Examining the Determinants of Renewable Energy Consumption in the Southern African Power Pool

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The main factors influencing the Southern African Power Pool's (SAPP) usage of renewable energy are examined in this article. The 12 nations that constitute the SAPP are the sources of the data from 1988 to 2018. The effect of GDP, gross fixed capital formation, labour, trade, and non-renewable energy on renewable energy in SAPP is estimated using the panel ARDL method. The empirical findings suggest that, in the long run, all coefficients of explanatory variables have positive signs, except for gross fixed capital formation and non-renewable energy, which have negative signs. Furthermore, all results were statistically significant at one to five percent. This implies that the reduction in renewable energy in the SAPP is caused by non-renewable energy and gross fixed capital formation in the long run, but not by any other explanatory variable. The results also showed that each SAPP member country's impact on renewable energy was varied. The SAPP could, therefore, encourage the adoption of renewable energy sources through the results presented in this report. Based on these findings, the study suggests that economic policies that hasten economic development and growth will increase renewable energy consumption.

Keywords: energy, electricity, sustainability, renewable energy, SADC, SAPP, income
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Introduction

There has been a notable shift towards using more renewable energy sources in recent years. This change has come about due to the harmful impact of non-renewable energy sources on the environment (Kumar 2020). As a result, global policies have been introduced to promote the use of renewable energy (Rajesh Kumar and Majid 2020).

This shift facilitated different policies, including the Paris Agreement. This agreement aims to limit global temperature rise to 1.5°C due to the fact that 65% of the carbon dioxide budget allowed to stay within the 2°C limit has already been used (Intergovernmental Panel on Climate Change 2018). According to the Obonyo (2021), to achieve this target, countries must make significant changes to their energy mix, to include an increase in renewable energy.

Apart firom policies, sustainable development goals (SDGs) have also been formulated, with some focusing on development, sustainable energy, and climate change (Adewuyi and Awodumi 2020). One such goal is SDG 7, which aims to provide affordable, reliable, sustainable, and modern energy to all. Power pools reduce electricity generation and investment costs, enhance system reliability, and play a crucial role in achieving SDGs.

The Southern African Power Pool (SAPP) is Africa's most liquid market, fulfilling 3.5% of the demand for energy share (Yang et al. 2022). The Southern African Power Pool is a partnership among national electricity companies in Southern Africa, operating under the Southern African Development Community (SADC) guidance. The member countries include Angola, Botswana, the Democratic Republic of the Congo, Eswatini, Lesotho, Mozambique, Malawi, Namibia, South Africa, Tanzania, Zambia, and Zimbabwe (Southern African Power Pool n.d.).

As the economies within the SAPP continue to grow, the energy demand also increases. According to Bowa et al. (2021), regional electricity demand is expected to grow at an average rate of 3 to 6 percent per year, in line with economic growth. According to the International Renewable Energy Agency (2015), the region's electricity demand is expected to double from 280 Terawatt-hours (TWh) in 2010 to 570 TWh by 2030. This poses a challenging question about how much non-renewable energy can be used and how much renewable energy can be substituted.

Africa contributes little to global CO_2 emissions, with many countries producing almost zero. In the SAPP, all member countries except for South Africa have lower CO_2 emissions per capita due to South Africa's greater reliance on fossil fuels (specifically coal) for electricity. However, South Africa is responsible for 48% of the CO_2 emissions from the region and is the world's fourteenth largest CO_2 emitter, with a per capita emission of 8.98 tonnes of CO_2 (Bowa et al. 2021). Addressing climate issues within the SAPP is closely tied to reducing South Africa's and the region's reliance on coal. The World Bank's (2018) report on emissions per capita shows that Botswana is the second-highest emitter at 3.642 metric tons per capita, followed by Namibia at 1.736 and Eswatini at 0.9593 tonnes of CO_2 per capita. However, the Democratic Republic of the Congo and Malawi had the lowest emissions per capita in the SAPP at 0.03 and 0.09, respectively.

The use of renewable energy sources such as biomass, wind, hydro, geothermal, and solar power is becoming increasingly popular (Bowa et al. 2021). A plan was set in 2012 to increase the share of renewable energy in the grid to 39% by 2030, up from the current 29%, and to achieve a 7.5% share of off-grid energy by the same year (South African Development Community 2016). As a result, the installed capacity of renewable energy in the region has grown from 11,821 megawatts (MW) in 2008 to 20,673 MW in 2017, and mid-2018 capacity increased to 21,760 MW (South African Development Community 2018), with hydropower remaining a vast source, then bioenergy, followed by wind and solar. According to IRENA's (International Renewable Energy Agency 2015) report, there is a planned yearly production capacity of 800 TWh from wind and solar energy combined, with 219.5 TWh from solar PV and 109.3 TWh from concentrated solar power. The report also predicts that the region's electricity generation capacity from renewable energy sources will be 62,781MW for consolidated energy systems and 24,725MW for decentralised off-grid projects between 2010 and 2030.

Bowa et al. (2021) report that new incentives and policies supporting renewable energy have increased investment in the sector. The China Exim Bank (CHEXIM), the Brazilian Development Bank (BNDES), and the Development Bank of Southern Africa (DBSA) are among the investors who have contributed approximately $10.1 billion (Muñoz Cabré et al. 2020).

In light of this, Akizu-Gardoki et al. (2018) contend that using renewable energy is essential for environmental preservation, but it also serves additional purposes. Kumar (2020) agrees, stating that renewable energy sources offer the best solution for economic growth, energy security, job creation, and poverty reduction, particularly for those who depend on natural resources.

Although there has been considerable research on the causes of non-renewable energy consumption, further investigation is needed to understand the factors that influence renewable energy consumption fully.

To understand the factors influencing the adoption of clean energy in economies within the SAPP, it is vital to conduct academic research and establish links between them. Policymakers may accelerate the adoption of clean energy in SAPP by finding these links. Additionally, no prior research has attempted to explore the factors of SAPP's expanding renewable energy. Furthermore, Olanrewaju et al. (2019) proposed that understanding the drivers behind renewable energy can protect against potential price increases in traditional fuels by broadening their energy options, assisting in maintaining stable trade and budget deficits.

It is in this view that the present study is commissioned to examine the determinants of renewable energy consumption in the SAPP. Furthermore, the study seeks to empirically investigate whether the determinants are uniform across the SAPP countries. With this aim, the study uses the Panel Autoregressive Distribution Lag (ARDL) to estimate the coefficient of each variable's short- and long-run.

This article is structured as follows. The second section reviews the existing literature. The third section describes the data used and sources, as well as the methodology used. The fourth section analyses the empirical models and results, while the fifth section concludes the article.

Literature Review

Numerous studies have been done on energy (both non-renewable and renewable). However, these studies have been centred around their impact on economic growth, such as Koçak and Şarkgüneşi (2017), Ntanos et al. (2018), and Wang and Lee (2022).

These studies often categorised their results into four hypotheses. The growth hypothesis explains that a rise in energy consumption causes the elevation of economic growth. Studies such as Mutumba et al. (2021) conducted a meta-analytic investigation of energy consumption and economic growth from 1974 to 2021. The study used a survey method to profile related literature on the energy consumption-economic growth nexus. The results indicated that the growth hypothesis is the most dominant outcome for country-based studies, accounting for 43.8%. At the same time, feedback was 18.5%, conservation 27.2%, and the neutrality hypothesis 10.5% for country-specific studies. Similarly, Caraiani, Lungu, and Dascălu (2015) found the long-run relationship between various sources of energy consumption and GDP per capita for emerging European countries supported the growth hypothesis. This hypothesis has a significant implication: a reduction in energy consumption would jeopardise the growth trajectory.

Conversely, the conservative hypothesis maintains a one-way causal relationship between economic growth and energy consumption. This assumption implies that policymakers' efforts to reduce energy consumption would have no adverse effect on economic growth. The works of Gorus and Aydin (2019) investigate the causal relationship between energy consumption, economic growth, and CO_2 emission. The study sampled eight oil-rich MENA countries, i.e. Algeria, Egypt, Iran, Iraq, Oman, Saudi Arabia, Tunisia, and the United Arab Emirates, from 1975 to 2014. Utilising single and multi-country Granger causality analysis, the results indicated that energy conservation policies do not harm economic growth in the short and intermediate run. However, at the same time, their long-term effects are adverse. Comparable results by Rahman and Velayutham (2020) explored the relationship between renewable and non-renewable energy consumption and economic growth for a panel of five South Asian countries from 1990 to 2014 using panel fully modified ordinary least squares and panel dynamic ordinary least squares estimation techniques. Their study found a positive impact of energy consumption (renewable and non-renewable) and fixed capital formation on economic growth. In addition, results showed a unidirectional causality from economic growth to renewable energy consumption, proving the conservation hypothesis was valid for the South Asian countries sampled.

The feedback hypothesis considers a two-way causal relationship between energy consumption and economic growth. Al-Mulali et al. (2013) investigated a bi-directional long-run relationship between renewable energy consumption and GDP growth for high-income, upper-middle-income, and lower-middle-income countries. They were using the fully modified OLS. The results showed that 79% of the countries in the sample had a positive bi-directional long-run relationship between renewable energy consumption and GDP growth, representing the feedback hypothesis. On the other hand, 19% of the countries showed no long-run relationship between the variables, and 2% showed a one-way long-run relationship from GDP growth to renewable energy consumption. A similar result by Raza, Shahbaz, and Nguyen (2015) investigated the energy-growth-trade nexus in Pakistan for the period from 1973 to 2013. Their results proved that Pakistan favoured the feedback hypothesis because they found a bi-directional causality between gross domestic product and energy consumption. They also revealed the presence of a long-run relationship between energy consumption and trade performance, a positive impact of GDP, exports, and imports on energy consumption, and a bi-directional causal relationship between exports and energy consumption.

Finally, the neutrality hypothesis advocates no causal relationship between energy consumption and economic growth. Yıldırım, Sukruoglu, and Aslan (2014), using the bootstrapped autoregressive metric causality approach, confirmed the causal relationship between economic growth and energy consumption in Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Pakistan, the Philippines, and Turkey. Their results found that all countries in the sample favoured the neutrality hypothesis except Turkey. Ozcan and Ozturk (2019) also found that 16 out of 17 emerging countries favoured the neutrality hypothesis when they conducted a study to analyse the relationship between renewable energy consumption and economic growth in 17 emerging countries from 1990 to 2016 using the bootstrap panel causality test.

The empirical studies discussed above emphasise the ambiguous agreement on the relationship between economic growth and energy. However, it is critical to observe that the relationship between these variables varies across nations and periods. Regardless, it is worth noting that energy usage has become an essential component of increasing economic activity worldwide.

The negative impact of environmental externalities within this context has prompted researchers to separately investigate the effects of renewable energies, in order to contribute to the literature and assist policymakers in developing policies that can reflect on this energy type in the interests of economic growth and environmental quality.

Sadorsky (2009) investigated renewable energy consumption, CO_2 emissions and oil prices in the G7 countries. The FMOLS and DOLS estimation methods were utilised in this study. The results yielded that increases in real GDP per capita and carbon dioxide emissions per capita are major drivers behind per capita renewable energy consumption. The elasticities estimate shows that a one percent increase in real GDP per person increases per capita renewable energy consumption by 8.44%, while a single percent increase in carbon dioxide emissions per person increases per capita renewable energy consumption by 5.23%.

Chen, Pinar, and Stengos (2021) studied the determinants of renewable energy consumption. They sampled 97 countries from the period 1995 to 2015. Using the dynamic panel regression (DPRM) analysis, results suggested that the previous growth rate of renewable energy is negatively associated with the current growth rate, meaning the overall growth of renewable energy consumption declined over time for all their samples. Furthermore, results indicated that higher economic growth rates are negatively related to the growth of renewable energy consumption in the whole sample, but developed countries showed a positive relationship to renewable energy when economic growth increased. On the other hand, countries with relatively higher economic growth in less democratic countries experience relatively lower growth rates in renewable energy consumption, suggesting that the increase in energy consumption in these countries was mainly from non-renewable energy sources. With regard to an increase in CO_2 emissions per capita, it leads to increased use of renewable energy consumption for the sample. Similarly, the growth of oil prices and the growth of renewable energy consumption were positively associated. Finally, increased trade openness lowered the growth of renewable energy consumption in developing countries, but increased the growth of renewable energy consumption in developed countries.

Zhao and Luo (2017) explored the development of renewable energy in China using the ARDL estimation method for the period 1978 to 2013. Their results indicated a quadratic relationship between renewable energy and income. Furthermore, they could not prove that renewable energy generation is a job creator when the lagged unemployment rate is included as an explaining variable; however, they did indicate that employment can promote the development of renewable energy.

Omri, Daly, and Nguyen (2015) analysed the drivers of renewable energy consumption for a panel of 64 countries, using both the static (pooled OLS, panel fixed and random effects) and dynamic (difference and system GMM) panel data estimation approaches. Results indicated that increases in per capita CO_2 emissions and per capita trade with foreign partners mainly drive the changes in per capita renewable energy consumption. There was also evidence of oil price effects on renewable energy consumption, which reflects the fact that renewable energy is just a complement and not a perfect substitute for crude oil, at least in the short run.

This type of investigation done on African countries is limited. However, this study recognises studies such as that of Kwakwa (2021), that determined renewable energy consumption in Ghana. The regression and variance decomposition techniques were used to analyse the data, for the period 1971 to 2014. Results of the study indicated that Ghana's renewable energy consumption is positively influenced by industrialisation, but negatively influenced by price, income, and financial development in the long run, while in the short run, industrialisation and financial development affect renewable energy consumption.

Ergun, Owusu, and Rivas (2019) studied the determinants of renewable energy consumption in Africa. They used fixed- and random-effects estimators for the long-run equilibrium relationships, while using Dumitrescu and Hurlin causality to investigate the direction of causality in a bi-variate relationship. The study showed an increase in the human development index, which reduces renewable energy consumption. They also observed that economic growth reduces renewable energy consumption, while the causality test results revealed a bi-directional causality between GDP per capita, human development index, trade openness, the level of democracy in a country and the share of renewables in energy consumption, except for foreign direct investment, which shows a unidirectional causality with renewable energy. A similar study by Olanrewaju et al. (2019) investigated the determinants of renewable energy consumption in Africa. The study employed panel data analysis involving five economies in each of the five regions of Africa, namely Nigeria (West), Egypt (North), Ethiopia (East), DR Congo (Central) and South Africa (South), with annual data from 1990 to 2015. The results showed that oil rent, coal rent and carbon intensity yield a significant and negative relationship with renewable energy consumption, excepting natural gas rent, which revealed a positive and significant relationship with renewable energy use in Africa.

The empirical studies discussed above plainly demonstrated that every study has been done on the determinants of renewable energy in general, but that there is no existing literature on renewable energy determinants in SAPP in particular. However, given the increasing significance of power pools in an environmentally conscious region, energy policymakers and government officials need to understand the drivers of renewable energies.

As a result, these problems motivate the current study to conduct empirical research on the determinants of renewable energy in the Southern African Power Pool. The findings of this research will lead to constructive policy recommendations for the SAPP to improve energy security in the region and ensure the countries' long-term economic development.

Data and Methodology

The study employs annual data from 1988 to 2018 of countries within the Southern African Power Pool (SAPP). The empirical objectives of the current study are pursued through an econometric analysis conducted using the EViews 13 computer software program.

To analyse the determinants of renewable energy, this study models the problem using existing literature, such as Zhao and Luo (2017) and Erugun, Owusu, and Rivas (2019), where their studies considered the environmental Kuznets curve (EKC) hypothesis.

According to the EKC hypothesis (inverted U-shaped) proposed by Grossman and Krueger (1991) and named by Panayotou (1993), an increase in GDP per capita leads to a rise in environmental pollution in the developing stages of an economy. Still, pollution decreases over time as the country's economy grows further (Erugun, Owusu, and Rivas 2019). Therefore, this study considered a quadratic model to illustrate the EKC hypothesis:

$$EQ = f(GDP,\ GDP^2,\ Z), \tag{1}$$

where EQ denotes environmental quality indicator, GDP is real gross domestic product, GDP^2 is the square of real GDP, and Z is the control variables that may affect environmental quality. For example, EKC theories typically examine ecological contamination such as CO_2, nitrogen oxide, sulphur dioxide emissions, and water pollutants. Zhao and Luo's (2017) study uses renewable energy instead to measure environmental quality, because renewable energy is developed toward environmentally friendly, clean energy supply. This paper contributes to the EKC theories by using the renewable energy generation as a metric for environment quality. Therefore, by replacing EQ with renewable energy (REN), the new equation is expressed as:

$$REN = f(GDP,\ GDP^2,\ Z). \tag{2}$$

Other variables considered for the model include gross fixed capital formation (CAP), which, according to Azam et al. (2023), influences energy consumption through higher accumulation and deployment of gross fixed capital formation for more production of goods and services, leading to faster income. Sheikh, Kocaoglu, and Lutzenhiser (2016) discovered that renewable energy has the potential to play a substantial role in meeting the employment criterion, thus total labour (LAB) as a proxy for labour is included in this model. Because the sample under research is a Power pool, an energy trading platform, trade openness (TRAD) as a proxy for trade is included in the model, as is a fossil fuel (FF) proxy for non-renewable energy, which according to the literature assumes that it increases the ecological footprint.

TABLE 1 Variable Acronym and Definition

Variable	Description	Measurement	Data source
LNREN	Renewable energy	Quadrillion Btu	United States Energy Information Administration
LNGDP	GDP	Constant 2015 US$	World Development Indicators
LNCAP	Gross fixed capital formation	Percentage of GDP	African Development Bank
LNLAB	Labour force	Total labour	World Development Indicators
LNTRAD	Trade	Percentage of GDP	World Development Indicators
LNFF	Fossil fuel	Quadrillion Btu	United States Energy Information Administration

With all variables considered, the model framework for 'examining the determinants of renewable energy consumption in the Southern African Power Pool' using EKC theories is shown as follows:

$$\log REN = \alpha_0 + \beta_1 \log GDP_t + \gamma \log(GDP_t)^2 + \beta_2 \log CAP_t + \beta_3 \log LAB_t + \beta_4 \log TRAD_t + \beta_5 \log FF_t + \mu X_t + \varepsilon_t . \quad (3)$$

Table 1 summarises the variables used in the study, including their abbreviations and sources from which they were obtained.

Following the possibility of asymmetries in response to the SAPP's determinants of renewable energy, this research employs the panel autoregressive distributed lag (ARDL) estimation approach to empirically analyse the functional forms above. The method demonstrates the long-run relationships and dynamic interactions between the variables of interest. It calculates the co-integrating accommodating regressors that are stable at levels I(0), or first difference, I(1). Furthermore, the long-run and short-run model parameters are calculated concurrently. Hence, the panel linear autoregressive distributed lag (ARDL) specification is written as:

$$LNREN = Y_0 + \sum_{j=1}^{m} y_{1j}\, LNREN_{t-j} + \sum_{j=0}^{m} y_{2j} LNGDP_{t-j} + \sum_{j=0}^{m} y_{3j} LNCAP_{t-j} + \sum_{j=0}^{m} y_{4j} LNLAB_{t-j} + \sum_{j=0}^{m} y_{5j} LNTRAD_{t-j} + \sum_{j=0}^{m} y_{6j} LNFF_{t-j} + \mu_t , \quad (4)$$

TABLE 2 Descriptive Statistics: Summary

	REN	GDP	CAP	LAB	TRAD	FF
Mean	0.0428	35,115,642,208	21.88473	7,534,592	77.0942	0.4367
Median	0.0203	11,347,684,667	19.38000	5,526,160	71.3550	0.0316
Maximum	0.249	358,429,917,588	64.96000	28,829,943	204.8600	5.5122
Minimum	0.0002	861,149,140	1.110000	221,812	4.05000	6.08E−5
Std. Dev.	0.0481	71,406,246,304	10.8504	7,267,959	37.62094	1.3051
Skewness	1.401	3.1315	1.1224	0.9447	0.7039	3.1239
Kurtosis	4.378	12.0315	4.583941	2.850872	3.157683	11.038
Jarque-Bera	151.1803	1872.345	116.999	55.68758	31.11209	1606.473
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	15.911	13,063,018,901,684	8141.120	2.80E+9	28679.06	162.462
Sum Sq.Dev.	0.8589	1.899E+24	43678.49	1.96E+16	525089.2	631.937
Observations	372	372	372	372	372	372

$$\Delta LNREN = \delta_0 + \sum_{j=1}^{m} \delta_{1j}\ \Delta LNREN_{t-j} + \sum_{j=1}^{m} \delta_{2j}\ \Delta LNGDP_{t-j} + \sum_{j=0}^{m} \delta_{3j} \Delta LNCAP_{t-j} + \sum_{j=0}^{m} \delta_{4j} \Delta LNLAB_{t-j} + \sum_{j=0}^{m} \delta_{5j} \Delta LNTRAD_{t-j} + \sum_{j=0}^{m} \delta_{6j} \Delta LNFF_{t-j} + \mu_t , \tag{5}$$

$$\Delta LNREN = \delta_0 + \sum_{j=1}^{m} \delta_{1j}\ \Delta LNREN_{t-j} + \sum_{j=1}^{m} \delta_{2j}\ \Delta LNGDP_{t-j} + \sum_{j=0}^{m} \delta_{3j} \Delta LNCAP_{t-j} + \sum_{j=0}^{m} \delta_{4j} \Delta LNLAB_{t-j} + \sum_{j=0}^{m} \delta_{5j} \Delta LNTRAD_{t-j} + \sum_{j=0}^{m} \delta_{6j} \Delta LNFF_{t-j} + \theta ECM_{t-j} + \mu_t . \tag{6}$$

Empirical Estimation and Discussion of Results

DESCRIPTIVE STATISTICS

To initiate the analysis process, this study begins with descriptive statistics (Table 2). For this study, the focus will be on the skewness, kurtosis and the Jarque-Bera, which is important for data investigation.

Skewness helps determine how symmetrical the distribution of a series is around its mean. The variables analysed in a series do not have normal skewness, indicating irregular symmetry. This is evident by looking at the skewness figures in the table for all observed variables. All figures

TABLE 3 Cross Sectional Dependence Test Result

Test	Statistics	d.f	Probability
Breusch - Pagan LM	503.7576	66	0.0000
Pesaran scaled LM	38.10191		0.0000
Pesaran CD	10.33915		0.0000

are greater than zero, indicating positive skewness, meaning all variables have a long right tail. The kurtosis measures the peakedness or flatness of the distribution series. Table 2 shows variable kurtosis values are greater than three, which indicates all data is leptokurtic, meaning that all data used have a peaked distribution, except Labour at 2.85, which is less than three, making it platykurtic, signifying the distribution is flat. Lastly, the Jarque-Bera asserts what is known based on the results from the skewness and the kurtosis test that the variables within the series are not normally distributed. With the Jarque-Bera p-values, all less than the 5% significance level, the study rejects the null hypothesis of a normal distribution.

CROSS SECTIONAL DEPENDENCE TEST

Results for the different panel cross sectional dependence test values and their corresponding probability values are summarised in Table 3.

Results for the different panel cross sectional dependence tests show all values of the variables in the study are significant at a 1% level, thus the study rejects the null hypothesis of cross-sectional independence, implying that there is sufficient cross-sectional dependency amongst variables across all countries sampled. Therefore, the study utilises the Panel ARDL estimation, which, according to Rahman and Alam (2021), accounts for cross sectional heterogeneity through the short term parameter and facilitates both long-run and short-run causality interferences.

UNIT ROOT

Unit root testing is a process where the panel series are analysed for the presence of unit roots or the absence thereof. The raw data is transformed to natural logarithms to convert all the variables to the same scale of measurement and reduce data variation before the test is undertaken. The summary of the result is reported in Table 4.

TABLE 4 Unit Root Test Results

Variables	LLC		IPC	
	Level	First difference	Level	First difference
LNREN	1.26866	−6.27258***	0.808	−8.04046***
LNGDP	0.40545	−3.69849***	2.91997	−5.96292***
LNCAP	−0.98834	−10.7679***	−0.65440	−11.5091***
LNLAB	5.0755	−6.701531***	8.96504	−7.22381***
LNTRAD	−0.94130	−7.562***	−1.64330**	
LNLFF	0.73623	−7.67935***	3.59860	−9.65218***

NOTES Data from WDI (https://databank.worldbank.org/source/world-development-indicators), AFDB (African Development Bank Group 2018) and US Energy Information Administration (EIA) (https://www.eia.gov/);
*, **, *** signify significance at 10%, 5% and 1% levels, respectively.

TABLE 5 Optimal Lag Selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	2179.623	NA	0.029137	13.49150	13.56151	13.51945
1	1694.987	7581.799	$1.49e^{-12}$	−10.20362	−9.713528	−10.00801
2	1826.249	251.9912	$8.29e^{-13}$*	−10.79166*	−9.881484*	−10.42837*

NOTE * indicates lag order selected by the criterion. LR: sequential modified LR test statistic (each test at 5% level). FPE: final prediction error. AIC: Akaike information criterion. SC: Schwarz information criterion. HQ: Hannan-quinn information criterion.

Table 4 indicates that, except for trade (LNTRAD), which showed stationarity at a level for IPC (unit root estimation), all variables gain stationarity only after the first difference for both LLC and IPC.

In conclusion of the unit root test, the series indicates that all variables are integrated of order I(1), except trade, showing integration at level I(0) for IPC, and none are integrated in the order I(2) – these compelling outcomes support the use of Panel ARDL.

The next step is to determine the appropriate optimum lag length for all the variables that would be used in the Panel ARDL estimation. To determine the optimal lag, the study uses the optimal lag selection criteria.

OPTIMAL LAG SELECTION

Having verified that the series has a mixed order of integration, the next step is to test for the best lag length. Table 5 summarises the test of which lag 2 of the Akaike information criterion (AIC) is selected as suitable for the study.

TABLE 6 Panel Cointegration Test

Alternative hypothesis: Common AR coefficients (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	−0.153	0.561	−1.586	0.944
Panel rho-statistic	1.029	0.848	1.949	0.974
Panel PP-statistic	−1.971	0.024	−1.635	0.051
Panel ADF-statistic	−0.018	0.493	−1.327	0.092
Alternative hypothesis: individual AR coefficients (between-dimension)				
			Statistic	Prob.
Group rho-statistic			2.611	0.996
Group PP-statistic			−2.552	0.005
Group ADF-statistic			0.0825	0.533

PANEL COINTEGRATION

The cointegration test is an estimation technique used to determine whether there is a long-run relationship between variables. The cointegration test is the next step in the study to see whether the variables have a long-term relationship. The Pedroni cointegration test is used in the study to arrive at this conclusion. The null hypothesis indicates that cointegration is not present. However, H_0 will not be rejected if the calculated test's probability value is greater than 0.05, indicating that the variables are cointegrated.

The result of the estimation shows that four of the 11 statistical tests, as shown in the results in Table 6, demonstrate that variables used in this study are cointegrated and sustain a long-term relationship. The panel PP-Statistic has a probability of 0.024. The weighted panel PP-Statistic and panel ADF-Statistic are 0.051 and 0.092, respectively. The second category, the group PP-Statistic, denotes 0.005.

This result then allows the Panel ARDL estimation to calculate both the long-run and short-run coefficients for this study.

PANEL AUTOREGRESSIVE DISTRIBUTED LAG (ARDL) TEST

The panel autoregressive distributed lag (ARDL) test is used to estimate the coefficients of the series. Table 7 presents the results of the panel ARDL estimation method. With a fixed lag length of 2 (as suggested after the calculation of the optimal lag length selection as seen in Table 5), renewable energy is the dependent variable, and GDP, investment (gross capital formation), labour, trade, and non-renewable energy represent the explanatory variables.

TABLE 7 Panel Autoregressive Distributed Lag (ARDL) Estimation

Variable	Coefficient	Std. error	t-Statistic	Prob.
Long-term coefficient				
Dependent variable: LNREN				
Variable	Coefficient	Std. error	t-Statistic	Prob.
LNGDP	0.390751***	0.040809	9.575065	0.0000
LNCAP	−0.036041**	0.015963	−2.257802	0.0246
LNLAB	0.790818***	0.047153	16.77116	0.0000
LNTRAD	0.085440***	0.019573	4.365294	0.0000
LNFF	−0.045097***	0.017075	−2.641111	0.0086
C	−18.81223***	0.893510	−21.05431	0.0000
Short-term coefficient				
Dependent variable: LNREN				
Variable	Coefficient	Std. error	t-Statistic	Prob.
COINTEQ01	−0.274415**	0.127533	−2.151712	0.0321
D(LNREN (−1))	0.192044**	0.078912	2.433665	0.0155
D(LNGDP)	0.639329	0.528771	1.209085	0.2275
D(LNGDP(−1))	−0.038969	0.491689	−0.079256	0.9369
D(LNCAP)	−0.080039	0.109792	−0.729009	0.4665
D(LNCAP (−1))	0.090670	0.137234	0.660699	0.5093
D(LNLAB)	−3.063742	3.541251	−0.865158	0.3876
D(LNLAB(−1))	3.089313	2.605469	1.185703	0.2366
D(LNTRAD)	0.048083	0.148343	0.324137	0.7460
D(LNTRAD(−1))	−0.200720	0.171146	−1.172803	0.2417
D(LNFF)	−0.262968	0.169096	−1.555139	0.1209
D(LNFF(−1))	0.002129	0.162873	0.013074	0.9896
C	−0.274415**	0.127533	−2.151712	0.0321
Log-likelihood	272.5414			

NOTE *, **, *** signify significance at 10%, 5% and 1% levels, respectively.

Results observed for the long run show that all coefficients of explanatory variables are statistically significant at 1% to 5%. The variables' parameters all indicate positive signs, except for gross fixed capital formation and non-renewable energy, which have negative signs. This result implies that an increase in the variables will positively impact renewable energy in the long run; meanwhile, an increase in gross capital formation and non-renewable energy harms renewable energy in the long run in the SAPP. These results are similar to those of Sadorsky (2009) and Salim and Rafiq (2012): their results also indicated a positive impact between GDP and renewable energy consumption. While Rasoulinezhad and Saboori (2018) found that trade openness impacted renewable energy consumption positively, Azretbergenova *et al.* (2021) also found that renewable energy has a positive effect on employment in the long run.

On the other hand, gross capital formation (CAP) has a negative and significant effect on renewable energy consumption, pointing to a lack of investment in renewable energy sources. Matei (2017) made a similar discovery. Non-renewable energy consumption's negative impact on renewable energy was identical to that of Omri, Ben Mabrouk, and Sassi-Tmar (2015).

The short-term result yielded some interesting observations. Firstly, the value of the error correction model (ECM) indicated minus 0.274415, and this is denoted as the speed of adjustment, which showed a 5% degree of significance and was correctly signed. This suggests that the convergence speed of equilibrium is 27.4%.

The short-term dynamic model indicates that none of the explanatory variables in the series, i.e. GDP, investment (gross capital formation), labour, trade, and non-renewable energy, have an impact on SAPP renewable energy. This conclusion is realised due to the probability values of the explanatory variables all being above the 10%, 5% and 1% significance levels.

Results from the individual countries' short-term coefficients show that an increase in GDP for Malawi and Zambia causes a rise in these countries' renewable energy, whereas an increase in GCF positively increases renewable energy in the DRC and Eswatini.

Countries such as Malawi and Tanzania (one-year lag (–1)), Mozambique and Lesotho (current) indicated a rise in their labour force, causing renewable energy to increase.

Countries where an increase in their trade caused a rise in their renewable energy included Mozambique (one-year lag (–1)).

Lastly, the Democratic Republic of the Congo (currently) is the only country that exhibits that an increase in their non-renewable energy increased their renewable energy. A summary of the results are presented in Table 8.

Conclusion, Recommendations and Limitations

While there have been numerous studies on the determinants of non-renewable energy consumption, few have considered the determinants of renewable energy consumption. In addition, very little research has been conducted on power pools in the Southern African region. As a result, this article contributes to that field by investigating the factors

TABLE 8 Summary of the Short-term Cross-section Coefficient for Individual countries

Countries	LNGDP	LNCAP	LNLAB	LNTRAD	LNFF
Angola	NS	NS	NS	NS	NS
Botswana	NS	NS	NS	NS	−1.410591**
Democratic Republic of the Congo	NS	0.060098***	NS	−0.070679 **	0.060730***
Eswatini	NS	0.666288***	NS	NS	NS
Lesotho	NS	NS	9.981155**	NS	NS
Mozambique	−0.834675	NS	1.895082*** −1.272986(−1)*	0.426090(−1)**	NS
Malawi	5.236360***	NS	−14.79774*** 10.84552(−1)*	NS	NS
Namibia	NS	NS	NS	NS	NS
South Africa	NS	NS	NS	NS	NS
Tanzania	NS	NS	−37.43503** 28.80026(−1)*	NS	NS
Zambia	0.747934(−1)**	NS	NS	NS	NS
Zimbabwe	NS	NS	NS	NS	NS

NOTES ***, **, * signify 1%, 5% and 10% significance level, respectively. (−1) = one-year lag & NS = Not Significant (for both current and one-year lag (−1)).

that influence renewable energy consumption in the Southern African Power Pool (SAPP) between countries that trade electricity in the region.

The impact of GDP, gross capital formation (investment), labour, trade, and non-renewable energy on renewable energy consumption in SAPP was investigated using the panel ARDL estimation method.

The study aimed to identify various determinants that impact renewable energy within the SAPP, of which the empirical findings suggest that, in the long term, the explanatory variables gross domestic product, renewable energy, labour force and trade all have a positive impact on renewable energy – all except gross capital formation (investments) and non-renewable energy, which harm renewable energy. All coefficients were statistically significant at 1 to 5 percent.

The study also wanted to discover whether the determinants are uniform across the individual countries within the SAPP. The empirical results from the respective countries' short-term coefficients indicated that an increase in GDP increased renewable energy in Angola, Zambia, and Mozambique's GDP with a one-year lag (−1). Similarly, a rise in gross fixed capital formation (investments) increased renewable energy in seven countries in the SAPP. A positive impact of labour on renewable energy was established in the Democratic Republic of the Congo and Mozambique (one-year lag) and the same applies to Zambia's labour (one-year lag). An increase in trade increased renewable energy in Angola and Tanzania. At the same time, current trade impacted renewable energy consumption in three countries. According to the results of Botswana, the Democratic Republic of the Congo, Eswatini and Zambia (one-year lag), when there was an increase in their non-renewable energy, an increase was observed in their renewable energy. This, therefore, indicates differential impact on renewable energy for the individual countries within the SAPP.

This article identified channels that the SAPP could use to promote renewable energy consumption and the impact thereof. Based on these findings, it is recommended that economic policies that accelerate economic growth and development should be implemented, which will enhance renewable energy use.

As a ripple effect through the economy, the acceleration of economic growth will also increase the creation of employment. An increase in labour will result in the rise of renewable energy consumption. Similarly, policies that stimulate trade should be encouraged to increase the switch to renewable energy consumption in the SAPP in the long run.

Centred on the results, since an increase in non-renewables reduces renewable energy consumption, it is logical to infer that the SAPP policies should be targeted at reducing non-renewable energy so that renewable energy may increase.

This study also recommends economic policies that address the growth and expansion of the renewable energy sector, which concurrently finance research and development activities aimed at promoting renewable technologies and related infrastructure to enhance renewable energy sources (Matei 2017). Concerning Gross fixed capital Investment, its negative impact on renewable energy implies that investment toward renewable energy is weak, and therefore this study recommends that policies to encourage investments toward renewable sources should be introduced and advanced.

This study only examined determinants of renewable energy for the period 1988 to 2018 due to the unavailability of data for some countries in the region, and the study also acknowledges that some variables identified in the literature were not included due to the unavailability of data. However, this study is not exhaustive, meaning that it also gives insight into areas of further research.

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