An increase of electricity generation can lead to economic growth in South Africa

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Abstract: This study analysis the increase in electricity generation and economic growth in South Africa. The study employs time series data spanning from 1985 to 2020. The study employs an Autoregressive Distributed Lag Model (ARDL), Error Correction Model and Granger causality test to analyse the short and long run relationships between the variables. The empirical results revealed that there is a positive relationship between electricity generation and economic growth both in the short and long run period. The study therefore proposed the increase in electricity generation to increase economic growth in South Africa.

Keywords: *Electricity generation, Economic growth, ARDL, Granger causality, South Africa.*

JEL Specification: *C01, C32, E03, Q13*

1. Introduction

South Africa is one of the water scarce countries in Africa and this has led to it mainly depending on fossil fuels for electricity generation. Most of the electricity generation plants in South Africa that are operated by Eskom are old and lack proper maintenance. There is pressure from the international world for South Africa to shift its electricity generation from non-renewable sources to renewable sources as Eskom was recently rated to be the most polluter in the whole world over America, India, and China. This study focuses on how electricity generation can lead to economic growth in South Africa.

Overview of the study: South Africa produces approximately 229 200 gigawatt-hours of electricity per year. Most of this electricity is used in the country, but about 12 000 gigawatt-hours are exported each year to Eswatini, Botswana, Mozambique, Lesotho, Namibia, Zambia, and Zimbabwe, as well as other Southern African Development Community countries that participate in the Sothern African Power Pool. South Africa supplements its electricity supply by importing around 9 000 GWh per year via the 1 920 MW Cahora Bassa high-voltage direct current transmission system, of which 1500 MW is sold to South Africa, from the Cahora Bassa hydroelectric generation station in Mozambique. Eskom owns and operates majority of power stations in South Africa.

These plants generate 95% of all electricity produced in South Africa and 45% of all electricity produced on the African continent (Eskom 2021). South Africa was the world's fourth largest investor in renewable energy in 2012, after Uruguay, Mauritius, and Costa Rica, in terms of the GDP share. The newly built coal fired power plants like Lethabo has not been able to produce at full capacity since the day they were commissioned. Cowan (2021) highlights that Andrew de Ruyter the CEO of Eskom had found clear evidence of sabotage that caused the pylon near Lethabo Power Station that sabotages electricity supply in South Africa. The constant loadshedding in South Africa is caused by numerous factors ranging from municipalities owing Eskom, lack of maintenance of generators, sabotage, and financial difficulties.

The Emalahleni local municipality owes Eskom R5 billion for unpaid electricity and it's seeking to recoup the money from defaulting customers while some of the residents cite Covid-19 pandemic as the hideous thing that left them without jobs and unable to pay their electricity bills (Mabona 2021). Eskom attorneys have handed over to about 30 large and small businesses in Emalahleni to make payment arrangements for electricity and all defaulting customers are subject to the municipality's credit control and debt collection policy, which it has adopted and is vigorously enforcing (Mabona 2021). Customers that do not will then have their power supply being cut-off for them to comply.

Eskom has been implementing rigorous stages of loadshedding from stage one to stage four as a way of trying to preserve electricity and avoid dark day and system overload. Eskom has refused to reconnect the electricity of several Soweto residents in Diepkloof Zone 3 until each household pays a fine of just over R6 000 (Seleka 2021). This is another area that has been owing Eskom more than R7.5 billion in 2021 from R12.8 billion in 2020, but this was because the power utility wrote off R5.3 billion. Local residents have been accused of having illegal connections, bypassing meters, and purchasing units from ghost vendors and as a result of this, Eskom turned off seven mini substations that supplied electricity to 700 households (Seleka 2021). Locals claim that the move has severely harmed them by limiting their income.

Eskom conducts network audits across the board, not just in Soweto and when criminal activities are discovered, the same disconnection procedure is followed. In identified areas, illegal connections would be removed to secure the network, infrastructure would be repaired, and disconnection fees would be issued to be paid before the supply was restored (Seleka 2021). Cable theft is another serious issue facing Eskom.

The Bedfordview substation was damaged as a result of cable theft in November 2021 that also included vandalism of the electricity infrastructure and this resulted in widespread blackouts (Fin24 2021). Repairs has been hampered by rains, vandalism and theft caused an electricity tower at the Bighorn substation near Marikana in the North West province to collapse. After being found in possession of 170 meters of copper cable stolen from Eskom's warehouse in Welkom, an Eskom employee was arrested and the cable had a value of R540 000 (Fin24 2021). Eskom continue to investigate and implement alternative measures that will assist in preventing theft and vandalism of its electricity infrastructure. Electricity is the back born of economic growth (Lenoke 2017).

Eskom's efforts of trying to secure immediate power to balance the gap between electricity demand and supply has been mate with some challenges. The issue is that regardless of how much Karpowership and other bidders' capacity is used, Eskom will be obligated to pay for 72.72 percent of it and this means that even Eskom obtains less than 72,72 percent of the official tariff, it will be required to pay a surcharge (van Rensburg 2021). This means that the seller is effectively earning more per kilowatt than the official rate.

Though there are newly built power stations, still the problem of electricity power cuts has not been decreasing since their commissioning. Due to a series of breakdowns and faults, Kusile, one of the country's newest power plants, is only producing a quarter of the electricity its three operational units are supposed to according to Eskom (Cronje 2021). As presented by Eskom recently, the energy availability factor (EAF) of the Mpumalanga power station has dropped to just 24.5 percent. This poses a serious threat to matching the gap between the ever-growing electricity demand and ever dropping electricity supply meaning that loadshedding will still prevail for a near future in the country.

Eskom, which provides more than 90% of the country's electricity, has experienced a series of unplanned outages at its aging coal-fired power plant fleet, limiting its ability to power the country and many of the coal-fired power plants have failed in recent years due to insufficient maintenance and the limited availability of diesel (Reuters 2019). The government has promised to inject R23 billion per year for the next three years into Eskom's balance sheet, as well as appointing a team of experts to devise a strategy to improve the company's operational performance.

The United States of America, United Kingdom, France, Germany and the European Union donated a multibillion-dollar to help South Africa finance transition from coal, which they hope will serve as a model for other countries (Staff 2021). South Africa is the 12th largest emitter of climate-warming gases and relies heavily on coal-fired power plants for electricity and the funds would help it meet a more ambitious pledge to cut emissions by 2030. South Africa pledged to cut emissions by 2030 in a contribution to global efforts, employed more than 90 000 people in coal mines alone in 2020 (Staff 2021).

The following tables is a list of South African electricity generating facilities with a capacity greater than 2 MW. It includes both currently operational and under construction facilities. The net power output in megawatts, that is, the maximum power the power station can deliver to the grid, is listed as far as possible.

Table 1: Coal electricity generation

Power Plant	Province	Capacity MW(Planned)	Date commissioned	Planned date of decommissioning	Operator
Arnot	Mpumalanga	2 352	1971-1975	2025-2029	Eskom
Camden	Mpumalanga	1 561	1967-1969, 2005-2008	2020-2023	Eskom
Duvha	Mpumalanga	3 600	1980-1984	2030-2034	Eskom
Grootvlei	Mpumalanga	1 180	1969-1977, 2008-2011	2025-2028	Eskom
Hendrina	Mpumalanga	1 893	1970-1976	2021-2027	Eskom
Kelvin	Gauteng	214	1957		Aldwych International
Kendal	Mpumalanga	4 166	1988-1992	2038-2043	Eskom
Komati	Mpumalanga	990	1961-1966, 2009-2013	2024-2028	Eskom
Kriel	Mpumalanga	3 000	1976-1979	2026-2029	Eskom
Kusile	Mpumalanga	(4 800)	2017-2021		Eskom
Lethabo	Free State	3 708	1985-1990	2035-2040	Eskom
Majuba	Mpumalanga	4 110	1996-2001	2046-2050	Eskom
Matimba	Limpopo	3 990	1987-1991	2037-2041	Eskom

Matla	Mpumalanga	3 600	1979-1983	2029-2033	Eskom
Medupi	Limpopo	1 588(4 764)	2015-2019		Eskom
Pretoria West	Gauteng	180	1952	2016	City of Tshwane
Rooival	Gauteng	300	1963	2025	City of Tshwane
Tutuka	Mpumalanga	3 654	1985-1990	2035-2040	Eskom
	Total	40 036 (8770)			

Source: Author’s own compilation

South Africa’s rich coal deposits are concentrated in the north-east of the country, so Mpumalanga province is home to most of the country’s coal fired power plants. Around 77 percent of South Africa’s energy needs are met directly by coal, and 81 percent of all coal consumed in the country is used to generate electricity (Eskom 2019). This has historically provided South Africa with cheap electricity, but it is also one of the primary reasons that the country is among the top 20 emitters of carbon dioxide gases.

Table 2: Gas Turbines

Power Plant	**Province**	**Installed Capacity MW**	**Date commissioned**	**Operator**
Acacia Station	Western Cape	171	1976	Eskom
Ankerlig Station	Western Cape	1338	2007	Eskom
Gourikwa Station	Western Cape	746	2007	Eskom
Newcastle Cogeneration Plant	KwaZulu-Natal	18	2007	IPSA Group
Port Rex Station	Eastern Cape	171	1976	Eskom
Avon Peaking Power	KwaZulu-Natal (Shakaskraal)	670	July 2006	International Power
Dedisa Peaking Power	Eastern Cape (Coega)	335	October 2015	International Power
	Total	3449		

Source: Author’s own compilation

Table 3: Hydroelectric

Power Plant	**Province**	**Installed capacity (Planned) MW**	**Date commissioned (planned)**	**Operator**
Tubatse Pumped Storage Scheme	Limpopo	1500		Eskom
Ingula Pumped Storage Scheme	KwaZulu-Natal	1332	2017	Eskom
Drakensberg Pumped Storage Scheme	Free State	1000	1981	Eskom
Gariep Dam	Free State-Eastern Cape border	360	1971	Eskom
Palmiet Pumped Storage Scheme	Western Cape	400	1988	Eskom
Steenbras Power Station (Pumped Storage)	Western Cape	180	1979	City of Cape Town

Vanderkloof Dam	Northern Cape	240	1977	Eskom
Colley Wobbles Power Station	Eastern Cape	42		Eskom
Ncora Dam Ncora Power Station	Eastern Cape	2.1		Eskom
Sol Plaatje Power Station	Free State (Bethlehem)	3	2009	Bethlehem Hydro
Merino Power Station	Free State	4	2010	Bethlehem Hydro
Kakamas Hydro Electric	Northern Cape	10	March 2015	Kakamas Hydro Electric Power
Kruisvallei Hydro		(5)		
	Total	3573 (5)		

Source: Author's own compilation

Table 3: Nuclear Power

Power Plant	Province	Capacity MW	Annual Output GWh	Capacity factor %	Date commissioned
Koeberg nuclear power station	Western Cape	1860	13668	84	1984

Source: Author's own compilation

The two reactors at Koeberg are only commercial nuclear power plants on the African continent as of 2017, and they generate about 5% of South Africa's electricity. The Vaalputs Radioactive Waste Disposal Facility in the Northern Cape disposes of low and intermediate waste. Nuclear is expensive and the fear of its side-effects on humans has led to political clashes about expanding the capacity of nuclear generators in South Africa.

Table 4: Wind Power

Power Plant	**Province**	**Capacity MW (planned)**	**Status**	**Date commissioned**	**Operator**
Coega	EC	1.8	Operational	2010	Electrawinds
Darling	WC	5.2	Operational	2008	Darling Wind Power
Klipheuwel	WC	3.16	Decommissioned	2002	Eskom
Sere	WC (Koekenaap)	100	Operational	Jan 2015	BioTherm Energy
Dassiesklip	WC	27	Operational	2014	MetroWind
Van Stadens	EC	27	Operational	2014	Umoya Energy
Hopefield	WC	65.4	Operational	2014	MetroWind
Noblesfontein	NC	73.8	Operational	2014	Umoya Energy
Kouga	EC	77.6	Operational	2015	Gestamp Wind
Dorper	EC	97.5	Operational	2014	Red Cap Investments
Jeffreys Bay	EC	135	Operational	2014	Sumiltomo and Dorper
Cookhouse	EC	135	Operational	2014	Globeleq

Waainek	EC	23	Operational	2014	African Clean Energy Developments
Grassridge	EC	60	Operational	2015	InnoWind
Gouda	WC	138	Operational	(2014)	InnoWind
Amakhala Emoyeni (Phase 1)	EC	134	Operational	2015	Acciona Energy South Africa
Tsitsikamma Community	EC	94.8	Operational	2016	Windlab
West Coast 1	WC	90.8	Operational	2016	Cennergi
Chaba Wind	EC	(20.6)	Operational	(2014)	Micawber 862
Gibson Bay	EC	(111)	Under construction	(Q1 2017)	Enel Green Power
Longyuan Mulilo De Aar 2 North Wind Energy Facility	NC	(139)	Under construction	(Nov 2017)	Longyuan Power
Nojoli	EC	(87)	Under construction	(June 2016)	Enel Green Power
Longyuan Mulilo De Aar Maanhaarberg Wind Energy Facility	NC	(96)	Under construction	(March 2016)	Longyuan Power
Khobab	NC	(140)	Under construction	(End 2017)	Mainstream Renewable Power
Noupoort Mainstream	NC	80	Operational	11 July 2016	Mainstream Renewable Power
Loeriesfontein 2	NC	140	Operational	Dec 2017	Mainstream Renewable Power
Roggeveld	NW-WC	(140)	Contracting		Building Energy
The Karusa	NC	(140)	Contracting	(Q2 2019)	Enel Green Power
The Nxuba	EC	(139)	Contracting	(Q3 2017)	Enel Green Power
Golden Valley Wind Energy Facility	EC	(117)	Contracting		BioTherm Energy
Oyster Bay	EC	(140)	Contracting	(Oct 2017)	Enel Green Power
The Soetwater	NC	(139)	Contracting	(Q2 2019)	Enel Green Power
Kangnas	NC	(137)	Contracting		Mainstream Renewable Power
Perdekraal East	WC	(108)	Contracting	(Q2 2017)	Mainstream Renewable Power
Excelsior Wind Energy Facility	WC	(32)	Contracting		BioTherm Energy
Wesley-Ciskei	EC	(33)	Contracting	(Q4 2017)	InnoWind
Copperton	NC	(102)	Under construction	(late 2017)	Gestamp Wind

Garob	NC	(136)	Under construction	(Oct 2018)	Enel Green Power
	Total	1369.1 (2096.6)			

Source: Author's own compilation

Eskom built a small-scale prototype wind farm near Darling in the Western Cape, and another demonstrator site near Klipheuwel is nearing completion. In bid window 1 of the Renewable Energy Independent Power Producer Procurement Programme, the South African Department of Energy allocated 634 MW of wind capacity. A total of 562.5 MW of capacity was allocated in bid window 2. About 787 MW were allocated in the bid window 3, about 676 MW was awarded in bid window 4 and an additional of 687 MW in the same window (Eskom 2019).

Table 5: Concentrated Solar Power

Power Plant	Province	Capacity MW	Annual Output GWh	Operator
Khi Solar One	Northern Cape, Upington	50	(190)	Abengoa
KaXu Solar One	Northern Cape, Pofadder	100	(320)	Abengoa
Bokpoort CSP	Northern Cape, Groblershoop	50	(200)	ACWA Power
Xina CSP South Africa	Northern Cape, Pofadder	100	380	Abengoa
Kathu Solar Park	Northern Cape, Kathu	100	383	Engie
Ilanga 1	Northern Cape, Upington	(100)		Karoshoek Consortium
Redstone Solar Thermal Power	Northern Cape, Postmasburg	(100)	(480)	ACWA Power
Rooipunt Concentrating Solar Power	Northern Cape, Upington	(150)	(730)	

Source: Author's own compilation

Molten salt energy storage in a tower or through configuration is used in concentrated solar power. In bid window 1 of the Renewable Energy Independent Power Producer Procurement Programme, the South African Department of Energy allocated 150 MW of concentrated solar power (CSP) capacity. A capacity of 50 MW was allocated to in the Renewable Energy Independent Power Producer Procurement Programme in window 2. A capacity of 200 MW was allocated in the Renewable Energy Independent Power Producer Procurement Programme in window 3 and a further 200MW in bid window 3.5.

Table 6: Solar PV Power

Power Plant	Province	Capacity MW	Status	Operator
Kalkbult	Northern Cape	75	Operational	Scatec Solar

SlimSun Swartland Solar Park	Western Cape	5	Operational	Slimsun
RustMo1 Solar Farm	North West	6.93	Operational	RustMo1
Konkoonsies Solar	Northern Cape, Pofadder	9.65	Operational	Globeleq
Aries Solar PV Energy Facility	Northern Cape	9.65	Operational	Globeleq
Greefspan PV Power Plant	Northern Cape, Douglas	10	Operational	AE-AMD Independent Power Producer 1
Herbert PV Power Plant	Northern Cape, Douglas	19.9	Operational	AE-AMD Independent Power Producer 1
Mulilo Renewable Energy Solar PV Prieska	Northern Cape, Copperton	19.93	Operational	Gestamp Solar
Soutpan Solar Park	Limpopo, Vivo, Limpopo	28	Operational	Globeleq
Witkop Solar Park	Limpopo, Polokwane	29.7	Operational	Core Energy (SunEdison)
Touwsrivier CPV Solar Project	Western Cape, Touwsrivier	36	Operational	Soitec
De Aar Solar Power	Northern Cape, De Aar	48.3	Operational	Globeleq
Mulilo Renewable Energy Solar PV De Aar	Northern Cape, De Aar	9.7	Operational	Gestamp Solar
Solar Capital De Aar	Northern Cape, De Aar	75	Operational	Solar Capital
Solar Capital De Aar 3	Northern Cape, De Aar	75	Operational	Solar Capital
SA Mainstream Renewable Power Droogfontein	Northern Cape, Kimberley	45.4	Operational	Mainstream Renewable Power South Africa
Letsatsi PV Project	Free State, Bloemfontein	64	Operational	SolarReserve
Lesedi PV Project	Northern Cape, Postmasburg	64	Operational	SolarReserve
Kathu Solar Energy Facility 1	Northern Cape	75	Operational	Building Energy
Sishen Solar Facility	Northern Cape	74	Operational	Building Energy
Aurora Solar Project	Western Cape	(9.00)	Operational	Aurora-Rietvlei Solar Power
Vredendal Solar Power Park	Western Cape	8.80	Operational	Solairedirect
Linde Solar Project	Northern Cape	36.8	Operational	Scatec Solar
Dreunberg Solar Project	Eastern Cape	32.3	Operational	Scatec Solar
Jasper Solar Energy Project	Northern Cape	75	Operational	SolarReserve
Boshoff Solar Park	Free State	57	Operational	Globeleq
Upington Solar PV	Northern Cape	8.90	Operational	

Adams Solar PV2	Northern Cape, Hotazel	(75)	Operational	Enel Green Power
Tom Burke Solar Park	Limpopo	57	Operational	Enel Green Power
Mulilo Sonnedix Prieska PV	Northern Cape, Copperton	8.90	Operational	Mulilo Renewable Energy
Paleisheuwel Solar Park	Western Cape	(75)	Operational	Enel Green Power
Pulida Solar Park	Free State, Jacobsdal	(60)	Operational	Enel Green Power
Mulilo Prieska PV	Northern Cape, Copperton	75	Operational	Mulilo Renewable Energy
Kathu Solar Energy Facility 2	Northern Cape	(28)	Under Development	Building Energy
Sirius Solar PV Project 1	Northern Cape, Upington	(75)	Contracting	Scatec Solar
Droogfontein 2 Solar	Northern Cape, Kimberley	75	Operational	ACED
Dyason's Klip 1	Northern Cape, Upington	(28)	Contracting	Scatec Solar
Dyason's Klip 2	Northern Cape, Upington	(75)	Contracting	Scatec Solar
Konkoonsies II Solar Facility	Northern Cape, Pofadder	75	Operational	BioTherm Energy
Aggeneys Solar Project	Northern Cape, Pofadder	(75)	Operational	BioTherm Energy
Solar Capital Orange	Northern Cape, Loeriesfontein	(75)	Contracting	Solar Capital
De Wildt Solar	North West, Brits	(50)	Under Development	ACED
Bokamoso Solar	North West, Leeudoringstad	(68)	Under Development	ACED
Zeerust Solar Power Station	North West, Zeerust	(75)	Under Development	ACED
Greefspan 2 Solar Park	Northern Cape, Douglas	(55)	Under Development	ACED
Waterloo Solar Park	North West, Vryburg	(75)	Under Development	ACED

Source: Author's own compilation

In bid window 1 of the Renewable Energy Independent Power Producer Procurement Programme, the South African Department of Energy allocated 631.53 MW of solar photovoltaic (PV) capacity, 417.1MW in bid window 2, 435 MW in bid window 3, 415MW in bid window 4, and 398MW in bid window 4 plus. These wind and solar power plants are still new and majority of them were commissioned starting in 2015.

Table 7: Landfill gas power

Power Plant	Province	Capacity MW	Date Commissioned	Operator
Johannesburg Landfill Gas to Electricity	Gauteng	(18)		

Mariannhill Landfill Gas to Electricity	KwaZulu-Natal	1	2006	eThekwini Metropolitan Municipality
Bisasar Road Landfill Gas to Electricity	KwaZulu-Natal	6.5	2009	eThekwini Metropolitan Municipality

Source: Author's own compilation

Table 8: Biomass Power

Power Plant	Province	Capacity	Date Commissioned	Operator
PetroSA Biogas Project	Western Cape, (Mossel Bay)	4.2	2007	PetroSA
Ngodwana Energy Project	Mpumalanga, Ngodwana	(25)	2018	Sappi
Mkuze	KwaZulu-Natal	(16.5)		

Source: Author's own compilation

Municipalities and redistributors, as well as private generators, provide the rest of 2 703 industrial, 51 848 commercial, 81 638 agricultural, and 6 million residential customers are served directly by Eskom. Eskom owns and operates a number of coal, gas, hydro, pumped storage power plants, as well as one nuclear power plant. South Africa has a problem of low economic growth and electricity generation has not been produced enough to boost the growth of South African economy. The significance of this study is to analyse the relationship between electricity generation in South Africa and economic growth.

2. Literature

Studies that found positive relationship: In Indonesia, Yoo and Kim (2006) looked into electricity generation and economic growth. The study used data from 1971 to 2002 as a time series. The relationship between electricity generation and economic growth was investigated using an Engle-Granger model. The study's findings revealed a one-way causal relationship between economic growth and electricity generation. The researchers also suggest that policies to reduce electricity generation in Indonesia can be implemented without affecting the country's economic growth.

In Bangladesh, Sarker and Alam (2010) investigated the relationship between electricity generation and economic growth. The study used data from 1973 to 2006 from a time series. The relationship between electricity generation and economic growth in Bangladesh was investigated using a Vector Autoregressive (VAR) model and the Granger causality test. The empirical findings looked at a short-run causal relationship between electricity production and economic growth. According to the study, strategies and policies that increase electricity generation should be promoted because it boosts Bangladesh's economic growth.

In 30 OECD countries, Bayraktutan, Yılgör et al. (2011) looked at the relationship between electricity generation and economic growth. The researchers used time series data from 1980 to 2007. The relationship between OECD electricity generation and economic growth was investigated using panel data estimation techniques. The empirical findings revealed that electricity generation and economic growth have a long-term positive relationship. Based on empirical findings, the researchers recommend that the 30 OECD countries implement policies to promote electricity generation to meet demand.

In Turkey, Alt and Kum (2013) conducted a multivariate Granger causality study examining the relationship between electricity generation, prices, exports, and economic growth. Annual time series data from 1970 to 2010 was used by the researchers. To examine the relationship between the variables, the researchers used a Granger causality model and an error correction model. The long run results looked at a causal relationship between the variables, while the short run looked at a bidirectional causality that runs from economic growth to electricity generation. Reduced electricity production, according to the researcher, is harmful to economic growth, and Turkey should implement policies to increase electricity generation to meet rising electricity demand. The researchers also emphasize the need for Turkey to construct new generation units to avoid a power shortage that would disrupt economic activity.

In 20 OECD countries, Ohler and Fetters (2014) investigated the causal relationship between renewable electricity generation and economic growth. The data was borrowed from a panel and spanned the years 1990 to 2008. To examine the relationship between the variables, the researchers used a panel error correction model. The empirical findings revealed that electricity generation and economic growth have a bidirectional causal relationship. Other findings looked at a negative relationship between biomass, hydroelectricity, waste, and wind energy and long-term economic growth. According to the researchers, it is critical for policymakers to consider environmentally friendly or economically beneficial energy policies.

In Greece, Marques, Fuinhas et al. (2014) investigated the relationship between electricity generation and economic growth. Data from August 2004 to October 2013 were used in the study. To examine the relationship between the variables, researchers used a vector error correction model. The findings showed that convectional fossil fuels have a short-term positive impact on economic growth. Other findings revealed that there is no link between renewable energy and economic growth in the short and long term. To boost economic growth, the study suggests that Greek technology be integrated into renewable electricity generation.

Marques, Fuinhas et al. (2016) investigated the relationship between the mix of electricity generation and economic growth in France. From January 2010 to November 2014, the study used monthly time series data. The relationship was investigated using an autoregressive distributed lag model. According to empirical findings, nuclear energy promotes economic growth in France, whereas renewable energy is detrimental to economic growth. According to the researchers, policymakers in France should be aware that any reduction in nuclear power is harmful to economic growth.

The impact of non-renewable and renewable electricity generation on economic growth in the 174 countries studied by Atems and Hotaling (2018). The research used time series data spanning the years 1980 to 2012. To examine the impact of non-renewable and renewable electricity generation on economic growth, the researchers used the Generalized Method of Moments (GMM) and the Granger causality approach. On the selected 174 panel, the study's empirical findings revealed a positive statistically significant relationship between non-renewable and renewable electricity generation on economic growth. The researchers recommend that, based on empirical findings, policies be developed to increase electricity investment to address the issue of power losses.

In South Africa, Khobai (2018) investigated the causal relationships between renewable electricity generation and economic growth. The research used quarterly data from the first quarter of 1997 to the fourth quarter of 2012. To examine the relationship between the variables, the researchers used a vector error correction model and granger causality tests. The empirical findings revealed a one-way causality between electricity generation and economic growth, as well as the fact that electricity generation from renewable energy sources boosts economic growth. According to the researchers, the South African government should make a concerted effort to choose energy policies that do not stifle economic growth.

In Iran, Oryani, Koo et al. (2020) investigated the impact of electricity generation mix on economic growth and emissions. Annual time series data was used in the study, which covered the years 1980 to 2016. The study used a Structural Vector Autoregressive model with Blanchard and Quah long run restrictions to examine the relationship between the variables. The empirical findings showed that increasing the share of renewable electricity in the grid has a positive impact on economic growth. To reduce carbon emissions, the researchers recommend tightening regulation of energy-intensive industries such as power plants and transportation.

In a study of 25 developing countries, Azam, Rafiq et al. (2021) looked at the relationship between renewable electricity generation and economic growth. The research used data from a panel that spanned the years 1990 to 2017. The relationship between electricity generation and economic growth in 25 developing countries was investigated using a panel Autoregressive Distributed Lag and Granger causality test. The empirical findings revealed a long-term positive statistically significant relationship between renewable energy generation and economic growth. In both the short and long run, the Granger causality results looked at bidirectional causality that runs from electricity generation to economic growth. Increased investment in renewable electricity generation through tax credits, renewable energy portfolio standards, and certification of renewable energy markets is recommended by the researchers to boost economic growth. The researchers also recommend that non-renewable energy sources be used less frequently.

Studies that found an inverse relationship: In Malaysia, Lean and Smyth (2010) conducted a multivariate Granger causality analysis between electricity generation, exports, prices, and GDP. Time series data from 1970 to 2008 were used in the study. To examine the relationship between the variables, the researchers used an autoregressive distributed lag model and a granger causality test. The empirical findings looked at the unidirectional causality between economic growth and electricity generation. The researchers recommend that Malaysia implement electricity conservation policies and strategies to reduce electricity generation without affecting economic growth.

Maslyuk and Dharmaratna (2013) conducted a study in Asia on renewable electricity generation, carbon emissions, and economic growth. Quarterly panel data from 1980 to 2010 was used in the research. To examine the relationship between the variables, the study used a structural vector autoregressive model. The empirical findings showed that energy generation and economic growth in these countries have a negative relationship. Countries should adopt policies that complement renewable energy generation while also improving energy efficiency, according to the researchers.

Hdom (2019) investigated the relationships between carbon dioxide, fossil and renewable electricity generation, and economic growth in South American countries. The study drew on panel data spanning the years 1980 to 2010. To examine the relationship between the variables, the study used a panel Autoregressive Distributed Lag model. The empirical results examined the negative relationship between fossil electricity generation in the short and long run, though the relationship to economic growth in the long run is insignificant. The researchers advise South American countries to continue generating long-term electricity from renewable sources.

Studies that found no relationship: In Nigeria, Adeola (2019) investigated the link between structural breaks, electricity generation, and economic growth. The researchers used quarterly time series data from 1970 to 2016. To examine the relationship between the variables, the researchers used a vector autoregressive model and a structural breaks approach-rolling impulse response model. The empirical findings revealed that electricity generation in Nigeria does not lead to economic growth. Nigeria, according to the researcher, requires large-scale investment in the electricity sector as well as the use of renewable energy to close the gap between demand and supply.

Most studies used various models such as the Vector Autoregressive (VAR) model, Vector Error Correction Model (VECM), Autoregressive Distributed Lag (ARDL) model, and panel estimation models to find a positive relationship between electricity generation and economic growth. These studies cover both developed and developing economies that generate electricity from various sources. Three of the studies used in this study found a negative relationship between electricity generation and the use of the ARDL model in Malaysia, the SVAR model in Asia's middle-income countries, and the panel ARDL in Latin America. This means that the relationship varies depending on the country in which the study is conducted, regardless of the methodology used to analyse the relationships.

3. Methodology

Table 9: Data sources and description

Variable	Description	Unit	Source
GDP	Gross domestic per capita	Annual percentage	World Bank
EGR	Electricity generated and available for distribution all producers in South Africa	Gigawatt-hours	Statistics South Africa
CO2	Carbon dioxide emissions	Metric tons per capita	World Bank and Statista
UNE	Unemployment rate	Percentage of total labour force	World Bank
RPOP	Rural population	Annual percentage	World Bank
GCF	Gross capital formation	Percentage of GDP	World Bank

Source: Author's own compilation

Empirical model estimation: The primary objective of the study is to analyse electricity generation and economic growth in South Africa through population, carbon dioxide (CO2) emissions, unemployment, and gross capital formation to formulate a multivariate model. The empirical model can therefore specify as:

$$LGDP_t = \beta_0 + \beta_1 LEGR_t + \beta_2 LRPOP_t + \beta_3 LCO2_t + \beta_4 LUNE_t + \beta_5 LGCF_t + \varepsilon_t \ldots\ldots\ldots\ldots \quad (1)$$

Where, β_0 *is an intercept*, $LGDP_t$ represent the natural logarithm of GDP, $LEGR_t$ represent logged electricity generation, $LRPOP_t$ rural population in natural logarithms, $LCO2_t$ represent logged carbon dioxide emissions, $LUNE_t$ is the unemployment rate, $LGCF_t$ gross capital formation in natural logarithms and ε_t is the error term.

Data analysis: The study employs the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root test to check for stationarity of variables and avoiding spurious regressions. The unit root results will be able to identify the order of integration of the variables, that is, whether variables are integrated of I(0) or I(1) to make it suitable to employ the ARDL model. Lag length criterion will be utilised and the Johansen Cointegration test to check if there is long run relationship between the variables. The study adopts a autoregressive distributed lag model (ARDL) used in the study by Marques, Fuinhas et al. (2016) and Lean and Smyth (2010) to analyse the short and long run relationship between the generation of electricity and economic growth in South Africa.

Estimating long run relationship: After identification of the long run relationships between the variables, the study therefore will estimate the long run relationship by making use of the following specified ARDL Levels regression equations below:

$$LGDP_t = \beta_{10} + \sum_{i=1}^{p} k_{11}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{12}\, LEGR_{t-i} + \sum_{i=1}^{q} k_{13}\, LRPOP_{t-i} + \sum_{i=1}^{q} k_{14}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{15}\, LUNE_{t-i} + \sum_{i=1}^{q} k_{16}\, LGCF_{t-i} + \varepsilon_t \ldots\ldots \quad (2)$$

$$LEGR_t = \beta_{20} + \sum_{i=1}^{p} k_{21}\, LEGR_{t-i} + \sum_{i=1}^{q} k_{22}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{23}\, LRPOP_{t-i} + \sum_{i=1}^{q} k_{24}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{25}\, LUNE_{t-i} + \sum_{i=1}^{q} k_{26}\, LGCF_{t-i} + \varepsilon_t \ldots\ldots \quad (3)$$

$$LRPOP_t = \beta_{30} + \sum_{i=1}^{p} k_{31}\, LRPOP_{t-i} + \sum_{i=1}^{q} k_{32}\, LEGR_{t-i} + \sum_{i=1}^{q} k_{33}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{34}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{35}\, LUNE_{t-i} + \sum_{i=1}^{q} k_{36}\, LGCF_{t-i} + \varepsilon_t \ldots\ldots \quad (4)$$

$$LCO2_t = \beta_{40} + \sum_{i=1}^{p} k_{41}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{42}\, LRPOP_{t-i} + \sum_{i=1}^{q} k_{43}\, LEGR_{t-i} + \sum_{i=1}^{q} k_{44}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{45}\, LUNE_{t-i} + \sum_{i=1}^{q} k_{46}\, LGCF_{t-i} + \varepsilon_t \quad \ldots\ldots (5)$$

$$LUNE_t = \beta_{50} + \sum_{i=1}^{p} k_{51}\, LUNE_{t-i} + \sum_{i=1}^{q} k_{52}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{53}\, LRPOP_{t-i} + \sum_{i=1}^{q} k_{54}\, LEGR_{t-i} + \sum_{i=1}^{q} k_{55}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{56}\, LGCF_{t-i} + \varepsilon_t \quad \ldots\ldots (6)$$

$$LGCF_t = \beta_{60} + \sum_{i=1}^{p} k_{61}\, LGCF_{t-i} + \sum_{i=1}^{q} k_{62}\, LUNE_{t-i} + \sum_{i=1}^{q} k_{63}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{64}\, LRPOP_{t-i} + \sum_{i=1}^{q} k_{65}\, LEGR_{t-i} + \sum_{i=1}^{q} k_{66}\, LGDP_{t-i} + \varepsilon_t \quad \ldots\ldots (7)$$

Estimating short run relationship: The short run relationships unrestricted dynamic ARDL Error Correction Model is derived from the above ARDL Levels regression equations through a simple linear transformation (Pesaran, Shin et al. 2001). The multivariate Unrestricted Dynamic ARDL Error Correction Model to analyse short run relationship employed in this study can therefore be specified as follows:

$$\Delta LGDP_t = \beta_{10} + \sum_{i=1}^{p} \alpha_{11}\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{12}\, \Delta LEGR_{t-i} + \sum_{i=1}^{q} \alpha_{13}\, \Delta LRPOP_{t-i} + \sum_{i=1}^{q} \alpha_{14}\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{15}\, \Delta LUNE_{t-i} + \sum_{i=1}^{q} \alpha_{16}\, \Delta LGCF_{t-i} + \psi_1 ECT_{t-1} + \varepsilon_t \quad \ldots\ldots (8)$$

$$\Delta LEGR_t = \beta_{20} + \sum_{i=1}^{p} \alpha_{21}\, \Delta LEGR_{t-i} + \sum_{i=1}^{q} \alpha_{22}\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{23}\, \Delta LRPOP_{t-i} + \sum_{i=1}^{q} \alpha_{24}\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{25}\, \Delta LUNE_{t-i} + \sum_{i=1}^{q} \alpha_{26}\, \Delta LGCF_{t-i} + \psi_2 ECT_{t-1} + \varepsilon_t \quad \ldots\ldots (9)$$

$$\Delta LRPOP_t = \beta_{30} + \sum_{i=1}^{p} \alpha_{31}\, \Delta LRPOP_{t-i} + \sum_{i=1}^{q} \alpha_{32}\, \Delta LEGR_{t-i} + \sum_{i=1}^{q} \alpha_{33}\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{34}\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{35}\, \Delta LUNE_{t-i} + \sum_{i=1}^{q} \alpha_{36}\, \Delta LGCF_{t-i} + \psi_3 ECT_{t-1} + \varepsilon_t \ldots\ldots (10)$$

$$\Delta LCO2_t = \beta_{40} + \sum_{i=1}^{p} \alpha_{41}\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{42}\, \Delta LRPOP_{t-i} + \sum_{i=1}^{q} \alpha_{43}\, \Delta LEGR_{t-i} + \sum_{i=1}^{q} \alpha_{44}\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{45}\, \Delta LUNE_{t-i} + \sum_{i=1}^{q} \alpha_{46}\, \Delta LGCF_{t-i} + \psi_4 ECT_{t-1} + \varepsilon_t \quad \ldots\ldots (11)$$

$$\Delta LUNE_t = \beta_{50} + \sum_{i=1}^{p} \alpha_{51}\, \Delta LUNE_{t-i} + \sum_{i=1}^{q} \alpha_{52}\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{53}\, \Delta LRPOP_{t-i} + \sum_{i=1}^{q} \alpha_{54}\, \Delta LEGR_{t-i} + \sum_{i=1}^{q} \alpha_{55}\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{56}\, \Delta LGCF_{t-i} + \psi_5 ECT_{t-1} + \varepsilon_t \ldots\ldots (12)$$

$$\Delta LGCF_t = \beta_{60} + \sum_{i=1}^{p} \alpha_{61}\, \Delta LGCF_{t-i} + \sum_{i=1}^{q} \alpha_{62}\, \Delta LUNE_{t-i} + \sum_{i=1}^{q} \alpha_{63}\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{64}\, \Delta LRPOP_{t-i} + \sum_{i=1}^{q} \alpha_{65}\, \Delta LEGR_{t-i} + \sum_{i=1}^{q} \alpha_{66}\, \Delta LGDP_{t-i} + \psi_6 ECT_{t-1} + \varepsilon_t \ldots\ldots (13)$$

Whereby LGDP, LEGR, LRPOP, LCO2, LUNE and LGCF represents gross domestic product per capita, total electricity generation, rural population, carbon dioxide emissions, unemployment rate and gross capital formation respectively. ε_t is the serial uncorrelated random error term in periods 1 to 6, ECT_{t-1} represents cointegration vectors in equation 1 to

6, ψ_i is the adjustment coefficient in equation 1 to 6 showing corrected equilibrium. $\psi_i ECT_{t-1}$ must be significant to find long term causality.

4. Results

Table 10: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root test

Variables	ADF unit root test				PP unit root test			
	Constant		Trend & Intercept		Constant		Trend & Intercept	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ
LGDP	-1.9314	-4.5471 ***	-1.5167	-4.8324 ***	-2.0784	-4.0834 ***	-1.4474	-4.4887 ***
LEGR	-3.0460 **	-3.3764 **	0.4176	-4.8312 ***	-2.8410 *	-3.2296 **	0.7176	-4.3359 ***
LRPOP	-0.3437	-6.4807 ***	-1.3306	-5.9057 ***	-2.3289	-5.4846 ***	-2.2682	-5.2110 ***
LCO2	-2.3193	-5.0417 ***	-2.2419	-5.2190 ***	-2.3499	-5.0415 ***	-2.2590	-5.2197 ***
LUNE	-1.3093	-5.2840 ***	-2.1925	-5.1951 ***	-1.3093	-5.2706 ***	-2.1925	-5.1794 ***
LGCF	-3.5996 **	-6.6067 ***	-3.4543 *	-6.8845 ***	-3.5089 **	-7.1406 ***	-3.1980	-10.653 ***

Source: Author's own computation

By employing the ADF and PP unit root test, the study aims to avoid the problem of spurious regression and identifying the order of integration of the variables. The results of ADF and PP unit root test in table 10 above shows that LGD, LEGR, LRPOP, LCO2, LUNE and LGCF are stationary at first difference. In other words, these variables are integrated of order one or I(1). This makes it suitable to employ the ARDL model since it is recommended that the variables must be stationary at level or first difference, integrated of I(0) or I(1) but no variable should be integrated of I(2). The study therefore continues to perform the VAR lag order criterion as given in table 11 below to determine the optimal number of lags to use in the study.

Table 11: Optimal lag length criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-143.6508	NA	0.000350	9.069747	9.341839*	9.161298*
1	-99.65566	69.325721*	0.000224*	8.585192*	10.48984	9.226047
2	-70.02095	35.92086	0.000415	8.970967	12.50817	10.16113

Source: Author’s computation

The study used the ADF and PP unit root tests, which revealed that all variables are stationary at first difference. As a result, the study used VAR Lag Order Selection Criteria, as shown in table 11, to determine that the optimal number of lags to include in the study is lag, as determined by the LR, FPE, and AIC criteria. According to the SC and HQ criteria, no lags must be used; however, in this study, we will use one lag to examine how electricity generation can lead to economic growth in South Africa, based on the results of the AIC, FPE, and LR. However, should 1 lag doesn’t give good results, Pesaran and Smith (1995) and Pesaran, Shin et al. (1997) highlights that increasing the lags of the model makes the results more efficient.

Table 12: ARDL Bounding test to cointegration

Null Hypothesis: No levels relationship				
F-Bounds Test				
Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
F-statistic	6.307499	10%	2.26	3.35
k	5	5%	2.62	3.79
		2.5%	2.96	4.18
		1%	3.41	4.68
t-Bounds Test				
t-statistic	-6.815140	10%	-2.57	-3.86
		5%	-2.86	-4.19
		2.5%	-3.13	-4.46
		1%	-3.43	-4.79

Source: Author’s computation

The results of the ARDL F-Bounds and t-Bounds test are given in table 12 above. The F-Bounds has an F-statistic of 6.307499 which is greater than the critical value at 1%, 2,5%, 5% and 10% level of significance implying the rejection of the null hypothesis H(0) of no levels relationship. The results of the t-Bounds test has a t-statistic of -6.815140 which is smaller than the critical values at 1%, 2,5%, 5% and 10% level of significance, implying the rejection of null hypothesis H(0) of no levels relationships. Based on both the results of the F-Bounds and t-Bounds test, we can conclude that there indeed exists a long run relationship between the variables in the model. The study therefore continues to estimate both the short and long run results based on the Unrestricted ARDL model below.

Table 13: ARDL Error Correction Model and short run relationships

ARDL ECM Regression Case 3: Unrestricted Constant and No Trend				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob**
C	-0.359925	0.194766	-1.847984	0.0781
D(LEGR(-1))	71.01673	15.57451	4.559806	0.0002
D(LRPOP(-1))	-2.263575	2.957688	-0.765319	0.4522
D(LCO2(-1))	0.298739	0.456657	0.654188	0.5198
D(LUNE(-1))	-0.138177	0.102158	-1.352573	0.1899
D(LGCF(-1))	-0.070773	0.023028	-3.073348	0.0056
CointEq(-1)*	-1.561662	0.229146	-6.815140	0.0000
R-squared	0.876161			
Adjusted R-squared	0.853228			
Durbin-Watson stat	1.672110			

Source: Author's computation

From the results in table 13 above, there is a positive statistically significant short run relationship between electricity generation and economic growth in South Africa. A 1% increase in electricity generation in the short run in South Africa, will significantly result in economic growth increasing by 71%, ceteris paribus. This means that electricity generation is of utmost importance for the growth of South African economy. Therefore, policies that leads to increase in electricity generation must be promoted and implemented to increase the growth of South African economy. These results are consistent with the results from the studies conducted by Khobai (2018), Marques, Fuinhas et al. (2014) and Marques, Fuinhas et al. (2016) that found that electricity generation boosts economic growth in South Africa, Greece and France respectively.

There is a negative statistically insignificant short run relationship between rural population and economic growth in South Africa. A 1% increase in rural population in the short run in South Africa, will insignificantly result in economic growth declining by 2.26%, ceteris paribus. This means that increase rural population in the short run is detrimental for the growth of South African economy. Therefore, policies that lead to a decrease in rural population in the short run must be promoted to increase economic growth in South Africa. These results contradict the results found in the study by Stungwa and Daw (2021) that found population having a positive impact on economic growth in South Africa.

Furthermore, the results reveal a positive statistically insignificant short run relationship between CO_2 and economic growth in South Africa. A 1% increase in CO_2 emissions in the short run in South Africa, will insignificantly result in economic growth increasing by 0.30%, ceteris paribus. This means that in the short run, CO_2 emissions are very important for the growth of South African economy. The increase in CO_2 emissions is because of electricity generation, industrialisation and increase in the number of people owning automobiles in South Africa. Therefore, policies that increase CO_2 emissions in the short run tend to have a positive impact on the growth of South African economy meaning the economy can not grow without these CO_2 emissions in the short run. These result are consistent with the Kuznets (1955) curve that outline the increase in CO_2 emissions being consistent with the increase in economic growth.

There is a negative statistically insignificant short run relationship between unemployment rate and economic growth in South Africa. A 1% increase in unemployment rate in the short run in South Africa, will insignificantly result in economic growth declining by 0.14%, ceteris paribus. This means that increase in the rate of unemployment is not good for the growth of South African economy in the short run as it contributes negatively. These results make economic sense because theoretically we expect that when unemployment rate increases, economic growth must decline.

There is a negative statistically significant short run relationship between gross capital formation and economic growth in South Africa. A 1% increase in gross capital formation in the short run in South Africa, will significantly result in economic growth declining by 0.07%, ceteris paribus. This means that increase in gross capital formation is not good for the growth of South African economy in the short run. This means that policies that result in the decrease in the gross capital formation in the short run in South Africa must be promoted to increase economic growth.

The ECT term is negative and statistically significant and consistent with the prior expectations. This coefficient is 1.561662, meaning that if there are errors in economic growth in South Africa, 156% of the error are adjusted towards long run equilibrium annually. The R-squared is 0.876161, meaning that 87.61% of the variation in economic growth is explained by the model. The adjusted R-squared is 0.853228, meaning that 85% is adjusted to the degrees of freedom and the model is a good fit. The Durbin-Watson is greater than the R-squared, meaning that the model is not a spurious regression. The study continues to estimate the long run relationship as shown in table 14 below.

Table 14: ARDL Levels Equation and long run relationship

ARDL Levels Equation **Case 3: Unrestricted Constant and No Trend**				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob**
LEGR(-1)	20.70725	16.07292	1.288332	0.2110
LRPOP(-1)	-1.449466	1.837558	-0.788800	0.4386
LCO2(-1)	0.191296	0.291445	0.656369	0.5184
LUNE(-1)	-0.088480	0.068543	-1.290871	0.2101
LGCF(-1)	0.155298	0.032754	4.741342	0.0001

Source: Author's computation

From table 14 above, there is a positive statistically insignificant long run relationship between electricity generation and economic growth in South Africa. A 1% increase in electricity generation in the long run in South Africa, will significantly result in economic growth increasing by 20.71%, ceteris paribus. This means that electricity generation is important for the growth of South African economy in the long run since it contributes positively. Therefore, policies that increase electricity generation in the long run in South Africa, must be promoted and implemented as this results in the increase in economic growth. These results are consistent with the studies conducted by Khobai (2018), Marques, Fuinhas et al. (2014), Marques, Fuinhas et al. (2016) and Sarker and Alam (2010) that found that electricity generation boosts economic growth in South Africa, Greece, France and Bangladesh respectively.

There is a negative statistically insignificant relationship between rural population and economic growth in the long run in South Africa. A 1% increase in rural population in South Africa in the long run, will insignificantly result in economic growth declining by 1.45%, ceteris paribus. This means that increase in rural population in South Africa in the long run is detrimental for economic growth. Therefore, policies that result in the reduction of rural population growth in the long run in South Africa must be promoted and implemented as this will result in an increase in economic growth. These results contradict the results found in the study conducted by Stungwa and Daw (2021) that found that population growth has a positive statistically significant relationship with economic growth in South Africa.

There is a positive statistically significant long run relationship between CO2 emissions and economic growth in South Africa. A 1% increase in CO2 emissions in the long run in South Africa, will insignificantly result in economic growth increasing by 0.19%, ceteris paribus. These results are consistent with the theory of Kuznets (1955) that stress an increase in CO2 emissions is consistent with economic growth. This means that CO2 emissions are important for the growth of South African economy in the long run. Furthermore, it can be emphasized that South African economy cannot grow without the increase in these CO2 emissions.

There is a negative statistically insignificant long run relationship between unemployment rate and economic growth in South Africa. A 1% increase in unemployment in South Africa in the long run, will insignificantly result in economic growth declining by 0.09%, ceteris paribus. These results are consistent with the results of the studies conducted by Makaringe and Khobai (2018), Yelwa, David et al. (2015), Dritsakis and Stamatiou (2016) and Misini and Badivuku-Pantina (2017) that found the detrimental effect of unemployment on economic growth in South Africa, Nigeria, Greece and Kosovo respectively. This means that unemployment is not good for the growth of South African economy in the long run. Therefore, policies that results in the decline in unemployment rate must be promoted and implemented to increase in economic growth in South Africa.

There is a positive statistically significant long run relationship between gross capital formation and economic growth in South Africa. A 1% increase in gross capital formation in the long run in South Africa, will result in economic growth significantly increasing by 0.16%, ceteris paribus. This means that the increase in gross capital formation in the long run is very important for the growth of South African economy. Therefore, policies that result in an increase in gross capital formation in the long run in South Africa, must be promoted and implemented to increase economic growth in South Africa.

Table 15: Granger Causality test

Pairwise Granger Causality Test		
Null Hypothesis	**F-statistic**	**Prob**
LEGR does not Granger Cause LGDP	0.56339	0.4584
LGDP does not Granger Cause LEGR	3.03839	0.0909
LRPOP does not Granger Cause LGDP	0.32530	0.5724
LGDP does not Granger Cause LRPOP	0.01925	0.8905
LCO2 does not Granger Cause LGDP	0.41400	0.5245
LGDP does not Granger Cause LCO2	1.27833	0.2666
LUNE does not Granger Cause LGDP	0.67113	0.4187
LGDP does not Granger Cause LUNE	2.10403	0.1566

LGCF does not Granger Cause LGDP LGDP does not Granger Cause LGCF	0.15896 2.53110	0.6928 0.1215
LRPOP does not Granger Cause LEGR LEGR does not Granger Cause LRPOP	1.71772 0.07402	0.1993 0.7873
LCO2 does not Granger Cause LEGR LEGR does not Granger Cause LCO2	0.97989 1.77317	0.3297 0.1924
LUNE does not Granger Cause LEGR LEGR does not Granger Cause LUNE	0.00019 2.26514	0.9891 0.1421
LGCF does not Granger Cause LEGR LEGR does not Granger Cause LGCF	1.06510 0.27000	0.3098 0.6069
LCO2 does not Granger Cause LRPOP LRPOP does not Granger Cause LCO2	0.02004 2.21602	0.8883 0.1464
LUNE does not Granger Cause LRPOP LRPOP does not Granger Cause LUNE	1.37640 7.36154	0.2494 0.0106
LGCF does not Granger Cause LRPOP LRPOP does not Granger Cause LGCF	0.83688 0.17555	0.3671 0.6780
LUNE does not Granger Cause LCO2 LCO2 does not Granger Cause LUNE	1.46995 0.09905	0.2342 0.7550
LGCF does not Granger Cause LCO2 LCO2 does not Granger Cause LGCF	0.01657 0.71471	0.8984 0.4042
LGCF does not Granger Cause LUNE LUNE does not Granger Cause LGCF	0.03661 0.82023	0.8495 0.3719

Source: Author’s computation

The results of the Granger causality test in table 15 above shows that there is a one-way causality running from economic growth to electricity generation at 10% level of significance, this means that policies that affect economic growth will have a causal effect on electricity generation in South Africa. The results further reveal a one-way causality running from rural population to unemployment rate, meaning that policies that affect or address rural unemployment will have a causal effect on unemployment rate in South Africa. The study performs the diagnostic tests as given in table 16 below.

Table 16: Diagnostic Tests

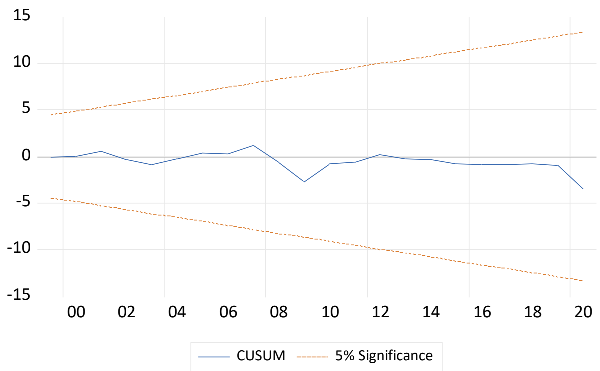
Test	**Probability**	**Decision**
Breusch-Godfrey-Pagan Heteroskedasticity test	0.4120	Accept H0
Breusch-Godfrey Serial Corelation test	0.3048	Accept H0
Jarque-Berra Normality test	0.8959	Accept H0
Ramsey RESET test	0.0586	Accept H0

Source: Author’s computation

The results given in table 16 above shows that the probability of Breusch-Godfrey-Pagan heteroskedasticity test is 0.4120, that is greater than the 0.05 critical value, implying the failure to reject the null hypothesis H(0) that the variables are homoscedastic. The results of Breusch-Godfrey serial correlation test has a probability value of 0.3048, which is greater than the 0.05 critical value, implying the failure to reject the null hypothesis H(0) that the residuals does not suffer from serial correlation.

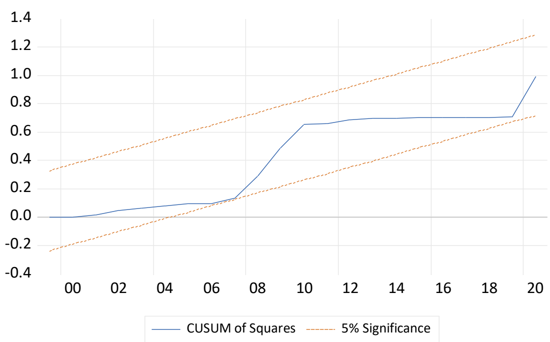
Furthermore, the results of the Jarque-Berra histogram normality test has a probability value of 0.8959, that is greater than the 0.05 critical value, implying the failure to reject the null hypothesis H(0) that the residuals are normally distributed. The results of the Ramsey RESET test has a probability value of 0.0586, that is greater than the 0.05 critical value, implying the failure to reject the null hypothesis H(0) that the model is correctly specified. Therefore, we can conclude that the model does not suffer from heteroskedasticity, serial correlation, normality problems and misspecification. The study, therefore, performs the CUSUM stability tests as shown in figures 1 and 2 below.

Figure 1: CUSUM test



Source: Author's computation

Figure 2: CUSUM of Squares test



Source: Author's computation

The results of the CUSUM and CUSUM squares are given in figures 1 and 2 above. The blue line drifts upwards and downwards without overshooting the 5% critical region (red lines) implying that the model is stable throughout the period from 1985 to 2020 except for the years 2007 and 2019 where the trendline drifts towards the lower boundary as shown on the CUSUM sum of squares.

5. Conclusion and Recommendations

The study analysed the relationship between electricity generation and economic growth and revealed that electricity generation lead to economic growth in South Africa by employing time series data spanning from 1985 to 2020. The study performed the ADF and PP unit root test and discovered that the variables are integrated of I(1). The study employed the Autoregressive

Distributed Lag Model and its corresponding dynamic Unrestricted Error Correction Model to analyse the nexus between the variables in both the long and short run period. Therefore, the policy implications of the study based on empirical results are as follows:

Firstly, there is a positive relationship between electricity generation and economic growth in both the short and long run period. This means that the policy makers must implement policies such as building more electricity generating powerplants in both renewable and non-renewable sources to increasing electricity generation and increase economic growth in South Africa. The already existing generating powerplants must be properly and timely maintained so that they can produce at their full capacity helping to balance the gap between high electricity demand and limited electricity supply that recently resulted in loadshedding.

Secondly, there is a negative relationship between rural population and economic growth in South Africa. This means that the policy makers must promote family planning methods in rural areas and one-child policy to reduce the increase the growth in rural population and increase economic growth in South Africa. The one-way causality running from rural population to unemployment means that, the reducing rural population growth will also help reduce the unemployment rate in South Africa and increase economic growth.

Thirdly, there is a positive relationship between CO_2 emissions both in the short and long run period in South Africa. This means that South African economy cannot grow without the increase in these CO_2 emissions. Therefore, policy makers must propose policies that aims on confirming to global CO_2 emissions, decarbonize automobiles and retrofit electricity generating powerplants to filter the hazardous emissions.

Fourthly, there is negative relationship between unemployment and economic growth both in the short and long run period in South Africa. This means that the private sectors, government, and policy makers must implement policies that are labour intensive to absorb the unemployed population thereby reducing its detrimental effect on the growth of South African economy both in the short and long run period.

Fifthly, there is a positive statistically significant short run relationship and negative statistically insignificant long run relationship between gross capital formation and economic growth in South Africa. This means that the policy makers must implement policies suitable for the increase in gross capital formation in the short run to increase economic growth. Policies that boost business confidence and increase investment in infrastructure such as road and powerplants must be implemented to increase economic growth in South Africa. Private, public and households' investment must be integrated and promoted to increase economic growth in the short run. In the long run, however, policies that reduce increase in gross capital formation must be implemented to avoid the economy from overheating.

The study's main objective was to demonstrate that electricity generation leads to economic growth. The objective was achieved by the discovery of a positive impact of electricity generation in both the short and long run period. The limitation of the study is that it covers only the period from 1985 to 2020 due to lack of data from StatsSA for total electricity generation for the period before 1985. In conclusion, it is indeed true that electricity generation leads to economic growth in South Africa as confirmed by the study analysing the period from 1985 to 2020.

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