ASSESSMENT OF THE IMPACT OF RENEWABLE ENERGY SUPPLY, CARBON DIOXIDE EMISSIONS, TRADE, AND ECONOMIC GROWTH NEXUS ON MAIZE PRODUCTION FROM 1979-2021.

By

Vhugala Charity Nevhutalu

Student NUMBER: 21121907

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DECLARATION

This dissertation, which I, Vhugala Charity Nevhutalu, hereby declare, has never before been submitted for any degree at this institution or any other higher education institution in South Africa, in fulfilment of the requirements for the Master of Science in Agricultural Economics degree. It has been designed and implemented uniquely, with proper acknowledgement given to all the sources it contains.

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Mr V.C Nevhutalu **Date**

DEDICATION

Since my beloved late grandma, Mrs. Nyamuofhe Nyavheani Tshifhumulo is not here to see all of my accomplishments, I dedicate this study to her as a gesture of gratitude.

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“Therefore, have no fear because I am with you, and have no fear because I am your God. I will sustain you with my upright hand, and I will strengthen and assist you”. With that said, I want to thank God first and foremost for his devotion, courage, and guidance during my studies. I thank you for holding my head high to see the ultimate goal when it seemed impossible.

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ABSTRACT

The economy most susceptible to climate change is the agriculture sector. Agricultural production is negatively affected by weather patterns and temperature which ultimately impacts the sector's economy. Food insecurity and a disturbance in the food supply chain are the aftereffects of climate change. A study by Wu et al. (2021). It is foretold that renewable energy utilization will reduce emissions responsible for climate change. The United Nations (UN) has also laid out a global mandate of "a clean and inexpensive energy for all" as part of the 17 Sustainable Development Goals (SDGs). This study specifically focuses on SDG 7 (affordable clean energy) and 13 (climate change). Many industrialized and emerging nations use maize as an energy crop; South Africa has rarely made use of this potential owing to valid food security concerns. Maize production trends in this study showed growth throughout the years despite a few declines which were mostly as a result of climate change. Trade trends also pointed out that there is minimal maize regional trade between South Africa and the rest of the African countries. At the aggregate level, maize production for human, and animal consumption and for biofuel feedstock depends on several macroeconomic factors, some of which were explored in this study. This study was backed by several macroeconomic theories namely: the Environmental Kuznets Curve (EKC), the Mercantilist Theory of Trade, the Export-Led Growth Theory, and the Endogenous Growth Theory. The main objective of this study was to assess the impact of Carbon Dioxide Emissions (CO_2), Renewable Energy Supply, Trade, and Economic Growth on maize production in South Africa from 1979 to 2021. The nexus offered vital insights on initiatives that could be prioritised to advance renewable energy in the South African agriculture industry. An Auto Regressive-Distributed Lag (ARDL) model using Bounds test econometric approach was employed to estimate the short and long-run nexus between renewable energy supply, carbon dioxide emissions, trade, economic growth, and the production of maize. The existence of unit root in the time-series data was examined using the Augment Dickey-Fuller and Phillips-Perron tests; the robustness of the long-run estimate was assessed using the Fully Modified Least Squares (FMOLS) and Canonical Cointegration Regression (CCR) models. The Pair-wise Granger Causality test was used to test for causality between carbon dioxide emissions, renewable energy supply, trade, economic growth, and maize production. The short-run results indicated that Carbon Dioxide Emissions reduce maize production and renewable energy supply increases maize production both in the short-run and long-run. Granger causality results indicated a unidirectional causality between carbon dioxide emissions, economic growth, and maize production. A bidirectional causality was observed between renewable energy supply and maize production. This study contributes to economic policy regarding the energy-climate nexus in South Africa's agricultural industry. The agricultural industry is not only an energy consumer but also has the potential to contribute to renewable energy, specifically bioenergy through the supply of biomass. Considering that maize is a major global energy crop, its demand globally trickles down to maize-producing countries, and this has implications for supply and demand locally and globally. The study’s emerging insights may be used to guide the use of renewable energy biomass supply and the impact of climate change on the agricultural economy (maize production).

Keywords: maize production; renewable energy supply; trade; carbon emissions; economic growth; ARDL; South Africa

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ADF	Augmented Dickey-Fuller test
AfCFTA	African Continental Free Trade Area
AIC	Akaike Information Criteria
ARCH	Autoregressive conditional heteroskedasticity
ARDL	Autoregressive distributed lag model
ARII	Africa Regional Integration Index
ARIMA	Autoregressive integrated moving average
AU	African Union
BAPEPSA	Biomass Action Plan for Energy Production in South Africa
BARDL	Bootstrap Autoregressive distributed Lag model.
BRICS	Brazil, Russia, India, China, and South Africa
CCEMG	Common Correlated Effects Mean Group (CCEMG)
CEN-SAD	Community of Sahel–Saharan States
CCR	Canonical Co-integrating Regression
CIPS	Cross-Sectional Augmented Panel Unit Root Test
COMESA	Common Market for Eastern and Southern Africa
COP	Conference of the Parties of the United Nations
CO2	Carbon Dioxide Emissions
CUSUM	Cumulative Sum
CUSUMQ	Cumulative Sum of Squares
DF	Dickey-Fuller Test
DOE	Department of Energy
DOLS	Dynamic Ordinary Least Squares
DTIC	Department of Trade, Industry and Competition
EAC	East African Community
ECCAS	Economic Community of Central African States
ECM	Error Correction Model
ECOWAS	Economic Community of West African States
EKC	Environmental Kuznets Curve
EU	European Union
EViews	Economic Views software package
FAO	Food and Agriculture Organization of the United Nations

FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLM	Generalized Least Model
GMM	Generalized Method of Moments
GSP	Generalised System of Preferences
IGAD	Intergovernmental Authority on Development
IPCC	Intergovernmental Panel on Climate Change
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
LM	Lagrange Multiplier
LR	Likelihood Ratio
LSTM	Long short-term memory
MEC	Member of the Executive Council
MPDUC	Maize Production
Mt	Metric Tons
NARDL	Non-Linear Auto Regressive Distributed Lag
NDP	National Development Plan
PJ	Petajoule
PP	Phillips–Perron test
PSVECM	Panel Structural Vector Error Correction Model
R & D	Research and Development
REC	Regional Economic Communities
RENS	Renewable Energy Supply
SADC	Southern African Development Community
SDG	Sustainable Development Goals
SSA	Sub-Saharan African Countries
T	Tonnes
TCI	Trade Complementarity Index
TDCA	Trade, Development and Cooperation Agreement
TWh	Terawatt hours
UK	United Kingdom
UMA	Arab Maghreb Union
UNECA	United Nations Commission for Africa

UNFCCC	United Nations Framework Convention on Climate Change
UNISA	University of South Africa
USA	United States of America
VAR	Vector Autoregression
VECM	Vector Error Correction Model
WAMZ	West African Monetary Zone
WDI	World Development Indicator
WTC	Wavelength Transform Coherence
WTO	World Trade Organisation

CHAPTER 1: INTRODUCTION

1.1. Background

According to the Intergovernmental Panel on Climate Change's (IPCC) sixth report, climate change has reached an unprecedented level posing greater threats to life, livelihoods, and the environment (Change, 2022). The human-induced carbon dioxide emissions (CO_2) have been pinpointed as the major causes of climate change. Climate plays an integral part in agricultural growth, as its success heavily relies on climatic conditions. According to Knox et al. (2012), climate change-related elevated temperatures, erratic rains, cyclones, floods, and droughts exacerbate agricultural yield fragility and significantly decline world food output. Malhi et al. (2021) also observed identical findings. Tshikororo, (2023) further ascertained that the consequences of climate variability on agriculture range from production to marketing of agricultural produce which culminates in starvation and food insecurity.

Agriculture's productivity is threatened by climate change as farmers operate in an environment beyond their control. According to Arora, (2019) increase in climate variability reduces crop yield and causes a rise in food prices, making it challenging to satisfy the population's increasing expectations. Therefore, it is imperative that the problem of climate change be addressed. Agricultural production growth is important, especially in developing economies as it is the backbone of the world's food supply to ensure food security. However, this is immensely threatened by climate change. According to a study by Abera et al. (2018) the preponderance of small-scale agricultural systems popular in underdeveloped African nations are nourished by rain, and thus directly influenced by fluctuations in temperature and precipitation, which can have a direct impact on yield reduction.

The climate change vulnerability will be most felt in the decline of productivity of staple food crops as this will directly impact food security. In South Africa, one of the key crops of interest is Maize as it is a primary food crop for South Africa and most African countries. A study by Muluneh et al. (2015) cited by Abera et al. (2018) revealed that by 2080 the yield of maize in semi-arid areas of Ethiopia will reduce by 46%, which will create serious problems. When production declines and prices rise, it will be harder for low-income consumers to get food because of market instability brought on by climate-related shocks to the grain industry (Tigchelaar, 2018). Renewable energy transition through the decrease of carbon dioxide emissions has been hailed as the principal solution to the climate change problem. However, in South Africa, the current energy mix is still largely predominated by fossil fuels (more than 70%) (Oyewo et al. 2019). South Africa's primary energy source is coal, and it is hugely criticized for polluting the environment and greenhouse gas emissions (Gets, 2013). This is a concern for the maize industry since coal-fired power stations have adverse environmental implications that have a diminishing impact on maize output (Mdhluli and Harding, 2021). These environmental implications include air pollution, water pollution, and soil pollution. In a study conducted by Zhang et al. (2021) in China, it was observed that as the use of fossil fuels decreased there was an increase in maize farm size. This means that increased farm size could be beneficial for maize sustainable production when matched with technical innovation and machinery coordination, supporting small-scale farmers to increase their resource use efficiency and sustainability is also key.

One of the primary drivers of every economy's expansion is energy since it has become one of the main factors of production in agriculture in many economies and a necessity for development (Tagwi, 2022). The renewable energy mix is constituted of energy from solar, wind, hydroelectric power, geothermal, and bioenergy. However, in South Africa, the focus and investments have been largely directed to solar and wind. Moreover, the contribution of bioenergy is too small and counted under 'other' in reporting, indicating its small impact on the energy mix. However, the agricultural sector is well-positioned to contribute to the renewable energy mix through bioenergy as the sector is a producer of feedstock (Tagwi and Chipfupa, 2022; Tagwi, 2023). Lastly, the use of maize as a bioenergy feedstock does not compete with food production in terms of land, water, fertilizer, and market (Barot, 2022). Therefore, the economic use of agricultural residues for energy production may lead to lower food prices.

Amongst the energy crops, one of the most often utilized staple crops is maize for energy production (Santpoort, 2020), especially in the global north. Literature has shown that renewable energy can improve environmental quality (Ansari et al. 2021), so it is of interest to see how this development impacts maize production and economic growth considering that the use of maize in energy markets can stimulate demand for its production and ultimately it's supply. Maize is a staple food in South Africa and other countries across Africa, although it was exempted from renewable energy as a direct feedstock due to food safety, it is now one of the identified energy crops earmarked in the South African Bioenergy Atlas (Hoffmann, 2016) in South Africa preferably in the form of residues.

Globally maize is still a huge energy crop with a yield of 11.86 tons/hectare on average. The United States of America (USA) tops the list of nations that produce the most maize for energy production, followed by the European Union (EU), Ukraine, China, Argentina, and India (Nithyashree et al., 2020). Of note, Brazil has doubled its production of corn-based ethanol during the past ten years, and more is anticipated throughout the upcoming years (Otto et al. 2022). About 59% of the renewable energy used in Europe in 2017 came from bioenergy, and 10% of this energy worldwide comes from agriculture. Maize, a significant bioenergy crop in Europe, is used to generate biogas and bioethanol. According to Skoufogianni et al. (2019), Brazil, the United States of America, Poland, Spain, Germany, France, and Austria are the top producers of bioethanol from the production of maize. An uptick in the yield of grain crops in Pakistan due to its favourable climatic conditions was observed to have increased renewable energy consumption (Khan et al. 2021). Energy insecurity has increased in developing countries due to poor infrastructure, and vertical integration systems that kill competition affecting service delivery quality. Electrical generation, transmission, and utilization gauges are key to the infrastructural development of a developing state (Bah and Azam, 2017). According to Khobai, (2018), the use of renewable energy sources contributes to economic development. So, the government must prioritize renewable energy laws that do not compromise economic growth.

Jahanger et al. (2022) also reiterated that the engine of the South African economy is energy as more than 70% of that energy is derived from coal. As one of the top African nations with a wealth of sustainable energy reserves, South Africa has the capacity to increase its green energy production capacity, and can also encourage industrialization, and create green jobs (Ibrahim et al. 2021). In addition, the supply of more renewable energy in South Africa can create long-term direct green jobs in rural communities (Borel-Saladin and Turok, 2013). South Africa has been faced with an energy crisis with rural and remote settlers mostly affected by electricity shortages. South Africa is also the biggest polluter in the continent, and this called for a decisive adoption of a policy framework to incorporate renewable sources such as solar, wind, bioenergy, geothermal, hydropower, and waste to come to the rescue (Jain and Jain, 2017).

Using agricultural waste such as crop residues to produce significant amounts of bioenergy has been a common practice in most developed countries (Kretschmer et al., 2012) such as India, Sweden, China, the UK, Spain, and Denmark. According to Urošević and Gvozdenac-Urošević, (2012), plant residues are utilized for bioenergy production; bagasse is the most often employed material owing to a lack of expertise. Comparable findings were reported by Venkatramanan et al. (2021) in a study conducted in India. South Africa has the potential to generate sustainable bioenergy using maize residues and can also increase the production of maize residues from 104 PJ currently to 238 PJ by adopting improved farming systems and practising no-till cultivation (Batidzirai et al. 2016). The challenge has been, that South Africa has a large agricultural production base but limited knowledge of the conversion of crop residues for bioenergy production (Cooper and Laing, 2007).

Although many have argued that food security issues can also be resolved by green energy through energy crops' increased production, which stimulates more international trade which can improve farmers' livelihoods at the grassroots level, Mahapatra et al. (2021) argued that the production of renewable energy from maize causes food insecurity as the number of crops needed to produce 1 T.J of energy can feed up to 90 to 110 people. Furthermore, Alola, (2022) reiterated that the United States is among the biggest producers of maize and stands a good chance in the production of renewable energy but also raised food security challenges. In developed countries, maize is a multipurpose crop being used as a commercial, fuel, and feedstock crop (Erenstein et al. 2022). However, this confirms the two schools of thought that show that the benefits of green energy are therefore not conclusive and depending on the context could be beneficial or detrimental.

International trade provides a thorough examination of the economic weight of maize globally. Commerce activities have a direct impact on the national use of energy ultimately influencing pollution patterns and economic growth. Maize is the most produced and traded cereal crop globally and serves as a crucial staple food for humans and as animal feed (Erenstein, 2022). Between 2007 and 2016, the amount of maize exported rose dramatically, from 312.3 thousand tonnes to 1,101.2 thousand tonnes in Romania (Popescu, 2018). USA, Brazil, Argentina, Ukraine, and Romania are the top maize net exporters in the world, each shipping 5-54 Mt/year whilst Japan, Mexico, Korea, Vietnam, and Spain are the top net importers, each importing 9–15 million tons annually (Erenstein et al. 2022).). The output of maize in China was significantly influenced by temperature rises, the output decreased by 5.19 kg (1.7%) due to climate change (Wu et al. 2021).

In a study by Grigg, (2019) it was emphasized that technological change and industrialization cause a significant increase in agricultural output and productivity. This is in line with the findings by Liu et al. (2020) who reported that a decline in agricultural output was associated with declining scale and technical efficiency. Additionally, infrastructural development has a significant impact on agricultural growth (Yaqoob et al. 2023). This just paints a bleak picture of agricultural development in the sense that if there isn't industrial and technical improvement the agricultural industry will always fall behind in terms of development and growth. Trade should be liberalized as it will bring in foreign technology which will foster agricultural production (Zakaria et al. (2019). In addition, encouraging economic growth can boost agricultural production by raising per capita income and enabling farmers to adopt mechanized farming (Takeshima and Liu, 2020). Lastly, the government should limit carbon emissions to boost agricultural output, as they negatively impact it.

South Africa is a major producer of maize(corn) with over 5 million metric tons yearly (Mandegari et al. 2019 and Wettstein et al. 2016) globally and it is one of the countries with a large agricultural base. Maize residue is one of the earmarked renewable energy feedstocks by the South African government as indicated in the Bioenergy Atlas reported by the Department of Science and Innovation. South Africa could capitalize on agricultural residues of maize (corncob) to produce renewable energy considering the commitments to renewable energy mix growth in the country and the local energy crisis due to load-shedding. Du Plessis, (2003) reported that South Africa produced up to 8,0 million metric tons of maize grain each year. The continuous growth of maize production in South Africa was confirmed by Galal, (2022) who emphasized that between the years 2000-2022, maize production recorded an increase of roughly 96.3%(15.3 million metric tons). Given the requirement for robust economic advancements and agricultural productivity that protects the environment, it is of interest in this study to assess the connection between maize production and other macroeconomic parameters. This is considering that maize production takes place in a globalization context, where customers and buyers are many and therefore its supply and demand are affected by the local and global market. This is important because it provides a deeper insight into the interactions between renewable energy, agricultural growth, and its impact on the South African economy and the environment.

1.2. Problem Statement

Maize is South Africa's most important cereal crop. However, climate change affects how well maize is produced in South Africa (Akanbi et al. 2021). Moreover, Maize is a staple food in most African nations and is rain-fed, so climate variability endangers the food security of most of the African population (Mulungu and Ng'ombe, 2019). A study by Wu et al. (2021) emphasized that climate change has a significant impact on crop yields, affecting the supply of agricultural products, jeopardizing global food security, and potentially causing serious socioeconomic implications. Coherently, it was reported that worldwide maize output will be negatively affected by an increase in temperature in the upcoming decade (Zampieri et al. 2019). Climate variability continues to impede output, endangering food security and smallholder farmers' livelihoods, necessitating the development of long-term sustainable climate change mitigation strategies.

According to Montoya et al. (2021), energy from non-renewable sources accounts for about 80% of carbon emissions leading to global temperature rise and enhancing the effects of climate change. To counteract climate change, reductions in greenhouse gas emissions must be significantly enhanced by renewable energy sources (Lima et al., 2020). According to Quaschning (2019), renewable energy can become our energy source in the next decade and therefore provide solutions to the dependence of economies on fossil fuels which causes severe climatic conditions and environmental damage. Olabi and Abdelkareem, (2022) also reiterated that renewable energy sources can be a solution to protect our environment from hazards connected with fossil fuel utilization. A study by Solaun and Cerdá, (2019) emphasized that a low-carbon future will depend heavily on renewable energy use.

Although this is much better compared to the rest of the continent, there’s an insufficient supply of power generation in South Africa, with one-third of the population still without electricity (Nicholas et al. 2019). This is also reflected today with frequent power outages. South African citizens succumb to losing power for about 10 hours daily at its worst. According to Bekun et al. (2019), South Africa's primary energy source is coal producing up to more than 70% of the electricity. It has indeed helped the country energy-wise but has also helped put the country amongst the top 10 GHG emitters globally. It is well noted that South Africa has been making enormous efforts to curb carbon dioxide emissions and renewable energy development.

In 2015, the Department of Energy (DOE), the Dutch government, and the country's energy provider, Eskom, had plans to fund the development of South Africa's Biomass Action Plan for Energy Production (BAPEPSA). Important to note that, the sustainability of the environment, stability in energy supply, and economic development are all important elements of the South African economy. Its dependence on energy derived from burning fossil fuels raised a lot of questions about the future’s environmental, energy, and economic policies (Nalule, 2020).

Important to note that strides have been made as South Africa has a Bio-energy Atlas offering extensive data and the country's bioenergy resource's potential and availability (Bezuidenhout, 2019). Various energy crops have also been identified as potential feedstock for bioenergy. Additionally, South Africa is establishing a renewable energy sector which is aimed at developing a biomass sector to curb the ever-rising carbon dioxide emissions (Akinbami et al. 2021). The country has also made large investments in solar and wind energy although it is not enough as bioenergy is still neglected, which is a lost untapped opportunity for farmers in the agricultural sector (Tagwi and Chipfupa, 2022). As has been demonstrated in various countries, there is ample evidence that the agriculture industry will play a vital part in renewable energy production in South Africa. If opportunities can be well explored, this can have spillover effects on the livelihood of the farmers in rural areas. However, this will require aggressive policy and investment in the agricultural sector as witnessed in developed countries.

South Africa needs major maize production investments and cutting-edge technology. Few studies on precision agriculture, biotechnology, and integrated environmental implications exist. To improve grid stability and energy security, South Africa should explore biofuel conversion technologies and integrate them with renewable energy systems. Food security and policy deficiencies must be addressed. Maize bioenergy's effects on local communities, food security, employment, and rural development must be studied using socio-economic impact studies in developed countries. These are the gaps this study seeks to fill.

1.3. Aim of the study

The main aim of this study was to contribute to the discourse of SDG 7 and 17 by assessing the long and short-run nexus of renewable energy production and agricultural economic activities for the last 42 years.

1.3.1. Main Objective

The main objective of this study was to determine the impact of renewable energy supply, carbon dioxide emissions (CO_2), trade, and economic growth on maize production in South Africa from 1979 to 2021.

1.3.2. Specific Objectives

i. To analyze maize production, import, and export trends in the period 1979-2021.

II. To estimate the short-run and possible long-run relationships between maize production and macroeconomic variables in the model.

III. To estimate causality between maize production and macroeconomic variables.

1.3.3. Hypothesis

i. **H_0:** renewable energy supply does not positively and significantly influence maize production.

ii. **H_0:** carbon dioxide emissions (CO_2) do not positively and significantly influence maize production.

iii. **H_0:** trade does not positively and significantly influence maize production.

iv. **H_0:** economic growth does not positively and significantly influence maize production.
v. **H_0:** renewable energy supply does not granger cause maize production.
vi. **H_0:** carbon dioxide emissions (CO_2) do not granger cause maize production.
vii. **H_0:** trade does not granger cause maize production.
viii. **H_0:** economic growth does not granger cause maize production.

1.4. Justification/ Contribution of the Study

A recent IPCC report (2022) on climate change has painted a bleak picture for the global economy in general and agriculture if climate change action fails. Transitioning to renewable energy is one of the immediate solutions proposed globally in the report. According to Agbugba et al. (2020), there is evidence throughout the world that maize farming has a lot of potential to provide job and income opportunities. Theoretically, agricultural productivity is a function of economic growth and subsequently affects trade performance. Conversely, growing economies drive energy demands. Therefore, in the context of climate change, it is vital to assess how maize production affects renewable energy supply, carbon emissions, trade, and economic growth. Assessing these relationships will provide a comprehensive picture useful for policymakers' pointing out key areas to prioritize in renewable energy investments.
The study will contribute to one of the objectives of the NDP 2030 which aims to champion a low-carbon economy by the year 2030 (Altieri et al. 2016). It will also contribute to the SDG 2030 goals number 7 and 13 which strive to guarantee that all people are entitled to clean, cheap, reliable, sustainable energy and climate action (Mawonde & Togo, 2019). Understanding what drives maize productivity in the context of renewable energy is important for our economy as this has production implications.

1.5. Limitations & delimitations of the study

Owing to the unavailability of data, the study solely paid attention to publicly available data to lessen this problem. It would have been interesting to examine data up to the year 2023, but owing to unavailability, only the association of these factors up to the year 2021 can be assessed. Only South Africa will be the subject of the study from 1979 to 2021. The study used data on maize production, carbon dioxide emissions, renewable energy supply, trade, and economic growth during the same period. The current embargo on using maize as an energy crop in South Africa can be a barrier to addressing policy in light of the results of the study.

1.6. Ethical Considerations

The study followed UNISA ethical research procedures and ensured that the research proposal was compliant with UNISA Ethics. Upon the completion of the study, the results will formed part of the bigger bioenergy project which seeks to influence policymakers on renewable energy policies in the agricultural sector. The study used publicly and credible available data.

1.7. Definition of key terms

- **Renewable energy-** Renewable energy is energy generated from sources that do not deplete and can be renewed during a human lifetime; it has the potential to reduce environmental repercussions, alleviate climate change, and increase energy security and economic prosperity (Kabeyi and Olanrewaju, 2022).
- **Carbon dioxide emissions-** are a significant component of greenhouse gas emissions, resulting from the combustion of fossil fuels such as coal, oil, and natural gas (Mardani et al. 2019).
- **Trade-** Trade is the buying and selling of goods and services between different economic players, such as countries, businesses, and individuals (Meltzer, 2019).
- **Economic growth-** Economic growth is a critical indicator of an economy's overall health and performance throughout time, and it is frequently used to forecast a country's economic trajectory (McClelland, 2019)
- **Bioenergy-** Bioenergy is defined as energy obtained from organic resources known as biomass, which comprise recently living (but now deceased) organisms, primarily plants (Kumar et al. 2023).

1.8. Outline of the study

The first chapter covered the study's background, problem statement, aim and objectives, research questions and hypothesis, study limitations and delimitations, study contribution, ethical considerations, and definition of key terms. The second chapter provides the conceptual and theoretical framework, literature review as well as and maize production and trade trends. The third chapter focuses on the methodology utilized in the study. Chapter 4 detailed maize and trade trends with a reference to the African Continental Free Trade Area (AfCFTA). Chapter 5 outlined the study's results and discussion. Chapter 6 focused on the results-based conclusion and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This study examines the interaction of numerous economic variables with maize production. South Africa needs economic agility in the agricultural sector to safeguard employment and food security (Samkange et al. 2021). The main challenge is that studies have reported an adverse relationship between environmental quality deterioration and economic growth. This is largely due to heavy reliance on fossil fuels to drive economic activities. According to a study by Radwan et al. (2022), the agricultural sector has energy-intensive activities that contribute largely to carbon emissions and environmental degradation. It is also important to note that the economy's ability to develop is severely restricted when energy is rare, but when energy is plentiful it contributes a large stake in economic growth (Gars and Olovsson, 2019).

Maize is a strategic crop in South Africa providing livelihoods to rural smallholder farmers and it is also a key energy crop used in bioenergy generation globally (Mathinya et al. 2022). This means maize plays a key role in the food and energy sector and depending on the priorities (developing vs developed stage) of the country, it will take different roles. Concerning the need for energy, any economic activity demands energy consumption which stimulates supply. Ikpesu and Okpe, (2019) emphasized that an increase in agricultural productivity is expected to attract an inflow of cash into the economy through trade, consequently boosting economic growth. Understanding how renewable energy supply, carbon emissions, trade, and economic growth interact with maize productivity in the economy is essential for the agricultural sector policy developments.

Therefore, this study was aimed at assessing the impact of renewable energy supply, carbon dioxide emissions, trade, and economic growth on maize output. The study used economic growth proxies measured by GDP growth per capita and maize productivity. Climate change was proxied by carbon dioxide emissions (CO_2). Theoretical frameworks underpinning this study included the Environmental Kuznets Curve (EKC), the Mercantilist Theory of Trade, the Export-Led Growth Theory, and the Endogenous Growth

Theory. The study employed these theoretical frameworks to explain the possible relationships between agricultural productivity and selected macroeconomic variables in the economy. The outcomes will be crucial in recommending possible policy remedial actions. Figure 2.1 below illustrates the possible interactions as guided by the selected theories.

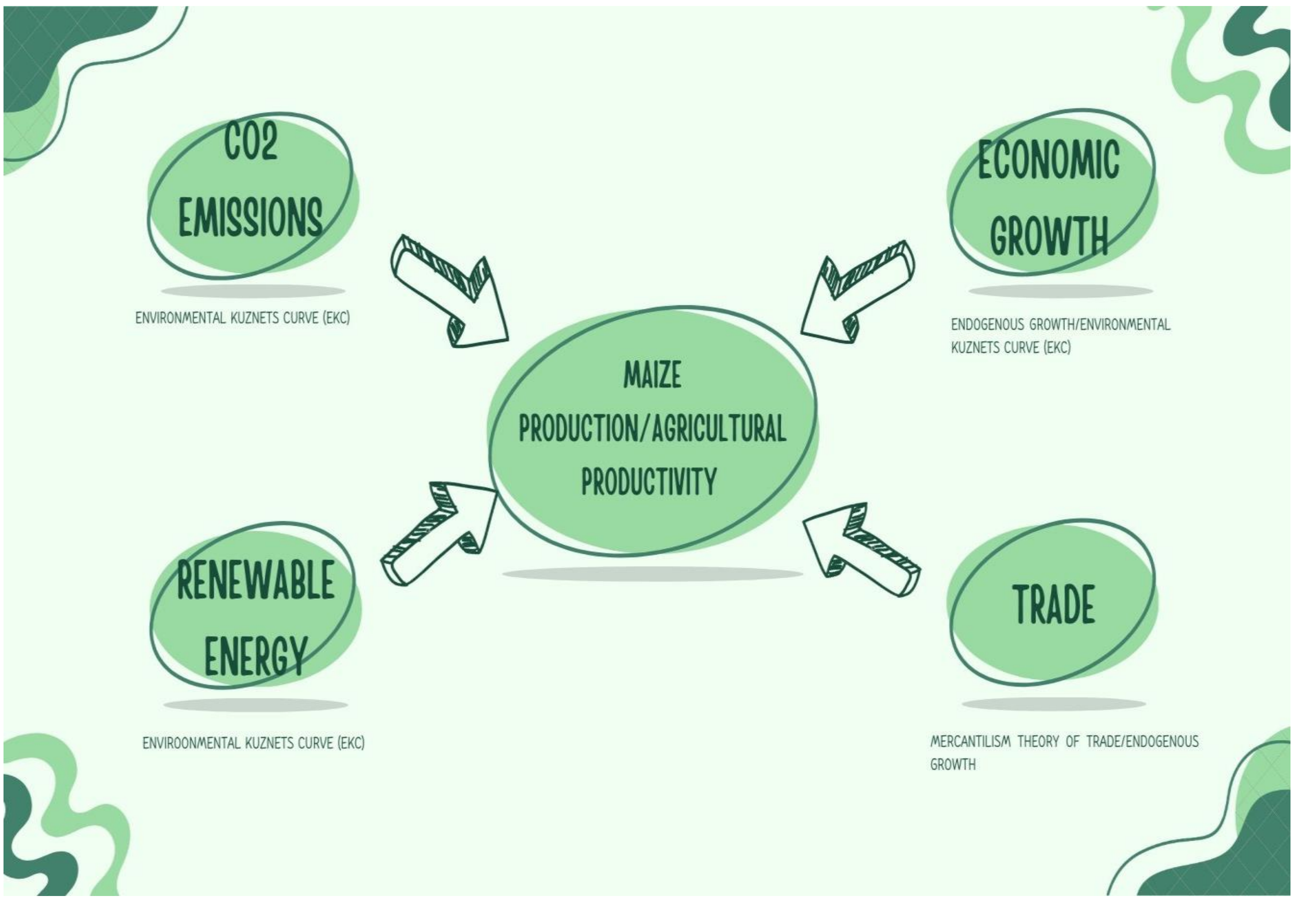

Figure 2.1: Graphical representation of the theoretical framework

Source: Author's Compilation (2024)

The graphical representation above shows the influence of the response variable as maize production, and the predictor variables as trade, carbon dioxide emissions, renewable energy supply, and economic growth. A study by Bandyopadhyay and Rej, (2021) reveals that the transition to a contemporary, cleaner energy pathway has attracted attention on a global scale. The UN's 2030 SDG goal number 7 advocates for global access to current, economical, credible, and environmentally friendly energy for all (Chirambo, 2018). According to Kosemani & Bamgboye, (2021), one important supply of feedstock for renewable energy is maize. Since maize is a viable crop to produce renewable energy, the increase in its production will have a major impact on the energy market. Although the SDG goals are a global mandate, a positive balance of trade and an increase in economic growth must be made. According to the selected theories it is expected that more production of maize will boost the green energy market feedstock, ultimately boosting economic growth and improving renewable energy supply, while improving environmental quality due to pollution reduction. The study variables' expected behaviour is discussed below using selected economic theories.

2.2. The Environmental Kuznets Curve (EKC)

2.2.1. Energy and Environment

The Environmental Kuznets Curve is a theory that links environmental degradation and income per capita. This theory explains interactions between pollution, energy, and economic growth. The theory states that pollution rises in the early stages of economic expansion but reverses itself when a specific nation's income level is attained. Further economic growth then leads to environmental improvement (Stern, 2018). In simple terms, EKC serves as a paradigm for how energy consumption, economic expansion, and environmental protection are related. It was named after economist and statistician Simon Kuznets. It also implies that the more income an economy generates the more the country will shift to more environmentally friendly ways of production which decreases pollution thus leading to a greener economy in the long term. It is shown in Figure. 2.2 below that environmental pollution rises during the early phases of prosperity, but after per capita income reaches a certain point, economic growth promotes environmental betterment (Stern, 2020). EKC therefore provides a framework for understanding points at which the economy will self-correct environmental losses and the importance of economic development for the transition to a green economy as integral components of sustainable development in developing countries.

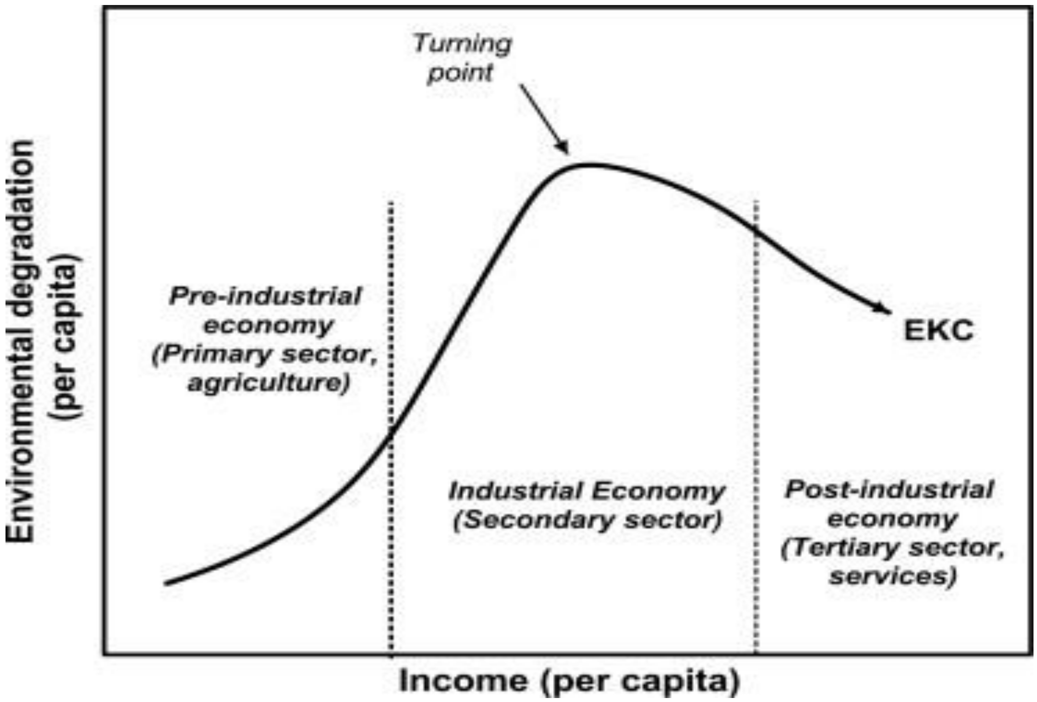

Figure 2.2: Environmental Kuznets curve (EKC)

Source: https://www.researchgate.net/figure/An-environmental-Kuznets-curve-EKC-Source-Kaika-and-Zervas-2013_fig1_360483880 (Accessed: 18-02-2024)

Pata et al. (2023) also implied that environmental damage may initially grow as income levels rise, but income could play a role in environmental quality as the process goes on. According to Mehmood (2022), An economy's capital formation is influenced by financial inflows, and capital formation fuels economic activity, which in turn uses more energy, contributing to environmental degradation. However, EKC supposes that if this happens continuously, the country can reach higher levels of income where the priorities can change to healthy economic production activities. He et al. (2021) state that green energy influences a cleaner environment. Destek et al. (2018) also revealed that environmental deterioration is lessened by renewable energy consumption and trade transparency. In a nutshell, the significance of the EKC lies in its potential to inform policymakers, economists, and environmentalists about the relationship between economic growth and environmental sustainability. In this study, EKC is relevant because we are assessing how maize production can influence CO_2 emissions as a proxy for environmental quality, and trade which can be used as a measure of economic growth since a country exports goods and services which ultimately boosts its Gross Domestic Product (GDP). EKC further enlightens scholars on the benefits and drawbacks of trade on environmental quality.

2.2.2. Trade

The EKC theory can also be used to explain trade activities in an economy. Grossman and Krueger, (1991) explain trade openness and environmental degradation by three effects namely: (i) According to the ***scale effect***, wherein trade openness and improved investment lead to faster economic expansion and environmental deterioration. (ii) ***The composition effect*** which states that when trade is opened for developing nations, trade becomes profitable but unfavourable to the environment, leading to a rise in emissions. (iii) ***The technique effect*** demonstrates how importing green technologies may help less developed and developing nations such as South Africa to minimize environmental harm through freedom of trade. Scale and composition impacts are probably going to be more important for emerging nations than technological influence. A study by Udeagha and Breitenbach, (2021) pointed out that, confirming the environmental Kuznets curve (EKC) theory is the scale effect that advocates for increasing CO_2 emissions while the technique effect decreases it. According to Udeagha and Ngepah, (2021), trade openness consequently boosts domestic output and economic activity, which in turn boosts energy consumption.

According to Jun et al. (2020), pollution will be reduced if trade raises demand for labour-intensive commodities since manufacturing these items does not increase emissions. It will also rise if the demand drives capital-intensive commodities as this requires more energy consumption. This implies that trade will raise pollution in developed nations and decrease it in less developed ones since developed countries are capital-intensive and developing countries are labour-intensive. However, EKC shows that over the long run, capital-intensive countries such as the U.S., Japan, and Germany will have less pollution in their own countries due to fewer manufacturing activities, and producing countries such as China, India, and Brazil will have more pollution. This means that, if producing countries' trade policies do not monitor economic activities, they can experience more pollution. A study by Bandyopadhyay and Rej, (2021) revealed that India's trade policy fosters green trade activities to protect the environment, and trade openness has been shown to positively impact environmental quality. Mahmood, (2023) concurred that indeed exports reduce CO_2 emissions in the home country and its neighbours. This means that trade openness does not only benefit the country in question in terms of the reduction of CO_2 emissions but also benefits the neighbouring countries.

According to Liu et al. (2019), the amount of maize exported from one country to another will have different volumes of CO_2 emissions for example, the export of 50 tonnes of maize without processing (labour intensive) will not have the same volume of CO_2 emission as compared to 50 tonnes of maize exported processed (capital-intensive). This means that well-developed countries that are capital-intensive will export more processed maize which will increase CO_2 emissions and less developed countries that are labour-intensive will export more unprocessed maize which decreases CO_2 emissions because of minimal usage of mechanization. This has been largely argued in international forums that producing countries pollute less while capital-intensive countries pollute more but producing countries are expected to pay for their green energy transition which should be paid by capital based on this context.

2.3. Mercantilist Theory of Trade

This is one of the first kinds of international economics, known as mercantilism, the theory explains trade and economic growth. It advocates for enormous exports over imports to build wealth, and the creation of a positive balance of payments and trade while remaining relevant in the modern economy (Chijioke et al. 2021). Mercantile theory suggests countries increase financial wealth through export-oriented protectionism, utilizing trade surpluses, government intervention, and colonization (Conti, 2018). Together, these three tactics influenced wealth building. Through the import of raw materials into their nations and the sale of finished goods throughout the world, the colonization of undeveloped regions retained trade surplus (Regissahui, 2019). Moreover, governments also interfered in import regulations and tariffs, giving firms incentives to increase exports because they believe that capital supply is essential for economic health and that global wealth is static (Chang and Andreoni, 2020). According to Ayres, (2023), the mercantile theory was founded by Jean-Baptiste Colbert in the 1600s and it is still of relevance today. A study by Doan, (2019) also emphasized that the only way a government or nation could become affluent and strong was by encouraging more exports of products and services to other nations while maintaining lower imports of those same goods and services. This theory suggests that capital-intensive countries will also engage in trade to horde raw materials to replenish their supplies ultimately driving production activities in countries producing the raw material which drives economic growth but also puts a strain on energy demand. Both academics and professionals have engaged in heated discussions on how trade affects economic growth, especially in developing countries. According to Abendin and Duan, (2021), It is widely acknowledged that enhanced trade opens advantageous conditions for the production of high-quality goods, which in turn accelerates economic growth. Therefore, it is thought that commerce has a major impact on economic expansion.

2.4. Export-led Growth Strategy

The Mercantilist theory of trade can further be supported by the Export-led growth strategy which aims to increase production capacity by putting a special emphasis on exports (Palley, 2012). The strategy also views trade as an engine of economic growth (Sunde et al. 2023). A study by Rangasamy (2009) stated that exports are important in driving economic growth by noting that higher exports benefit emerging nations with smaller economies and constrained local markets benefiting from economies of scale. Consequently, a study by Mosikari and Eita, (2020) observed that exports in Namibia between the years 2010 and 2018 led to an average of 111% growth in GDP. This confirms that countries' openness to international trade improves economic growth. According to Iqbal et al. (2019), international trade has transformed economies into great players. A higher degree of trade openness has been observed to encourage a greater infusion of foreign capital (Malefane, 2018). An economy's ability to expand is influenced by factors such as foreign investment. The success of the East-Asian countries has been attributed to the adoption of the export-led growth strategy and as a result experienced high economic growth (Mosikari and Eita, 2020).

2.5. Endogenous Growth Theory

Economic growth activities can be explained by the Endogenous growth theory. Paul Romer, an economist, developed the endogenous growth hypothesis in 1986, stressing that efforts by academics and entrepreneurs who take advantage of financial incentives lead to technological improvement (Jones, 2019). According to Maré, (2004), the theory states that steady economic growth is influenced by three driving forces which are capital, labour, and technology. Jones, (2019) also supported the idea that investment in capital, labour, and technology accelerates economic growth. A combination of all three production-related factors (capital, labour, and technology) is essential for economic growth. To attain economic growth, food security, employment generation, and poverty reduction goals, the endogenous growth theory advocates for large investments in agriculture as a solution (Kabini, 2022). In this context, to boost agricultural production, in addition to trade, South Africa must also raise and maintain its investments in agricultural research and development to create capital and improve labour. This will spur technological advancement and reveal untapped possibilities (Sredojević et al. 2016). However, due to risks and collateral requirements, smallholder farmers' communal land ownership restricts agricultural investment at the grassroots level creating a capital vacuum, reducing financial possibilities, and restricting agricultural loans. A study by Balana and Oyeyemi, (2022) emphasized that inadequate collateral is the main barrier for rural smallholder farmers to attract investment and acquire loans for technological advancements. This problem has implications for renewable energy projects by farmers.

To maximize agricultural productivity a combination of endogenous factors (capital, labour, and technology) will be vital for economic growth at the local level. Endogenous growth takes place within a system due to internal factors rather than external pressures (Chandra and Chandra, 2022). It is expected that with favourable internal conditions, maize production can be improved further driving trade and ultimately improving economic growth. Growth in agricultural productivity is critical in South Africa considering the current level of poverty and inequality. Paul Romer’s endogenous growth theory aims at eliminating diminishing, constant returns and promoting increasing returns in the process of growth (Schilirò, 2019). In addition, the Endogenous growth theory incorporates human capital for responsive labour and Research and Development (R&D) expenditures to improve output (Chandra, 2022). Chirwa and Odhiambo (2018) also reported knowledge, human capital, and research as indicators of innovative capital that boost returns to scale.

Human capital is critical in advancing the agricultural industry which is dynamic due to alterations in technology, climate change and globalization. Low investments in human capital will lead to low labour productivity resulting in slow economic growth, high unemployment, and high poverty rates (Osiobe, 2019). This creates a snowball effect in the economy where access to vital resources (education, health, food) also becomes limited. Access to these resources, especially education, creates positive feedback in the economy. Sarwar et al. (2021) supported the idea that financial and advancement of human capital had an advantageous impact on economic expansion. Investment in human capital encourages the division of labour and specialization whilst knowledge has limitless growth opportunities as it is a non-rival good (Olopade et al. 2020). Although Benhabib (1994) had previously found human capital to have zero impact on economic growth there is enough evidence from literature that still supports its importance. The next section reviews empirical research of the behaviour of variables of interest in the study and their interaction with agricultural productivity across the globe.

2.6. Review of used variables in the study

2.6.1. Agricultural Productivity and Carbon Dioxide Emissions

According to Raihan and Tuspekova, (2022b) and Raihan et al. (2022), increased agricultural output was observed to decrease CO_2 emissions using the Dynamic Ordinary Least Squares (DOLS) method for India from 1990 to 2020. In Bangladesh from 1972 to 2018 using the Autoregressive Distributed Lag (ARDL) bounds testing approach similar findings were reported. The autoregressive distributed lag (ARDL) bounds testing method was employed by Raihan & Tuspekova, (2022b), who then utilized the Dynamic Ordinary Least Squares (DOLS) method for Nepal from 1990 to 2019 and found similar results. In addition, Raihan (2023) using the Granger causality and the DOLS method for the Philippines from 1990 to 2020 also found that increased agricultural productivity lowered

CO_2 Emissions. In all the countries mentioned above, agricultural productivity improved environmental quality.

According to Rehman et al. (2022), there was a favourable relationship between CO_2 emissions, crop production, and land usage in Bhutan between 1980 and 2020 utilizing the ARDL model, Stepwise, and Robust Least Squares. Using the autoregressive distributed lag (ARDL) bounds testing approach for Nigeria from the 1981-2017 period, Gershon (2020) found that an increase in agricultural production leads to a decrease in CO_2 Emissions. According to Shah et al. (2023), an increase in CO_2 emissions negatively affected agricultural productivity, these were the results for BRICS from 1990 to 2019 using the Long-run elasticity estimates. To maintain a steady expansion and lessen the effects of climate change, lowering CO_2 emissions and improving environmental quality have become a global priority. An increase in agricultural production was observed to increase environmental quality using the ARDL and DOLS for Thailand from 1990-2020 period (Raihan et al. 2023a). Similar results were reported by Yahya and Lee (2023) using the second-generation panel unit root and cointegration tests for 90 countries from the period of 1991 to 2019. In addition, using panel quantile regression, Karimi Alavijeh et al. (2022) found that agricultural value added positively impacted CO2 emissions for the 15 most populated developing nations.

Using the DOLS method for Mexico from 1990 to 2019, Raihan and Tuspekova (2022c) emphasized that a rise in crop yield decreased CO_2 emissions. Raihan, (2023) reported similar results for a study conducted in Chile, using the DOLS approach for the period of 1990 to 2020. Furthermore, Waheed et al. (2018) confirmed that agricultural production favourably impacted CO_2 emissions for Pakistan using the ARDL between 1990 and 2014. Additionally, a study by Guo et al. (2022) indicated that financial injections in China's agricultural industry significantly reduced CO_2 emissions through increased production, as shown by ARDL and Granger causality tests for the period 2000-2019.

Zandi and Haseeb, (2019) further confirmed that agricultural production significantly enhanced environmental quality in Sub-Saharan African (SSA) countries, as confirmed by the Cross-Sectional Augmented Panel Unit Root Test (CIPS), Westerlund (2007) bootstrap cointegration, and the Fully Modified Ordinary Least Squares (FMOLS) tests from 1995 through 2017. Similar findings were reported for Portugal by Leitao and Balogh ,(2020) using the ARIMA model, Granger causality, Autoregressive Distributed Lag (ARDL), and Newey–West Standard Errors regression for the period of 1960-2015. In addition. Chandio et al. (2020) reported that the impact of agricultural productivity on CO_2 emissions was unfavourable for China from 1990 to 2016 whilst using the ARDL, Fully Modified Ordinary Least Squares (FMOLS), Canonical Co-integrating Regression (CCR) model and the Granger causality test.

A study by Appiah et al. (2018) found that increased agricultural productivity led to an increase in CO_2 emissions in emerging economies from 1971-2013 using DOLS and FMOLS. Using the Gregory–Hansen cointegration test and bootstrap ARDL approach for Turkey from 1970 to 2017 period, Yurtkuran, (2021) also found that an increase in agricultural activities increased environmental pollution. Similar results were reported by Razman et al. (2022), using ARDL and wavelet transform coherence (WTC) approaches for Pakistan from 1961 to 2018. Employing ARDL, FMOLS, DOLS, and CCR for South Africa from 1990 to 2021 the growth of the agricultural sector led to a deterioration in environmental quality (Tagwi, 2023). Alam et al. (2023) reported similar findings using Bootstrap Autoregressive Distributed Lag (BARDL) for India from 1990 to 2018.

Using the DOLS and the FMOLS for BRICS countries from 1990 to 2014, Balsalobre-Lorente, (2019) opined that high agricultural productivity had an adverse impact on the environment. According to Raihan et al. (2023b), carbon emissions from agricultural production are set to skyrocket due to the high demand for food, this was forecasted for Bangladesh using 1990-2018 data estimated by the DOLS technique. Ehigiamusoe et al. (2023) confirmed that agricultural production grows at the expense of environmental quality, based on the EKC framework and the ARDL procedure for Malaysia for the period of 1980-2018. Jebli and Youseff, (2017) revealed a bidirectional causality between agricultural value added and CO_2 emissions in Tunisia spanning the period 1980-2011 using the Vector Error Correction Model (VECM) and Granger causality tests.

According to Chopra et al. (2022), CO_2 emissions reduced agricultural production for ASEAN countries from the year 1992-2016 using the ARDL model. In addition, a study by Gurbuz et al. (2021) inferred that agricultural productivity had a negative impact on environmental quality using the ARDL model between 1992 and 2014. A study by Selcuk et al. (2021) reported that maize production had a negative impact on CO_2 emissions for the 11 countries that have emerging markets that could potentially become some of the world's largest economies (Next Eleven countries) from 1991 to 2019 using the Common Correlated Effects Mean Group Estimator (CCEMG) and Dumitrescu–Hurlin panel causality test.

2.6.2. Agricultural Productivity and Renewable Energy

Using the ARDL bounds testing approach for Pakistan from 1984 to 2016, Chandio et al. (2019) reported that agricultural production positively affected renewable energy consumption in both the long-run and short-run. Consecutively, Rokicki et al. (2021) found that agricultural production enhanced energy usage for European Union (EU) countries from 2005 to 2018 using Spearman's rank and Kendall's Tau correlation coefficient. According to Rehman et al. (2020), energy consumption in Pakistan had a positive relationship with agricultural growth from the 1980-2016 period using Granger causality and ARDL. Similar findings were reported by Wang, (2022) for China between 1985 and 2019 using the ARDL approach. According to the findings by Shastri et al. (2020), renewable energy supply stimulated growth in India during the 1971-2017 period using the ARDL model and asymmetric causality tests.

Similar findings were reported by Azam et al. (2021) in a study of 25 emerging economies from 1990-2017 period using the ARDL model. Additionally, a study By Ageli, (2022) reported similar results for Saudi Arabia during the 1995-2021 period using the Bootstrap Autoregressive Distributed Lag (BARDL). In Sub-Saharan African countries (SSA), the ARDL model showed that renewable energy enhanced agricultural production by improving the value-added sector during the 1985-2017 period (Fotio et al. 2022). According to Qiao et al. (2019), renewable energy use enhanced agricultural economic growth in the G20 countries from 1990 to 2014 period using FMOLS. The incorporation of renewable energy was observed to boost productivity for a panel study from 1985 to 2019 period using the Generalized Method of Moments (GMM), Non-Linearity Autoregressive Distributed Lag (NARDL), and heterogenous causality test (Qamruzzaman, 2022).

A study by Ben Jebli and Ben Youssef, (2017) revealed a bidirectional relationship between agricultural productivity and renewable energy use in Tunisia spanning the period 1980-2011 using the VECM and Granger causality tests. In contrast, Gurbuz et al. (2021) reported a unidirectional causality between agricultural value added and renewable energy use using the Granger causality test for Azerbaijan from the 1992-2014 period. Comparable findings were reported by Chopra et al. (2022) for ASEAN countries using the Pairwise Dumitrescu and Hurlin Panel Causality tests using 1992-2016 data. A rise in agricultural development was caused by a rise in the use of renewable energy in China during the 1998-2018 period using the ARDL model (Koondhar et al. 2021). According to a study by Tagwi, (2023) in South Africa, a negative link between the economic expansion of agriculture and the provision of renewable energy was observed during the 1990-2021 period using the ARDL, FMOLS, DOLS, and CCR econometric analysis. According to Xin-gang and Jin, (2022), renewable energy consumption had minimal impact on agricultural growth compared to fossil energy consumption in eastern, central, and western China regions from 2000 to 2018 period using panel Granger causality tests based on VECM. A study by Hao, (2022) revealed a strong negative relationship between renewable energy consumption and agricultural commerce in China over the 1990-2020 period using the co-integration test, causality test, and impulse response analysis.

2.6.3. Agricultural Productivity and Trade

According to Ghimire et al. (2021), agricultural trade significantly promoted growth in Bangladesh using the ARDL model during the 1972-2019 period. A study by Ben Jebli and Ben Youssef, (2017) revealed a bidirectional causality between agricultural value added and trade in Tunisia from the 1980-2011 period using VECM and Granger causality tests. Using the Unit root, co-integration, Ordinary Least Square assumption tests, Least

Square estimation model, Pearson Coefficient, and Generalized Least Model (GLM) for Nigeria from 1970 to 2016 period. Adeosun et al. (2019) reported that the amount of maize imported limited the amount of local maize production. According to Ren et al. (2018), low production of maize due to the water not being suitable for food production contributed to more imports of maize from the Beijing-Tianjin-Hebei regions in China during the 2002-2012 period.

According to a study by Kashifi et al. (2022), Saudi Arabia's trading of main grain commodities decreased maize production but had significant impacts on energy and CO_2 emissions savings from the 2011-2019 period using the long-term global averages of the water footprint. Huan and Liu, (2023) pointed out that an increase in local agricultural production led to an increase in global agricultural trade for Europe, Oceania, Asia, America, and Africa from the 2000-2019 period using coupling models, complex network analysis, and mathematical programming. In a European Union (EU), African, Caribbean, and Pacific countries study, Balogh and Leitão, (2019) indicated that abundant agricultural products produced in Africa were exported to Europe during the 1996-2017 period using the gravity model. Agricultural trade was also found to have a long-lasting substantial impact on agricultural production in Sub-Saharan African countries from 1990-2016 period, using the Panel Structural Vector Error Correction Model (PSVECM) (Ogunlesi, (2018). A study by Khan et al. (2020) found a bidirectional causality within agricultural production and agricultural product export in Pakistan during the 1976-2016 period using the ARDL and the VECM. Similarly, a study by Khan et al. (2021) reported that an investment in agricultural inputs increased the export of agricultural products in Pakistan using 1976 to 2017 data estimated by the ARDL bounds test. Furthermore, a study by Zang et al. (2022) revealed that agricultural growth contributed to the general rise in agricultural trade in China from 2002 to 2020 period using the Unit Root Test, Model lag order selection, Johansen cointegration test, Model stability test and the predictive variance decomposition method.

A study by Sylvester et al. (2023) recommended that non-traditional agricultural exports should be supported by the government since they contributed heavily to the agricultural GDP in Ghana from 1961 to 2019 using the ARDL model. Similarly, Kastratović, (2023a) observed that foreign direct investment in agriculture had a positive impact on agricultural exports in a panel of 80 developing countries from 2005-2017 data employing the Pedroni and Kao approaches. Similar results were reported by Kastratović, (2023b) using the Tobit model for Serbia for the 2014-2017 period. A study by Adekunle and Ndukwe, (2018) inferred that real exchange rates were the forces behind agricultural production in Nigeria from 1981 to 2016 period employing the VECM, Granger Causality test, Error Correction Model (ECM), Two-stage least squares, and the FMOLS. Mamba and Ali, (2022) found that agricultural exports enhanced agricultural growth for the Economic Community of West African States (ECOWAS) during the 1996-2018 period using the instrumental variables approach for endogeneity.

2.6.4. Agricultural Productivity and Economic Growth

A study by Oyakhilomen and Zibah, (2014) revealed that agricultural production influenced economic growth in Nigeria between 1970 and 2011 using the ARDL approach. Michael's, (2017) study in Nigeria during the 1980-2014 period using the Granger causality test found a unidirectional causality between agricultural production and economic growth. Using the VECM, ADF, and the Johansen Cointegration Trace and Max Eigen-Value tests, Koyuncu, (2023) reported a linear relationship between economic growth and agricultural productivity in Nigeria from 1981 to 2015. Ehighebolo, (2023) also observed a linear relationship between agricultural production and economic expansion in Nigeria during the 1981-2021 period using the Eagle-Granger Co-integration and the ECM model.

A study by Nora et al. (2018) showed a unidirectional relationship between agricultural productivity and real GDP in Peru from 1998-2016 period using the Ordinary Least Square regression, the Augmented Dickey-Fuller test, the Phillip Perron test, and the Granger Causality test. Aboyitungiye and Prasetyani, (2021) found a linear relationship between agricultural development and economic growth in the Republic of Burundi during the 1970 to 2016 period using the ARDL approach. Using the ADF test, ARDL, and the Bounds co-integration test for the period of 1981 to 2018. Anderu and

Omotayo, (2020) found that government spending on agriculture enhanced agricultural production in Nigeria.

Enilolobo et al. (2019) also found a bidirectional causality between agricultural growth and the unemployment rate for the 1981-2016 period using the Granger causality test, the ARDL bounds test, the ADF unit root test, and the ARDL error correction model in Nigeria. Abubakar, (2017) observed a positive and significant association between economic globalization and agricultural production in Turkey from the 1970-2008 period using the NARDL. A study by Moh'd, (2020) revealed that economic expansion influenced agricultural export revenue in Tanzania from the 1990-2019 period using the multiple linear regression analysis. Iwegbu and de Mattos, (2022) found that financial development for agriculture had a more positive impact on the agricultural productivity of BRICS than that of West African Monetary Zone (WAMZ) member countries for the 1990-2019 period using the fixed effect panel regression and the dynamic fixed effect. Ali et al. (2023) reported that an increase in GDP increased agricultural productivity for SSA countries for the 1997-2020 period using the two-step difference GMM. Using the Engle-Granger causality tests, a unidirectional causality was observed from economic growth to agricultural exports in Pakistan from 1970 to 2014 (Mahmood and Munir, 2018). A study by Ahmad et al. (2020) revealed that foreign direct investment had a positive but not much of an influence on agricultural growth in China from 1984 to 2017 using the ARDL model and Granger Causality test. In China, Bakari and Tiba (2022) found that agricultural productivity contributed to job creation and other opportunities for the economy during the 1984-2017 period using the ARDL bounds testing approach. Agricultural development was also perceived as an engine for growth in the Arab World from 1980-2018 using the Johansen test and the ARDL bound test (Mohammed, 2020).

2.7. Research gap

From the above literature, it can be seen that maize is a significant energy crop being utilized by developing countries such as Brazil, Japan, and China just to mention a few. So it is also important to note that for a country like South Africa to adopt this strategy a lot of investment has to be directed to the production of maize. There is a need for advanced technological innovations and comprehensive environmental impact assessments. Specifically, South Africa lacks research on precision agriculture, biotechnology for high-yield maize, and integrated environmental impacts such as soil health, water usage, and lifecycle greenhouse gas emissions. References from developed countries like the United States and the European Union, where such technologies and assessments are more advanced, highlight the potential benefits of adopting similar approaches in South Africa as highlighted by the above literature. In addition, technological innovations in bioenergy conversion technologies and their integration with South Africa’s renewable energy systems should be studied to enhance grid stability and energy security. Comparative studies with other energy crops will help identify the most effective and sustainable bioenergy options for the country.

Secondly, there is an embargo in South Africa for using maize as a bioenergy feedstock due to food security concerns. South Africa needs to identify and address policy gaps to support sustainable bioenergy development. Developed countries like Germany and the United States offer robust policy frameworks that could serve as models for South Africa. Additionally, there is a lack of socio-economic impact studies focusing on the effects of maize bioenergy on local communities, food security, employment, and rural development. Research from developed countries demonstrates the importance of understanding and addressing these socio-economic impacts to ensure equitable and sustainable development. Addressing these gaps as justified by the above literature will contribute to climate resilience and sustainable energy production in South Africa.

2.8. Maize as an energy crop

Maize serves as a versatile energy crop, primarily used to produce bioethanol, biogas, and electricity (Assaf et al. 2024). Ethanol is generated from maize grains and combined with petrol to provide a greener alternative to fossil fuels and anaerobic digestion of maize silage and leftovers produces biogas, which provides renewable energy for electricity, heating, and transportation (Malik et al. 2024). Additionally, maize residues, including leaves and stalks, are utilized for biomass energy, either directly in biomass power plants or processed into pellets for fuel (Sikiru et al. 2024). Despite its benefits, there are significant concerns surrounding the use of maize for energy in South Africa. According to Grote et al. (2021) one of the primary issues is food security; diverting maize from food and animal feed production to energy can increase food prices and reduce availability, potentially impacting vulnerable populations. However, a preponderance of literature has shown that these concerns are farfetched because not the actual maize is used for the energy conversion but it's leftovers, stalks, and leaves, etc and all these will not compete with people or animals for any resources. In any case, more food will be available if there is an expansion of the maize industry. Farmers and investors face financial risks, and the lack of adequate technological infrastructure, such as biorefineries and biomass power plants, poses challenges for scaling up maize-to-energy initiatives in South Africa (Imoisili and Jen, 2024). Balancing these concerns with the benefits of renewable energy and sustainable agricultural practices remains a critical challenge for policymakers and stakeholders in the region.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter covered the review of the analytical framework, research design, study area, variables, and data collection and data analysis approach, used in this study.

3.2. Review of the Analytical Framework

This section reviews relevant estimation techniques that can be used to forecast time series data. From the literature, many techniques can be used to estimate forecast relationships in time series. In this study, Auto Regressive Integrated Moving Average (ARIMA), Vector autoregression (VAR), Autoregressive Distributed Lag (ARDL), Vector Error Correction Models (VECM), SeriesNet, and Exponential smoothing techniques will be briefly discussed.

3.2.1. Auto-Regressive Integrated Moving Average (ARIMA) model

The ARIMA model was developed by George Box and Gwilym Jenkins in 1976 (Harvey and Todd, 1983). The ARIMA model is a statistical analysis model that predicts future trends using past trends. To forecast future values, it combines lagged observations (AR), differencing (I), and moving averages (MA) capturing temporal patterns within a single time series (Chatfield and Xing, 2019). The model assumes that it considers the linearity of time series data (Newbold, 1983). As per the ARIMA's assumptions of linearity and stationarity, we can deduce that the model has the potential for parsimony and parameterization, thus providing a balance between simplicity and accuracy. The ARIMA model is the most efficient in short-term forecasting and prediction (Ariyo et al. 2014). Parameter estimation, diagnostic checking, and model identification are the phases involved in creating an ARIMA model (Tabachnick and Fidell, 2001). The study intends to estimate both short and long-run relationships and therefore this technique is limited.

3.2.2. Vector Autoregression (VAR)

To comprehend the connections between several time series data, Vector Autoregressive (VAR) models are used (Docheshmeh-Gorgij et al. 2022). They illustrate how the previous values of each variable and the previous values of the other variables impact each other. In the setting of a multivariate time series, VAR models aid in interaction analysis and future value dynamic forecasting (Beard et al. 2019). The VAR model was introduced by Christopher Sims in the 1980s as a model that can account for the dynamic effects of multiple variables (Sims,1986). Forecasting future trends based on current or past events is key, precisely because the effects of an action or event can happen immediately or gradually and therefore to account for this, the lagged effects must be considered in the analysis (Wagner et al. 2002). VAR is suitable for larger sample sizes; however, the limitation of the VAR is that it does not account for cointegration (long-term equilibrium). Cointegration indicates that despite possible short-term changes in series, several variables move together over the long term. VAR also requires that series should be integrated in the same order, either at level (I (0)) or at the first difference (I(1)), and the lags should also be of the same order. This will not be sufficient for this study.

3.2.3. Autoregressive Distributed Lag (ARDL)

Considering that economic events are not static and therefore introduce a lot of dynamics in economic data, econometric models that can capture the dynamics are important. The ARDL model is known for its ability, it is employed for analyzing the dynamic effects of variable changes and is capable of handling mixed integration orders in multivariate data (Pesaran et al. 2001). ARDL is intended to investigate the relationships between dependent and independent variables while accounting for both short-term and long-term impacts by including both **Autoregressive (AR)** and **Distributed lag components**. The AR Component illustrates the relationship between the ***dependent variable's*** present value and its previous values (lags). This component shows short-term relationships, considers transient dependencies, and assists in detecting any serial correlation in the data. The Distributed Lag Component shows how the lagged values of the ***independent variable(s)*** influence the dependent variable's current value. This component shows both short- and long-term relationships. Therefore, the ARDL models using historical values of both the dependent variable and the independent variables help us to understand recent and long-term effects. Pesaran et al. (2001) introduced the Autoregressive distributed lag model (ARDL) to test for cointegration, determine whether a dependent variable and a set of independent variables have a level relationship, and determine the short- and long-run equilibrium for a subset of time series data. The ARDL can analyze both at the level, first difference, and even mutually cointegrated, which gives it an advantage over a simple cointegration technique due to the variables' flexible stationary properties (Pesaran and Shin, 1998).

A small sample can yield reliable and effective evidence using the ARDL approach (Khan et al. 2021). Simultaneously, it may calculate the short- and long-term coefficients of one variable on another, as well as the impact of the endogenous explanatory variable (Pesaran & Shin 1998; Pesaran et al. 2001). A few of the ARDL's stated flaws include that it only takes into account one degree of correlation between the variables and that the findings may be affected by lag selection. It presupposes linearity between the independent and dependent variables and is not appropriate for larger sample sizes (Tagwi, 2022). Larger sample sizes are unsuitable for this approach. The ARDL is primarily concerned with discovering interactions between variables that have the potential to cointegrate, whereas VAR models aim to capture interactions among different variables in a more general multivariate setting. Even when series are incorporated into several orders, ARDL can still be applied. This approach is the most appropriate for analyzing the data in this study since it takes into account the main purpose, the quantity of observations, and the properties of the ARDL.

3.2.4. Vector Error Correction Models (VECM)

The cointegrated relationship, which causes the variables to move closely together over time while permitting a wide variety of short-term dynamics, could be tested using the error correction model *Error Correction Model* (ECM) (univariate model) (Lu et al., 2018). A negative and significant coefficient value (ECM) is expected which indicates the ability of the economy to self-correct in the long run (Asari et al. 2011). Thus, series may be different in the short-run but be tied together in the long-run (Granger, 1981). The ECM (Error Correction Model) demonstrates how cointegrated variables recover to equilibrium following deviations by focusing on short-term adjustments among them. To capture both short-term and long-term dynamics interactions among cointegrated variables comprehensibly, ECM extends to multiple variables to become VECM (Vector Error Correction Model) which becomes a multivariate model. A thorough understanding of how variables interact throughout time is provided by VECM. VAR models are restricted and unsuitable when co-integrating relationships. When two variables exhibit a similar trend and their linear combination remains constant, this phenomenon takes place (Engle and Granger, 1987). The Granger causality test is done in the absence of cointegration, and the VECM is used to assess the short-run effects if it exists. If the research finds evidence of co-integration, then the VECM can be run.

3.2.5. SeriesNet

SeriesNet is a specialized model designed to analyze time series data by leveraging two distinct networks: an LSTMs (Long Short-Term Memory networks) network to capture overall patterns and features, and a dilated causal convolution network to capture information across various time intervals (Shen et al. 2020), this unique combination allows SeriesNet to achieve superior predictive accuracy. SeriesNet was proposed as an alternative to established time series forecasting techniques like ARIMA and Exponential Smoothing. The model incorporates residual learning and batch normalization techniques to enhance its ability to generalize, make more robust predictions and merge time series features (Mao et al. 2016). SeriesNet can forecast non-linear and non-stationary economic data compared to other models (Shen et al. 2018). Additionally, Cheng et al. (2020) emphasized that, compared to other models, SeriesNet has the finest forecasting accuracy. Economic time series data displays complex and non-linear temporal patterns that are difficult to detect using conventional techniques like ARIMA and SeriesNet can account for. SeriesNet can become complex with many layers and demands, **hyperparameter tuning** which can be time-consuming and computationally intensive. In this study, this technique will be complex and therefore not preferred.

3.2.6. Exponential smoothing

Exponential smoothing is a time series forecasting model best known for its practical considerations in short-run forecasting and the on-point accuracy of predictions with the least amount of effort in model identification (Gardner, 1985). It was put forward in the late 1950s (Brown, 1959; Holt, 1957) and went on to become one of the best forecasting models. Exponential smoothing simplifies seasonal changes, supports various seasonality time series, and is adaptable enough to accommodate non-integer seasonal periods (Hyndman and Athanasopoulos, 2018). Exponential smoothing is not dependent on stationarity and differencing since differencing alters the data scale and makes the information criteria values between models with different orders of differencing incomparable (Seong and Lee, 2021). This technique pays more attention to recent data and less to old data contrary to the ARDL. Since the study intends to estimate both the short and long-run effects this technique will not be sufficient.

3.3. Research Design

The research philosophy used in this study was positivism. A type of philosophy that has a strong emphasis on accounting only for facts and raw data that has not been manipulated by the interpretation of human bias (Scotland, 2012). The research aims to discover observable, measurable facts, and regularities, fostering credibility and meaningfulness in data, it seeks causal relationships, law-life generalization, and important fundamental principles and theories to support and explain the behaviour of variables (Alharahsheh and Pius, 2020). The deductive research approach was used since it is an approach used in quantitative research to test theories by deducing evidence to either support or deny them. It is also used in arguments based on laws, theories, rules, or other widely accepted principles (Soiferman, 2010). A quantitative methodological choice was used in this study. It deals with data that are numerical or can be transformed into numerical data (Sheard, 2018). This type of research typically applies statistical methods to test causal hypotheses using *a priori* theoretical constructs (Waljee et al., 2014). Numerical data was collected and analyzed over a selected period, 1979-2021 to be precise, this was influenced by the degrees of freedom (at least 30 observations) applicable in time series analysis, in addition, the period was selected based on the consistency of the available data on the variables. Yearly data used in the study were sourced from several sources. There are various research strategies, such as experimental research strategy (analyzes the cause-and-effect relationship) (Rust et al. 2019), however in this study exploratory strategy was used, as historical data was used to estimate future possibilities. And longitudinal research design/time horizon was used since it is a type of research design that demands quality and consistent data available for public consumption, assesses them over time, examining changes and reasons behind them (Menard, 2007).

3.4. Study area

South Africa, the southernmost country in Africa with a population of more than 60 million, served as the study's location (Stats SA, 2022). South Africa is 1,219,602 square kilometres in size (GCIS, 2018). Figure 3 below illustrates how the country borders Namibia, Botswana, Zimbabwe, Mozambique, and Eswatini, and how South African territory encloses the mountainous kingdom of Lesotho in the southeast. According to Michel et al. (2003), South Africa experiences 464 mm of annual rainfall, making it a relatively dry country. Maize production in South Africa is estimated to be at about 15.0 million metric tonnes for the period 2021/22 which is a 2% increase from the previous period of 2020/21 (Agbiz, 2022). The South African Gross Domestic Product (GDP) stands at 405.87 billion US dollars, whilst the trade % share to GDP sits at 64.91% (Worldbank, 2022). South Africa’s carbon emissions status is estimated to be at about 7.34 tonnes (Our World in Data, 2021).

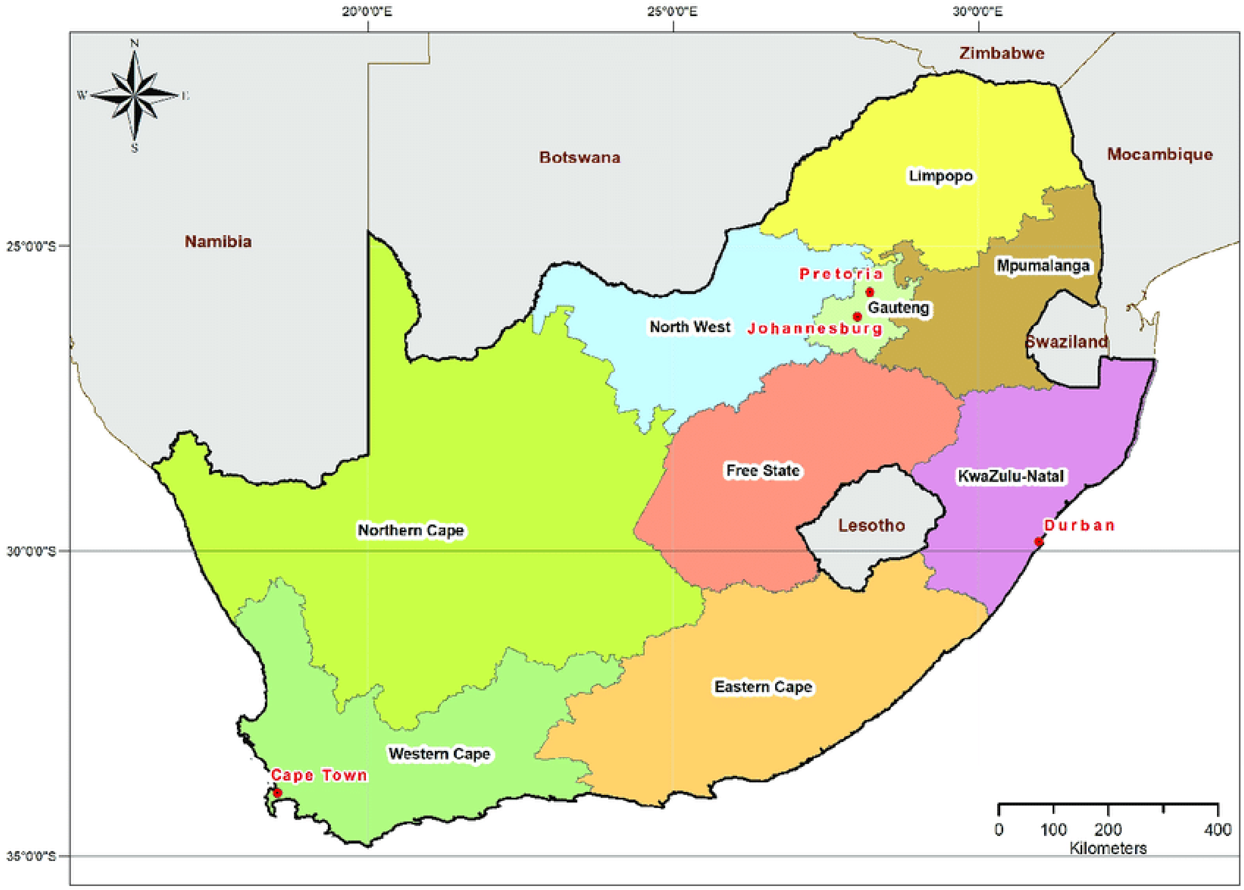

Figure 3.1: South African Map
Source: WorldAtlas.com (2024)

3.5. Variables and data collection in the study

The study seeks to assess the impact of renewable energy supply, carbon emissions, trade, and economic growth on maize production in South Africa by applying the ARDL method with annual time series data from the Food and Agriculture Organization (FAO) that is accessible to the general public, World Development Indicators (WDI), and BP statistics over 42 years from 1979 to 2021. The variables of interest in the study were, Maize Production (MPDUC) which is the response variable in the study whilst Carbon Dioxide Emissions (CO_2), Renewable Energy Supply (RENS), Trade (TRADE), and Economic Growth (GDP) are the explanatory variables. Maize Production in tonnes (t) was sourced from FAO statistics, Carbon Dioxide Emissions in millions of tonnes (Mt), and Renewable Energy Supply in terawatt-hours (TWh) was obtained from BP statistics whilst trade (represented in % of GDP) and Economic Growth (represented in GDP per capita) were acquired from World Development Indicators (WDI). Economic Views software package (EViews) 13 and STATA 18 were used to analyze the data.

Table 3.1: Variable description

CODE	VARIABLE	UNIT OF MEASUREMENT	DATA SOURCES
MPDUC	Maize Production	Tons (t)	FAO
CO2	CO2 Emissions	Million tons (Mt)	BP stats
RENS	Renewable Energy Supply	Terrawatt-hours (TWh)	BP stats
TRADE	Trade	% of GDP	WDI
GDP	Economic Growth	GDP per capita	WDI

Source: Author's Compilation (2024)

3.6. Data analysis

3.6.1. Structural break

To ensure that the results of the model will not be spurious, the reliability of the data set was checked. There are various ways of checking for data stability, in this study structural break tests were conducted. The structural break is when time series data unexpectedly changes at a certain moment in time (Zhou, 2013). The unexpected changes could be due to an economic shock, regime change, or a recession. It is crucial to take structural breaks into consideration since they provide deep insights into potential problems which can lead to serious forecasting errors and lastly suggest that the model is unreliable (ön et al. 2021). In this study, the Chow test, which is a statistical test for structural breaks developed by Gregory Chow in 1960 was used. We use a Chow test to determine if there is a structural break point in the data at a certain point in time (Dao, 2022). Should structural breaks be detected, this will be corrected by the inclusion of dummies in the model.

3.6.2. Trend analysis

Publicly available data was used to analyze maize and trade trends. Specifically from Our World in Data, World Integrated Trade Systems, and World Bank.

3.6.3. Descriptive Statistics

Measures of dispersion (standard deviation, skewness, and kurtosis), minimum and maximum, and measures of central tendency (mean, median, and mode) were used to analyze the descriptive statistics for each variable in the study, both independent and dependent.

3.6.4. Inferential Statistics

3.6.4.1. Autoregressive distributed lag model (ARDL)

In this study, the ARDL model was used to examine the relationship between the dependent variable (maize production) and the independent variables (CO_2 emissions, renewable energy supply, trade, and economic expansion) both in the short-run and long-run. Figure 1 below shows the ARDL approach analytical technique steps that were followed in this study:

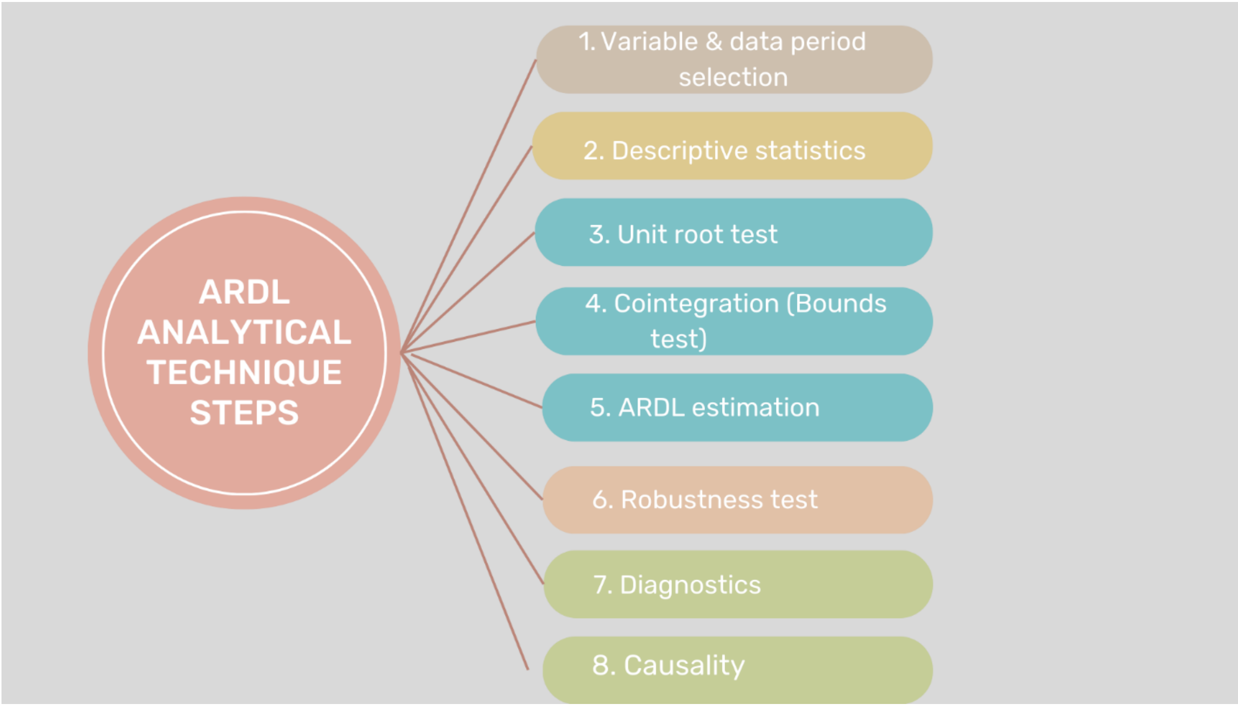

Figure 3.2: Study analytical techniques steps

Source: Author's Compilation (2024)

Finding pertinent macroeconomic factors that would account for the economy's production of maize was the first step. The variables that have been identified include trade, economic growth, supply of renewable energy, and CO_2 emissions. Next, a suitable range of data (1979–2021) was selected to best explain the production of maize. The stationarity unit root test was carried out using the Philip-Perron (PP) and Augmented Dickey-Fuller (ADF) tests after descriptive statistics were analyzed. The ARDL model was then estimated using both a long-run and short-run estimation, followed by a bounds test to verify cointegration. The FMOLS, DOLS, and CCR models were then used to assess the robustness of the model. The jarque-bera test for normalcy was used to perform the diagnostic tests; the Breusch-Godfrey serial correlation test was used to test the serial correlation; and finally, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) techniques were used to validate the stability of the model. Finally, the Pairwise Granger Causality Test was used to conduct a Granger causality test in order to ascertain the direction of causality within the series.

3.6.4.2. Multicollinearity, autocorrelation, and heteroskedasticity check

Multiple independent variables and their lagged values are used in ARDL models, and problems with multicollinearity might arise when these variables are highly correlated. To correct for this appropriate lag selection was automated in the model. Correlation Matrix was also checked to check for multicollinearity problems. High correlation values (close to 1 or -1) indicate potential multicollinearity. Where high multicollinearity is observed, appropriate theoretical justification was provided. When data points in a time series are correlated with their previous or future values, this is known as serial correlation (autocorrelation). Displaying trends of high or low values over time can have an impact on statistical tests and forecasts and therefore this was checked using the Durbin-Watson Test. A formal statistical approach to finding autocorrelation in residuals is the Durbin-Watson test. It offers test statistics that range from 0 to 4. No autocorrelation is present when the value is near 2. Significantly lower numbers than 2 indicate a positive serial correlation, whilst significantly higher values indicate a negative serial correlation. Time series data also suffers from the problem of heteroskedasticity which refers to a situation where the difference between the actual and predicted values (residuals) largely varies across multiple levels of the independent variables. If not corrected, standard errors might be biased, leading to spurious results. This was checked using scatterplots of residuals, the Breusch-Pagan test, and the White test. Transforming the variables was used as a measure to correct these statistical variability problems.

3.6.4.3. Empirical model

The relationship is stated as follows in a general estimation form:

$$Y_t = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon_t \quad (1)$$

3.6.4.4. Specified model

Equation 2 shows the general fitted form. The variables are expressed in a log form.

$$LnMPDUC_t = f\ (LnCO2t + LnRENSt + LnTRADEt + LnGDPt) \quad (2)$$

Where LnMPUDC represents the log of maize production, LnCO2 represents the log of carbon dioxide emission, LnRENS represents the log of renewable energy supply, LnTRADE represents the log of trade, and LnGDP represents the log of gross domestic product.

Equation 2 can further be expanded in equation 3 as follows:

$$LnMPDUC_t = \alpha_0 + \varphi_1(LnCO2)_{t-1} + \varphi_2(LnRENS)_{t-1} + \varphi_3(LnTRADE)_{t-1} + \varphi_4(LnGDP)_{t-1} \quad (3)$$

Equation 4 shows the specified ARDL model where φ represents the long-run elasticities coefficients and θ represents the short-run elasticities coefficients. The p and q represent the lag lengths of the regressand and regressors respectively. The disturbance term is represented by ε_t

$$\Delta LnMPDUC_t = \alpha_0 + \varphi_1(LnCO2)_{t-1} + \varphi_2(LnRENS)_{t-1} + \varphi_3(LnTRADE)_{t-1} + \varphi_4(LnGDP)_{t-1} + \sum_{i=1}^{p}\theta_1\Delta(LnMPDUC)_{t-1} + \sum_{i=1}^{q}\theta_2\Delta(LnCO2)_{t-1} + \sum_{i=1}^{q}\theta_3\Delta(LnRENS)_{t-1} + \sum_{i=1}^{q}\theta_4\Delta(LnTRADE)_{t-1} + \sum_{i=1}^{q}\theta_5\Delta(LnGDP)_{t-1} + \varepsilon_t \quad (4)$$

Equation 5 shows the long-run relationship:

$$\Delta LnMPDUC_t = \alpha_0 + \varphi_1(LnCO2)_{t-1} + \varphi_2(LnRENS)_{t-1} + \varphi_3(LnTRADE)_{t-1} + \varphi_4(LnGDP)_{t-1} + \varepsilon_t \quad (5)$$

Equation 6 shows the short-run relationship:

$$\Delta LnMPDUC_t = \alpha_0 + \sum_{i=1}^{q}\theta_1\Delta(LnCO2)_{t-1} + \sum_{i=1}^{q}\theta_2\Delta(LnRENS)_{t-1} + \sum_{i=1}^{q}\theta_3\Delta(LnTRADE)_{t-1} + \sum_{i=1}^{q}\theta_4\Delta(LnGDP)_{t-1} + \varepsilon_t \quad (6)$$

Equation 7 shows the error correction model (ECM) with short- and long-run relationships. The error correction model is represented by μECM. The ECM measures how long it will take for the long-run disequilibrium to be corrected (speed of adjustment). The error term should be significantly negative for the correction to hold, and the relationship be established.

$$\Delta LnMPDUC_t = \alpha_0 + \varphi_1(LnCO2)_{t-1} + \varphi_2(LnRENS)_{t-1} + \varphi_3(LnTRADE)_{t-1} + \varphi_4(LnGDP)_{t-1} + \sum_{i=1}^{p}\theta_1\Delta(LnMPDUC)_{t-1} + \sum_{i=1}^{q}\theta_2\Delta(LnCO2)_{t-1} + \sum_{i=1}^{q}\theta_3\Delta(LnRENS)_{t-1} + \sum_{i=1}^{q}\theta_4\Delta(LnTRADE)_{t-1} + \sum_{i=1}^{q}\theta_5\Delta(LnGDP)_{t-1} + \mu ECM_{t-1} + \varepsilon_t \quad (7)$$

CHAPTER 4: RESULTS OF MAIZE PRODUCTION AND TRADE TREND

4.1. Introduction

In this chapter, the production and trade trends spanning from 1979 to 2021 were discussed. The chapter also discussed the trade complementarity index (TCI), the trade opportunities for African countries using the African Continental Free Trade Area (AfCFTA) as a reference.

4.2. Maize production trends in South Africa

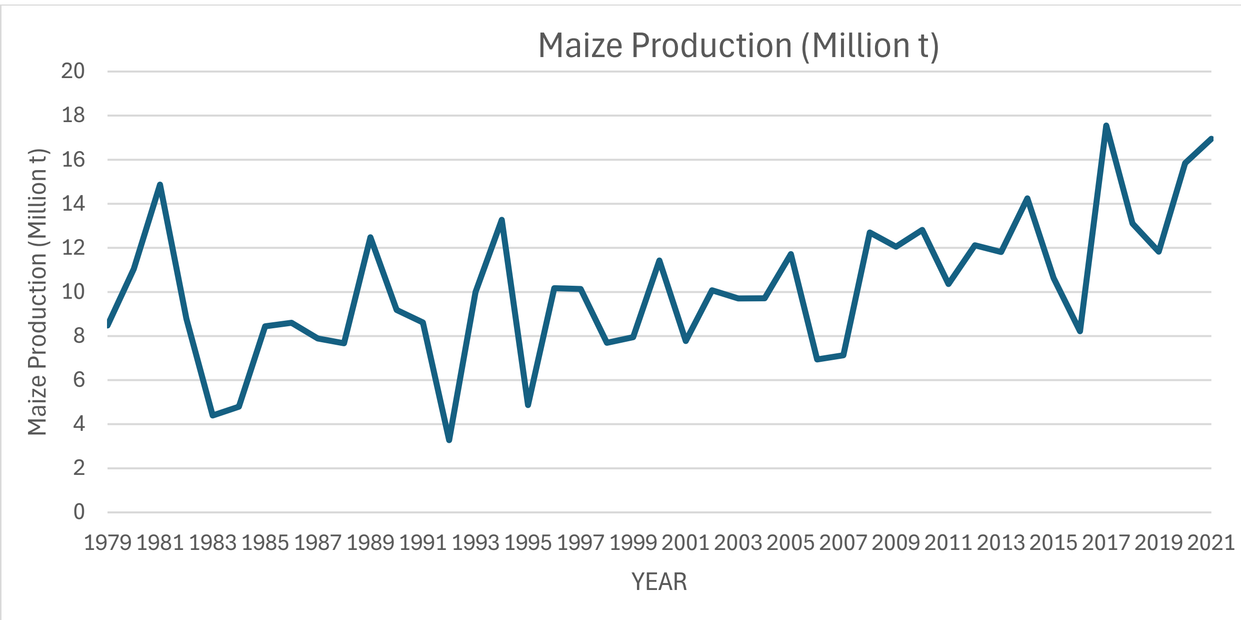

Figure 4.1: Historical trend of maize production

Source: Our World in Data, (2024)

Figure 4.1. shows the historical trends of maize production from 1979 to 2021. Maize in South Africa was introduced in 1655 and has since become one of the main food crops produced in all the provinces (Sihlobo, 2018). In 1981 there was a notable surge in maize production (14.87 million t), a study by De Klerk (1983) reported that technological advancement, weeding, an increase in the surface area of farms in 1968, and an increase in wages of farm workers made the difference, between 1968 and 1981, mechanized crop harvesting increased from 30% to 95%, while weed spraying expanded from 15% to 95% of the total crop area. 1973-1977 saw a 75% increase in average farm size, and real

wages for permanent workers rose by 150% from 1970 to 1981. These changes reflect significant mechanization and productivity growth in South Africa's agriculture sector.

There was deficient production of maize between the years 1982/83/84, 1991/92 and 2006/07, studies by Payne et al. (1990) and Du Toit and Prinsloo, (2001) opined that these were the El Niño years characterized by deficient rainfall and severe drought conditions which led to meagre harvests. Similar findings were reported by Moeletsi et al. (2011). In 1989 there was a high peak of production at about 12.48 million t. This was the case because of the restructuring of market-related agricultural policies, which included shifting subsidy policy and, in some cases, eliminating subsidies; exposing farmers to market-related interest and exchange rates, and extensively deregulating restricted marketing systems (Van Zyl et al. 1992). A rise in the production of maize during the years 1993/94 was a result of the political, regime, and democratic transition which brought along a restructure of agricultural policies. These policies advocated for investment in rural small-scale agriculture, employment, and the deregulation of agricultural marketing which boosted the industry's competitiveness (African National Congress, 1994).

A study by Mqadi, (2007) emphasized that a drop in the production of maize in 1995 and 1998 was influenced by competition in the global markets and varying climatic conditions as these were the El Niño years characterized by low rainfall and drought conditions. During the years 2008/09/10 maize production almost doubled from the previous two seasons 2006/07 and this was a result of these years being the La Niña years which are characterized by high rainfall events that are very much favourable for improved production (Moeletsi et al. 2011). A drop in the production of maize in the season 2015/16 was driven by the severity of drought and heat stress which was recorded as the strongest in the history of El Niño (Setimela et al. 2018). Null, (2019) reported similar findings. In a study by Haarhoff et al. (2020), it was reported that an increase in maize production in 2017 was a result of crop breeding which resulted in more drought and disease-tolerant crops.

The development of these drought and disease-tolerant crops was influenced by numerous El Niño seasons previously before 2017. Grain SA, (2021) opined that an increase in production of maize in 2017 was a result of the area under cultivation increasing from 2.5 million Ha in 2016 to 2.9 million Ha in 2017. In 2019, the decrease in maize production was attributed to delayed rainfall which led to a decline in the amount of area planted (Akanbi et al. 2021). Abubakar et al. (2020) opined that the decline in maize production in 2019 was due to extreme drought conditions. Coleman, (2021) reported that an increase in the production of maize in the season 2020/21 was a result of complementary and timely rainfall received in that season which allowed farmers to plant very early into the season. Most seasons have been affected by this, the El Niño years mostly affected the production of maize. The production trend confirms that climate change has created climate variability which creates uncertainty, threatening food security and farmers' well-being. Climate variability plays a major role in maize production in South Africa, constituting the basis of this study. The following figure below shows the historical trends of precipitation (rainfall) for 42 years (1979-2021).

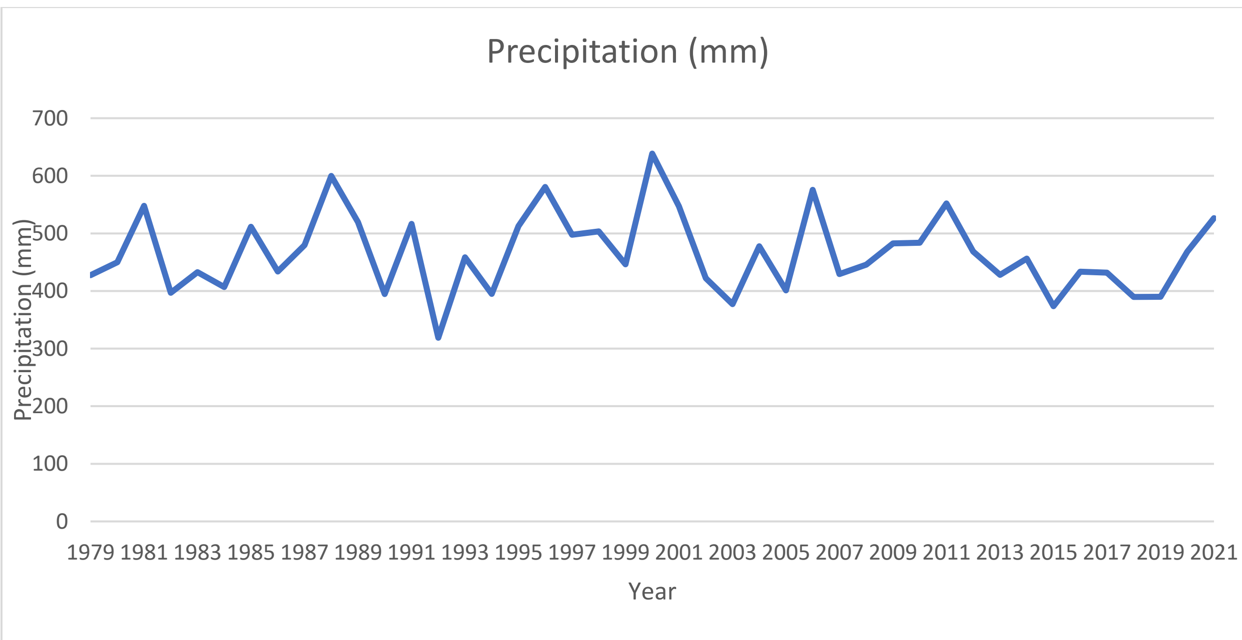

Figure 4.2: Historical trend of precipitation (rainfall)

Source: Author's compilation (2024)

4.3. Agricultural trade in South Africa

Agriculture faces challenges in meeting global food demands, urbanization demands, and generating jobs. Although trade can potentially increase environmental externalities, deforestation, and production relocation, the sector supports rural livelihoods, mostly in developing countries. (Balogh and Jambor, 2020). Globalization opens up agricultural markets providing more opportunities for trade for the sector and stimulating local production and job creation. A study by Smith and Glauber (2020) opined that international trade for agricultural products will be more important in the future as it bolsters food insecurity, starvation, and malnutrition globally. Similarly, Brenton et al. (2022) emphasized that imports and exports of agricultural products are equally important, especially in the climate change era. Exporting agricultural products is a key fundamental in a country’s foreign currency injection (Nhamo et al. 2018). It has been estimated that the total agricultural exports in 2022 in South Africa amounted to about R118 billion and imports amounted to about R39 billion (Department of Trade, Industry and Competition, 2023). According to Sihlobo, (2022), maize was one of the top exportable products in 2022. This of course has been achieved through different trade agreements with several countries. The advent of renewable energy production increase globally is expected to influence global maize production as maize can be used for bioenergy generation, especially in developed countries. In this era maintaining global trade relations has even become more important for the agricultural sector.

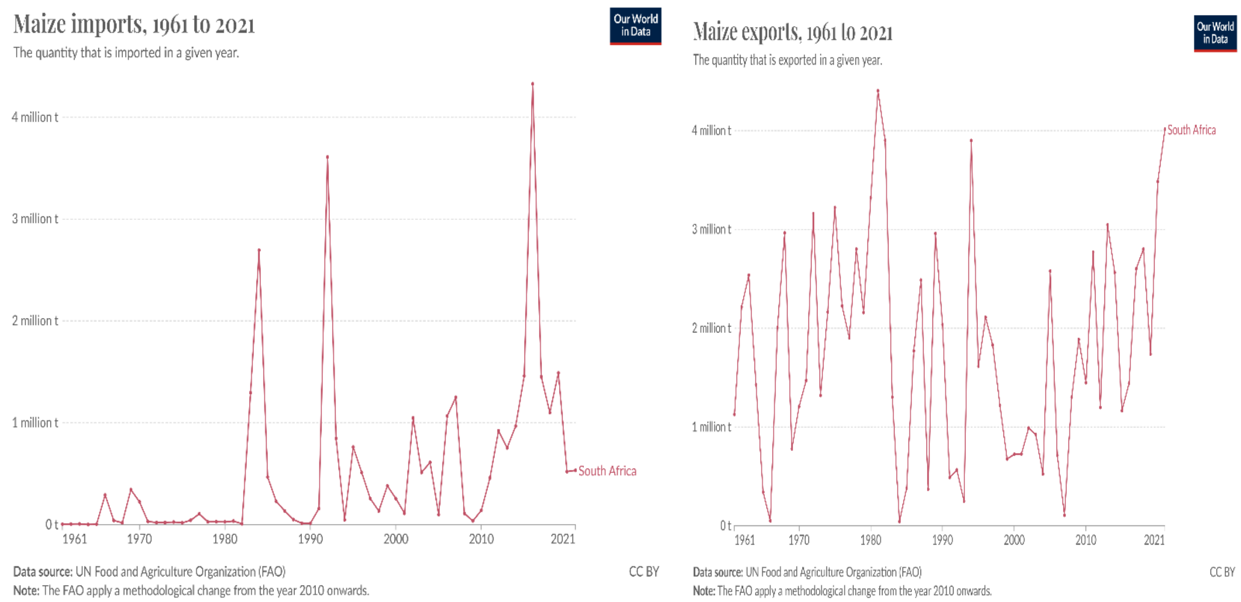

Figure 4.3: South Africa's maize imports and exports trends

Source: Our World In Data (2024)

4.3.1. South Africa's top 5 trading partners

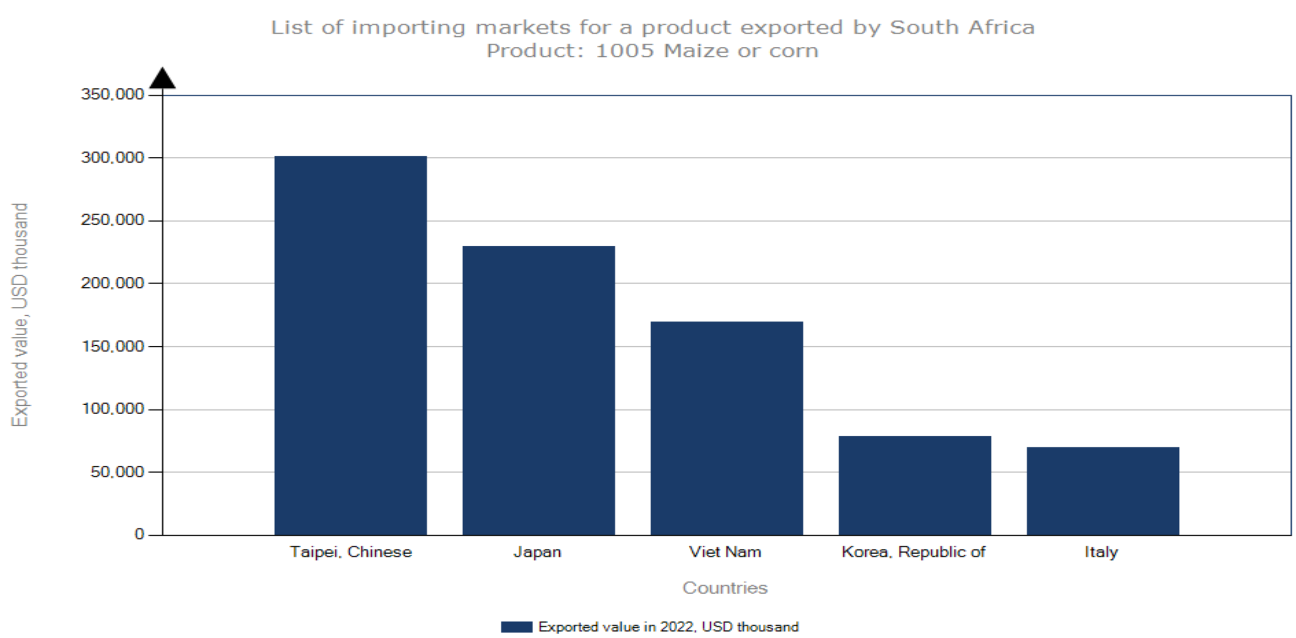

Figure 4.4: South Africa's top 5 maize exporters

Source: World Bank (2022)

From the figure above, it is evident that South Africa exports most of its maize mostly to Asian countries and Europe. According to the World Bank, (2022) China, Japan, Vietnam, South Korea, and Italy are the top 5 trading partners for South African maize. Taipei, China imports most of South Africa's maize at the value of 1,212,170 US$. According to Alden and Wu, (2014), South Africa has close relations with China since they're aiming for greater strategic collaboration and are considering their shared objectives, as well as their bilateral economic relations. In SSA countries, China has been a leading and most important trading partner, also in terms of infrastructural development, technology, and a source of FDI and loans (Jenkins, 2022). However, China-Africa relations have been a source of debate as Alden, (2019) opined that the relations are somewhat a symbol of colonialism extracting natural resources and selling them back to the continent as finished goods.

According to Sihlobo, (2016), China is a major importer of South African maize. Zondi, (2022) opined that South Africa and China's relations started in the early 20th century with common goals of strengthening trade cooperation, direct investments, and agricultural cooperation, particularly on maize exports from South Africa. Japan has been identified as South Africa's potential strategic partner in the export of maize (Kapuya and Sihlobo, 2014). A study by Mawasha, (2020) reported similar findings. Vietnam is one of the consistent exporters of maize from South Africa (Htwe, 2020). Similarly, Erenstein et al. (2022) emphasized that Vietnam imports most of South Africa's Genetically Modified (GM) maize. Poor rainfall in the past years has been a major contributor to Vietnam's high importation of maize from South Africa (Gummadi et al. 2022). A study by Kok, (2018) reported that approximately 90% of South Africa's maize has been exported to Japan and South Korea. South Korea is more vulnerable to climate change which calls for imports of products such as maize and other cereal crops to bolster food security (Odey et al. 2023).

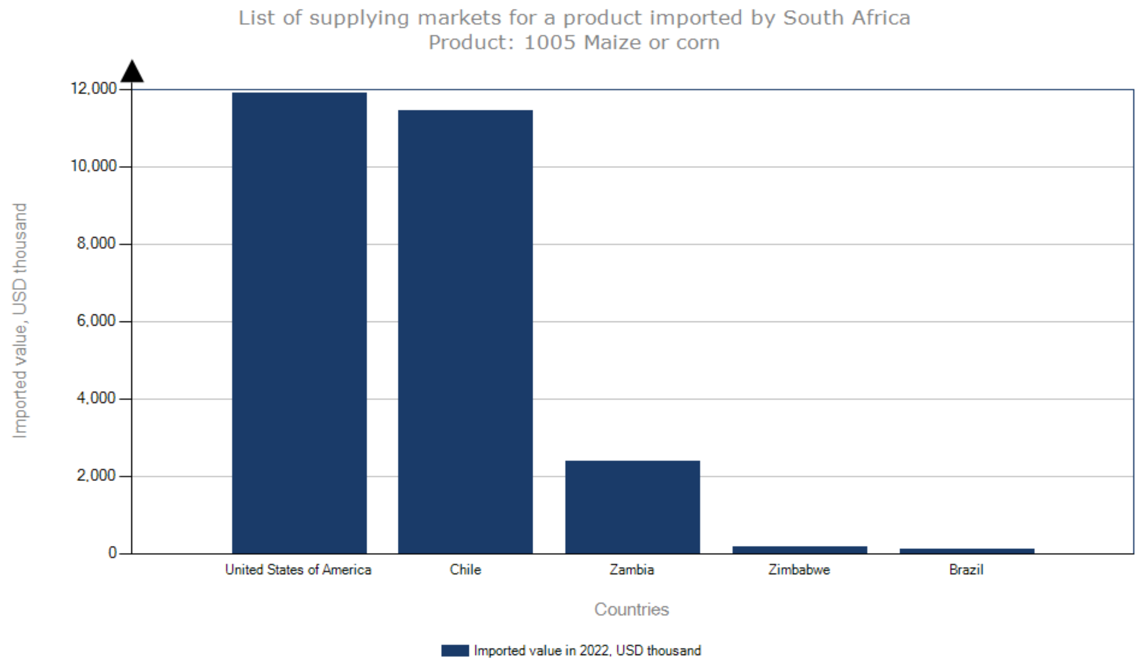

Figure 4.5: South Africa's top 5 maize importers

Source: World Bank (2022)

According to the World Bank, (2022), the United States of America (USA), Chile, Zambia, Zimbabwe, and Brazil are the top 5 importing trading partners for South African maize. According to Erenstein et al. (2022), the USA is not only South Africa's top importing partner but also the top producer of maize globally. Kaul et al. (2019) reported that the USA and Brazil use maize as animal feed and a significant source of oil and biofuel hence the high production and import ratios. South Africa has in the past years experienced a major outbreak of fall armyworm which causes major yield losses, enhances food insecurity, and calls for massive imports of maize from the USA and other Southern African countries (Makgoba et al. 2021).

Europe and Asia's expanding need for biofuels led to an increase in the demand for cereal crops particularly maize feedstock which led to an influx of imports from African nations (Santpoort, 2020). As the renewable energy global demand is expected to increase maize trade, Africa with its natural resource endowment is expected to benefit from trade if a conducive environment for production is created for the agricultural sector. There are more opportunities for increasing exports from Africa as most countries' trade is not complimentary creating a lot of trade balances, and these balances can be closed by more volumes. Africa also has a low-hanging fruit for trade amongst itself through the African Continental Free Trade Area (AfCFTA) with a 1.3 billion population market.

4.3.2. Trade Complementarity Index

According to the Africa Regional Integration Index (ARII), (2023), the degree to which the import and export profiles of two countries are similar is measured by the trade complementarity index (TCI). Another study by Anukoonwattaka, (2017) reported that the TCI gauges the extent to which the exports and imports of two trading partners overlap each other. The trade complementarity index has a value between 0 and 1, where 0 denotes no complementarity and 1 represents full complementarity (or matching) (Villafuerte, 2018). A TCI of 0.30 and below shows low complementarity, a TCI that lies between 0.30 and 0.50 shows moderate complementarity, and a TCI of 0.50 and above shows high complementarity. In the following table, a Trade Complementarity Index was run for South Africa (Reporter) with all its top 5 trading partners.

Table 4.1: South Africa’s trade complementarity index with the top 5 trading partners

REPORTER: South Africa	
Partner	**Index**
Taipei, China	0.55
Japan	0.57
Vietnam	0.51
South Korea	0.67
Italy	0.59
USA	0.66
Chile	0.50
Zambia	0.52
Zimbabwe	0.54
Brazil	0.63

Source: World Integrated Trade Solution (WITS. 2024)

Based on the measures of trade complementarity, the Republic of South Korea, the USA, Brazil, Italy, Japan, Tapei, China, Zimbabwe, Zambia, Vietnam, and Chile have a high trading complementarity respectively. This level of complementarity indicates that South Korea, the USA, Brazil, Italy, Japan, Tapei, China, Zimbabwe, Zambia, Vietnam, and Chile are natural trading partners to South Africa, meaning that South Africa stands to benefit from increased trade with these countries and vice versa. World Bank, (2022) expressed the same sentiments. The results also indicate that South Africa's export profile closely matches the import profiles of the countries in question meaning that these countries have a potential for collaboration and trade partnerships, exploiting each country's strengths and degree of specialization to enhance trade flows, efficiency, and global competitiveness. A study by Manzano and Martin, (2014) opined that a higher TCI (0.50+) indicates that these countries match the demands of each other through specialization. Zapata et al. (2023) shared similar sentiments. The higher the TCI value the more likely there is mutual trade between two nations (Hoang, 2018).

A study by Chen et al. (2021) emphasized that these movements of goods are mostly successful because of trade agreements and partnerships between countries hence a high TCI. Similar findings were reported by Shnyrkov and Pliushch, (2019). For example, the Belt and Road cooperation between South Africa and China, the Generalised System of Preferences (GSP) which consists of Japan and Italy under the European Union, the African Continental Free Trade Area (AfCFTA) for African states, and the Trade, Development and Cooperation Agreement (TDCA) representing South Africa and the European Union member states just to mention a few. Within Africa, more benefits are yet to be seen with the full adoption of the African Continental Free Trade Area (AfCFTA). Chen et al. (2020) and Wang et al. (2023) found that most of these trade agreements have championed complementarity over competitiveness, which is an area of concern especially for Africa. This is just an indication of how trade agreements and partnerships can influence the trade patterns of one nation to another. In addition, a high trade complementarity just indicates how countries are benefiting from each other and a broader bilateral and regional trade relationship (Quintana-Romero et al. 2020). Of note, Maize trade within Africa is still not strong although there are more opportunities.

4.3.3. The African Continental Free Trade Area (AfCFTA)

The AfCFTA is a significant trade agreement in Africa, aiming to boost economic progress, reduce poverty, promote industrialization, and align trade policies among African nations, and it is the world's biggest trade agreement after the formation of the WTO in 1994 (African Union (AU). The 28th United Nations Climate Change Conference or Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) was held from 30 November to 12 December 2023 at Expo City, Dubai, United Arab Emirates more commonly known as COP28 and emphasized increasing renewable energy globally. This call means that there will be more value for energy crops in the agricultural sector in the future as global bioenergy production will be stimulated. Considering that Maize is a food and energy crop with huge market value, the AfCFTA is a strategic economic tool for Africa that can boost maize trade within Africa. This can reduce food insecurity and provide long-term opportunities for bioenergy generation for African countries.

The AfCFTA has drawn together 55 of the African Union (AU) states and 8 of the Regional Economic Communities (REC) Namely, Arab Maghreb Union (UMA), Common Market for Eastern and Southern Africa (COMESA), Community of Sahel–Saharan States (CEN–SAD), East African Community (EAC), Economic Community of Central African States (ECCAS), Economic Community of West African States (ECOWAS), Intergovernmental Authority on Development (IGAD), Southern African Development Community (SADC). Its overall mandate is to create one African market with a population of 1.3 billion people, and a fused GDP of US$ 3.4 trillion (Wapmuk and Ali, 2022). According to Engel and Herpolsheimer, (2021), eliminating import charges would increase trade between African countries by 52.3 percent; if non-tariff barriers were also removed, trade might double.

Furthermore, the AfCFTA seeks to reduce non-tariff barriers to trade, eliminate import levies to increase inter-African commerce by 53.3%, improve incomes by 7%, empower and lift 30 million people out of poverty by 2035 according to the United Nations Commission for Africa (UNECA) and the World Bank estimates (World Bank, 2020; Döring and Engel, 2021). In addition to emphasizing the vital role that women and young people play in accomplishing these objectives and realizing Africa's potential, the African Union's efforts to expedite the AfCFTA also centre on enabling them to do so (Ngom, 2023). Lastly, the AfCFTA is compliant with the 2030 Agenda for Sustainable Development of the United Nations, it helps achieve objectives including inclusive economic growth, employment generation, and poverty alleviation (Liza, 2021).

Looking at South Africa’s top traders, it is significant to note that regional trade is happening although not satisfactory, particularly with Zambia and Zimbabwe standing out. According to Workman, (2022) Botswana and Mozambique fall within the top 10 trading partners of South Africa. This shows that there is some regional trade going on amongst the AfCFTA member countries. Agricultural products form part of the commerce between South Africa and the region’s top traders (Arndt and Roberts, 2018). Mlambo et al. (2019) reported comparable results. Maize and many other cereal crops are one of the traded commodities due to it being a staple food for most African countries. According to ARII, (2019), the lack of regional integration in Africa is mostly because of the geographical area, countries that share borders tend to commerce more goods and services with each other since transaction costs are low, and these countries trade more with countries that have policies aligning with theirs. Hence South Africa's top trading partners in Africa are its neighbouring countries namely, Botswana, Mozambique, Namibia, and Zimbabwe.
According to the World Bank, (n.d), regional integration promotes economic growth by creating integrated marketplaces, diversifying the economy, and removing barriers to the capital's free flow, ideas, products, and services. A report by ARII (2023) provided principal recommendations for the success of integration between African nations which include, improving a slow-moving production line, better cross-border cooperation, investment in R&D on proper value chains, identifying relevant skillset and labour enhancement, infrastructural development, have a greater visa frankness for human mobility, and have favourable policies for member states.

According to Yeo et al. (2020), trade infrastructure and logistics can improve intra-regional trade. A study by Suleymenova and Syssoyeva-Masson, (2017) indicated that public-private partnerships should be encouraged since they foster investment, and entrepreneurship and play a role in promoting intra-regional trade. Similar findings were reported by Malpass, (2021). Maize as a food crop and energy crop for the global community will create more opportunities for those with the capacity to produce it. The AfCFTA will undoubtedly alter the maize and other agricultural products trade landscape in terms of promoting intra-African commerce (Songwe, 2019). However, it is key to note that the success of the AfCFTA requires effective policy instruments, streamlined processes, and cooperation among member states. The AfCFTA is a long-term project that aims to bring about transformative change in Africa's trade landscape. This chapter shows opportunities for maize trade in Africa and internationally.

CHAPTER 5: DESCRIPTIVE AND INFERENTIAL ANALYSIS

5.1. Introduction

The descriptive and empirical study results are presented in this chapter. Several tests, including the unit root (PP and ADF) tests, lag length selection, cointegration test, ARDL diagnostic test, model robustness, and causality test, were carried out.

5.2. Descriptive Statistics

Table 5.1: Descriptive statistics

	LNMPDUC	LNGDP	LNCO2	LNRENS	LNTRADE
mean	16.08	8.60	19.74	1.76	25.42
median	16.13	8.60	19.75	1.92	25.45
maximum	16.68	8.75	20.02	2.86	26.02
minimum	15.00	8.43	19.20	0.95	24.71
Std dev	0.35	0.10	0.21	0.72	0.46
skewness	0.91	0.03	0.72	1.80	0.11
kurtosis	2.09	1.63	2.92	1.02	1.45
Jarque-Bera	0.08	1.46	0.71	0.25	1.39
Probability	0.06	0.20	0.60	4.52	0.11
Sum	691.43	369.84	848.85	75.80	1092.89
Sum Sq. Dev.	5.23	0.46	1.80	21.64	9.02

Source: Author’s compilation (2024)

The descriptive statistics for every variable in the study are displayed in Table 5.1. The response variable LNMPDUC has a mean value of 16.08 and a standard deviation of 0.35. For the explanatory variables LNGDP, LNCO2, LNRENS, and LNTRADE, the corresponding mean values were 8.60, 19.74, 1.76, and 25.42, while the corresponding standard deviations were 0.10, 0.21, 0.72, and 0.46. All of the variables' standard deviations were less than their mean values, suggesting that the data was stable, and the variables weren't erratic over the time period. This is in line with findings by Ntiamoh et al. (2022) who reported that the results of this nature suggest that the variables are not volatile. The kurtosis values of all the variables were less than three, indicating a normal distribution of the variables. The probability statistics of all the variables are greater than 0.5 significance level which shows that the variables are normally distributed.

5.3. Correlation matrix

Table 5.2: Correlation matrix

	LNMPDUC	LNCO2	LNGDP	LNRENS	LNTRADE
LNMPDUC	1.000	0.361	0.468	0.205	0.584
LNCO2	0.361	1.000	0.555	0.156	0.901
LNGDP	0.468	0.555	1.000	0.135	0.706
LNRENS	0.205	0.156	0.135	1.000	0.209
LNTRADE	0.584	0.901	0.705	0.205	1.000

Source: Author's compilation (2024)

Table 5.2 revealed a moderate positive correlation between maize production and carbon dioxide, economic growth, and trade, and a weak positive correlation between maize production and renewable energy supply. The results imply that maize production has a moderate association with carbon dioxide emissions, economic growth, and trade meaning that a change in one variable will result in a moderate change in the other variable. The change can range in between 40%-60%. Furthermore, maize production and renewable energy have a weak association meaning that a change in one variable will have little to no effect on the other variable.

5.4. Inferential statistics results

Inferential statistics results are aligned with the steps depicted in Chapter 3, beginning with unit root tests, and concluding by conducting the causality that exists between the selected variables.

5.4.1. Unit root test analysis

The existence of a unit root or non-stationarity in a time series analysis leads to spurious results which suggest that the data is unreliable furthermore, the series must be stationary as it is important in policy-making decisions (Rath and Akram, 2021). A series is stationary when its variance, covariance, and mean are all constant (Khan et al. 2022). It is therefore very crucial for a series to be only integrated of order (0) and order I (1) and not order I (2) or higher. The Dickey-Fuller (DF-GLS), Augmented Dickey-Fuller (ADF), Phillips-

Perron (PP) Kwiatkowski-Phillips-Schmidt-Shin (KPSS), Narayan, and Popp are commonly used unit root tests (Schneider and Cai, 2023). The ADF and PP have been utilized in this study as the most used unit root tests (Afriyie et al. 2020). Bahmani-Oskooee et al. (2018) stated the unit root's null and alternative hypothesis as follows:

H0: Does not have a unit root/ stationary (I (0) or I (1)).

H1: Has a unit root/ non-stationarity (I (2)).

Table 5.3: Augmented Dickey-fuller (ADF) and Phillips-Perron (PP) unit root test results.

	ADF		**PP**		
Variable	**level**	**1st difference**	**Level**	**1st difference**	**Conclusion**
LNMPDUC	-6.00***	-6.10***	-6.11***	-31.52***	I (1)
Prob.	***(0.00)***	***(0.00)***	***(0.00)***	***(0.00)***	
LNGDP	-2.12	-4.70***	-1.54	-4.63***	I (1)
Prob.	***(0.52)***	***(0.00)***	***(0.80)***	***(0.00)***	
LNCO2	-2.60	-6.90***	-2.60	6.90***	I (1)
Prob.	***(0.30)***	***(0.00)***	***(0.30)***	***(0.00)***	
LNRENS	-6.70***	-6.33***	-6.70***	-31.60***	I (1)
Prob.	***(0.00)***	***(0.00)***	***(0.00)***	***(0.00)***	
LNTRADE	-1.59	-5.50***	-1.80	-5.44***	I (1)
Prob.	***(0.80)***	***(0.00)***	***(0.70)***	***(0.00)***	

Source: Author's compilation (2024)

The results from Table 5.3 show that the series were stationary at first difference i.e. all the variables were integrated of order I (1). The unit root null hypothesis was rejected since neither of the variables was non-stationary and integrated of order I (2). In that case, we fail to reject the alternative hypothesis since there's no unit root and the series is stationary at 1st difference. The results further shows that the data is reliable and will not lead to spurious results therefore, we can conclude that we can use the ARDL approach (Jordan and Philips, 2018).

5.4.2. Lag Selection

This study carried out the lag order selection criterion (Table 5.4) to ensure that the VAR model accurately captures the relationships and dynamics among the variables under investigation (Shrestha and Bhatta, 2018). Table 5.4 shows the unimpeded VAR model's optimal lag length selection using the LogL, LR, FPE, AIC, SC, and HQ criteria. According to Zhang et al. (2020), the criterion with the lowest value yields the best model outcome, so this is the rule of thumb for choosing the maximum lag order. The SC and the HQ showed that the optimal lag length was 0. However, A study by Kripfganz and Schneider, (2023) opined that the Akaike Information Criteria (AIC) is the most utilized, and therefore the optimal lags for the ARDL model were determined using the AIC. The AIC criteria indicated that the 2nd lag was the best lag for the model.

Table 5.4: Lag length selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-6.901209	NA	0.102477	0.559036	0.729658*	0.620254*
1	-6.844185	0.099428	0.107629	0.607394	0.820671	0.683916
2	-4.368528	4.189574*	0.099889*	0.531719*	0.787652	0.623546
3	-4.248943	0.196241	0.104656	0.576869	0.875457	0.684000
4	-4.194440	0.086645	0.110072	0.625356	0.966599	0.747791

Source: Author’s compilation (2024)

5.4.3. Cointegration (bounds) test

The bounds test for cointegration in Table 5.5 is a statistical test used to determine whether a long-run relationship exists between two or more variables (Sam et al. 2019). An ARDL testing approach was conducted to determine whether a long-run relationship exists or not since the variables were found to be integrated of order I(0) and I(1). The lower and upper bounds values were the two critical values developed from the bounds test. Montenegro, (2019) stated the null hypothesis as follows:

H0: no long-run relationship (no cointegration)

Table 5.5: Bounds test

Test Statistic	Value	K
F-statistic	11.110541	4
	Critical Value Bounds	
Significance	I (0) Bounds	I (1) Bounds
10%	2.70	3.90
5%	3.30	4.63
1%	4.60	6.47
Outcome		**Cointegrated**

Source: Author's compilation (2024)

Table 5.5 results show that a long-run conjunction existed between the response and explanatory variables in the study, meaning that a cointegration exists between the variables. This is validated by the F-statistic value which is greater than both the lower bounds and the upper bounds at all the three significance levels making cointegration probable. Therefore, confidently it can be concluded that we reject the null hypothesis since the results indicate that there is a presence of cointegration between the variables.

5.4.4. ARDL Error correction model and short-run estimates and discussion

Table 5.6: Short-run estimates and ECM

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ*	-0.904791	0.194928	-8.027524	0.0000***
D(LNMPDUC(-1))	0.348964	0.127101	2.745565	0.0103***
D(LNCO2)	-0.498771	0.843074	-0.591610	0.5587
D(LNCO2(-1))	-1.575791	0.831665	-1.894743	0.0681
D(LNCO2(-2))	-0.478352	0.778741	-0.614263	0.5438
D(LNCO2(-3))	-1.767346	0.834090	-2.118892	0.0428**
D(LNRENS)	0.109729	0.050216	2.185131	0.0371**
D(LNRENS(-1))	0.208822	0.058824	3.549970	0.0013***
D(LNRENS(-2))	0.136631	0.049826	2.742154	0.0103***
C	-8.565381	1.072449	-7.986749	0.0000***
R-squared	0.737612	Mean dependent var		0.016743
Adjusted R-squared	0.656181	S.D. dependent var		0.430610
S.E. of regression	0.252493	Akaike info criterion		0.301688
Sum squared resid	1.848829	Schwarz criterion		0.728243
Log-likelihood	4.117078	Hannan-Quinn criteria.		0.454732

F-statistic	9.058127	Durbin-Watson stat	2.358446
Prob(F-statistic)	0.000002***		

** and *** denote 5% and 1% levels of significance respectively

Source: Author's compilation (2024)

Table 5.6 shows the results of the ECM and the ARDL short-run estimates. The results show that the error correction model was significant at a 1% significance level. The ECM's coefficient was highly significant and negative as expected and reported by Wanzala, (2018). The results further show that there exists a stable short-run relationship and a significant correction mechanism in the model. This indicates that over some time there is a significant likelihood that the variables will compensate for abnormalities from their equilibrium relationship (Kumar, 2021). It further suggests that it takes an average speed of 90% to adjust from the short run to the long run if there's any disequilibrium within the system. In layman's terms, this means that the speed of adjustment it will take to correct for deviations or say there be a recession in the economy will be 90% for maize production to return to equilibrium alongside carbon dioxide emissions and renewable energy supply.

According to Ediriwickrama and Pathirana, (2021), a high R-squared value indicates a good fit to the data. It estimates the percentage of the dependent variable's variance that the model's independent variables can account for. The R-squared and the adjusted R-squared values show that the model is a good fit for the data. This indicates that the independent variables in the model account for around 74% of the variance observed in the response variable. The F-statistic value shows that the model passes the overall significant test at a 1% significance level. This means that the model is a good fit. The Durbin-Watson stat suggests a negative serial correlation, meaning that the residuals are correlated in a negative direction, it furthermore indicates that autocorrelation is not a concern.

5.4.4.1. ARDL short-run significant results and discussion

In the short-run results, it was found that carbon dioxide emissions were statistically significant at a 5% significance level with a negative coefficient. The negative coefficient signifies that a 1% increase in carbon dioxide emissions will lead to a decrease in the production of maize by 1.80% in the short run. Furthermore, the lagged value (-3) shows that an increase in CO_2 emissions today will decrease maize production by 1.80% 3 years from now. The results are in conjunction with the findings by Chopra et al. (2022), who reported that CO_2 emissions reduced maize production. Similar findings were reported by Selcuk et al. (2021). The results may be because pests, weeds, and fungi may all thrive and spread more readily in environments with elevated CO_2 levels. Farmers may face difficulties as a result, as these organisms may impair agricultural production and compete with crops for resources. This is consistent with EPA (2017) findings.

South Africa is a developing country with approximately 2.5 million small-scale farmers and around 35000 large-scale farmers (Born et al. 2021), this may contribute to the short-run results from Table 5.7 since most small-scale farmers are not able to survive the aftereffects (climate change) of CO_2 emissions which leads to low productivity. This is so because of the lack of access to loans, skills enhancement, and a lack of government support for small-scale farmers. Similarly, Tshikororo et al. (2021) reported that climate change poses a significant threat to developing nations, causing crop failures, disease outbreaks, and food and nutrition insecurity.

However, contrasting findings were reported by Appiah et al. (2018), and Chandio et al. (2020) who found that agricultural productivity enhances CO_2 emissions. Similarly, Raihan et al. (2023b) reported that CO_2 emissions from agricultural production are set to skyrocket due to the high demand for food. This might be due to the high mechanization that uses fossil fuels during agricultural production. A study by Guan et al. (2023) emphasized that agricultural mechanization enhanced CO_2 emissions. Similarly, Guo et al. (2022) inferred that agricultural mechanization hugely contributes to CO_2 emissions in the short term. Devakumar et al. (2018) shared similar sentiments.

Another possible cause could be market failure emanating from food wastage from the markets which contributes heavily to emissions. Most small-scale farmers don’t have access to markets which results in food waste and lower prices. In commercial markets, food waste is still prevalent. According to Buzby, (2022) food wastage results in wasted inputs and a significant greenhouse gas footprint, CO_2 emissions, and methane emissions from food production and in landfills, transportation, and storage. Food wastage contributes about 6% of emissions globally (Ritchie, 2020). This means that food wastage not only results in food insecurity but also the unsustainable utilization of natural resources which has adverse long-term effects on future production. Pandey, (2021) observed similar findings.

Renewable energy supply was found to be statistically significant at a 5% significance level with a positive coefficient. The positive coefficient signifies that a 1% increase in renewable energy supply will result in an increase in maize production by 0.11% in the short run. The lagged variables are both statistically significant at a 1% significance level with a positive coefficient. The positive coefficients denote that a 1% increase in renewable energy supply leads to a 0.21% and 0.14% increase in maize production respectively. In addition, the lagged variable (-1) denotes that a 1% increase in renewable energy supply currently led to a 0.21% increase in maize production a year from now on. The lagged variable (-2) denotes that a 1% increase in renewable energy supply currently led to a 0.14% increase in two years.

In a country like South Africa, the results above are expected since we are in a situation where agricultural production has adversely declined in the past few years due to the unreliability of energy from fossil fuels and climate change. This is in line with the findings by McLennan, (2021) who reported that the agricultural sector is immensely benefiting from the supply of renewable energy (McLennan, 2021). Wang et al. (2023) emphasized that it is very important for countries particularly SSA countries to engage more in the renewable energy sector since it boosts agricultural economic growth and sustainable development. In addition, an increasingly sustainable and dependable energy supply can result from the agriculture sector's use of renewable energy to help satisfy this demand and diversify the mix of power generation (Akinbami et al. 2021). Another study by Chimhangwa, (2020) emphasized that green energy lessens the effects of climate change on agricultural output while also supporting sustainable farming methods. Amid the low scale of production of renewable energy in South Africa Winkler, (2022), its positive impacts on the agricultural sector and the economy are starting to be evident.

According to Qiao et al. (2019), renewable energy production improves agricultural economic growth. A study by Mier et al. (2022) revealed that the renewable energy sector is beneficial to the agricultural industry since in most developed countries, farmers who've tapped into the sector have turned into independent power producers and sell excess electricity to the national grid. On the other hand, Majeed et al. (2023) opined that the energy efficiency brought by renewable sources significantly improves food systems thus ensuring food security. Bieber et al. (2023) emphasized that for the realization of all the benefits of renewables, the agricultural sector should be empowered to contribute to the sector by producing biomass and biogas, also increasing the share of renewable energy and counterattacking CO_2 emissions. Amid all this, it is very important to note that the agricultural sector is one of the key sectors of any economy since it eradicates poverty and improves food security. Similarly, Pata, (2021) opined that the agricultural sector should be given special attention to encourage sustainable practices to mitigate CO_2 emissions. It is evident therefore that South Africa should invest heavily in renewable energy production, and steer favourable policies onboard for renewable energy production, because of its potential positive impact on the agricultural sector together with the economy.

5.4.5. ARDL Long-run estimates and discussion

Table 5.7: ARDL Long-run results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNCO2(-1)	1.159815	0.870069	1.333015	0.1911
LNRENS(-1)	0.194751	0.091826	2.120873	0.0411**
LNTRADE	-0.085077	0.300579	-0.283045	0.7788
LNGDP	0.055063	0.480113	0.114688	0.9093

****represents a 5% level of significance**

Source: Author's compilation (2024)

5.4.5.1. ARDL long-run significant results and discussion

Table 5.7 above shows the long-run results. A long-run relationship was found to have existed between the response variable and the explanatory variables as the bounds test confirmed it. In the results, renewable energy supply was found to be statistically significant at a 5% significance level with a positive coefficient. The positive coefficient demonstrates that a 1% increase in renewable energy supply will lead to a 0.19% increase in maize production. Furthermore, the lagged value (-1) indicates that an increase in renewable energy supply currently will increase maize production by 0.19% a year from now on. This is in line with a study by Caputo et al. (2021) who opined that renewable energy supply is an important factor for agricultural growth and food systems discussions should not exclude renewable energy concepts since most of these food crops can be used to produce renewable energy. Similar findings were reported by Fox-Kämper et al. (2023). Renewable energy production was reported to have a long-run relationship with agricultural activities (Naseem et al. 2021).

According to UMass Amherst, (2022), renewable energy incorporation in agriculture promotes sustainable farming, and environmental conservation, reduces greenhouse gas emissions, and promotes self-sufficiency among farmers. In addition, Rikonnen et al. (2019) opined that small-scale farmers' participation in renewable energy production serves as a boost for the agricultural industry not only in terms of production but also can serve and grow as a market-based business. Furthermore, Minoofar et al. (2023) emphasized that renewable energy produced by small-scale farmers can largely compensate for grid failures. For all this to be achieved, policies should be strengthened to promote the production of energy crops (Lombardi and Berni 2021). Similar findings were reported by Baležentis et al. (2023). A study by Busu, (2020) reported that renewable energy supply has a positive relationship with economic growth, meaning that an increase in the supply of renewable energy results in an increase in the economic growth of a country. The agricultural sector of any economy contributes a chunk to the growth of that economy, meaning that there is no developed economy without a stable agricultural sector. That is, if renewable energy production boosts economic growth the agricultural sector of that economy tends to benefit as well. This is in conjunction with findings by Ali et al. (2023) who reported that agricultural productivity boosts economic growth. Mirzabaev, (2020) opined that the utilization of renewable sources in the agricultural sector boosts productivity resulting in enhanced food security.

5.4.6. ARDL diagnostic test

Table 5.8: ARDL diagnostic test

Diagnostic Statistics	p-values	Outcome
Breusch-Godfrey LM	0.984	No serial correlation
Autoregressive Conditional Heteroskedasticity (ARCH)	0.669	No Heteroskedasticity
Jarque-Bera Test	0.201	Normal residuals

Source: Author's compilation (2024)

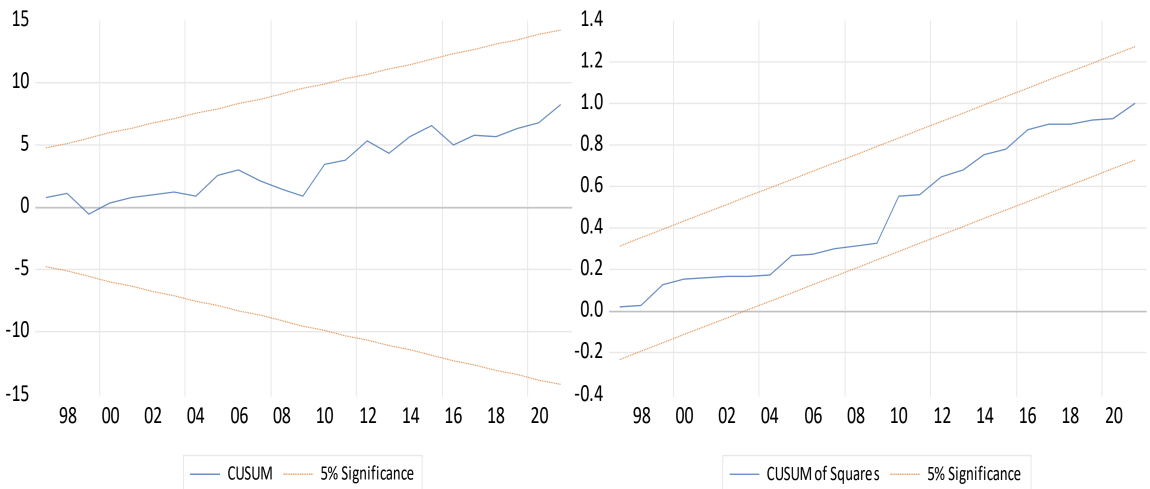

Figure 5.1: CUSUM AND CUSUMSQ plots

Source: Author's Compilation (2024)

After carrying out the ARDL model, a diagnostic test was run to check the stability of the model to make sure that it was correctly estimated. The Breusch-Godfrey Serial Correlation LM Test was conducted to check whether the model has a serial correlation. Serial correlation is when a time series has a linear relationship with a lagged version of itself (Dotis, 2019). In time series, it is very important to understand the importance of accounting for serial correlation since it impacts the accuracy of statistical models and projections. The p-value as presented in Table 5.8 above shows that it is not significant as it is greater than 0.05 therefore, we fail to reject the null hypothesis of no serial correlation in the series.

The ARCH test was carried out to check the presence of heteroscedasticity in the model. Heteroscedasticity is the existence of shifting variance in a time series model's residuals or error component (Coker-Farrell et al. 2021). Heteroscedasticity is a problem in time series since its presence may result in incorrect hypothesis testing and inaccurate forecasts. The p-value in Table 5.8 was insignificant since it was greater than 0.05. We therefore fail to reject the null hypothesis of no heteroscedasticity. Jarque-Bera test was conducted to ascertain that the residuals are normally distributed. The results from Table 5.8, show a p-value that is not significant because it was greater than 0.05 and the null hypothesis of no presence of normal residuals is rejected. It can then be concluded that there was no serial correlation and heteroscedasticity in the model and that the residuals were normally distributed. The diagnostic tests were further run through the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) to confirm the stability of the model. The blue line in the middle of the red line shows that the model is stable as depicted in Figure 5.1 above, indicating that the model was stable at a 5% significance level.

5.4.7. Model Robustness

Table 5.9: Fully Modified Least Squares (FMOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNCO2	-0.975624	0.488726	-1.996259	0.0533
LNGDP	0.648124	0.489134	1.325044	0.1933
LNRENS	0.061650	0.052277	2.179296	0.0418
LNTRADE	0.609674	0.225257	2.706567	0.0102
C	14.18048	6.039314	2.348029	0.0243

Source: Author’s Compilation (2024)

Table 5.10: Canonical Cointegrating Regression (CCR)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNCO2	-0.827302	0.413772	-1.999414	0.0529
LNGDP	0.600773	0.488363	1.230179	0.2264
LNTRADE	0.568404	0.209888	2.708126	0.0102
LNRENS	0.073314	0.074869	2.979232	0.0358
C	12.68611	5.281382	2.402044	0.0214

Source: Author’s Compilation (2024)

Tables 5.9 & 5.10 above show the models used to check the robustness of the long-run estimation. The models confirm the stability and the sensitivity of the model. The FMOLS and the CCR were used to test for robustness in this study. Both the FMOLS and the CCR results indicated that renewable energy supply was positive and significant at a 5% significance level. These results reflect the long-run estimates, and it can be concluded that the model is robust.

5.4.8. Causality Test

It was evident that there was a presence of short-run and long-run relationships between the variables in this study. Therefore, granger causality tests were further run to help determine if one variable can predict or forecast another variable. In layman's terms, the Granger causality test helps determine the direction of the relationship between the variables, it can either be unidirectional or bidirectional. The Pairwise Granger causality test was conducted to test for causality as shown in Table 5.11 below.

Table 5.11 Pairwise Granger Causality Tests

Null Hypothesis:	Causality	F-Statistic	Prob.
LNCO2 does not Granger Cause LNMPDUC	Unidirectional	3.83634	0.0309**
LNMPDUC does not Granger Cause LNCO2		0.00405	0.996
LNRENS does not Granger Cause LNMPDUC	Bidirectional	4.27185	0.0066***
LNMPDUC does not Granger Cause LNRENS		3.57619	0.0154***
LNTRADE does not Granger Cause LNMPDUC		0.64279	0.6802
LNMPDUC does not Granger Cause LNTRADE		0.67389	0.7325
LNGDP does not Granger Cause LNMPDUC		0.19783	0.8214
LNMPDUC does not Granger Cause LNGDP	Unidirectional	3.70339	0.0345**

***** and ** represents 1%, 5%**

Source: Author's Compilation (2024)

The causality test in Table 5.11 above shows that CO_2 emissions granger caused maize production and the null hypothesis of no causality was rejected at a 5% significance level. A unidirectional causality was observed between CO_2 emissions and maize production, and the direction was from CO_2 emissions to maize production. This means that the effects of CO_2 emissions have an impact on maize production. Similarly, Ali et al. (2022) found a unidirectional relationship between CO_2 emissions and agricultural production. Furthermore, Chopra et al. (2022) emphasized that this is because most farmers are not able to cope with climate change effects from CO_2 emissions, so this hampers their productivity. Renewable energy supply was found to have a bidirectional causality with maize production. This means that renewable energy supply has an impact on maize production and maize production has an impact on renewable energy production. The null hypothesis of no causality was rejected at a 1% significance level. These results are a priori expectation since agricultural production would thrive under a constant supply of energy and several crops are energy crops that can also be utilized to stabilize the supply of energy (Wang et al. 2023) and (Minoofar et al. 2023). So, the relationship between renewable energy supply and agricultural production is complementary.

Maize production was found to granger cause economic growth at a 5% level of significance. The results show unidirectional causality between the variables running from maize production to economic growth. These results are a priori expectation since the agricultural sector is one of the most important sectors of any economy. So, the results emphasize that an increase in agricultural production results in an increase in economic growth. The results are also in line with studies by Michael (2017), and Ehighebolo (2023). Furthermore, Ali et al. (2023) also reported that agricultural productivity and economic growth have a unidirectional relationship.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

This study aimed to assess the long and short-run nexus of renewable energy production and agricultural economic activities for the last 42 years. This was achieved through the ARDL model, which showed a long and short-run relationship between maize production and CO_2 emissions, renewable energy supply, trade, and economic growth. This study was based on the following objectives:

Objective 1: to analyze maize production, import, and export trends in the period 1979-2021.

Objective 2: to estimate the short-run and possible long-run relationships between maize production and macroeconomic variables in the model.

Objective 3: to estimate the causality between maize production and macroeconomic variables.

The abovementioned objectives were backed up by the following hypotheses: H0: There is no short and long-run relationship between maize production and macroeconomic variables and H1: There is a short and long-run relationship between maize production and macroeconomic variables, and H0: macroeconomic variables do not granger cause maize production, and H1: macroeconomic variables granger cause maize production.

6.2. Conclusion

6.2.1. Objective 1: to analyze maize production, import, and export trends in the period 1979-2021.

6.2.1.1. Maize production trends in South Africa

From the results, it is evident that there has been a significant increase in the production of maize from 1979 to 2021. Although there were fluctuations between the years caused by several environmental and economic factors in the 4 decades studied in this study. From 1979 to 1989 there was an increase in the production of maize, and this was driven by technological advancement, an increase in real wages for farm workers, a change in market-related policies, and an increase in land under cultivation. However, in the early

1980s, there was a drop in production because it was the El Niño season characterized by low rainfall and high drought conditions. From 1990 to 2000, this decade was characterized by more drops than highs. The reasons for these drops mostly include climate change and global market competition. In the decade 2000 to 2010, the performance in the early to mid-2000s was characterized by low rainfall and severe drought activities, and high performance in the late 2000s was because of high rainfall which was known as the La Niña years. From 2010 to 2021, the dip in the 2015/16 season was because of the poor rainfall and severe drought conditions, and a rise in production in the year 2017 was a result of the use of more drought-tolerant crops. And lastly, the season 2020/21 had high production due to timely rainfall which was favourable for production.

6.2.1.2. Maize Trade trends

From these findings, it is more evident that Asian countries dominate South Africa's market for maize. This is mainly because most of these Asian countries use maize as a staple food and a primary source of feed for livestock and poultry. South Africa imports most of its maize from the USA and Chile and imports less fractions from Zambia, Zimbabwe, and Brazil. All these American countries produce maize in large fractions since it is used as animal feed and feedstock for biofuels hence, they also import it in large quantities. Regional trade is evident amongst the top 5 importers but can still be improved since it is not enough. There is also no regional trade within the top 5 exporting countries which is worrying.

6.2.2. Objective 2: to estimate the short-run and possible long-run relationships between maize production and macroeconomic variables in the model.

6.2.2.1. Carbon dioxide emissions and maize production

The study through the short-run estimates showed that CO_2 emissions were statistically and negatively significant. This meant that we rejected the null hypothesis of no short-run relationship between CO_2 emissions and maize production. It is also important to acknowledge the importance of the agricultural sector in South Africa since it is the backbone of economic growth, job creation, food security, and rural development. CO_2

emissions effectively contribute to climate change which is a calamity that most farmers struggle to cope with. Small-scale farmers are the most vulnerable to climate change since they operate in an environment beyond their control, and they are the most under-resourced. Small-scale farmers maintain food security and sustain livelihoods in the rural communities. It is therefore evident that climate change is an alarming concern in South Africa and radical tackling should be implemented to effectively deal with its adverse effects.

6.2.2.2. Renewable energy supply and maize production.

Renewable energy supply and maize production were found to be statistically and positively significant both in the short-run and the long-run. This meant that we rejected the null hypothesis of no short and long-run relationship between maize production and renewable energy supply. With these results, we can deduce that there is a very close relationship between the agricultural sector and the renewable energy industry. Maize is one of the energy crops being used in several countries to produce energy.

With the unreliability of South Africa's national grid to produce energy, renewable energy is seen as an alternative across most developed countries to counter the use of fossil fuels to produce electricity. It is well noted that there is an embargo on the use of maize as an energy crop as this might raise food security questions as maize is also an important staple crop in South Africa. However, it is important to note that developed countries exporting maize from South Africa still use it for energy production. The embargo then influences local energy production. Using maize as an energy crop might not impact food security if the residues, and trash are used in the production of energy. Most of our farmers currently burn a substantial amount of these residues in the fields further impacting the environment negatively. An alternative opportunity can be created by commercializing these residues for the energy market or rather farmers themselves can use the residues at the farm level for energy production through a gasification process and this can reduce their energy costs. Moreover, the agricultural sector showed a tremendous decline in production due to the 2022/2023 blackouts, therefore the findings in this study suggest that the more we normalize the use of renewable energy sources in the agricultural sector the more we stabilize and grow the agricultural sector thus ensuring food security and ensuring that there is enough feedstock for bioenergy production. All these efforts will be in the right direction to achieving SDG 7 and 13 which aims at ensuring access to affordable, reliable, clean, sustainable and modern energy for all and to take urgent action to combat climate change and it's impacts respectively (Khan et al. 2023).

6.2.3. Objective 3: to estimate the causality between maize production and macroeconomic variables.

6.2.3.1. CO_2 emissions and maize production

Using the Pairwise Granger Causality Test, the results showed that CO_2 emissions granger caused maize production unidirectionally running from CO_2 emissions to maize production. This means that we reject the null hypothesis of no causality between CO_2 emissions and maize production. This indicates that changes in the level of CO_2 emissions can be used to forecast the behaviour of maize production. In layman's terms, CO_2 emissions drive maize production.

6.2.3.2. Renewable energy supply and maize production

The Pairwise Granger Causality Test results showed that there was a bidirectional causal relationship between renewable energy supply and maize production. We therefore reject the null hypothesis of no causality between the two variables. These results indicate that renewable energy supply and maize production are complementary variables in the sense that they both influence each other positively. In simple terms, an increase in maize production increases the amount of feedstock for renewable energy supply. An increase in renewable energy supply enhances maize production since production heavily relies on reliable energy supply.

6.2.3.3. Economic growth and maize production.

The Pairwise Granger Causality Test revealed that a unidirectional causal relationship was found between maize production and economic growth. The direction of the causality is from maize production to economic growth. We therefore reject the null hypothesis of no causality between the two variables. These results were also a priori expectation since the agricultural sector is one the key sectors that make up an economy. Thus, when more maize is produced, more is traded, and more money is in the economy improving economic growth.

6.3. Recommendations

6.3.1. Objective 1: to analyze maize production, import, and export trends in the period 1979-2021.

6.3.1.1. Maize production trend

The production trends have shown without reasonable doubt that climate change has been a major contributor to the performance of maize over the years. According to the results, production dropped in the years that were characterized by El Niño. It is also noted that in South Africa it has been a norm that government extension officials do not render their designated duties to farmers due to traveling budgets and capacity constraints, and nothing gets to be done about it. To deal with this issue, It is therefore recommended that climate change agricultural extension for farmers be stationed at the university level, as researchers can easily advise farmers as they are directly conducting various research on climate change and production. Climate change mitigation and adaptation strategies education at this level can improve the situation.

6.3.1.2. Maize Trade Trends

There's a major concern from the results of this study since they show slow to no regional trade. Promoting regional commerce is crucial for African countries to work together and thrive economically. It is therefore recommended that to promote regional commerce, African countries should intentionally collaborate to coordinate trade laws, policies, and guidelines that encourage maize regional trade. To facilitate smoother cross-border trade, this involves standardizing tariffs, technological standards, and customs procedures. This can improve AfCFTA regional trade goals.

6.3.2. Objective 2: to estimate the short-run and possible long-run relationships between maize production and macroeconomic variables in the model.

6.3.2.1. Carbon Dioxide emissions and maize production.

This study's results have shown the detrimental effects of carbon dioxide emissions on maize production. Considering the pivotal part played by the agricultural industry in the South African economy, it is safe to conclude that emissions need to be tackled urgently. Climate change poses a significant threat to the agricultural industry and the livelihoods of most farmers, especially rural farmers since they are the most under-resourced. It is, however, worth commending and acknowledging the South African government for their willingness to tackle climate change-related issues as revealed in Chapter 5 of the National Development Plan (NDP) 2030, launching the Climate Change Bill, National, and the Presidential Climate Commission both in a quest to address climate change issues. One of the mandates of the bill is that mayors and MECs should carry out climate change awareness, mitigation, and adaptation activities in their respective municipalities and/or provinces. This is a good and progressive mandate but, in a country, characterized by cadre deployments instead of qualification-based deployments, this mandate might end up not achieving its purpose. It is therefore recommended that local municipality officials should be empowered with knowledge about climate change and a deep understanding of the need and the urgency to act swiftly to reduce climate change-contributing activities. And again, this should be done in collaboration with institutions of learning.

6.3.2.2. Renewable energy supply and maize production.

The results of this study have shown that renewable energy supply and maize production are positively significant, meaning that an increase in the production of renewable energy leads to an increase in the production of maize. This just signifies that a consistent and reliable energy source is important in producing maize. Maize serves as a staple food source for many African countries so its cultivation should be safeguarded. South Africa's focus on renewable energy has been mostly limited to wind and solar energy production, which shows good progress in the willingness to combat the use of fossil fuels for energy production. Having a consistent and reliable energy source is crucial for the agricultural sector. South Africa is one country full of bioenergy potential and the potential has not been fully exploited. Modern biomass remains an untapped source of energy in South Africa, with the agricultural sector possessing a large share of it. It is therefore recommended that more investment should be driven towards research and development (R&D) with a mandate to harness the potential of renewable energy production, with a special focus on maize as an energy crop, and provide explicit policy mandates to explore pathways of farmers' participation on biomass production for renewable energy.

6.3.3. Objective 3: to estimate the causality between maize production and macroeconomic variables.

6.3.3.1. Carbon dioxide emissions and maize production

Carbon dioxide emissions have been found to granger cause maize production. This means that in the absence of other external factors and variables, carbon dioxide emissions have a direct impact on maize production. It is therefore recommended that the government encourage maize production practices that reduce emissions, especially at the local level, encouraging farmers to generate and use energy from the crop residues is also an alternative to offset emissions.

6.3.3.2. Renewable energy supply and maize production

The results in this study have found that renewable energy supply granger cause maize production, and the relationship was bidirectional. This means that in the absence of other variables, the two variables both have a positive causal on each other. Renewable energy supply indicates the capacity of the state to meet renewable energy demand. The more supply we have, the more likely it will be to use renewable energy. If the maize sector also supplies more biomass for renewable energy, the more likely it will be for the country to use renewable energy even in rural areas. It is recommended that the government initiates farmer biomass supply schemes that incentivize farmers’ environment-friendly practices as the collection of biomass from farmers will mean less burning of residues in the fields and at the same time generate income for farmers.

6.3.3.3. Economic growth and maize production

The results of this study showed that there exists a unidirectional relationship between maize production and economic growth running from maize production to economic growth. This means that maize production granger causes economic growth in the absence or without the influence of other variables. These results were a priori expectation since it is known that the agricultural industry is key to the economic growth of any country. Maize production in South Africa has consistently risen since the early 2000s but the area under cultivation has remained at an ultimate low. It is therefore recommended that land reform programs should address the issue of land unavailability for maize production. More land should be dedicated to maize production to strengthen our economy and attract foreign currency through exports since maize is a staple food and a bioenergy feedstock for developing and developed countries globally.

6.4. Areas for future research

It is key to note that the study only used carbon dioxide emissions, renewable energy supply, trade, and economic growth while assessing their nexus with maize production. The study is limited, and more macroeconomic variables/ proxies can be added to augment the work. This study provided deep insights into the impact of climate change on maize production, and how renewable energy supply impacts the production of maize. As this study was at the macro level, future studies can still be carried out at both micro and macro levels looking at agro-waste management to address the issue of climate change at the farmers' local, national, and international market levels. In addition, future studies can also be carried out in South Africa checking the feasibility of using maize for sustainable renewable energy supply with reference to other developing countries mostly in Asian and African countries.

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