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Exploring the Causal Relationship Between Energy Consumption and Economic Growth: Evidence from Eastern Africa

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Abstract: Understanding the relationship between energy consumption and economic growth is crucial for Eastern Africa, a region experiencing rapid economic expansion alongside persistently low energy use. This study intends to determine whether energy consumption drives economic growth or merely results from it in 13 Eastern African countries using annual panel data from 2012–2021. Employing the Dumitrescu-Hurlin panel causality test and a two-step System Generalized Method of Moments estimator, the findings reveal unidirectional causality from energy consumption to economic growth, consistent with the growth hypothesis. Specifically, a 1% increase in energy consumption is associated with a 0.1 percentage point increase in GDP ($p < 0.01$), while a 1% increase in energy prices reduces growth by about 0.073 percentage points ($p < 0.05$). Further analysis using a Granger non-causality test indicates bidirectional causality between natural logarithm of energy consumption (LnEnergy) and GDP ($p = 0.017$), confirming that GDP also influences LnEnergy. Similarly, bidirectional causality between LnPrice and GDP is observed at the 1% significance level, suggesting that economic performance affects energy prices. These findings reveal the complex feedback channels linking energy use, prices, and economic activity, and support the need to expand regional energy infrastructure, stabilize energy prices, and enhance capital investment efficiency within Eastern Africa's economic dynamics. Overall, the results emphasize adopting a holistic methodological approach that considers interrelated factors rather than relying solely on one-way causal explanations of the energy–growth relationship.

Keywords: Economic Growth; Energy Consumption; Causality; SGMM

1. Introduction

In developed and developing nations, energy is considered one of the most important elements for promoting economic growth [1]. According to Xiaoman et al. [2], it is a key development facilitator, supporting regional development agendas, the African Agenda 2063, and Sustainable Development Goal 7. Together, these frameworks acknowledge that energy will play a critical role in raising living standards, promoting economic expansion, and tackling a variety of social, economic, and environmental issues by 2030 [3,4]. According to reports, energy is a major component of production worldwide and is a crucial sign of expanding economies [5]. According to numerous reports, a nation's energy consumption is directly related to nearly every stage of economic growth [6], but the binary connection between energy consumption and economic expansion remains controversial [7,8].

While some studies contend that energy consumption and economic growth are strongly positively correlated, others counter that there isn't always a positive correlation between the two. Energy is a basic input for economic production, and its significance in propelling economic growth cannot be overstated, according to the positive relationship argument [7]. Energy is essential for enabling productivity and growth in several economic sectors, such as manufacturing, transportation, and agriculture. Economic growth is stimulated by increased productivity, which is a direct result of increased energy consumption. This relationship has been further cemented by industrialization and technological advancements. Energy demands increase in tandem with economic development and industrialization. As a result, there is a positive feedback loop whereby increased energy use stimulates economic growth. Notably, mining and heavy manufacturing are two examples of energy-intensive industries that significantly contribute to the GDP. As a result, raising energy use in these industries can greatly increase total economic output.

Conversely, research supports the negative relationship argument, which holds that energy consumption has diminishing returns. Stated differently, the additional economic benefits decrease with increasing energy consumption, thereby decreasing the effectiveness of energy consumption as a growth driver. Environmental constraints are another issue that cannot be disregarded. Increases in energy use that happen too quickly can cause pollution and greenhouse gas emissions, among other environmental problems, which can eventually have a negative economic impact. Therefore, increasing energy consumption in the name of economic growth may have unfavorable and unsustainable environmental effects, which could eventually hurt economic prospects. Additionally, the volatility of energy prices is a major obstacle. Energy price fluctuations may cause the economy to become unstable. When energy prices fluctuate, a nation that relies too heavily on energy as its main engine of growth may be vulnerable to economic shocks and instability. Thus, even though there are unquestionably positive aspects of the connection between economic growth and energy consumption, these counterarguments emphasize the necessity of a sustainable and balanced approach to both economic development and energy policy.

In a similar vein, the significant recent increase in the use of alternative energy sources and economic growth have all been identified as factors contributing to rising energy consumption [9]. This emphasizes the urgent need to address energy-related issues, such as equitable access to energy resources, effective resource allocation, policy formulation and decision-making, and energy security, both now and in the future. In contrast to the industrial sector, which uses a lot more energy, empirical research has demonstrated that people who work in less energy-intensive industries, like the service and knowledge-based sectors, tend to use less energy when economic growth slows down [3,5]. On the other hand, other research indicates that excessive energy consumption tends to negatively impact the environment and change the course of economic growth [6–12]. Consider the study by Li and Leung [13], which found that lower-income countries' economic growth has a negative and substantial impact on energy consumption. However, in developed nations, there is a widespread perception that increased energy use is essential for promoting economic expansion [14].

Because economic structures, factor endowments, and consumption patterns vary among nations and regions, it is necessary to conduct specific, empirical research on the causal relationship between energy consumption and economic growth to guide the development of appropriate policy measures. Interestingly, different levels of energy consumption arise as economies expand and cross-sector transitions take place, leading to implications for maintaining the economy [12,15–19]. The causal relationship between energy consumption and economic growth, however, has drawn more scholarly attention because of the possible policy ramifications [3,5,6,10]; there is still unclear agreement on whether rising energy consumption promotes economic expansion or not. Four hypotheses have also been predicted by the current research, each with a variety of policy implications [20–23]. Growth hypotheses, for example, support policies that encourage energy consumption to promote economic growth, as economic growth drives energy consumption [24,25]. On the contrary, the conservation hypothesis posits that energy consumption is driven by economic growth, highlighting the fact that energy policies do not impact economic growth but rather that shifts in economic growth lead to shifts in energy consumption [18,26].

According to several studies, energy consumption and economic growth are correlated in both directions, presuming that they are interdependent [21,27–29]. Energy use and economic growth are not causally related, according to the neutrality hypothesis. Such policies are unlikely to significantly affect economic growth, according to Li and Leung, Nwaka, Mangla, Dye and Hasan et al. [13,30–33]. All of these have spurred debate regarding the contribution of energy to economic growth in a particular nation or region, as well as the causal relationship between energy consumption and economic growth. In our view, developing growth-energy policies without empirical support for causality and the directionality of the relationship between these variables is equivalent to coming up with unsuitable strategies for attaining steady economic growth and could have unintended consequences. Energy consumption is low in Africa, which has an average economic growth rate of 5% [34], where the average amount of oil consumed per person is around 0.1 tons, which is much less than the global average of 0.9 tons [35,36]. The assertion is confirmed by AFDB, Cannon et al., Ozcan et al., Dye, Ozcan, and Ozturk [29,37–39], who argue that even though global energy consumption has increased by 2–3%, Africa has the lowest energy consumption. The area uses roughly 3.3 percent of the world's energy, which is less than other areas and unmatched by the fast economic and population growth [40,41]. According to Banday and Aneja [42], the average economic growth in African sub-regions is 5–6% in the East, 4–1% in the North, 3–7% in the West, 3–2% in Central Africa, and 1–2 percent in Southern Africa. At the same time, their respective energy consumption rates are 9–22%, 43%, 10%, and 16%. This demonstrates that although these sub-regions use less energy than other regions, they have greater economic growth [43,44]. Nevertheless, the findings above run counter to the research conducted by Ozcan and Ozturk [39] as well as Solow [45,46], demonstrating that rapid economic expansion or growth tends to boost energy consumption due to the expansion of the energy-intensive industrial sector.

It is anticipated that the East African region will continue to grow and maintain its economic strength in the years to come [31,32], but numerous studies indicate that energy is still an issue [25,47–49]. They found that most regions have low energy consumption. The energy landscape in the region is varied, encompassing both conventional sources like hydropower and biomass as well as the application of numerous projects and strategies. A few notable examples are the gas pipeline that connects Tanzania and Kenya, the crude oil pipeline that connects Tanzania and Uganda, and the Stiegler's Gorge Dam in Tanzania. With the ultimate goal of fostering regional economic growth, these programs were created specifically to increase East Africa's energy production and consumption [46,50,51]. Significant cross-border energy project collaborations are thought to have the potential to change regional energy dynamics and spur economic expansion. In the absence of a clear answer, decision-makers may be misled when formulating policy actions related to regional energy and growth, which could result in less-than-ideal outcomes [29–32]. Nevertheless, a critical question is still unanswered: Does increased energy consumption cause economic growth, or is it a requirement for it in this specific region? Thus, a comprehensive study of the causal relationship between energy consumption and economic growth in the particular context of this region is needed.

With a focus on improving energy resources, the region has set ambitious development goals at the same time, such as the Sustainable Development Goals of the UN and Agenda 2063 of the African Union. The contribution of energy consumption to regional economic growth is a critical factor in the achievement of these goals. The accessibility, affordability, and dependability of energy, however, are frequent problems for East African countries, all of which have a significant impact on regional productivity and could have a detrimental effect on economic growth. While there is a plethora of research, including Manirambona et al. [52], on the causal relationship between energy consumption and economic growth at the national and international levels such as AFDB, EIA, Mangla et al., Bekun and Alola, Awodumi and Adewuyi, Rahman et al. [21,28,32,53–55], there is a dearth of thorough regional research, particularly about East Africa. To close this gap, this study looks at the possible advantages of regional cooperation in the areas of economic prosperity and energy. To address the current ambiguity surrounding the causal relationship between energy consumption and economic growth in the East African region, this study considers regional specificity rather than individual countries.

The East African region also stands out as being particularly distinctive in the theoretical landscape due to its significant economic growth and comparatively low energy consumption. Even though this observation is intriguing, it defies accepted wisdom, such as that of Khan et al. [1], that rising energy consumption leads to greater economic growth. It suggests that higher energy use might be a byproduct of regional economic growth rather than a necessary condition for it per se. The purpose of this study is to highlight energy consumption holistically by incorporating a broad range of energy sources, including both renewable and non-renewable. This methodology recognizes the ongoing importance of energy in all its forms in promoting economic development and provides a thorough grasp of how total energy affects regional economic growth in the East African context. The region can create policies that take into consideration the varied energy mix that exists within its borders instead of concentrating only on specific energy types thanks to the inclusive approach. To help with well-informed decision-making about the energy-economic policy implications for the particular region, this study attempts to address the lack of empirical evidence.

Moreover, it makes sense to recognize the economic growth achieved when labor and capital, the primary production inputs, are available. Growth theories have consistently emphasized the direct and significant impact of these factors on economic output and productivity, especially in neoclassical growth models [56]. Exploring the causal relationship between the main variable of interest is made richer by this addition. Additionally, it is crucial to acknowledge the crucial role that energy prices play. Because it is well known that changes in energy prices affect the cost structures of households and production sectors, which in turn affect patterns of energy consumption and the results of economic growth, the study takes into account how energy prices affect the causal relationship between economic growth and energy use. In addition, it looks at how labor and capital contribute to regional economic expansion and energy use. In order to demonstrate empirically how energy consumption, energy prices, and primary inputs of production contribute to regional economic growth, the study will acknowledge the significance of these important variables. The study specifically answers two questions: (1) what are the causal relationships exist between energy consumption and economic growth, such as whether energy drives economic growth, economic growth drives energy consumption, or if there is a bidirectional relationship? (2) What is directional relationship existing between these key variables, and how consistent are the effects of changes in energy consumption on economic growth?

The study broadens its scope by looking into other factors such as how price affects the causality directions between economic growth and energy consumption. Contributing new insights to the field, these variables illuminate how energy prices affect the dynamics of the relationship between the core variables. Although East Africa is the primary geographic focus, the research's implications apply to other developing economies dealing with comparable issues. Section 2 gives a summary of the literature, Section 3 describes the methodology, Section 4 shows the findings and discussion, and Section 5 draws conclusions.

2. Review of the Literature

2.1. Theoretical Background

This paper is grounded on the neoclassical growth theory developed by Solow [45,46], and extends it to the East African setting by incorporating labour, capital, energy consumption, and energy price. The primary objective is to determine whether energy consumption is the driving force behind economic growth or if it is economic growth that stimulates energy consumption in a region characterized by low energy use, rapid economic and population growth, urbanization, and abundant renewable resources [43,57,58]. Historically, neoclassical theorists have lent substantial support to the Solow growth model, which postulates that economic growth hinges on the accumulation of both capital and labour. The theory presents the relationship between the inputs and outputs, and details the factors influencing economic growth. Similarly, Cvetanović et al. [44] refined this by quantifying the individual contributions of labour and capital to output, while Ehigiamusoe, Lean, and Smyth [59] emphasized the moderating role of energy consumption in the emissions–income nexus, highlighting energy's critical position in growth-related frameworks. Similarly, Romer [60] highlighted the role of technology as a separate factor that enhances the productivity of both labour and capital. Thus, neoclassical growth model underscores the importance of capital accumulation and its efficient utilization in driving economic growth [56]. Building on this foundation, capital–labour interactions further shape aggregate production, and technological advances augment input efficiency [57,58]. Although Solow's original formulation omits energy, we argue that energy consumption is a fundamental production factor and catalyst for growth. Energy use underpins industrial operations and household activities, thereby boosting overall productivity and fostering economic expansion. This perspective views energy as a near-universal input across sectors. On one hand, Saad and Taleb [61] argued for the inclusion of energy as a production input, highlighting its role in industrial processes and household activities. On the other hand, Tamba, Nsouandélé, and Lélé [62] examined the impact of energy price volatility and found that fluctuations in energy costs significantly influence economic growth trajectories. Lee in the study by Cevik et al. [16] further augmented the Solow model by incorporating both energy consumption and energy price alongside capital and labour, underscoring energy's status as a core production component.

Kraft and Kraft (1978) [47] conducted the first empirical Granger-causality test of energy consumption and economic growth in the United States. Santos and Rodrigues [50] extended that analysis to developing economies and confirmed a robust positive link. Nguyen [63] applied a panel-ARDL approach to ASEAN countries and found that higher energy consumption significantly increases per-capita GDP. Ali [64] examined South Asian economies and demonstrated that increases in energy use lead to higher levels of industrial output. Chen [65] used time-series data from China to show that energy consumption drives long-term economic expansion. Rahman [66] reported a strong positive relationship between energy use and per-capita income in Middle Eastern countries. Silva [67] analyzed Latin American economies and confirmed that energy consumption remains a key determinant of economic development across diverse contexts. Underscoring energy's status as a core production component. These prior contributions underscore the need to account explicitly for both energy consumption and energy price in growth analyses.

Complementary literature across other regions reveals additional dimensions. For instance, Rahman [55] demonstrated that variations in energy intensity across industries explain differences in growth performance, highlighting efficiency as a key driver. Li and Leung [13] found that increased use of renewable energy sources amplifies energy's positive effect on GDP in Scandinavian countries, underscoring the role of sustainable policies. Lee and Park [68] further showed that technological innovation in energy production intensifies the impact of energy consumption on GDP across OECD nations, emphasizing innovation's critical importance. Turning to emerging Asian markets, Shahbaz [69] provided evidence from India that investment in energy infrastructure is essential for sustaining long-term economic expansion, indicating the need for strategic capital allocation. Kumar [70] linked trade openness to enhanced energy efficiency and stronger growth outcomes in South Asia, illustrating globalization's benefits. Yan et al. [71] documented that targeted subsidy policies in East Asia significantly strengthen the energy–growth nexus, pointing to effective government intervention. Saidi [72] identified sectoral composition as a key moderator of the energy–growth link in Middle Eastern economies, suggesting that economic diversification matters for maximizing energy use benefits. In Sub-Saharan Africa, Shahbaz [73] reported that institutional quality moderates the energy–growth relationship, implying governance is a crucial factor. Together, these prior contributions underscore the need to explicitly account for both energy consumption and price to evidence region-specific unique insights for appropriate energy-growth-tailed policy actions and decisions.

Therefore, this study employs an augmented Solow model that integrates labour (L_{it}), capital (C_{it}), total energy consumption (EC_{it}), and energy price (EP_{it}) when examining per-capita GDP in Eastern Africa. This region requires region-specific empirical evidence due to its unique combination of rapid economic growth and persistent energy challenges. Accordingly, our model specification follows the conventional production function outlined in

$$Y_{it} = \beta_0 + \beta_1 C_{it} + \beta_2 L_{it} + \beta_3 EC_{it} + \beta_4 EP_{it} + \mathcal{E}_{it} \quad (1)$$

where the Y_{it} represents per capita GDP in East African countries during different time periods, denoted by the subscripts i and t. The variables C_{it}, L_{it}, EC_{it}, and EP_{it} are associated with physical capital, labour, energy consumption, and energy price, respectively, for each country and time period, and the term $\mathcal{E}_{it}$ stands for the error term, specific to each country and time period.

2.2. Empirical Review

The energy–growth nexus has been extensively studied, yielding insights that vary by sector, region, and analytic approach. Initially, there is varying empirical evidence on whether increases in energy consumption support economic growth or hamper it. Studies reveal that declines in output within less energy-intensive industries correspond with reduced energy consumption. For instance, in ECOWAS manufacturing, declines in output within less energy-intensive sectors lead directly to lower energy use and in U.S. manufacturing, lower production levels correspond with proportional drops in energy consumption. Nwaka [33] applies quantile regression and decomposition analysis, showing that output shifts in specific crop subsectors non-linearly affect CO_2 emissions and thus energy use across low- and high-production quantiles. Emirmahmutoglu et al. [74] employs frequency-domain causality tests for the U.S. and demonstrates that changes in GDP and energy consumption are tightly coupled across all frequencies, indicating a persistent two-way link between economic activity and energy needs.

Conversely, IEA [22] documents that excessive energy use accelerates environmental degradation, creating a negative feedback loop that suppresses GDP growth. IEA [23] extend this by showing that overuse of energy resources in emerging markets generates pollution costs which further dampen economic expansion; furthermore, Zaidi and Ferhi [66] quantify these pollution-related economic damages and illustrate how they feedback negatively on overall growth. Kim and Park [35] uses a nonlinear causality framework across multiple timescales and finds that the direction of causality between energy use and output in OECD countries depends on the horizon short-run links differ markedly from longer-run dynamics. Lorenzo and Oscar [75] review sustainable energy planning in Burundi and highlight how policy frameworks mediate the relationship between energy infrastructure development and economic growth in nascent markets.

Analytic approach assessments highlight persistent inconsistencies in causality results arising from differences in sample composition, temporal scope, and econometric framework. Scholars employing panel and time-series techniques [16,30], along with considerations of cointegration and causality testing protocols [76,77] and underscore how these choices shape conclusions and contribute to ongoing debate. Research on the direction of causality within this nexus can be categorized into three core hypotheses. First, the growth hypothesis; energy-growth is supported by panel cointegration and Granger causality evidence in emerging economies [19], and the OECD countries [78], as well as South Asia [79,80]. For instance, non-linear ARDL analysis in seven Eastern nations [81] affirms unidirectional energy-driven growth dynamics, while wavelet coherence techniques in G7 [82] and the UK nuclear sector [79] further verify low-frequency energy-growth causality.

Second, the conservation hypothesis; growth-energy emerges in Latin American settings through ARDL bounds testing [83] and in oil-dependent economies under Granger frameworks Blundell and Bond [84], indicating that robust economic expansion precedes higher energy consumption. Whereas the third one is feedback hypothesis; bidirectional causality is observed in Sub-Saharan Africa via system GMM [66,85] and dynamic simultaneous-equation models in Azerbaijan and broader African samples like of Vlăduț, et al. [86] and Hansen, et al. [87] corroborated by vector error correction findings in Southeast Asia [40]. Lastly is neutral hypothesis, denoting the absence of causality, it has also been proposed in oil economies and India, using nonlinear ARDL and nonparametric methods to illustrate context-specific neutrality [76,88]. Further methodological advancements have refined our analytical approach, improved heterogeneous-panel causality tests [89], dynamic GMM implementations (xtabond2) [77,87], and instrumental-variable critical for modern system GMM estimations [76,84].

The Dumitrescu–Hurlin framework [89] and comprehensive panel causality buildings [90] address heterogeneity and cross-sectional dependence, while global panels underscore the joint role of energy prices and consumption in shaping GDP trajectories [91]. Despite these sophisticated contributions, the literature often underemphasizes regional socio-economic contexts. Our study addresses this gap by focusing on Eastern Africa, a region characterized by relatively low per-capita energy use, rapid demographic growth, and evolving industrial structures to provide empirically grounded policy insights that balance economic expansion with energy security.

3. Methodology

3.1. Data

This study used yearly panel data to examine the impacts, directions, and causal relationships between important variables in East Africa. East Africa was selected because of its unique economic trajectory, which is characterized by comparatively low energy consumption and unique socioeconomic factors that are anticipated to lead to higher energy consumption [92]. Ethiopia, Kenya, Madagascar, Mauritius, Mozambique, Rwanda, South Sudan, Sudan, Tanzania, Burundi, Comoros, Djibouti, and Uganda were among the thirteen [13] nations that were included in the analysis. These nations were picked because they were close to one another in East Africa, pertinent data was readily available, and it was necessary to record the region's varied energy and economic dynamics. The selection of nations was done to capture the economic and energy diversity of East Africa while also recognizing their commonalities. This methodology guarantees the findings' relevance to the wider East African context while avoiding the assumption of total homogeneity among the chosen nations. The success of the study also heavily depends on the quality of the data. In terms of the variables of interest, GDP per capita for economic growth, total energy consumption (EC) in kg of oil equivalent per capita assumed to captures both formal and informal sources, labor force (L), growth of capital formation (C), and energy price (EP) from the consumer price index, only nations with up-to-date, easily accessible, and reliable data were chosen. The use of current and reliable information is ensured by this careful selection.

To ensure that the most recent data is included and to comply with statistical test requirements for a balanced dataset, the study dataset covers the panel data of 2012–2021. In addition, the following data processing and measurement methods were used: GDP per capita for economic growth was computed by dividing each nation's total GDP by its population size for each year in the dataset. Data on total energy consumption (EC) was obtained directly from the U.S. Energy Information Administration and provided the total energy consumption for each nation over the given period. Each country's total working-age population for the corresponding years was represented by the labor force (L) data, which were taken from the Global Economy database. To show the percentage of a nation's GDP devoted to capital formation, gross capital formation (C) was computed as a percentage of GDP. The World Development Indicators provided the data for the consumer price index (EP), which illustrates price levels relative to base year 2010. The uniformity and dependability of the dataset were ensured by the consistent execution of these measurements and computations across all selected nations and years. However, as **Table 1** illustrates, energy price, labor force, and consumption were transformed into their respective natural logarithmic forms (LnEnergy, LnPrice, and LnLabor). Additionally, **Figures 1** and **2** present time-series trends of key variables for selected Eastern African countries over the 2010–2021 period, offering preliminary descriptive insights that complement the panel econometric analysis.

Table 1. Description of Variables.

Variables	Units of Measurement	Source
GDP per capita growth	Annual Percentage	https://databank.worldbank.org/source/world-development-indicators
Consumer price index	2010 = 100	https://databank.worldbank.org/source/world-development-indicators
Gross capital formation	Percentage of GDP	https://databank.worldbank.org/source/world-development-indicators
Total energy consumption	Terajoules	https://www.eia.gov/international/data/world
Labour force	Total working group	https://www.theglobaleconomy.com/rankings/labor_force

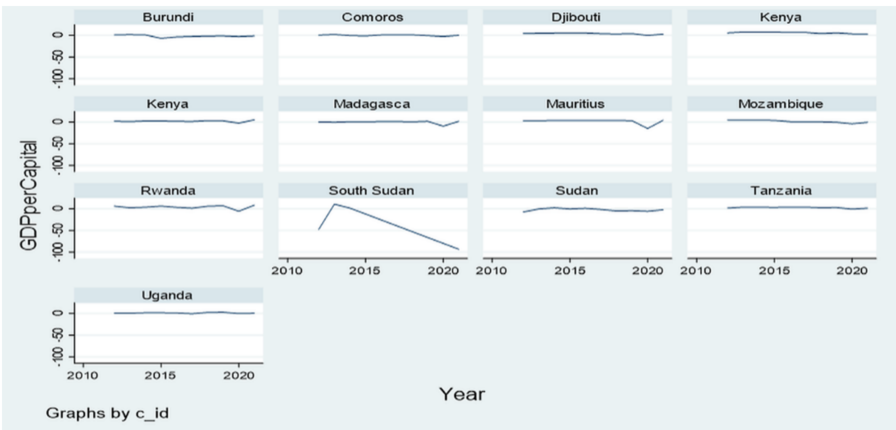

Figure 1. Trend of Gross Domestic Product.

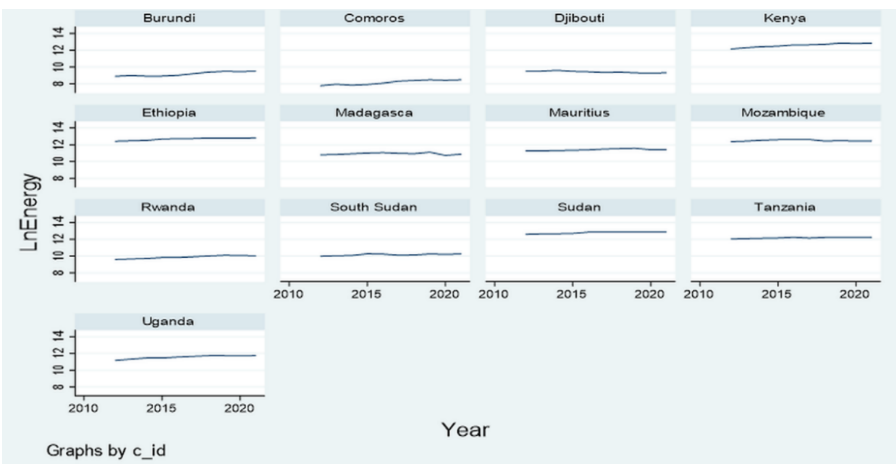

Figure 2. Trend of Energy Consumption.

3.2. Estimation Strategies

In this study, causality [89] and generalized estimation methods (SGMM) developed by Arellano and Bover [76,93] and Blundell and Bond [84] were used for analysis. As a first step to determine whether causality and directional relationships exist between the variables of interest, researchers use the panel root test, while allowing for cross-sectional dependencies [94]. This step is essential before conducting a causality test, as it determines the robustness of the data set [95]. The testing of panel roots is crucial to avoid spurious regression results in time series or panel contexts. In our study, the Breusch-Pagan Lagrange Multiplier (LM) and Pesaran Cross-Sectional Dependence (CD) tests were first carried out to determine whether the panel data was affected by cross-sectional dependencies [96]. It is of particular importance in regional blocs such as East Africa, where countries are economically and geographically interdependent.

The study replaced the previous Levin-Lin-Chu (LLC) and Hadri LM tests with the second-generation Cross-Sectionally Augmented Im-Pesaran-Shin (CIPS) test after cross-sectional dependence was detected in our analysis. The CIPS test is favored because it validates that the variables are stationary in level or first difference and is robust in panels with interdependencies and non-synchronous shocks. Accordingly, this substitution guarantees that the stationarity conditions were examined utilizing techniques suitable for panels with cross-sectional correlation [97,98]. The Dumitrescu and Hurlin Granger causality test was then used in the study to determine the types of causality and the directional relationships between the variables. This test was chosen because it has several benefits that are appropriate for the research setting. It can manage cross-sectional dependencies, which is essential in an area where economies may be intertwined like the East African economy. Additionally, the test leverages panel data effectively, covering a variety of data dimensions across time and entities. This test explicitly allows for correlated shocks across countries by aggregating pair-wise statistics, and accommodates country-specific slope heterogeneity before forming a global causality indicator.

The panel data analysis takes into consideration the countries' heterogeneity, acknowledging that each has distinct qualities that may affect the dynamics of energy consumption and economic growth. For this study, its capacity to provide robust and dependable causal inference results while accounting for these intricate regional variations makes it an indispensable tool [79]. Using the GMM framework, the dynamic effects of energy consumption on economic growth were further investigated. However, as described in the study of Li, et al. [99], the ordinary least square (OLS) and fixed effect (FE) were used to determine which dynamic panel model should be used between the difference generalized methods of moments (DGMM) and the system generalized methods of moments (SGMM). Due to the asymptotic greater power of the statistical test based on the two-step estimator, the study chose to use the two-step difference and system-GMM rather than the one-step approach [100]. In addition, it is more reliable and effective when considering autocorrelation and heteroskedasticity. The two-step SGMM additionally leverages both differenced and level instruments to address endogeneity, while its system formulation captures unobserved fixed effects and heterogeneity across countries.

Furthermore, a two-step SGMM has been selected instead of a difference GMM because it has the potential to solve endogeneity problems in variables, as endogeneity may arise due to the potential for feedback effects between energy consumption and economic growth, where each variable influences the other [101]. For instance, increased economic activity may lead to higher energy needs, while simultaneously, energy shortages can constrain economic outputs. In a two-stage SGMM, the instruments are designed with differentiation and a level playing field [100]. SGMM uses lagged values of the endogenous variables as instruments, both in levels and in differences, to address potential biases. Introducing a level equation in SGMM increases the number of valid instruments and improves efficiency compared to DGMM, especially when dealing with weak instruments [77]. Furthermore, causality analysis using the Dumitrescu and Hurlin test [89,93] indicated the presence of feedback effects between energy consumption and economic growth, reinforcing the need to account for potential endogeneity in our model.

Also controls for bias and inefficient estimates of the value of Φ in finite samples whenever the dependent variables are close to a random walk (i.e., $\Phi \rightarrow 1$) and it is acute when the period is small (small T, large N). Therefore, this study fulfilled the criteria for the estimation of the SGMM. Diagnostic tests have been performed to confirm the estimation results and to ensure the reliability of the instruments used in the double-phase SGMM and double-phase DGMM systems, as recommended by Roodman [70] and Ullah et al. [101], as stated in the study by Bond [102]. To contextualize our chosen methodology, **Table 2** provides a comparative overview of various panel data estimators, highlighting their strengths and weaknesses with respect to handling cross-sectional dependence, slope heterogeneity, endogeneity, performance in small-T/large-N panels, and modeling dynamic feedbacks.

Table 2. Comparison of Panel Estimation Techniques.

Criterion	D-H Causality	2-Step SGMM	CS-ARDL	CCEMG/AMG	Panel VAR
Cross-section dependence	✗ Doesn't model common shocks	✓ Instruments mitigate cross-sectional shocks	✓ Accounts for unobserved common factors	✓ Common correlated effects	✗ Assumes residual independence
Slope heterogeneity	✓ Country-specific slopes allowed	✗ Homogeneous slope dynamics	✓ Heterogeneous long-run slopes	✓ Mean-group heterogeneity	✓ Fully heterogeneous dynamics
Endogeneity control	✗ No direct control	✓ GMM instruments for endogenous regressors (Ahmad et al., 2022)	✓ Controls for endogeneity through common correlated effects	✓ Controls for endogeneity through common correlated effects	✓ Endogeneity addressed through system of equations
Data Requirements (T, N)	✓ Designed for short panels	✓ Well-behaved when N≫T	✗ Needs moderately long time dimension (T > 10)	✗ Convergence issues with small T	✗ Poor small-T performance
Dynamic feedbacks	✓ Detects direction of causality	✓ Captures dynamic lag structure	✓ Long- and short-run parameter estimates	✗ Focus on long-run heterogeneity	✓ Rich impulse–response analysis
Causality	✓ Granger causality test	✓ Instrumental variables approach	✓ Addresses endogeneity through correlated effects	✓ Addresses endogeneity through correlated effects	✓ System of equations approach

Notes: "✓" indicates the method accommodates the feature; "✗" indicates it does not.

3.3. Study Estimation Models

3.3.1. Dumitrescu and Hurlin 's Causality Model

The panel Granger non-causality test proposed by Dumitrescu and Hurlin [89] was used, as given in Equation (2), to determine the presence and direction of causality between the explanatory variables, physical capital (C), labor (L), energy price (EP), and energy consumption (EC), and the outcome variable (GDP per capita, represented by (Y). This test is preferred for heterogeneous panel data due to its ability to account for both heterogeneity and cross-sectional dependence, making it more appropriate for the East African context than alternatives [53]. The null hypothesis (H_0) states that there is no homogeneous causality across cross-sectional units, while the alternative hypothesis (H_1) assumes the presence of causality in at least some countries.

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} Y_{ik} Y_{i,t-k} + \sum_{k=1}^{K} \beta_{ik} \beta_{i,k} X_{i,t-k} + \varepsilon_{it} \quad (2)$$

where $Y_{i,t}$ represents per capita GDP, α_i is the country-specific intercept, $Y_{i,k}$ and $\beta_{i,k}$ are coefficients for lagged variables. These lagged variables are $Y_{i,t-k}$ and $X_{i,t-k}$. This equation is applied across East African countries and time periods (i = 1 to N, t = 1 to T), and the coefficients are time-invariant. The lag order K is consistent for all countries, and the panel data is balanced.

3.3.2. Arellano-Bond Generalized Method of Moments Models

To examine the effects of energy consumption on economic growth, the study employed the Arellano-Bond Generalized Method of Moments (GMM) estimation framework, drawing from an augmented production model consistent with International Energy Agency [22] and Shahbaz, et al. [69]. The general form of the model is given in

$$Y_{it} = \beta_0 + \beta_1 Y_{i,t-1} + \beta_2 Z_{i,t-1} + \beta_3 X_{i,t-1} + \varepsilon_{i,t} \quad i = 1, 2, ..., N; t = 1, 2, ..., T \quad (3)$$

where represents GDP, indicates the explanatory variable, signifies the control variable, $Y_{i,t-1}$ denotes the lagged values of GDP and represents the error term specific to individual countries and specific time periods.

To control for endogeneity, unobserved heterogeneity, and serial correlation, the dynamic panel GMM estimator was applied using both level and first-difference specifications. The functional forms are given in

$$Y_{it} = \beta_0 Y_{i,t-1} + \beta_1 C_{it} + \beta_2 \ln L_{it} + \beta_3 \ln EC_{it} + \beta_4 \ln EP_{it} + \varepsilon_{it} \quad (4)$$

$$\Delta Y_{it} = \beta_0 \Delta Y_{i,t-1} + \beta_1 \Delta C_{it} + \beta_2 \Delta \ln L_{it} + \beta_3 \Delta \ln EC_{it} + \beta_4 \Delta \ln EP_{it} + \Delta \varepsilon_{it} \quad (5)$$

Where Y_{it}, represents lagged real GDP, is capital formation, $\ln L_{it}$, $\ln EC_{it}$, and $\ln EP_{it}$ represent the natural logarithms of labor force, energy consumption, and energy price respectively, Δ is the difference of one period and is error term while the subscript i denotes the country, and t denotes the period.

4. Results and Discussion

4.1. Descriptive Statistics and Correlation Matrix

Table 3 presents the descriptive statistics for the panel data covering thirteen [13] East African countries from 2012 to 2021. The average GDP per capita growth rate across the sample is −1.768, with a standard deviation of 14.828, indicating substantial cross-country heterogeneity.

Table 3. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP	130	−1.768	14.828	−93.42	10.493
Capital	130	23.989	15.868	−7.712	110.893
LnPrice	130	5.323	1.067	4.196	10.024
LnLabor	130	15.477	1.721	12.145	17.839
LnEnergy	130	11.029	1.495	7.77	12.871

The minimum value of −93.42, observed in South Sudan, reflects severe economic contraction, while the maximum value of 10.493, recorded in Rwanda, denotes robust economic growth. This wide variation suggests that in some countries, population growth may be outpacing economic performance on a per capita basis. The mean values for consumer prices, labor force size, and energy consumption are 5.323, 15.477, and 11.029, respectively, reflecting notable cross-country differences in economic structure and resource utilization. These descriptive statistics provide important contextual insight into the region's macroeconomic characteristics. The core empirical analysis centers on panel estimation techniques, namely the Dumitrescu and Hurlin [89] panel causality test and the two-step System Generalized Method of Moments (SGMM) estimator, as both are suited to addressing unobserved heterogeneity, endogeneity, and dynamic relationships in panel data.

Table 4 presents the Pearson correlation matrix, which explores the statistical relationships among the study variables. A moderate negative correlation is observed between GDP per capita growth and price (−0.772), suggesting that higher price levels are associated with weaker economic performance. In contrast, GDP per capita growth exhibits positive but relatively weak correlations with capital formation (0.395), labor (0.022), and energy consumption (0.139). Importantly, none of the pairwise correlations exceed the commonly accepted threshold of 0.8, and the mean variance inflation factor (VIF) remains below 2.7, indicating that multicollinearity is not a concern in the subsequent model estimations.

Table 4. Pairwise Correlations.

Variables	GDP	Capital	LnPrice	LnLabour	LnEnergy
GDP	1.000				
Capital	0.395***	1.000			
LnPrice	−0.772***	−0.249**	1.000		
LnLabor	0.022	0.336***	0.241**	1.000	
LnEnergy	0.139	0.492***	0.183**	0.743***	1.000
VIF		1.56	1.26	2.29	2.69
Mean VIF		0.639	0.796	0.436	0.371
1/VIF					1.95

Note: *** $p < 0.01$, ** $p < 0.05$.

4.2. Cross-Sectional Dependence and Panel Unit Root

To ensure the robustness of the panel analysis and avoid spurious regression results, the study first tests for the presence of cross-sectional dependence among the countries. Evidence from both the Breusch-Pagan LM test and the Pesaran CD test confirms significant cross-sectional dependence. In light of this, the Cross-sectionally Augmented IPS (CIPS) test, a second-generation panel unit root test, is employed to assess the stationarity properties of the variables. This test is appropriate in the presence of cross-country correlation, which is common in regional groupings such as Eastern Africa. As shown in **Table 5**, not all variables are stationary at level. For instance, we found that GDP is stationary in terms of level in both constant and trend. In contrast, capital, labor, energy, and price showed mixed results in level but were also confirmed to be stationary at first difference under both constant and trend specifications, confirming their integration of order one. Therefore, the results support the use of panel models that are compatible with variables integrated of order zero or one, provided none is integrated of order two [99,102]. On this basis, the study applies the Dumitrescu and Hurlin [89] panel causality test and the two-step System GMM estimator, both of which account for cross-sectional dependence, dynamic relationships, endogeneity, and country-specific heterogeneity.

Table 5. Cross-Sectional Dependence and Panel Unit Root.

	Cross-Section Dependency (CD)		**Cross-Sectionally Augmented IPS (CIPS) Panel Unit Root**			
	Breusch-Pagan LM Test	**Pesaran CD Test**	**CIPS Panel Unit Root**		**CIPS First Difference**	
Variables	**Test Statistics**	**Test Statistics**	**Constant**	**Constant and Trend**	**Constant**	**Constant and Trend**
GDP	219.191***	12.142***	−2.812***	−3.562**		
Capital	160.435***	2.810***	−1.396	−2.405	−2.558**	−2.623
LnPrice	721.751***	18.449***	−0.531	−0.375	−0.615	−2.714*
LnLabor	711.417***	26.541***	−2.012	−1.866	−1.857	−3.291**
LnEnergy	409.906***	12.867***	−2.053	−1.782	−2.348*	−2.138

Note: Significance levels: *** 1%, ** 5%, * 10%.

4.3. Dumitrescu and Hurlin Panel Causality Results

The findings in **Table 6**, based on the panel causality test employed by Dumitrescu and Hurlin [89], reveal several unidirectional causal relationships among the study variables. The first notable relationship is from energy consumption to GDP, which is statistically significant at the 1% level, with a p-value of 0.0078. This indicates that increases in energy consumption contribute to economic growth in the region. However, no reverse causality from GDP to energy was detected, suggesting that energy consumption serves as a driver rather than an outcome of economic performance. The second significant causal link is from price to GDP, with a p-value of 0.0001, and from price to capital, with a p-value of 0.0071; both are statistically significant at the 1% level. These results imply that energy prices influence both economic growth and investment behavior. Rising prices may dampen GDP by increasing production costs and reducing consumer purchasing power, while also affecting capital accumulation by altering cost structures and investment returns.

Table 6. Causality Test Results.

Panel Causality Test (Lag Order: 1)			
Null Hypothesis:	**W-Stat.**	**Zbar-Stat.**	**Prob.**
LnEnergy does not homogeneously cause GDP	3.9732	2.6586	0.0078**
GDP does not homogeneously cause lnEnergy	0.82653	−0.72395	0.4691
LnLabor does not homogeneously cause GDP	7.6464	6.60718	0.0004***
GDP does not homogeneously cause lnLabor	1.38953	−0.11875	0.9055
LnPrice does not homogeneously cause GDP	7.17619	6.10172	0.0001***
GDP does not homogeneously cause lnPrice	1.57126	0.0766	0.9389
Capital does not homogeneously cause GDP	19.1032	18.9228	0.0002***
GDP does not homogeneously cause Capital	4.65129	3.38754	0.0007***
LnLabor does not homogeneously cause lnEnergy	2.08283	0.62652	0.531
LnEnergy does not homogeneously cause lnLabor	1.34302	−0.16874	0.866
LnPrice does not homogeneously cause lnEnergy	1.7508	0.2696	0.7875
LnEnergy does not homogeneously cause lnPrice	2.9629	1.57257	0.1158
Capital does not homogeneously cause lnEnergy	3.53854	2.19137	0.0284**
LnEnergy does not homogeneously cause Capital	2.47665	1.04987	0.2938
LnPrice does not homogeneously cause lnLabor	2.3921	0.95898	0.3376
LnLabor does not homogeneously cause lnPrice	10.754	9.94779	0.0002***
Capital does not homogeneously cause lnLabor	1.857	0.38376	0.7012
LnLabor does not homogeneously cause Capital	3.373	2.01342	0.0441**
Capital does not homogeneously cause lnPrice	2.62232	1.20646	0.2276
LnPrice does not homogeneously cause Capital	4.00653	2.69444	0.0071**

Note: Causality was tested using the Dumitrescu and Hurlin [89] panel causality approach at significance levels: *** 1%, ** 5%, * 10%.

A third causal pathway is observed from labor to GDP and to price, with p-values of 0.0004 and 0.0002, respectively, both significant at the 1% level. These findings underscore the productive role of labor in driving economic activity and influencing inflationary trends. The absence of reverse causality from GDP to labor further reinforces the view that labor supply is an exogenous input in the region's growth dynamics. Additionally, the study shows bidirectional causality between capital and GDP, with both directions significant at the 1% level and *p*-values of 0.0002 from capital to GDP and 0.0007 from GDP to capital, indicating mutual feedback effects. This suggests that while capital formation drives GDP growth, economic expansion also stimulates further investment, reinforcing cyclical growth mechanisms. Furthermore, we found that capital Granger-causes energy consumption (*p*-value 0.0284) and labor causes capital formation (*p*-value 0.0441); both are significant at the 5 percent level. These results demonstrate how crucial capital is in determining how resources are used and the amount that can be produced in Eastern Africa.

Collectively, the results indicate that energy consumption, labor, and price are key drivers of economic growth in the region. These findings are consistent with the work of Raza, et al. [103] and Perera, et al. [104], who reported unidirectional causality from energy to growth. However, they differ from the studies of Cevik, et al. [16], which found bidirectional causality between energy consumption and economic growth. The observed two-way causality between capital and GDP aligns with the findings of Yeboah, et al. [105], as well as studies conducted in US, Europe, Asia, and Africa [11,55]. In contrast, it contradicts the conclusions of the studies of Nwaka, et al. [31] and Raza, et al. [103], who reported a one-way relationship between capital and economic growth in selected African and American contexts.

Employing Juodis, Karavias, and Sarafidis [41] Granger non-causality test, the results presented in **Table 7** reveal several causal relationships among economic growth (GDP), capital formation (Capital), and energy consumption (LnEnergy). In 13 Eastern African nations, the results show clear bidirectional and unidirectional relationships between energy consumption (LnEnergy), energy price (LnPrice), economic growth (GDP), capital formation (Capital), and labor force (LnLabor).

Table 7. Causality Test Results.

Granger Non-Causality Test Results (Lags = 2)		
Null Hypothesis	**HPJ Wald Stat**	***p*-Value**
Capital does not Granger-cause GDP	18.0621	0.0001***
GDP does not Granger-cause Capital	3.3178	0.1903
LnEnergy does not Granger-cause GDP	8.1518	0.0170*
GDP does not Granger-cause LnEnergy	9.3006	0***
LnPrice does not Granger-cause GDP	14.8144	0.0006***
GDP does not Granger-cause LnPrice	155.3479	0.0000***
LnLabor does not Granger-cause GDP	40.2431	0.0000***
GDP does not Granger-cause LnLabor	12.9853	0.0015**
Capital does not Granger-cause LnEnergy	17.5973	0.0002***
LnEnergy does not Granger-cause Capital	2.8371	0.2421
LnPrice does not Granger-cause Capital	64.5804	0.0000***
Capital does not Granger-cause LnPrice	1.6004	0.000***
LnLabor does not Granger-cause Capital	30.7954	0.0000***
Capital does not Granger-cause LnLabor	1.7006	0.0000***
LnEnergy does not Granger-cause LnPrice	7.2001	0.0273*
LnPrice does not Granger-cause LnEnergy	8.4285	0.0148*
LnLabor does not Granger-cause LnEnergy	7.5701	0.0227*
LnEnergy does not Granger-cause LnLabor	1.7003	0.0000***
LnPrice does not Granger-cause LnLabor	4.9007	0.0000***
LnLabor does not Granger-cause LnPrice	23.1726	0.0000***

Note: Results are based on the test developed by Juodis, Karavias and Sarafidis [41] at significance levels: *** 1%, ** 5%, * 10%.

A robust pattern of bidirectional causality is evident in the results, suggesting that different economic variables are mutually dependent on one another. For example, GDP and energy consumption (LnEnergy) are causally related in both directions: GDP causes LnEnergy (*p*-value = 0.0000), and LnEnergy causes GDP (*p*-value = 0.0170). The relationship between energy prices (LnPrice) and GDP is also strongly bidirectional, with GDP Granger-causing LnPrice (*p*-value = 0.0000) and LnPrice Granger-causing GDP (*p*-value = 0.0006). Further, GDP and the labor force (LnLabor) exhibit a causal relationship, with GDP influencing LnLabor (*p*-value = 0.0015) and LnLabor influencing GDP (*p*-value = 0.0000). In addition to GDP, strong bidirectional causalities are found between LnPrice and Capital, where LnPrice Granger-causes Capital (*p*-value = 0.0000) and Capital Granger-causes LnPrice (*p*-value = 0.0000*); between LnLabor and Capital, where LnLabor Granger-causes Capital (*p*-value = 0.0000*) and Capital Granger-causes LnLabor (*p*-value = 0.0000*); and directly between important energy variables, where LnEnergy and LnPrice influence one another (LnEnergy -> LnPrice: *p*-value = 0.0148). Furthermore, there's a bidirectional relationship between LnLabor and LnEnergy (LnLabor -> LnEnergy: p-value = 0.0227; LnEnergy -> LnLabor: p-value = 0.0000).

Table 7 revealed only two distinct unidirectional causality relationships, as opposed to many bidirectional relationships. First, there is a one-way causal relationship between capital and energy consumption (LnEnergy). The null hypothesis that capital does not cause LnEnergy to Granger was rejected (p-value = 0.0002), but the converse was not (p-value = 0.2421). This suggests that, while capital formation has a significant impact on energy consumption, energy consumption does not directly cause capital formation.

Second, the null hypothesis that Capital does not Granger-cause GDP was rejected (p-value = 0.0001), but the converse hypothesis—that GDP does not Granger-cause Capital—was not rejected (p-value = 0.1903), indicating that causality runs from Capital to GDP. In this model, there is no statistically significant inverse relationship between GDP and capital accumulation, indicating that capital formation is a key driver of economic growth in the region.

Generally, the comprehensive findings presented in **Table 7** show that Eastern Africa's economy is highly interconnected, with several important feedback loops involving energy variables, capital, labor, and economic growth. The strong evidence of bidirectional causality, particularly between energy consumption and GDP and labor and GDP, offers a more comprehensive and varied view than the findings in **Table 6**, which provide more straightforward unidirectional explanations. Our findings underscore the importance of holistic policy approaches, as changes in one area are likely to have an impact on other areas of the economy.

4.4. Effects of the Consumption of Energy on Economic Growth

Table 8 presents the results from different modeling techniques used to examine the effects of energy consumption on economic growth. The pooled OLS estimates show a positive coefficient for energy consumption (LnEnergy), which is statistically significant at the 10% level. As established in the literature, both pooled OLS and fixed effects (FE) models tend to suffer from biases, with pooled OLS generally producing upward bias and fixed effects downward bias, particularly in the presence of a lagged dependent variable [99,101]. For this reason, these models are used mainly as a reference for comparison rather than for drawing conclusions. The pooled OLS model shows that lagged GDP is statistically significant at the 1% level, capital is positive but not statistically significant, and labor is also not significant. In the FE model, lagged GDP remains positive and significant, labor becomes statistically significant at the 10% level, while energy shows a negative and statistically insignificant effect. These results highlight the limitations of using pooled OLS and FE estimators in dynamic panel settings, and their outputs are presented primarily for diagnostic comparison.

Table 8. Results of Robustness Check and SGMM Estimation.

Variables	(1) Pooled OLS	(2) FE	(3) 2Step Diff GMM	(4) 2Step Syst GMM
L.GDP	0.580***	0.372***	0.752***	0.982***
	(0.076)	(0.082)	(0.023)	(0.093)
Capital	0.001	−0.072	−0.763***	−0.922**
	(0.061)	(0.087)	(0.140)	(0.453)
LnPrice	−6.159***	−10.018***	−8.487***	−7.269**
	(0.932)	(1.212)	(1.220)	(3.168)
LnLabor	0.195	18.849*	9.686	−0.252
	(0.531)	(10.880)	(7.623)	(1.486)
LnEnergy	1.363*	−1.772	−2.386	7.271***
	(0.703)	(4.956)	(2.707)	(1.946)
Constant	14.037**	−218.139		−16.628
	(6.173)	(139.075)		(14.579)
Observations	117	117	104	117
R-squared	0.825	0.699		
Number of countries		13	13	13
AR(1)			0.124	0.165
AR(2)			0.201	0.216
Hansen			0.455	0.146
Sargen			0.695	0.276
Number of Instruments			13.000	9.000

Note: Standard errors in parentheses *** $p < 0.001$, ** $p < 0.05$, * $p < 0.1$.

The difference GMM (DGMM) and system GMM (SGMM) estimators were then applied to address potential endogeneity and improve the consistency of the estimates. The lagged value of GDP is estimated at 0.752 under DGMM and

0.982 under SGMM, indicating that GDP is highly persistent over time. According to Blundell and Bond [84], when the coefficient on the lagged dependent variable approaches one, the difference GMM estimator may produce downward-biased results, particularly in panels with a short time dimension. Therefore, the system GMM estimator is preferred, as it incorporates level moment conditions and helps reduce bias in estimating persistent dynamics. In the SGMM results, shown in Column 4 of **Table 8**, the coefficient on LnEnergy is statistically significant at the 1% level, with a value of 7.271 indicating a strong positive effect on economic growth. This implies that a 1% increase in energy consumption is associated with a 0.0727 unit increase in GDP per capita growth, holding other factors constant. This finding underscores the importance of energy in stimulating economic activity in the Eastern Africa region and aligns with previous studies such as Mutumba, et al. [106] in Sub-Saharan Africa and Khan, et al. [100] in China, both of which found a positive relationship between energy use and economic growth. These findings have important implications for future research and policy, especially in guiding energy sector interventions in Eastern Africa.

4.5. Robustness Checks and SGMM Estimation

We performed robustness checks on the SGMM model to evaluate the validity of the instrumental variables and identify any potential serial correlation in the error term. The Autoregressive test for second-order serial correlation (AR(2)) and the Hansen test of over-identifying restrictions were two important tests used to guarantee the analysis's dependability. The null hypothesis that the model's instruments are reliable and unrelated to the error term is assessed by the Hansen test. It is stated by Roodman [77] that care should be taken when interpreting the findings of the Hansen test. An overly high *p*-value may suggest issues like instrument proliferation or weak identification, whereas a significant *p*-value (usually below 0.05 or 0.1) may indicate that the instruments are invalid. The *p*-value for the Hansen test should ideally be negligible but not unreasonably high. Since the *p*-value of 0.146 in this instance is within an acceptable range, the null hypothesis is not rejected, and the instruments employed are therefore regarded as legitimate. These robustness checks confirm that the SGMM model satisfies important diagnostic requirements, strengthening the reliability of the estimated results. Additionally, there is no evidence of second-order autocorrelation, as the AR(2) falls with $p = 0.216$. Overall, both the Hansen and serial correlation tests support the validity of the instruments ($p = 0.146$ and 0.276, respectively).

In contrast, energy price, with a coefficient value of –7.269, is statistically significant at the 5% level, indicating a negative relationship with economic growth. Rising energy prices are likely to increase production costs and reduce consumption, thereby constraining GDP growth. This finding suggests that stabilizing or reducing energy prices could serve as an important policy tool for promoting growth in regional economies. Capital, with a coefficient of –0.922 and statistically significant at the 5% level, also shows a negative effect on GDP. This is counterintuitive, as theory generally suggests that capital accumulation fosters growth. However, this finding may reflect diminishing returns to capital investment, poor allocation of capital resources, or low efficiency in public investment, particularly where capital is directed toward non-productive sectors. These may suggest the need for deeper investigation and region-specific research to assess the quality and sectoral allocation of capital formation in Eastern Africa. Lastly, the labor, which has shown a statistically significant causal effect on GDP in the Dumitrescu and Hurlin causality test, appears statistically insignificant in the SGMM estimation. This disparity may arise from labor being captured only in terms of quantity rather than quality, or a potential time lag between workforce expansion and its effect on GDP. Therefore, while labor's direct contribution may not be visible in the SGMM estimates, its role remains important and warrants future analysis. Therefore, the SGMM findings confirm that energy consumption is a statistically significant and positive driver of regional economic growth; while rising energy prices and inefficient or misallocated capital formation exert negative effects. These results highlight the need for policies focused on expanding energy access for increased consumption, stabilizing energy prices, and improving the quality and efficiency of capital investments to support economic growth in Eastern Africa.

4.6. Limitations

While our 13-country East African panel offers robust internal insights into the energy–growth nexus, caution is warranted when extrapolating these findings to other contexts. We contribute by examining a relatively under-researched region with rigorous panel-data methods. However, Eastern Africa's youthful demographic profile (median age ≈ 18 years) and rapid urbanization drive energy demand and economic linkages in ways that may differ substantially in regions with older populations or slower urban growth. Hence, sustainable growth considerations are critical when extending energy-transition models beyond our sample. Likewise, the regional energy mix, dominated by hydropower, biomass and emerging fossil-fuel infrastructure, affords greater price stability and supply predictability than systems reliant on coal-fired baseload or high shares of intermittent renewables, whose volatility can dampen or distort growth effects. This evolving infrastructure also presents unique investment and technology transfer opportunities that may further modulate the energy-growth relationship. Institutional and market characteristics, such as widespread fuel subsidies, uneven grid development and variable regulatory quality, also shape consumption patterns and investment incentives. Taken together, these demographic, technological and policy specificities imply that our results should be applied to other developing regions only with careful attention to local population structures, energy portfolios and market frameworks. Finally, this study focuses on aggregate energy consumption due to limited availability of consistent sectoral data across countries; however, sector-specific dynamics are acknowledged as a valuable future direction.

5. Conclusions

In this study we found that energy consumption clearly drives GDP growth in Eastern Africa, according to the study's findings, which support the growth hypothesis. Our findings indicated that a % increase in energy consumption is linked to a 0.073%-point increase in GDP growth. This important finding highlights how crucial a sufficient and dependable energy supply is to the region's economic growth. Although the Dumitrescu-Hurlin test showed unidirectional causality between energy consumption and GDP, the non-causality test used by Juodis, Karavias, and Sarafidis Granger showed a strong pattern of bidirectional causality between energy consumption and GDP, indicating mutual dependence. Granger non-causality test is more comprehensive and varied than the straightforward unidirectional explanations. The study also found that energy prices are negative for economic growth, meaning that lowering or stabilizing prices might stimulate economic growth. In other words, capital formation had a significant negative impact on GDP, which may be due to diminishing returns, poor resource allocation, or poor public investment efficiency. While the role of labor was a causal factor in the Dumitrescu-Hurlin test, it was statistically insignificant in the SGMM estimate, perhaps because it was captured only in quantity rather than in quality or time lags.

The generalizability of our findings is limited by several limitations that we acknowledge. Because of the region's unique characteristics, such as a young population and rapid urbanization, which are likely to affect energy demand and economic ties differently than in areas with older populations or slower urban growth, it advises against extrapolating findings to contexts outside of the 13 East African countries under study. Compared to systems that rely heavily on more volatile sources, which may influence how the energy-growth relationship appears elsewhere, the regional energy mix, which primarily consists of hydropower and biomass with emerging fossil fuel infrastructure, provides greater price stability and supply predictability. Finally, recognizing that sector-specific dynamics were not adequately captured, the study relied on aggregate energy consumption data due to constraints.

To overcome these limitations, the study highlights a number of important areas that require more investigation. Given the importance of the manufacturing, services, and agricultural sectors to the region's GDP and the likelihood that they will show unique patterns of energy consumption and sensitivity to energy availability and pricing, future research should focus on sector-specific analyses. The economic effects of large energy infrastructure projects, like dams and pipelines, must also be carefully examined, considering not only how they contribute to GDP growth and energy supply but also the trade-offs they have on the environment and society. The study concludes by recommending investigating developments in distributed energy technologies, such as battery storage and microgrids, as well as new computational techniques, like fuzzy-cloud frameworks, to account for uncertainties and non-linearities in quickly changing energy systems.

Author Contributions

Conceptualization and methodology, N.F.M. and Y.J.K.; formal analysis, investigation, data curation and preparation of the initial manuscript draft, N.F.M.; validation, critically reviewing the paper, writing the manuscript and interpreting the results, Y.J.K. Both authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All datasets supporting the findings of this study are publicly available. GDP per capita growth, the consumer price index, and gross capital formation were obtained from the World Bank's World Development Indicators. Total energy consumption data were sourced from the U.S. Energy Information Administration, and labour force figures were obtained from TheGlobalEconomy.com.

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Conflicts of Interest

The authors declare no conflict of interest.

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