}	9.47	0.1056
$lnEC_{it}$	6.34	0.1577
$lnGE_{it}$	5.56	0.1797
$lnTO_{it}$	1.78	0.5611
$lnGFC_{it}$	1.74	0.5733
$lnFD_{it}$	1.53	0.6547
Mean VIF	4.40	

Source: Author calculation based on data used in the regression

5.2. Slope Homogeneity Test

To detect slope heterogeneity, Swamy (1970) introduced a pooled estimator designed to measure the dispersion of individual regression coefficients. The null hypothesis of slope homogeneity is tested against the alternative hypothesis of slope heterogeneity. For large panel datasets, Pesaran and Yamagata (2008) refined this approach by developing a slope homogeneity test based on Swamy's original methodology, as detailed in Equation (8).

$$\tilde{S}\% = \sum_{i=1}^{N}(\hat{\beta}_i - \bar{\beta}_{EFP})'\frac{X_i' M_t X_i}{\sigma_i^2}(\hat{\beta}_i - \bar{\beta}_{EFP}) \tag{13}$$

In which is ordinary least squares regression coefficient for each country i (i = 1; 2;…;N), and $\bar{\beta}_{EFP}$ is the weighted fixed-effect cluster estimator (FCE), M_t indicates the identity matrix, and is an estimate of. For details see Swamy (1970).

5.3. Panel Unit Root Test

In this study, we opt for second-generation unit root tests that are robust to the presence of cross-sectional dependence (Phillips and Sul, 2003; Pesaran, 2007). Therefore, two notable second-generation tests are used in this paper, namely the cross-sectionally augmented Dickey-Fuller (CADF) test Pesaran (2004) and the cross-sectionally augmented Im-Pesaran-Shin (CIPS) test Pesaran (2007). The CADF statistic is given in equation (9):

$$\Delta Y_{i,t} = \alpha_i + \beta_i Y_{i,t} + \gamma_i \bar{Y}_{t-1} + \delta_i \Delta\bar{Y}_{i,t} + \varepsilon_{it} \quad \text{Avec} \quad \bar{Y}_{t-1} = \frac{1}{N}\sum_{i-1}^{N} Y_{i,t-1}$$
$$\text{et } \Delta\bar{Y}_{i,t} = \frac{1}{N}\sum_{i-1}^{N}\Delta Y_{i,t} \tag{14}$$

The CIPS statistic proposed by Pesaran (2007) is calculated from the average of the CADF statistics for each country in the panel data (i = 1;2;…N) calculated from t ratios of β_i demonstrated in equation (10):

$$CIPS = \frac{1}{N}\sum_{i-1}^{N} CADF_i \tag{15}$$

5.4. Panel Cointegration Test

In situations characterized by significant cross-sectional dependence, the long-term relationship between the variables is examined using the panel cointegration test introduced by Westerlund (2007). This test assesses the presence of an error correction mechanism both at the individual country level and across the entire panel. The error correction term, denoted as (ε_t), quantifies the speed at which deviations from equilibrium are corrected.

$$\Delta Y_{i,t} = \delta_i^{\prime} d_t + \varepsilon_t (Y_{i,t-1} - \beta_{t,t-1}^{\prime}) + \sum_{j=1}^{P} \varphi_{ij} Y_{i,t} X_{i,t-j} + \mu_{1,t} \quad (16)$$

The Westerlund (2007) cointegration test uses the statistics G_τ et G_α to detect whether co-integration occurs in at least one country in cross-section. Similarly, and statistics reveal whether cointegration occurs in entire panel. These statistics, which are also used to examine the null hypothesis of no cointegration, can be written as follows:

$$G_\tau = \frac{1}{N} \sum_{i-1}^{N} \frac{\varepsilon_i}{se(\hat{\varepsilon}_i)}; G_\alpha = \frac{1}{N} \sum_{i-1}^{N} \frac{T\varepsilon_i}{\varepsilon_i^{\prime}}; P_\tau = \frac{\hat{\varepsilon}_i}{Se(\hat{\varepsilon}_i)}; P_\alpha = T\hat{\varepsilon} \quad (17)$$

5.5. Long and Short Panel Estimates

The estimation procedure used is the PMG-MG method. The Mean Group (MG) and Pooled Mean Group (PMG) estimators proposed by Pesaran and Smith (1995) and Pesaran et al. (1999; 2001) provide robust results. The advantage of the first estimator is that it accounts for the heterogeneity of the long-run coefficients by taking their mean, while the second considers the combination of pooling and the mean of the coefficients. To check the robustness of our results, we also use recent estimation methods that allow for heterogeneity in the adjustment dynamics of the variables towards the long-run relationship, such as the fully modified ordinary least squares (FMOLS) Phillips (1995) estimator, the augmented mean group (AMG) estimator proposed by Eberhardt and Teal (2010) and the common correlated effect augmented mean group (CCEMG) estimator, also carried out by Pesaran (2006).

The estimation procedure employed is the Pooled Mean Group (PMG) method. The Mean Group (MG) and Pooled Mean Group (PMG) estimators, developed by Pesaran and Smith (1995) and Pesaran et al. (1999; 2001), offer robust analytical results. The MG estimator captures heterogeneity in the long-term coefficients by averaging them across groups, while the PMG estimator combines pooling with the averaging of coefficients to account for both short-term dynamics and long-term relationships. To enhance the robustness of our findings, we also utilize recent estimation techniques that accommodate heterogeneity in the adjustment processes of variables toward their long-run equilibrium, such as the Fully Modified Ordinary Least squares (FMOLS) estimator (Phillips, 1995), the Augmented Mean Group (AMG) estimator (Eberhardt and Teal, 2010), and the Common Correlated Effects Augmented Mean Group (CCEMG) estimator, also proposed by Pesaran (2006).

5.6. Tests de Causalité en Panel

Dumitrescu and Hurlin (2012) developed the panel data causality test from Granger (1969), which is illustrated as:

$$Y_{it} = \alpha_i + \sum_{k=1}^{P} \gamma_{ik} Y_{i,t-k} + \sum_{k=1}^{p} \beta_{ik} X_{i,t-k} + \mu_{i,t} \quad (18)$$

The equation (12), Y_{it} et X_{it} are the variables, indices $i(i = 1; 2\ldots; N)$ and denote the country and time respectively, P is the length of the delay $t(t = 1;2\ldots;T)$, γ_{ik} and β_{ik} indicate the autoregressive and regression coefficients respectively. In addition, β_{ik} may vary between countries but remains constant over time. And the lag length P is the same for countries and must be positive number. Finally, the panel data is assumed to be balanced. The null hypothesis assumes that there is no causal relationship between variables for countries:

$$H_0: \beta_{i1} = \beta_{i2} \ldots \beta_{iP} = 0, \forall_i = 1,2,\ldots,N \quad (19)$$

The alternative hypothesis is formulated as:

$$H_1: \beta_{i1} = \beta_{i2} \ldots \beta_{iP}, \forall_i = 1,2,\ldots,N_1 \quad (20)$$

$$H_1: \beta_{i1} \neq 0 \text{ ou } \beta_{i2} \neq 0 \ldots \beta_{i1} \neq 0; \forall_i = 1,2,\ldots,N_1 + 1; \forall_i = 1,2,\ldots,N_1 + 2 \quad (21)$$

(With N_1, positive integer from 0 and N). According to Dumitrescu and Hurlin (2012), the average Wald statistic for the null hypothesis (i.e. no causality in all countries) is obtained by regressing the equation (12) and by conducting F tests for P linear assumptions such as $\beta_{i1} = \beta_{i2} \ldots \beta_{iP} = 0$. See (Dumitrescu and Hurlin, 2012) for more details.

6. EMPIRICAL RESULTS

It is of paramount importance to check for cross-sectional dependence using the Pesaran (2004) test (CADF). The results presented in Table 5 clearly show that there is a strong presence of cross-sectional dependence at the 1% level for the countries considered in the sample.

Table 6 shows the result of slope homogeneity test proposed by Pesaran and Yamagata (2008). The null hypothesis of the presence of homogeneity was rejected and statistically significant at the 1% level. We therefore concluded that there is heterogeneity of the slope.

The estimation starts with the test of Im et al. (2003). Since this test requires the assumption of cross-sectional independence

Table 5: Cross-sectional dependence test (CADF)

Variable	CD-test	P-value
lny_{it}	73.11	0.000
$lnEC_{it}$	55.83	0.000
$lnGE_{it}$	70.42	0.000
$lnTO_{it}$	78.77	0.000
$lnGFC_{it}$	68.82	0.000
$lnFD_{it}$	44.50	0.000
lny_{it}	78.76	0.000

Source: Author calculation based on data used in the regression

Table 6: Slope homogeneity test

Test	Statistic	P-Value
Delta-tilde	3.540*	0.000
Delta-tilde-Adj	4.750*	0.000

Source: Author calculation based on data used in the regression
*indicates significance at 1% level.

of observations, it is appropriate as it allows us to control for unobserved common effects that are correlated with countries. The results in Table 7 show that the variables are integrated at the level and in the first difference, i.e. stationary.

Then, the second-generation unit root test in the presence of cross-sectional dependence, called CIPS, proposed by Pesaran (2007), was carried out. From the test results presented in Table 8 below, we can conclude that the variables are stationary.

Similarly, in the presence of cross-sectional dependence and slope heterogeneity, the appropriate cointegration test is the one proposed by Westerlund (2007). The P-values reported in Table 9 have been calculated using a bootstrapping method and are robust to the presence of common factors (cross-sectional dependence) in the time series. According to the results in Table 9, the hypothesis of non-cointegration is rejected for the Pτ test at a 10% significance level, based on the robust p-values.

To estimate the long-term parameters, we utilized estimators that are robust to cross-sectional dependence and slope heterogeneity, including AMG (Bond and Eberhardt, 2009; Eberhardt and Teal, 2010), MG (Pesaran and Smith, 1995), CCEMG (Pesaran, 2006), FMOLS (Phillips, 1995), and PMG-MG (Pesaran and Smith, 1995; Pesaran et al., 1999). The PMG-MG estimator was selected as the primary method for analysis, with the other estimators employed for robustness checks. Given that the PMG-MG estimator is central to this study, we will highlight the relevant coefficients obtained through this approach. The Hausman joint test was conducted, and the results indicated a probability value exceeding 5%, leading us to accept the null hypothesis that the PMG estimator is appropriate and efficient. Consequently, we proceeded with the PMG estimator for our main analyses. The long-run results derived from the PMG estimator, as presented in Table 10, suggest that energy consumption (EC) has a negative impact on economic growth. Specifically, a 1% increase in per capita energy consumption is associated with a 0.79% reduction in GDP per capita. The FMOLS estimator produced consistent results in the long run.

This conclusion is corroborated by the FMOLS estimator. Variables such as gross fixed capital formation, government final consumption expenditure per capita, trade openness, and financial development have demonstrated positive and statistically significant impacts on economic growth. Specifically, a 1% increase in gross fixed capital formation is associated with a 0.28% increase in GDP per capita. Likewise, a 1% rise in trade openness results in a 0.29% increase in GDP per capita, while a 1% improvement in the financial development index corresponds to a 0.06% enhancement in GDP per capita. The current findings suggest that disparities between countries regarding energy

Table 7 : IPS unit root test

Variables	*I* (0)	*I* (1)
lny_{it}	6.119	−9.675*
$lnEC_{it}$	5.286	−13.133*
$lnGE_{it}$	5.529	−9.840*
$lnTO_{it}$	7.982	−11.580*
$lnGFC_{it}$	6.347	−12.832*
$lnFD_{it}$	−1.068	−14.979*
$lnIQ_{it}$	−2.783*	−12.805*

Source: Author calculation based on data used in the regression
*indicates significance at 1% level

Table 8: CIPS unit root test

Variables	*I* (0)	*I* (1)
lny_{it}	−2.566*	−2.244*
$lnEC_{it}$	−1.691**	−2.072*
$lnGE_{it}$	−3.311*	−2.390*
$lnTO_{it}$	−0.833	−1.903*
$lnGFC_{it}$	−1.384***	−2.012*
$lnFD_{it}$	−6.503*	−3.017*
$lnIQ_{it}$	−1.987**	−2.120*

Source: Author calculation based on data used in the regression
*; ** and *** respectively indicate significance at the 1% level; 5% and 10%

Table 9: Panel cointegration test Westerlund (2007)

Statistics	Value	Z-value	Robust P value
Gτ	−2.152	1.396	0.130
Gα	−3.045	6.735	0.350
Pτ	−10.447***	0.501	0.070
Pα	−3.087	4.107	0.270

Source: Author calculation, based on data used in the regression
***indicates significance at the 10% level

Table 10: Long and short run estimation results

Regressors	FMOLS	AMG	MG	CCEMG	PMG
Long run					
$lnEC_{it}$	−0.635***	−0.012	0.041	0.023	−0.793***
	(−3.85)	(−0.16)	(0.53)	(0.25)	(−16.20)
$lnGE_{it}$	0.204***	0.315***	0.32***	0.421***	0.519***
	(8.43)	(4.41)	(4.42)	(6.08)	(15.09)
$lnTO_{it}$	0.195***	0.232***	0.259***	0.292***	0.293***
	(6.04)	(4.25)	(4.62)	(3.49)	(12.76)
$lnGFC_{it}$	0.459***	0.249***	0.232***	0.188***	0.277***
	(16.93)	(5.15)	(4.76)	(3.54)	(9.81)
$lnFD_{it}$	0.115	−0.734	−0.049	−0.115***	0.057*
	(0.59)	(−1.35)	(−0.96)	(−2.15)	(1.70)
$lnIQ_{it}$	0.62***	−0.046	−0.005	−0.116	0.038
	(2.66)	(−0.49)	(−0.06)	(−0.64)	(0.72)
Constant	0.443***	−2.075***	−2.459	−2.862***	−0.218***
	(4.25)	(−2.75)	(−3.08)	(−2.22)	(−4.07)
Short run					
$lnEC_{it}$				−0.348	0.131***
				(−1.01)	(2.43)
$lnGE_{it}$				−0.111	0.260***
				(−0.76)	(4.16)
$lnTO_{it}$				0.009	0.203***
				(0.05)	(4.38)
$lnGFC_{it}$				0.231***	0.130***
				(−2.03)	(3.27)
$lnFD_{it}$				0.718***	−0.132***
				(3.08)	(−3.66)
$lnIQ_{it}$				0.136	0.056
				(0.74)	(0.83)
ECT_{it}					−0.151***
					(−2.18)
	Hausman test			0.8981	
Observations			486		
Countries number				27	

Source: Author calculation, based on data used in the regression
***; ** and * respectively indicate the significance at 1%; 5% and 10% level. ECT is error correction term

Table 11: Panel causality tests

Variables	lnY_{it}	$lnEC_{it}$	$lnGE_{it}$	$lnTO_{it}$	$lnGFC_{it}$	$lnFD_{it}$	$lnIQ_{it}$
lny_{it}	-	4.198* (11.752)	5.196* (15.417)	2.276* (4.690)	3.899* (10.653)	4.371* (12.388)	1.162* (0.596)
$lnEC_{it}$	2.654* (6.076)	-	4.386* (12.443)	1.882* (3.239)	2.710* (6.285)	3.318* (8.516)	1.807* (2.965)
$lnGE_{it}$	1.255 (0.937)	2.137* (4.177)	-	2.895* (6.962)	2.858* (6.828)	3.921* (10.731)	0.801 (-0.732)
$lnTO_{it}$	5.915* (18.062)	5.404* (16.182)	9.942* (32.854)	-	7.109* (22.447)	5.547* (16.709)	1.793* (2.912)
$lnGFC_{it}$	2.854* (6.811)	3.700* (9.921)	5.565* (16.771)	3.119* (7.788)	-	4.689* (13.553)	0.715 (-1.045)
$lnFD_{it}$	2.879* (6.906)	1.932* (3.425)	2.976* (7.260)	2.591* (5.846)	2.488* (5.457)	-	1.251 (0.924)
$lnIQ_{it}$	5.250* (15.616)	3.387* (8.769)	4.886* (14.279)	3.527* (9.284)	5.510* (16.571)	4.154* (11.591)	-

Numbers given are W statistics. Z statistics are shown in parentheses. * and ** indicate significance at the 1% and 5% level, respectively. Y→X indicates the null hypothesis that X does not cause Y

Source: Author, base on data used in the regression.

resources and growth are more effectively analyzed over the long term. Establishing stable long-term relationships requires an adaptation period. It is also evident that energy prices vary significantly across nations due to taxation policies, which tend to remain relatively constant over extended periods. The cross-sectional data provides insights into how economies adjust to differing energy prices over longer time horizons.

Furthermore, analysis of the data concerning the relationship between energy consumption and economic growth across various nations clearly indicates that the correlation between these two factors is not positive. Instead, it reveals a modest negative trend. The findings of this study align with those presented in the article by Bretschger (2008). It is noted that all variables demonstrate positive and significant effects in all countries included in the study, both in the short-term and long-term, with the exception of institutional quality, which shows an insignificant impact. In this context, it can be hypothesized that increases in energy prices may stimulate innovation in sectors such as finance, trade, investment, and public spending optimization. The goal of this process would be to enhance energy efficiency and, consequently, promote overall economic growth. These results are consistent with the conclusions reported by Hicks (1932).

In the short term, all variables demonstrate a positive and statistically significant impact on GDP per capita at the 1% level, except for the quality of institutions, which is not statistically significant despite showing a positive trend. This suggests that the quality of institutions remains below optimal levels in both the short and long term, indicating that other factors such as political instability and inadequate governance also contribute to this situation. Additionally, there is a notable change in the sign of energy consumption, which becomes positive and statistically significant at the 1% level in the short term, highlighting the important role of energy in South countries' economies. Furthermore, the results from the error correction model indicate that the coefficient related to the speed of adjustment is negative (-0.151) and significant at the 1% level. This implies that deviations from the long-term equilibrium trigger adjustments in the short-term evolution of economic growth and other explanatory variables within the model, guiding the system toward long-term stability. The magnitude of this coefficient reflects the rate at which any disparities between expected and actual GDP per capita are corrected, estimated to occur within approximately 1 year.

After the long- and short-run estimation of the panel data, we now examine the causality between the variables by the Dumitrescu and Hurlin (2012) test, to ensure the robustness of our study. The results are presented in Table 11.

Our analysis confirms significant feedback effects between economic growth and variables such as energy consumption, trade openness, gross fixed capital formation, financial development, and institutional quality, as indicated by the statistical significance observed in pairs involving GDP. The relationship between economic growth and public expenditure appears to be unidirectional. Additionally, our findings suggest that gross fixed capital formation, institutional quality, energy consumption, financial development, government expenditure, and trade openness are determinants that drive economic growth. Conversely, economic growth influences these factors, except for public expenditure. This indicates that economic development in Sub-Saharan African and Latin American countries is influenced by the roles of finance, investment, energy use, international trade, government spending, and institutional strengthening.

7. CONCLUSION AND IMPLICATION

This research explores the relationships among energy consumption, public expenditure, institutional quality, financial development, trade openness, and economic growth across 27 Southern countries, utilizing an extended Cobb-Douglas framework with annual data from 2002 to 2020. The analysis employs advanced panel data econometric methods to account for cross-sectional dependence and slope heterogeneity. Following the identification of these panel characteristics, stationarity properties are examined using unit root tests developed by Im et al. (2003) and the CIPS test by Pesaran (2007). The Westerlund (2007) cointegration test is employed to verify long-term relationships, while the Pooled Mean Group (PMG) and Mean Group (MG) estimators are used to derive parameter estimates with robustness checks. Additionally, Dumitrescu and Hurlin's (2012) causality tests are conducted to analyze the directional relationships among variables.

The empirical results indicate an unexpected negative association between energy consumption and economic growth in the long run, a finding consistently supported by both FMOLS and PMG estimators. This may suggest inefficiencies, structural constraints, or misallocation of resources within the energy sectors of these countries that hinder economic development. Conversely, public expenditure, institutional quality, financial development, and trade openness are found to have positive long-term effects on growth. In the short run, most variables positively influence growth, except for financial development and institutional quality, indicating differential effects over time. Causality analysis further confirms bidirectional relationships between energy consumption and economic growth, as well as between trade openness, financial development, and growth.

These findings offer important policy insights for Southern countries. The negative long-term relationship between energy consumption and growth highlights the need for policies focused on energy efficiency and structural reforms in the energy sector, rather than solely increasing supply. Investing in renewable energy sources, infrastructure upgrades, and energy-saving technologies could help transform this relationship. The positive impact of institutional quality emphasizes the importance of governance reforms and capacity-building initiatives. The study advocates for integrated policy strategies that consider the interconnectedness of energy, financial, trade, and institutional factors. Strengthening institutional frameworks, implementing energy efficiency measures, and coordinating financial sector development are essential for fostering sustainable long-term economic growth in these nations.

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ANNEX

Table A1: Countries listed

1	South Africa	11	Mozambique	21	Chile
2	Benin	12	Namibia	22	Colombia
3	Botswana	13	Nigeria	23	Equator
4	Cameroun	14	Senegal	24	Paraguay
5	Democratic Republic of Congo	15	Soudan	25	Perou
6	Côte d'Ivoire	16	Tanzania	26	Uruguay
7	Gabon	17	Togo	27	Venezuela
8	Ghana	18	Argentina		
9	Kenya	19	Bolivia		
10	Mauritius	20	Brazil		

Source: Author