THE IMPACT OF RENEWABLE ENERGY GENERATION ON PRODUCTIVITY IN SELECTED DEVELOPING COUNTRIES

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Abstract

This study is an empirical analysis of the impact of renewable energy generation on productivity in seven countries in the South African Development Community (SADC). The study operationalizes the alternative hypothesis that renewable energy generation exerts an impact on productivity in the SADC from 1990 to 2019. The study contributes to the literature by employing renewable energy generation as the independent variable, and not renewable energy consumption, which is the case in most studies. The empirical analysis was employed using the panel autoregressive distributed lag (ADRL) model (da Silva, Cerqueira, & Ogbe, 2018). It was established that renewable energy generation had a significant and positive impact on productivity, as measured by gross domestic product (GDP), over the long term. Countries should implement policies aimed at increasing electricity generation from renewable energy sources in order to meet the growing demand for electricity. Infrastructure development, skills training, technical support, and a Just Energy Transition should be the primary emphasis of policy initiatives.

Keywords: Renewable Energy Generation, Productivity, SADC, Panel ARDL

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1. INTRODUCTION

There is an increasing body of literature on the relationship between renewable energy generation and productivity (Ali, Adaa, Lin, & Youssouf, 2017; Shahbaz, Loganathan, Zeshan, & Zaman, 2015; Tuna & Tuna, 2019). The general consensus in these studies is that renewable energy is a catalyst for economic growth, poverty eradication, development, and the well-being of citizens. The green economy is perceived as consistent with the broad concept of sustainable development, where the United Nations Environmental Programme (UNEP) defines a green economy as one that results in improved human wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP, 2011). A green economy uses renewable energy to drive industrialization and is derived from the concept of green growth. Green economies are enabled by transitioning to low-carbon emission models that use technologies such as wind, solar, geothermal, and hydroelectric power. Proponents of green growth suggest that a strategic green growth framework delivers higher incomes, creates more jobs, and sustains higher wealth. Investments in green growth sources are required to help increase economic activity and employment, a much-needed action for developing economies that are still characterized by high levels of unemployment. In turn, the investments in green energy sources can have spillover effects to induce productivity growth and therefore ensure long-term growth. Emerging economies like Brazil, China, India, and Indonesia demonstrate this trend.

Renewable energy resources vary in the South African Development Cooperation (SADC) member states. Access to electricity is a major concern in the region, with levels as low as 48% in some countries (REN21, 2018). The demand for energy in SADC continues to grow due to an increase in population growth and a surge in socio-economic activities. SADC is already home to several major energy resource producers, including South Africa and Angola, and these have been joined by emerging producers such as Mozambique and Tanzania. SADC countries are generally endowed with abundant renewable energy potential, which they could harness so that, by 2040, renewables would provide more than 40% of all power generation capacity in the region, varying in scale from large hydropower dams to mini- and off-grid solutions in more remote areas. Although non-hydro renewable energy supply technologies, particularly those based on solar, wind, geothermal, and biomass, are currently small contributors to global heat and electricity supply, they are growing at the fastest rate of any of the technologies. As of 2018, the SADC region had 21,760 megawatss (MW) of installed renewable energy capacity. The share of hydropower was more than 70% (REN21, 2018). Concerning the developments made by all SADC countries, installed capacity has more than doubled in the last decade, from roughly 10,000 in 2000 to more than 22,000 MW in 2019. Renewable energy generation has also more than doubled, from around 35,000 gigawatt-hours (GWh) in 2010 to more than 72,000 GWh in 2019. This represents significant progress toward the 2030 goals. The top five countries in renewable energy generation in the region are Mozambique, Zambia, DRC, Zimbabwe, and Angola. The bottom five countries in renewable energy generation are Botswana, Comoros, Seychelles, Eswatini, and Lesotho. Hydropower has an installed capacity of almost 17,000 MW, while solar energy has an installed capacity of almost 5 500 MW worldwide. Bioenergy is the least significant contributor, with an installed capacity of 761 MW as of 2019.

This study is driven by SADC's need to increase renewable energy use in pursuit of economic growth through increased productivity. The key problem is that energy production in the SADC has historically remained low for decades. According to this constellation of states, there is a predicament that comes with the introduction of efficient technologies (such as energy efficiency technologies and renewable energy generation). Whereas these technologies can increase employment in productive sectors such as oil, gas, and mining, there is also the demand to extend the skill requirements necessary for those jobs that become available (International Labour Office [ILO], 2015). Given this problem, this article strives to answer the following question:

RQ: Is there a relationship between renewable energy generation and productivity?

The objective of the study is consequently designed to investigate the impact of renewable energy generation on productivity in the SADC region. The study operationalizes the alternative hypothesis that renewable energy generation has an impact on productivity in the SADC from 1990 to 2019. The study extends the current body of knowledge in that it focuses on the supply side of renewable energy. Existing literature focuses on the demand side of renewable energy, that is,

renewable energy consumption, rather than the supply side which is renewable energy generation (Akintande, Olubusoye, Adenikinju, & Olanrewaju, 2020; Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016; Cheng, 1999; Lin & Moubarak, 2014). Furthermore, existing literature on renewable energy is drawn from Europe, the United States of America, and South East Asia (Ahmad, Hassan, Abdullah, Rahman, Majid, & Bandi, 2012; Ahmad & Zhao, 2018; Bulut & Menegaki, 2020; Destek, 2017; Rodrik, 2004). The SADC continues to rely heavily on fossil fuels in most industrial sectors. As many countries in the region have argued, they strive to industrialize through the use of low-cost energy sources, to learn from the successful experiences of Western countries during the Industrial Revolution in the 1800s. This study employs the panel autoregressive distributed lag (ARDL) model to examine the relationship between renewable energy generation and productivity in the SADC region. It utilizes a selection of SADC countries that have begun to green their economies. These selected countries are a good representation of the region. The analysis seeks to demonstrate that the changes that have been implemented in this region have had a positive impact on productivity in the global market and that other developing countries could replicate these developments to boost their economies. The study also delves into country-level analysis, which contributes to the development of national strategies, particularly in this era when clean energy is of current interest in international fora. SADC governments are faced with a dilemma of how quickly to adopt and transition to clean energy technologies, knowing the impact of these technologies on productivity and economic growth in policy formulation.

Studies on renewable energy in SADC are scarce. The majority of such studies have concentrated on developed countries and emerging markets outside of Africa (Li & Lin, 2017; Lin & Moubarak, 2014; Zhou, Ang, & Zhou, 2012). In the SADC, there is a gap in the literature, notably the thorough analyses derived from panel data and incorporating all renewable energy sources. The researcher confirmed that studies either employ a single source of energy as the renewable energy dependent variable or use cross-sectional data where only one country is examined (Ozturk & Bilgili, 2015; Phiri & Nyoni, 2016; Solarin & Shahbaz, 2013). To the best of the researcher's knowledge, the growing body of literature has concentrated on single-country assessments. In the SADC, there is a gap in the literature on renewable energy generation. The main dependent variable in most studies on the relationship between renewable energy and growth in renewable energy consumption (Al-mulali & Binti Che Sab, 2012; Odhiambo, 2009). The main dependent variable in this study is renewable energy generation, in contrast to renewable energy consumption, which is directed at consumers, our strategy is directed at policymakers responsible for the inception of renewable energy generation. As a result, policymakers must be well informed when deciding which energy sources to develop in their economies. Furthermore, this study integrates political instability which is not commonly recognized in similar studies as a variable exerting an impact on renewable energy generation.

It is critical to have evidence-based studies on renewable energy generation to encourage supply-side policies that bolster energy resources in developing countries. Because the economic characteristics of SADC differ from those of developed and emerging nations, it is difficult to create policy objectives based on evidence from developed and emerging countries. This research makes a significant contribution to the body of information that could be used to propose solutions for developing countries. According to the findings of this study, the relationship between renewable energy generation and economic growth is statistically significant in the SADC region.

This study is organized as follows. Section 2 reviews the relevant literature on renewable energy generation and productivity. Section 3 analyses the methods used to conduct empirical research. Section 4 presents the results of the study, Section 5 presents a discussion of the research findings and lastly, Section 6 provides the conclusion.

2. LITERATURE REVIEW

2.1. Theoretical literature

The terms "*green growth*" and "*green industrialization*" are now keywords in global economic policy debates and discourses. While neoclassical growth models explain growth without incorporating energy, most recent growth models show that energy is a significant driver of economic growth and that technological progress may boost productivity by allowing for additional energy consumption (Matei, 2017). Economic growth is linked to a variety of environmental problems, ranging from resource depletion to climate change. Several researchers have explained the theoretical basis for the claim that growth can be green. Holdren and Ehrlich (1974) established the explanatory identity $I = PCT$ to establish this link, where I represents environmental effect, P represents the population, C represents consumption, and T represents the productivity of technology about environmental use. If the population grows and consumption rises (as a result of economic expansion), environmental impact surely increases unless the rate of technological advancement is fast enough to keep pace with the growth (Holdren & Ehrlich, 1974).

The environmental Kuznets curve (EKC) hypothesis emphasizes the relationship between environmental degradation and economic growth. The assumption that environmental degradation and economic growth exhibit an inverted U-shaped curve was first introduced in literature by (Grossman & Krueger, 1991). It is predicted under the EKC hypothesis that environmental deterioration occurs during the early phases of economic development up to a certain degree and that the process of economic development will eventually restrict the environmental degradation induced during the early stages of development (Kaika & Zervas, 2013). This is attributed to factors such as growing public awareness of environmental degradation. According to early 1990s experts, any economy's objective should be growth, and any environmental issues would be addressed as a byproduct of economic expansion (Panayotou, 1993; Shafik & Bandyopadhyay,

1992). The EKC relationship is influenced by a variety of factors, including per capita income, international trade, structural changes, renewable energy generation, technical progress, and increases in energy efficiency. The income elasticity of demand for environmental improvement validates the EKC hypothesis, depending on a country's economic development.

2.2. Empirical literature

There has been an influx of renewable energy studies, particularly in the last decade, as a result of the global sustainable development agenda that seeks to address climate change (Bayraktutan, Yilgor, & Ucak, 2011; Kazar & Kazar, 2014; Noronha, Zanini, & Souza, 2019; Odhiambo, 2010; Phiri & Nyoni, 2016; Singh, Nyuur, & Richmond, 2019; Yang & Kim, 2020). These studies apply different analyses, including the nexus of renewable energy, food, and water, the causal relationship between renewable energy and economic growth, comparisons of the benefits of renewable energy and non-renewable energy, renewable energy consumption and trade, and renewable energy consumption and job creation.

The relationship between renewable energy generation and economic growth and productivity has been rarely studied; rather studies concentrate on the relationship between renewable energy consumption and economic growth. The crucial question in most studies relates to whether renewable electricity generation affects economic growth or whether economic growth increases the renewable electricity generated. Bulut and Menegaki (2020) investigated the relationship between solar energy production and economic growth in 10 countries with the highest installed solar energy production capacity as of 2017 (China, the USA, Japan, Germany, Italy, India, the UK, France, Australia, and Spain, respectively). The researchers employed panel cointegration and causality methods and found that the coefficient of solar energy is insignificant in the empirical model and that there is no causality between solar energy and GDP.

Singh, Nyuur, and Richmond (2019) conducted a similar study in which they examined relationships between renewable energy generation and economic growth and the differential impact on not only developed countries but also on developing countries in Europe and Asia. The study applied the fully modified ordinary least square (FM-OLS) regression model to a sample of ten developed and ten developing countries for the period 1995–2016. The results of the study show that renewable energy generation is associated with a positive and statistically significant impact on economic growth in both developed and developing countries. A study by Azam, Rafiq, Shafique, and Yuan (2021) analyzed the relationship between renewable energy generation and economic growth in a panel of 25 developing countries using the panel ARDL approach. The main finding predicted a positive and significant relationship between renewable energy generation and economic growth.

Qudrat-Ullah and Nevo (2021) used panel data, for thirty-seven African countries, and employed the system generalized method of moments estimation technique to analyze the impact of renewable energy consumption and environmental

sustainability on economic growth in Africa. According to the study, renewable energy adoption and development will lead to an increase in economic growth in Africa, both in the long run and short run.

Noronha et al. (2019) analyzed the relationship between renewable energy generation, non-renewable energy generation, and economic growth in Brazil from 2009 to 2017. It employed the vector autoregressive (VAR) and autoregressive distributed lag (ARDL) methodologies. The study established, through the modification of the ARDL model, that socioeconomic characteristics have a long-term impact on electricity production variables, both renewable and non-renewable.

In a study by Yang and Kim (2020), the researchers introduced a new hypothesis to the renewable energy growth nexus. The study investigated the role of the renewable manufacturing industry in contrast to renewable energy generation studies, based on sales volume and revenue. The results showed that renewable electricity Granger causes economic growth in target countries. An increase in the manufacturing of renewable energy technologies proved to cause economic growth.

In contrast to the scarce literature on renewable energy generation, a lot of studies have been conducted on the relationship between renewable energy consumption (REC) and economic growth. Most of these studies have focused on developed countries and emerging economies. Apergis and Payne (2010a, 2010b), Bowden and Payne (2010), and Menegaki (2011) carried out studies in which they concentrated on growth and renewable energy consumption in developed countries. Most of these studies confirm bidirectional long tern causality between renewable energy consumption and economic growth.

In the African context, renewable energy studies also focus on renewable energy consumption rather than renewable energy generation (Amusa & Leshoro, 2013; Odhiambo, 2010; Ozturk & Bilgili, 2015; Phiri & Nyoni, 2016; Solarin & Shahbaz, 2013). All of the studies verified causality between electricity consumption and economic growth.

It is critical to have evidence-based studies on renewable energy generation to encourage supply-side policies for renewable energy resources in developing countries. In light of the fact that the economic characteristics of SADC differ from those of developed and emerging nations, it is difficult to create policy objectives based on evidence from developed and emerging countries. This research makes a significant contribution to the body of information that could be used to propose solutions for developing countries.

3. METHODOLOGY

3.1. Conceptual framework

Historically, neoclassical economic growth models in developed countries have been based on capital, labor, and technological progress. The Cobb–Douglas production function is a popular approximation of actual production that is used to develop the model in this study. Estimating and analyzing the linkages between renewable energy generation (REG) and

productivity provides information to governments to make appropriate environmental policies such as pollution and energy taxes by incorporating REG into the production function (Salim, Hassan, & Shafiei, 2014).

The standard production function approach is as follows:

$$Y = f(L, K) \qquad (1)$$

where, Y is the quantity of output measured in the real GDP; L is the quantity of labor used measured in total employment, and K is the quantity of capital employed, measured in real gross fixed capital.

We analyze the impact of renewable energy generation on productivity by directly including renewable energy generation into the production function, assuming that there is a direct effect of energy generation on economic output (Bowden & Payne, 2009; Oh & Lee, 2004). Gross fixed capital formation is used as a proxy for capital. We also add carbon emissions, population growth, and political rights index, variables that may affect output in equation (2):

$$Y_{it} = f(REG_{it}, CE_{it}, GFCF_{it}, PG_{it}, PRI_{it}) \qquad (2)$$

3.2. The panel autoregressive distributed lag model

The panel autoregressive distributed lag (ARDL) model is based on three different estimators, namely, the Mean Group (MG) estimator, pooled mean group estimator (PMG), and dynamic fixed effects (DFE). The MG approach estimates and separates equations for each country and computes the coefficient means, thereby providing consistent estimates of the average of the coefficients (Pesaran & Smith, 1995). This approach does not assume any restriction and it takes into consideration the fact that coefficients can vary and be heterogeneous in the long run and short run. The MG approach assumes a large time-series dimension of data and therefore is not suitable for the dataset in this study. It also neglects the fact that certain coefficients may be homogenous across countries. The DFE estimator is similar to the PMG estimator. It forces limitations on the slope coefficient and error variances to be equivalent across countries in the long run. The DFE further restricts the short-run coefficients and the speed of adjustment coefficients to be homogeneous. The model, however, features country-specific intercepts and has a cluster option to estimate the intragroup correlation with the standard error (Blackburne & Frank, 2007).

The PMG estimator was proposed by Pesaran, Shin, and Smith (1999). It is an intermediate estimator between the MG and the DFE. The PMG estimator constrains the long-run coefficients to be homogeneous and allows the short-run coefficients, error correction terms, intercepts, and error variances to differ freely across groups. It generates consistent estimates of the mean of the short-run coefficients by taking the simple average of individual unit coefficients. In this study, we used the Hausman test whose results support the appropriateness of the PMG test. Furthermore, the countries in this study all have renewable energy generation potential given the vast sources of renewable energy. Hence, the expectation is that

there is a long-run equilibrium relationship across countries. The PMG model assumes that the subsequent residual of the error correction model must be serially uncorrelated, and the explanatory variables can be dealt with as exogenous. Such conditions can be satisfied by including the ARDL (*p*, *q*) lags for the dependent (*p*) and independent variables (*q*) in the error correction form.

An alternative method to conducting the research is the use of the generalised method of moments (GMM) estimator proposed by Arellano and Bover (1995), and Blundell and Bond (1998). The GMM system allows for solving econometric problems such as serial correlation, and the endogeneity of independent variables.

We apply the PMG model to examine the relationship between renewable energy generation and productivity in the SADC region from 1990 to 2019. The countries covered are The Democratic Republic of the Congo (DRC), Eswatini, Mozambique, Namibia, South Africa, Tanzania, and Zimbabwe. The choice of countries was because data available for these countries remained consistent from 1990 to 2019. These countries are good representatives of

the SADC region as they share socioeconomic factors with other countries that were not chosen.

The variables in the study are renewable energy generation (*REG*), carbon emissions (*CE*), gross fixed capital formation (*GFCF*), population growth (*PG*), and political rights index (*PRI*). Renewable energy generation is the main independent variable for this analysis. The variable *REG* consists of total renewable electricity generation in gigawatt hours for each country. Renewable energy sources included are solar, wind, biomass, and hydropower. The carbon emissions (*CE*) variable is measured by kilograms per 2010 United States dollars of GDP. We use gross fixed capital formation (*GFCF*) as a proxy for capital. The measure for GFCF in this study is constant at 2010 US dollars. Population growth (*PG*) is measured by the annual percentage growth for each country. The political rights index (PRI) is used as a proxy for political stability. Data for REG was sourced from International Renewable Energy Agency (IRENA). Data for GFCF, CE, and PG were as sourced from World Bank (World Development Indicators, WDI), while data for PRI was sourced from *The Freedom House.*

Table 1. Variable descriptions, units of measurement, sources, and expected signs

Variable	Variable name	Unit measurement	Source	Expected sign
REG	Renewable energy generation	Gigawatt-hours	International Renewable Energy Agency	+
GFCF	Gross fixed capital formation	United States dollars	World Bank (WDI)	+
CE	Carbon emissions	KG per 2010 US$ of GDP	World Bank (WDI)	+/–
PG	Population growth	Annual percentage	World Bank (WDI)	+/–
PRI	Political rights index	Index (7 – weak, 1 – strong)	The Freedom House	–

3.3. Model specification

As noted in subsection 3.1, we analyze the impact of renewable energy generation on economic growth by directly including renewable energy generation into the production function in equation (1), assuming that there is a direct effect of energy generation on economic output (Bowden & Payne, 2009; Oh & Lee, 2004):

$$Y_{it} = f(REG_{it}, CE_{it}, \quad GFCF_{it}, PG_{it}, PRI_{it}) \quad (3)$$

Equation (3) is derived from the theory of the Cobb–Douglas production function. *Y* is the dependent variable that represents GDP, while *REG*, *CE*, *GFCF*, *PG*, and *PRI* are independent variables. The index *i* refers to each country in the panel and *t* refers to the time period. There exists a confirmed relationship between renewable energy and GDP as postulated by Chien and Hu (2008). According to the Cobb–Douglas function, the impact of renewable energy generation and other explanatory variables on GDP can be estimated using the following equation:

$$ln\,GDP_{it} = \beta_0 + \beta_1 lnREG_{it} + \beta_2 lnCE_{it} + \beta_3 lnGFCF_{it} + \beta_4 lnPG_{it} + \beta_5 lnPRI_{it} + \varepsilon_{it} \quad (4)$$

Equation (4) represents the fundamental model of this study in log-linear form. The equation assumes that gross fixed capital formation, renewable energy generation, energy imports, and carbon emissions are the driving forces of productivity.

To examine the long-run and short-run relationship between variables, we applied the panel autoregressive distributed lag (ARDL) model based on the pooled mean group (PMG) estimator. The panel ARDL model was developed by Pesaran et al. (1999) and amended by Pesaran, Shin, and Smith (2001). Advantages of panel ARDL are as follows: the panel ARDL estimation technique deals

with the stationarity problem of different orders of integration, that is, it can be used where variables have mixed order of integration, such as I(0), I(1) or both, but not I(2); the model generates logical and strong results in both the short-run and long-run relationship between the exogenous and endogenous variables; the technique produces unbiased estimates even in the presence of endogenous covariates; it is effective even if the variables have different optimal lag lengths; panel ARDL is applicable to small sample sizes.

The empirical long-run model is specified as follows:

$$lnGDP_{it} = \sum_{j=1}^{p} \lambda_{ij} GDP_{i,t-j} + \sum_{j=0}^{q} \beta_{1ij} REG_{i,t-j} + \sum_{j=0}^{q} \beta_{2ij} CE_{i,t-j} + \sum_{j=0}^{q} \beta_{3ij} GFCF_{i,t-j} +$$
$$\sum_{j=0}^{q} \beta_{4ij} PG_{i,t-j} + \sum_{j=0}^{q} \beta_{5ij} PRI_{i,t-j} + \mu_i + \varepsilon_{it} \quad (5)$$

where, $i = 1, 2, \ldots 7$ is the number of cross-section units and $t = 1990, 1991, \ldots 2019$; λ_{ij} is a scalar; β represents the short run coefficients; μ_i is a group of specific effects and ε_{it} is the "error term".

Cointegrated variables react to any deviation from long-run equilibrium, implying an error correction model. This occurs when the short-run dynamics of the system's variables are influenced by the deviation from equilibrium. Equation (6) is the reparametrized short-run ARDL model that we follow:

$$\Delta GDP_{it} = \lambda_i \left[GDP_{i,t-j} - \vartheta_i X_{it} \right] + \sum_{j=1}^{p-1} \beta_{1j} \Delta GDP_{i,t-j} + \sum_{j=1}^{q-1} \beta_{2j} \Delta REG_{i,t-j} + \sum_{j=1}^{q-1} \beta_{3j} \Delta CE_{i,t-j} +$$
$$\sum_{j=1}^{q-1} \beta_{4j} \Delta GFCF_{i,t-j} + \sum_{j=1}^{q-1} \beta_{5j} \Delta PG_{i,t-j} + \sum_{j=1}^{q-1} \beta_{6j} \Delta PRI_{i,t-j} + \mu_i + \epsilon_{it} \tag{6}$$

where, λ is the error correction term that shows the speed at which the economic conditions should change to reach the long-run equilibrium. The negative sign is expected to show the long-run association and where there is a positive sign that means there is no cointegration to long-run equilibrium indicating that for that country the model would be explosive. X_{it} represents a matrix of observations on the regressors that vary across both groups and time periods (Pesaran et al., 1999). The number of cross-section units $i = 1, 2, \ldots 5$ and $t = 1990, 1991, \ldots, 2019$; $\beta_{1j} \ldots \beta_{6j}$ are the short run coefficients; ϑ is a scalar; μ_i is a group of specific effect.

3.4. Estimation procedures

We begin the estimation procedures by employing descriptive statistics followed by correlation analysis. This is followed by panel unit root testing, lag length selection criteria, cointegration tests, Hausman test, panel ARDL and a discussion on why we chose the pooled mean group estimator. We carry out estimation diagnostic tests for validating the model employed. We test the variables for unit roots using the Im–Pesaran–Shin (IPS). Im, Pesaran, and Shin (2003) panel unit root test and the Fisher type test by Maddala and Wu (1999) and Choi (2001). We specify the Akaike information criteria (AIC) to determine the optimal lag length.

The stationarity tests confirmed that some variables are stationary I(0) while others are integrated of order I(1); we, therefore, carried out cointegration tests. To ensure the broad applicability of any panel cointegration test, it is important to allow for as much heterogeneity as possible among the individual members of the panel (Pedroni, 2004). Two main tests were carried out, the Pedroni cointegration test and the Kao residual cointegration test. To test for the suitable panel regression model between the mean group (MG) and the pooled mean group (PMG) we used the Hausman test. The null hypothesis (H_0) is that there is a long-run homogeneity restriction which is tested against the alternative hypothesis. The results support the appropriateness of the PMG test. The PMG estimator was proposed by Pesaran et al. (1999). The PMG model assumes that the error correction model's subsequent residual must be serially uncorrelated and that the explanatory variables can be treated as exogenous. Such conditions can be met by incorporating the ARDL (*p, q*) lags for the dependent (*p*) and independent (*q*) variables in error correction form. A large *T* and *N* are required by the PMG estimator as this allows for the use of the dynamic panel method, which reduces the likelihood of biased average estimators and resolves the issue of heterogeneity. In this study, we have a heterogeneous panel with large *T* = 30 and small *N* = 7.

To check the reliability of the PARDL, three main diagnostic tests were utilized. The Breusch–Pagan LM test was used to test for cross-sectional dependence (Breusch & Pagan, 1980), while the cross-sectional dependence test by Pesaran (2004) was utilized to check for cross-sectional dependency among countries due to unnoticed common shocks or model misspecification that become part of the error terms. To test for serial correlation, we used the tests for autocorrelation by Wooldridge (2002).

4. RESULTS

4.1. Descriptive statistics

The descriptive statistics in Table 2 are discussed in this segment of the article. GDP, the dependent variable, shows a minimum of US$2.3 billion and a maximum of US$430 billion for all of the countries in the panel. The highest GDP was recorded in South Africa in 2018. South Africa had the highest real GDP in SADC in 2018 (World Bank, 2019), and this could potentially explain this conclusion. In 1990, the lowest GDP value on record. Eswatini and South Africa both had the lowest renewable energy generation of 150 GWh in 1990 and 1993, respectively. In the first three years investigated in this study, Namibia had no data on renewable energy generation. Eswatini does, however, create biomass energy, but it is insufficient to meet demand, thus the country imports electricity from South Africa's state-owned enterprise, *Eskom*. Mozambique generated the most renewable energy in 2019, with a total of 20290 GWh. This is due to Mozambique's Cahora Bassa hydroelectric power facility, which is one of the largest in Southern Africa. In 2017/2018, South Africa imported the least amount of power, but it also imported the most in 2007. South Africa experienced consistent load shedding for the first time in the same year.

GDP, renewable energy generation, and carbon emissions have a positive skewness, while gross fixed capital formation, population growth, and political rights index are negatively skewed. The skewness of the variables indicates that the data is asymmetric, meaning that most of the higher values on the right of the distribution are higher than the mean for those with positive skewness and vice versa. All the variables have positive kurtosis values, indicating that they form peaked distributions. This implies leptokurtic distribution where there are higher values in the vicinity of the mean.

Table 2. Descriptive statistics for all variables

Variable	GDP (billion USD)	REG (GWh)	CE (kg/2010 USD of GDP)	GFCF (biliion USD)	POP GROWTH (%)	PRI
Mean	58	3938.12	0.45	91.38	2.14	4.4
Std. dev.	112	4356.04	0.36	53.44	0.92	1.95
Minimum	2.34	0	0.06	1	0.23	1
Maximum	430	20290	1.33	177	4.01	7
Skewness	2.3	1.61	1.01	-0.13	-0.2	-0.16
Kurtosis	6.7	4.95	2.49	1.7	2.03	1.62
Observations	210	209	209	207	210	210

Source: Authors' estimation results from Stata 15.1.
Note: Skewness and Kurtosis values are not measured in the indicated units.

4.2. Correlation analysis

Table 3 shows the correlation analysis results. A careful look into the relationships between independent variables shows that there is a weak correlation among them and this translates into the fact that the data does not pose a problem of multicollinearity, where one explanatory variable can give a linear prediction of the other during the estimation process.

Table 3. Correlation matrix

Variable	LOGGDP	LOGREG	LOGGFCF	LOGPG	LOGCE	PRI
LOGGDP	1					
LOGREG	0.303	1				
LOGGFCF	0.888	0.129	1			
LOGPG	0.052	0.168	0.224	1		
LOGCE	0.455	-0.06	0.297	-0.445	1	
PRI	-0.477	0.026	-0.479	-0.197	-0.372	1

Source: Authors' estimation results from Stata 15.1.

4.3. Stationarity test results

The results of the unit root tests for the variables used in the panel ARDL model are summarized in Tables 4 and 5. The unit root test results in Table 4 give a mix of orders of integration that are at levels and first difference which led to the use of panel ARDL instead of traditional panel data methods. Table 5 reports the Fisher ADF unit root test results which investigates the hypothesis that all panels are stationary, that is, panels contain unit roots against the alternative hypothesis that at least one panel is stationary. The same decision as derived from the IPS unit root test results can be made since these variables show the same levels of stationarity in both the mean and the time trend. However, the political rights index (PRI), failed to reject the null hypothesis that all panels contain unit roots at levels but at first differencing. The IPS and Fisher ADF unit root tests both agree on the direction of the model since they all confirm mixed orders of integration. The next section discusses the optimal lag length that determines the model.

Table 4. Im–Pesaran–Shin (IPS) unit root test results

Variable	Intercept		Intercept and trend		Order of integration
	Statistics	P-value	Statistics	P-value	
LOGGDP	-4.7403	0.0000***	-3.1226	0.0009***	l(1) stationary
LOGREG	-6.3617	0.0000***	-5.0297	0.0000***	l(1) stationary
LOGGFCF	-5.3324	0.0000***	-5.0057	0.0000***	l(1) stationary
LOGPG	-12.7811	0.0000***	-12.6992	0.0000***	l(0) stationary
LOGCE	-1.9781	0.00240***	-2.5519	0.0054***	l(0) stationary

Source: Authors' estimation results from Stata 15.1.
*Note: ***, **, * mean 1%, 5%, 10% level of significance. PRI was omitted because it provides an "insufficient number of time periods to compute W-T-bar statistic".*

Table 5. Fisher ADF unit root test results

Variable	Intercept		Intercept and trend		Order of integration
	Statistics	P-value	Statistics	P-value	
LOGGDP	56.7501	0.0000***	42.2764	0.0001***	l(1) stationary
LOGREG	86.2395	0.0000***	67.2986	0.0000***	l(1) stationary
LOGGFCF	68.5449	0.0000***	65.4914	0.0000***	l(1) stationary
LOGPG	226.4078	0.0000***	233.0828	0.0000***	l(0) stationary
LOGCE	32.6875	0.0032***	34.9422	0.0015***	l(0) stationary
PRI	66.0241	0.0000***	53.5397	0.0000***	l(1) stationary

Source: Authors' estimation results from Stata 15.1.
*Note: ***, **, * denote significance at 1%, 5% and 10%, respectively.*

4.4. Lag length selection criteria

Table 6 shows the optimal lags used in the panel ARDL model. The model used ARDL (1, 0, 1, 0, 0, 0) model specification during estimation.

Table 6. Lag length selection criteria results

Variable	Lag
LOGGDP	1
LOGREG	0
LOGGFCF	1
LOGPG	0
LOGCE	0
PRI	0

4.5. Lag length selection criteria

Results of the Pedroni panel cointegration test are presented in Table 7. Two of the three statistics reject the null hypothesis that there is no cointegration at 1% and 10% levels of statistical significance respectively. The ADF statistic is the only one that fails to reject the null hypothesis of no cointegration. Overall, because the majority of the statistics reject the null hypothesis, ascertaining that all the panels are cointegrated, there is an error-correcting pattern in GDP, renewable energy generation, gross fixed capital formation, carbon emissions, population growth rate, and the political rights index.

Table 7. Summary of Pedroni cointegration test results

Pedroni test for cointegration	Statistics	P-value
Modified Phillips-Perron	2.7759	0.0028***
Phillips-Perron	1.4022	0.0804*
Augmented Dickey-Fuller	1.1124	0.1330

Source: Authors' estimation results from Stata 15.1.
*Note: *** means 1% level of significance; ** means 5% level of significance; * means 10% level of significance.*

Results of the Kao cointegration test are presented in Table 8. Modified Dickey–Fuller (DF) tests reject the null hypothesis of no cointegration at 1%, while DF and augmented DF do so at 10% each. The unadjusted statistics failed to reject the null hypothesis (H_0) of no cointegration since the majority of the statistics are significant and supported by Kao (1999). Based on these results, we conclude that there is a strong cointegration between the productivity in selected SADC countries and renewable energy generation, gross fixed capital formation, carbon emissions, population growth, and the political rights index.

Table 8. Summary of Kao cointegration test results

Kao test for cointegration	Statistics	P-value
Modified Dickey-Fuller	-1.8413	0.0328**
Dickey-Fuller	-1.4717	0.0706*
Augmented Dickey-Fuller	-1.2830	0.0998*
Unadjusted modified Dickey-Fuller	-0.7932	0.2138
Unadjusted Dickey-Fuller	-1.0183	0.1543

Source: Authors' estimation results from Stata 15.1.
*Note: ***, **, * mean 1%, 5%, and 10% level of significance.*

5. DISCUSSION

5.1. Long-run and short-run coefficients: Panel autoregressive distributed lag model (ARDL)

The PMG model results for both the short-run and the long-run are presented in Table 9. Looking at the significance of the long-run coefficients, there is cointegration among variables. The panel autoregressive distributed lag (ARDL) approach has been employed to estimate the PMG model. Because the PMG model assumes long-run homogeneity — that the long-run coefficients are the same — cointegration is ascertained from these coefficients and the error correction term (ECT). The short-run estimates are assumed to be heterogeneous.

Table 9 depicts a positive relationship between renewable energy generation and productivity in selected SADC countries. A one percent change in renewable energy generation would increase SADC GDP by an average of 0.18% in the long-run, *ceteris paribus*. This is consistent with the correlation established earlier between the two variables and also in line with expectations of the outcomes of this study. It is therefore evident that, according to the results from this model, renewable energy generation enhances growth in GDP in the SADC region in the long run. Therefore, regional efforts such as the SADC Centre for Renewable Energy and Energy Efficiency (SACREEE) mandated to make a significant contribution to the growth of regional renewable energy markets (SADC & SARDC, 2018), should result in positive economic outcomes were they to successfully implement the use of renewable energy.

A one percent increase in gross fixed capital formation would lead to an average of 0.58% increase in GDP at a one percent level of significance, in the long-run, *ceteris paribus*. A one percent increase in population growth rate reduces GDP in SADC by an average of 0.44% in the long run, holding other factors constant. A one percent increase in carbon emissions would lead to a decrease in GDP by an average of 0.22% in the long run, significant at a one percent level of statistical significance, *ceteris paribus*. A one-unit increase in the political rights index is associated with an average of 0.12 units decrease in the level of productivity, in the long run.

Short-run dynamics were established and results are presented in Table 10, to understand how country-level short-run shocks affect long-run relationships. In this case, any deviations from a long-run equilibrium after a shock in the short-run are corrected at different adjustment speeds for each country where the error correction term is significant. The results depict the adjustment speeds as follows: DRC (13.9%), Eswatini (3.2%), Mozambique (1.4%), Namibia (0.04%), South Africa (0.09%), Tanzania (0.7%) and lastly Zimbabwe (5.7%). In the short run, renewable energy generation (LOGREG) showed a short-run causality with GDP that is statistically significant only in DRC, at a 5% level of significance. A one per cent increase in renewable energy generation decreases GDP by an average of 0.018% in the short run, holding other factors constant. We conclude that this is understandable in the short run because we do not expect renewable energy generation to yield

productivity benefits in the short run simply because economies are still transitioning and using resources to develop sectors along the value chain that could be distracted by the decarbonization process. The impact of gross fixed capital formation on GDP is negative and statistically significant in DRC but positive and significant in Namibia, South Africa, and Tanzania. Hence, we generally conclude that in the short-run, investment correlates with productivity. The population growth rate (*LOGPG*) short-run coefficient is positive and statistically significant in Eswatini and Zimbabwe but negative yet weakly significant in Mozambique and Tanzania at 10%. Carbon emissions (*LOGCE*) are negatively related to GDP and are statistically significant at 1%

in three countries: DRC, Namibia, and Tanzania but significant at 10% in South Africa. Finally, the political rights index (*LOGPRI*) coefficient is only significant in DRC at a 10% level of significance while insignificant in the rest of the countries in the panel. A unit increase in the political rights index leads to an increase in GDP by an average of 0.118 units in the short run.

The negative sign for the error correction term indicates the presence of the long-run association between independent variables and the dependent variable. With a coefficient of -0.049, this means that any deviation from the long-run equilibrium following a shock in productivity is corrected at a 4.9% adjustment speed.

Table 9. Summary of long run and pooled mean group (PMG) estimation model (1, 0, 1, 0, 0, 0)

Explanatory variable	Coefficient	Standard error	Z-statistic	P-value
LOGREG	0.1776909	0.0961882	1.85	0.065*
LOGGFCF	0.5765953	0.0476821	12.09	0.000***
LOGPG	-0.4433531	0.1003025	-4.42	0.000***
LOGCE	-0.2175352	0.1367213	-1.59	0.112
PRI	-0.1245366	0.0373813	-3.33	0.001***

Source: Authors' estimation results from Stata 15.1.
*Note: Dependent variable: LOGGDP. ***, **, * mean 1%, 5%, and 10% level of significance. The optimal lag lengths are selected by AIC information criteria.*

Table 10. Summary of short run and pooled mean group (PMG) estimation model (1, 0, 1, 0, 0, 0)

Lagged variables	DRC	Eswatini	Mozambique	Namibia	South Africa	Tanzania	Zimbabwe
△LOGREG (0)	-0.018 (0.057)**	0.003 (0.859)	0.012 (0.587)	0.000 (0.977)	0.001 (0.752)	0.003 (0.723)	-0.010 (0.853)
△LOGGFCF (1)	-0.076 (0.005)***	-0.021 (0.207)	-0.022 (0.742)	0.085 (0.001)***	0.233 (0.000)***	0.094 (0.001)***	-0.017 (0.392)
△LOGPG (0)	-0.126 0.137	0.063 (0.001)***	-0.089 (0.035)*	0.066 (0.540)	-0.002 (0.974)	-0.12 (0.040)**	0.222 (0.008)***
△LOGCE (0)	-0.065 (0.004)***	0.010 (0.449)	-0.063 (0.178)	-0.206 (0.000)***	-0.097 (0.072)*	0.048 (0.007)***	-0.039 -0.780
△PRI (0)	0.009 (0.037)**	0.009 (0.125)	0.003 (0.443)	-0.011 (0.227)	0.0008 (0.647)	0.003 (0.301)	0.008 (0.452)
ECT (-1)	-0.139 (0.000)***	-0.032 (0.001)***	-0.014 (0.285)	-0.0009 (0.932)	-0.007 (0.246)	-0.057 (0.049)**	-0.173 (0.000)***

Source: Authors' estimation results from Stata 15.1.
*Note: The significant corresponding p-values are presented in parentheses. ***, **, * mean 1%, 5%, and 10% level of significance.*

5.2. Diagnostics tests

Table 11 shows the summary results from the tests of heteroskedasticity, autocorrelation, and cross-sectional dependence across the general sample of seven countries under study. Results show that

the model does not suffer from heteroskedasticity. Wooldridge's test for autocorrelation ascertains that there is no serial autocorrelation. The Pesaran cross-sectional dependence test result shows that there is no cross-sectional dependency between countries in the region.

Table 11. Summary of diagnostic tests

Problem	Test	Statistic	P-value	Decision
Heteroskedasticity	Breusch-Pagan: H_a: Homoskedasticity	Chi-square = 85.58	0.175	Reject H_0
Autocorrelation	Wooldridge: H_a: No first-order autocorrelation	F(1, 6) = 27.542	0.231	Fail to reject H_0
Cross-sectional dependence	Pesaran CD: H_a: No cross-sectional dependence.	PCSD = 5.280	0.306	Reject H_0

Source: Authors' estimation results from Stata 15.1.

6. CONCLUSION

The objective of the study was to examine the impact of renewable energy generation on productivity in selected SADC countries over the period from 1990 to 2019 using the panel ARDL model. A derivative from the findings confirms that the relationship between renewable energy generation and economic growth is statistically

significant in the SADC region. In the long run, a one percent increase in renewable energy generation would increase SADC gross domestic product by an average of 0.18% assuming that all other factors remain constant. The results confirm the expectation that renewable energy generation should boost GDP growth in the SADC region if the region successfully implements the use of clean energy technologies. According to a large body of literature,

increasing renewable energy generation and consumption has a positive impact on economic growth. These findings are consistent with what this study generated.

Key findings demonstrate that renewable energy generation initiatives are important. It is critical for governments to address the obstacles that renewable energy generation initiatives from succeeding. Taking into consideration the significant finding of increased economic growth associated with renewable energy generation, SADC countries should implement policies aimed at increasing electricity generation from renewable energy sources to meet the growing electricity demand. With the depletion of fossil fuels and the fluctuating value of speculative commodities, countries have been forced to look for alternative sources of power. The use of renewable energy sources for electricity generation must be increased, with both private and public stakeholders playing important roles in the transitioning process. It is possible to put into effect the policy recommendations made here.

Furthermore, governments should focus on reducing bureaucratic red tape to make doing business in their countries easier. In the face of the COVID-19 pandemic, the results of this study prove that economies must focus on a green recovery. A Just Energy Transition, however, is important to ensure that the interests of those who would be affected are taken into consideration by policymakers. This helps to prevent the emergence of new forms of poverty and inequality, such as in the coal mining industry's supply chain. We recommend that, as governments work to achieve their green energy objectives, they take steps to address the employment issues that inevitably arise as a result of these efforts. Policies can be put in place to reskill employees and provide them with professional training so that they can remain relevant in the production of new energy-related technologies in the future. In order to address the unemployment problem, appropriate labor policies must be put in place first. Rather than delaying action, governments should begin collecting demographic information on the populations who could be affected as soon as possible. For this to be effective, it must be a continuous process that is constantly monitored and evaluated.

This research exhibits some negative externalities to the renewable energy agenda that ought to be considered. Many questions remain unanswered, such as what could happen to the populations whose livelihoods are dependent on non-renewable energy value chains. Such dynamics create a gap that would necessitate further investigation. The researcher suggests additional SADC-based research on renewable energy and job creation, as well as renewable energy and the food-water nexus.

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