BRICS JOURNAL OF ECONOMICS
DOI 10.3897/brics-econ.7.e138473
2026 Volume 7 Number 1

What is the role of financial development and economic growth on energy consumption in the SADC countries? New evidence from the PARDL approach

Palesa Lefatsa[1], Gabila Nubong[1]

1 *North West University, Potchefstroom (South Africa)*

Corresponding author: Palesa Lefatsa (plefatsa@matatiele.gov.za)

Academic editor: Sheresheva M. | Received 3 October 2024 | Accepted 5 February 2025 | Published 27 May 2026

Citation: Lefatsa, P., & Nubong, G. (2026). What is the role of financial development and economic growth on energy consumption in the SADC countries? New evidence from the PARDL approach. *BRICS Journal of Economics, 7*(1), 237–274. https://doi.org/10.3897/brics-econ.7.e138473

Abstract

This study investigates the interconnections between financial development, economic growth, and energy consumption within the Southern African Development Community (SADC) region between 1980 and 2023. Using the Panel Autoregressive Distributed Lag (PARDL) model alongside Dumitrescu and Hurlin (2012) causality tests, the research provides new insights into the dynamics of these variables. The study reveals a significant positive correlation between financial development, economic growth, and energy consumption. The key finding is the negative relationship between energy consumption and urbanization, while no significant linkage is found between energy consumption and industrialization. The Granger causality test reveals a unidirectional causal link between financial development, urbanization, and energy consumption, and a bidirectional relationship between economic growth and energy consumption. These findings contribute to existing literature by offering a more nuanced understanding of the region's energy consumption dynamics compared to previous studies that have often presented inconclusive or context-specific results. This study extends previous research by examining the unique economic and energy challenges faced by the SADC countries, providing fresh evidence for policymakers focused on integrating financial sector development with sustainable energy policies. The study suggests that investing in renewable energy and expanding electricity access, especially in rural areas, could enhance both urbanization and financial sector growth, fostering broader economic development. The diagnostic checks affirm the robustness and reliability of the model, ensuring the validity of the findings.

Keywords
PARDL; financial development; economic growth; energy consumption.

JEL: Q43, Q41, G20, O11, C23.

1. Introduction

Energy is vital for the Southern African Development Community. Beyond its use in daily life, fuel and electricity catalyze infrastructure projects that drive both regional integration and economic growth (Onyango, 2021). Meeting the challenges associated with energy consumption and its financial aspects should contribute to the SADC's economic growth and ultimate attainment of the regional industrialization agenda (Umar et al., 2021). Although SADC includes some of the continent's middle-income and fast-growing economies, the region still faces difficulties in the energy sector that could be resolved by more growth and greater financial development (Huang et al., 2023).

According to the 2019 Regional Infrastructure Development Master Plan Assessment Report, only 32% of rural areas and about 50% of the whole population of the region have access to electricity. The region is lagging behind many other African countries: North African economies, for example, already have 100% access to electricity. Electricity shortages have strained the region since 2007. Although these shortages were expected to be resolved by 2019, projects aimed at addressing the issue have fallen behind schedule due to insufficient funding. Delays in switching to cost-reflective tariffs, inadequate project preparation, issues with power purchase agreements and absent regulatory frameworks stunt investment in the energy sector. Coal accounts for 62% of power generation in Southern Africa, but this reliance is considered a major contributor to global warming. Weak infrastructure and foreign commitments inhibit the use of the region's abundant oil and gas resources; pricing and infrastructure challenges in grid connections, manufacturing, and quality testing impede the development of the region's renewable energy potential.

Some of these challenges could be addressed through economic growth and prosperity, which would provide the resources needed to invest in the energy sector (Umar et al., 2021). It is hypothesized that such prosperity typically accompanies advancements in the financial sector, which in turn are supported by financial development. (Onyango, 2021).

On a global scale, almost all advanced economies have experienced increases in energy demand with a total growth of 2.6% in 2023, led by the European Union (3.5%) and United States (2.6%) (IEA, 2023). Developing countries, too, have continued to increase their demand for energy. China (2.6%) accounted for an overwhelming 90% of the net growth in the global energy demand in 2022 (IEA, 2022); Southern Asia's energy demand grew by 3.0% and Africa's by 1.5% in 2022 (Thebuho et al., 2022).

An upsurge in aggregate energy demand in advanced economies directly leads to high levels of energy consumption, followed by energy supply shortages resulting from a shift to high-carbon energy sources with higher generator losses (Umar et al., 2021). Similarly, in the SADC countries, high energy consumption may be caused by the rapid growth of energy use in their industry as they enter the heavy industrialization stage of industrial development (Sadorsky, 2010). It may also be caused by the use of outdated technology and lack of research and development in the area (Nkalu et al, 2020).

According to the existing literature, the main factors that determine energy consumption are financial development and economic growth (Merven et al., 2010; Waite, 2018; Nkalu et al., 2020; Sunde, 2020; Onyango, 2021). Financial development as a catalyst for technological progress can contribute to improvements in energy consumption. Yet, most of the previous research into the relationship between financial development and economic growth on the one hand and energy consumption on the other has not so far produced consistent results (Al-Mulali & Lee, 2013; Adu & Denkyirah, 2018; Destek & Sarkodie, 2019; Akinsola & Odhiambo, 2020; Lefatsa et al., 2021; Mukhtarov, 2022; Huang et al., 2023).

This study has considerable practical value for the SADC economies because energy shortages and inefficiencies in the region are a serious obstacle to economic growth and social development. By analyzing the role of financial development and economic growth in energy consumption, this study provides actionable insights for policymakers seeking to address these challenges. Financial institutions and development agencies also stand to benefit from this research by gaining a deeper understanding of how financial and economic factors influence energy consumption patterns. This can inform the development of policies and investment frameworks to improve energy access and infrastructure.

The findings of this study contribute to the existing body of knowledge by addressing gaps in literature, particularly the lack of comprehensive analyses integrating financial development, energy consumption, and economic growth in the SADC region. Understanding these relationships can aid in designing energy-efficient strategies that align with SADC's industrialization agenda, promote renewable energy adoption, and foster inclusive economic growth.

The paper aims to find out if financial development and economic growth enhance and sustain energy consumption in the SADC countries. The findings will inform policies that encourage investments in energy infrastructure, promote innovation in energy systems, and ultimately contribute to the region's success in achieving sustainable development goals.

2. Literature review

This section discusses both theoretical and empirical studies.

2.1. Theoretical literature

2.1.1. Research into Economic Growth and Energy Consumption

The debates on energy consumption primarily focus on energy efficiency, often referred to as energy conservation. These theoretical perspectives provide crucial insights into the dynamic interplay between energy use, efficiency, and economic growth, forming the foundation for this study's exploration of energy consumption in the SADC region. The key theories are the Rebound Effect Theory (Jevons, 1865), Khazzoom-Brookes Theory (Khazzoom, 1980), Sustainable and Green Growth Theories, and the Cobb-Douglas production function.

- **Rebound Effect Theory (Jevons, 1865)**

Proposed by William Stanley Jevons, this theory argues that technological advancements do not reduce coal consumption; instead, efficient use of fuel may increase overall consumption.

The Rebound Effect theory is critical for understanding how energy efficiency initiatives may paradoxically lead to increased energy demand in the SADC region, especially when industrialization and economic growth spur energy consumption. It highlights the unintended consequences of energy efficiency improvements and provides a framework for analyzing the limits of technology-driven energy policies. At the same time, it is mostly focused on fossil fuel consumption, which limits its applicability to renewable energy, and does not consider regulatory measures that could mitigate rebound effects.

- **Khazzoom-Brookes Theory (Khazzoom, 1980; Brookes, 1990)**

This theory suggests that improvements in energy efficiency can lead to increased energy consumption, as reduced costs encourage higher usage, thereby stimulating economic growth. It explains why energy consumption may increase despite efficiency improvements, offering insights into the energy-growth dynamics within SADC. Revealing the economic link between cost reduction and energy demand, this theory provides a basis for studying energy efficiency policies and their broader economic implications. However, it focuses on the demand-side response, ignoring supply-side factors, and does not account for differences between developed and developing economies.

- **Sustainable and Green Growth Theories**

These theories emphasize the role of energy efficiency in reducing CO2 emissions and environmental pollution when promoting sustainable economic growth. They align with global sustainability goals and provide a framework for examining how energy policies in SADC can balance economic growth with environmental preservation. Moreover, these theories encourage long-term perspective on energy and environmental sustainability and renewable energy adoption. They also have their limitations: lack of resources may inhibit sustainable economic development; economic trade-offs of transitioning to green energy tend to be underestimated.

- **Cobb-Douglas production function**

Mainstream economic growth models, such as the Cobb-Douglas production function and the Solow growth model, often overlook the direct role of energy, treating it as an intermediate input (Nkalu et al., 2020). However, the integration of energy with technological progress reveals a crucial interdependence in the production process. Though not energy-specific, the Cobb-Douglas model provides a foundational framework for exploring how energy as an input interacts with other factors, like labor and capital, to influence economic growth in SADC. It offers a simple but effective structure for modeling production and growth, facilitating the integration of energy into broader economic analyses. Yet, it ignores the direct contribution of energy to production and growth and assumes constant returns to scale, which may not hold true for energy-intensive industries.

These theories collectively inform the present research into energy consumption in the SADC region by addressing the multifaceted relationship between energy efficiency, economic growth, and environmental sustainability. The Rebound Effect Theory and Khazzoom-Brookes Theory underscore the challenges of managing energy demand amid efficiency improvements. The Sustainable and Green Growth Theories emphasize the importance of aligning energy policies with environmental and sustainability goals. The Cobb-Douglas Production Function provides a macroeconomic perspective, highlighting the interaction of energy with other growth factors.

By integrating these perspectives, the study aims to provide a comprehensive analysis that accounts for the complexities of energy consumption and its implications for financial development and economic growth in SADC.

2.1.2. Financial Development and Economic Growth

It is generally accepted that financial development is crucial for economic growth. Early theorists, such as Bagehot (1873), and then Hicks (1969) emphasized the importance of financial institutions in supporting industrialization. McKinnon (1973) and Shaw (1973) advocated for financial liberalization in order to create financial systems that would help allocate resources more effectively, reduce transaction costs, and boost economic growth.

Endogenous growth models, such as those by Greenwood and Jovanovic (1990), argue that well-functioning financial systems enhance human and physical capital efficiency, leading to technological innovation and economic expansion. Positive relationship between financial development and economic growth has been proved by numerous empirical studies; yet, some research indicates that excessive financial development may hinder growth.

2.1.3. Financial Development and Energy Consumption

Financial development exerts influence on energy consumption. The growth hypothesis suggests that increased financial development drives energy consumption, thereby supporting economic growth. The theories by Schumpeter (1912), McKinnon (1973), and Shaw (1973) underscore the role of financial systems in facilitating investment, improving transparency, and promoting economic expansion. Financial liberalization, while beneficial for growth, must be properly managed to avoid adverse effects on energy consumption and sustainability.

The literature on causal relationships between financial development, economic growth, and energy consumption is vast and varied, particularly concerning the direction of causality between these factors. The question often arises: is there a significant link between financial development, economic growth, and energy consumption in developing countries? Policymakers, business analysts, and researchers have paid serious attention to this relationship, anticipating that financial development and economic growth are crucial determinants of energy consumption.

Numerous hypotheses about Granger causality between these variables have been proposed, with the main ones being feedback (bidirectional), growth (unidirectional), conservation, and neutrality causality relationships (Odhiambo, 2019).

- **Feedback (Bidirectional) Hypothesis**

This hypothesis suggests mutual interdependence between financial development, economic growth, and energy consumption. An increase or decrease in one variable leads to a corresponding change in the others. Blackburn and Hung (1998) designed theoretical models proving bidirectional causality between economic growth and financial development. Studies by Abdelhamid, Ozatac and Taspinar (2023), and others found bidirectional causality between financial development and energy consumption, and between financial development and economic growth. The results vary depending on the empirical context.

- **Growth Hypothesis**

This hypothesis asserts a unidirectional causality from financial development or economic growth to energy consumption. It posits that increases in financial investment and economic output may influence energy consumption negatively or positively, depending on various factors. Studies supporting this hypothesis have found evidence of unidirectional causality from financial development to energy consumption and from economic growth to energy consumption (Narayan & Smyth, 2005; Payne, 2010).

- **Conservation Hypothesis**

The conservation hypothesis posits a reverse causal relationship, where energy consumption drives financial development and economic growth. Authors like Foon Tang (2009) and Balcilar Bekun and Uzuner (2019) argue that financial development and economic growth are dependent on energy consumption, especially in energy-scarce economies.

- **Neutrality Hypotheses**

This hypothesis suggests that financial development and economic growth have no significant causal link to energy consumption, meaning that policies aimed at promoting financial development or economic growth may not influence energy consumption directly. Studies like those by Ghosh (2009) and Payne (2009) found no causality between these variables, supporting the neutrality hypothesis.

2.1.4. Research Gap

The existing research into the relationship between financial development, economic growth, and energy consumption has produced mixed results. While there is support for the growth hypothesis, evidence varies widely across contexts, with some studies failing to establish consistent causality. For example, Odhiambo (2019) found a unidirectional relationship between financial development and energy consumption in South Africa, but Sunde (2020) discovered a bidirectional causality in a broader SADC analysis and Mukhtarov (2022) also emphasized the bidirectional causality. This demonstrates the need for more robust methodologies.

Moreover, few studies integrate financial development, economic growth, energy consumption, urbanization, and industrialization within the SADC region into their analysis. Thus, Nkalu et al. (2020) and Lefatsa et al. (2021) examine financial development and energy consumption largely ignoring urbanization and industrialization, both of which are critical to shaping energy demand in developing regions. Al-Mulali and Lee (2013) and Destek and Sarkodie (2019) also focus on isolated variables, such as the financial development-energy consumption nexus, but fail to integrate urbanization and industrialization into their frameworks.

Another gap in research is caused by what can be called regional neglect: studies that analyze financial development and energy consumption in Africa often extrapolate their findings to Sub-Saharan Africa, overlooking SADC-specific contexts (Akinsola & Odhiambo, 2020).

Addressing these gaps, the present paper integrates financial development, economic growth, energy consumption, urbanization, and industrialization into a unified framework. It applies advanced empirical techniques, such as the Panel Autoregressive Distributed Lag (PARDL) model, to examine relationships specific to the SADC region.

2.2. Empirical literature

The question of whether financial development and economic growth affect the rate of energy consumption in a region or country has been thoroughly discussed in academic literature. This interest is driven primarily by the implications of research results that may determine the choice of policies aiming to accelerate economic growth, financial development and energy consumption. Empirical studies, however, have produced conflicting outcomes and so economists' views on the issue are not unanimous. This section gives an overview of empirical studies that addressed the impacts of the four variables on energy consumption.

El-Karimi (2022) carried out a research into causality between economic growth and energy consumption in Morocco for the period 1980-2019 through an extension of the Cobb-Douglas production function and the Toda-Yamamoto causality test. The Granger causality test supported a neutrality hypothesis between economic growth and energy consumption. Majewski, Mentel, Salahodjaev and Cierpiał-Wolan (2022) investigated the causal relationships between economic growth and electricity consumption in South Asian economies between 1950 and 2018 using Pedroni's panel cointegration. The Dumitrescu-Hurlin Panel Causality test confirmed the neutrality hypothesis in Sri Lanka, Bangladesh, India, and Pakistan. Adoption of sustainable energy and technology is linked with changing organizational behavior.

Most recently, Usman, Balsalobre-Lorente, Jahanger and Ahmad (2023) used an econometric model to analyze the causal linkage between economic growth and energy use in Mercosur countries over the period 1990-2018. The results from the Granger causality test confirmed a bidirectional causal link between economic growth and energy consumption. Likewise, Dahmani and Mabrouki and Youssef (2023), while using the CS-ARDL technique and the Dumitrescu-Hurlin Panel Causality test during 1980-2018, found that economic growth Granger caused energy consumption and vice versa in Mena countries. Using the same approach for the years 2000-2018, Amin and Song (2023) looked into a causality relationship between economic growth, energy consumption including carbon emission, trade, and urbanization. The Granger causality test revealed a bidirectional causality between economic growth and energy consumption. To decouple pollutant emissions from economic growth, it may be necessary to use carbon storage and capturing techniques.

Conversely, Jamil (2022) found a unidirectional causality relationship running from energy consumption to economic progress in low, high, and upper-middle-income countries between 1971 and 2021 by applying Granger causality test and Ordinary Least Squares (OLS) approach. In a recent study by Minh and Van (2023), the long run unidirectional causality from economic growth to energy consumption and gross fixed capital formation was corroborated using ARDL and ECM approaches for Vietnam in 1995-2019. Furthermore, Ren, Tong, Sun and Yan (2022) conducted a short and long-term study in China using newly developed techniques to analyze the causality association between economic growth, financial development, urbanization, and energy use in 1965-2018 using the Granger causality test. The empirical results confirmed a short and long-run unidirectional causality link running from economic growth to energy use. Leakages in the system that could reduce economic growth should be controlled by fiscal discipline in the short-run and long-run dynamics.

Having employed system GMM estimation, Saygin and İskenderoğlu (2022) studied the causality relationship between financial development and renewable energy consumption during the period 1990-2015 in 20 emerging economies. The Granger causality test confirmed the neutrality between financial development and renewable energy consumption. Sart, Ozkaya and Bayar (2022) studied the causality relationship between financial development and primary energy consumption in BRICS between 1990 and 2019; the Granger causality test confirmed neutrality between financial development and primary energy consumption. Bozkurt, Toktaş and Altiner (2022) obtained similar results in MENA countries over the period 1980-2017 by employing Hatemi-J panel hidden cointegration test and VECM analysis. Development in the financial sector enhances energy use only when measured by stock market capitalization.

Usman, Alola and Saint Akadiri (2022) assessed the causality link between financial development and renewable energy consumption in European Union member countries during the period 2001Q1-2017Q4 by GMM estimation of Panel Vector Autoregressive (PVAR) with IMFs and found a bidirectional causality among the variables. Having examined the causal link between financial development and renewable energy consumption in 64 Belt and Road Initiative countries in 2003-2018 using GMM approach and Dumitrescu-Hurlin Granger Causality test, Sheraz, Deyi, Mumtaz and Ullah (2022) discovered a bidirectional causality between the variables. Wang, Pham, Sun, Wang, Bui, and Hashemizadeh (2022) had similar results for 11 countries over the period 1990-2015 from Driscoll-Kraay and Dumitrescu-Hurlin Panel Causality test. Similarly, Saadaoui and Chtourou (2023) found a bidirectional causality link between human capital, ecological footprint, financial development, and renewable energy consumption in the Middle East and North Africa region in 1980-2018 using the ARDL approach and Granger causality test. Financial innovation should be encouraged in the country to meet the demand for sustainable development.

Saadaoui and Chtourou (2022) conducted a similar study during the period 1984-2017 by symmetric and asymmetric ARDL approach and non-linear Granger causality test. They found a unidirectional causal link running from financial development to renewable energy consumption in Tunisia. Further, Adebayo and Ağa (2022) findings are the same as those above during the period 1990Q1-2019Q4 by the novel Bootstrap Fourier Granger causality in MINT countries. Their model produced tail-causal and asymmetric causal connections between the indicators within the Fourier estimate, as opposed to Toda-Yamamoto Causality and other conventional Granger tests. There is a need to develop a strong financial system, allocate more funds to up-to-date and eco-friendly energy projects, and improve energy efficiency.

Using PVECM, VAR approach and a Granger causality test, Belazreg and Mtar (2020) found that from 2001 to 2016 financial development and economic growth in 27 OECD countries had no obvious causal association. When studying the causality relationship between financial development and economic growth in the BRICS economies, Asafo-Adjei, Boateng, Isshaq, Idun, Owusu and Adam (2021) employed Bivariate, Partial, and Wavelet Multiple (BPWM) analysis and confirmed neutrality hypothesis for the variables of interest. Additionally, Ekanayake and Thaver (2021) discovered similar results for 138 emerging economies between 1980 and 2018. In the countries where the supply-leading theory is applicable, policymakers need to pay more attention to political, legal, and regulatory determinants of financial development, which can be used as a tool for achieving sustainability in the economy.

Most recently, Almassri, Ozdeser and Saliminezhad (2023) analyzed the causality relationship between financial development and economic growth in Hong Kong from 1980 to 2019 using the Quantile-on-Quantile (QQ) approach of Sim and Zhou (2015) and the Granger causality test. The findings revealed a bidirectional causality between the variables. Dada and Akinlo (2023) studied the causality relationship between financial development, economic growth, and remittances from Nigeria for the period 1986-2017 employing the ARDL approach and VEC Granger causality test. The results pointed to a bidirectional causality between financial development and economic growth in the long run for Nigeria. In India, Giri, Mohapatra and Debata (2023) obtained similar results using NARDL and Hetemi J asymmetric causality tests, both in the short and long run. The countries in question need more emphasis on developing strategies aimed at higher mobilization of savings to boost domestic investors' confidence and also attract more foreign investment.

Moon and Hossain (2023) recently investigated the causality relationship between financial development, monetary policy instruments, and economic growth in Bangladesh from 1974 to 2019 using VECM approach, Johansen cointegration, and Granger Causality test. Dada, Ajide and Arnaut (2023) conducted a similar study of 30 African economies in 1991-2017 employing augmented mean group estimator and Dumitrescu-Hurlin Panel Causality test. The results confirmed a short-run unidirectional causality running from financial development to economic growth. In Algeria, Nid and Bouabdallah (2023) found unidirectional causality running from economic growth to financial development over the period 1964-2020. This means that different types of financial development and country risk environments have varying impacts on economic growth.

To explore the relationship between economic growth and energy consumption from 1995 to 2014 in post-communist countries, Umurzakov et al. (2020) used Panel DOLS estimates and a growth model along with an economic complexity indicator to measure capabilities for exporting sophisticated products. He found that escalations in economic growth accelerate energy consumption. The same conclusion was made by Zeraibi, Balsalobre-Lorente and Shehzad (2020) who assessed the correlation between economic growth, technological innovation, and energy consumption in China between 1980 and 2018 using the NARDL econometric approach. Ozcan, Tzeremes and Tzeremes (2020) identified the long-term and positive effect of economic growth on environmental degradation and energy consumption in 35 OECD countries over the period 2000-2014 by GMM-PVAR approach. Patterns of both economic growth and energy consumption indicate the need for sustainable development practices.

To assess energy consumption in China over 2004-2017 and 2000-2018, Dong, Taghizadeh-Hesary and Zhao (2022), and Lee and Wang (2022), respectively, evaluated the effect of financial development, industrialization, technological innovation, and environmental degradation on energy consumption in the country's 30 provinces using differential GMM approach with FEM, REM, instrumental variable estimation, and a panel threshold. The studies discovered a positive link between financial development and energy consumption. Pata, Yilanci, Zhang and Shah (2022) found a positive impact of financial development on renewable energy consumption at high quantiles in the United States between 1980 and 2019 using the NARDL model and the novel Fourier quantile causality test with wavelet transforms. Again, Dimnwobi, Madichie, Ekesiobi and Asongu (2022) had similar results in Nigeria between 1981 and 2019 using the ARDL model. Financial development and economic growth led to increases in energy consumption albeit with higher environmental pollution.

Konyeaso, Eregha and Vo (2023) unbundled the relationship between financial development, renewable energy consumption and economic growth in 32 selected African economies for the period 1996-2018 using PMG, AMG and DOLS techniques. The study grouped countries according to their income levels and amounts of oil they could produce, and found a significant and positive impact of financial development on economic growth except in non-oil-rich African countries. Anthony-Orji, Orji, Ogbuabor and Uka (2023) in Nigeria analyzed the impact of financial development on economic growth from 1981 to 2019 using the classical linear regression modeling technique. The results indicated that financial development had significant positive impact on economic growth in the long run. Wang, Xue and Han (2023) examined the nexus between financial development, technological innovation, urbanization, and economic growth in China from 2000 to 2020 using the Difference-in-Difference (DID) approach. The results confirmed that financial development improved economic growth both in the short and long run. This suggests that variables are apparently influenced by country effects only.

Islam, Irfan, Shahbaz and Vo (2022) studied the effect of economic growth on energy consumption in Bangladesh by various econometric approaches. They discovered a negative effect of financial development on economic growth. Having employed PARDL during the period 1988-2018, Hendrawaty, Shaari, Kesumak and Ridzuan (2022) examined the relationship between economic growth and energy consumption in Asian countries. The results revealed a significant and negative impact of economic growth on energy consumption in the short run. Jia, Jia, Wu, Guo, Yang, Wang and Xiao (2022) analyzed the link between economic growth and energy consumption in 30 provinces of China during the period 2017-2016 using a non-parametric and additive regression model. The results reveal a negative relationship between economic growth and energy consumption in the long run, which means that the country needs to develop domestic energy resources to protect itself from any undesirable external energy.

Financial development has also been found to reduce energy consumption for MENA countries using CS-ARDL method (Dahmani et al., 2023). Aslan, Gozbasi, Altinoz and Altuntas (2021) analyzed the impact of financial development on energy consumption in the G7 countries and top 10 emerging economies in 1990-2015 using the panel VAR approach and concluded that financial development led to decreased energy consumption in the short run. Mohsin, Taghizadeh-Hesary and Shahbaz (2022) employed econometric methods to examine the influence of financial development on energy consumption in Latin America between 1995 and 2015. Their empirical results indicated that financial development reduced energy consumption. Countries therefore should take advantage of globalization by improving technology and knowledge related to renewable-to-renewable electricity consumption in all areas.

Wang, Zhang and Zhang (2021) investigated the correlation between financial development and economic growth in China in 1997-2017 using the PMG-ARDL approach and the Granger causality test. The results confirm that financial development adversely affects economic growth in China. Yasin, Ahmad, and Chaudhary (2021) investigated the impact of financial development on economic growth in 59 less-developed economies between 1996 and 2016 using the cross-sectionally weighted Estimated Generalized Least Square (EGLS) methodology, Arellano-Bond Generalized Method of Moment (A-B GMM), and Orthogonal-Deviation GMM (O-D GMM). They argue that financial development is always unfavorable for economic growth; this negative effect is greater in high-income countries, and lower in the middle- and low-income countries. Zhe, Yüksel, Dinçer, Mukhtarov and Azizov (2021) examined the relationship between financial development and economic growth in 1990-2015 using the VAR model; they found a negative effect of financial development on economic growth in Turkey. Money supply and inflation rates should be taken into account as they also can contribute to a decline in economic growth. However, existing studies often fail to adequately consider the joint effects of financial development, energy consumption, and macroeconomic variables such as money supply and inflation rates. For example, the studies by Al-Mulali and Lee (2013) and Sadorsky (2010) explore financial development and energy consumption but largely ignore the influence of monetary policy, particularly in the developing regions like SADC.

The present study addresses these gaps by integrating macroeconomic variables, such as money supply and inflation rates, into the analysis of financial development, economic growth, and energy consumption. Unlike previous studies, which typically focus on a subset of these variables, the present research takes a holistic approach by examining their interdependencies within the unique socioeconomic and industrialization context of the SADC region.

The study takes a comprehensive view of financial development, economic growth, energy consumption, urbanization, industrialization, and macroeconomic factors, which is rarely done in existing literature. Unlike broad generalized analyses of Sub-Saharan Africa (Nkalu et al., 2020) or MENA countries (Dahmani et al., 2023), this study focuses on the SADC region, providing context-specific insights regarding its energy infrastructure challenges, limited financial development, and policy constraints. The use of advanced econometric techniques, such as the Panel Autoregressive Distributed Lag (PARDL) model and Granger causality tests, ensures robust and reliable results that address inconsistencies found in prior studies. Focusing on the underexplored SADC region, it contributes to the existing literature by integrating macroeconomic factors into the nexus of financial development, economic growth, and energy consumption.

3. Methodology

The study employs several variables to assess the relationship between financial development, economic growth, and energy consumption in the SADC countries from 1980 to 2023. The dependent variable is energy consumption, and independent variables include financial development, economic growth, industrialization, urbanization, and a dummy variable to capture exogenous shocks.

The Table 1 below presents the variables used, their definitions, sources, and units of measurement.

Table 1

Variable	Definition	Source	Unit of Measurement	Expected Sign
Energy Consumption (EC)	Total energy consumption per capita, including electricity, gas, oil, and coal consumption.	Odhiambo (2019); Karakurt & Aykutalp (2020)	kWh per capita	Dependent Variable
Financial Development (FD)	Domestic credit to the private sector by banks as a percentage of GDP.	Acquah and Ibrahim (2020); Haque (2020)	% of GDP	Positive
Economic Growth (GDP)	GDP per capita growth annual percentage.	Al-Mulali & Lee (2013)	Annual percentage (%)	Positive
Industrialization (IND)	Industry, including construction, as a value-added percentage of GDP.	Liu & Chu (2024)	% of GDP	Positive
Urbanization (URB)	Urban population as a percentage of the total population.	Amir (2019);	% of total population	Positive
Dummy Variable (DT)	Captures financial crises and the Covid-19 pandemic to account for exogenous shocks.	Liu and Chu (2024)	Binary (1 for crisis years, 0 otherwise)	Ambiguous

This section outlines the techniques employed, which include unit root tests, correlation analysis, Granger causality tests, and diagnostic assessments.

3.1. Panel cointegration

The optimal formulation of the energy consumption function is shaped by the cointegration characteristics of the variables. When these variables are cointegrated, the relationship between energy consumption, economic growth, and financial development represents a long-term equilibrium, with any deviations tending to revert to the mean. However, traditional unit root and cointegration tests often have limited power when compared to stationary alternatives. In this context, panel tests provide an advantage. By incorporating a cross-sectional dimension, they draw on a broader dataset, enhancing the robustness of the results and yielding more reliable insights.

3.1.1. Panel unit root tests

The study employs a fixed panel unit root test to address the potential non-stationarity of macroeconomic variables used in the analysis. Given the nature of these variables, it is essential to determine the order of integration to establish a long-term relationship between them. Traditional first-generation unit root tests are often unreliable and prone to bias when cross-sectional dependencies are present. To overcome these limitations, the study uses the cross-sectional augmented Im, Pesaran, and Shin (CIPS) unit root test, as developed by Im et al. (2003), and the cross-sectional augmented Dickey-Fuller (CADF) unit root test, proposed by Pesaran (2007). These tests are specifically designed to account for cross-sectional dependencies, ensuring more accurate results. Both the CIPS and CADF tests are conducted under the null hypothesis that the variables are non-stationary, with the alternative hypothesis suggesting stationarity. The CADF unit root test statistic is computed using the following expression:

$$\Delta y_{it} = ai + b_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum_{j=0}^{s} d_{ij} \Delta \overline{y}_{t-j} + \sum_{j=1}^{s} \delta_{ij} \Delta \overline{y}_{t-j} + e_{it} \quad (1)$$

Where $\overline{y}$ and $\Delta\overline{y}$ denote the cross-sectional averages of the lagged and first differences respectively. The CIPS unit root test statistic is derived from the t-statistic estimated from the CADF regression model, which is as follows:

$$\text{CIPS} = N^{-1} \sum_{i=1}^{N} \text{CADF}_i \quad (2)$$

This is followed by panel cointegration analysis.

3.1.2. Panel Cointegration tests

The next step in the empirical analysis involves investigating the long-term relationships between the selected variables by using Westerlund's (2005) second-generation panel cointegration test, based on the Durbin-Hausman principle. This method is particularly advantageous because it effectively addresses issues of cross-sectional dependence and data heterogeneity, which are limitations of the traditional first-generation panel cointegration tests. Besides, this approach does not require adjustments for time dependence within the data. The test can be applied to a mix of I(1) and I(0) variables without needing prior knowledge of their integration order; it is most effective when the dependent variable is I(1). To examine the null hypothesis of no cointegration, the following autoregressive model based on panel regression residuals is employed:

$$\overline{\vartheta}_{it} = \widehat{\rho_i \vartheta}_{it-1} + u_{it} \quad (3)$$

Where, $\hat{Z}_{it} = \sum_{j=1}^{t} \hat{\vartheta}_{it}$ and $\hat{R}_{it} \sum_{j=1}^{T} \hat{\vartheta}_{it}^{2}$.

Westerlund (2005) proposes two VR test statistics obtained by testing for a unit root in the predicted residuals using the DF regression as in Eq (3). Those are panel variance ratio statistics (VR_p) and a group mean-variance ratio (VR_g) statistics. These two VR tests are based on Phillips and Ouliaris (1990) and Breitung (2002), where the test statistic is constructed as a ratio of variances. The null hypothesis is H_0:$\rho_i = 1$ for all $i = 1$ meaning no cointegration, whereas the alternative hypothesis is different in both cases.

The panel variance ratio statistics can be specified as, $VR_p = \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{Z}_{it}^{2} \left(\sum_{i=1}^{N} \hat{R}_{it} \right)^{-1}$, with an alternative hypothesis that cointegration exists for all units i.e. H_1:$|\rho_i = \rho| < 1$.

Similarly, the group mean-variance ratio test is defined as $VR_g = \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{Z}_{it}^{2} \hat{R}_i - 1$ with an alternative hypothesis that cointegration exists for some of the cross-sectional panel units i.e. H_1:$|\rho_i < 1$.

3.1.3. Panel long-run estimates

Once it is confirmed that variables are cointegrated, the next step is to estimate the long-run and short-run relationship by applying a group of panel estimators. The study adopted two estimators assuming slope heterogeneity and cross-sectional dependencies. Those are the Mean Group (MG) and Pooled Mean Group (PMG) estimators. The first one is the Mean Group (MG) estimator proposed by Pesaran and Smith (1995) which includes a regression model to apply for each panel unit separately and then take the average of the individual coefficients to obtain a mean group estimator.

The second one is the Pooled Mean Group (PMG) approach by Pesaran, Shin and Smith (1999), which is used to estimate the short-run and long-run parameters of the Panel Error Correction Model (PECM) based on the Panel Autoregressive Distributed Lag (ARDL) approach. The difference between MG and PMG estimator is that MG allows all coefficients to vary as well as to be heterogeneous both in the short run and long run, while PMG imposes homogeneity restrictions on long-run coefficients, although there is heterogeneity in the short-run coefficients and error variances. However, Pesaran et al. (1999) show that PMG estimators are more efficient than MG estimators under the long-run homogeneity.

Following Pesaran et al. (1999), the equation may be written in an ARDL form as follows:

$$LnEC_{i,t} = \beta_0 + \sum_{j=i}^{p_1} \beta_{1,ij} \cdot LnEC_{i,t-j} + \sum_{j=i}^{p_2} \beta_{2,ij} \cdot LnFD_{i,t-j} + \sum_{j=i}^{p_3} \beta_{3,ij} \cdot LnGDP_{i,t-j} +$$
$$+\sum_{j=i}^{p_4} \beta_{4,ij} \cdot Ln(FD \cdot EG)_{i,t-j} + \sum_{j=i}^{p_5} \beta_{5,ij} \cdot LnIND_{i,t-j} + \sum_{j=i}^{p_6} \beta_{6,ij} \cdot LnURB_{i,t-j} + DT + e_{i,t} \quad (4)$$

Where Ln shows the log-form, EC is the energy consumption, FD is the financial development, GDP is the economic growth, IND is the industrialisation, URB is the urbanisation, i represents the number of groups; t represents the number of years; β_0 represents the group-specific effects, and $B_i's$ are associated coefficients. In the presence of cointegration, Eq. (4) can be specified in an error correction form as:

$$\Delta LnEC_{i,t} = \varnothing_i (\ln nEC_{i,t-1} - \theta \ln Y_{it}) \sum_{j=i}^{p_{1-1}} \beta^*_{1,ij} \cdot \Delta LnEC_{i,t-jj} +$$
$$+\sum_{j=i}^{p_{2-1}} \beta^*_{2,ij} \cdot \Delta LnFD_{i,t-j} + \sum_{j=i}^{p_{3-1}} \beta^*_{3,ij} \cdot \Delta LnGDP_{i,t-j} + \sum_{j=i}^{p_{4-1}} \beta^*_{4,ij} \cdot \Delta Ln(FD \cdot EG)_{i,t-j} +$$
$$+\sum_{j=i}^{p_{5-1}} \beta^*_{5,ij} \cdot \Delta LnIND_{i,t-j} + \sum_{j=i}^{p_{6-1}} \beta^*_{6,ij} \cdot \Delta LnURB_{i,t-j} + DT + e_{i,t} \quad (5)$$

Here, Δ is the first difference operator, $\varnothing_i = 1 - \sum_{j=i}^{p_1} \beta_{1,ij}$ indicates the speed of adjustment to long-run equilibrium which must be negative for the long-run relationship to exist.

In the present study, we estimated Eq. (4) by applying MG and PMG estimators and then made a comparative analysis of the results. The Hausman's test is used to determine the best among the two variants of Mean Group estimators. The null hypothesis (H_0) of The Hausman Test between and PMG is that both MG and PMG are consistent, while MG is inefficient against the alternative hypothesis (H_1) of PMG being consistent. Finally, the results are analyzed for a suitable model based on Hausman's selection criteria.

3.2. Granger causality

The direction of the systematic risk propagation can be empirically detected by the Granger causality test (Tanner & Wong, 2010). X is said to "Granger cause" Y if past values of X contain information that helps predict Y beyond the information contained in the past values of Y alone (Granger, 1969). Let X_t and Y_t be two stationary time series and for simplicity let's assume that they have zero mean. Their linear relationship model:

$$y_t = \alpha + \sum_{k=1}^{k} \gamma_k y_{t-k} + \sum_{k=1}^{k} \beta_k x_{t-k} + \varepsilon_t, \text{ with } t = 1, \ldots, T \quad (6)$$

can then be used to test whether x causes y. Essentially, if past values of x are significant predictors of the current value of y even when past values of y have been included in the model (Granger, 1969), then x exerts a causal influence on y.

3.3. Diagnostic tests

Previous studies have found that many diagnostics produce results that are difficult to interpret and potentially misleading, even in idealised settings. (Kroese et al., 2014). This section offers recommendations on how to proceed in this thorny area. The convergence diagnostics of Gelman and Rubin (1992) currently is the most popular in the statistical community (Gelman et al., 1995), partly because computer programs for their implementation are available from their creators (Brooks et al., 2011).

This research applies Bayesian approach via Metropolis-Hasting and Gibbs samples as MCMC methods to estimate the impact of financial development and economic growth on energy consumption. It employs panel autoregressive distributive lag to test for integration between the variables and Dumitrescu and Hurlin (2012) and Diagnostic tests to check the causality between all the variables in question and to check the accuracy of the data and model.

4. Findings

This section presents the results for correlation, descriptive statistics, PARDL as the main model of the study, and diagnostic tests for the model.

4.1. Preliminary tests: correlation

To make sure that there is no multicollinearity among the explanatory variables, the process of estimation starts with preliminary tests that check correlations. The correlation matrix is presented in Table 2 below.

Table 2. Correlations among the variables in the model

VARIABLE	EC	FD	GDPC	IND	URB
EC	1	0.4648	0.0352	-0.0056	0.4815
FD	0.4648	1	0.0428	0.0526	0.3763
GDPC	0.0352	0.0427	1	0.0303	-0.0417
IND	-0.0056	0.0526	0.0303	1	0.3262
URB	0.4815	0.3786	-0.0417	0.3263	1

Source: Authors' own computation constructed by Eviews 9

Among the explanatory variables, no multicollinearity problem is identified as can be inferred from the absolute value range (0.0056-0.464) in the table 2; the values are lower than the benchmark of 0.80 (Nkalu et al., 2020).

4.1.1. Descriptive statistics

This section presents summary statistics for the primary variables under scrutiny. These statistics are displayed in Table 3, highlighting the mean, standard deviation, minimum, and maximum values, along with the count of observations.

Table 3. Descriptive statistics

VARIABLES	EC	FD	GDPC	IND	URB
Mean	6344.807	22.39907	1.097317	27.21004	34.82678
Median	2079.720	13.44104	1.352928	25.29462	32.38500
Maximum	100013.9	142.4220	19.93898	72.71737	72.22400
Minimum	0.000000	0.000000	-26.34912	0.000000	9.050000
Standard Deviation	1087.41	27.51986	4.815903	13.04445	14.24986
Skewness	3.060194	2.274988	-0.720561	0.675643	0.486139
Kurtosis	15.47225	7.839631	6.446489	3.806848	2.538088
Jarque-Bera	5509.003	1259.381	398.3023	70.69702	33.07082
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	4346193.0	15343.36	751.6620	18638.88	23856.34
Sum Sq. Dev	8.09E+10	518022.3	15863.96	116387.8	138892.1
Observations	685	685	685	685	685

Source: Authors' own computation constructed by Eviews 9

Table 3 indicates that there is no normal distribution from all the series employed. This is shown by the Jarque-Bera which had a probability value of more than 0.0000.

4.2. Panel unit root tests

Unit root tests are statistical tests used to determine whether a time series variable is non-stationary and if it has a unit root. Non-stationary data can have significant implications for time series analysis, particularly in econometrics, as they may cause misleading statistical inferences.

4.2.1. Graphical analysis

The study first carried out a graphical analysis to check the stationarity status of the variables.

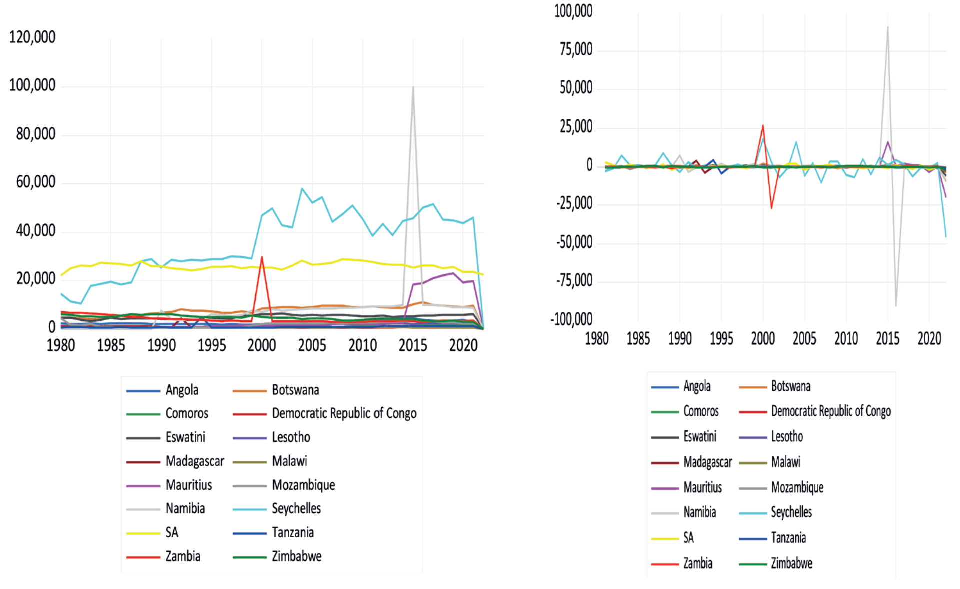


Figure 1. Graphical analysis of the variable EC. *Source*: Authors' own computation constructed by Eviews

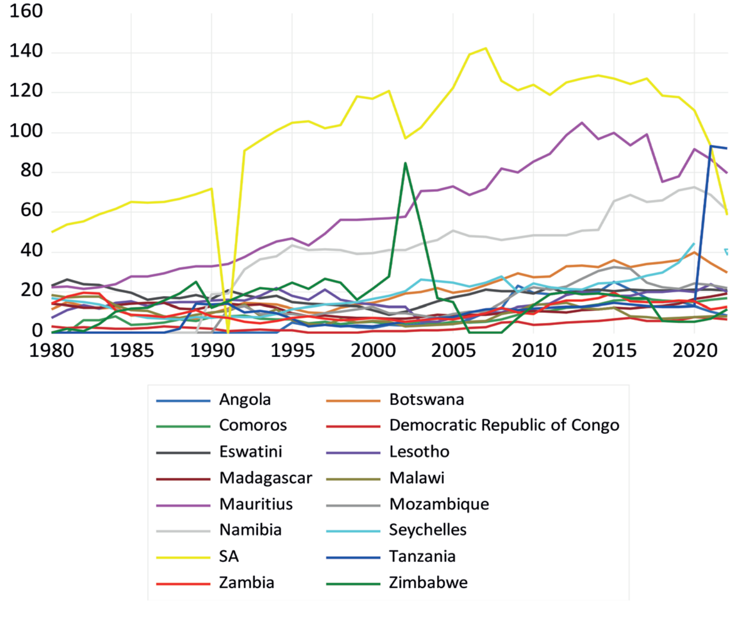


Figure 2. Graphical analysis of the variable FD. *Source*: Authors' own computation constructed by Eviews 9

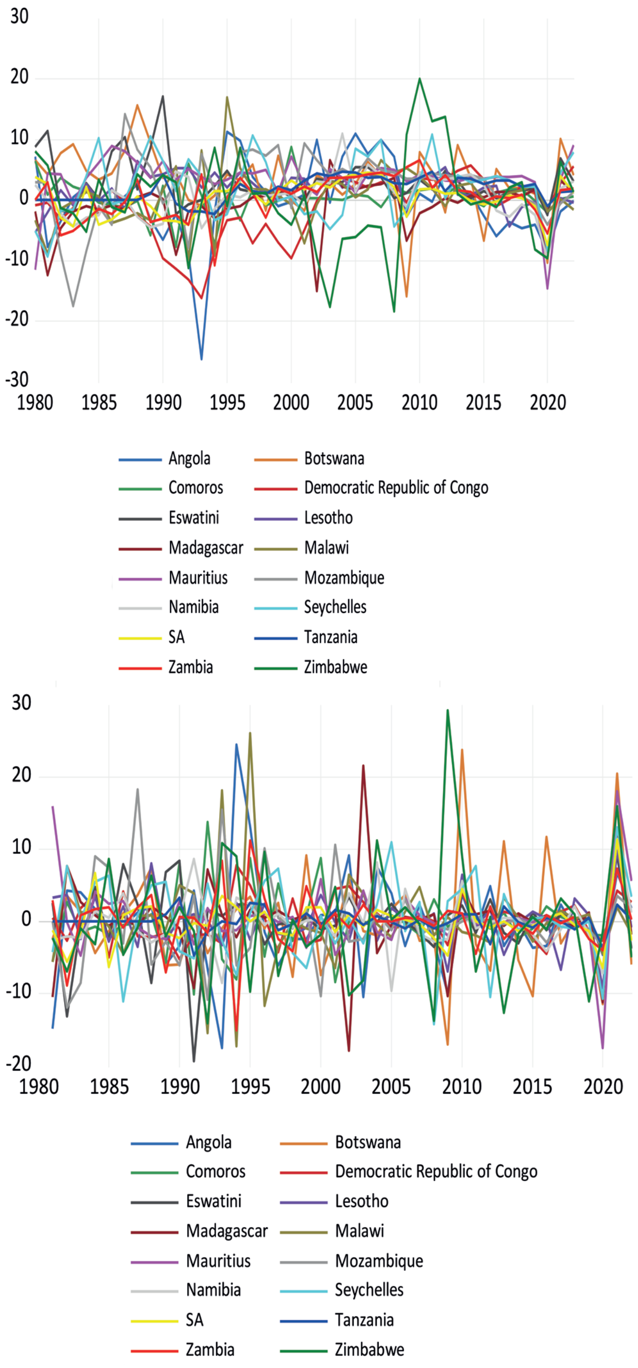


Figure 3. Graphical analysis of the variable GDPPC. *Source*: Authors' own computation constructed by Eviews 9

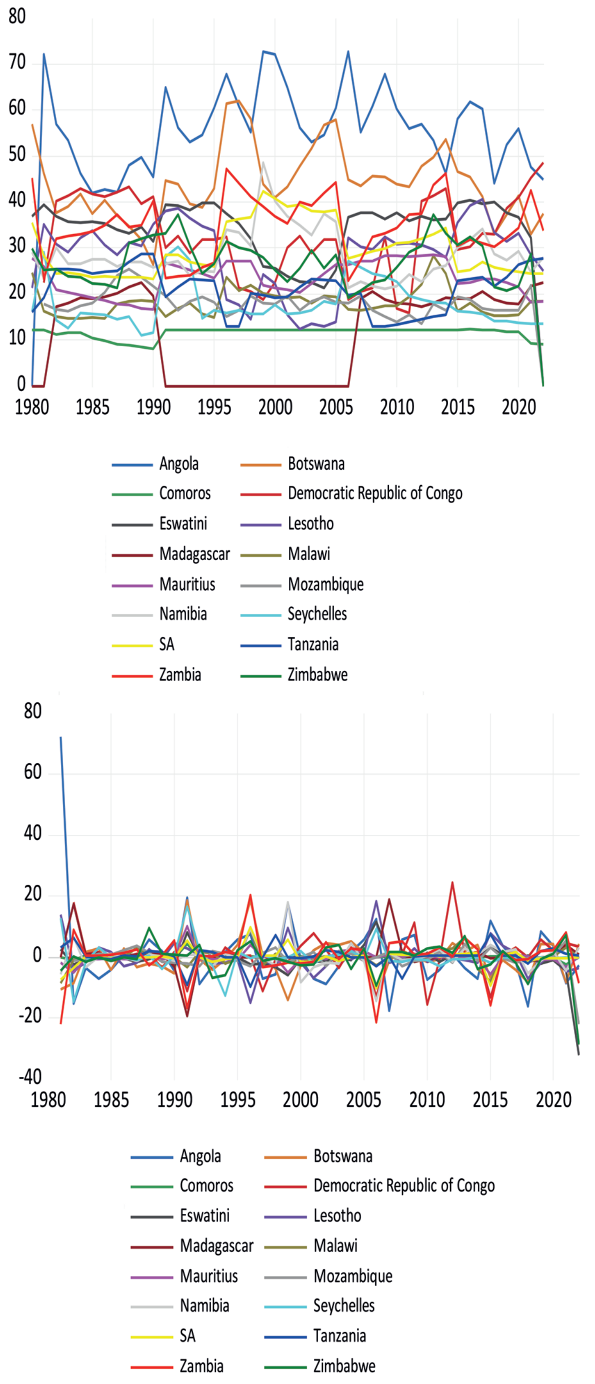
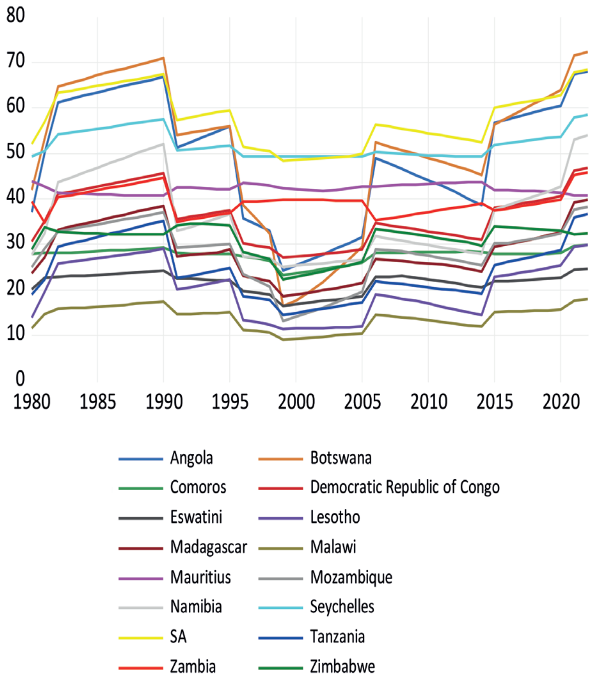


Figure 4. Graphical analysis of the variable IND. *Source*: Authors' own computation constructed by Eviews 9



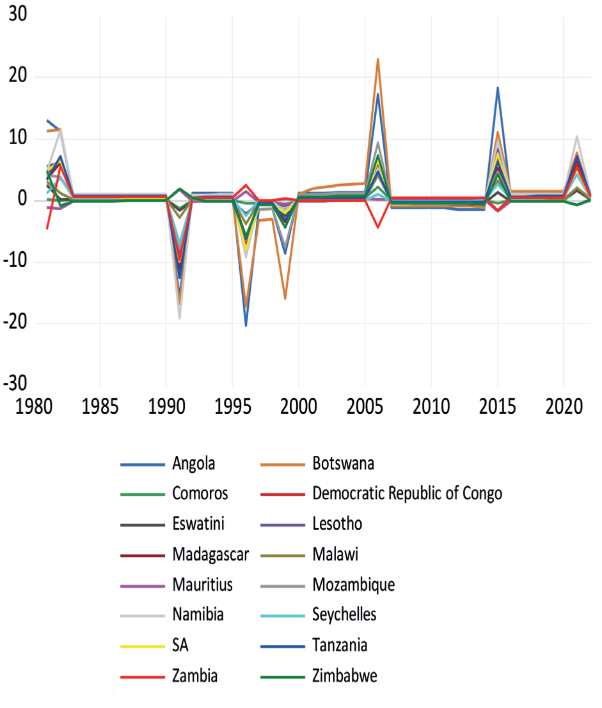


Figure 5. Graphical analysis of the variable URB. *Source*: Authors' own computation constructed

All Figures show that the variables were not stationary at levels. In all Figures, the sets labelled (left) show variables at levels. The graphs indicate that the variables became stationary after first differencing. This is shown by the lines hovering around zero in the sets labeled (right). This is an indication that the variables were stationary after first differencing.

4.2.2. Formal analysis

The results from the LM Pesaran test suggest that only two variables were stationary at their levels. These were IND and GDP. The rest of the variables became stationary after being differenced once.

Table 4. Stationarity

Variable	t-statistic	p-value
EC	-1.4695	0.0708
	-6.3177	0.0000
FD	1.3712	0.9148
	11.4708	0.0000
GDP	10.3879	0.0000
IND	3.9365	0.0000
URB	4.685	0.6803
	12.7120	0.0000

Source: Authors' own computation constructed by Eviews 9

4.3. Cointegration

The study performed a Pedroni cointegration; the results are displayed in Table 5 below.

Table 5. Pedroni Cointegration

Alternative hypothesis: common AR coef. (within-dimension)				
				Weighted
	Statistic	Prob.	Statistics	Prob.
Panel v-Statistic	0.989204	0.1613	-1.433489	0.9241
Panel rho-Statistic	-7.065312	0.0000	-3.766124	0.0001
Panel PP-Statistic	-11.70625	0.0000	-7.557384	0.0000
Panel ADF-Statistic	-4.614442	0.0000	-1.139414	0.1273
Alternative hypothesis: common AR coef. (between-dimension)				
	Statistic	Prob.		
	Group rho-Statistic		-1.489898	0.0681
	Group PP-Statistic		-3.081982	0.0010
	Group ADF-Statistic		1.489884	0.9319

Source: Authors' own computation constructed by Eviews 9

Panel v-Statistic:

Statistic: 0.989204 (with a p-value of 0.1613)

Interpretation: Panel v-Statistic is a test for the null hypothesis that there is no cointegration. A higher statistic value (close to 1) with a p-value greater than 0.05 suggest that there is no cointegration for the panel data when considering the „within-dimension" approach. Since the p-value (0.1613) is greater than 0.05, the null hypothesis of no cointegration cannot be rejected at conventional significance levels.

Panel ADF-Statistic:

Statistic: -4.614442 (with a p-value of 0.0000)

Interpretation: Panel ADF-Statistic is a test for unit roots that evaluates the stationarity of the panel data. The negative value of -4.614442 and the p-value of 0.0000 suggest strong evidence against the null hypothesis of a unit root. This indicates that the series are stationary, and therefore there is cointegration in the data when considering the „within-dimension" approach.

Group ADF-Statistic:

Statistic: 1.489884 (with a p-value of 0.9319)

Interpretation: Group ADF-Statistic is another test for unit roots, but it assesses the „between-dimension" relationship in the data. The positive statistic and extremely high p-value (0.9319) suggest that there is no evidence of cointegration in the „between-dimension," implying that the series may not be stationary when considering cross-sectional differences across the groups.

Panel rho-Statistic:

Statistic: -7.065312 (with a p-value of 0.0000)

Interpretation: The Panel rho-Statistic tests for the null hypothesis of no cointegration, and a highly negative statistic with a very low p-value (0.0000) indicates strong evidence against the null hypothesis. This suggests that there is cointegration in the panel data, confirming the presence of a long-run relationship between the variables when assessed in the „within-dimension" approach.

Panel PP-Statistic:

Statistic: -11.70625 (with a p-value of 0.0000)

Interpretation: Similar to Panel rho-Statistic, the Panel PP-Statistic tests for the null hypothesis of no cointegration and shows a very negative statistic with a p-value of 0.0000. This indicates strong evidence of cointegration in the data, reaffirming that there is a long-run relationship when assessed in the „within-dimension" approach.

Group rho-Statistic:

Statistic: -1.489898 (with a p-value of 0.0681)

Interpretation: Group rho-Statistic, for the „between-dimension," indicates a p-value of 0.0681, which is close to the 0.05 threshold but still above it. This suggests that there is some evidence of cointegration in the between-dimension but it is not statistically significant at the conventional 5% level.

Group PP-Statistic:

Statistic: -3.081982 (with a p-value of 0.0010)

Interpretation: The Group PP-Statistic is also for the „between-dimension" and has a p-value of 0.0010, which is highly significant and provides strong evidence against the null hypothesis of no cointegration. This implies that there is cointegration in the „between-dimension."

Overall Interpretation:

Panel v-Statistic and Group ADF-Statistic provide mixed evidence for cointegration, with Panel v-Statistic failing to reject the null of no cointegration (due to a high p-value) and Group ADF-Statistic showing no cointegration in the between-dimension.

However, the Panel rho-Statistic, Panel PP-Statistic, and Group PP-Statistic strongly suggest cointegration, indicating that there is a long-run relationship between the variables being tested, especially in the „within-dimension."

Given the significant results of the multiple tests, the study can conclude that there is cointegration between the variables in the panel data when considering the appropriate subtests (Panel rho-Statistic, Panel PP-Statistic, and Group PP-Statistic). It is also important to mention that „within-dimension" cointegration results are more reliable.

4.4. PMG results

Table 6. PMG Results

Variable	Coefficient	Standard Error	t-Statistic	Probability Value
GDPC	0.016481	0.009989	1.649972	0.0995
IND	0.001168	0.004704	0.248235	0.8045
FD	0.034116	0.034116	0.004768	0.0000
URB	-0.010656	-0.010656	0.006048	0.0786

Source: Authors' own computation constructed by Eviews 9

Interpretation of Results:

GDP and Energy Consumption

The results show that GDP has a small (0.016) but positive relationship with energy consumption, indicating that as GDP increases, energy consumption also increases. This suggests that when economic growth rises in the SADC countries, so does energy demand. If energy supply is constrained, it may limit economic growth. As the SADC countries' economic growth increases, energy demand also increases, meaning that if energy is constrained, economic growth pulls back, in turn. The results concur with Zhang, Zheng, Li, Chen and Liao (2025), who concluded that a long-run positive relationship existed between economic growth and energy consumption in 30 Chinese provinces from 2000 to 2019. Also, evidence was drawn from the Asia-Pacific Economic Cooperation (APEC) Economies and 18 Asian countries between 1995 and 2020.

Navarro-Chávez, Ayvar-Campos and Camacho-Cortez (2023) and Nasreen, Mbarek and Atiq-ur-Rehman (2020) discovered a long-run positive relationship between economic growth and energy consumption from 1980 to 2017. Countries should work on creating new sources of energy and improving energy efficiency. Furthermore, when countries become more productive, they will produce greater output and use more resources, and, most importantly, energy consumption and production will also increase. Conversely, Miah, Islam, and Raihan (2025) discovered a negative and long-run relationship between economic growth and energy consumption for Bangladesh from 1990 to 2019. Raza, Khan and Bakhtyar (2025) and Hlongwane, (2025) documented a long-run negative relationship between economic growth and energy consumption for BRICS and, in particular, for South Africa in 1975-2020 and 1990-2019. Governments should implement policy measures that will help to make the use of energy more efficient and promote healthy relations in the broader economy.

Industrialization and Energy Consumption

The results show that industrialization (0.0012) has no significant long-run relationship with energy consumption. This suggests that industrialization alone does not drive changes in energy consumption and probably has no impact on it. These findings concur with Gupta, Kumari, and Singh (2024) who discovered no significant long-run relationship between industrialisation and energy consumption in selected G20 countries using a Panel ARDL model. Onatunji (2025) found no significant relationship between industrialisation and energy consumption in Nigeria between 1971 and 2017. Improving energy efficiency in industry is also difficult due to the high complexity of industrial energy systems. On the other hand, Keser, Işik, Aliyev, Dineri and Kose (2025) revealed a long-run positive relationship between industrialisation and energy consumption in the NATO countries from 1995 to 2018. Aimon and Amar (2024) found a strong positive long-run relationship between industrialisation and energy consumption in Indonesia from 1984 to 2022. Expanding industrialisation in newly industrialised countries is driving the intensive use of energy. However, Mentel *et al*. (2022) discovered a negative long-run relationship between industrialisation and energy consumption from 2000 to 2018 in Europe and Central Asia. Across 30 African countries between 2000 and 2021, Chen, Wu, and Nguea (2025) with the help of Driscoll-Kraay and IV-GMM techniques also found that industrialisation has a negative effect on energy consumption in the long run, because of the impact of labour-intensive, skilled technology in the early stages of industrialisation at the current human resource level.

Financial Development and Energy Consumption

Financial development was found to have a positive relationship (0.034) with energy consumption, meaning that as financial development improves, energy consumption increases. These findings are in line with Lefatsa *et al*. (2021), who discovered that financial development positively affects energy consumption in the long run for South Africa from 1980 to 2018. Thebuho *et al*. (2022) found a long-run positive effect of financial development on energy consumption in 21 SSA countries between 1990 and 2016. Virtuous-performing stock markets stimulate growth, thereby increasing investor confidence. Nevertheless, Khah, and Ahmad (2025) obtained the opposite results. They found a long-run negative relationship between financial development and energy consumption in India using an augmented autoregressive distributed lag (AARDL) model from 1980 to 2021.

Urbanization and Energy Consumption

Urbanization was found to have a (-0.011) negative correlation with energy consumption, indicating that as urbanization increases, energy consumption decreases. This shows that when urbanisation increases, there will be a decrease in energy consumption. The findings are in line with Rehman, Radulescu, Cismaș, Cismaș, Chandio, and Simoni (2022), who found a long-run negative effect of urbanisation on energy consumption in Romania between 1990 and 2020. Olubiyi, Adedeji and Akiwale (2025) revealed a long-run negative relationship between urbanisation and energy consumption in Nigeria and South Africa between 1980 and 2022. The findings suggest that countries must frame their urban policy in such a manner that creates positive externalities. However, the results from Can, Balsalobre-Lorente, Adedoyin and Mercan (2025) revealed long-run positive relationship between urbanisation and energy consumption among G7 countries from 1970 to 2020.

Table 7. Granger causality: GDPC and EC (bidirectional) causality results

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
EC does not homogeneously cause GDPC	3.11439	1.75164	0.0798
GDPC does not homogeneously cause EC	3.86172	3.07377	0.0021

Source: Authors' own computation

Based on the test results, the study concludes that there is a bidirectional Granger causality between economic growth and energy consumption. This shows that the relationship runs in both directions. These findings concur with Chen *et al*.'s studies (2022) of the BRICS economies from 1990 to 2019 and from 2000 to 2018. They discovered a bidirectional causality effect between economic growth and energy consumption. Further openness to international markets brings technological advances to BRICS, innovative energy-efficient technology in particular.

Table 8. Granger causality: FD and EC (FD → EC)

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
FD does not homogeneously cause EC	3.34660	2.16153	0.307
EC does not homogeneously cause FD	2.90746	1.38481	0.1661

Source: Authors' own computation

The results point to a unidirectional causality running from financial development to energy consumption, i.e. financial development Granger causes energy consumption. According to Adebayo and Ağa (2022), in the MINT countries from 1990Q1 to 2019Q4, there was a unidirectional causality running from financial development to energy consumption. Countries need to address their socioeconomic problems and energy deficits in order to improve sustainable environments and generate new economic activities.

Table 9. Granger causality: IND and EC (no causality)

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
IND does not homogeneously cause EC	2.60630	0.85152	0.3945
EC does not homogeneously cause IND	1.59591	-0.93518	0.3497

Source: Authors' own computation, Eviews 9 using statistics from the World Bank (2024)

The results do not show any causality between the variables in question. Energy is the foundation of the modern industrial economy. Affordable and reliable energy is a co-requisite for improved industrial productivity and competitiveness, and thus a crucial element in economic diversification. The results contradict the findings of Gungor and Simon (2017), who discovered a bidirectional causality effect between industrialisation and energy consumption in South Africa from 1970 to 2014.

Table 10. Granger causality: URB and EC (URB →EC)

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
URB does not homogeneously cause EC	3.57493	2.56640	0.0103
EC does not homogeneously cause URB	2.12334	-0.00166	0.9987

Source: Authors's own computation, Eviews 9 using statistics from the World Bank (2024)

The results show that there is a unidirectional causality running from urbanisation to energy consumption, which means that urbanisation is causing energy consumption.

4.6. Diagnostic tests

The diagnostic tests conducted in the study show that the model is both correct and a good fit for analyzing the relationship between financial development, economic growth, and energy consumption in the SADC region. These tests were essential to ensuring the reliability and validity of the results. The absence of abnormalities indicates that the assumptions underlying the econometric model were satisfied, and no unusual patterns were detected in the residuals. Consequently, the model accurately represents the dynamics between the variables, providing robust and trustworthy conclusions.

5. Discussion and Conclusions

5. 1. Research Limitations

The study provides useful insights into the relationship between financial development, economic growth, and energy consumption in the SADC region; however, there are several limitations to consider.

Data Limitations: data availability and quality may vary across the SADC countries, particularly for energy consumption and financial development indicators. Missing data or inconsistencies across countries could affect the robustness of the results.

Model Limitations: the study used Granger causality tests to analyze the relationships. While Granger causality can detect short-term relationships, it may not fully capture long-term dynamics or causal mechanisms. Other econometric models, such as Vector Error Correction Models (VECM), could have been used to capture long-run relationships more effectively.

Country-Specific Variations: the SADC region consists of diverse countries with different economic structures, levels of financial development, and energy consumption patterns. This heterogeneity might limit the generalizability of the results for all countries in the region.

Exogenous shocks: the study period from 1980 to 2023 includes several political, economic, and global crises, such as the 2008 global financial crisis. Exogenous shocks caused by these events might have distorted the observed relationships between financial development, economic growth, and energy consumption.

5. 2. Consistency with Research Questions

The study addresses three key research questions.

First: is there a specific trend between financial development, economic growth, and energy consumption in SADC countries over the period 1980 to 2023?

Findings: the study finds evidence of a bidirectional causality between economic growth and energy consumption, suggesting that economic growth drives energy demand. However, there is no significant direct relationship between financial development and energy consumption in the region. This aligns with the hypothesis that economic growth and energy consumption are interrelated, but financial development does not consistently drive energy consumption.

Trend: The data suggest that economic growth leads to increased energy consumption, particularly in urbanised and industrialised economies, while financial development does not have a significant impact on energy consumption trends over time.

Second: is there a relationship between the SADC countries' financial development, economic growth, and energy consumption in 1980-2023?

Findings: The study has shown that economic growth and urbanization influence energy consumption in the SADC countries. Financial development does not appear to materially affect energy consumption, contrary to some expectations based on global studies.

Relationship: The relationship between financial development and energy consumption is weaker than anticipated, suggesting that other factors, such as infrastructure development or international energy prices, may play a more significant role in energy consumption patterns in the SADC region.

Third: what is the direction of causality between financial development, economic growth, and energy consumption in the SADC countries?

Findings: The study confirms that economic growth drives energy consumption, but energy consumption does not Granger cause economic growth. Urbanization also appears to drive energy demand, indicating that the increasing concentration of populations in urban areas leads to higher energy consumption. Financial development does not significantly cause energy consumption or economic growth in this context.

Causality: The results suggest that the causal relationship between economic growth and energy consumption is unidirectional, going from economic growth to energy consumption, with no reverse causality observed. Financial development does not exhibit a clear causal link to energy consumption or economic growth.

5. 3. Major Findings and Link to Research Hypothesis

First, the study identified bidirectional causality between economic growth and energy consumption, and unidirectional causality from urbanization to energy consumption. Financial development did not show significant causality to or from energy consumption, suggesting that while financial systems may support economic growth, they do not directly influence energy demand.

Second, it has shown that economic growth drives energy consumption, as economic growth was found to have a significant positive effect on energy demand.

Third, the study detected no significant role of financial development, contrary to some studies that posit a direct relationship between financial development and energy consumption (Al-Mulali et al., 2015). This suggests that the impact of financial development on energy consumption in the SADC countries may be indirect or mediated by other factors such as government policy, infrastructure investment, or global energy markets.

Fourth, the study supports the idea that urbanization drives energy consumption (Khan et al., 2018): a growing urban population means greater demand for infrastructure, housing, transport and therefore energy.

5. 4. Conclusions and Policy Implications

Although financial development may have no direct impact on energy consumption, sustainable economic growth requires stronger financial institutions. Governments should improve access to finance for energy projects, especially in the renewable energy sector. This can help achieve long-term energy sustainability in the region.

The findings emphasize the need for investing in energy infrastructure and energy efficiency to ensure that energy systems are resilient, sustainable, and capable of meeting the growing demand without compromising environmental goals. It is also essential to develop energy-efficient urban planning strategies.

References

Abdelhamid, A., Ozatac, N., & Taspinar, N. (2023). Investigating the Nexus between Energy Consumption and Financial Development via Considering Structural Breaks: Empirical Evidence from Argentina. *Sustainability*, *15*(11), 8482. https://doi.org/10.3390/su15118482

Acquah, A. M., & Ibrahim, M. (2020). Foreign direct investment, economic growth and financial sector development in Africa. *Journal of Sustainable Finance & Investment*, *10*(4), 315-334.

Adebayo, T. S., & Ağa, M. (2022). The Race to Zero Emissions in MINT Economies: Can Economic Growth, Renewable Energy and Disintegrated Trade Be the Path to Carbon Neutrality?. *Sustainability*, *14*(21), 14178. https://doi.org/10.3390/su142114178

Adu, D. T., & Denkyirah, E. K. (2018). Economic growth and environmental pollution in West Africa: Testing the Environmental Kuznets Curve hypothesis. *Kasetsart Journal of Social Sciences*, *40*(2), 281-288.

Aimon, H., & Amar, S. (2024). Economic Growth and Environmental Degradation in Indonesia: The Roles of Investment, Inflation, Income Inequality, Fossil Consumption, and Poverty. *International Journal of Sustainable Development & Planning*, *19*(5), 1941-1946. https://doi.org/10.18280/ijsdp.190532

Akinsola, M. O., & Odhiambo, N. M. (2020). Asymmetric effect of oil price on economic growth: Panel analysis of low-income oil-importing countries. *Energy Reports*, (*6)*, 1057-1066. https://doi.org/10.1016/j.egyr.2020.04.023

Al-Mulali, U., & Lee, J. Y. (2013). Estimating the impact of the financial development on energy consumption: Evidence from the GCC (Gulf Cooperation Council) countries. *Energy*, (*60)*, 215-221. https://doi.org/10.1016/j.energy.2013.07.067

Almassri, H., Ozdeser, H., & Saliminezhad, A. (2023). Revisiting the finance-growth nexus in Hong Kong: fresh insights from nonparametric analysis. *Journal of Economic Studies*, *50*(5), 1073-1086. https://doi.org/10.1108/JES-03-2022-0161

Amin, N., & Song, H. (2023). The role of renewable, non-renewable energy consumption, trade, economic growth, and urbanization in achieving carbon neutrality: A comparative study for South and East Asian countries. *Environmental Science and Pollution Research*, *30*(5), 12798-12812. https://doi.org/10.1007/s11356-022-22973-2

Amir, A., 2019. *The Impact of Government Efficiency on Financial Development* (Master's thesis, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ)). http://hdl.handle.net/11129/5030

Anthony-Orji, O. I., Orji, A., Ogbuabor, J. E., & Uka, L. C. (2023). Money matters a lot: empirical analysis of financial development, financial inclusion and economic growth in Nigeria.

International Journal of Economic Policy in Emerging Economies, *17*(1), 100-117. https://doi.org/10.1504/IJEPEE.2023.128386

Asafo-Adjei, E., Boateng, E., Isshaq, Z., Idun, A. A. A., Owusu Junior, P., & Adam, A. M. (2021). Financial sector and economic growth amid external uncertainty shocks: insights into emerging economies. *Plos one*, *16*(11), e0259303. https://doi.org/10.1371/journal.pone.0259303

Aslan, A., Gozbasi, O., Altinoz, B., & Altuntas, M. (2021). Impact of financial development and economic growth on energy consumption: A panel vector autoregressive analysis for the comparison of G7 and top 10 emerging market economies. *Energy & Environment*, *32*(7), 1315-1330. https://doi.org/10.1177/0958305X211004113

Bagehot, W. (1873). *Lombard Street*. Richard D. Irwin.

Balcilar, M., Bekun, F. V., & Uzuner, G. (2019). Revisiting the economic growth and electricity consumption nexus in Pakistan. *Environmental Science and Pollution Research*, (*26)*, 12158-12170. https://doi.org/10.1007/s11356-019-04598-0

Belazreg, W., & Mtar, K. (2020). Modelling the causal linkages between trade openness, innovation, financial development and economic growth in OECD Countries. *Applied Economics Letters*, *27*(1), 5-8. https://doi.org/10.1080/13504851.2019.1605581

Blackburn, K., & Hung, V. T. (1998). A theory of growth, financial development and trade. *Economica*, *65*(257), 107-124. https://doi.org/10.1111/1468-0335.00116

Bozkurt, E., Toktaş, Y., & Altıner, A. (2022). Energy Consumption and Financial Development: Evidence from MENA Countries with Panel Hidden Cointegration. *JOEEP: Journal of Emerging Economies and Policy*, *7*(1), 253-264.

Breitung, J. (2002). Nonparametric tests for unit roots and cointegration. *Journal of econometrics*, *108*(2), 343-363. https://doi.org/10.1016/S0304-4076(01)00139-7

Brookes, L. (1990). The greenhouse effect: the fallacies in the energy efficiency solution. *Energy policy*, *18*(2), 199-201. https://doi.org/10.1016/0301-4215(90)90145-T

Brooks, S., Gelman, A., Jones, G., & Meng, X. L. (2011). *Handbook of markov chain monte carlo*. CRC press.

Can, M., Balsalobre-Lorente, D., Adedoyin, F. F., & Mercan, M. (2025). The impact of trade openness, export concentration and economic complexity on energy demand among G7 countries. *Energy & Environment*, *36*(2), 638-659. https://doi.org/10.1177/0958305X231177740

Chen, J., Wu, W., & Nguea, S. M., (2025). Combining the effects of industrialization and oil prices on CO2 emissions: What role do renewable energy, urbanization and financial crisis play?. *Sustainable Development*, *33*(2), .2780-2796. https://doi.org/10.1002/sd.3264

Chowdhury, F., Audretsch, D. B., & Belitski, M. (2019). Institutions and entrepreneurship quality. *Entrepreneurship theory and practice*, *43*(1), 51-81. https://doi.org/10.1177/1042258718780431

Dada, J. T., Ajide, F. M., & Arnaut, M. (2023). Income inequality, shadow economy and environmental degradation in Africa: quantile regression via moment's approach. *International Journal of Development Issues*, *22*(2), 214-240. https://doi.org/10.1108/IJDI-11-2022-0248

Dada, J. T., & Akinlo, T. (2023). Remittances-finance-growth trilogy: do remittance and financial development complement or substitute each other to affect growth in Nigeria?. *Economic Annals*, *68*(236), 105-138. https://doi.org/10.2298/EKA2336105D

Dahmani, M., Mabrouki, M., & Ben Youssef, A. (2023). The ICT, financial development, energy consumption and economic growth nexus in MENA countries: dynamic panel CS-ARDL evidence. *Applied Economics*, *55*(10), 1114-1128. https://doi.org/10.1080/00036846.2022.2096861

Destek, M. A., & Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. *Science of the total environment*, (*650)*, 2483-2489. https://doi.org/10.1016/j.scitotenv.2018.10.017

Dimnwobi, S. K., Madichie, C. V., Ekesiobi, C., & Asongu, S. A. (2022). Financial development and renewable energy consumption in Nigeria. *Renewable Energy*, (*192)*, 668-677. https://doi.org/10.1016/j.renene.2022.04.150

Dong, K., Taghizadeh-Hesary, F., & Zhao, J. (2022). How inclusive financial development eradicates energy poverty in China? The role of technological innovation. *Energy Economics*, (*109)*, 106007. https://doi.org/10.1016/j.eneco.2022.106007

Dumitrescu, E. I. and Hurlin, C., (2012). Testing for Granger non-causality in heterogeneous panels. *Economic modelling*, *29*(4),1450-1460.

Ekanayake, E. M., & Thaver, R. (2021). The nexus between financial development and economic growth: Panel data evidence from developing countries. *Journal of Risk and Financial Management*, *14*(10), 489. https://doi.org/10.3390/jrfm14100489

El-Karimi, M. (2022). Economic growth and non-renewable and renewable energy consumption nexus in Morocco: causality analysis in VAR model. *International Journal of Sustainable Economy*, *14*(2), 111-131. https://doi.org/10.1504/IJSE.2022.122092

Foon Tang, C. (2009). Electricity consumption, income, foreign direct investment, and population in Malaysia: new evidence from multivariate framework analysis. *Journal of Economic Studies*, *36*(4), 371-382. https://doi.org/10.1108/01443580910973583

Gelman, A., Carlin, J. B., Stern, H. S., & Rubin, D. B. (1995). *Bayesian data analysis*. Chapman and Hall/CRC.

Gelman, A., & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical science*, *7*(4), 457-472. https://doi.org/10.1214/ss/1177011136

Ghosh, S. (2009). Electricity supply, employment and real GDP in India: evidence from cointegration and Granger-causality tests. *Energy Policy*, *37*(8), 2926-2929. https://doi.org/10.1016/j.enpol.2009.03.022

Giri, A. K., Mohapatra, G., & Debata, B. (2023). Technological development, financial development, and economic growth in India: Is there a non-linear and asymmetric relationship?. *Journal of Economic and Administrative Sciences*, *39*(1), 117-133. https://doi.org/10.1108/JEAS-03-2021-0060

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: journal of the Econometric Society*, 37(3), 424-438. https://doi.org/10.2307/1912791

Greenwood, J., & Jovanovic, B. (1990). Financial development, growth, and the distribution of income. *Journal of political Economy*, *98*(5, Part 1), 1076-1107. https://doi.org/10.1086/261720

Gupta, M., Kumari, I. and Singh, A. K., 2024. Impact of human capital on SDG1 in selected G20 countries. In *Interlinking SDGs and the Bottom-of-the-Pyramid Through Tourism* (pp. 21-48). IGI Global. https://doi.org/10.4018/979-8-3693-3166-8.ch002

Haque, M.I, (2020). The growth of private sector and financial development in Saudi Arabia. *Economies*, *8*(2), 39.

Hendrawaty, E., Shaari, M.S., Kesumah, F.S.D., & Ridzuan, A.R. (2022). Economic growth, financial development, energy consumption and life expectancy: fresh evidence from ASEAN countries. *International Journal of Energy Economics and Policy*, *12*(2), 444-448. https://doi.org/10.32479/ijeep.12670

Hicks, J.R. (1969). *A theory of economic history*. Oxford University Press.

Hlongwane, N.W., 2025. Determinants of electricity consumption in South Africa: Insights from linear and nonlinear modeling approaches. *Economics, Management and Sustainability*, *10*(1),6-26. https://doi.org/10.14254/jems.2025.10-1.1

Huang, Y., Kuldasheva, Z., Bobojanov, S., Djalilov, B., Salahodjaev, R., & Abbas, S. (2023). Exploring the links between fossil fuel energy consumption, industrial value-added, and carbon emissions in G20 countries. *Environmental Science and Pollution Research*, *30*(4), 10854-10866. https://doi.org/10.1007/s11356-022-22605-9

Im, K.S., Pesaran, M.H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of econometrics*, *115*(1), 53-74. https://doi.org/10.1016/S0304-4076(03)00092-7

IEA. (2022). *Electricity market report*. https://www.iea.org/reports/electricity-market-report-july-2022

IEA. (2023). *Africa Energy outlook 2023. World energy outlook special*. https://www.iea.org/reports/world-energy-outlook-2023

Islam, M.M., Irfan, M., Shahbaz, M., & Vo, X.V. (2022). Renewable and non-renewable energy consumption in Bangladesh: The relative influencing profiles of economic factors, urbanization, physical infrastructure and institutional quality. *Renewable Energy*, (*184)*, 1130-1149. https://doi.org/10.1016/j.renene.2021.12.020

Jamil, M.N. (2022). Critical analysis of energy consumption and its impact on countries economic growth: an empirical analysis base on countries income level. *Journal of Environmental Science and Economics*, (*1)*, 1-12. https://doi.org/10.56556/jescae.v1i2.11

Jevons, W.S. (1866). *The coal question; an inquiry concerning the progress of the nation and the probable exhaustion of our coal-mines*. Macmillan.

Jia, W., Jia, X., Wu, L., Guo, Y., Yang, T., Wang, E., & Xiao, P. (2022). Research on regional differences of the impact of clean energy development on carbon dioxide emission and economic growth. *Humanities and Social Sciences Communications*, *9*(1), 1-9. https://doi.org/10.1057/s41599-021-01030-2

Karakurt, M., & Aykutalp, A. (2020). *Can Social Media Be Seen as a New Public Sphere in the Context of Hannah Arendt's Public Sphere Theory?* https://www.researchgate.net/publication/344432422

Keser, A., Işik, N., Aliyev, P., Dineri, E. & Kose, Z. (2025). The Impact of Militarization and Industrialization as a Threat to Sustainable Environmental Development in NATO Countries. *Sustainable Development*. 33(6), 8706-8720. https://doi.org/10.1002/sd.70126

Khah, A.M., & Ahmad, M. (2025). Assessing the impact of output growth, renewable energy consumption and financial development on environmental quality: empirical evidence from India. *Journal of Financial Economic Policy,* 17 (5), 732–757. https://doi.org/10.1108/JFEP-03-2024-0082

Khazzoom, J.D. (1980). Economic Implications of Mandated Efficiency in Standards for Household Appliances. *The Energy Journal*, *1*(4), 21-40. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol1-No4-2

Konyeaso, A.W., Eregha, P.B., & Vo, X.V. (2023). Unbundling the dynamic impact of renewable energy and financial development on real per capita growth in African countries. *Environmental Science and Pollution Research*, *30*(1), 899-916. https://doi.org/10.1007/s11356-022-22109-6

Kroese, D.P., Taimre, T. and Botev, Z.I. (2013). *Handbook of monte carlo methods*. John Wiley & Sons.

Lee, C.C., & Wang, C.S. (2022). Financial development, technological innovation and energy security: Evidence from Chinese provincial experience. *Energy Economics*, (*112)*, 106161. https://doi.org/10.1016/j.eneco.2022.106161

Lefatsa, P.M., Sibanda, K., & Garidzirai, R. (2021). The relationship between financial development and energy consumption in South Africa. *Economies*, *9*(04), 158. https://doi.org/10.3390/economies9040158

Liu, W.P., & Chu, Y.C. (2024). FinTech, economic growth, and COVID-19: International evidence. *Asia Pacific Management Review*, *29*(3), 362-367.

Majewski, S., Mentel, U., Salahodjaev, R., & Cierpiał-Wolan, M. (2022). Electricity consumption and economic growth: Evidence from South Asian Countries. *Energies*, *15*(4), 1327. https://doi.org/10.3390/en15041327

McKinnon, R.I. (1973). *Money and Capital in Economic Development*. Brooking Institution.

Merven, B., Hughes, A., & Davis, S. (2010). An analysis of energy consumption for a selection of countries in the Southern African Development Community. *Journal of Energy in Southern Africa*, *21*(1), 11-24. http://dx.doi.org/10.17159/2413-3051/2010/v21i1a3246

Miah, M.D., Islam, M.S. and Raihan, A., 2025. Dynamic impact of economic growth, energy use, foreign direct investment and population on greenhouse gas emission in Bangladesh. *Innovation and Green Development*, *4*(4), 100259. https://doi.org/10.1016/j.igd.2025.100259

Minh, T.B., & Van, H.B. (2023). Evaluating the relationship between renewable energy consumption and economic growth in Vietnam, 1995–2019. *Energy reports*, (*9)*, 609-617. https://doi.org/10.1016/j.egyr.2022.11.074

Mohsin, M., Taghizadeh-Hesary, F., & Shahbaz, M. (2022). Nexus between financial development and energy poverty in Latin America. *Energy Policy*, (*165)*, 112925. https://doi.org/10.1016/j.enpol.2022.112925

Moon, J.S. & Hossain, S.M. (2020). Interrelationship between Financial Development, Monetary Policy Instruments and Economic Growth in Bangladesh. *JnU Journal of Economics*, 4(1), 112-133

Mukhtarov, S. (2022). The relationship between renewable energy consumption and economic growth in Azerbaijan. *International Journal of Energy Economics and Policy*, *12*(1), 416-419. https://doi.org/10.32479/ijeep.11948

Narayan, P.K., & Smyth, R. (2005). Electricity consumption, employment and real income in Australia evidence from multivariate Granger causality tests. *Energy policy*, *33*(9), 1109-1116. https://doi.org/10.1016/j.enpol.2003.11.010

Nasreen, S., Mbarek, M.B. and Atiq-ur-Rehman, M., 2020. Long-run causal relationship between economic growth, transport energy consumption and environmental quality in Asian countries: Evidence from heterogeneous panel methods. *Energy*, (*192)*, 116628. https://doi.org/10.1016/j.energy.2019.116628

Navarro-Chávez, C. L., Ayvar-Campos, F. J. and Camacho-Cortez, C., 2023. Tourism, economic growth, and environmental pollution in APEC economies, 1995–2020: An econometric analysis of the Kuznets hypothesis. *Economies*, *11*(10), 264. https://doi.org/10.3390/economies11100264

Nid, S., & Bouabdallah, A. (2023). Causality Between Economic Growth and Bank Deposit: Evidence from Algeria. *Journal of Economic Additions*, 7(1), 673-687.

Nkalu, C. N., Ugwu, S. C., Asogwa, F. O., Kuma, M. P., & Onyeke, Q. O. (2020). Financial development and energy consumption in Sub-Saharan Africa: Evidence from panel vector error correction model. *Sage Open*, *10*(3), 2158244020935432. https://doi.org/10.1177/2158244020935432

Odhiambo, N. M. (2019). Energy consumption and financial development in South Africa: An empirical investigation. *Ekonomski pregled*, (*70)*, 41-61. https://doi.org/10.32910/ep.70.1.3

Olubiyi, E. A., Adedeji, A. O., Akiwale, I. T. (2025). Energy consumption, foreign direct investment, and urban development: The cases of Nigeria and South Africa. *The Review of Black Political Economy*, 52(3), 00346446241308838. https://doi.org/10.1177/00346446241308838

Onatunji, O. G., 2025. Electricity consumption and industrial output: fresh evidence from economic community of West African states (ECOWAS). *Journal of Economic and Administrative Sciences*, *41*(1), 381-398. https://doi.org/10.1108/JEAS-09-2021-0177

Onyango, R. B. A. (2021). *Energy Use and Economic Growth in the Southern African Development Community (SADC).* University of KwaZulu-Natal, Howard College.

Ozcan, B., Tzeremes, P. G., & Tzeremes, N. G. (2020). Energy consumption, economic growth and environmental degradation in OECD countries. *Economic Modelling*, (*84)*, 203-213. https://doi.org/10.1016/j.econmod.2019.04.010

Pata, U. K., Yilanci, V., Zhang, Q., & Shah, S. A. R. (2022). Does financial development promote renewable energy consumption in the USA? Evidence from the Fourier-wavelet quantile causality test. *Renewable Energy*, (*196)*, 432-443. https://doi.org/10.1016/j.renene.2022.07.008

Payne, J. E. (2009). On the dynamics of energy consumption and output in the US. *Applied energy*, *86*(4), 575-577. https://doi.org/10.1016/j.apenergy.2008.07.003

Payne, J. E. (2010). Survey of the international evidence on the causal relationship between energy consumption and growth. *Journal of Economic Studies*, *37*(1), 53-95. https://doi.org/10.1108/01443581011012261

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, *22*(2), 265-312. https://doi.org/10.1002/jae.951

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of econometrics*, *68*(1), 79-113. https://doi.org/10.1016/0304-4076(94)01644-F

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American statistical Association*, *94*(446), 621-634.

Phillips, P. C., & Ouliaris, S. (1990). Asymptotic properties of residual based tests for cointegration. *Econometrica: journal of the Econometric Society*, 58(1), 165-193. https://doi.org/10.2307/2938339

Raza, A., Khan, M. A. and Bakhtyar, B., 2025. Exploring the linkage between energy consumption and economic growth in BRICS countries through disaggregated analysis. *Journal of the Knowledge Economy*, *16*(1),.3869-3891. https://doi.org/10.1007/s13132-024-02045-1

Rehman, A., Radulescu, M., Cismaș, L. M., Cismaș, C. M., Chandio, A. A., & Simoni, S. (2022). Renewable energy, urbanization, fossil fuel consumption, and economic growth dilemma in Romania: Examining the short-and long-term impact. *Energies*, *15*(19), 7180. https://doi.org/10.3390/en15197180

Ren, X., Tong, Z., Sun, X., & Yan, C. (2022). Dynamic impacts of energy consumption on economic growth in China: Evidence from a non-parametric panel data model. *Energy Economics*, (*107)*, 105855. https://doi.org/10.1016/j.eneco.2022.105855

Saadaoui, H., & Chtourou, N. (2023). Do institutional quality, financial development, and economic growth improve renewable energy transition? Some evidence from Tunisia. *Journal of the Knowledge Economy*, *14*(3), 2927-2958. https://doi.org/10.1007/s13132-022-00999-8

Sadorsky, P. (2010). The impact of financial development on energy consumption in emerging economies. *Energy policy*, *38*(5), 2528-2535. https://doi.org/10.1016/j.enpol.2009.12.048

Sart, G., Ozkaya, M. H., & Bayar, Y. (2022). Education, financial development, and primary energy consumption: An empirical analysis for BRICS economies. *Sustainability*, *14*(12), 7377.https://doi.org/ 10.3390/su14127377.

Saygin, O., & Iskenderoglu, O. (2022). The nexus between financial development and renewable energy consumption: a review for emerging countries. *Environmental Science and Pollution Research*, *29*(10), 14522-14533. https://doi.org/10.1007/s11356-021-16690-5

Schumpeter, J. A. (1912). *The theory of economic development*. Routledge.

Shaw E. S. (1973). *Financial Deepening in Economic Development*. Oxford University Press.

Sheraz, M., Deyi, X., Mumtaz, M. Z., & Ullah, A. (2022). Exploring the dynamic relationship between financial development, renewable energy, and carbon emissions: A new evidence from belt and road countries. *Environmental Science and Pollution Research*, *29*(10), 14930-14947. https://doi.org/10.1007/s11356-021-16641-0

Sunde, T. (2020). Energy consumption and economic growth modelling in SADC countries: an application of the VAR Granger causality analysis. *International Journal of Energy Technology and Policy*, *16*(1), 41-56. https://doi.org/10.1504/IJETP.2020.103846

Tanner, M. A., & Wong, W. H. (2010). From EM to Data Augmentation: The Emergence of MCMC Bayesian Computation in the 1980s. *Statistical Science*, *25*(4), 506-516. https://doi.org/10.1214/10-STS341

Thebuho, W., Opperman, P., & Steenkamp, L. A. (2022). The asymmetric effect of financial development on energy consumption in sub-Saharan Africa. *Cogent Economics & Finance*, *10*(1), 2095770. https://doi.org/10.1080/23322039.2022.2095770

Umar, M., Rizvi, S. K. A., & Naqvi, B. (2021). Dance with the devil? The nexus of fourth industrial revolution, technological financial products and volatility spillovers in global financial system. *Technological Forecasting and Social Change*, (*163)*, 120450. https://doi.org/10.1016/j.techfore.2020.120450

Umurzakov, U., Mirzaev, B., Salahodjaev, R., Isaeva, A., & Tosheva, S. (2020). Energy consumption and economic growth: Evidence from post-communist countries. *International Journal of Energy Economics and Policy*, *10*(6), 59-65.

Usman, O., Alola, A. A., & Saint Akadiri, S. (2022). Effects of domestic material consumption, renewable energy, and financial development on environmental sustainability in the EU-28: Evidence from a GMM panel-VAR. *Renewable Energy*, (*184)*, 239-251. https://doi.org/10.1016/j.renene.2021.11.086

Usman, M., Balsalobre-Lorente, D., Jahanger, A., & Ahmad, P. (2023). Are Mercosur economies going green or going away? An empirical investigation of the association between technological innovations, energy use, natural resources and GHG emissions. *Gondwana Research*, (*113)*, 53-70. https://doi.org/10.1016/j.gr.2022.10.018

Waite, C. N. A. (2018). *Energy consumption and investments for economic growth in Southern Africa Development Community (SADC).* Universidade da Beira Interior.

Wang, Z., Pham, T. L. H., Sun, K., Wang, B., Bui, Q., & Hashemizadeh, A. (2022). The moderating role of financial development in the renewable energy consumption-CO2 emissions linkage: the case study of Next-11 countries. *Energy*, (*254)*, 124386. https://doi.org/10.1016/j.energy.2022.124386

Wang, J., Xue, Y., & Han, M. (2023). Impact of carbon emission price and natural resources development on the green economic recovery: fresh insights from China. *Resources Policy*, (*81)*, 103255. https://doi.org/10.1016/j.resourpol.2022.103255

Wang, J., Zhang, S., & Zhang, Q. (2021). The relationship of renewable energy consumption to financial development and economic growth in China. *Renewable Energy*, (*170)*, 897-904. https://doi.org/10.1016/j.renene.2021.02.038

Westerlund, J. (2005). New simple tests for panel cointegration. *Econometric Reviews*, *24*(3), 297-316. https://doi.org/10.1080/07474930500243019

Yasin, I., Ahmad, N. and Chaudhary, M. A., 2021. The impact of financial development, political institutions, and urbanization on environmental degradation: Evidence from 59 less-developed economies. *Environment, Development and Sustainability*, *23*(5), pp.6698-6721.

Zeraibi, A., Balsalobre-Lorente, D. and Shehzad, K., 2020. Examining the asymmetric nexus between energy consumption, technological innovation, and economic growth; does energy consumption and technology boost economic development?. *Sustainability*, *12*(21), p.8867. https://doi.org/10.3390/su12218867

Zhang, T., Zheng, W., Li, H., Chen, W. and Liao, H., (2025). Economic development and CO2 emissions in China: a multi-dimensional analysis. *Journal of the Asia Pacific Economy*, 1-22. https://doi.org/10.1080/13547860.2025.2479311

Zhe, L., Yüksel, S., Dinçer, H., Mukhtarov, S., & Azizov, M. (2021). The positive influences of renewable energy consumption on financial development and economic growth. *Sage Open*, *11*(3), 21582440211040133. https://doi.org/10.1177/21582440211040133