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Financial development, economic growth, and energy consumption in SADC region

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Abstract

The paper presents an empirical study of the relationships between financial development, economic growth, urbanisation and energy consumption in the Southern African Development Community for the years 1980 to 2023. The researchers applied the Bayesian approach via Metropolis-Hasting and Gibbs samples as the MCMC methods, and Dumitrescu and Hurlin (2012) and Diagnostic tests to check the causality among all the variables in question and accuracy of the data and model. Over time, there has been a significant positive correlation between financial development, economic growth, industrialization, urbanization, and energy consumption. The results of the Granger causality test showed a unidirectional causal relationship between financial development, urbanization, and energy consumption supporting the alternative hypothesis that there is a relationship between financial development and energy consumption in the Southern African Development Community. It has been found that there is a Bi-directional (feedback) Granger causal relationship between economic growth and energy consumption in the Southern African Development Community; this also supports the alternative hypothesis. The results align with endogenous growth theory, which emphasizes that economic growth is driven by internal factors such as capital accumulation, innovation, and improved efficiencies, where energy plays a significant role. This also supports the view that energy infrastructure development is vital for sustaining economic growth in the region. The diagnostic tests confirm that the model is correct.

Keywords

Industrialization, urbanization, Bayesian-inferior, Dumitrescu-Hurlin Granger.

JEL: E01, G17, O12.

1. Introduction

This study investigates the relationship between financial development and energy consumption by incorporating economic growth which is considered a basic indicator of production for the Southern African Development Community (SADC) over the period 1980-2023. Broadly defined, energy deficiency refers to a level of energy consumption that does not meet specific basic needs (Shen & Ren, 2023). Globally, SADC countries perform the worst when it comes to energy access rates (Lefatsa et al., 2021). The resulting energy deficiency impedes sustainable economic growth and has consequences for the advancement of development objectives in the SADC countries. According to the International Energy Agency (IEA) (2019), more than 50% of the SADC countries have insufficient energy supply and 25% rely on traditional fuels (World Bank, 2019). The main consumers of energy in these economies are households, industry and transport (Tao et al., 2022). The SADC countries have experienced considerable fluctuations in their energy supply (Ndlovu & Inglesi-Lotz, 2019).

The extreme shortage and inaccessibility of energy in some of the SADC member countries that may be attributed to a lack of investments in energy infrastructure and technologies (Lefatsa et al., 2021) severely hampers sustainable economic development (Tao et al., 2022) of the countries that have to depend on unsustainable energy sources and outdated power generation plants. The poorly maintained and often outdated power plants are no longer capable of meeting the demand from consumers (IEA, 2020) and thus occasion energy conservation policies, e.g. load-shedding practices that have become common in most SADC countries. Despite prior research into financial development and energy consumption, there remains an evident research gap in examining these factors specifically within the SADC region that faces unique socio-economic and infrastructural challenges distinct from other regions.

A well-developed sophisticated financial system makes it easier for the country's consumers to save, invest and borrow funds at a cheaper cost and purchase consumable energy products spurring the overall demand for energy (Ndlovu & Inglesi-Lotz, 2019). It brings about improvements in financial market infrastructure, which help entrepreneurs to expand their businesses by investing in more advanced machinery and equipment, buying existing plants and factories or building the new ones. Increased demand for energy may lead to energy crises if maintenance of the generation fleet is delayed and so the power plants become unable to meet future demand (Tao et al., 2022). Today, the SADC countries with their annual energy consumption of 518 kWh (Dada & Akinlo, 2023) are in desperate need of sound power supplies; for them, energy is a much scarcer commodity than for the developed world.

The linkage between financial development, economic growth, and energy consumption has been studied by many researchers. Yet, the results of the existing studies have not always been conclusive. For example, Tinoco-Zermeño, (2023) examined the relationship between financial development, economic growth and energy consumption in Lebanon in 2000-2010. The obtained results using the ARDL model show that financial development had a positive impact on energy consumption in both the short and long run. The empirical study reveals that there is a unidirectional causality from economic growth to energy consumption, and a bidirectional effect between financial development and energy consumption, a clear Feedback effect. The study by Miguel (2023) based on panel data for 23 developing countries produced mixed results indicating a unidirectional short-run causality from financial development to energy consumption and a bidirectional long-run causality between economic growth and energy consumption. The present research distinguishes itself by employing a Bayesian inference with Markov Chain Monte Carlo sampling to analyze SADC-specific challenges over an extended time frame (1980-2023), which is a new approach to the issue under analysis.

Most previous studies were conducted in a linear framework using the frequentist inference. The present study adopts a Bayesian inference approach through the integrated Markov chain Monte-Carlo sampler to provide probabilistic interpretations of model uncertainty and varying effects of financial development and economic growth on energy consumption. The advantage of Bayesian inference compared to frequentist inference is that it deals with the probability of a hypothesis given a set of data.

To address the omission of variable bias, the study will include industrialization and urbanization as intermittent variables between financial development, economic growth, and energy consumption. This study may guide researchers to formulate new or extend current models to help institutions improve energy consumption and promote financial development for better economic growth.

2. Literature review

This section considers both theoretical and empirical studies.

2.1. Overview of Economic Growth Theories

Economic growth theories offer critical insights into the long-term drivers of economic progress, each providing a different perspective on the roles of capital, technology, finance and innovation. The subsection reviews the main theories relevant to understanding the finance-growth-energy nexus in the Southern African Development Community (SADC).

Classical Growth Theory emphasizes capital accumulation, labour force expansion and productivity as primary sources of economic growth. While this theory underscores the importance of efficient resource allocation, it lacks the dynamic factors, e.g. technological advancement, that drive modern economic development. For SADC, where capital scarcity and labour productivity constraints are prevalent, classical perspectives are limited in explaining how financial development could spur broader growth.

Neoclassical Growth Theory extends classical thought by incorporating technological progress as an exogenous factor driving long-term growth. According to neoclassical models, continual productivity improvements, typically through innovation and investment in human capital, are crucial for sustainable growth. This aligns with SADC's need to improve productivity through investment in education, infrastructure, and technology — a process that robust financial development could help facilitate by providing accessible credit and investment opportunities.

Endogenous Growth Theory, championed by economists such as Lucas and Romer, identifies internal drivers of growth, particularly human capital, knowledge, and innovation. Lucas's perspective on the finance-growth nexus underscores that well-developed financial systems are essential for accumulating human capital, as they enable investments in education and skill development. In SADC, where human capital is critical for improving productivity and resilience, access to financial services can empower individuals and businesses to contribute meaningfully to economic growth. This theory is particularly relevant as it suggests that targeted financial policies can directly impact growth by fostering human capital and innovation within the region.

Neo-Schumpeterian Theory, an extension of Schumpeter's work on creative destruction, emphasizes the dynamic role of innovation, finance, industry, and science in economic growth. According to Hanusch and Pyka (2007), financial markets and institutions play a critical role in this process by allocating resources to innovative sectors and facilitating technological advancements. In the SADC context, the Neo-Schumpeterian approach highlights the importance of supporting industries with high growth potential, such as renewable energy, which can address both economic and environmental goals. The theory suggests that proactive financial policies encouraging innovation and industrial upgrading are vital for the SADC countries as they can help diversify their economies and develop energy infrastructure in a way that promotes sustainability.

In summary, these growth theories illustrate the essential roles of financial systems and innovation in driving sustainable economic growth, particularly within structurally constrained regions like SADC. By fostering access to finance and supporting investments in technology and human capital, policymakers can steer the economy to a growth path that is resilient, inclusive, and sustainable.

2.2. Review of empirical literature

The question of how financial development and economic growth sway the relationship between energy consumption and other economic variables has been a focal point of inquiry among economists for an extended period. This sustained interest is driven by the significant policy implications of research results, which can determine the choice of strategies to accelerate economic growth, enhance financial development and manage energy consumption. However, empirical studies in this domain have yielded conflicting results, leading to disagreements among economists. This section presents an empirical review of studies that have explored the impacts of financial development and economic growth on energy consumption.

This section is organized into four subsections: (1) causal relationship between financial development, economic growth, and energy consumption; (2) the impact of financial development and economic growth on energy consumption; (3) a summary of the empirical literature; and (4) a conclusion.

2.2.1. Causal relationship between financial development, economic growth, and energy consumption

This subsection discusses the causality link between financial development, economic growth, and energy consumption under the three hypotheses: neutrality, feedback, and unidirectional. Studying a causality relationship between the variables helps to see that a change in one variable causes a change in another (Adeel-Farooq et al., 2022).

The neutrality hypothesis implies that energy conversion will not lead to decreased economic growth and energy consumption will not be stimulated by economic growth. The studies that support the neutrality hypothesis include Ghosh (2009), Payne (2009), Ozturk and Acaravci (2010), Warr and Ayres (2010), Ozturk and Acaravci (2011), Shahbaz and Lean (2012), Ozcan and Ozturk (2019), Rajkumuri (2020), Fang and Wolski (2021), Majewski, Mentel, Salahodjaev and Cierpiał-Wolan (2022). Most recently, Aydin (2023) assessed the causality linkage between economic growth, trade openness, carbon emissions, foreign direct investment and energy usage for a sample of the Group of Eight (G8) countries. The study employed the Error Correction Model (ECM) panel test for cointegration and the Augmented Mean Group (AMG) estimator method along with the Dumitrescu-Hurlin Panel Causality test over the period 1980-2018. The empirical Granger causality test results were consistent with the neutrality hypothesis of relationship between economic growth and energy consumption. In the same vein, Cheriyambadan, Villanthenkodath, and Shareef (2023) explored the causality relationship between economic growth, cashew nut production, carbon emission, and energy consumption in India from 1975 to 2021 using the Bayer and Hanck (2013) combined cointegration analysis. The study further employed FMOLS-DOLS approaches and the Granger causality test to study the long-run effect and found a neutral relationship between economic growth and energy consumption, which could be explained by the uneven and insufficient exploitation of renewable energy facilities.

Studies using cross-country and within-country samples have found a bidirectional causality link between economic growth and energy consumption, confirming the feedback hypothesis. This means that not only does economic growth drive increased energy consumption, but higher levels of energy consumption in their turn stimulate further economic growth. This interdependent relationship highlights the critical role of energy in sustaining and enhancing economic activities while also recognizing that economic expansion can lead to greater energy demands

(Bhattacharya et al., 2016; Rafindadi & Ozturk, 2017; Saqib, 2018; Arminen & Menegaki, 2019; Fatima & Abdurrahman, 2020; Dokas et al., 2022; Amin & Song, 2023). Azam et al. (2023) applied the Dumitrescu-Hurlin Panel Causality test to the evidence from 30 developing countries over the period 1990-2017 in order to investigate the causal relationship between economic growth and energy consumption. The results obtained during the study revealed that a bidirectional causation exists between economic growth and energy consumption. Again, Xie, Zhu, Hu, and Huang (2023) explored the causal link between economic growth and energy consumption in 1990-2020 using the second-generation panel unit root test and a non-parametric panel data approach in the Next Eleven (N-11) countries. The panel causality tests indicate the presence of bidirectional causation between economic growth and energy consumption. Using the same approach in South America for the period 1995-2022, Ali et al. (2023) revealed bidirectional causality between economic growth, social and political globalization, and energy consumption. Given the existence of bidirectional causality, energy shortages have clear consequences for economic growth in the economy.

Several studies have shown significant results of a unidirectional causality link between economic growth and energy consumption allowing the researchers to conclude that the impact of economic growth on energy consumption exists, which supports the growth hypothesis (Payne, 2010; Menyah & Wolde-Rufael, 2010; Fang, 2011; Govindaraju & Tang, 2013; Omri, 2014; Umit & Bulut, 2015; Dogan & Turkekul, 2016; Kurniawan & Managi, 2018; Asongu et al., 2019). A similar study by Berradia et al. (2023) was centered on Saudi Arabia; it included carbon dioxide emissions in their Bootstrapped Autoregressive Distributed Lag (BARDL) model and Granger causality test for the period 1980-2017. The results showed unidirectional causality running from economic growth to energy consumption. Alkasasbeh et al. (2023) discovered similar relationships in the Middle East economies in 1980-2020 using Cross-Sectional Augmented Im-Perasan-Shin (CIPS) Unit Root Test, Centre Augmented Dickey-Fuller (CADF) techniques and Dumistrescu-Hurlin Granger Causality test. Mohsin, Taghizadeh-Hesary, and Shahbaz (2023) applied the PARDL approach and VECM Granger causality test in the top 20 crypto-trader countries between 2012 and 2019 to study the short and long-run unidirectional causality link between gross domestic product, exponential crypto-trade growth, carbon dioxide emissions, and energy use. The findings pointed to the existence of a unidirectional causal link running from gross domestic product to energy use. Clean energy, technological development, and investment by public and private entities are required to help reduce dependency on traditional energy use. Very few studies, however, directly addressed the impact of domestic credit on the private sector, GDP per capita growth, and urbanization in SADC, where energy deficits, traditional fuel reliance, and inadequate infrastructure limit broader insights into financial development impacts.

A well-set-up and properly functioning financial system can perform the essential function of channeling funds to households and firms enabling them to consume energy (Minsky & Kaufman, 2008). The relationship between financial development and energy consumption can also be discussed along the lines of the neutrality, feedback (bidirectional), and unidirectional hypotheses (Odhiambo, 2019) as is shown below.

Numerous studies that used different datasets, explored different countries and employed different econometric models have concluded that there is no causality relationship between financial development and energy consumption (Menegaki, 2011; Keskingoz & Inancli, 2016; Burakov & Freidin, 2017; Denisova, 2020; Saygini & İskenderoğlu, 2022; Sart et al., 2022; Hysa et al., 2023). Most recently, Hysa et al. (2023) analyzed the causal link between financial development, technical innovation, and energy consumption in Central and Eastern Europe (CEE) countries over 2000-2019 by econometric techniques and the Granger causality test. The results confirmed the neutrality hypothesis of the relationship between financial development and energy consumption. Likewise, Tong, Ortiz, and Wang (2023) employed the BARDL method to study the causality relationship between financial development, energy consumption, and carbon dioxide emissions in China in 1977-2017. The Granger causality test discovered the presence of the long-run neutrality between financial development and energy consumption. Tran (2023) conducted a similar study for 148 countries from 1990 to 2019 by the Feasible Generalized Least Squares (FGLS) model and found a neutrality relationship between financial development and energy consumption. The opposite occurred between financial development, urbanization, and environmental degradation. It follows that endorsing the exploration of new and alternative energy sources to reap the optimal fruits of trade will be highly beneficial.

The immense number of empirical studies revealed a bidirectional causal link between financial development and energy consumption (Shahbaz & Lean, 2012; Al-mulali & Lee, 2013; Tang & Tan, 2014; Komal & Abbas, 2015; Ali et al,, 2018; Ullah et al., 2022; Saud et al., 2023; Song et al., 2023). Saud et al. (2023) examined the causal relation between financial development and energy consumption for the six BRI economies in 1990-2018 using the Driscoll-Kraay standard error estimation technique. Their results from the Dumitrescu-Hurlin Panel Causality test revealed a long-run bidirectional relationship between financial development and energy consumption. Finally, Song et al. (2023) analyzed the causality link between financial development and renewable energy consumption in 30 provinces of China over the period 2006-2018; using the Granger causality test they found a two-way causality association between financial development and energy consumption and also a significant and temporal correlation. All this means that there is a need to strengthen environmental protection laws in all regions.

The causality relationship between financial development and energy consumption is one of the most controversial issues in economics. Many studies have found unidirectional causality from financial development to energy consumption (Kar & Pentecost, 2000; Husaini & Lean, 2015; Kahouli, 2017; Kassi et al, 2017; Mahalik et al, 2017; Eren et al., 2019; Odhiambo, 2019; Nkalu et al., 2020; Isiksal, 2021; Saadaoui & Chtourou, 2022). Amin et al. (2022) investigated the causality link between financial development and energy consumption over the period 1990-2018 by cointegration econometrics methods and the Granger causality test. The outcomes revealed a unidirectional causality running from financial development to energy consumption in selected South Asian countries. Most recently, Zhang (2023) empirically examined the causality link between financial development and energy consumption in China from 2010 to 2020 by Cross-Sectional (CS)-ARDL approach and Granger causality test; the results, too, revealed a unidirectional causality running from financial development to energy consumption in the long run. It follows that there is a need to address socioeconomic problems and energy deficits to build sustainable environment and facilitate new economic activity.

It is generally accepted that the financial system plays a pivotal role in economic development by mobilizing funds for investment projects with the highest probability of success (Minsky & Kaufman, 2008). The relationship between financial development and economic growth can also be discussed along the lines of the neutrality, feedback (bidirectional), and unidirectional hypothesis (Lefatsa et al., 2021) as shown below.

Studies found a broken relationship between financial development and economic growth between countries by different econometric models, data sets periods, and variables (Deidda & Fattouh, 2002; Soytaş & Küçükkaya, 2011; Hsueh et al,, 2013; Kenza & Mohamed, 2015; Gupta & Rao, 2018; Opoku et al., 2019; Onuonga, 2020; Mtar & Belazreg, 2021; Nigo & Gibogwe, 2023). Most recently, Kartal (2023) with Nigo and Gibogwe (2023) empirically examined the causality relationship between financial development and economic growth in four South Asian and Sub-Saharan Africa (SSA) countries using GMM techniques. Mustafa supported the neutrality hypothesis between financial development and economic growth for all the countries in 1990-2019. Likewise, Nigo and Gibogwe found a causality link between domestic credit to the private sector and economic growth for 14 countries in SSA from 1990 to 2020. Turgut (2023) had the same results for five fragile countries over the period 1980-2018 using the Delta homogeneity approach and the Dumitrescu-Hurlin Granger Causality test. It can be concluded that investment in human capital both in terms of emerging entrepreneurial skills and education will improve national absorptive capabilities and develop the innovation potential of their countries.

Several studies have noted a bidirectional causality between financial development and economic growth in different countries, with different econometric models, and variables across different periods (Lewis, 1955; Lewis, 1966; Wood, 1993; Luintel and Khan, 1999; Abu-Bader and Abu-Qarn, 2008; Nayak and Yingnan, 2019; Sharma, 2020; Khan, Chenggang, Hussain and Kui, 2021; Dada, Adeiza, Noor and Marina, 2022; Almassri, Ozdeser and Saliminezhad, 2023). Having examined the causal relationship between financial development, energy consumption, and economic growth in 11 Asian economies from 1980 to 2016, Minh and Ngoc (2023) employed three popular models: spatial error model, spatial autoregressive model, and spatial Durbin model. The study further proposed a novel test by Juodis, Karavias, and Sarafidis (2020) to test Granger's non-causality between the variables in question that confirmed the existence of a bidirectional causality link. Ray, Aditya, and Pal (2023) had the same results for ten

Asian economies over the period 1980-2019 using the Estimated General Least Squares (EGLS) approach. Verma, Dandgawhal, and Giri (2023) examined the causality relationship between financial development, Information, and Communication Technology (ICT) diffusion, and economic growth in 88 emerging economies for the period 2005-2019 by FMOLS, DOLS approaches, and the panel Granger causality test found a bidirectional causality between the variables. It means that government should shift its focus towards achieving higher economic growth to boost its financial development.

Empirical studies have confirmed unidirectional causality running from financial development to economic growth for different countries, methodologies, variables, and data periods (Berthelemg and Varoudakis, 1996; Ahmed and Ansari, 1998; Rajan and Zingales, 1998; Christopoulos and Tsionas, 2004; Odhiambo and Nyasha, 2019; Pinshi, 2020; Sethi, Das, Sahoo, Mohanty, and Bhujabal, 2020; Bouabdallah, 2023; Mtar and Belareg, 2023). Likewise, Liu and Liu (2023) investigated the causality link between financial development, inbound tourism development, and economic growth and found a long-run unidirectional causality between the variables of interest from Fujian Province in China over the period 1994-2019 by Johansen cointegration test and Granger causality test. Lastly, Mtar and Belareg (2023) analyzed the causal relationship innovation, trade openness, financial development, and economic growth in 11 European countries in 2001-2016 by panel-VAR approach. The Granger causality test results revealed a unidirectional causal link from financial development to economic growth. The results suggest that further regulation of financial systems and the quality of funding are important components of the policy aiming to foster economic growth.

2.2.2. Impact of financial development and economic growth on energy consumption

Studies on the impact of financial development and economic growth on energy consumption are diverse in scope: variables, indicators, data period, sample countries, and econometric approaches. However, the extant literature has produced mixed evidence on the relationship between financial development, economic growth, and energy consumption. Moreover, the latter can be either positive or negative.

Recently, economic growth has been a significant factor of increasing energy consumption, and this phenomenon has received much attention from scholars (Stern, 2000; Toman and Jemelkova, 2003; Stern and Cleveland, 2004; Yoo, 2005; Aziz, 2011; Kalyoncu, Gürsoy and Göcen, 2013; Long, Ngoc and My, 2018; Wang, Su and Ponce, 2019; Ha and Ngoc, 2020). Some studies have also investigated the impact of economic growth on energy consumption using an ARDL approach, i.g. Sadiq, Ou, Duong, Van, Ngo, and Bui (2023) for China between 1981-2019 and Ngcobo and Wet (2024) for 10 developing countries of Asia in 1990-2019. Sadiq et al. (2023) unveiled a significant and positive effect of economic growth on energy consumption. Asante, Takyi, and Mensah (2023) uncovered a significant and positive impact of energy consumption on economic growth in SSA countries during the period 2000-2019 using the system-GMM technique. Further, Guo and You (2023) in Guangdong Province of China, confirmed the positive impact of economic growth on energy consumption and carbon emission for the period 2006-2021 by the Tapio decoupling indicator method. It follows that there is a need to strengthen core technology research in the energy sector and promote industrial transformation to upgrade the key industries.

Studies on the relationship between financial development and energy consumption are diverse in scope (data period, and the types of variables adopted), sample countries, and econometric methodologies (Sadorsky, 2010; Sadorsky, 2011b; Shahbaz and Lean, 2012; Pradhan, 2017; Odhiambo, 2018; Ulucak, 2021; Mukhtarov, Yüksel and Dinçer, 2022; Latif et al., 2023). Other recent studies on financial development, higher education, technological progress, and energy consumption correlation have shown promising results in China. Yu and Tang (2023) used a non-convex meta-frontier data envelope analysis approach for the period 2011-2015, Zhou, Yin, and Yue (2023) employed Consumer Lifestyle Approach for 2003-2019. Having introduced two instrumental variables into the baseline model to address endogeneity they found that broadened access to credit significantly encourages households to improve energy consumption with higher energy use in the long run, which, however, adversely impacted economic growth. Further, Latif, Shunqi, Fareed, Ali, and Bashir (2023) obtained similar results for the Regional Comprehensive Economic Partnership (RECP) economies between 1990 and 2020 using a novel method of moments quantile regression. The same applies to Wu, Adebayo, Yue, and Umut (2023), who had similar results for the period 1980-2020 in the Nordic nation's CS-ARDL model. These findings should provide insights to financial regulators about the necessity to enhance their focus on clean energy use which is important for the economic growth of the country.

Empirical studies on the positive nexus between financial development and economic growth have been carried out with data sets from many counties, using different econometric models and variables (Al-Mulali, Tang, and Ozturk, 2015; Charfeddine and Kahia, 2019; Ibrahiem, 2020; Tariq, Khan, and Rahman, 2020; Nawaz, Hussain and Hussain, 2021; Alola and Adebayo, 2022; Fareed and Pata, 2022; Wu, Wu, and Zhao, 2022; Anthony-Orji, Ogbuabor, and Uka, 2023; Razzaq, Sharif, Ozturk and Skare, 2023). Most recently, Cao, Kannaiah, Ye, Khan, Shabbir, Bilal, and Tabash (2023) explored the link between financial development, technological innovation, and economic growth in South Asian countries from 1980 to 2018 employing the ARDL model. The results revealed a significant and positive effect of financial development on economic growth in selected South Asian countries. Using the FMOLS approach, Manta, Badareu, Bădîrcea, and Doran (2023) empirically examined the impact of financial development on economic growth in CEE countries over 2010-2021 and discovered that improving financial accessibility boosts economic growth. Razzaq et al. (2023) observed the impact of financial development on economic growth in China between 2007 and 2019 using the method of moments quantile regression. The results confirmed that financial development positively impacts economic growth at middle to higher quantiles in central and eastern regions. In the western regions, however, there was no significant impact on the variables under consideration. These findings showed that financial development significantly improves economic growth through increasing energy consumption in both developing and advanced economies.

A number of studies have claimed that there is a negative relationship between economic growth and energy consumption (Ocal and Aslan, 2013; Esen and Bayrak, 2017; Magombedze, 2019; Mukhtarov, Humbatova, Hajiyev, and Aliyev, 2020; Hendrawaty, Shaari, Kesumak, and Ridzuan, 2022; Ha and Ngoc, 2023). More recently, Odhiambo (2023) studied the correlation between economic growth and energy consumption in South Africa over 1981-2020 using the ADRL approach. The researcher found a negative relationship in the short and long run between economic growth and energy consumption, mostly from oil and coal. According to Ha and Ngoc (2023), in the long run, increased economic growth led to lower energy consumption for 11 Asian countries during the period 1980-2016. Further, Simionescu (2023) analyzed the association between economic growth and nuclear energy consumption in the European Union over the period 2002-2021 using an extended Cobb-Douglas production function. The results confirmed the significant and negative effect of economic growth on nuclear energy consumption for the European Union. Manufacturing activity declined resulting in lower industrial pollution and environmental degradation.

Other studies revealed a negative relationship between financial development and energy consumption (Tamazian, Chousa, and Vadlamannati, 2009; Jalil and Feridun, 2011; Chtioui, 2012; Mahalik and Mallick, 2014; Farhani and Solarin, 2017; Ouyang and Li, 2018; Destek, 2018; Khan, Peng and Li, 2019; Assi, Isiksal and Tursoy, 2020; Aslan, Gozbasi, Altinoz and Altuntas, 2021). A pioneer study by Nguyen (2022) analyzed 13 Asian countries between 1990-2015 using POLS, FEM, and REM; it found a significant and negative relationship between private credit and renewable energy use.

Most recently, the link between financial development and renewable energy consumption was explored by Ding (2023) for the group of G7 countries during 1990-2020 using the novel method of moment quantile regression, and by Tariq, Sun, Fernandez-Gamiz, Mansoor, Pasha, Ali and Khan (2023) for the BRICS countries in 2000-2020 using the PMG-ARDL approach. The results of both groups of researchers confirmed the negative relationship between financial development and renewable electricity consumption. Industries will produce less pollution and are most likely to move to environments with flexible regulations on environmental pollution.

Some of the research papers have revealed the negative relationship between financial development and economic growth (Nyasha, 2014; Chong, Mody and Sandoval, 2017; Mahalik et al., 2017; Ouyang and Li, 2018; Hao, Wang and Lee, 2020; Shi and Deng, 2020; Tinta, Ouedraogo and Thiombiano, 2021; Prempeh, 2023). Dahmani, Deidda and Fattouh (2023) examined the association between financial development, ICT, and economic growth, including energy consumption in MENA countries for the period 1980-2018 using the CS-ARDL model. The results indicated that the development of the financial sector exerted negative and significant influence on economic growth. Likewise, Prempeh (2023) employed ARDL, FMOLS, CRR, DOLS, and VECM to analyze the relationship between financial development and economic growth, including energy consumption in Ghana. The results confirmed the significant and negative effect of financial development on economic growth. Wolf (2024) in G7 economies using the PARDL approach, found that in the long run financial development significantly reduces economic growth. These economies will either opt to accept low growth based on domestic energy generation or attempt to maximize growth by meeting the demand for energy through imports.

2.2.3. Summary and assessment of the empirical literature

The literature review shows that there is an unfinished debate on the relationship between financial development, economic growth and energy consumption, in which researchers use economic growth models and endogenous growth models. The results are rather mixed on the whole. In SADC, there is a positive and significant relationship between these variables; yet, their contribution has been small compared to what it could be, which can be explained by many challenges in the energy sector including variations in research designs, data collection, and study settings.

On the other hand, for the SADC countries no studies have jointly examined the indicators of electricity consumption (kWh per capita), domestic credit to the private sector (% of GDP), GDP per capita growth (annual %), industry (including construction), value added (% of GDP), and urban population (% of total population). Besides, the literature includes many papers that use linear frameworks (ARDL, VAR and Johansen cointegration test) but very few studies focus on the SADC countries. It would be interesting to discuss the influence of domestic credit to the private sector and GDP per capita growth on electric power consumption in the SADC countries, which may cause difficulties in case of excessive industrialization and urbanization.

The present paper aims to close the knowledge gap by employing the Bayesian inference approach through the integrated Markov chain Monte-Carlo sampler for the SADC countries. It is the first study in SADC that uses the Bayesian inference approach to the subject under consideration.

2.2.4. Conclusion

Economic growth and the degree of industrialization directly impact energy consumption in an economy; its financial development and urbanization exert indirect influence through the models of economic growth and endogenous growth. Based on the literature reviewed, this study adopts the Bayesian inference approach through the integrated Markov chain Monte-Carlo sampler to provide probabilistic interpretations of model uncertainty and varying effects of financial development and economic growth on energy consumption. In this study energy consumption is taken as the dependent variable, whereas financial development and economic growth are independent variables; industrialization and urbanization have been added to address the omission of variable bias.

3. Methodology

The main aim of this study is to evaluate the relationship between financial development, economic growth, and energy consumption in the SADC countries. The methodological and analytical approaches, employed in this research, are drawn from the literature on finance, growth and energy. Therefore, this section presents data sources, model specifications, the definition of variables and expectations, estimation techniques, and a conclusion.

3.1. Data sources

The paper uses a sample of annual data for 1980-2023 to estimate a panel data model made up of the sixteen SADC countries. The data was sourced from the World Bank (2023) for all the five variables used in the study: financial development, energy consumption, economic growth, industrialization and urbanization. A sample size of 43 years in the time series was wide enough to allow for stability in the model (Ma and Fu, 2020).

3.2. Model specification

This study modified the model used by Ma and Fu (2020), who examined the relationship between financial development and energy consumption, and included the variables used by Sahoo and Sethi (2020) and by Naeimi, Jahantigh and Varahrami (2023). The technique of econometric analysis is based on the panel model of dynamics as used by Sbia, Shahbaz and Ozturk (2017) with all the elements of cross-sectional and time series employed by Gungor and Simon (2017). The estimated model was formerly specified as follows:

$$EC_{i,t} = \alpha + \beta_0 FD_{i,t} + \beta_1 GDP_{i,t} + \gamma Control_{i,t} + \mu_i + e_{i,t} \qquad \text{(Eq. 1)}$$

Ultimately, in equation Eq. 1 above $EC_{i,t}$ represents energy consumption, $FD_{i,t}$ and $GDP_{i,t}$ denotes financial development and economic growth, α shows the intercept, β's represent the coefficient (%) of the conforming independent variables, $\gamma Control_{i,t}$ denotes the control variables to avoid bias (urbanization and industrialization); μ_i is the unobserved country-specific effect; $e_{i,t}$ denotes the residual term; and lastly, i and t represent the country (SADC countries) and the period, respectively (Ma and Fu, 2020).

Eq. 1 above given by Ma and Fu (2020) is now remodeled into equation Eq. 2 following Shahbaz and Leon (2012). Compared to the linear functional form, the log-linear specification provides better results (Sahoo and Sethi, 2020). Further, all the data in this study were transferred into natural logarithmic ones. The above-estimated model can be written as a log-log model below:

$$\mathrm{Ln}EC_{i,t} = \beta_0 + \upsilon_i + \beta_1 \cdot \mathrm{Ln}FD_{i,t} + \beta_2 \cdot \mathrm{Ln}GDP_{i,t} + \beta_3 \cdot \mathrm{Ln}(FD \cdot EG)_{i,t} + \\ + \beta_4 \cdot \mathrm{Ln}IND_{i,t} + \beta_5 \cdot \mathrm{Ln}URB_{i,t} + DT + e_{i,t} \quad \text{(Eq. 2)}$$

Where: Ln — Natural logarithm, *EC* — Energy consumption, *FD* — Financial development, *EG* — Economic growth, *IND* — Industrialization, *URB* — Urbanization, $(FD \cdot EG)$ — Interaction variable, *i* — the country (1,…, N: including all chosen countries), *t* — time (1,…, T: from 1980-2023), υ_i — random intercepts, β′s = Coefficient, $e_{i,t}$ — error term and *DT* — dummy variable.

3.3. Definition of variables, apriori expectation

Energy consumption, denoted as EC, is the total energy consumption measured as kWh per capita (Odhiambo, 2018). kWh per capita is used to capture total energy consumption per capita as the dependent variable (Ma and Fu, 2020). Energy consumption includes indicators such as electricity, gas, oil, and coal consumption (Karakurt and Aykutalp, 2020). Electric power per capita (kWh) is the production of power plants, combined heat and powerless transmission, distribution and transformation losses, and own use by heat and power plants, divided by mid-year population (Strauss, Li and Cui, 2021).

Financial development, denoted as FD, is measured as banks' domestic credit to the private sector as a percentage of GDP (Ma and Fu, 2020). There are different measures for financial development, including pension fund assets, mutual fund assets and insurance premiums, life and non-life (Odhiambo, 2018). The study by Sahoo and Sethi (2020) used domestic lending to the private sector to measure financial development. This measure is preferred because it captures the full degree of intermediation in developing countries, where governments borrow from financial markets to build infrastructure for economic development (Ulucak, 2021). Following Odhiambo's (2018) findings, Karakurt and Aykutalp (2020) expected this variable to increase energy consumption because easy access to credit enables consumers to purchase more energy.

Economic growth denoted as GDP is measured as the GDP per capita growth annual percentage (Ibrahiem, 2020). This shows the rate at which a nation's GDP grows from year to year (Ma and Fu, 2020); capturing the distribution of income, it enables cross-country comparisons (Lefatsa et al., 2021). Following Denisova's (2020) findings, the study expected this variable to increase energy consumption because the growing size of the economy results in higher energy use.

Industrialization (control variable), denoted as IND, is measured as value added share (%) of GDP in the industry including construction (Eren, et al., 2019). Industrialization is seen among the drivers of global pollution (Ma and Fu, 2020).

More industrialized area demands more energy supply (Sadorsky, 2019). This variable was expected to increase energy consumption, according to Odhiambo (2018).

Urbanization (a control variable), denoted as URB, is measured as the percentage share of urban population in the total population (Sare, 2019). According to Chowdhury, Chowdhury, Chowdhury, Islam, Saidur and Sait (2019), cities have higher energy consumption compared to the countryside. This variable was expected to increase energy consumption (Odhiambo, 2018).

All independent variable coefficients were expected to be positive, except the ambiguous dummy variable (Enoki et al., 2019). The dummy variable was used to gauge any exogenous factors that might affect the tested variables (Sare, 2019). A dummy variable, denoted as DT, was also used to control for the effect of the financial crisis and covid-19 (Cao et al., 2020). There were some years and areas without financial crises (Lefatsa et al., 2021), but covid-19 affected the whole world.

3.4. Estimation techniques

This research followed a study that was conducted in ASEAN + six countries by Hoang (2021) who applied the Bayesian approach via the Metropolis-Hasting and Gibbs samplers as Markov chain Monte-Carlo (MCMC) methods from 1980 to 2016, as recommended in the literature review. The study applied the Bayesian approach via the Metropolis-Hasting and Gibbs samplers as MCMC methods from 1980 to 2023 to estimate the impact of financial development and economic growth on energy consumption for the SADC countries. Finally, the study used Dumitrescu and Hurlin (2012) and Diagnostic tests to check the causality between all the variables and the accuracy of the data and model.

3.5. Conclusion

The study applied the Bayesian approach via Metropolis-Hasting and Gibbs samples as the MCMC methods to estimate the impact of financial development and economic growth on energy consumption. The study employed 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 accuracy of the data and model.

4. Results and discussion

4.1. Preliminary tests: correlation

To make sure that there is no multicollinearity amongst explanatory variables, the process of estimation starts with preliminary tests that check correlation. The correlation matrix is presented in Table 1 below.

Table 1. 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: Figure constructed by Eview 9 using statistics from World Bank (2024)

The absence of multicollinearity among explanatory variables, as indicated by the correlation values between 0.0056 and 0.464, suggests that the variables are not highly correlated. With a benchmark threshold of 0.80 (Irfan, 2014), this range confirms no multicollinearity problem. Thus, all variables can be included in the model without concern for inflated variances in estimated coefficients.

4.2. Descriptive statistics

This section presents the summary statistics for the primary variables under scrutiny. These statistics are displayed in Table 2, highlighting the mean, standard deviation, minimum, and maximum values, along with the count of observations.

Table 2. Descriptive statistics (authors' own computation)

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

Table constructed by Eview 9 using statistics from World Bank (2024)

Table 2 shows the Jarque-Bera test results, with probability values exceeding 0.0000, indicating that none of the series in the dataset follows a normal distribution.

While non-normality does not invalidate regression analysis, it could affect inference in smaller samples, particularly for estimators that assume normality. However, robust estimators or large-sample properties (central limit theorem) may mitigate this concern.

4.3. Panel unit root tests

The unit root tests indicate that the variables, at levels, are non-stationary but become stationary after first differencing. This is observed in the figures, where the series at levels fluctuate without convergence but exhibit stability around zero after first differencing. Formally, the LM Pesaran test confirms that only two variables, IND and GDP, are stationary at levels, while the rest require differencing to achieve stationarity.

Implication: Given that most variables are integrated of order one (I(1)), the dataset is suitable for cointegration analysis to capture long-term relationships. Non-stationary series can lead to spurious results if analyzed directly, so this test supports the use of a model that accommodates cointegration for I (1) series.

4.3.1. Graphical analysis

The study first did a graphical analysis to examine the stationarity status of the variables. Figure 1 shows the graphical analysis of the variables.

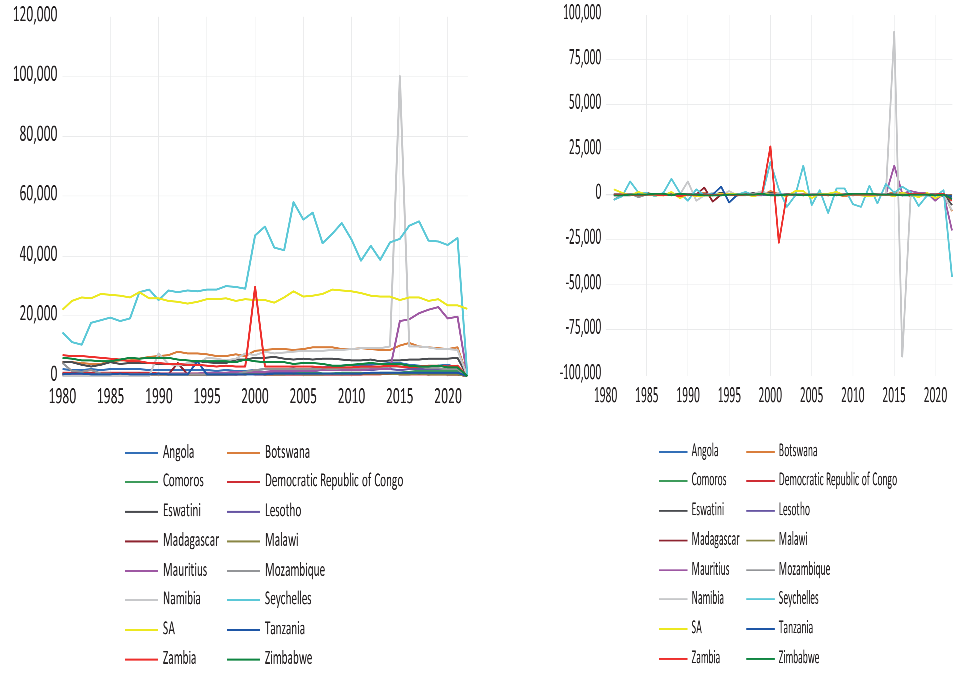

Figure 1. Energy Consumption. *Source*: Figure constructed by Eview 9 using statistics from World Bank (2024)

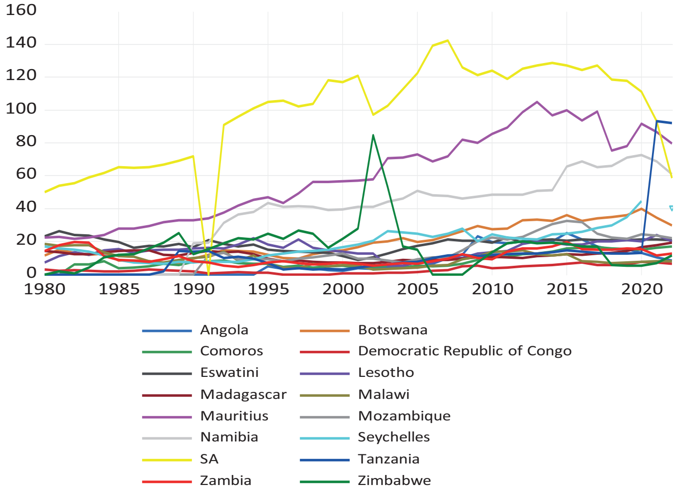

Figure 2. Financial Development. *Source*: Figure constructed by Eview 9 using statistics from World Bank (2024)

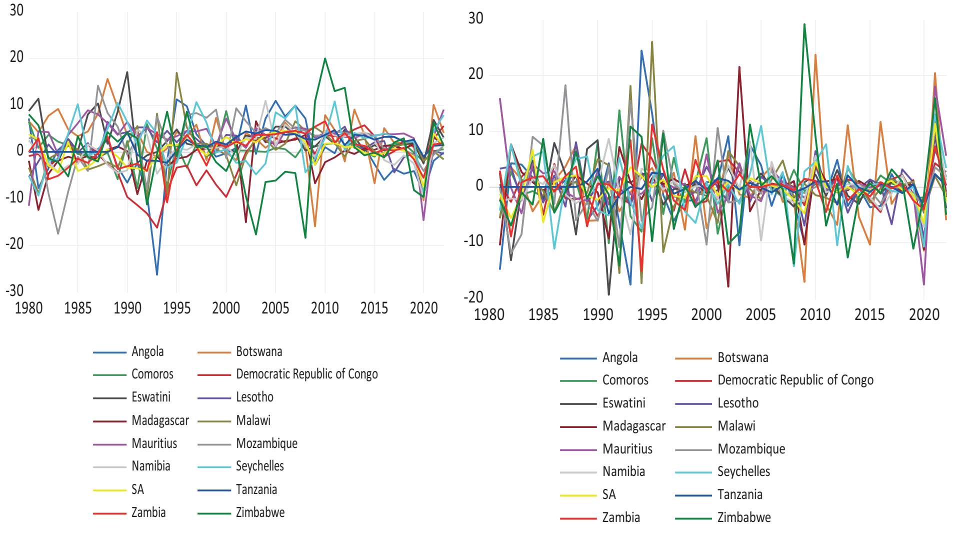

Figure 3. Economic Growth. *Source*: Figure constructed by Eview 9 using statistics from World Bank (2024)

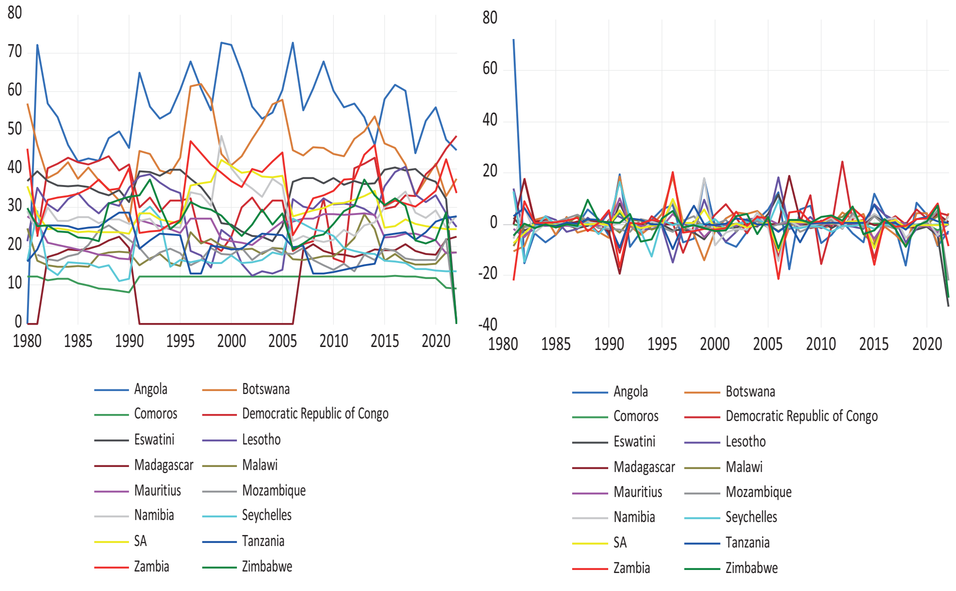

Figure 4. Industrialisation. *Source*: Figure constructed by Eview 9 using statistics from World Bank (2024)

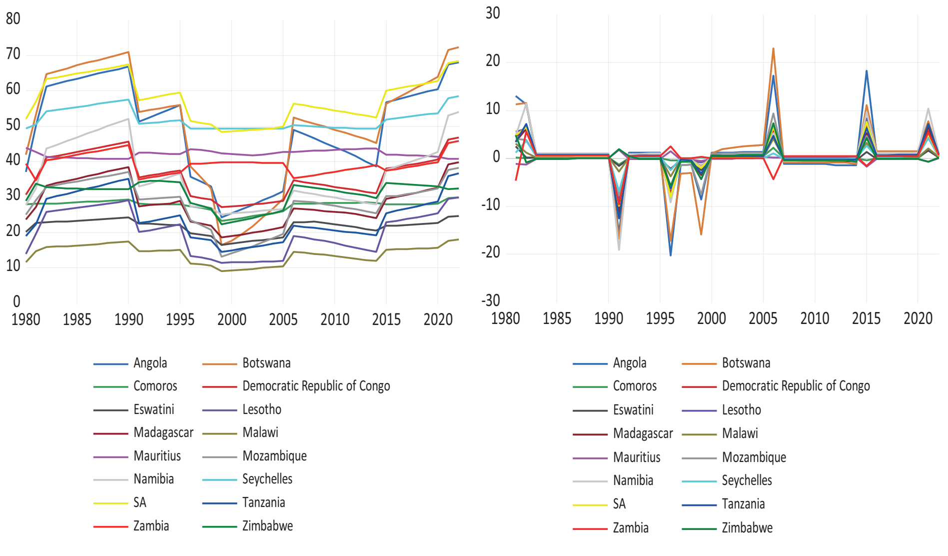

Figure 5. Urbanisation. *Source*: Figure constructed by Eview 9 using statistics from World Bank (2024)

All Figures show that the variables were not stationary at levels. The sets labeled (left) show variables at levels. The graphs show that the variables became stationary after being first differenced. This is indicated by the lines hovering around zero in the sets labeled (right). This is an indication that the variables were stationary after first differencing.

4.3.4. Formal analysis

The results from the LM Pesrana test suggest that only two variables were stationary at their levels. These were Industrialisation and Economic Growth. The rest of the variables became stationary after being differenced once.

Table 3. Stationarity

Variable	t-statistic	p-value
Energy Consumption	-1.4695 -6.3177	0.0708 0.0000
Financial Development	1.3712 11.4708	0.9148 0.0000
Economic Growth	10.3879	0.0000
Industrialisation	3.9365	0.0000
Urbanisation	4.685 12.7120	0.6803 0.0000

Source: Table constructed by Eview 9 using statistics from World Bank (2024)

4.4. Cointegration

The study performed a Pedroni cointegration and the results are displayed in Table 4 below.

Table 4. 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: Table Constructed by Eview 9 Using Statistics from World Bank (2024)

The Pedroni Test, which has eight weighted subtests including panel-v, panel-rho, panel PP, and panel ADF statistics, is represented by the first panel in the table. Most of the tests have a p-value that is less than 0.05 and this shows that there was cointegration. This means that the study had to adopt some panel cointegration regressors.

4.5. Pooled Mean Group RESULTS

Table 5. Pooled Mean Group Results

Variables	Long	Run	Equation
Economic Growth (GDP)	0.016481 0.0995	0.009989	1.649972
Industrialisation (IND)	0.001168 0.8045	0.004704	0.248235
Financial Development (FD)	0.034116 0.0000	0.034116	0.004768
Urbanisation (URB)	-0.010656 0.0786	-0.010656	0.006048

Source: Table constructed by Eview 9 using statistics from World Bank (2024)

Results show that GDP has a small but positive long run relationship with energy consumption. It means that when GDP is increasing energy consumption also increases. As the SADC countries' economic growth increases, energy demand rises, too, meaning that if energy is constrained, economic growth pulls back in turn. The results concur with Zhao et al. (2023) who concluded that a long run positive relationship exists between economic growth and energy consumption in 30 Chinese provinces over a period 2000-2019. Also, evidence was drawn from the OECD and European Union Member States between 1980 and 2013, and between 2010 and 2019 by Gozgor et al. (2018); Laszlo (2023), who discovered a long run positive relationship between economic growth and energy consumption. Countries should work on creating new sources of energy and improving energy efficiency. Furthermore, when countries become more productive, they will produce more output and put in more resources, and most importantly, energy will also increase. Conversely, Darrian et al. (2023) discovered a negative and long run relationship between economic growth and energy consumption for Indonesia during the period 1985-2019. Molele (2018); Ahmed and Elfaki (2023) documented a long run negative relationship between economic growth and energy consumption for 15 economies from Asia, the Pacific, and Latin America; and South Africa in 1990-2018 and 1980-2012. Governments of these regions should implement policy measures encouraging efficient use of energy to promote healthy relations in the broader economy.

Industrialisation was not seen as having a significant long run relationship with energy consumption and so, presumably, it does not influence energy consumption. These findings concur with Lloyd (2017) who discovered no significant long run relationship between industrialisation and energy consumption in India, China, Indonesia, and Brazil over the period 1960-2014. Abdulkadir and Isik (2020) found no significant relationship between industrialization and Nigeria's energy consumption between 1985 and 2017. Improving energy efficiency in industry is also difficult because of high complexity of industrial energy systems. On the other hand, Sadorsky (2014) revealed a long run positive relationship between industrialisation and energy consumption in emerging economies for the period 1971-2008. Elfaki et al. (2021) detected a strong positive long run relationship between industrialisation and energy consumption in Indonesia in 1984-2018. Expanding industrialization in the newly industrialised countries is driving the intensive use of energy. Nevertheless, Mentel et al. (2022) discovered a negative long-term relationship between industrialisation and energy consumption over 2000-2018 for Europe and Central Asia. Franck and Galor (2019) also found that industrialisation had negative effect on the use of energy in the long run as the adoption of labour-intensive skilled technology in the early stages of industrialisation at the current human resources level tends to reduce energy consumption and thus become an incentive to further introduce skills-intensive technologies.

Financial development was considered to be having a positive long run relationship with energy consumption, i.e. when financial development improved, energy consumption would grow. Lefatsa et al. (2021) discovered that, in the long run, financial development positively affected energy consumption in South Africa over the period 1980-2018. Thebuho et al. (2022) found a long run positive effect of financial development on energy consumption in 21 SSA countries between 1990 and 2016: well-performing stock markets stimulated growth, thereby increasing investor confidence. Nevertheless, the results obtained by Shahbaz et al. (2019) run contrary to those above. They revealed a long run negative relationship between financial development and energy consumption in India over the period 1960Q1-2015Q4. Ma et al. (2022) detected the same kind of relationship in 67 developing countries between 1995 and 2018. It follows that availability of corporate credit for resolving energy-related issues should be provided for in these countries' plans.

Urbanisation was seen as having a negative long run relationship with energy consumption: when the former increases, there should be a decrease in the latter. Research discovered negative effects of urbanisation on energy consumption in the Indian and Iranian economies between 1971-2013. Ali (2021) revealed a long run negative relationship between urbanisation and energy consumption in 49 SSA countries over 1980-2014. At the same time, the results obtained by Sheng et al. (2017) show a long run positive relationship between urbanisation and energy consumption in 72 countries during 1995-2012. Zhao and Qamruzzaman (2022) also discovered a long-run positive relationship between urbanisation and energy consumption for Belt and Road countries over the period 2004-2020. Obviously, the urban sprawl and motorisation contributed to energy consumption growth. In either case, the findings suggests that countries must frame their urban policies to create positive externalities.

4.6. Bayesian Results

Running Bayesian inference after estimating a PMG model provides deeper insights into parameter uncertainty, allows for the incorporation of prior knowledge, and enhances the overall robustness and flexibility of the analysis. This approach aligns well with the thesis focus on Bayesian methods, offering a comprehensive framework for interpreting long-term relationships in the panel data. The Bayesian model is the main model of the study; its results are shown in Table 6 below.

Table 6. Bayesian Results

Parameter	Posterior Mean	Standard Deviation	95% Credible Interval	P-value
Economic Growth (GDP)	.0167972	.0084851	-.0003353	.0328601
Industrialisation (IND)	0.0184121	.0016254	.0152145	.0215424
Financial Development (FD)	.0385767	.0033303	.0320625	.045168
Urbanisation (URB)	.0120711	.0034556	.0053085	.0190246

Source: Table constructed by Eviews 9 using statistics from the World Bank (2024)

These results show that economic growth has a positive effect on electricity consumption. When the economy is growing organizations and individuals consume more energy. This relationship is not very pronounced: even though an increase in economic growth should necessitate higher energy consumption, higher rates of economic growth bring about more productive energy use. These results are in line with Kahouli (2019) and Can and Korkmas (2019) who were the first to observe the nexus between economic growth in 34 OECD countries and Bulgaria over 1990-2016 and found a positive relationship between these variables. The results demonstrated the importance of economic growth for renewable energy consumption but also showed the negative effects of high pollution. It is therefore necessary to expand these countries' clean renewable energy projects to curb pollution. At the same time, Ngoc and Tram (2024) discovered a negative effect of economic growth on nuclear energy consumption for 11 Asian countries between 1980 and 2016; Simionescu (2023) saw the same effect in the European Union over 2002-2021: manufacturing activities were reduced resulting in low industrial pollution and environmental degradation.

Research has also shown that financial development positively influences electricity consumption, which means that financial development should not hinder increased energy consumption from the regional perspective but these processes need to be balanced. According to Zhe, Yüksel, Dinçer, Mukhtarov, and Azizov (2021) it holds true for China during in 1990-2015. Also, Ulucak (2021) confirmed a significant and positive relationship between financial development and energy consumption in Pakistan from 1980 to 2017. This suggests that a sound financial system attracts foreign investors and improves economic efficiency. Yet, Ding (2023) and Tariq et al. (2023) found a negative relationship between financial development and energy consumption in the G7 countries over 1990-2020 and in BRI countries over 2000 to 2020 respectively. Financial development may also cause improvements in the environment through funding environmental projects at reduced costs.

Results show that industrial development has a positive effect on electricity consumption. This suggests that, as industries develop, they consume more electricity. Hence there is a positive relationship between industrial development and electricity consumption. That is what we observe in the SADC region which is experiencing a huge growth in the industrial sector that brings about increased demand for energy. According to Simionescu (2023), growing industrial activity leads to greater use of advanced machinery compared to traditional agriculture and basic manufacturing, and this, too is always linked with expanding energy consumption. Simonescu's findings are in line with those by Lefatsa et al. (2021) who proved the existence of a positive link between industrial development and energy use in South Africa for the period 1980-2023. Also, according to Sadorsky's (2014) findings, industrialization is a major factor contributing to higher levels of energy consumption caused by the need to fuel machinery and increase automation of production processes. However, Li and Lin (2015) obtained the opposite results: their analysis showed that industrialization reduced energy consumption in 73 countries over the period 1971-2010. Zhang, Qamruzzaman, Karim, and Jahan (2021) also discovered a negative relationship between industrialization and energy consumption in 30 China's provinces and cities in 2008-2017. Energy poverty inhibits the optimization of the energy consumption structure and thus prevents improvement in energy efficiency of the construction industry.

Results show that urbanization has a positive effect on electricity consumption because individuals and organizations in cities need more energy. Rapid growth of the urban population creates huge demand for the construction of housing and commercial real estate, roads, bridges and other infrastructure, thus increasing energy use. These results are consistent with the findings of Liu (2009), and Shahbaz and Lean (2012) who posited that urbanization significantly increased energy consumption. Empirical evidence shows that production methods and processes can cause urbanization and hence growing energy consumption as they become more and more energy intensive (Lefatsa, 2021). This, however, contradicts the conclusions made by Sadorsky (2014) who found that energy consumption may be reduced by urbanization, albeit not significantly, in a small sample of 18 developing economies, including South Africa. Furthermore, Sekantsi and Motlokoa (2015) detected no significant correlation between these variables in Lesotho over the period 1972-2011. The growing demand for energy threatens the energy supply, leading to a peak power deficit being met through exports.

4.7. Dumitrescu-Hurlin Granger results test

Table 7. Granger causality Energy Consumption and Economic Growth

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: Table constructed by Eviews 9 using statistics from the World Bank (2024)

Based on the test results, the study concludes that there is a bi-directional Granger causality between economic growth and energy consumption. These findings concur with Chen, Saud, Bano, and Haseeb (2022) and Iqbal, Tang and Rasool (2022) who made a research into the BRICS economies in 1990-2019 and 2000-2018 and discovered a bidirectional causality effect running between economic growth and energy consumption. They maintain that further openness to international markets contributes to the use of advanced energy-efficient technologies and production methods. At the same time, a research by Aydin (2023) and Cheriyambadan et al. (2023) into the economy of Asian countries in 1980-2018 and 1975-2021 detected no causality effect between economic growth and energy consumption. The neutrality hypothesis explains this by the uneven and insufficient exploitation of renewable energy sources.

Table 8. Granger causality Financial Development and Energy Consumption

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: Table constructed by Eviews 9 using statistics from the World Bank (2024)

The results show a unidirectional causality running from financial development to energy consumption, i.e. financial development causes greater energy consumption. Adebayo and Ağa (2022) in MINT countries from 1990Q1-2019Q4 and Zhang (2023) in China between 2010-2020 obtained similar results, discovering a unidirectional causality running from financial development to energy consumption. It signals the need to address socioeconomic problems and energy deficits to create sustainable environment and encourage new economic activity.

Table 9. Granger causality Industrialisation and Energy Consumption

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: Table constructed by Eviews 9 using statistics from the World Bank (2024)

The results presented in the table do not indicate any causality between the variables in question. These findings concur with the results obtained by Shahbaz and Lean (2012) in the United Arab Emirates over the period 1975-2011 and by Zhang and Broadstock (2016) in China between 1963 and 2010, who both failed to find a causality effect between industrialization and energy consumption even though energy is the cornerstone of the modern industrial economy: affordable and reliable energy as a co-requisite for improved industrial productivity and competitiveness is a crucial element in the process of economic diversification. Their conclusions contradict the findings of Gungor and Simon (2017) who discovered a bidirectional causality effect between industrialization and energy consumption in South Africa during the period 1970-2014. In a similar way, using data from Bangladesh over the period 1975-2018, Rahman and Alam (2021) detected bidirectional causality between industrialization and energy consumption. The efficient availability of energy increases industrial productivity.

Table 10. Granger causality Energy Consumption and Urbanisation

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: Table constructed by Eviews 9 using statistics from the World Bank (2024)

The results in Table 10 point to a unidirectional causality that is running from urbanization to energy consumption, i.e. urbanization is causing higher energy consumption. They are in line with Khan, Amin and Rahman (2018) who found a unidirectional causality running from urbanization to energy consumption in Bangladesh in 1980-2015. Also, Wang, Li, and Tarasov (2021) obtained similar results for China between 2000 and 2017. As cities grow and more people move into them, the demand for energy increases.

4.8. Diagnostic statistics

The results from the Bayesian analysis were subjected to a number of tests to see if the model was correct.

Figure 6 shows a diagnostic graph that contains a trace plot, a histogram and density plots for the MCMC sample, and a correlogram. The trace plot has a stationary pattern, which shows that the model was correct. The histogram does not have any unusual features, such as multiple modes. The kernel density plots for the full sample, the first half of the chain, and the last half of the chain all look similar and do not show any strange features such as different densities for the first and last half of the chain.

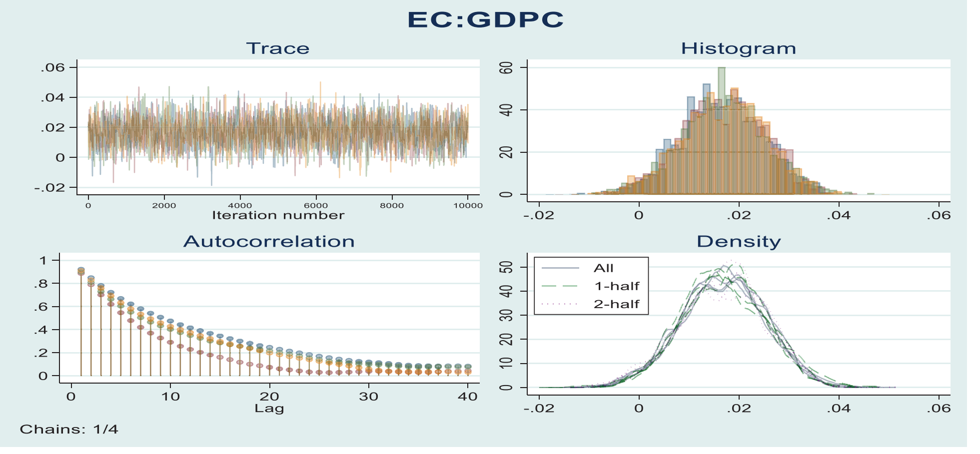

Figure 6. Convergence of Energy Consumption and Economic Growth. *Source*: Figure constructed by Eviews 9 using statistics from the World Bank (2024)

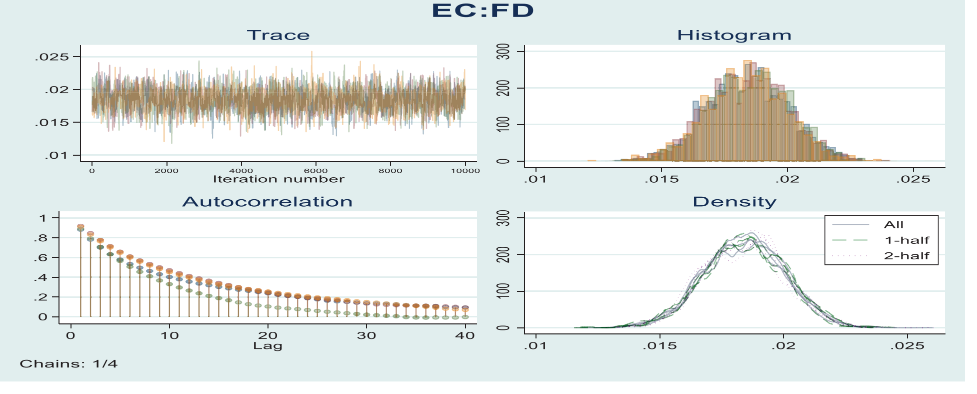

Figure 7. Convergence of Energy Consumption and Financial Development. *Source*: Figure constructed by Eviews 9 using statistics from the World Bank (2024)

Figure 7 shows a diagnostic graph that contains a trace plot, a histogram and density plots for the MCMC sample, and a correlogram. The trace plot has a stationary pattern, which shows that the model was correct. The histogram does not have any unusual features such as multiple modes. The kernel density plots for the full sample, the first half of the chain, and the last half of the chain all look similar and do not show any strange features such as different densities for the first and last half of the chain.

Figure 8 shows a diagnostic graph that contains a trace plot, a histogram and density plots for the MCMC sample, and a correlogram. The trace plot has a stationary pattern, which shows that the model was correct. The histogram does not have any unusual features such as multiple modes. The kernel density plots for the full sample, the first half of the chain, and the last half of the chain all look similar and do not show any strange features such as different densities for the first and last half of the chain.

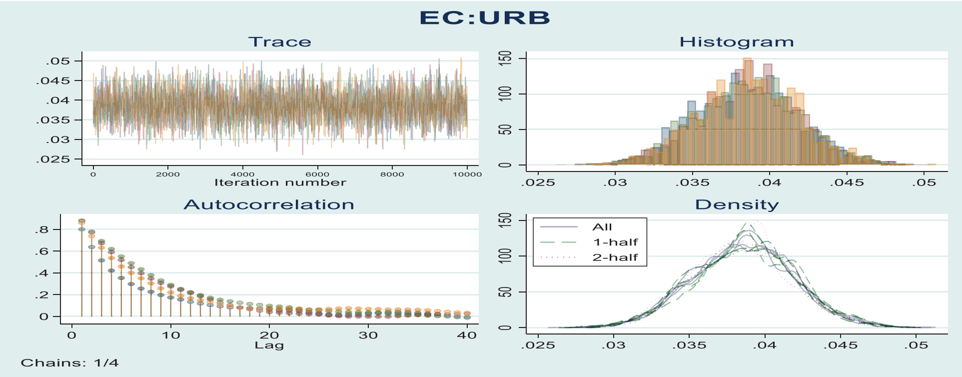

Figure 8. Convergence of Energy Consumption and Urbanisation. Source: Figure constructed by Eviews 9 using statistics from the World Bank (2024)

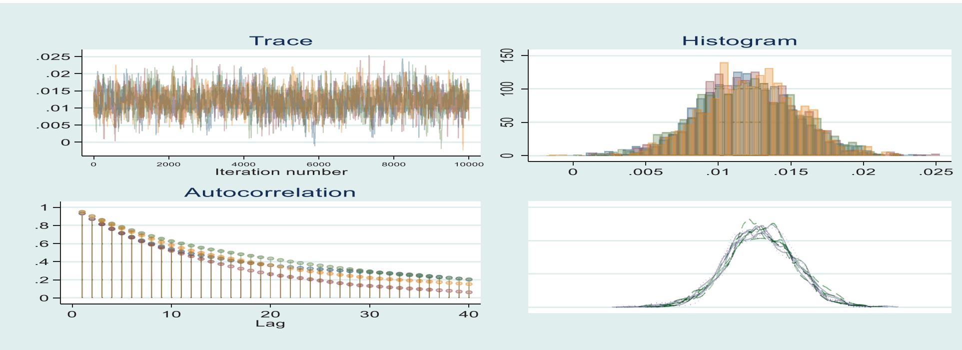

Figure 9. Convergence of Energy Consumption and Industrialisation. *Source*: Authors own computation, Eviews 9 using statistics from the World Bank (2024)

Figure 9 shows a diagnostic graph that contains a trace plot, a histogram and density plots for the MCMC sample, and a correlogram. The trace plot has a stationary pattern, which shows that the model was correct. The histogram does not have any unusual features such as multiple modes. The kernel density plots for the full sample, the first half of the chain, and the last half of the chain all look similar and do not show any strange features such as different densities for the first and last half of the chain.

5. Discussion of Results

This study's findings illuminate critical interactions between financial development, economic growth, and energy consumption in the SADC region, offering valuable implications for policymakers. The observed bi-directional Granger causality between economic growth and energy consumption signifies a mutually reinforcing relationship, where energy availability supports economic expansion, which in turn heightens energy demand. This feedback loop underscores the necessity for reliable energy infrastructure to foster sustainable industrialization and urbanization. Policymakers can leverage these insights by creating supportive environments for growth, anchored in accessible and consistent energy.

The positive long-term association between financial development and energy consumption highlights the role of financial access in stimulating energy use, especially through business expansion and industrial activities. With improved financial development, private sector growth is likely to accelerate, enabling local businesses to innovate and adopt energy-efficient practices. This underscores the importance of expanding credit access, which can empower enterprises to invest in sustainable energy technologies and mitigate environmental impacts.

Furthermore, the study suggests that urbanization influences energy consumption, as rapid urban growth increases infrastructure and energy needs. Policymakers must consider this when planning urban development, ensuring that energy systems can sustainably accommodate growing populations.

5.1. Conclusion

This research underscores the importance of aligning financial and energy policies to support sustainable economic development in the SADC countries. The key recommendations include:

Incentivizing Renewable Energy Investments: Encouraging renewable energy adoption can help reduce dependency on traditional energy sources, contributing to energy security and environmental sustainability.

Expanding Financial Access: Improving credit availability for small-to-medium enterprises and industries can facilitate capital flows toward energy-efficient and innovative technologies.

Strengthening Energy Infrastructure: Upgrading infrastructure to meet rising energy demand from industrial and urban growth is essential for economic resilience.

Implementing these strategies will enable the SADC countries to unlock economic potential, improve quality of life and position the region competitively on a global scale by integrating economic, environmental and social priorities.

5.2. Limitations and Future Research

This study has several limitations worth noting. First, it relies on data spanning from 1980 to 2023, and inconsistencies in reporting standards and data availability across the SADC countries may impact the accuracy of the findings. Additionally, the key variables like financial development and energy consumption are measured using broad indicators, potentially obscuring sector-specific differences, such as those between industrial and residential energy use. Although Bayesian inference and the PMG model provide robust insights, they may not fully capture non-linear dynamics or structural breaks, especially during significant events like economic crises. Moreover, the study does not account for external shocks, such as global energy price fluctuations or geopolitical factors, which may influence energy consumption and economic growth in the region.

Future research could address these limitations by incorporating disaggregated sectoral data to better understand how financial development impacts different industries. Including environmental variables, such as carbon emissions and renewable energy adoption, would provide a more comprehensive view of sustainable growth. Using non-linear or threshold models could capture complex interactions and reveal structural shifts over time. Comparative studies with other regional blocs, such as ECOWAS or ASEAN, could further contextualize the SADC region's energy-economy relationship, highlighting unique dynamics and exploring the applicability of similar policy interventions across regions. Finally, examining the effects of specific policy changes or external shocks on these relationships could improve our understanding and inform more targeted policy recommendations for sustainable development in the SADC region.

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