ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE, RENEWABLE ENERGY CONSUMPTION, ECONOMIC AND POPULATION GROWTH ON SUGARCANE PRODUCTIVITY IN SOUTH AFRICA FROM 1972-2021.

by

NONKULULEKO NDABA

STUDENT NUMBER: 61231630

Submitted in accordance with the requirements of the Degree in

MASTER OF SCIENCE IN AGRICULTURE

in the

Department of Agriculture and Animal Health

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: PROF A TAGWI

CO-SUPERVISOR: DR U CHIPFUPA

DISSERTATION

JANUARY 2024

DECLARATION

I **NONKULULEKO NDABA** hereby declare that the Master's dissertation with the following title:

"ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE, RENEWABLE ENERGY CONSUMPTION, ECONOMIC AND POPULATION GROWTH ON SUGARCANE PRODUCTIVITY IN SOUTH AFRICA"

is my original work. I attest that all the references utilized in this dissertation have been appropriately acknowledged. I affirm that this dissertation has not been presented to any other academic institution.

Signed: ________________________

NONKULULEKO NDABA

STUDENT NUMBER: 61231630

JANUARY 2024

DEDICATION

I dedicate this dissertation to my Queen, my mother, Ms Pretty Ncamisile Wendy Ndaba; my aunt, Ms Phumzile Patience Ntombiyedwa Ndaba; my brother, Siyabonga Khanyisani Ndaba; and my late Dad, Chief Mbongeleni Wellington Zondi. I am here today because of your everlasting love, support, and patience.

I appreciate you.

ACKNOWLEDGEMENTS

I would like to begin by thanking God Almighty for seeing it worthy to create, provide for, and protect me in my journey of life, and saw it worthy that I contribute to the body of knowledge. I appreciate my phenomenal mother, supervisor and leader of the Green Team, Prof Aluwani Tagwi, for her valuable support and supervision that has made this product what it is. There were times where I could have given up, but she lifted me up, and reminded me of who God was in my life. I will forever be grateful to her and the contributions she has made in my life and what I, today, call my own original Master’s dissertation.

I would further like to thank Dr Unity Chipfupa for the mere fact that I am even here today; we worked together on a project before and he simply believed in me, my dreams and encouraged me to go for my Masters. Indeed, nothing could stop me, as he had provided me with all the necessary support and has co-supervised me in this dissertation. He gave me “tough love” and there were no free passes with him, but I can safely say that it was worth it; Thanks Doc.

I would like to thank my sisters Ms Nqobile Sithole, Ms Nokubonga Ndaba, Ms Samkelisiwe Ndaba, Ms Pretty Zondi & Ms Mbalenhle Ximba for their sisterly support and encouragement in times where I needed it the most. Again, thank my brothers Mr Mfundo Zondi, Mr Nzuzo Zondi, Mr Ndumiso Ndaba & Mr Sabelo Ndaba for having my back in all kinds of ways, I love them very much.

A special thank you goes to Ms Zandile Msomi, Ms Yolokazi Siroqo, Mr Sphelele Dlangisa, and Mr Nhlakanipho Ndaleni for a significant impact they had in my life and academic journey. To my daughter, little Miss Universe, Zenande Ndaba, thank you for giving me a reason to live, push and be the best Mommy I can be for you. Questions like “Mommy when are you submitting?”, comments like “ihe Doc will kill you”, and requests like “Mommy can I use your phone for YouTube so you can focus on your work” went a long way my baby.

To my family at large, the Gcaba Family and generations, the Zondi Family, and Ndaba Family, I love and appreciate all of you. Your love, support, and encouragement are always appreciated.

To my Green Team, Ms Shiluva Baloyi and Mr Vhugala Nevhutalu, I know have family that isn’t blood through you guys, Thank you, siblings.

ABSTRACT

Sugarcane production in South Africa is influenced by several factors, including environmental dynamics (climate change, carbon dioxide emissions), consumption of renewable energy, population expansion, and economic growth. Understanding the intricate interdependencies between these variables is essential for sustainable agricultural planning. Using the Autoregressive Distributed Lag (ARDL) method, this study examines the effects of climate change, renewable energy consumption, carbon dioxide (CO_2) emissions, population growth, and economic growth on sugarcane production in South Africa. The study utilizes time-series data collected annually from various institutions between 1972 and 2021. This methodology facilitates a comprehensive assessment of both short- and long-term dynamics and their interactions by considering the variables of interest in this study. In the long run, temperature and carbon dioxide levels have a statistically significant negative impact on sugarcane yield, with significance levels at 10% and 1%, respectively. Conversely, rainfall, renewable energy consumption, and gross domestic product exhibit a statistically significant positive relationship with sugarcane yield. In the short run, the analysis showed that rainfall has a statistically significant negative effect on sugarcane yield at the 1% significance level. However, renewable energy consumption and carbon dioxide emissions have statistically significant positive effects on sugarcane yield, both at the 10% significance level. The causality results indicated insufficient evidence to establish a causal relationship between sugarcane yield and temperature, renewable energy consumption, GDP, carbon dioxide emissions, and population growth. Nevertheless, a uni-directional causal relationship was identified from rainfall to sugarcane yield, indicating that changes in rainfall patterns may lead to changes in sugarcane yield. The study recommends focusing on growing the renewable energy sector by allocating resources to agriculture for bioenergy production.

Keywords: ARDL, carbon dioxide emissions, climate change, economic growth, granger causality, population growth, renewable energy consumption, sugarcane yield

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

ADF	Augmented Dickey Fuller
AIC	Akaike Information Criterion
ARC	Agricultural Research Council
ARDL	Auto Regressive Distributive Lag
CCKP	Climate Change Knowledge Portal
CO_2	Carbon Dioxide
CSIR	Council of Scientific and Industrial Research
CUSUM	Cumulative Sum
DEMR	Department of Energy and Mineral Resources
DOE	Department of Education
DOLS	Dynamic Ordinary Least Squares
DTI	Department of Trade and Industry
ECM	Error Correction Model
EIA	Energy Information Administration
EKC	Environmental Kuznets Curve
FAO	Food and Agriculture Organization
FMOLS	Fully Modified Ordinary Least Squares
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LR	Long run
NDCs	Nationally Determined Contributions

NGOs	Non-Government Organizations
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PP	Phillips Perron
REIPPP	Renewable Energy Independent Power Producer Procurement
SA	South Africa
SACU	South African Customs Union
SASA	South African Sugar Association
SDGs	Sustainable Development Goals
SR	Short run
TIKZN	Trade and Investment KwaZulu-Natal
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Population Fund
US$	American United States Dollar
VAR	Vector Auto Regression
VECM	Vector Error Correction Model
WDI	Word Development Indicators
WEF	World Economic Forum

CHAPTER 1: INTRODUCTION

1.1 Background

Life-threatening weather events including droughts, floods, storms, and heatwaves are becoming more common and intense because of climate change. Crop yields are anticipated to decline in many countries due to rising temperatures and shifting rainfall patterns (IPCC, 2022). The Intergovernmental Panel on Climate Change (PCC) report indicated that climate change is already impacting the agricultural sector. In many regions of the world, these events are resulting in crop failures, decreased yields, and diminished food security (FAO, 2020). Additionally, water availability, the incidence of pests and diseases, and soil health are all being impacted by climate change, making it more difficult for farmers to cultivate crops.

Agriculture is the second largest emitter of greenhouse gases (GHG) due to the use of fertilizers derived from fossil fuels, agricultural machinery, and the combustion of biomass (Qiao et al., 2019). According to Climate Watch (2023), approximately 28.6 million tons of emissions come from the agricultural sector in Africa, which is around 18% of world emissions (5,79 billion tons). According to the National Oceanic and Atmospheric Administration (2023), the worldwide mean atmospheric carbon dioxide level peaked at a record high of 417.06.ppm in 2022, marking the 11th consecutive year of a yearly increase surpassing 2 ppm, with a rise of 2.13 ppm from 2021. This indicates that the world is emitting more every year, and this requires global attention from all spheres, including research and development. According to FAO (2023), approximately three-quarters of the world’s global carbon dioxide emissions come from energy sources (73.2%).

South Africa is currently faced with an energy crisis, with load shedding being prevalent in most parts of the country. Research recommendations have included renewable energy as part of the solution (Shah and Solangi, 2019; Chien et al., 2021; Yaseen et al., 2020).

According to the exploration of the transformational potential of the electric power sector in South Africa amongst four other African countries by the International Renewable Energy Agency (IRENA) (2021), South Africa can align their goals with the continental and world climate change targets and back local renewables market expansion. The country can also leverage renewables for universal energy access; and craft personalized power sector plans using innovative strategies, under fair policies for inclusive transitions. Case studies have proven that South Africa has the potential to grow the country's renewable energy industry (Msimanga and Sebitotsi, 2014; Aliyu et al., 2018; Hochstetler, 2020; An and Mikhaylov, 2020).

Crops like sugarcane have been identified as solutions to alleviate the impacts of climate change and combat the national energy grid through bioenergy production (Raza et al., 2019). Sugarcane is a multifunctional crop utilized not only for the manufacture of sugar but also for the generation of biofuel, specifically ethanol. The surge in demand for alternative energy, such as biofuels, has the potential to impact the cultivation practices of sugarcane (Zabed et al., 2017). Southern African countries have considerable sugarcane industries that have the potential to serve as a noteworthy and sustainable means of generating heat, power, and biofuels (IRENA, 2019). According to the OECD-FAO Agricultural Outlook 2021-2030, developing countries are forecasted to be the source of the majority of the anticipated increase in sugar output (FAO, 2021a). This has implications for a country's Gross Domestic Product (GDP) through improved volumes of production, creating employment opportunities, and increased exports (contributing to foreign exchange earnings).

According to the Food and Agriculture Organization of the United Nations (FAO), sugarcane is one of the most important crops globally, for sugar and energy production, with approximately 26 million hectares of land devoted to sugarcane cultivation worldwide (FAO, 2021b). South Africa's land allocation for sugarcane cultivation was recorded at 295 461 hectares in 2021 (FAO, 2023). Sugarcane is renowned for its increased productivity, use in high-tech processes, high-quality raw material, and production of sugars (sucrose, glucose, and fructose) and ethanol from its stalk (de Matos et al., 2020).

About 57% of the plant's mass consists of water, with the remainder consisting of fibre, bagasse, and sugar. Concern has been expressed regarding the effect that the production of biofuels will have on the cost of food for the impoverished. In South Africa's Biofuels Industrial Strategy, the prohibition of maize and the preference for sugar cane as feedstocks are the result of this concern (Kohler, 2016). This indicates sugarcane is a preferred bioenergy crop since it does not trigger food security concerns.

Brazil is the leading global producer of sugarcane and the country's production more than doubled in recent years to meet export demands, reduce dependency on fossil fuels, and mitigate climate change (Gouvêa et al., 2021; Bordonal et al., 2018). India leads second in world sugarcane production. According to Cardoso et al. (2018), the typical output of cane stalks ranges from 60 to 100 tonnes per hectare annually, and variation depends on factors such as climate change and input choices amongst other factors in Brazil. Thailand is the third largest producer of sugarcane. The country is also a major exporter of sugarcane, with backward and forward linkage sectors in the country being affected by the vulnerability of sugarcane production; with a significant climate change impact on sugarcane yield (Pipitpukdee et al., 2020). According to the South African Sugar Association (SASA) (2023), the South African sugarcane sector yields around 2.2 million tonnes of sugar every season on average. About three-fifths of this sugar is distributed within the Southern African Customs Union (SACU). The surplus is shipped to markets in Africa, Asia, and the Middle East.

Temperature, rainfall, GDP, renewable energy usage, energy-related CO_2 emissions, and population expansion might affect a country's long-term sugarcane output (Coelho and Goldermberg, 2019). Temperature and precipitation affect agricultural production and crop growth. GDP fluctuations affect agricultural infrastructure and technological investments, which affect sugarcane cultivation and crop yield. Renewable energy promotion may impact land usage and sugarcane production. Population growth affects sugarcane consumption, market dynamics, and production methods. Examining these features helps policymakers and stakeholders develop sustainable sugarcane production and management strategies.

Sugarcane production in South Africa is mainly concentrated in the rural areas of KwaZulu-Natal and Mpumalanga and the industry produces an average 19 million tons of cane each year (SASA, 2019). An estimated 65,000 individuals are directly employed in the sector, with an additional 270,000 people employed indirectly. The industry additionally supports 1 million livelihoods (SASA, 2020b). Sugar cane cultivation and processing in South Africa primarily aim to produce refined sugar and molasses for local usage and raw sugar for international trade. Millers have engaged in diversified production to some extent throughout the years, such as the co-generation of energy and animal feed. and bioethanol. Sugarcane remains an important energy crop globally.

South Africa's population size is currently 60 481 893 million at a growth rate of 1.05% from 2022 with 3123 and 1786 births and deaths per day (birth rate is more than double the death rate), respectively, along with 160 migrations per day (UNFPA ,2023). The country is projected to continue to grow at an average rate of 1.28% until 2082 (PwC, 2023). This has implications for economic growth, competition for resources, and human capital resources in industries such as agriculture (WEC, 2021). It is thus important to investigate the nexus between population growth and agricultural productivity, for future projections and policy recommendations.

The United Nations (UN) has been mandated to support international efforts to combat climate change through the United Nations Framework Convention on Climate Change (UNFCCC). This is achieved through encouraging a reduction in greenhouse gas emissions (UNFCCC, 2020). In April 2016, South Africa signed the Paris Agreement adopted in 2015 to limit global warming to well below 2 degrees Celsius (aiming for 1.5 degrees Celsius) (UNFCCC, 2015; UNTC, 2023). It prioritizes reducing greenhouse gas emissions and enhancing climate resilience through collaborations by the Conference of the Parties (COP). This was the beginning of a commitment to achieving Sustainable Development Goals (SDGs) through Nationally Determined Contributions (NDCs) (Liu and Raftery, 2021).

However, since 2016, South Africa amongst many other countries, has not met its targets (350–420 $MtCO_2e$) and has thus weakened its NDCs, taking the emissions target range to 398 and 614 MtCO2e (Leggett, 2020; GroundUp, 2021). The country's share of global GHG emissions is currently 1.13%. According to the World Resources Institute (2020), South Africa is among 80% of the countries that submitted new NDCs with reduced total emissions. It is to be noted though, that this new NDC comes with a higher score for recognition of the importance of people's health (12/15) by the Global Climate and Health Alliance (2023). South Africa has emerged as the frontrunner among the world's 20 largest greenhouse gas emitters in implementing measures to safeguard the health of its population, just before COP26 in Glasgow, 2021. These commitments are a clear indication of South Africa's willingness to curb the effects of climate change and protect the livelihoods of the people of South Africa and subsequent contributions to the total emissions globally.

Minimizing greenhouse gas emissions is crucial for shifting towards sustainable energy and mitigating environmental consequences. Although South Africa has developed some policies such as the Just Energy Transition Investment Plan (JET IP) and the South African Renewable Energy Masterplan (SAREM), the country remains at a rating of inadequate policy action according to the Climate Action Tracker (2023). The Renewable Energy Independent Power Producer Procurement (REIPPP) programme is a notable effort to encourage the advancement of renewable energy projects inside the country (ICLG, 2023). The South African government, through the Department of Energy and Mineral Resources' Integrated Resource Plan (IRP2019), implemented the REIPPP programme to promote private sector investment in renewable energy production, mitigating greenhouse gas emissions, and enhancing the diversity of the nation's energy sources. However, the focus has been on solar and wind projects and little to nothing has been done on bioenergy production.

It is against this background that the short and long-run effects of climate change, renewable energy consumption, and economic and population growth on sugarcane productivity are studied. This study will provide important insights into the dynamic relationships between sugarcane yield, temperature, rainfall, renewable energy consumption, GDP, CO_2 emissions, and population growth.

The research findings aim to provide policymakers, farmers, and other stakeholders in the sugarcane and renewable energy sectors with evidence-based insights into how climate variables, renewable energy consumption, and economic factors impact sugarcane productivity. This knowledge is intended to guide the development of effective strategies to mitigate the adverse effects of climate change, optimize resource allocation, and improve sustainable agricultural practices. Additionally, the research seeks to inform policies that support the integration of renewable energy sources to enhance energy security and reduce carbon emissions in the agricultural sector, offering sugarcane farmers opportunities to adopt more resilient farming techniques, improve crop yields, and explore new revenue streams through renewable energy initiatives.

1.2 Problem Statement

Human-induced global warming, with a 1.1-degree Celsius rise in average global temperatures, has already spurred unprecedented climate changes, including more extreme weather and rising sea levels, impacting ecosystems and communities globally, with future risks set to escalate with further temperature increases (World Research Institute, 2023). These risks are posed by the excessive use of fossil fuels in energy generation and economic activities worldwide (Johnsson et al., 2019). South Africa’s economy is also at threat, with the national grid on the verge of collapse due to prolonged load-shedding, maintenance issues, sabotage, diesel shortages, aging infrastructure, and widespread corruption (CNN, 2023; NPR, 2023). The unemployment rate is also rising at 32.9%, a rise of 0.2% from the previous quarter (GIBS, 2023; Statistics South Africa, 2023b). According to Pegkas (2020), it is nearly impossible to achieve economic growth without degrading the environment. However, the detrimental effects on the environment cannot be overlooked. South Africa has moved up to the 12th position among the world's major carbon emitters, up from 15th place in 2016 (Polity, 2021; Worldometer, 2016). The country’s significant coal output is the main reason for this situation, highlighting the pressing need for the country to reduce its carbon emissions and shift towards more sustainable energy sources to lessen environmental harm and tackle climate change efficiently.

According to Chandio et al. (2019), the agricultural sector is the most vulnerable to climate change, which threatens food security and livelihoods. South Africa faces substantial hurdles in mitigating climate change due to its historically high energy intensity and ongoing energy development (Tagwi, 2022). Simultaneously, the nation has very formidable growth obstacles, which are worsened by the enduring effects of apartheid. The South African agricultural sector is largely volatile and highly influenced by climatic conditions, political actions, and social change and it is predicted to be the key driver of economic growth in the country and worldwide (Future Growth Insights, 2021). According to SA Cane Growers (2021), the sugarcane industry was foreseen to lose R723 million in 2023 because of load-shedding, which caused major irrigation challenges for the sector.

The sugar industry, which considerably raises the Gross Domestic Product (GDP) of South Africa, is a vital sector of the nation's economy (Statistics South Africa, 2019). The South African Sugar Association (2021) reports that the sugar sector employs more than 85,000 people and brings in over R14 billion annually. The introduction of the Health Promotion Levy (HPL), commonly known as the sugar tax by SARS (2021), a government initiative to reduce the consumption of sugary beverages, has had a detrimental effect on the sector. Furthermore, the industry's viability has been put in jeopardy by global competition, notably from nations that produce sugar, such as Brazil (South African Sugar Association, 2019).

In addition, the sector is faced with droughts, floods, and other extreme weather occurrences among the severe effects of climate change that South Africa is currently facing (Department of Environment, Forestry, and Fisheries, 2021). The effects have already been felt in South Africa through floods that continue to negatively impact the economy in the region and country. Reference is to be made to the April 2022 floods that took more than 400 lives, destroying infrastructure and threatening people’s livelihoods (News24, 2022). Moreover, global energy sources for the agricultural sector come from fossil fuels, which largely contribute to climate change and carbon dioxide emissions.

According to Ngavara et al. (2019), South Africa's dependence on livestock production (the sector's largest emitter of carbon dioxide) will hinder any progress in adhering to the country's commitments if remedial actions are not taken by the sector. Carbon dioxide emission reduction is a challenge because it increases with increases in economic growth (Nguyen et al., 2015). Shafiq et al. (2021) found a significant long-run association between temperature, rainfall, and sugarcane production. Temperature was found to have a negative relationship while rainfall had a positive relationship with sugarcane production. This study will use temperature and rainfall as measures of climate change to assess the association between climate change and sugarcane production in South Africa.

According to Sridharan et al. (2018), global energy sources for the agricultural sector are mainly sourced from fossil fuels, which contribute more to carbon emissions. The world must take decisive climate action to curb global emissions. To contribute towards climate action, this study will determine short-run and long-run relationships between renewable energy production and sugarcane production. This information can be useful for policymakers, farmers, and other stakeholders in the sugarcane and renewable energy sectors.

1.3 Aim

The main aim of this study is to assess the impact of energy and climate change on sugarcane production for the last 50 years.

1.3.1 Main Objective

The objective of this study is to determine the short run and long run effects of temperature, rainfall, renewable energy consumption, carbon dioxide emissions, real GDP, and population growth on sugarcane production in South Africa.

1.3.2 Specific Objectives

The specific objectives of the study are as follows:

i. To analyze sugarcane production trends from the 1972-2021 period.
ii. To determine the short-run and possible long-run relationships between sugarcane yield, temperature, rainfall, renewable energy consumption, GDP, CO_2 emissions, and population growth (herein referred to as variables).
iii. To identify causality between the variables.

1.3.3 Research Questions

The research objectives give rise to the following questions:

1. What has been the performance of sugarcane production over the past 50 years?
2. Is there a long-run relationship between sugarcane yield, temperature, rainfall, renewable energy consumption, GDP, CO_2 emissions, and population growth? i.e., are the variables cointegrated? If not, what are the short-run relationships between the variables? If yes, at what speed is the short run expected to adjust to reach long-run equilibrium?
3. Are there any causal relationships between the variables?

1.3.4 Research Hypotheses

To assess the effects of climate change, renewable energy consumption, economic growth, carbon dioxide emissions, and population growth on sugarcane productivity, the following hypotheses were formulated:

H_{01}: Temperature has no significant impact on sugarcane productivity in South Africa.
H_{A1}: Temperature has a negative impact on sugarcane productivity in South Africa.

H_{02}: Rainfall has no significant impact on sugarcane productivity in South Africa.
H_{A2}: Rainfall has a positive impact on sugarcane productivity in South Africa

H_{03}: Increased renewable energy consumption has no significant impact on sugarcane productivity in South Africa.
H_{A3}: Increased renewable energy consumption has a positive impact on sugarcane productivity in South Africa

H_{04}: CO_2 emissions have no significant impact on sugarcane productivity in South Africa.
H_{A4}: CO_2 emissions have a negative impact on sugarcane production in South Africa.

H_{05}: Economic growth has no significant impact on sugarcane productivity in South Africa.
H_{A5}: Economic growth has a positive impact on sugarcane productivity in South Africa.

H_{06}: Population growth has no significant impact on sugarcane productivity in South Africa.
H_{A6}: Population growth has a positive impact on sugarcane productivity in South Africa

1.4 Significance of the Study

The majority of the world's energy needs are met by non-renewable resources, which are not only swiftly depleting but also increasing greenhouse gas emissions and having adverse environmental impacts (Amin et al., 2022; Chien, 2021). Globally, changes in temperature, rainfall patterns, and soil moisture are harming agricultural production, particularly sugarcane. The sugarcane industry is a significant contributor to the world economy, with a projected 1.9 billion metric tonnes of production in 2021 (USDA, 2021). Sugarcane can be used as a feedstock for biofuels like ethanol, which can aid in lowering greenhouse gas emissions (Liu et al., 2023). Over 85,000 people in South Africa receive employment and income from sugarcane (SASA, 2021). However, the production of sugarcane in South Africa has decreased recently because of climate change effects, such as droughts and extreme weather events, among other factors (SASRI, 2019).

Sugarcane holds significant strategic importance in the provinces of KwaZulu-Natal and Mpumalanga, as it serves as a primary crop in both regions. Its cultivation contributes significantly to the overall gross farming income derived from field crops in both provinces (SASA, 2020a). In 2019/2020, 21,926 registered sugarcane growers yielded 20M metric tonnes from 14M hectares in regions spanning KwaZulu-Natal to Mpumalanga Lowveld. Representation is through the South African Cane Growers Association (SACGA) and South African Farmer's Development Association (SAFDA) with 20,711 small-scale, 1,126 large-scale, and 89 miller-cum-planters. The industry was now in jeopardy because of climate change, the government's sugar tax on sugary drinks, and negative global sentiment associated with the negative dietary effects of eating too much sugar.

Sugarcane is a highly suitable crop to produce bioenergy due to its C4 characteristics, which allow for the generation of large amounts of biomass per unit area. Additionally, the ability of sugarcane to till and ratoon makes it an attractive option to produce biofuels (Huang et al., 2020). The processing of one tonne of sugarcane yields approximately 85-100 kg of sugar and 35-45 kg of molasses (Raza et al., 2019). Through fermentation, this molasses can be converted into ethanol, which is a low-carbon fuel used in the transportation sector. The crop is thus key in the renewable energy sector for its potential.

Based on the energy potential benefits and livelihood outcomes highlighted, it is, therefore, critical to investigate how climate change, renewable energy, economic growth, and carbon dioxide emissions affect the production of sugarcane in South Africa because the crop is crucial to the nation's economy and the livelihoods of many farmers.

1.5 Limitations and Delimitations of the Study

Macroeconomic data availability is a challenge, and where available, is expensive for most developing countries. In this case, some data relevant to the study were not available for some variables (e.g. technological progress and capital accumulation). Econometric models may also allow a certain number of variables depending on the sample size for reliable and non-spurious regression results. Therefore, the focus is on data that is in the public domain, i.e. South African data from 1972 to 2021. The following data was collected: sugarcane yield, climate change measured by temperature and rainfall, carbon dioxide emissions, renewable energy consumption, and economic growth measured by gross domestic product.

1.6 Ethical Considerations

Ethical considerations in research are essential for safeguarding participants, fostering trust, and maintaining credibility. They ensure the prevention of harm, adherence to rules, and preservation of research integrity, thereby encouraging public acceptability and long-term impact, while also advocating for responsible and accountable research techniques (Horstkötter and de Wert, 2020). This study is a time-series analysis study that has utilized data from secondary sources. All sources of the data and any pertinent data owners or developers have been properly credited. Since the information was gathered from publicly accessible secondary sources, no personally identifying information was present. The researcher took steps to lessen the impact of any potential data flaws, such as measurement bias, on the analysis. This study was carried out in accordance with all applicable ethical standards at the University of South Africa (UNISA). Feedback will be disseminated within the broader Rural Bioenergy Programme during feedback sessions with stakeholders.

1.7 Definitions of Key Terms

The following key definitions will be adopted by the study:

- **Auto-Regressive Distributed Lag:** The Autoregressive Distributed Lag (ARDL) model is a statistical technique employed to examine the enduring connections between variables within a time series framework (Shrestha and Batta, 2018). The model combines autoregressive and distributed lag components to effectively describe the dynamic interactions between variables across time (Greenwood-Nimmo et al., 2021).
- **Carbon Dioxide Emissions:** The context of this study refers to energy-related carbon dioxide emissions which arise from the combustion of fossil fuels such as coal, oil, and natural gas to generate power, facilitate transportation, provide heating, and support industrial activities (EIA, 2016). They make a substantial contribution to climate change by effectively retaining thermal energy within the Earth's atmosphere.
- **Climate Change**: Refers to the long-term alteration of temperature and typical weather patterns in a place. It includes changes in temperature, precipitation, and frequency of extreme weather events such as heatwaves, droughts, and floods (IPCC. 2018).
- **Economic Growth**: Ogundari and Awokuse (2018) define economic growth as real GDP per capita. This study will adopt the same definition of economic growth.
- **Environmental Kuznets Curve:** posits a curvilinear association between economic growth and environmental degradation, indicating that pollution tends to worsen initially but subsequently diminishes as economies progress and income levels increase (Chen et. al., 2019).
- **Pairwise Granger Causality:** is the utilization of the Granger causality idea to analyze numerous variables in a paired fashion. The purpose of this assessment is to determine if one variable within a group of variables may more accurately predict another variable compared to the opposite situation (Khana and Tan, 2019). This evaluation is done by analyzing each pair of variables individually.

- **Gross Domestic Product:** Gross Domestic Product (GDP) refers to the total market worth of all end-stage products and services manufactured within a nation during a specified timeframe (PEC, 2003). This study utilizes per capita GDP (constant 2015$), which is GDP.
- **Population Growth:** The average annual percentage change in a country's population, resulting from a surplus (or deficit) of births over fatalities and the balance of immigrants entering and exiting the country (CIA, 2023). The rate could be either positive or negative.
- **Renewable Energy Consumption**: Refers to the use of energy sources that are replenished naturally and can be used repeatedly, such as solar, wind, hydro, and geothermal energy (Lee & Kim, 2020).
- **Sugarcane yield**: Crop yields refer to the amount of harvested output achieved from a given cultivated area for agricultural products (OECD, 2023). Sugarcane yield is therefore the amount of sugarcane output produced per hectare.

1.8 Outline of the study

The outline of the study is as follows:

- **Chapter One:** encompasses the background, the problem statement, the aims and objectives, and the contribution of the study, among others.
- **Chapter Two:** entails a theoretical framework and a theoretical review for the study.
- **Chapter Three:** provides the research methodology used in the study.
- **Chapter Four:** provides the trend analyses for variables included in the study as well as some information on the trade of sugarcane.
- **Chapter Five:** provides both the descriptive and empirical results of the study and the discussion thereof.
- **Chapter Six:** provides the summary of the study, conclusions, recommendations, and areas for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents the Theoretical Framework, Literature Review, and the chosen Analytical Framework for the assessment of the effect of climate change (rainfall and temperature), renewable energy consumption, economic growth (GDP Constant $), and carbon dioxide ($CO_2$) emissions from energy sources and population growth on sugarcane yield.

2.2 Theoretical Framework

Theoretical frameworks underpinning this study include the Environmental Kuznets Curve (EKC), Sustainable Development, and the Malthusian Theory of Population. The study uses these theoretical frameworks to elucidate the potential connections between agricultural production and selected macroeconomic factors in the economy. and further guide possible policy remedial actions. **Figure 2.1** graphically presents the theoretical framework for the relationship between CO_2 emissions, climate change, economic growth, renewable energy consumption, and sugarcane production.

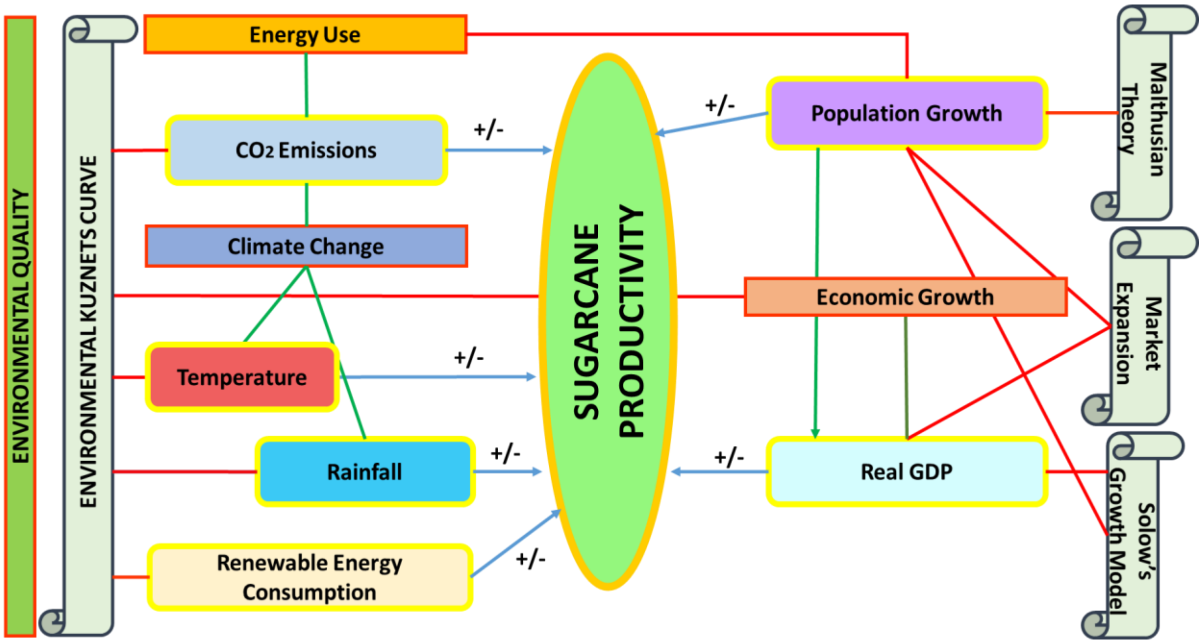


Figure 2.1: Theoretical Framework for selected variables and sugarcane production nexus

Source: Author's compilation (2024)

Figure 2.1 illustrates that food production stimulates economic activity, by increasing the demand for energy in the economy, thus resulting in environmental pollution. These developments can be explained by four theories: The Environmental Kuznets Curve, the Malthusian theory, Solow's Growth Model, and the theory of Market Expansion.

2.2.1 The Environmental Kuznets Curve Theory

Initially introduced by Kuznets (1955), the Environmental Kuznets Curve (EKC) theory offers a structure for comprehending the connection between economic progress and environmental threats. (Kaika and Zervas, 2013). As countries experience economic growth, pollution initially increases but then declines at a certain level of development (Stern, 2018; Tenaw and Beyene, 2021). **Figure 2.2** below shows the EKC theory.

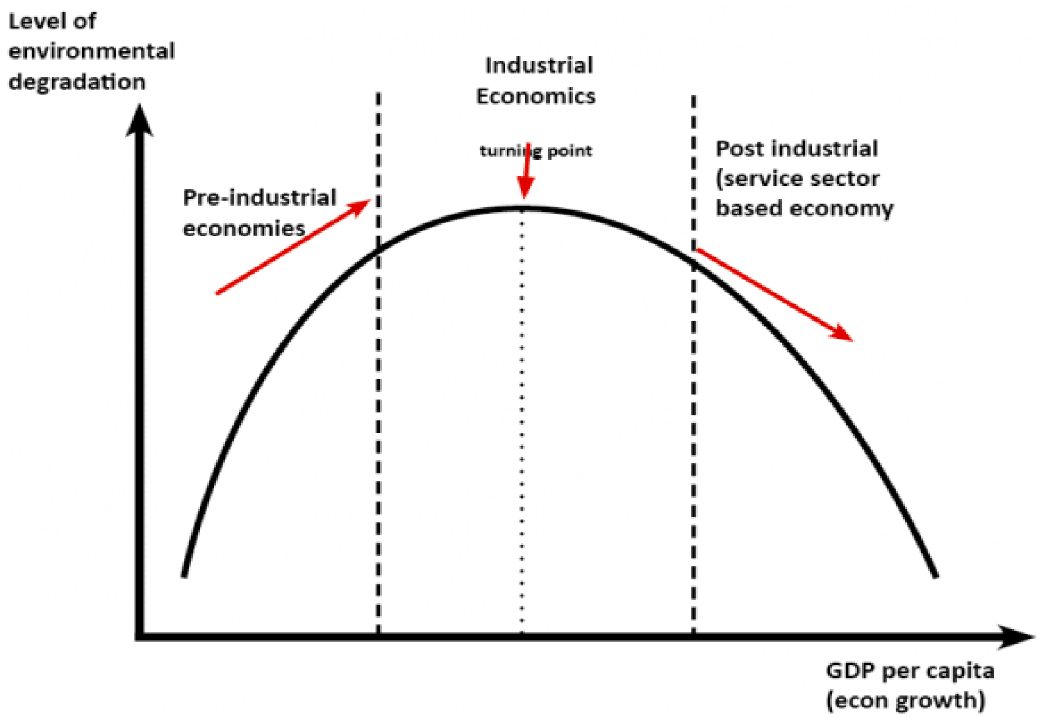


Figure 2.2: Environmental Kuznets Curve

Source: Pettinger (2019)

The EKC theory suggests that environmental degradation follows a distinct pattern across pre-industrial, industrial, and post-industrial stages, with degradation increasing during industrialization but declining in the post-industrial stage due to technological advancements, regulations, and awareness (Espoir and Sunge, 2021; Tagwi, 2022). In the case of South Africa's sugarcane production, it is hypothesized that as the economy develops, initial demand leads to increased production and potential environmental degradation due to resource and fossil fuel consumption (Adu and Denkyirah, 2019). The EKC will be used in this study, to explain the relationship between climate change, renewable energy consumption, economic growth, CO2 emissions, and sugarcane yield.

The assumption of the EKC theory is, at the primary stage of development, the economy grows (increases in real GDP and sugarcane yield) with increases in industrialization, which occurs at a disadvantage to the environment (Appiah et al., 2018). This then leads to higher carbon dioxide emissions and contributes to climate change, which may lead to alterations in rainfall patterns and higher temperatures and have negative impacts on sugarcane yields. As South Africa progresses along the EKC, it is assumed that climate change impacts and hence awareness may trigger investments in renewable energy and potentially mitigate the effect of climate change. This awareness will result in adaptive practices and technologies, potentially mitigating adverse effects on sugarcane yield and improving agricultural conditions.

The EKC highlights the importance of reaching a balance where economic growth and environmental sustainability are aligned for the benefit of agricultural productivity and overall well-being. The study will check whether this theory holds for the South African sugarcane industry. *A priori*, the relationship between CO_2 emissions and sugarcane productivity and economic growth is thus expected to be positive in the SR and negative in LR, based on this theory.

2.2.2 The Solow-Swan Growth Model

The Solow-Swan growth model, a neoclassical theory, explains how factors like capital accumulation, technological progress, and population growth shape long-term economic development (Zhang, 2018). In sugarcane production, this comprises capital investment in machinery, irrigation systems, and infrastructure, improving productivity and output, and driving economic expansion (Sánchez et al., 2022).

Technological advancements, such as innovative sugarcane varieties and improved processing methods, enhance efficiency and reduce costs, further promoting growth. Population growth contributes to the industry by providing a larger labor force for increased production activities (Jayne et al., 2018). However, sustainable economic growth requires the convergence of population growth with capital accumulation and technological advancement. The Solow-Swan Growth model, which is part of the neoclassical growth theory, sheds light on the relationship between sugarcane production and economic development by emphasizing the importance of investing in physical capital, technological innovation, and a growing workforce to facilitate industry growth.

2.2.3 The Malthusian Theory of Population

The theory proposed by Thomas Malthus, argues that population expansion outpaces resource availability, causing scarcity and environmental degradation (Ankomah, 2020). Malthus, in *"An Essay on the Principle of Population"*, predicted that population growth will be so rapid that food production will be unable to meet demand (Okunola and Festus, 2018; WEF, 2021). He warned that unchecked population growth exceeding food production could result in famines and advocated for population control measures such as education, delayed marriages, and contraceptive use. Emphasis was also made on the connection between population control and the economic stability of a nation (Sebikabu et al., 2020). Stone (2021) discussed how food, water, and land become scarce as the population grows exponentially, causing poverty, starvation, and civil upheaval.

According to Ouessar (2021), this paradigm emphasizes sustainable resource management and population control for long-term environmental and social stability. In the context of sugarcane production, the Malthusian theory will highlight potential challenges associated with population growth. As the population increases, there may be a greater strain on land, water, and other resources necessary for sugarcane cultivation. If the growth in sugarcane production fails to keep up with the increasing demand driven by population growth, it can lead to resource depletion, environmental degradation, and food scarcity. According to Ahmed (2019), the theory emphasizes the need for sustainable agricultural practices and efficient resource management to meet the growing demand for sugarcane products and will therefore be adopted in this study.

2.2.4 The Market Expansion Theory

The theory emphasizes the positive connection between population growth and economic expansion. Population growth, according to this theory, generates larger markets, stimulates demand, and promotes economic expansion (Rada and Fuglie, 2019). The link between sugarcane production and market expansion is that: Population growth can contribute to the expansion of the consumer market for sugarcane-based products, thereby fueling the need for increased sugarcane production. This theory suggests that an expanding population can generate economic opportunities, thereby encouraging farmers and businesses to invest in sugarcane cultivation, processing, and distribution. It emphasizes the prospective advantages of population growth for the sugarcane industry, as it leads to larger markets and more revenue opportunities.

2.3 Review of variables used in the analysis.

Various researchers have studied the association between climate change, renewable energy consumption, economic growth, CO_2 emissions and agricultural productivity, with differing views and findings (Salim et al., 201; Chandio et al. 2020b, 2020; Ceesay et al., 2022; Raihan et al., 2023). This section reviews the findings of different authors in different countries on the relationships between the variables in this study.

2.3.1 Climate Change and Agricultural Productivity

In Pakistan, an Auto Regressive Distributive Lag (ARDL) analysis for a data period of 29 years, found maize production to be positively influenced by temperature in the long run, suggesting the implementation of policies that conserve agriculture to reduce the carbon footprint (Rehman et al., 2020). These results are contrary to the EKC theory, as it would assume a positive SR relationship but later negative as the law of diminishing returns kicks in. Data from the 1984-2019 period in Pakistan yielded a positive relationship between temperature and agricultural productivity when an ARDL model was fitted (Zahoor et al., 2022). In addition to adopting other greenhouse gas mitigation strategies, such as reforestation renewable energy, and water conservation policies, the study recommended agriculture technological improvements.

Another study in the same country (Pakistan), found temperature to have a negative impact on rice production using the ARDL model between the 1970-2018 period, recommending the adoption of policies that tackle climate change effects and contribute to food security (Gul et al., 2022). In the 1985-2018 data period, Shafiq et al. (2021) used the ARDL and found a negative relationship between temperature and agricultural productivity, whereas rainfall had a positive impact. The study looked at different crops including sugarcane production which had a Short-run significant negative relationship with temperature.

A 1968-2014 data assessment in Turkey, recommended agriculture-specific adaptation policies that build resilience, upon findings of both short-run and long-run adverse effects of CO_2 emissions and temperature on cereal production (Chandio et al., 2020b). Chandio et al. (2021) also examined the impact of climate change in Turkey by employing the ARDL bounds test on a 1980-2016 dataset. A negative relationship between temperature and wheat production was recorded for this study. Utilizing Cross-sectional (CS)-ARDL in Malaysia, the Philippines, and Thailand (ASEAN-4 countries) and data from 1990-2016, results were found to show a long-run relationship between climate change and agricultural production (Chandio et al., 2022a). This study also suggested renewable energy focus by these countries as it can significantly reduce environmental impacts.

Asfew and Bedemo (2022) used the ARDL and Granger approaches for the 1971-2014 data period in Ethiopia and found crop production to increase with increases in rainfall. These findings were in line with those of Ketema (2020) who studied the same variables observed between 1980-2018, using the same modelling techniques. Rainfall had a long-run positive effect on agriculture in Sub-Saharan Africa using observations from 1985-2018, when panel Pulled Mean Group (PMG) and ARDL approaches were applied in the study (Affoh et al., 2022). These results were also contrary to the expectation of the EKC theory, that the law of diminishing returns would hold as more rainfall will not mean more productivity. However, these results proved otherwise for Sub-Saharan Africa. The study suggested the formulation of policies to build resilience and sustainability in agriculture.

In Somalia, Warsame et al. (2021) analyzed data spanning from 1985-2016 using the ARDL bounds technique and found rainfall to advance crop production in the LR. Abbas (2022) utilized the PMG model and found a significant negative relationship between temperature and major crops in Pakistan during the 2000-2019 data period. There was no evidence of a positive long-run association between rainfall and agricultural productivity in Bangladesh (Salim et al., 2019). This was after a PMG estimation was done for 61 years' worth of data, recommending research and development improvements. Linnenluecke et al. (2020) used the regional fixed effect model to test the relationship between climate change variables and agricultural output in 3 Australian regions. There was no evidence of a significant rainfall-agriculture relationship but a significant negative relationship between temperature and agriculture.

Chandio et al. (2020a) examined the climate change effects on agricultural output in China from 1982 to 2014. They found that temperature and precipitation had a negative impact on agricultural production in the long term. These outcomes are in line with the expectation that any increase in temperature or rainfall will eventually have no positive impact on yield (EKC). Jena (2021) utilized a Panel ARDL model using data observed for 1993 to 2019, and found that climate changes had negatively impacted Indian agricultural production, making it an emergent topic in agricultural research.

A 58-year data analysis of different crops in India (including sugarcane), found rainfall to negatively affect agricultural productivity, including sugarcane yield, while a positive association was recorded for temperature (Guntukula, 2020). In China, findings from Chandio et al. (2020) show that rainfall and temperature affected agricultural output adversely in the long run (1982-2014 data period). This would have implications for policy development in the SR to assist in curbing the long-term effects of climate change in the country.

2.3.2 Energy, Growth and Agricultural Productivity

Observations from 1990-2016 were studied for Indonesia, Malaysia, the Philippines, and Thailand, where Westerlund cointegration tests were utilized and found agricultural production to increase with an increase in renewable energy consumption (Chandio et al., 2022a). Chopra et al. (2022) studied relationships between the Association of Southeast Asian Nations (ASEAN) countries and found renewable energy consumption to be positively associated with agricultural productivity. Furthermore, a bi-directional causality was reported for the two variables. In a panel cointegration analysis for 107 countries (1990-2013), Nguyen and Kakinaka (2019) discovered a negative relationship between renewable energy consumption and output in low-income countries and a positive one in high-income countries, recommending that national policies must match each nation's developmental stage. In Gambia, Ceesay et al. (2022) employed the ARDL technique and found a negative relationship between agricultural growth and GDP growth in both the short run and long run.

A Nigerian study by Udemba (2020), found a positive impact of GDP on agriculture between the 1981 and 2018 data period, with no evidence of causality. The study recommended the adoption of clean energy policies. Applying the ARDL model in Ethiopia, the effect of GDP on agricultural productivity was analysed, specifically cereal productivity (Shita et al., 2018). The time series data analysis of the years 1990-2016 revealed a positive relationship between the two variables. According to the findings of Zakaria et al. (2019) in South Asia (1973-2015), GDP and agricultural productivity had a positive relationship in the short run and postulated a negative relationship in the long run.

2.3.3 Pollution and Agricultural Productivity

In South Africa, Ngavara et al. (2019) found a positive correlation between agricultural CO_2 emissions and agricultural value added. The study rejected the EKC hypotheses and advised transitioning to renewable energy sources due to challenges in reducing carbon emissions from livestock production reliance. Khan et al. (2020) found a positive relationship between energy consumption, economic growth, and CO_2 emissions in Pakistan, using data from 1965 to 2015. The study used ARDL and recommended promoting renewable energy adoption to meet demand, reduce emissions, and ensure sustainable economic growth.

A heterogeneous panel data approach was utilized in Asian countries from 1980-2016 and showed proof of a positive short-run relationship between CO_2 emissions and agricultural productivity, though this turns negative in the long run (Ozdemir, 2022). A 25-country panel data ARDL analysis found that CO_2 emissions positively impacted food availability between 1985 and 2019 data period (Afoh et al., 2021). Findings by Raihan et al. (2022a) in Bangladesh (observed from 1972 to 2018), indicated a negative relationship between agricultural productivity and CO_2 emissions when DOLS and ARDL were utilized. The study recommended the adoption of greener technologies and innovation in the agricultural sector and the integration of renewable energy.

Ridzuan et al. (2020) validated the EKC for Malaysia (observed from 1978 to 2016) when they found CO_2 emissions to increase with increases in agricultural productivity in the short run but decrease with increases in agricultural productivity in the long run. Agricultural Land expansion was found to have a positive association with CO_2 emission in Peru, during the 1990-2018 data period, in a study by Raihan and Tupeskova (2022d). Recommendations focused on promoting a low-carbon economy, the use of renewable energy, and climate-smart agriculture. In China, using observations for 1985-2019, Koondhar et al. (2021) discovered that a reduction in CO_2 emissions from agriculture improved cereal production, with a unidirectional causality running from cereal production to CO_2 emissions from agriculture.

Applying DOLS and ARDL resulted in a negative relationship between CO_2 emissions and agricultural productivity for Kazakhstan, using observed data for 1990-2020 (Raihan and Tuspeskova, 2022a). In Sub-Saharan Africa, using observations from 1981-2016 and the FMOLS cointegration technique, Alhassan (2021) found a significant negative relationship between CO_2 emissions and agricultural productivity, recommending agricultural policies improving environmental quality. The Dynamic Ordinary Least Squares (DOLS) cointegration technique was applied in a Mexican analysis of data for the period between 1990 and 2019, and findings indicated a negative association between CO_2 emissions and agricultural productivity (Raihan and Tuspekova, 2022d), recommending climate-smart agricultural practices. These results emphasize the need for robust carbon reduction initiatives in the agricultural industry to curb the potential effects.

Chandio et al. (2022a) also examined the impact of climate change (mean rainfall and temperature), and CO_2 emissions on cereal production in Bangladesh, using observed data for the 1988-2014 period and the ARDL methodological approach. CO_2 emissions were found to have a significant negative impact on cereal production, indicating that cereal production would decrease with increases in CO_2 emissions.

A heterogeneous panel data approach was utilized in Asian countries for 1980-2016 data, and showed proof of a positive short-run relationship between CO_2 emissions and agricultural productivity, though this turns negative in the long run (Ozdemir, 2022). Using ARDL and the Granger Causality test, a 28-year data study in Nigeria (1990-2017) found that agricultural output increased, and CO_2 emissions decreased with no causal relationship. To mitigate greenhouse gas emissions in Nigeria, the study emphasized increasing agricultural production and decreasing energy consumption (Jun et al., 2023). A 29-year data and Brazilian DOLS analysis by Raihan and Tuspekova (2022b), found agriculture value added and economic growth as contributors to reducing environmental quality; However, the opposite was found for renewable energy consumption. The study, like many others, had recommendations for sustainable development.

2.3.4 Empirical findings of interactions between the variables in the study

Using data observed between 1980 to 2018, researchers in Vietnam analyzed the impact of renewable energy consumption, national income, and fossil fuel use on greenhouse gas (GHG) emissions (Nguyen et al., 2022). Consuming renewable energy reduces greenhouse gas emissions, whereas a higher national income and the use of fossil fuels increase emissions. Among the recommendations are the promotion of sustainable behaviours, the implementation of green technologies, and the encouragement of the efficient use of natural gas in various sectors. Using the Gregory-Hansen cointegration test, Turkey's agricultural sector and economic globalization were found to be a contributor to increases in environmental pollution (Yurtkuran, 2021). Between the 1980 and 2012 data period, Kahia et al., (2019) used the panel vector ARDL in 12 Middle Eastern and North African countries and found that economic growth led to environmental degradation with bidirectional causality.

Pata (2021) studied the impact of renewable energy, globalization, and agriculture on ecological footprint and CO_2 emissions for BRICS countries, using observed data for 1971 to 2016. Findings highlighted renewable energy's positive effect on reducing environmental pressure in China, while globalization increased pollution. Agriculture and environmental degradation exhibited reciprocal causality. Renewable energy policies were suggested for Russia and India. A study in Nepal, for the 1990-2019 data period, by Raihan and Tuspekova (2022c) found CO_2 emissions to increase with increases in economic growth. Policy recommendations include robust regulations for sustainable growth and preventing environmental deterioration.

In Vietnam, Raihan (2023) employed the ARDL and Vector-Error Correction Model using time series data from 1984 to 2020, where economic expansion caused environmental degradation and had a significant negative relationship with the environment. According to the outcomes from Shahbaz et al. (2019) in Vietnam (19740-2016), there was a positive relationship between economic growth and CO_2 emissions in the short run and a negative relationship in the long run. A targeted effort on long-term economic and environmental strategies was recommended.

Using the ARDL approach, Rehman examined the relationship between renewable energy consumption, CO_2 emissions and GDP for Pakistan over the period 1990–2017 (Rehman et al., 2019). Findings indicated a positive long run relationship between CO_2 emissions and GDP, while renewable energy had a negative relationship with GDP. In Turkey, Acaroğlu and Güllü (2022) utilized the ARDL and Toda-Yanamoto causality test to model and observations from 1980-2019 to study the relationship between growth, energy and climate change. Findings implied that renewable energy consumption might be the solution to reducing climate change impacts, as an inverse relationship between renewable energy consumption and temperature was witnessed. Using ARDL and DOLS techniques, Raihan (2023b) found an inverse association between renewable energy consumption, agricultural productivity, and CO_2 emissions in the Philippines, while a positive relationship was recorded for economic growth and CO_2 emissions, suggesting shifts towards renewable energy usage. Hussain and Rehman (2021) found an opposing association between CO_2 emissions and renewable energy consumption short run (SR) & long run (LR) in Pakistan, for the 1975 to 2019 data period. The study recommended modernization and structural formations.

A 29-year data and Egyptian study found an improvement in environmental quality to be influenced by investments in agricultural productivity and renewable energy while an inverse relationship was recorded for GDP and CO_2 emissions (Raihan et al., 2023). Climate-smart agricultural practices and further investment in renewable energy consumption were suggested. Rehman et al. (2021) employed a Non-linear ARDL (NARDL) technique and contrastingly found that renewable energy consumption significantly contributed to short run environmental damage in Pakistan, and significant improvement in environmental quality in the long run, using observations between 1975-2017.

The findings of Dilanchiev et al. (2023), indicated that renewable energy increases and GDP per capita decreases in Romania, Azerbaijan, Russia, Turkey, Bulgaria, and Greece, for the 1995-2020 data period. The study recommended renewable energy incentives from the sampled States.

In South Africa, Samour et al. (2022) explored the relationship between energy, economic growth banking sector development (economic growth) and CO_2 emissions during the 1986 & 2017 data period and found that renewable energy consumption had a negative relationship with CO_2 emissions. The study promoted investments in renewable energy by South African policymakers. From 1990-2019 data period, Argentina recorded a positive relationship between economic growth and CO_2 emissions, while renewable energy led to a reduction in CO_2 emissions (Raihan et al., 2022).

These were the results of an ARDL and DOLS cointegration analysis, advocating for renewable energy use to ensure environmental sustainability. Abbasi et al. (2022) examined the relationship between fossil fuel energy, renewable energy, GDP, and CO_2 emissions in China, using data from 1980 and 2018 (Abbasi et al., 2022). The results indicated that GDP had positive long-term effects but negative short-term effects on CO_2 emissions, suggesting renewable energy prioritization. According to the findings of Naseem et al. (2020) in Pakistan (data observed between 1969 and 2018), an increase in agricultural value-added decreased CO_2 emissions, which was an uncommon outcome. Using the ARDL approach and observations from 1990-2017, Rehman et al. (2019) examined the relationship between renewable energy, carbon dioxide emissions, and GDP in Pakistan. Findings indicated a positive long-run relationship between CO_2 emissions and GDP, while renewable energy had a negative relationship with GDP.

2.4 Analytical Framework

The Autoregressive Distributed Lag (ARDL) model is appropriate for evaluating the effects on sugarcane production due to its ability to manage mixed properties of time series data, capture short-run and long-run effects, and account for lagged relationship (Jun et al., 2023). It incorporates both stationary and non-stationary variables, which is crucial for comprehending the dynamics of sugarcane production. It also allows for evaluating cointegration, enabling the identification of stable equilibrium relationships.

The VECM (Vector Error Correction Model) and Johansen's procedure are two procedures that are similar to the ARDL model in that they can both describe long-term and short-term relationships between variables. The ARDL model is more accommodating of cointegration relationships involving variables with varying orders of integration (Goh et al., 2017). According to Gokmen (2021), VECM presumes that all variables are I (1), which is not always true. Both ARDL and VECM models can account for endogeneity by incorporating lagged variables and error correction terms (Menegaki, 2019).

VECM models the long-run equilibrium relationship and short-run dynamics separately, whereas ARDL simplifies coefficient interpretations by incorporating both short- and long-term effects into a single model (Koondhar et al., 2021; Alam et al. 2021; Rasool et al., 2020). In contrast, VECM coefficients capture only short-term dynamics, necessitating additional computations to determine long-term relationships. Vietnam recorded a positive relationship between economic growth and CO_2 emissions, while agricultural value added was found to improve environmental quality (Raihan, 2023a). These were the results when an ARDL model was utilized using 1984-2020 data; FMOLS and CCR confirmed the model's robustness and recommendations were around promoting a low-carbon economy, renewable energy, and sustainable agriculture.

2.5 Summary

This chapter discussed the Theoretical Framework, Literature Review and the chosen analytical Framework for the assessment of the effect of climate change (rainfall and temperature), renewable energy consumption, economic growth (per capita GDP), and carbon dioxide emissions (CO_2) from energy sources and population growth on sugarcane yield. The Theoretical Framework is built upon the Environmental Kuznets Curve, the Malthusian theory, Solow's Growth Model, and the theory of Market Expansion. The Environmental Kuznets Curve suggests that environmental deterioration increases in the early stages of economic expansion but improves as income levels increase.

The Malthusian theory suggests that population increase exceeds the supply of resources, resulting in scarcity and poverty. The Solow Growth Model highlights the importance of capital accumulation and technical advancement in achieving long-term economic growth. Market Expansion theory posits that economic growth is dependent on enlarging markets through innovation and globalisation.

The chapter presented a review of energy, growth and agricultural productivity, climate change and agricultural productivity, pollution and agricultural productivity, and empirical findings of interactions between the variables in the study. The chapter also presented the analytical framework of the study, which is centred around the ARD modelling technique.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter details the research design for the study, the study area, variable descriptions, data sources, how the data was analyzed (descriptives, empirical and specific model).

3.2 Study area

This study is conducted in and for South Africa. The country has an area of 0.471 million square miles and is one of the largest countries in Africa. The extent of the country's land border is 3,021 kilometers. The country's international border was established in the late 19th century because of treaties signed by European colonial powers while the country was still a colony (World Atlas, 2018). South Africa's neighbors are Botswana, Lesotho, Mozambique, Namibia, Swaziland, and Zimbabwe. One of the six countries, Lesotho is an enclave because is encircled by South Africa. South Africa's longest international border is with Botswana, whereas its shortest international border is with Zimbabwe. South Africa has a population size of approximately 60.6 million people according to the Stats SA (2022) mid-year estimates. South Africa's mean annual temperature and rainfall are 18.23 degrees Celsius and 463.42 millimeters respectively (CCPK, 2022). Figure 3.1 shows the South African Map. Sugarcane-producing regions are KwaZulu-Natal and Mpumalanga regions.

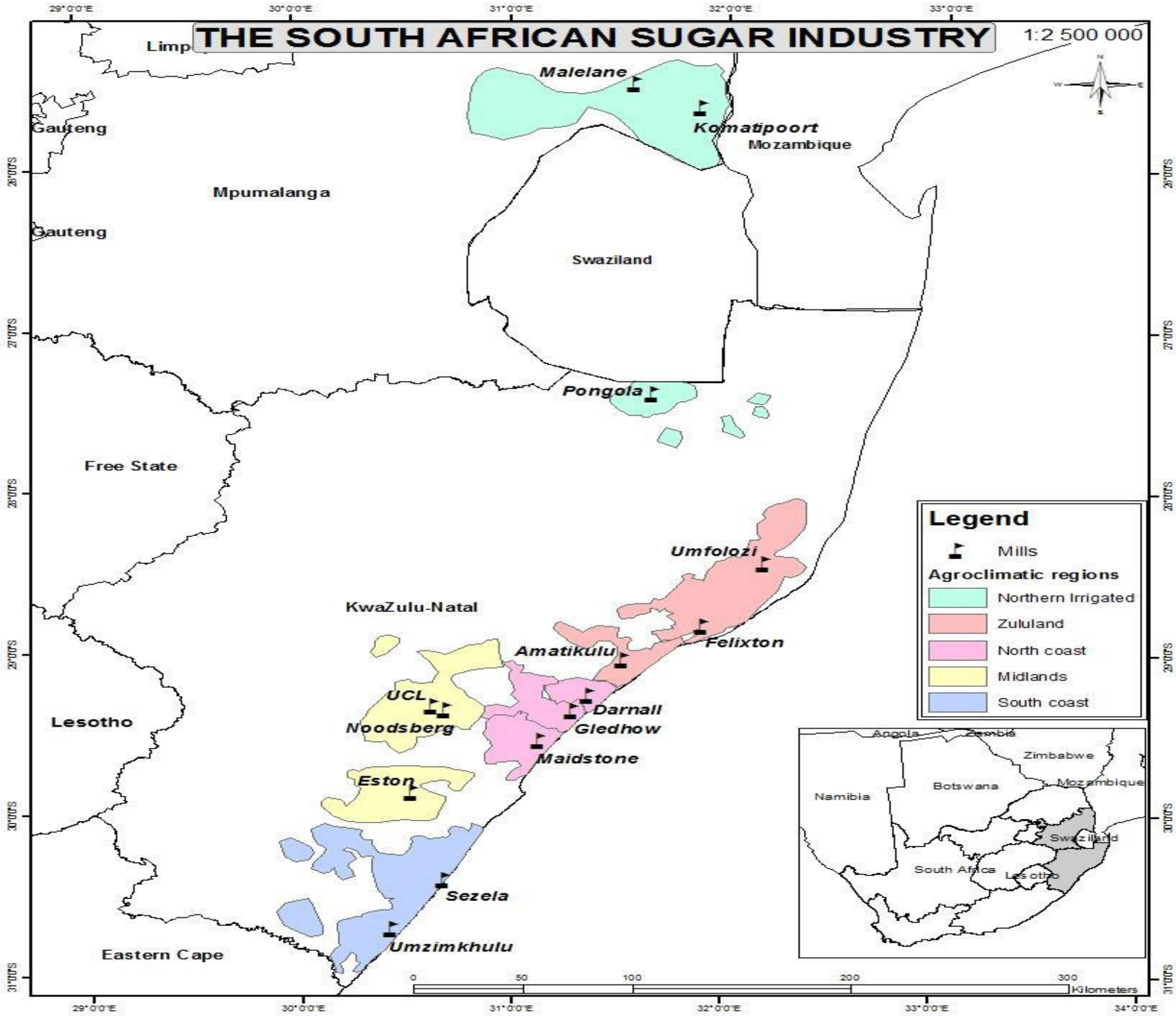


Figure 3.1: Study Area-South Africa

Source: *South African Sugarcane Research Institute, Geographic Information Systems office (2023)*

3.3 Variables and data collection in the Study

The study utilizes data collected over 49 years (i.e., 1972-2021) for South Africa. The period was chosen according to available data sources and previous studies informed the choice of variables (Tagwi 2022; Jones and Singels, 2018; Katal, 2023). The data collected includes carbon dioxide emissions, fossil fuel consumption, rainfall, temperature, renewable energy consumption, economic growth, population growth, and sugarcane production as variables in the model. In no order, the data was sourced from World Development Indicators (WDI), Food and Agriculture Organization Statistics (FAOSTAT), BP Statistics, World Bank Climate Change Knowledge Portal (CCKP). Table 3.1 details the study variables and data sources.

Table 3.1. Variable keys, measurements, and sources

Variables	Description	Logarithmic forms	Units	Sources
SUG	Sugarcane Yield	LNSUG	Tonnes per hectare (t/ha)	FAOSTAT
TMP	Temperature as a Proxy for Climate Change	LNTMP	Mean Annual Temperature in degrees Celsius [°C]	Climate Change Knowledge Portal [CCKP]
RNF	Rainfall as a Proxy for Climate Change	LNRNF	Annual Precipitation [mm]	Climate Change Knowledge Portal [CCKP]
REC	Renewable Energy Consumption	LNREC	Terawatt hours (TWh)	BP Statistics
GDP	Gross Domestic Product per capita	LNGDP	Constant 2015 US dollars	World Development Indicators [WDI]
CO_2	Carbon Dioxide Emissions from Energy Sources	LNCO2	Metric tons (Mt)	BP Statistics
POP	Population Growth	LNPOP	Percentage (%)	WDI

Source: Author's compilation (2024); FAO (2023), CCKP (2023), BP Statistics (2022), WDI (2022)

3.4 Data analysis

The time series data on the variables was analyzed through descriptive statistics and Inferential Statistics. EVIEWS statistical package version 10 was utilized to compute the results, which have been discussed in Chapter 5.

3.4.1 Descriptive statistics

The study utilized descriptives to analyze the data before inferential statistics. Descriptives include the mean, kurtosis, and skewness of the data amongst important descriptives to analyze. Descriptives were compiled and calculated for the original data for sugarcane yield, temperature, rainfall, renewable energy consumption, GDP, carbon dioxide emissions from energy and population growth. This was done for interpretability purposes.

3.4.2 Inferential statistics

This study is a time-series analysis and assesses the effect of carbon dioxide emissions, fossil fuel consumption, rainfall, temperature, renewable energy consumption, economic growth, and population growth on sugarcane yield. The study has applied a well-known approach by Pesaran et al. (2001) called the Auto-Regressive Distributed Lag (ARDL) approach. The ARDL model is considered as the best econometric method compared to others in a case when the variables are stationary at I (0) or integrated of order I(1) (Mathew et al., 2018); Based on the study objectives, it is a better model than others to catch the short run and long run impact of independent variables on sugar production. The technique and steps that have been followed are discussed below.

3.4.2.1. Autoregressive distributed lag model (ARDL)

The ARDL Cointegration Approach steps that have been used in this study are depicted in Figure 3.2.

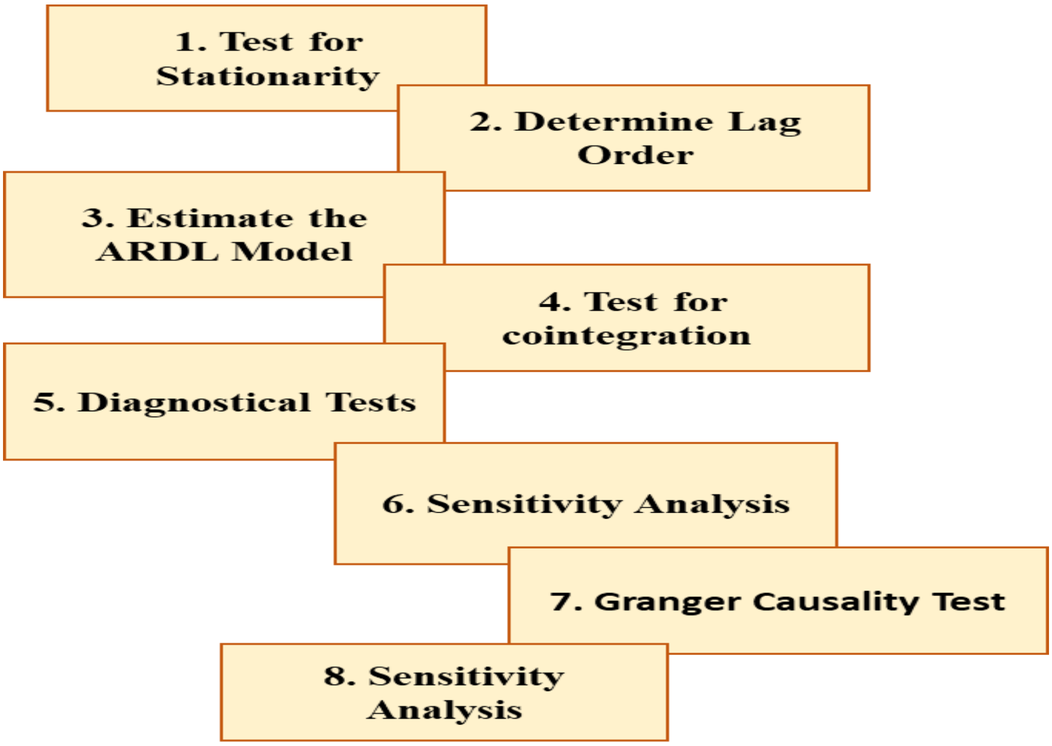


Figure 3.2: ARDL Approach Steps

Source: Author's compilation (2024)

Steps of the ARDL Model

1. **Test for Stationarity:** The stationarity of the variables using appropriate tests was checked using the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests (Chandio et al., 2020a). It is important to ensure that all variables in the model are stationary or can be made stationary through differencing or suitable transformations (Naseem et al. 2020). Unit root tests are done in order to determine the order of integration of the variables in the model, whether they are integrated of I(0) or I(1) (Gokmenoglu and Sadeghieh, 2019). If variables are integrated of I(2) or are non-stationary, the results may be spurious and non-reliable. The data in this study was transformed to logarithms to achieve stationarity. The study has utilized both the ADF and PP models to test stationarity.

2. **Determine Lag Order:** According to Behera and Mishra (2020), information criteria are then used [e.g., Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC)] to select the optimal lag length for each variable in the ARDL model. Considering the criteria's recommendations while balancing model complexity and goodness of fit is essential. This study has utilized the AIC information criteria to determine lag order.
3. **Estimate the ARDL Model:** The ARDL model was then estimated using Ordinary Least Squares (OLS) (Abbasi et al., 2021).The lagged variables and any additional covariates deemed necessary for the analysis are included.
4. **Test for Cointegration:** In accordance with Alam and Adil (2019), a bounds test was then conducted to examine the existence of a long run equilibrium relationship among the variables. This step is crucial for identifying cointegrated relationships within the ARDL framework.
5. **Diagnostic Checking:** Diagnostic tests were then conducted to assess the goodness-of-fit and statistical properties of the estimated ARDL model (Peçe et al., 2023). Issues such as autocorrelation, heteroscedasticity, and normality of residuals were checked, and any problems identified were addressed using appropriate remedial measures.
6. **Sensitivity Analysis:** The study has utilized cumulative sum and cumulative sum of squares plots to test for structural breaks and the stability of the model (Chopra et al. 2022; Rehman et al., 2021).
7. **Granger Causality Tests:** Granger causality tests were then conducted to examine the causal relationships between all the variables included in the ARDL model (Ceesay et al., 2022). The appropriate lag length for the tests was determined using the AIC method. This tests the hypothesis of whether one variable Granger causes another variable by examining the significance of the lagged coefficients.

Using the Autoregressive Distributed Lag (ARDL) model as described and carried out with EViews V.10 software gives a strong foundation for exploring how the study's factors are connected. By following the steps above, the accuracy and validity of the findings of this study was ensured.

3.4.2.2 Model stability diagnostics

Table 1.1 provides other hypotheses that the study has tested, i.e. pre-modelling, while modelling and post-modelling. As per the ARDL steps, stationarity, the presence of cointegration, and diagnostics must all be performed.

Table 1.1: Stability hypotheses tested in the study

Test	Hypothesis	Method
Pre-Modelling		
Stationarity	H_0: Series contains a unit root/series is non-stationary	Augmented Dickey-Fuller (ADF) and Philips Perron (PP)
Modelling		
Cointegration	H_0: There is no long run relationship among the variables in the model	Autoregressive Distributed Lag (ARDL) Bounds Test
Post-Modelling		
Diagnostics		
Serial correlation	H_0: The residuals (or errors) in the time series model are not correlated with the residuals/errors from previous time steps (i.e., they are independent).	Breusch-Pagan
Heteroskedasticity	H_0: The residuals in the regression model have constant variance across all levels of the predictor variables (i.e., residuals exhibit no heteroskedasticity)	Autoregressive Conditional Heteroskedasticity (ARCH)
Normality	H_0:The residuals of the model are normally distributed in the population.	Jarque-Berra
Sensitivity Analysis		
Cumulative Sum and Cumulative Sum of Squares	H_0: There is no structural break or shift in the time series data.	CUSUM
Causality Test		
Causality amongst variables in the model	H_0: variables in the model do not granger-cause each other	Pairwise Granger Causality

Source: Author’s compilation (2024)

These tests, under the stipulated hypotheses, are as important (if not more important) as testing for relationships between the variables in the model. The outcomes determine whether the results can be relied upon or not.

3.4.2.3 Empirical and Specific Model

The following is an expression of the general estimation of the associations and a multivariate sample model:

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

Expressed in a fitted form, the association is as follows:

$LnSUG_t = f(LnTMP_t + LnRNF_t + LnRNC_t + LnGDP_t + LnCO2_t + LnPOP_t)$ **(2)**

The equation can be further fitted as follows:

$$LnSUG_t = \alpha_0 + \beta_1 LnTMP_t + \beta_2 LnRNF_t + \beta_3 LnRNC_t + \beta_4 LnGDPt + \beta_5 LnCO2t + \beta_6 LnPOPt \quad (3)$$

The ARDL model can be expressed as follows:

$$\Delta LnSUG_t = \alpha_0 + \varphi_1 (LnTMP)_{t-1} + \varphi_2 (LnRNF)_{t-1} + \varphi_3 (LnRNC)_{t-1} + \varphi_4 (LnGDP)_{t-1} + \varphi_5 (LnCO2)_{t-1} + \varphi_6 (LnPOP)_{t-1} + \sum_{i=1}^{p} \theta_1 \Delta (LnSUG)_{t-1} + \sum_{i=1}^{q} \theta_2 \Delta (LnTMP)_{t-1} + \sum_{i=1}^{q} \theta_3 \Delta (LnRNF)_{t-1} + \sum_{i=1}^{q} \theta_4 \Delta (LnRNC)_{t-1} + \sum_{i=1}^{q} \theta_5 \Delta (LnGDP)_{t-1} + \sum_{i=1}^{q} \theta_6 \Delta (LnCO2)_{t-1} + \sum_{i=1}^{q} \theta_7 \Delta (LnPOP)_{t-1} + \varepsilon_t \quad (4)$$

The long-run association is modelled as follows:

$$\Delta LnSUG_t = \alpha_0 + \varphi_1 (LnTMP)_{t-1} + \varphi_2 (LnRNF)_{t-1} + \varphi_3 (LnRNC)_{t-1} + \varphi_4 (LnGDP)_{t-1} + \varphi_5 (LnCO2)_{t-1} + \varphi_6 (LnPOP)_{t-1} + \varepsilon_t \quad (5)$$

The short-run association is modelled as follows:

$$\Delta LnSUG_t = \alpha_0 + \sum_{i=1}^{q} \theta_1 \Delta(LnTMP)_{t-1} + \sum_{i=1}^{q} \theta_2 \Delta(LnRNF)_{t-1} + \sum_{i=1}^{q} \theta_3 \Delta(LnRNC)_{t-1} + \sum_{i=1}^{q} \theta_4 \Delta(LnGDP)_{t-1} + \sum_{i=1}^{q} \theta_5 \Delta(LnCO2)_{t-1} + \sum_{i=1}^{q} \theta_6 \Delta(LnPOP)_{t-1} + \varepsilon_t \quad \mathbf{(6)}$$

In a case where a long-run relationship exists, an error correction model can further be fitted to calculate the speed of adjustment in the short run to achieve long-run equilibrium (Kripfganz and Schneider, 2018):

$$\Delta LnSUG_t = \alpha_0 + \varphi_1 (LnTMP)_{t-1} + \varphi_2 (LnRNF)_{t-1} + \varphi_3 (LnRNC)_{t-1} + \varphi_4 (LnGDP)_{t-1} + \varphi_5 (LnCO2)_{t-1} + \varphi_6 (LnPOP)_{t-1} + \sum_{i=1}^{p} \theta_1 \Delta(LnSUG)_{t-1} + \sum_{i=1}^{q} \theta_2 \Delta(LnTMP)_{t-1} + \sum_{i=1}^{q} \theta_3 \Delta(LnRNF)_{t-1} + \sum_{i=1}^{q} \theta_4 \Delta(LnRNC)_{t-1} + \sum_{i=1}^{q} \theta_5 \Delta(LnGDP)_{t-1} + \sum_{i=1}^{q} \theta_6 \Delta(LnCO2)_{t-1} + \sum_{i=1}^{q} \theta_7 \Delta(LnPOP)_{t-1} + \mu ECM_{t-1} + \varepsilon_t \quad \mathbf{(7)}$$

Where:

LnSUG=log of Sugarcane Yield

LnTMP=log of mean Temperature

LnRNF=log of annual Rainfall

LnRNC=log of Renewable Energy Consumption

lnGDP=log of per capita Gross Domestic Product

LnCO2=log of per capita Carbon Dioxide Emissions

α_0=Constant or Autonomous Sugarcane Yield

φ_i=Long run percentage change in sugarcane yield caused by explanatory variables

θ_i=Short run percentage change in sugarcane yield caused by explanatory variables

ε_t=Error term

ECM=the short run Speed of Adjustment required to reach long run equilibrium

3.5 Summary

This chapter presented the methodology adopted by this study. The study area for this project is South Africa, and sugarcane is cultivated in the KwaZulu-Natal and Mpumalanga regions. The data used in this study was sourced from FAO Statistics (2023), CCKP (2022), WDI (2022), and BP Statistics (2022). Sugarcane yield data was found from FAO in tons per hectare, temperature (°C), and rainfall (mm) data was obtained from CCKP (2023), BP Statistics was requested for CO_2 emissions (Mt) and renewable energy consumption (TWh) data, and GDP per capita ($) & population growth (%) data was obtained from WDI (2022).

The study utilized both descriptives and inferential statistics for data analysis. Descriptives of interest are the mean, kurtosis, and skewness of the data. The model that was deemed fit for this analysis, due to its ability to utilize data at I(0) and I(1) level of stationarity, is the ARDL model. The process of running such a model requires that stationarity tests be performed (the study utilized the ADF and PP unit root tests), lag order selection, cointegration (F-Bounds test), and estimation of the equation in the short run and long run be performed. Upon findings of a long-run relationship, it is then necessary to calculate the speed of adjustment using the ECM. Diagnostic checks for serial correlation, normality in the residuals, and heteroskedasticity are then performed. CUSUM and CUSUM of squares plots were used for ascertaining model stability. Model robustness is also necessary to compare results from other similar methods. This study utilized FMOLS, DOLS, and CCR for model robustness.

CHAPTER 4: ANALYSIS OF VARIABLE TRENDS

This chapter discusses the trends of sugarcane yield, climate change (temperature and rainfall), renewable energy consumption, economic growth measured by gross domestic product (constant 2015$), carbon dioxide from energy sources, and population growth. The chapter explains the peaks and troughs in the trends, especially the events that contributed to them in the period 1972-2021. The chapter also identifies and discusses the top 5 South Africa's sugarcane trading partners.

4.1 Sugarcane Production and Trade

Sugarcane holds global significance for its diverse industrial applications, primarily geared towards sugar production as a crucial sweetening agent in the food and beverage industry. Beyond its role in sweetening, sugarcane is pivotal in generating ethanol, a renewable biofuel that aids in lowering greenhouse gas emissions (Gonçalves et al., 2021). Sugarcane biomass, particularly bagasse, contributes to bioenergy development, providing heat and electricity and bolstering renewable energy resources (Tun et al., 2019). The sugarcane industry not only creates jobs but also stimulates economic growth, generating income and foreign currency. Through carbon sequestration and reduced reliance on fossil fuels, sugarcane agriculture offers environmental benefits. Additionally, by-products like molasses find varied applications in other industries, enhancing the overall value of sugarcane. In summary, sugarcane plays a crucial role in sugar and bioenergy production, job creation, economic development, and environmental sustainability (Wani et al., 2023).

One of the specific objectives of this study was to analyze sugarcane production trends over the period 1972-2021. The study used data for sugarcane yield to determine these trends over time. Sugarcane yield refers to the amount of sugarcane that is gathered per unit of land and it is an important way to measure how productivity and performance of sugarcane farming (Rossi Neto et al., 2018).

4.1.1 World Sugarcane Production

Table 4.1 below shows world sugarcane production by country. According to FAO Stats (2021), the top 5 producers of sugarcane are Brazil, India, China, Pakistan and Thailand. Although Brazil is the largest producer of sugarcane worldwide in terms of production, China has the highest sugarcane yield followed by India. This indicates high levels of productivity and efficiency in farming operations by the countries. Advanced technology in sugarcane farming has driven a shift to a sustainable, profitable, and self-sufficient industry through improved production, management, and a bio-based approach in India and China (Solomon and Swapna, 2022; Li and Yang, 2015b; Zhang and Govindaraju, 2018).

Table 4.1: World Sugarcane production by country

Country	Production (tons)	Production per person (Kg)	Acreage (hectares)	Yield (Kg/hectare)
Brazil	715 659,2	3 415,5	9 971,0	71 774,4
India	405 399,0	303,3	5 159,2	78 577,6
China	107 258,7	77,0	1 136,2	94 401,4
Pakistan	88 650,6	439,1	1 260,3	70 341,4
Thailand	66 278,5	958,0	1 495,4	44 321,1

Source: FAO Stats (2021)

It is also observed that Brazil has a larger portion of land dedicated to sugarcane farming, followed by India, Thailand, Pakistan, and China. However, regardless of China’s lower allocation of land relative to the other countries that belong to the top 5 sugarcane-producing countries, it is more productive with a 94.4 kg/ha yield. China achieved a higher sugarcane yield per unit of land compared to other countries, despite potentially having lower allocations of resources such as land, labour, and inputs like fertilizers and irrigation. According to Li and Yang (2015a), China prioritized research and development for the sugarcane industry, including germplasm innovation, breeding and new variety propagation, and advancement of affordable Drought-Tolerant Cultivation Technologies. This could explain some of the successes in China’s sugarcane industry today. Figure 4.1 shows the trends in the top 5 sugarcane-producing countries in the world from 1961 to 2021 in million tons.

There has been a general increasing trend in sugar production in all 5 of the countries, with more than 300 million tonnes of sugarcane production for Brazil between 2000 and 2021.

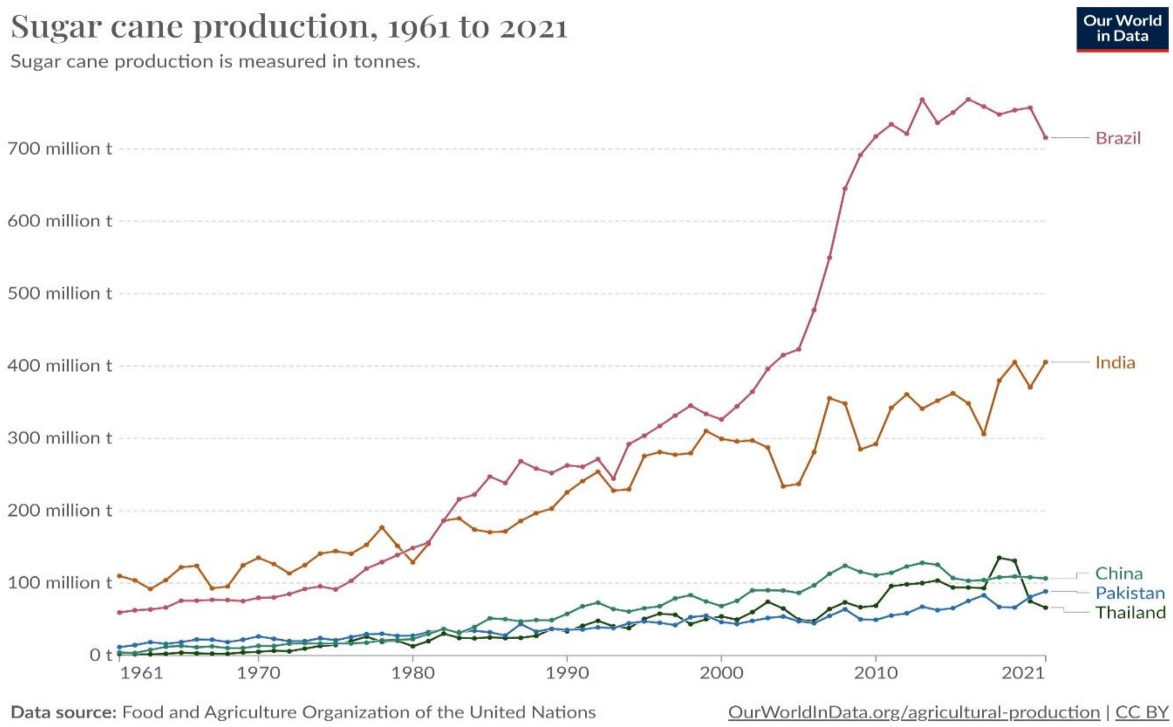


Figure 4.1: Sugarcane production trends in the top 5 world sugarcane producers

Source: FAO Stats (2021)

Although an increasing trend was also observed for China, Pakistan, and Thailand; sugarcane production has generally been growing at a far lower rate than in Brazil. Based on Table 4.1, this could be explained by more allocation of land to sugarcane production in Brazil and India, i.e. approximately 10 ha and 5 ha per farmer, respectively. A decrease in production for Thailand was observed between 2017 and 2021, and according to Silalertruksa and Gheewala (2018), this can be attributed to water scarcity issues in the country. Brazil and India are expected to lead global sugar production with 21% and 18% market shares by 2030, respectively. In comparison to the period from 2018 to 2020, output in Brazil (+5.8 Mt), India (+5.1 Mt), and Thailand (+3.2 Mt) has increased significantly.

Due to a mix of poor weather and low pricing, which limited plantings, Thailand's production was lowered for two consecutive seasons (2019 and 2020) (FAO, 2021a). However, rising prices are anticipated to assist in restoring production.

4.1.2 Sugarcane Trade

4.1.2.1 South Africa’s sugarcane top 5 trading partners

South Africa's sugarcane industry is closely linked to international trade, with several key countries serving as its major trading partners. These trading partners play a significant role in shaping South Africa's sugarcane market and export dynamics. By examining the top five sugarcane trading partners, valuable insights into the global connections and economic relationships that contribute to the success and growth of South Africa's sugarcane sector can be gained**.** Figure 4.2 shows the top five countries that South Africa imports sugarcane from.

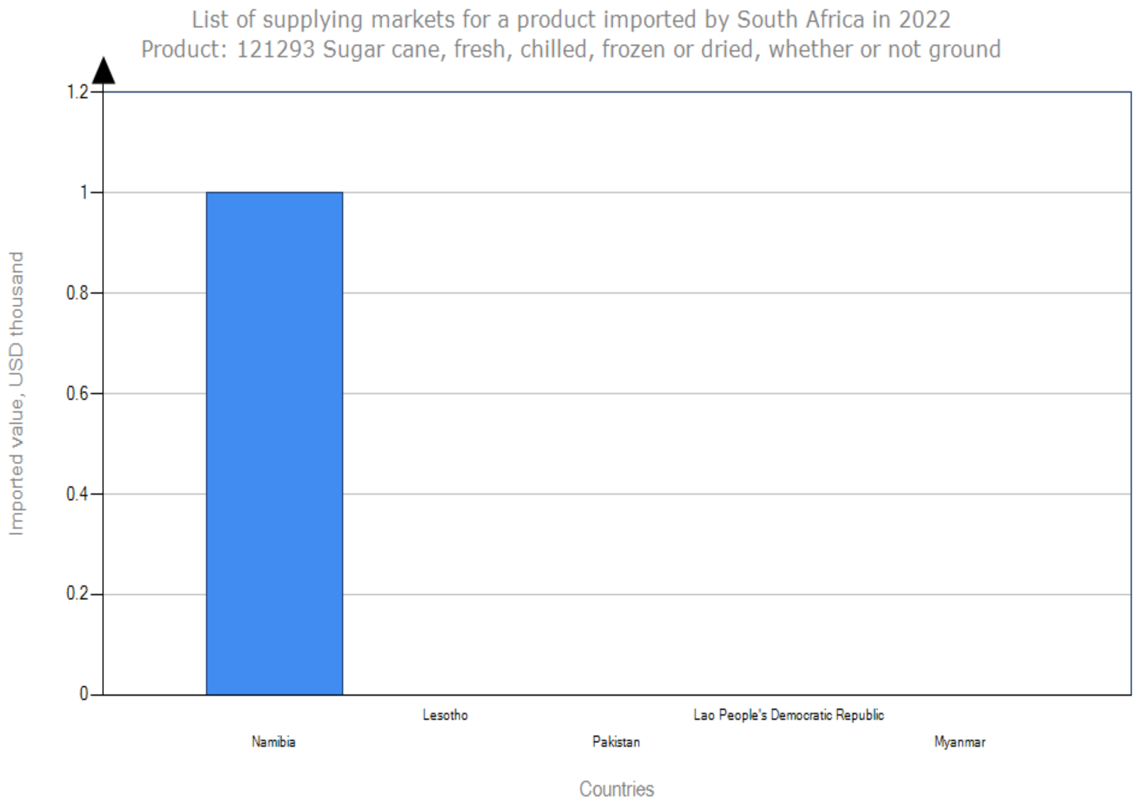


Figure 4.2: Top 5 countries exporting sugarcane to South Africa

International Trade Centre (ITC) (2022b)

The data collected was for South African sugarcane imports for the year 2022. Figure 4.2 shows that, in 2022, South Africa imported 1000 US$ worth of sugarcane from Namibia. Although Lesotho, Pakistan, Lao People's Democratic Republic, and Myanmar form part of the top 5 import partners for South Africa, no sugarcane was imported from them in the year 2022. Figure 4.3 shows the top 5 export partners for South Africa, and the value of sugarcane exported to these countries in the year 2022, as extracted from ITC (2022a).

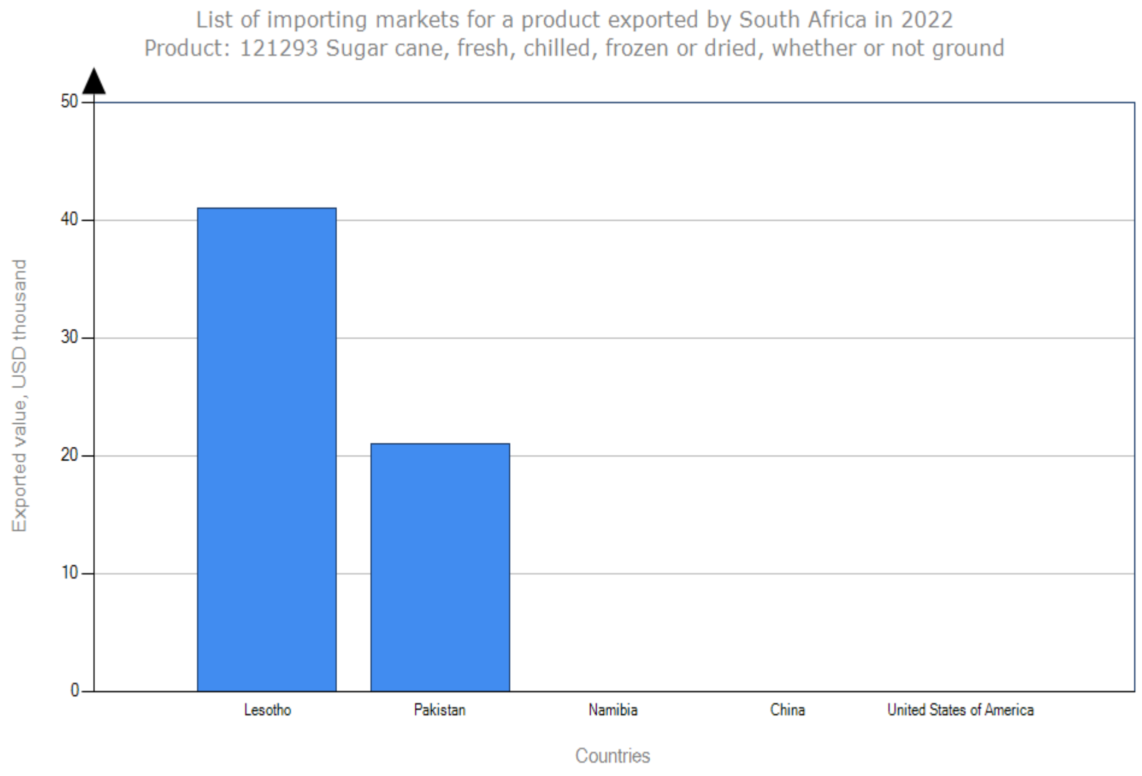


Figure 4.3: Top 5 countries importing sugarcane from South Africa

ITC (2022a)

The top 2 sugarcane export partners for South Africa are Lesotho (40 000 US$) and Pakistan (20 000 US$). Lesotho accounted for a higher value of sugarcane exports compared to Pakistan. This suggests that there is a significant demand for South African sugarcane in Lesotho's market. According to Noyakaza (2019), Lesotho implemented zero tariffs because of the trade agreements within the Southern African Customs Union (SACU), as both nations are part of this regional trading group. This could explain the higher value of sugarcane imports from South Africa by Lesotho.

High imports of cheap sugar from deep-water and SACU sources have disrupted demand for South African-grown and processed sugar (SA Canegrowers, 2020). Imports have led to the export of domestic surplus to a "dumped" or oversupplied global market, resulting in decreased Recoverable Value (RV) prices, sometimes below agricultural production costs. Pakistan also represents a notable export market for South African sugarcane, albeit with a lower value.

On the other hand, although Namibia, China, and the United States of America are among South Africa's top five export partners, it is interesting to note that they did not import any sugarcane from South Africa in the year 2022. This may indicate that the trade relationship between South Africa and these countries in the sugarcane sector might be focused on other products or commodities rather than sugarcane itself. Although the integration of the continent through the African Continental Free Trade Area (AfCFTA) includes concerns about substantial losses in tariff income and an unequal distribution of costs and benefits (UNCTAD, 2022), the agreement still presents worthwhile opportunities for trade for South Africa. The OECD FAO Agricultural Outlook predicts declining sugar imports for South Africa, the European Union, and Iran, for the 2020-2030 period (FAO, 2021a). This suggests a potential focus on boosting domestic sugar production, impacts on global market dynamics, economic ramifications, and the need for strategic policy responses to ensure agricultural sustainability and trade balance.

4.1.3 Sugarcane Production Trends

Edmund Morewood introduced sugarcane cultivation on the KwaZulu-Natal North Coast in 1848 (Du Bois, 2015). The first export of KwaZulu-Natal sugar to the Cape occurred in 1853. In 1861, indentured workers from India arrived in the region. This is how Sugarcane production started in South Africa as a result of colonialism. Figure 4.4 and Figure 4.5 depict sugarcane production and sugarcane yield patterns over the period 1961-2021, respectively. Although sugarcane production was relatively increasing over the period, sugarcane productivity has generally been declining. It is to be noted that trends will be discussed from 1961, even though the data series utilized for this study is 1972-2021. This will shed light on events that might have led to observations in 1972. Sugarcane production represents the volume of output of sugarcane produced, while yield measures the productivity of land as a resource input (Doss, 2018).

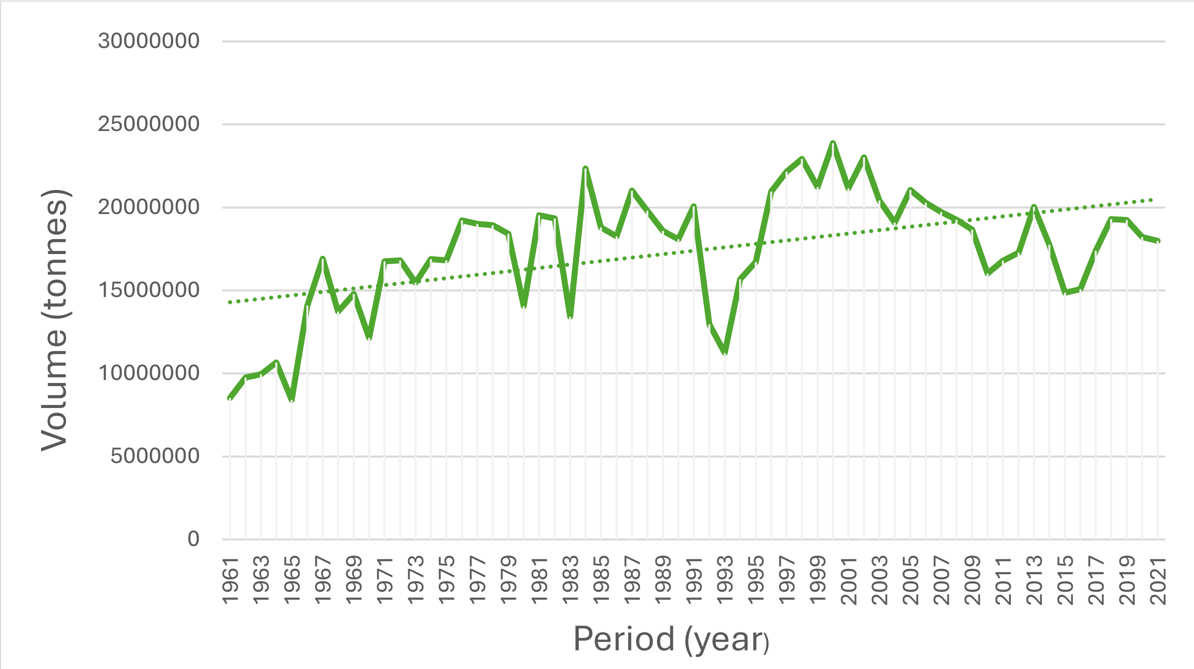


Figure 4.4: Sugarcane production in South Africa between 1961-2021

Source: Author's compilation (2024); data sourced from FAO (2023)

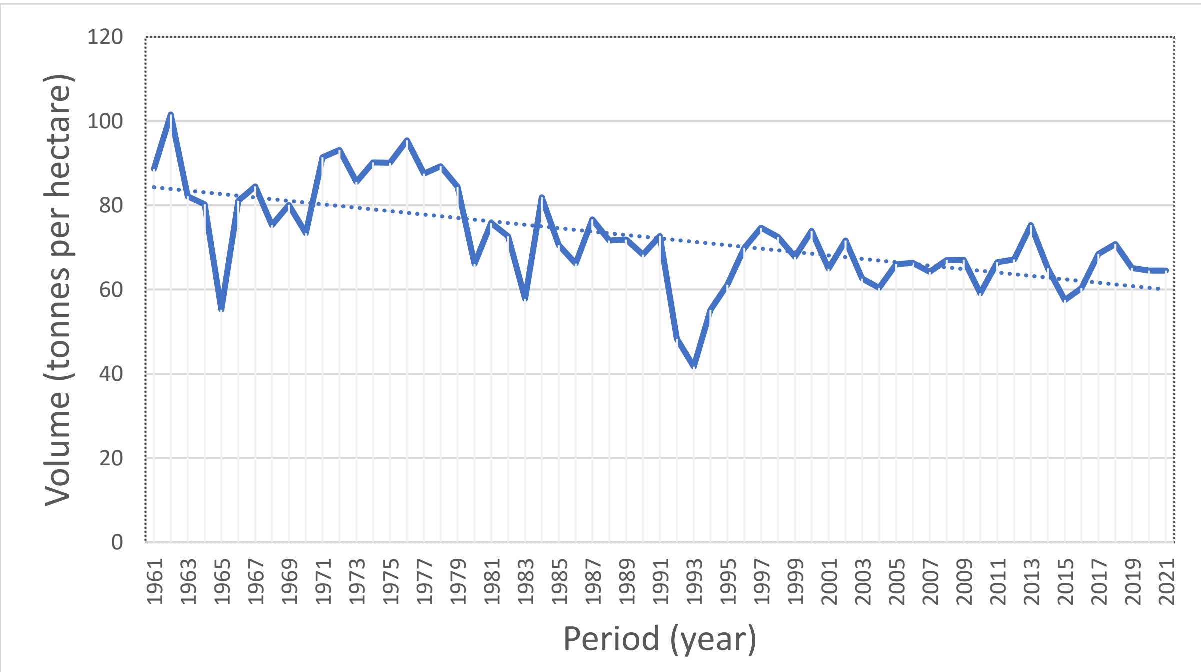


Figure 4.5: Sugarcane yield in South Africa between 1961-2021

Source: Author's compilation (2024); data sourced from FAO (2023)

Between 1961-1964 sugarcane production was rising in South Africa, with increasing productivity (yield) from 1961-1962. However, production was increasing with decreasing productivity from 1962. Sugarcane production declined between 1964 and 1965, while yields continued to drop until 1965. According to Markin (1997), in 1961 South Africa had withdrawn from the British Commonwealth but thereafter engaged in negotiations to establish a new bilateral arrangement with Britain, agreeing to provide an annual supply of 150,000 tonnes. This would generally impact the country's trade and decrease exports. However, this was not the case since in 1962 new markets for sugarcane were established in Canada and Japan (Evenson, 1976). The lowest volume of sugarcane produced in South Africa was observed in 1965 and was 8,4 million tons.

In 1964 the bilateral agreement with Britain came to an end; in the same year, the South African Sugar Millers' Association was officially registered. There was also the launch of the Sugar Industry Trust Fund for Education (SITFE) dedicated to assisting with education, skills enhancement, and community empowerment in the industry, with the ultimate goal of promoting economic expansion and long-term viability in the KwaZulu-Natal (KZN) and Mpumalanga regions (SASA, 2024). The programme has assisted 10200 beneficiaries to date. In 1965 The Bulk Sugar Terminal, which had a storage capacity of 180,000 tonnes, was constructed and the very first N-variety of cane was produced and selected in KZN (Witthohn, 2022). This resulted in some strides in the industry as sugarcane production rose at an increasing rate between 1965 and 1967. The performance of the sector was also improving as yields were also increasing.

In 1973, the Small Growers' Financial Aid Fund was set up with a grant of R5 million by SASA. The goal of this fund was to help small-scale sugarcane growers with funds to support their businesses, boost production, and make the sugar industry more sustainable (Minnaar, 1991).The opening of an Industrial Training Centre in 1974 was a major step forward in the sugarcane industry. It made it easier for people to learn the skills they needed for growing and handling sugarcane (Galloway, 2005). By 1975, the amount of sugarcane products consumed in the country had reached a million tonnes (Dubb, 2016).

This was due to strong demand within the country, which was caused by population growth and more commercial use of sugar and its derivatives. This contributed to a steady rise in volumes of sugarcane produced in the country between 1973 and 1976, while productivity improved as well.

A decreasing production trend was observed in 1977 to 1980. During this period the South Africa Sugar Act 9 of 1978, a statutory law that governs the operations of the sugar industry in South Africa, was enacted. It established a structure for managing, organizing, and advancing the manufacturing, refining, and selling of sugar and its associated goods (Government Gazette,1978). The Act sought to safeguard the interests of sugar growers, processors, and consumers. Subsequent improvements in production were seen between 1980 and 1982. Amendments to the Sugar Act were made in 1984, 1987, and 1992.

Although sugarcane production was declining between 1976 and 1980, improved yields were observed in 1980. In 1981-1983, volumes of sugarcane produced started decreasing with decreasing productivity, despite the establishment of the Gauteng bulk sugar facility in 1981. In 1983-1984, production increased with increasing productivity. During this period the 1984 amendment to the Sugar Act was enacted and intended to provide rules and oversight for the transfer of sugarcane from farmers to sugar mill operators (Government Gazette, 1984).

According to the Government Gazette (1987), the Sugar Act was yet again amended in 1987 to further regulate the Minister's powers to set the conditions of the Sugar Industry Agreement, alter it retrospectively, temporarily validate the Cane Transport Rules, and address incidental problems. However, the implementation of political sanctions in 1986 led to the loss of Canadian and USA markets, which had a detrimental effect on the sugar sector in South Africa (Kaempfer and Lowenberg, 1988). Hence the observed decline in production between 1987 to 1990 and 1991 to1993. Production increased with increasing in productivity between 1993 and 1998.

This was after the United States quota was reinstated at 2.3%, permitting the annual export of 26,000 tonnes of sugar (1991) and the Small Grower Development Trust (1992) aimed at providing assistance and empowerment to small-scale producers in the business was established (SASA, 2023).

The South African Sugar Association was given authority to enforce fines, establish upper limits on industrial pricing for sugar sector goods, and oversee selling prices during certain periods to improve regulatory oversight in the sugar industry (Government Gazette, 1992). This allowed the association to uphold equitable pricing, preserve market stability, and tackle concerns regarding competition and industrial sustainability. It also enabled effective resource management and created a favorable climate for industry growth and development. However, regardless of these attempts, the industry was experiencing declining yields. The industry was disturbed by floods in KZN that interrupted the operations of mills, affecting areas where sugar cane is grown (Pillay and Ballabh, 2016).

The government that took over after apartheid passed many land reform laws and policies. These include but are not limited to, the Land Restitution Act of 1994, the Land Redistribution for Agricultural Development (LRAD) programme, and the Communal Land Rights Act of 2004 (SAHO, 2014). The laws and policies were aimed at reclaiming the land rights of dispossessed people or communities and supporting vulnerable farmer homeland communities with inputs and equipment. According to the NAMC (2013), the Sugar Industry demonstrated consistent profitability between 1996 and 2010. Nevertheless, the profits gradually diminished during this timeframe as a result of the decline in real revenue (adjusted for inflation) and the increase in costs, such as energy.

In 1991-1993 prolonged periods of little to no rainfall occurred, resulting in a significant decline in production to 1.5 million tonnes and 1.171 million tonnes in the 1992/93 and 1993/94 seasons, respectively (Dube and Jury, 2000; Reason et al., 2005). Despite these events, the sugarcane industry recorded its longest increase in production period between 1993 and 1998. This 5-year increasing trend was attributed to the Small Grower Development Trust established the year before to provide assistance and empowerment to small-scale producers in the sector.

In 1994, an incremental deregulation programme was also implemented, signifying a change in the regulatory structure of the industry, and the Sugar Industry Central Board was dissolved, altering the industry's governance framework (Child, 2004). In 1995, President Mandela initiated the Siyakha programme, allocating a budget of R12 million to aid the industry (Mandela, 1995). This initiative assisted in infrastructure development, job creation, and improving social services. In 1997, Illovo Sugar Ltd solidified its presence in southern Africa by the acquisition of Lonrho's sugar sector for R1.62 billion. In the period 1998-1999, there was a decrease in volumes of sugarcane produced and a subsequent decline in yield. This could be explained by disturbances in the labour market through the termination of the sucrose payment system, which relied on pools, resulting in changes to the way growers are remunerated (Peackok and Schorn, 2002).

Between 1997 and 2002, the industry recorded the highest volumes of sugarcane of above 20 million tons, recording the highest quantity produced of approximately 23,9 million tons, produced in the year 2000. These strides can be attributed to increased allocation of land to sugarcane production of more than 300 000 hectares (See Figure 4.6; FAO, 2023). Sugarcane yield was also relatively high at more than 60 tonnes per hectare. In 2004, the Inkezo Land Company was founded to make a valuable contribution to land development in the industry. These developments might have positively impacted the industry as increases in sugarcane yield were observed between 2004-2006. The South African sugar industry has long understood the need to encourage diversified ownership of agricultural land under sugarcane and has a variety of support tools to sustain measures to change the ownership profile. According to SASA (Industry measures have helped black growers acquire 21% of freehold sugarcane land from white planters) (SASA, 2023).

There was a 5-year decline in volumes produced of sugarcane between 2005 and 2010. This could be due to the handing over of the uMfolozi Mill to a black empowerment group called Umvoti Transport Ltd, by Illovo Sugar Ltd (SASA, 2023). Changes in ownership of the Mill might have contributed to the inefficient running of the mill and changes in administration that were negatively impacting the industry. Moreover, the global community saw sugar prices reach their highest level in a quarter of a century in 2006.

In 2007 and 2008, the Maputo Terminal enabled trade between SA and Swaziland, and SASA was designated as the implementing agency for a fertilizer project initiated by the KZN Government. The project aimed to provide fertilizer worth R60 million to assist small-scale growers. Despite these efforts, sugarcane production was still declining, due to the global financial crisis at the time (International Monetary Fund, 2010). The financial crisis led to creeping increases in global imbalances, poor monetary policies, and insufficient supervision and regulation in the financial sector worldwide, during 1999 and 2007. According to Van den Berg et al. (2008), the KZN region was also affected by increased rainfall around this time, negatively impacting production. Between 2010 and 2013, the industry again started performing better. In 2011, the industry experienced sugar price hikes, which have not gone down ever since (World Economic Forum, 2023).

Following the law of supply, indeed sugarcane production was seen increased between 2010 and 2013 to maximize revenue. During these years, particularly in 2012, the National Minister of Land Reform and Rural Development praised the sector for allocating 21% of privately owned land for sugarcane cultivation to black farmers (Moyo, 2014). This encouraged farmers to be involved in the sector and increase the volumes of sugarcane produced by the industry. In 2013, the lack of a successful tariff resulted in substantial sugar imports, which endangered the long-term viability of the sector. This put pressure on local prices and minimized revenues.

In 2018, SASA, with the backing of the Department of Trade and Industry and the Department of Economic Development, urgently requested the International Trade Administration Commission to reassess the Dollar-Based Reference Price to tackle the surge of imports. Various industry stakeholders, including small-scale black farmers, united to endorse the proposal and organise a march towards Pretoria. A new reference price denominated in US dollars, specifically $680, was put into effect. Figure 4.6 shows how land was allocated to sugarcane production during 1961-2021. This figure gives light to yield patterns observed in Figure 4.5, as land use directly impacts productivity.

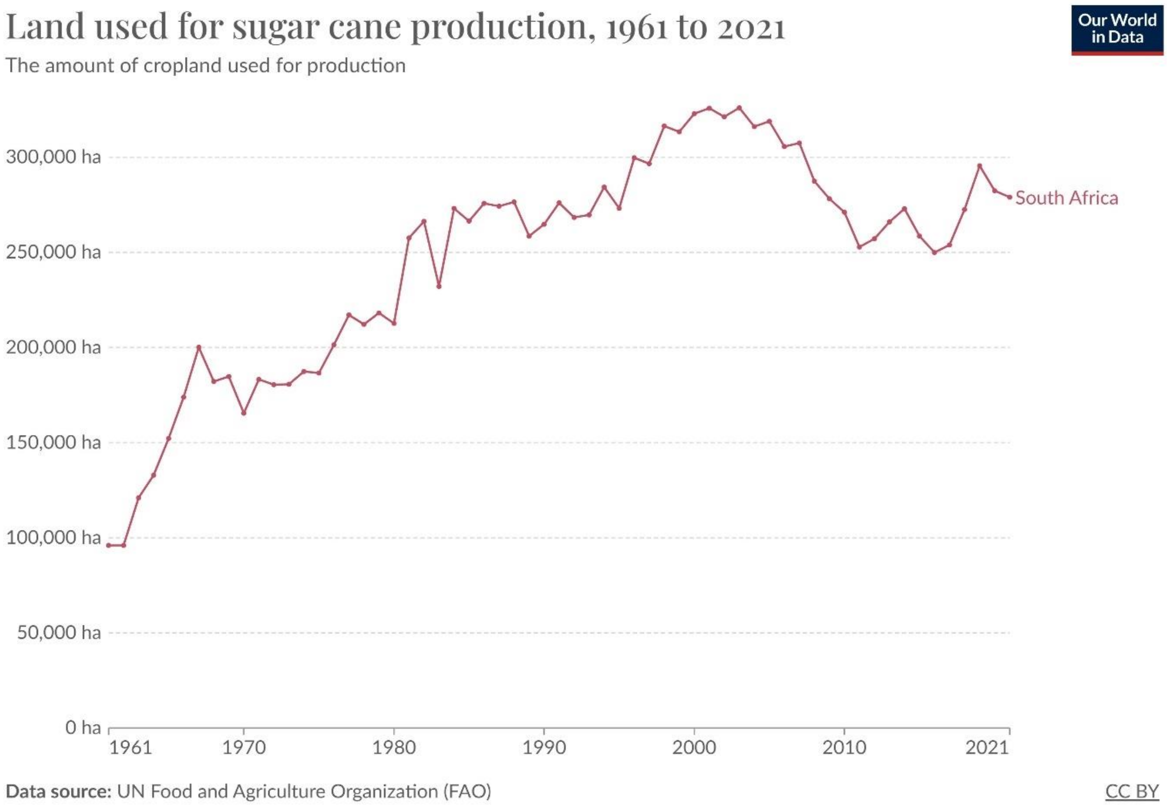


Figure 4.6: Land allocation to sugarcane production in South Africa (1961-2021)

Source: FAO (2023)

An increasing trend in sugarcane yield was also observed between 2010-2013, which can be attributed to changes in land ownership that were implemented at the time. According to SASA (2023), industry measures such as establishing an independent land reform entity were taken and helped improve land allocation for sugarcane production. Declining sugarcane yields were recorded from 2018 to 2021, coupled with a decrease in land allocated to sugarcane production. According to the annual review report produced by SA Canegrowers (2020) for the year 2019/20, growers struggled to recover from the greatest drought in history due to the low Recoverable Value (RV) Price since 2018. The industry was affected by distorted worldwide pricing, lower than South Africa's manufacturing costs, and COVID-19, amongst other factors (DTI, 2021). The government also imposed the Health Promotion Levy (HPL), commonly known as the Sugar Tax, in 2018, aimed at reducing the consumption of non-alcoholic Sugar-Sweetened Beverages (SSBs).

This announcement was made amid rising global obesity concerns related to sugar overconsumption (National Treasury, 2016). Obesity is a widespread and serious problem worldwide, and it is a major contributing factor to non-communicable diseases (NCDs) such as heart disease, type 2 diabetes, and various forms of cancer (Banjare and Bhalerao, 2016). Additionally, the industry was affected by cheap imports from South African Customs Union (SACU) members (Greenberg et al., 2017). According to SASA (2020), the number of sugarcane farmers has also declined by 60% during this timeframe, while employment opportunities in the industry have also decreased by 45%. These reasons have contributed to the observed decline in sugarcane yield between 2018 and 2021. According to Mr. Trikam's (CEO of SASA) interview with Farmer's Weekly (2023), following the introduction of the sugar tax in April 2018, the industry experienced a loss of revenue of approximately R1.2 billion per season. This is expected to be the case or even worsen, especially should the government increase the sugar tax rate.

4.2.Environmental Dynamics

4.2.1 Climate Change Trends

The global occurrence and extent of natural catastrophes have escalated during the previous two decades and are projected to persistently rise. Vulnerable nations experience a range of negative consequences, including physical, economic, social, and environmental harm, as well as loss of human life. According to Cable News Network (CNN) (2024), overall world greenhouse gases came to a total of 50 billion metric tonnes in 2022, and China was reported to be the leading polluter, contributing 30% of the recorded emissions. This is due to the many industrial activities that the country has and the rapid growth of its economy.

Climate change refers to the alteration of climatic patterns primarily resulting from the release of greenhouse gases by both natural processes and human actions (Fawzy et al., 2020). Climate change is mainly associated with increasing temperatures, declining total rainfall with increasing intensity and frequency, and droughts and floods. Climate variability and change are critical in projecting future farming, crop production, and food systems since shifts in seasons are substantially modifying the environment (Godfray *et al.*, 2010). The consequences of a changing climate are intensified in the hydrological cycle in terms of frequency, intensity, and duration of precipitation events which impose huge impacts on society and the environment (McBride et al., 2022).

Agriculture is the most vulnerable sector to climate change which is exacerbating the existing situation. In numerous regions, such as southern Africa, the majority of cultivated land, specifically 95%, depends on rainfed agriculture (Nhamo et al., 2019). Particularly, sugarcane yield is affected by climate change variables such as temperature, rainfall, and sunlight (Hussain et al., 2018). An analysis of climate change provides a scientific foundation for developing environmental policy and making well-informed judgments. Through analyzing past data and recognizing emerging trends, policymakers can formulate measures to reduce and adapt to the problems presented by climate change and its accompanying hazards (Zhang et al., 2019). It was therefore imperative that this study also analyze the temperature and rainfall trends in South Africa for the period being studied.

Natural climate phenomena such as El Niño and La Niña exert an influence on global temperature fluctuations. The recurrent phenomena, distinguished by alterations in sea surface temperatures in the equatorial Pacific Ocean, possess extensive effects on weather patterns and can profoundly shape regional and worldwide climates (Merchant et al., 2019).

4.2.1.1 Temperature Trend

Temperature is a vital measure of heat or coolness in the environment, influencing ecological processes like behaviour, chemical interactions, and species distribution (Mashwani, 2020). Studying temperature fluctuations helps understand climate patterns, biological adaptations, and the impacts of climate change on ecosystems, informing environmental management and conservation decisions (Nordhaus, 2019). The temperature variation patterns in South Africa over the 1972-2021 period is shown in Figure 4.7 Global weather patterns are affected by El Nino and La Nina events. El Niño and La Niña are distinct phases of the tropical Pacific El Niño-Southern Oscillation (ENSO) climatic trend (Ramírez-Gil et al., 2020). During El Niño, sea surface temperatures rise, trade winds weaken, and global rainfall patterns change. La Niña, on the other hand, involves decreased sea surface temperatures, stronger trade winds, and altered air circulation, impacting precipitation patterns (Cai et al., 2020).

Both events greatly impact global weather, especially temperature. El Niño causes above-average temperatures, heatwaves, and droughts, while La Niña causes cooler temperatures, changed precipitation, and higher rainfall or snowfall in certain areas. ENSO phases shape global heat and moisture distribution and atmospheric circulation. It was reported that over the rest of this century, average temperatures in South Africa are expected to rise significantly (Ngepah et al., 2022). Observed and simulated climate trends across South Africa in the period 1980–2014 are studied and showed air temperatures have increased by $0.02°C·yr^{-1}$ (Jury, 2018). In line with this, it is observable that Figure 4.7 in this study is also showing the same pattern. The temperature trend is relatively positive and upward-sloping, indicative of temperature rising over the period 1972-2021.

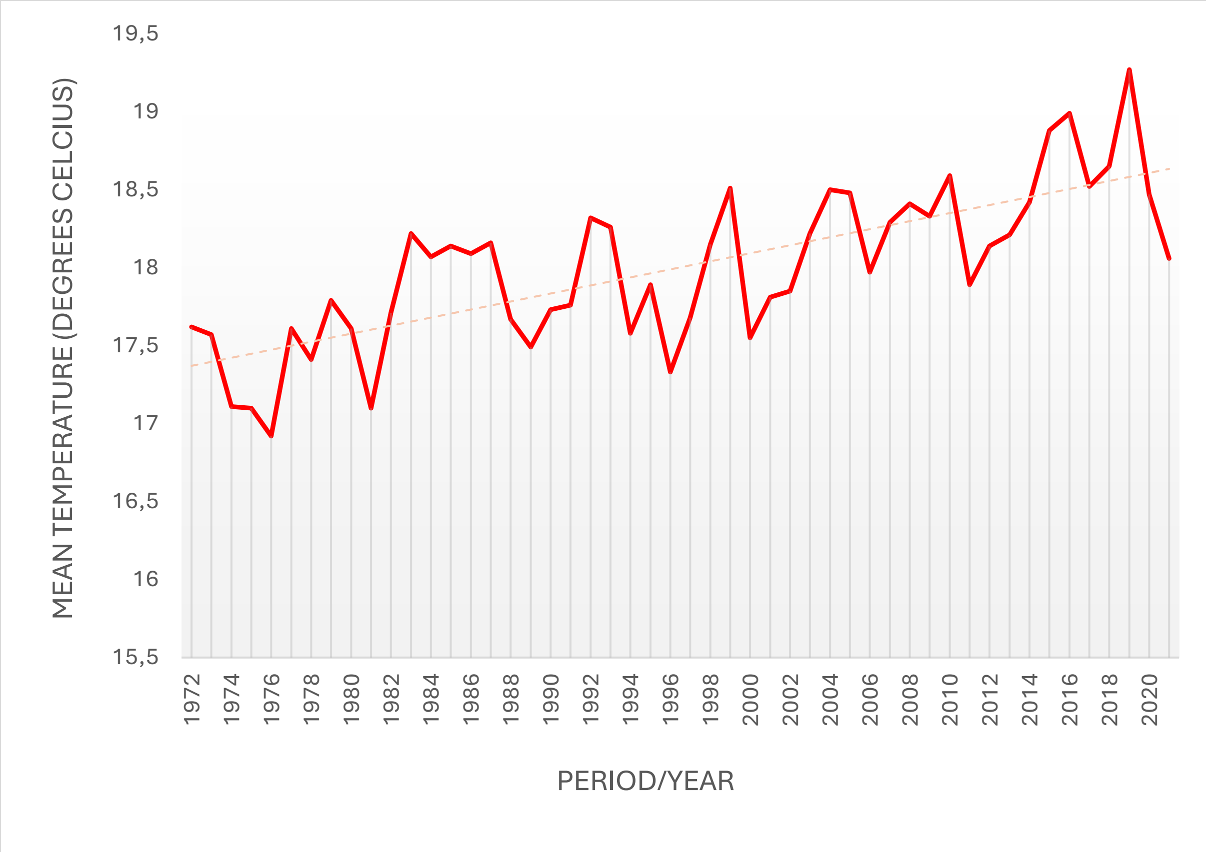


Figure 4.7: Mean temperature trend

Source: Author's compilation (2024); data sourced from CCKP (2023)

Figure 4.7 shows that the mean temperature was fluctuating a lot during this period. Studies from 1901 to 2014 showed that the global surface temperature has increased notably due to anthropogenic warming which attained about 1°C above the preindustrial period (Donner & Large, 2008; Shrestha, 2014). Major temperature peaks were recorded for 1977, 1988, 1983, 1992, 1999, 2004, 2009, 2016, and 2019 which were associated with increasing temperature patterns whereas the major troughs observed in the years 1976, 1981,1981, 1990, 1994, 2000, 2006, 2011 were showing low average temperatures over those years. In the 21st century, both highest and lowest surface temperature events are likely expected to increase significantly which is manifested by the peaks and troughs of the study. According to Wright et al. (2021) analyzing temperatures in southern Africa from 1901 to 2009 found a consistent increase in annual minimum and maximum temperatures, with average rates of 0.057◦C per decade and 0.046◦C per decade, respectively.

This trend is anticipated to continue unless effective measures are implemented to address climate change in the region (Iyakaremye et al., 2021; Nhamo et al., 2019). It is therefore crucial that efforts to mitigate the effects of climate change are made, and policies implemented, combined with global coordination to find alternatives to coal-generated energy.

4.2.1.2 Rainfall Trend

Rainfall is the quantity of precipitation, usually in the form of rain, that occurs in a certain region during a defined timeframe (Segoni et al., 2018). It is a vital element of the Earth's water cycle, as it involves the condensation of water vapor in the atmosphere into droplets that subsequently descend to the Earth's surface. Rainfall is quantified using measurements such as millimeters or inches and has a crucial role in establishing the climate and environment of a given area. The rainfall variation patterns in South Africa over the period are shown in Figure 4.8.

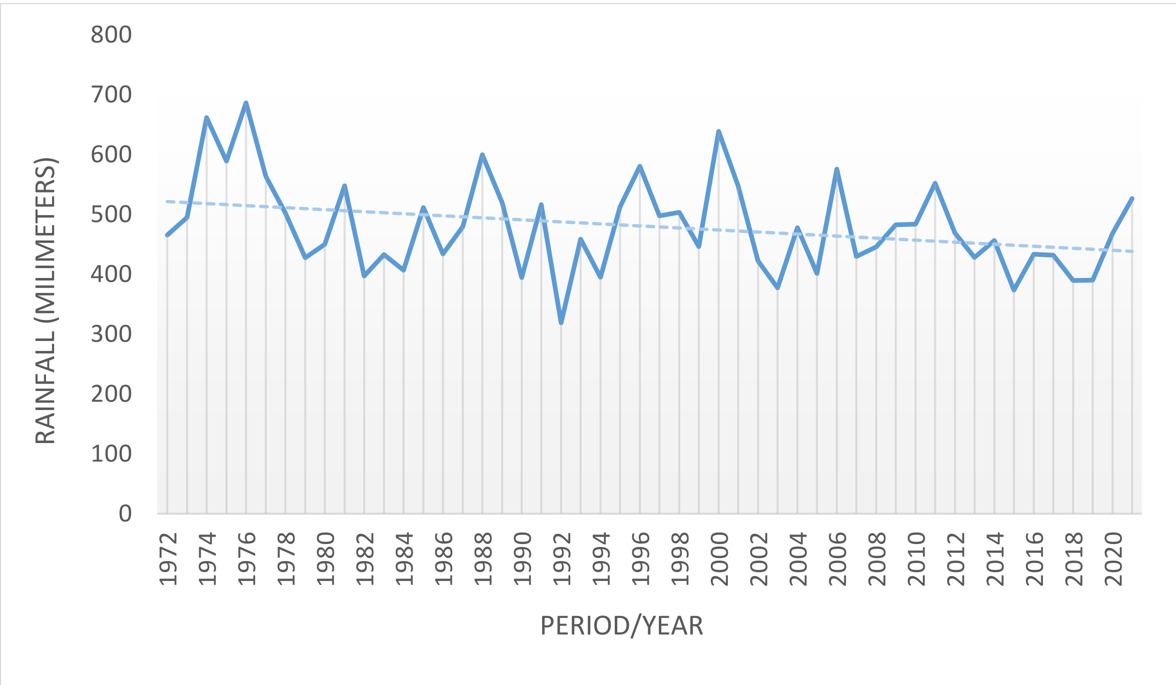


Figure 4.8: Rainfall patterns in South Africa for the period 1972-2021

Source: Author’s compilation (2024); data sourced from CCKP (2023)

South Africa's rainfall patterns have slightly been decreasing between 1971 and 2021, almost in a constant manner over this period. The maximum rainfall was received between 1975 and 1980 whereas the minimum rainfall was recorded in 1992 which implies that the variation is significant as demonstrated by previous research (Makellar et al., 2014; Archer et al., 2017; Botai et al., 2018). This huge variation can cause seasonal shifts which in turn impose a significant impact on sugarcane crop production. Changes in rainfall patterns in the sub-Saharan Africa region are expected which will affect areas suitable for growing many crops including sugarcane crops (Nhamo *et al.*, 2019). Trends in rainfall and moisture stress are notable in different bioclimatic regions across the South African provinces (Ndlovu *et al.*, 2021).

South Africa has experienced frequent floods lately, due to climate change. KwaZulu-Natal one of the biggest sugarcane regions experienced floods in 2022 which contributed to the loss of lives (over 400 individuals), and damaged a lot of infrastructure (DW, 2022). The government has since incurred costs of refurbishment of infrastructure and fixing the damages experienced. Recently, the province has been affected by floods and people continue to die. This shows the level at which climate change is impacting South Africa. Climate-induced rainfall inconsistency threats are anticipated to increase in duration, frequency, and severity under climate change (Adeola *et al.*, 2022). In another study, decreasing rainfall trends will reduce water availability for agricultural water use and domestic water supply (Makungo and Mashinye, 2022). This indicates that climate change, uncurbed, will continue to have tremendous impacts on our country.

4.2.2 Carbon Dioxide Emissions Trend

Carbon dioxide (CO_2) emissions are the discharge of carbon dioxide gas into the atmosphere, mostly caused by human activity; CO_2 is classified as a greenhouse gas due to its capacity to retain heat within the Earth's atmosphere (Letcher, 2020). Anthropogenic activities, including the use of fossil fuels (coal, oil, and natural gas) for energy production, industrial operations, and the clearing of forests, make a substantial contribution to the rise in atmospheric carbon dioxide levels (Rastogi et al., 2002; Xi-Liu and Qing-Xian, 2018).

This means that CO_2 emissions can directly measure the amount of fossil fuel consumption in a country. In other words, the more fossil fuels a country uses, the higher its CO_2 emissions are likely to be, reflecting the scale of its industrial and energy-related activities. Figure 4.9 shows the carbon dioxide emission in South Africa over the period 1961-2021.

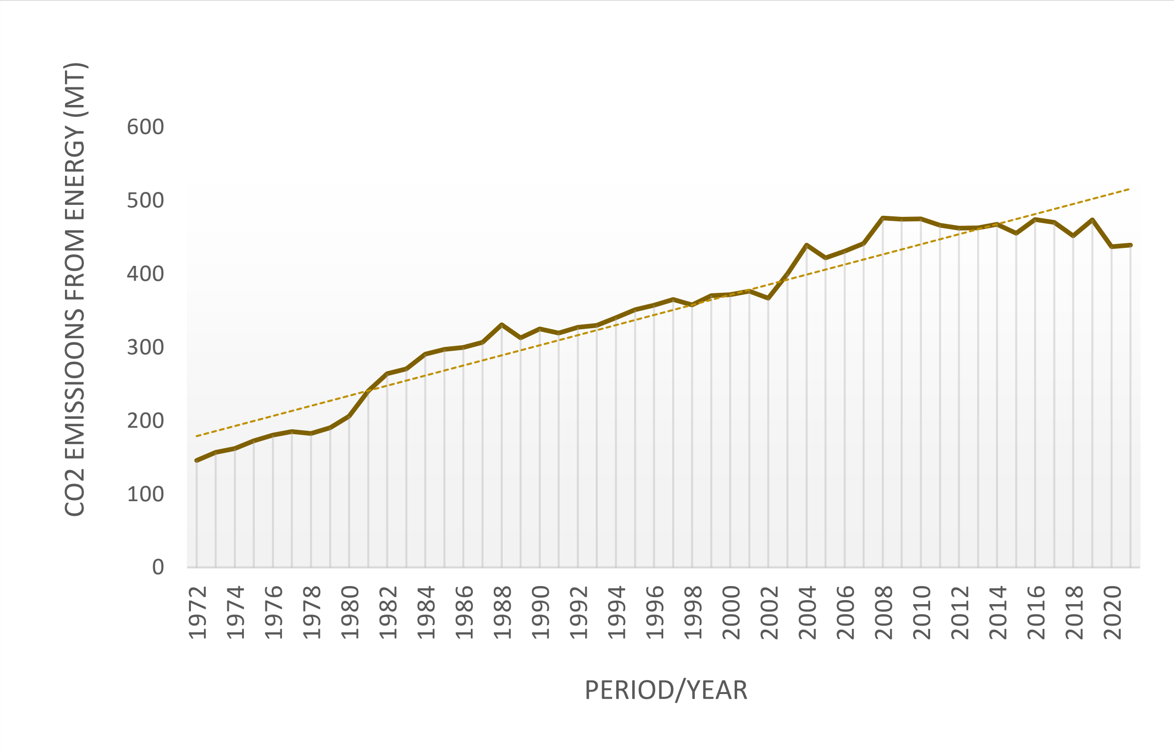


Figure 4.9: Carbon dioxide emissions from energy in South Africa between 1972-2021

Source: Author's compilation (2024); data sourced from BP Statistics (2022)

Over the years the carbon dioxide emissions trend has generally been increasing. This is observed to be growing at a similar pace as economic growth and is due to an increase in energy demand through industrialization, technological improvement, and mechanization. According to Raheem & Ogebe (2017), the Industrial Revolution revolutionized society through economic growth, increased production, and transportation, and improved living conditions.

However, it also led to high CO_2 emissions due to the intensive use of fossil fuels. Similarly, Dong et al. (2020) suggested that carbon dioxide emissions resulting from industrial activity had contributed to a rise in climate change. Similar findings were reported by Anderson, (2023) & Little, (2023). There were no major peaks and troughs observed in this trend. however, the period 2019-2021 had a decline, which can be attributed to COVID 19 due to slow production or industrial activity nationally and the whole world. South Africa introduced a carbon tax in 2019 to encourage the decrease of greenhouse gas emissions and support the use of cleaner energy technologies, such as renewable energy (Government Gazette, 2019). The carbon tax is applicable to major polluters in different industries and has the objective of incentivizing companies to make investments in energy-efficient measures and renewable energy alternatives. The rate is currently sitting at R144 and will continue to increase to encourage a decrease in CO_2 emissions by avoiding the penalty (Baker, 2022).

4.3 Renewable Energy Consumption Trend

Renewable energy consumption pertains to the utilization of energy obtained from renewable sources that are naturally renewed within a timeframe relevant to humans (Ehrlich et al., 2022). The sources encompass solar, wind, hydroelectric, geothermal, and biomass energy (Paraschiv and Paraschiv, 2023). Renewable energy, in contrast to finite fossil fuels like coal, oil, and natural gas, originates from sources that are always accessible and may be utilized without exhausting them in the long run. According to Tagwi's (2022) findings, the adoption or utilization of renewable energy sources within South Africa is negligible or substantially below anticipated or targeted levels.

To achieve global emission objectives and realize substantial cost savings, South Africa should give priority to the development and implementation of renewable energy sources (Van Zyl et al., 2018). Figure 4.10 shows the renewable energy consumption trend in South Africa during the period 1972-2021. The figure clearly shows that renewable energy consumption has relatively been increasing over the period.

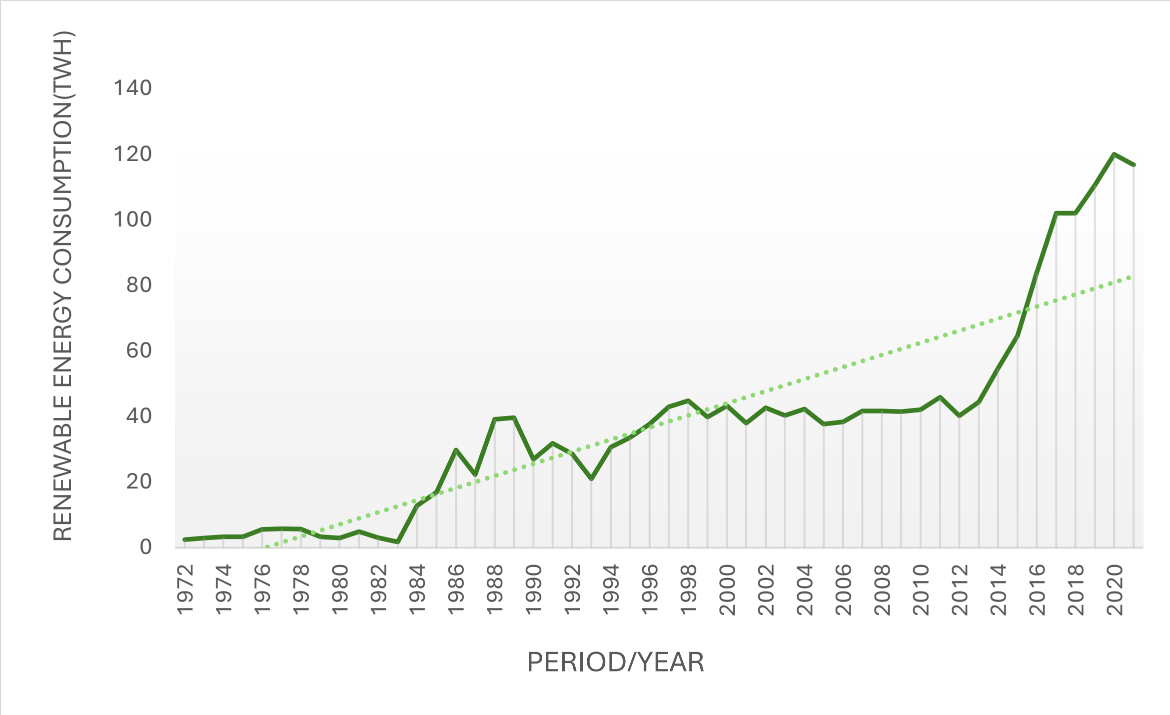


Figure 4.10: Renewable energy consumption in South Africa between 1972-2021

Source: Author's compilation (2024), data sourced from BP Statistics (2022)

Major shifts were recorded for 1981-1983 when there was a major dip in the trend. Renewable energy consumption increased sharply from 2012 to 2020. This may be due to the increasing costs of coal-generated electricity over the years, forcing South African consumers to find alternative energy sources. Policies that have been adopted to encourage clean energy may also have played a role in the observed increase. According to BP Statistics (2019), the use of plant residues for energy is projected to continue rising until 2050, and this will be largely influenced by the allocation of land as a resource to the sector. This has implications for growth in this sector and growth in the economy of South Africa.

4.4 Gross Domestic Product Trend

The Gross Domestic Product (GDP) of a country is a crucial economic metric that quantifies the aggregate value of all commodities and services generated within a nation's boundaries within a designated timeframe (Basheer et al., 2022).

It serves as a comprehensive metric for evaluating a nation's economic performance and is frequently seen as a key indicator of its overall economic well-being (Jean-Paul and Martine, 2018). According to Masood (2016), GDP can be expressed as the sum of domestic consumption, investments, public or government expenditure, and net exports.

Moreover, the GDP can be impacted by exogenous variables such as natural calamities, geopolitical occurrences, technology disturbances, and global economic patterns (Tawiri, 2011; Golda et al., 2020). These factors have the potential to influence the total level of economic activity and contribute to variations in GDP growth rates. Although any state's initial response to decreasing economic growth would be to implement monetary policy; It was found by Sims and Wolf (2018) that citizens are more likely to spend less in periods of recessions than they would in periods of economic growth. This implies that government spending may not be as effective in improving the economy during economic shocks. South Africa's GDP has slowly been increasing over the period 1972-2021 (Figure 4,11).

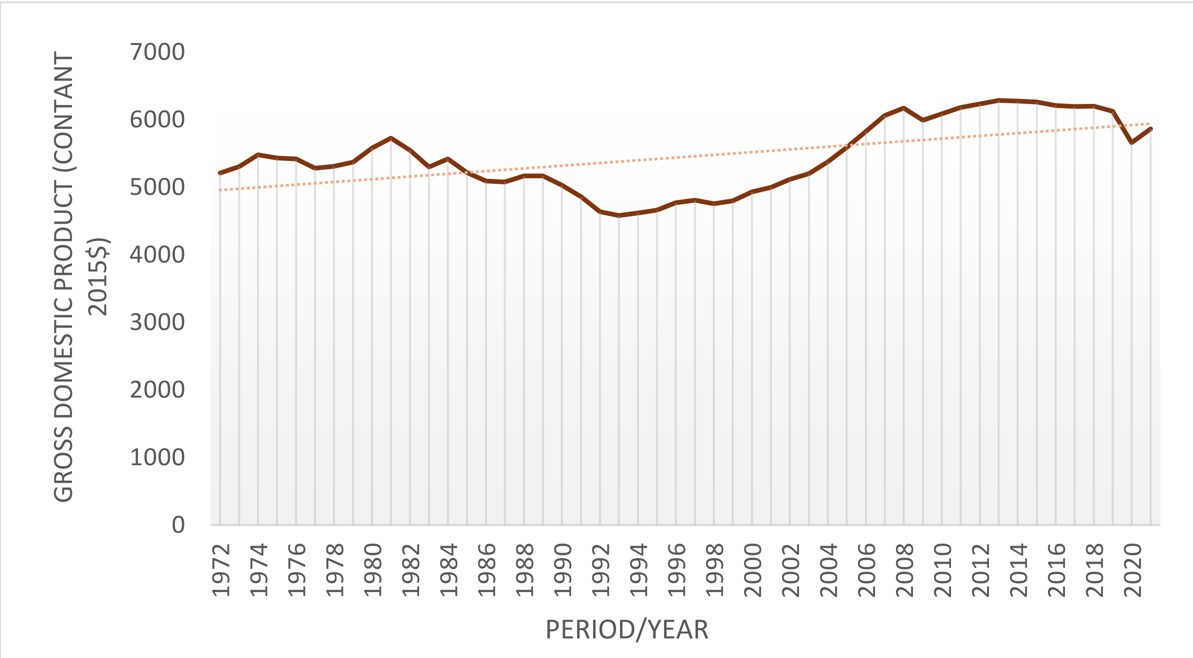


Figure 4.11: South African Gross Domestic Product (GDP Constant $) between 1972-2021

Source: Author's compilation (2024); sourced from WDI (2023)

This scenario implies a steady but slow economic climate where growth may not be fast enough to boost employment, earnings, or investment. Despite rising GDP, depressed consumer demand, low company investment, and foreign economic concerns may slow economic growth. Policymakers and experts may need to explore the causes of slow growth and take focused actions to boost economic activity and long-term growth. Between 1985 and 2006 GDP was below the increasing trend line, which implies economic performance that was below average during this period. In 2022, the agricultural sector accounted for around 2.57 percent of South Africa's GDP, while the industrial and service sectors provided 24.44 and 62.61 % of the total value added, respectively (Statista, 2024a). Figure 4.12 shows the contribution to GDP by various economic sectors in South Africa, in the third quarter of 2023.

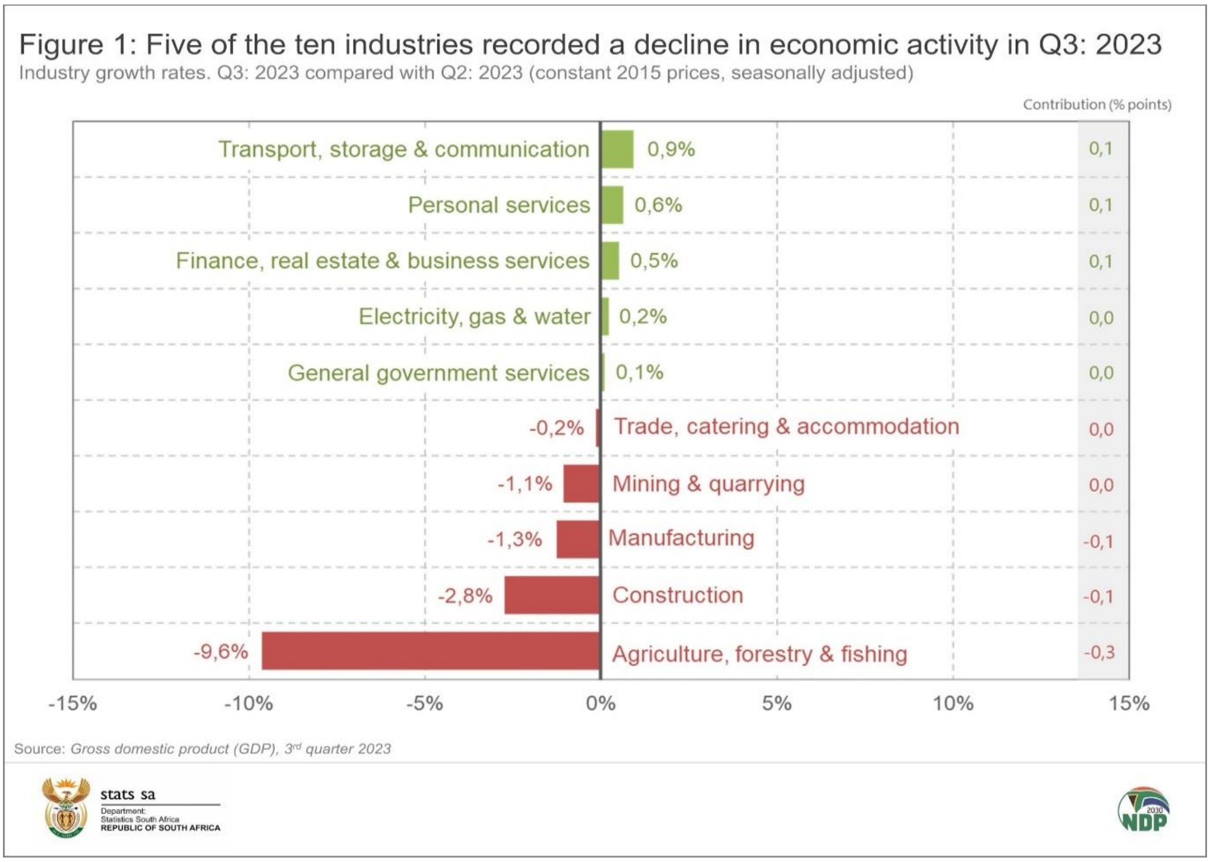


Figure 4.12: GDP contribution by industry in the third quarter of 2023

Source: Statistics South Africa (2023a)

South Africa's Agricultural industry continues to perform poorly in the economy, having contributed negatively to GDP in the 3rd quarter of the year 2023 (Figure 4.12). The three major industries that have been identified as drivers for economic growth according to the National Development Plan performed the weakest (National Planning Commission, 2012). Although some sectors like transport, storage and communication, personal services, and finance positively influenced GDP, a GDP contraction of 0.2% in the third quarter was still experienced. This follows an expansion of 0.6% in the second quarter, largely driven by consumption and government expenditure. In the third quarter, net exports had a negative impact on GDP spending. The export of goods and services saw a 0.6% growth, mostly driven by increasing trade in automobiles and transport equipment, pearls, precious and semi-precious stones, precious metals, and vegetable products (Stats SA, 2023). Figure 4.13 shows the volume of goods and services exported and imported in South Africa between 1960 and 2022.

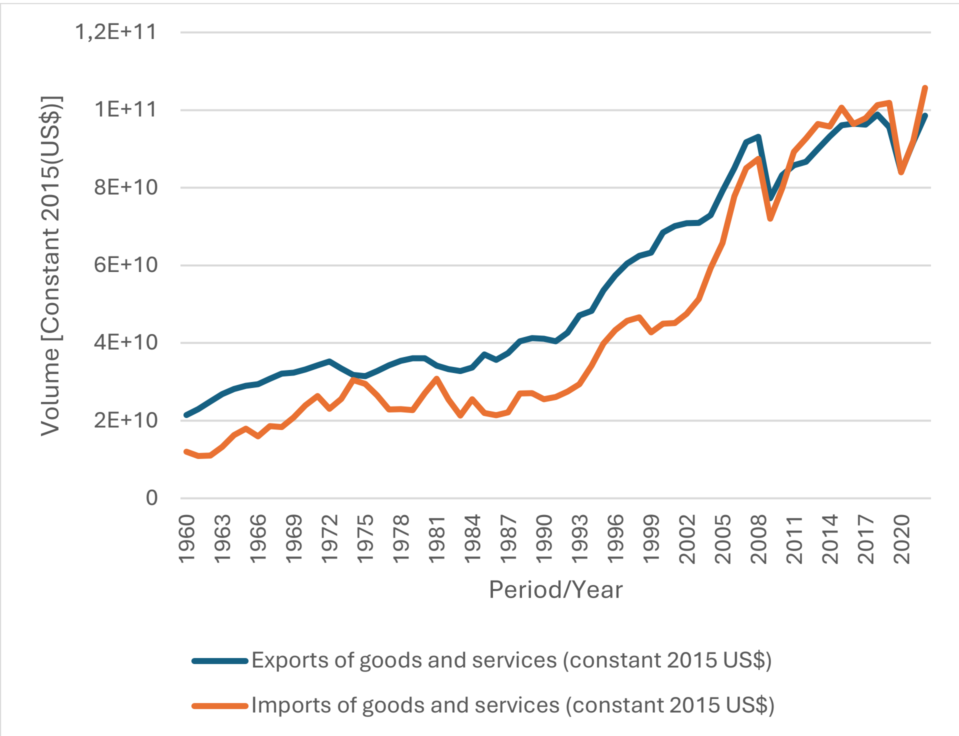


Figure 4. 13: Net Exports for South Africa between 1960-2022

Source: Author's compilation (2024), data sourced from World Development Indicators (2023)

It is observed that South Africa has always been a net exporter of goods and services before the global financial crisis in 2008. However, volumes of both exports and imports started decreasing from 2008-2009 and again this dip is seen from 2019-2020. This can be explained by the global financial crisis in 2008 which led to a recession in the country, again the COVID-19 pandemic had major impacts on trade (Rena and Msoni, 2014; Verschuur et al., 2021). The increase in unemployment and poverty has led to a larger need for state resources, despite a decrease in income. As a result, there is growing political pressure on the government to reassess its economic policies.

.

4.6 Population Growth Trend

Gaining insight into prospective trends in population levels is essential for forecasting and strategizing for evolving age distributions, resource and healthcare requirements, and environmental and economic conditions (Vollset et al., 2020). Population growth refers to the phenomenon of the gradual rise in the number of people residing in a specific geographical region or within a particular group of individuals within a specified timeframe. Typically, it is conveyed as a percentage or a precise numerical value. Figure 4.14 shows population growth trends during the period 1972-2021.

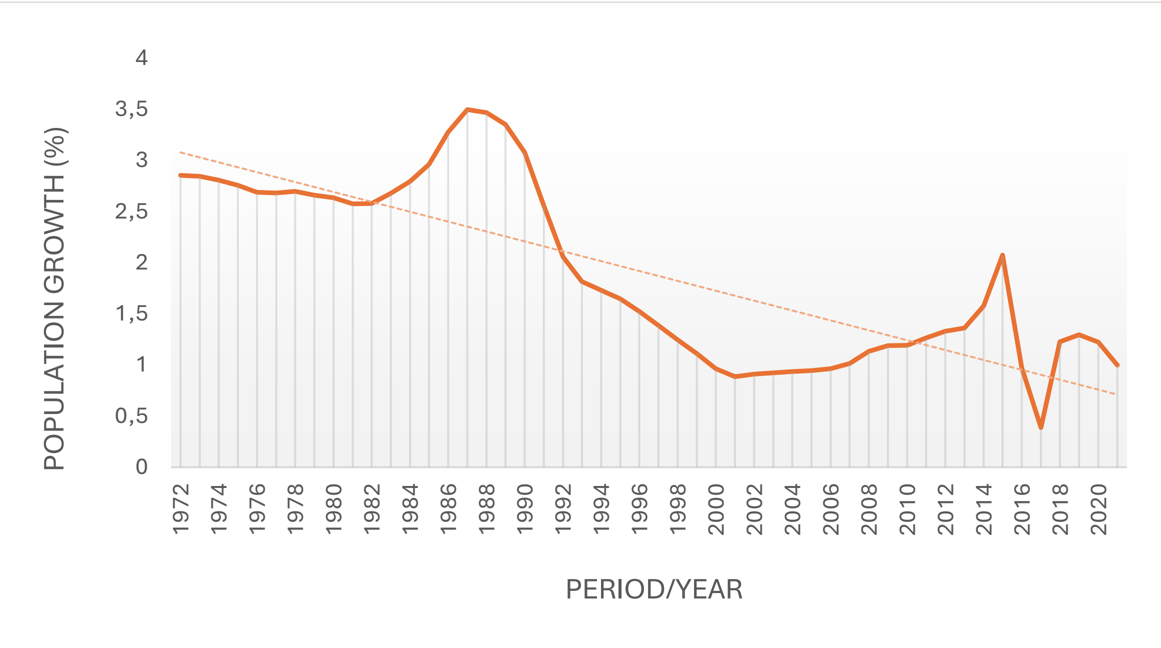


Figure 4.14: Population growth in South Africa over a period of 49 years

Source: Author's compilation (2024); data sourced from WDI (2023)

Although the South African population has relatively been increasing (WDI, 2023), population growth however has relatively been declining. In 1987, South Africa saw its highest recorded rise of 3.49 percent, and the most minimal growth with just a 0.39 percent gain was seen in 2017. The mean age in South Africa saw a 4.40-year increase from 2012 to 2023, going from 25.70 to 30.10 years (as the median figure) (Worlddata, 2023). Approximately 68 percent of the population resides in the major urban centres of the nation. The rate of urbanization is seeing an annual growth of 1.6 percent (Statista, 2024b). Population growth has been decreasing ever since the COVID-19 pandemic. This indicates the impact that the disease had on the population.

4.7 Summary

This chapter presented sugarcane production trends and the trends of all variables included in this study. Sugarcane production was found to have a generally increasing trend with decreasing sugarcane productivity (measured by yield or tonnes per hectare). This can be attributed to land allocation on sugarcane cultivation over time, the state of the economy, increase in exports and trade revenue amongst other factors.

The following trends were recorded for the period 1972-2021; rainfall and population growth have been decreasing over the period, while temperature, carbon dioxide emissions and renewable energy consumption have generally been increasing over the same period. GDP indicated a slow growth rate despite some upward movement. The economy has seen slight growth without any notable shifts, which might suggest limited productivity or cautious consumer and investor sentiment. Population growth had a declining trend.

CHAPTER 5: RESULTS AND DISCUSSION

This chapter presents the results of the descriptive and inferential analysis, and the discussion. The ARDL model was selected as the suitable method of analysis for this study, together with the ECM for calculating the speed of adjustment for the model. The Chapter presents the results of the Granger causality tests, model sensitivity analysis and model robustness results. Robustness was tested using the FMOLS, DOLS and CCR techniques to compare outcomes.

5.1 Descriptive Statistics Results

Table 5.1 shows the descriptive results of the data used in this study through measures of central tendency and measures of dispersion.

Table 5.1: Descriptives

Variables Descriptors	**SUG**	**TMP**	**RNF**	**RNC**	**GDP**	**CO2**	**POP**
Mean	70.16	18.00	479.89	37.57	5448.99	347.30	1.89
Median	68.03	18.07	468.32	38.21	5372.95	357.43	1.61
Maximum	95.44	19.27	686.36	120.01	6284.86	475.95	3.50
Minimum	41.10	16.92	318.82	1.76	4581.22	145.69	0.39
Std. Dev.	11.02	0.51	78.04	30.61	529.15	104.12	0.88
Sum	3507.89	900.10	23994.31	1878.75	272448.80	17364.75	94.73
Sum Sq. Dev.	5945.18	12.52	298418.10	45923.27	13719972.00	531169.60	37.56
Skewness	0.29	0.06	0.60	1.16	0.16	-0.45	0.27
Kurtosis	3.38	2.80	3.12	4.04	1.84	2.04	1.63
Jarque-Bera	1.00	0.12	3.06	13.38	3.02	3.62	4.51
Probability	0.62	0.942	0.22	0.00	0.22	0.16	0.10
Observations	50	50	50	50	50	50	50

Source: Author’s compilation (2024); EViews output (Appendix B)

The average sugarcane yield was found to be 70,16 t/ha. The median was 68.03 t/ha and was slightly lower than the mean, indicating a right-skewed distribution. The highest sugarcane yield observed in the dataset was recorded at 95.44 t/ha while the lowest was 41.10 t/ha. The standard deviation was 11.02 t/ha, indicating moderate variability in sugar yield. The skewness of 0.29 was indicative of a right-skewed distribution, and the kurtosis was 3.38, indicating that the distribution had slightly heavier tails than a normal distribution. According to DeCarlo (1997), a kurtosis of 3 means that the distribution is normal. Jarque-Bera of 1.00 with a probability of 0.62 meant the data did not significantly deviate from normality.

On average, the mean temperature was found to be 18℃, and the median was18.07℃. The median was very close to the mean, suggesting a relatively symmetrical distribution. Maximum and minimum temperatures were recorded at 19.27℃ and 16.92℃, respectively, with 0.51℃ as the standard deviation. This indicated relatively low variability in the dataset. Skewness was recorded at 0.06, indicating a very slight right-skewed distribution, and kurtosis was 2.80 showing heavier tails than a normal distribution. The data did not significantly deviate from normality based on the Jarque-Bera test, supported by a high p-value (Jarque-Bera: 0.12 with a probability of 0.942).

Average rainfall was about 480 mm, with a median of 468.32mm. The median was slightly lower than the mean, indicating a right-skewed distribution. Maximum and minimum rainfall was observed to be 686.36mm and 318.82mm, respectively. A standard deviation of 78.04 mm showed moderate variability in rainfall. The skewness was 0.60, indicating a right-skewed distribution, indicating that there may be a longer tail on the right side of the distribution. Kurtosis was 3.12 and indicated a distribution with slightly heavier tails than a normal distribution. The data did not significantly deviate from normality based on the Jarque-Bera test, supported by a relatively high p-value (Jarque-Bera: 3.06 with a probability of 0.22).

Renewable energy consumption was about 38 Terawatt hours on average, with a median of 38.21. The median was slightly higher than the mean, indicating a left-skewed distribution. The highest and lowest renewable energy consumption observed in the dataset was 120.01 TWh and 1.76 TWh, respectively.

The standard deviation was 30.61 TWh, indicating considerable variability in renewable energy consumption. A Skewness of 1.16 showed that the data is right-skewed and that there may be a longer tail on the right side of the distribution. Kurtosis of 4.04 indicated that the distribution of the dataset had heavier tails than a normal distribution. Jarque-Bera was 13.38 with a probability of 0.00, indicating that the data significantly deviated from normality (low p-value).

GDP was recorded at $5449 on average and median at $5372.95. The median was slightly lower than the mean, indicating a right-skewed distribution and the maximum GDP was $6284.86, and the minimum was $4581.22. There was substantial variability, a slightly right-skewed distribution, and higher tails than a normal distribution in GDP, with a standard deviation of $529.15, skewness of 1.84, and a kurtosis of 1.84, respectively.

The mean for carbon dioxide emissions from energy sources was observed to be 347 metric tons (Mt) and the median was 357.43Mt. The median is slightly higher than the mean, indicating a left-skewed distribution supported with a skewness of 0.27. The highest and lowest CO_2 emissions observed in the dataset were 475.95 Mt and 145.69 Mt, respectively. The standard deviation was recorded at 104.12 Mt, indicating considerable variability in CO_2 emissions, and kurtosis was 2.04, indicating that the distribution had slightly heavier tails than a normal distribution. The data did not significantly deviate from normality (Jarque-Bera: 3.62 with a probability of 0.16).

Population growth rate depicted a right-skewed distribution with a median of 1.61% lower than the mean of 1.89% and a skewness of 0.27. The highest population growth rate observed in the dataset was 3.5% while the minimum was 0.39%. The standard deviation was 0.88, indicating moderate variability in population. Kurtosis: 1.63 - The distribution has slightly heavier tails than a normal distribution. The Jarque-Bera test statistic of 4.51 with a probability of 0.10 indicated that the data did not significantly deviate from normality.

5.2 Inferential Statistics Results

5.2.1 Correlations

According to Schober et al. (2018), correlation may be defined as a quantitative measure of the link between variables. When two variables are positively correlated (moving in the same direction) or negatively correlated (moving in the opposite direction), we say that the two variables are connected. Table 5.2 shows the correlations between the variables in the dataset.

Table 5.2: Correlation Matrix

Variables	LNSUG	LNTMP	LNRNF	LNRNC	LNGDP	LNCO2	LNPOP
LNSUG	1						
LNTMP	-0,59	1					
LNRNF	0,49	-0,63	1				
LNRNC	-0,49	0,63	-0,22	1			
LNGDP	0,07	0,42	-0,11	0,22	1		
LNCO2	-0,63	0,73	-0,33	0,90	0,36	1	
LNPOP	0,37	-0,51	0,15	-0,67	-0,32	-0,72	1

Source: Author's compilation (2024); EViews output (Appendix B)

Correlations in this study have been interpreted in absolute terms in line with Assefa et al. (2018), Alamanda (2021), and Wealleans et al. (2021) as follows:

- 0.00-0.19: Very weak correlation
- 0.20-0.39: Weak correlation
- 0.40-0.59: Moderate correlation
- 0.60-0.79: Strong correlation
- 0.80-1.00: Very strong correlation.

In this study, for interpretability purposes, very weak & weak correlations have been grouped as "weak" correlations and very strong & strong correlations have been grouped as "strong" correlations. A weak negative correlation was observed for rainfall & renewable energy consumption, rainfall & GDP, rainfall & CO_2 emissions, and GDP & population growth.

This means that as rainfall increases, small decreases in renewable energy consumption, GDP and CO_2 emissions may be observed, and vice versa for each scenario. The same goes for GDP and population growth. This implies that the association is negative but poor. A moderate negative correlation was found between sugarcane yield & temperature, sugarcane yield & renewable energy consumption, and temperature & population growth. This means that as one variable increases, the other decreases moderately. Sugarcane yield and CO_2 emissions, temperature & renewable energy consumption, renewable energy consumption & population growth, and carbon dioxide emissions & population growth, all exhibited strong negative correlations. This indicates that as one variable (in the sets) increases, the other decreases considerably so, and vice versa. This means change in one of the variables in the set, strongly predicts changes in the other.

Sugarcane yield & GDP, rainfall & population growth, renewable energy consumption & GDP, renewable energy consumption & population growth, and GDP & CO_2 emissions, all had weak positive correlations. This means that as one variable increases, the other one does not greatly increase, and vice versa. A moderate positive correlation was observed for Sugarcane yield & rainfall, and temperature & GDP. The moderate positive correlations suggest a somewhat stronger relationship between sugarcane yield and rainfall, as well as between temperature and GDP. While these variables show a moderate tendency to move together, the connections are not exceedingly strong, indicating that other factors may also influence their dynamics. Temperature & renewable energy consumption, temperature & carbon dioxide emissions, and renewable energy consumption & carbon dioxide emissions had strong positive correlations. Strong positive correlations indicate that as one variable increases, the other increases as well and this association is robust. Although these correlations are strong, it is crucial to understand that correlation does not indicate causation, and there may be other factors influencing these associations (Rohrer, 2018).

5.2.2 Tests for Stationarity

A time series is considered stationary if both its mean and variance remain constant across time (Mohamed, 2020). This study employed the Phillips Perron (PP) and Augmented Dickey-Fuller (ADF) tests to test for unit roots or stationarity. The results of the two tests are shown in Table 5.3 below.

Table 5.3: Unit Root Tests

Order	**Variables**	**PP**	**ADF**
		With Constant	
		p-values	
At Level	**LNSUG**	0,02**	0,02**
	LNTMP	0,05*	0,04**
	LNRNF	0,00**	0,00***
	LNRNC	0,50	0,50
	LNGDP	0,72	0,72
	LNCO2	0,01***	0,03**
	LNPOP	0,50	0,78
At First Difference	**d(LNSUG)**	0.00***	0,00***
	d(LNTMP)	0,00***	0,00***
	d(LNRNF)	0,00***	0,00***
	d(LNRNC)	0,00***	0,00***
	d(LNGDP)	0,02***	0,00***
	d(LNCO2)	0,00***	0,00***
	d(LNPOP)	0,00***	0,36

Notes: Significant at 10%=*, 5%=**, 1%=***

*MacKinnon (1996) one-sided p-values.

Source: Author's compilation (2024); EViews output (Appendix B)

Both the PP and ADF tests found sugarcane yield, temperature, rainfall, and CO_2 emissions from energy to be significantly stationary at level. This indicates statistical significance in the variables' original form and constant variance and mean over time. Renewable energy consumption and GDP were significantly stationary at first difference, indicating the need for data transformation before inclusion in the regression model, and constant mean but varying variance over time in the series.

Population growth was only found to be significant for stationarity at first difference using the PP test, while the ADF test results indicated non-stationarity both at level and first difference.

5.2.3 Optimal Lag Order Selection

Lag order selection in Autoregressive Distributed Lag (ARDL) models involves calculating the optimal number of lags for both the dependent variable and the independent variables in the model (Nigusse et al., 2019). It involves selecting the most appropriate number of lagged variables to include in a model. ARDL models are frequently employed in econometric analyses to examine the enduring associations between variables. Table 5.4 shows the optimal lag order selection for this study, using the Akaike Information Criterion (AIC).

Table 5.4: Optimal Lag Order Selection using Akaike Information Criterion

Lag	LogL	LR	FPE	AIC	SC	HQ
0	184,2944	NA	1,06E-12	-7,70845	-7,43018	-7,604212
1	419,3236	388,309	3.34e-16*	-15,7967	-13.57050*	-14.96274*
2	465,0923	61,68831	4,45E-16	-15,6562	-11,4821	-14,09255
3	499,1829	35,57277	1,30E-15	-15,008	-8,88598	-12,71462
4	596,8782	72.20962*	4,12E-16	-17.12514*	-9,05527	-14,10212

* Indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Source: Author's compilation (2024); EViews output (Appendix B)

The optimal lag order for sugarcane yield was selected as the 4^{th} lag. According to the chosen criteria (AIC), the model achieves superior performance or greater simplicity by using data from the previous four time periods. Each lag corresponds to a previous observation, and incorporating many lags enables the model to capture the historical trends and interdependencies in the sugarcane yield data.

5.2.5 Tests for Cointegration

The ARDL approach was employed to test for the relationships that exist in the model (Pesaran et al., 2001). The ARDL F-bounds test was performed to check whether there was a long-run relationship in the model, i.e., the presence of a cointegration/levels relationship (Table 5.5). To prove the presence of a long-run relationship, the F-statistic should be above both the lower [I(0)] and upper bounds [I(1)]. If it is less, it is concluded that there is no long-run relationship, and if found to be within the upper and lower bounds, the results are deemed inconclusive.

Table 5.5: ARDL Bounds Test

Critical Values								
Leg Length	**Test statistic**	**k**	**10%**		**5%**		**1%**	
			I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
ARDL(4, 0, 3, 4, 0, 4, 0)	F=7,563	6	2,12	3,23	2,45	3,61	3,15	4,43
	t=-0,058		-2,57	-4,04	-2,86	-4,38	-3,43	-4,99

Source: Author's compilation (2024); EViews output (Appendix B)

The F-statistic (7,563) was greater than the upper and lower bound values at all levels of significance. It is therefore concluded that there is a long-run relationship between at least one of the explanatory variables on the model and sugarcane yield. A t-statistic that is less than the absolute values of upper and lower bound values at all levels of significance also indicates the existence of some long-run relationship between the independent variables in the model and the dependent variable. In this case, 0,058 is less than all upper and lower bounds at all significance levels. Therefore, cointegration was found in this model, resulting in the estimation of an error correction model.

5.2.4 ARDL Short-Run or Error Correction Model Results

The presence of a long-run relationship is a prerequisite for running an Error Correction Model (ECM). The ECM was then performed upon finding a long-run relationship between the explanatory variables in the model and sugarcane yield, to find out the speed of adjustment in the short run. Table 5.6 below shows the short-run results and error correction term, which informs the model's speed of adjustment.

Table 5.6: Short-run Relationships or ECM

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4,53	0,56	8,10	0,00 ***
D(LNSUG(-1))	0,44	0,11	3,89	0,00 ***
D(LNSUG(-2))	0,12	0,11	1,10	0,28
D(LNSUG(-3))	0,20	0,09	2,17	0,04 **
D(LNRNF)	-0,05	0,06	-0,75	0,46
D(LNRNF(-1))	-0,41	0,11	-3,72	0,00 ***
D(LNRNF(-2))	-0,14	0,09	-1,69	0,10
D(LNRNC)	0,17	0,03	5,66	0,00 ***
D(LNRNC(-1))	0,01	0,03	0,34	0,74
D(LNRNC(-2))	0,06	0,03	1,87	0,07 *
D(LNRNC(-3))	0,09	0,03	3,03	0,01 **
D(LNCO2)	-0,23	0,24	-0,96	0,35
D(LNCO2(-1))	0,97	0,25	3,89	0,00 ***
D(LNCO2(-2))	0,57	0,29	1,97	0,06 *
D(LNCO2(-3))	0,54	0,27	2,00	0,06 *
CointEq(-1)*	-1,12	0,14	-8,13	0,00 ***
R-squared	0,86	Mean dependent var		-0,01
Adjusted R-squared	0,79	S.D. dependent var		0,13
S.E. of regression	0,06	Akaike info criterion		-2,49
Sum squared resid	0,11	Schwarz criterion		-1,86
Log-likelihood	73,32	Hannan-Quinn criteria.		-2,25
F-statistic	12,40	Durbin-Watson stat		1,88
Prob(F-statistic)	0,00 ***			

Notes: Significant at 10%=*, 5%=**, 1%=***

*MacKinnon (1996) one-sided p-values.

Source: Author's compilation (2024); EViews output (Appendix B)

The results show that the ARDL model is significant (p-value=0.00) and therefore the results are reliable to explain changes in sugarcane yield caused by the explanatory variables included in the model. According to the results, 79% of the variation in sugarcane yield can be explained by temperature, rainfall, renewable energy consumption, GDP, CO_2 emissions from energy, and population growth. ARDL models exclude some variables due to insignificance and improve the fit of the model (Kripfganz & Schneider, 2018). Temperature, GDP, and population growth were excluded because of their non-contribution to the error correction mechanism.

Sugarcane yield was also found to be significant and impacted positively by the previous year's production patterns. A 1% increase in the previous year's sugarcane yield increases the current year's sugarcane yield by 0.44%, while a 1% increase in yield 3 years ago increases the current yield by 0.2%. The previous year's rainfall patterns were also found to significantly impact sugarcane yield negatively, with a 1% increase in rainfall the previous year decreasing sugarcane yield by 0.41% in the current year. Renewable energy consumption was significant in the model. A 1% increase in renewable energy consumption was found to increase sugarcane yield by 0.17%. Renewable energy consumption 2 years ago and 3 years ago was found to be significant, where a 1% increase is associated with a substantial increase in current sugarcane yield of 0.06 % and 0.09% respectively.

CO_2 emissions from Energy from a year, 2 years, and 3 years ago were also found to be significant in explaining changes in the current year's sugarcane yield; with a 1% increase in CO_2 from energy 1, 2, and 3 years ago increasing sugarcane yield by 0.97%, 0.57%and 0.54%, respectively. The error-correction term was found to be significant at 1 % and negative, however slightly over 1 (-1,12), which indicates that the speed of adjustment in the short run is relatively fast at 112%. This means that if any economic disturbance occurred in the model, it would take the sugarcane industry a relatively short amount of time for yields to go back to equilibrium. Taking the reciprocal of the ECM: 1/1,12= 0,89, 0.89*12 months=10,7. This implies that it would take around 11 months for the sugarcane industry to adjust back to equilibrium should an economic shock happen.

According to Narayan and Smyth (2006), a lagged error correction term that is between -1 and -2, shows that the error correction mechanism dampens around the long-run value rather than monotonically converging to the equilibrium route. However, convergence to the equilibrium path is fast after this process. This means that the South African sugarcane industry may react quickly at first, but the change process may slow down over time as the industry gets closer to balance. At this point, the rate of change slows down as the system gets closer to its long-term balance point. This impact contributes to market stability by reducing the rate of price fluctuations. This may be explained by the industry's high regulation (government intervention) and the impact of weather patterns which may alter production levels, and so there will be gradual adjustment of prices. Despite short-term fluctuations and deviations from equilibrium, the sugarcane industry shows resilience and stability over the long term. This stability might be attributed to factors such as the adaptability of farmers, the flexibility of production methods, and the responsiveness of market mechanisms.

5.2.5 ARDL Long run Results

The F-bounds test found that the model had the existence of cointegration between one or more variables. The ARDL cointegration technique was then performed, as shown in Table 5.7, to show exactly where the long run relationships existed in the model.

Table 5.7: Long run Relationships

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTMP	-2,09783	1,150545	-1,82333	0,0807 *
LNRNF	0,345059	0,183899	1,87635	0,0728 *
LNRNC	0,089657	0,043872	2,04363	0,0521 *
LNGDP	0,712716	0,132575	5,375966	0 ***
LNCO2	-0,39931	0,121437	-3,28822	0,0031 ***
LNPOP	-0,05614	0,035762	-1,56991	0,1295

Notes: Significant at 10%=*, 5%=**, 1%=***

*MacKinnon (1996) one-sided p-values.

Source: Author's compilation (2024); EViews output (Appendix B)

In the long run, temperature and CO_2 emissions have a statistically significant negative relationship with sugarcane yield at 10% and 1% levels of significance, respectively. For every 1% change in temperature and CO_2 emissions from energy, sugarcane yield decreases by 2,1% and 0.06%, respectively, ceteris paribus. On the contrary, rainfall, renewable energy consumption, and GDP were found to have a statistically significant positive impact on sugarcane yield. For every 1% increase in rainfall, renewable energy consumption, and GDP, sugarcane yield is observed to increase by 0.34%, 0,89%, and 0.73%, respectively, keeping other variables constant.

5.2.6 Diagnostics

The study employed the Breusch-Godfrey LM Test for serial correlation, the Breusch-Pagan test for heteroskedasticity, and the Jarque-Bera test for normality of the residuals in the model (Table 5.8). This was done to check model reliability and validity (Epaphra, 2018).

Table 5.8: ARDL Diagnostics

Diagnostic Test	p-value	Outcome
Breusch-Godfrey Serial Correlation LM Test	0,38	No Serial Correlation
Breusch-Pagan Heteroskedasticity Test	1,00	No Heteroskedasticity
Jarque-Bera Normality in the Residuals Test	0,84	Normal residuals

Notes: Significant at 10%=*, 5%=**, 1%=***

*MacKinnon (1996) one-sided p-values.

Source: Author's compilation (2024); EViews output (Appendix B)

Serial correlation tests and Heteroskedasticity tests are done to test the null hypothesis of no serial correlation and no heteroskedasticity, respectively; where the null hypothesis is rejected if the p-value is less than 0.05 (Ali et al., 2018). The Jarque-Bera test for normality in the residuals tests the null hypothesis that the residuals are normally distributed. There was no evidence of serial correlation, heteroskedasticity, and abnormality in the residuals as all p-values were found to be insignificant.

5.2.7 Model Robustness

It is always great to compare results with other similar tests and see if the results are the same or different. Ordinary Least Squares equations were estimated using the Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegration Regression (CCR) techniques to check model robustness (Table 5.9). FMOLS, DOLS, and CCR were able to explain at least 57%, 63%, and 56% of the variation in sugarcane yield caused by the explanatory variables in the models, respectively.

Table 5.9: FMOLS, DOLS, and CCR Ordinary Least Squares Tests

Variable	FMOLS				DOLS				CCR			
	Coeff.	SE	t-Stat	Prob,	Coeff.	SE	t-Stat	Prob,	Coeff.	SE	t-Stat.	Prob,
LNTMP	1,26	0,97	1,29	0,20	4,25	2,97	1,43	0,17	0,67	1,49	0,45	0,66
LNRNF	0,19	0,12	1,50	0,14	1,05	0,32	3,23	0,00***	0,27	0,20	1,37	0,18
LNRNC	0,07	0,03	2,41	0,02**	0,04	0,05	0,73	0,47	0,06	0,03	1,92	0,06*
LNGDP	0,61	0,17	3,54	0,00***	0,19	0,28	0,67	0,51	0,57	0,19	2,99	0,00***
LNCO2	0,50	0,12	4,20	0,00***	0,47	0,15	3,04	0,00***	0,49	0,12	4,20	0,00***
LNPOP	0,02	0,04	0,61	0,54	0,06	0,06	0,86	0,34	0,02	0,04	0,40	0,69
C	4,23	3,04	1,39	0,1	13,57	8,34	1,63	0,12	2,27	4,60	0,49	0,62
R-squared	0,5732				0,6337				0,5628			

Notes: Significant at 10%=*, 5%=**, 1%=***

*MacKinnon (1996) one-sided p-values.

Source: Author's compilation (2024); EViews output (Appendix B)

Similar to the findings of this study, FMOLS and DOLS both found GDP to significantly increase sugarcane yield. This implies that economic expansion has a substantial impact on increasing agricultural production, especially in the cultivation of sugarcane. The results highlight the significance of comprehensive economic development strategies in improving agricultural performance and rural lives. DOLS also found rainfall to significantly influence sugarcane yield positively, which was similar to the findings of this study. The findings of the CCR and FMOLS cointegration techniques also found renewable energy consumption to be significant in explaining sugarcane yield patterns. A positive association was found between the two variables, implying that as renewable energy increases, sugarcane yield increases. This suggests a possible connection between using renewable energy and increasing agricultural productivity, emphasising the significance of sustainable energy methods in promoting agricultural growth and potentially indicating chances for combined strategies for economic and environmental sustainability.These results support the results found in this study by the ARDL model, thus proves the model robustness and hence reliability of the results from the model.

5.2.5 Sensitivity Analysis

The model **ARDL(4, 0, 3, 4, 0, 4, 0)** was tested for stability of parameters using the cumulative sum and cumulative sum of squares plots, generated using standardized recursive residuals. The plots test the null hypothesis that the model does not have any structural breaks against the alternative that it does (Muthuramu and Maheswari, 2019). Figure 5.1 represents the results of these plots. According to Ahmed et al. (2023), the rule of thumb for CUSUM and CUSUM of Squares plots is that the blue lines should be within the red lines of significance (5%) for one to fail to reject the null hypothesis of no structural breaks.

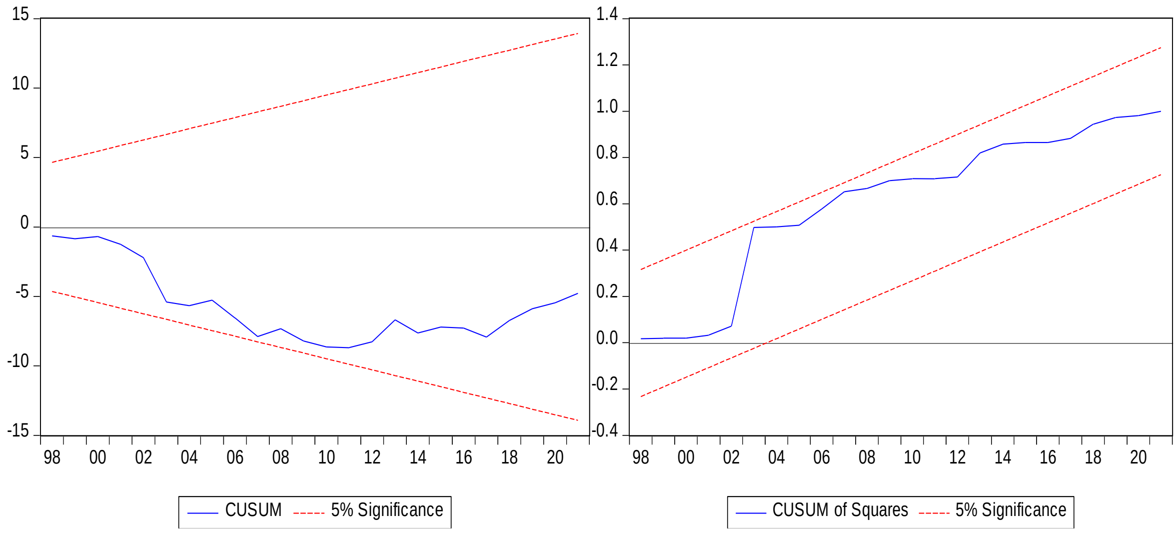


Figure 5.1: Cumulative sum and cumulative sum of squares (Y=sugarcane yield)

Source: Author's compilation (2024); EViews output (Appendix B)

It is visible that the blue lines are within the red lines which proves that the model is stable. If they were moving outside the red lines, this would prove model instability. Figure 5.1 shows model stability through the cumulative sum of squares plots. The results showed that the chosen model was stable and therefore yields reliable results.

5.2.7 Granger Causality Tests

Table 5.10 shows the results of the Pairwise Granger Causality Test done on the variables in the model.

Table 5.10: Causal relationships amongst variables

Null Hypothesis	p-value	Decision
LNTMP does not Granger Cause LNSUG	0,5974	Fail to Reject Null Hypothesis
LNSUG does not Granger Cause LNTMP	0,3158	Fail to Reject Null Hypothesis
LNRNF does not Granger Cause LNSUG	0,0913*	Reject Null Hypothesis
LNSUG does not Granger Cause LNRNF	0,5819	Fail to Reject Null Hypothesis
LNRNC does not Granger Cause LNSUG	0,1482	Fail to Reject Null Hypothesis
LNSUG does not Granger Cause LNRNC	0,1059	Fail to Reject Null Hypothesis
LNGDP does not Granger Cause LNSUG	0,433	Fail to Reject Null Hypothesis
LNSUG does not Granger Cause LNGDP	0,1935	Fai to Reject Null Hypothesis
LNCO2 does not Granger Cause LNSUG	0,1539	Fail to Reject Null Hypothesis
LNSUG does not Granger Cause LNCO2	0,3033	Fail to Reject Null Hypothesis

Null Hypothesis	p-value	Decision
LNPOP does not Granger Cause LNSUG	0,8011	Fail to Reject Null Hypothesis
LNSUG does not Granger Cause LNPOP	0,2157	Fail to Reject Null Hypothesis
LNRNF does not Granger Cause LNTMP	0,3727	Fail to Reject Null Hypothesis
LNTMP does not Granger Cause LNRNF	0,8405	Fail to Reject Null Hypothesis
LNRNC does not Granger Cause LNTMP	0,0216**	Reject Null Hypothesis
LNTMP does not Granger Cause LNRNC	0,0136**	Reject Null Hypothesis
LNGDP does not Granger Cause LNTMP	0,156	Fail to Reject Null Hypothesis
LNTMP does not Granger Cause LNGDP	0,2697	Fail to Reject Null Hypothesis
LNCO2 does not Granger Cause LNTMP	0,0018*	Reject Null Hypothesis
LNTMP does not Granger Cause LNCO2	0,9089	Fail to Reject Null Hypothesis
LNPOP does not Granger Cause LNTMP	0,0221**	Reject Null Hypothesis
LNTMP does not Granger Cause LNPOP	0,2118	Fail to Reject Null Hypothesis
LNRNC does not Granger Cause LNRNF	0,4211	Fail to Reject Null Hypothesis
LNRNF does not Granger Cause LNRNC	0,0334**	Reject Null Hypothesis
LNGDP does not Granger Cause LNRNF	0,4069	Fail to Reject Null Hypothesis
LNRNF does not Granger Cause LNGDP	0,8295	Fail to Reject Null Hypothesis
LNCO2 does not Granger Cause LNRNF	0,1658	Fail to Reject Null Hypothesis
LNRNF does not Granger Cause LNCO2	0,111	Fail to Reject Null Hypothesis
LNPOP does not Granger Cause LNRNF	0,6203	Reject Null Hypothesis
LNRNF does not Granger Cause LNPOP	0,617	Reject Null Hypothesis
LNGDP does not Granger Cause LNRNC	0,5139	Reject Null Hypothesis
LNRNC does not Granger Cause LNGDP	0,0342**	Fail to Reject Null Hypothesis
LNCO2 does not Granger Cause LNRNC	0,0177**	Reject Null Hypothesis
LNRNC does not Granger Cause LNCO2	0,0759*	Reject Null Hypothesis
LNPOP does not Granger Cause LNRNC	0,9301	Fail to Reject Null Hypothesis
LNRNC does not Granger Cause LNPOP	0,1088	Fail to Reject Null Hypothesis
LNCO2 does not Granger Cause LNGDP	0,1186	Fail to Reject Null Hypothesis
LNGDP does not Granger Cause LNCO2	0,1738	Fail to Reject Null Hypothesis
LNPOP does not Granger Cause LNGDP	0,0705*	Reject Null Hypothesis
LNGDP does not Granger Cause LNPOP	0,8095	Fail to Reject Null Hypothesis
LNPOP does not Granger Cause LNCO2	0,1709	Fail to Reject Null Hypothesis
LNCO2 does not Granger Cause LNPOP	0,2192	Fail to Reject Null Hypothesis

Notes: Significant at 10%=*, 5%=**, 1%=*** ,

*MacKinnon (1996) one-sided p-values.

Source: Author’s compilation (2024); EViews output (Appendix B)

There was insufficient evidence of causality between sugarcane yield and temperature, renewable energy consumption, GDP, CO_2 emissions, and population growth. A uni-directional relationship going from rainfall to sugarcane yield was found. This means that there was sufficient evidence to indicate that any changes in rainfall patterns may cause changes in sugarcane yield. Bi-directional causality was found between temperature & renewable energy consumption, CO_2 emissions & renewable energy consumption, rainfall & population growth. This indicates that changes in temperature cause changes in renewable energy consumption, changes in CO_2 emissions cause changes in renewable energy consumption, and changes in rainfall cause changes in population growth and vice versa for each scenario.

Further uni-directional causality was found going from rainfall to renewable energy consumption, GDP to renewable energy consumption, CO_2 emissions to temperature, and population growth to temperature. This outcome means that there is a direct link between rainfall and renewable energy consumption, changes in rainfall patterns cause changes in renewable energy consumption. Evidence that changes in economic growth caused changes in renewable energy consumption, changes in CO_2 emissions directly caused temperature changes, and changes in population growth caused temperature changes was found.

5.3 Discussion

The empirical results found the existence of a long run relationship between sugarcane yield and at least one of the explanatory variables in the model using the F-bounds cointegration test. Temperature was found to have a long run significant negative impact on sugarcane productivity in South Africa, while insignificant in explaining sugarcane yield changes in the short run. This means sugarcane yield decreases with temperature increases in the long run. These results were in line with Chandio et al. (2020) and Gul et al (2022)'s findings; however, they were contrary to Zahoo et al. (2022). This means that temperature may have no impact (either negative or positive) on sugarcane productivity in the short run, however, productivity may decrease with increases in temperature in the long run.

These results were obtained with no evidence of causality between the two variables and were in line with the hypothesized outcome. This implies that although sugarcane productivity may increase with rising temperatures in the long run, none of the changes are caused by either variable. Ali et al. (2021), found similar findings in terms of temperature being insignificant in the short run, however, rainfall was found to have a significant positive impact on sugarcane yield in the short run when studying climate change dynamics in Pakistan (1989-2015). Temperature was also found to have a significant negative impact on agricultural productivity in Africa, Europe and Oceania in a Panel data analysis done by Husnain et al. (2018). In the same study, contrary results to this study were found for Asia and South America which found that temperature had a positive impact in those countries. Chandio et al. 2020, also found temperature to have a long run negative impact on sugarcane yield (1968-2014).

The model demonstrates the susceptibility of sugarcane to variations in temperature, which has a direct impact on its overall production over an extended period. Temperature variations exert physiological strain on plants, diminishing their development and heightening their vulnerability to pests (Yanagi, 2024). The immediate effects may not be immediately apparent, but gradually, the productivity decreases. Policies should encompass climate-resilient strategies to minimize enduring risks and uphold the sustainability of the South African sugarcane sector in the face of evolving environmental circumstances. These outcomes were in line with the hypothesized outcomes of a negative correlation between temperature and sugarcane yield.

It was hypothesized that rainfall has a positive impact on sugarcane productivity in South Africa. Rainfall patterns were found to be significant in explaining changes in sugarcane yield in the short run. The association between sugarcane yield and rainfall was found to be significant and positive. These results were similar to those of Salim et al. (2019) and Asfew & Bedemo (2022). Similarly, Affoh et al. (2022) found a positive long run relationship between the two variables for Sub-Saharan countries. Contrary to these findings were those of Warsame et al (2021), who found a positive short run relationship instead of a negative one. The results may be influenced by time lag effects, threshold effects, crop adaptation, other factors, and methodological differences (Chen et al., 2023).

These factors contribute to the complex relationship between rainfall and sugarcane productivity in South Africa, requiring further research for a comprehensive understanding. A positive impact on sugarcane productivity in South Africa was expected from economic growth, with the assumption that as the economy grows, more resources may be allocated to sugarcane production. For the South African sugar industry, GDP and productivity were found to have an inverse relationship in the short run and a positive correlation in the long run, contrary to the EKC. Furthermore, there was no evidence of causality between the two variables, in line with Udemba (2020)'s findings for Nigeria. However, according to the findings by Zakaria et al. (2019) in South Asia (1973-2015), GDP and agricultural productivity had a positive relationship in the short run and postulated a negative relationship in the long run. These results mean that for South Africa, an increase in GDP is associated with increases sugarcane yield in the short run, and this association is negative in future. Changes in sugarcane yield are not caused by changes in economic growth (GDP) and vice versa.

This could be explained by the fact that over time, when economies progress, they frequently allocate resources towards infrastructure, technology, and agricultural research, which have the potential to enhance agricultural production. This includes improvements in irrigation infrastructure, market accessibility, mechanization, and agricultural extension services. Furthermore, a growth in GDP per capita can stimulate a greater demand for agricultural goods, which in turn encourages investments in improving efficiency, quality, and innovation (Tahir et al., 2021). These investments ultimately help the agricultural industry in the long term.

Increased renewable energy consumption was hypothesized to have a positive impact on sugarcane productivity in South Africa. In line with Chandio et al. (2022b) and contrary to the findings by Nguyen and kakinaka (2019), the results of this study found a positive association between renewable energy consumption both in the short and long run for South Africa. These outcomes came with no evidence of causality, suggesting that changes in renewable energy consumption do not significantly cause changes in sugarcane yield.

The results also indicated that carbon emissions from a year to 3 years ago have a positive impact on sugarcane yield today; however, there was a significant negative impact in both the short run and the long run. A bi-directional causality was also found between these variables, implying that increases in carbon emissions from energy cause decreases in sugarcane yield and vice versa. Koondhar et al. (2021) and Alhassan (2021)found the same results for China and Sub-Saharan Africa, respectively.

Dogan (2016), while examining the long run association between CO_2 emissions and agriculture, found a significant negative relationship between the two variables. Increases in agricultural production are associated with a decrease in CO_2 emissions both in the short and the long run. These results proved the EKC to be valid for Turkey between 1968 and 2010, with 70% speed of adjustment. The negative impact of CO_2 emissions on both the short run (SR) and long run (LR) in South Africa could be due to increased greenhouse gas concentrations leading to climate change, resulting in adverse effects on agricultural productivity, water availability, and ecosystem health. Additionally, high levels of CO_2 emissions can contribute to air pollution, causing respiratory and other health issues, which can ultimately impact overall economic and social well-being.

5.4 Summary

This chapter presented the descriptive and empirical results of the study. The variables in the model were tested for stationarity. The ARDL model was chosen and performed for this study. The F-bounds test was used to analyze whether there was a cointegration relationship between sugarcane yield and a series of other variables. The results were compared with those for FMOLS, DOLS, and CCR. The model was tested for diagnostics, i.e., normality in the residuals, serial correlation, and heteroskedasticity. Sensitivity was observed using CUSUM and CUSUM plots. Granger-causality tests were then performed to check whether there were any causal relationships in the model and the direction of the causality.

A significant long run negative relationship between temperature & sugarcane yield, and carbon dioxide emissions & sugarcane yield was found in this study. Rainfall, renewable energy consumption(including lags 2 and 3), GDP, and carbon dioxide (1-3lags) were all found to significantly impact sugarcane yield positively. Temperature, GDP, CO2, and population growth were all insignificant in explaining sugarcane yield changes in the short run. Unidirectional causality was found going from rainfall to sugarcane yield, rainfall to renewable energy consumption, carbon dioxide emissions to temperature, GDP to renewable energy consumption, and rainfall to renewable energy consumption. Bidirectional causality was found between temperature and renewable energy consumption, carbon dioxide emissions and renewable energy consumption, and rainfall and population growth.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Recapping the purpose of the research

Climate change has been and continues to be a serious issue worldwide. The effects such as floods, droughts, and heatwaves largely impact smallholder farmers, and sugarcane farmers in South Africa have not been immune to them. The industry not only faces such impacts but also, the recently imposed sugar tax, which calls for alternative uses of sugarcane that could still generate income and assist in the current energy crisis. Sugarcane is one of the crops that can solve the energy problem through bioenergy production. The interest was therefore on how climate change and other variables such as renewable energy consumption, carbon dioxide emissions, economic growth measured by GDP, and population growth affect sugarcane productivity. This study measured sugarcane productivity using sugarcane yield, and temperature & rainfall were used as proxies for climate change.

Irrespective of investments that the country has made thus far on alternative options for coal-generated electricity or on renewable energy production initiatives, the country remains energy-short, and load-shedding is still an issue. Such investments have been made on solar, wind and hydro-generated electricity but rarely in bioenergy production (i.e. energy from crops and livestock). This means that the agricultural industry has not been active in providing solutions to the country's energy shortages. Based on this background and the identification of sugarcane as an energy crop that could potentially provide an alternative energy source, this study needed to be carried out.

The purpose of this study was therefore to assess the impact of energy and climate change on sugarcane production in the past 50 years. The study did this through the following specific objectives:

I. To analyse sugarcane production trends from 1972-2021 period.
II. To determine the short run and possible long run relationships between sugarcane yield, temperature, rainfall, renewable energy consumption, GDP, carbon dioxide emissions from energy and population growth.
III. To identify causality between sugarcane production and macroeconomic variables.

The study utilized the ARDL model to examine if there were any short-run and possible long-run relationships between sugarcane yield and the explanatory variables mentioned above.

6.2 Conclusions

6.2.1 Sugarcane production trends from the 1972-2021 period

The pattern indicates a decrease in productivity despite an increase in crop output, most likely caused by the deterioration of resources, misuse of inputs, limited adoption of technology, and environmental issues. To tackle these problems, it is necessary to implement sustainable practices, foster technical innovation, and provide supporting policies that guarantee the long-term sustainability of agriculture.

6.2.1 Short-run and possible long-run relationships between sugarcane yield and variables of interest

Findings indicated a strong negative correlation between temperature, carbon dioxide emissions, and sugarcane yield in the long run, it seems that higher temperatures and more carbon dioxide emissions decrease sugarcane output. This result shows how climate change and greenhouse gas production might affect the amount of food that can be grown.

The fact that rainfall, green energy use, GDP, and carbon dioxide lags have positive effects on sugarcane yield in the long run shows that these variables help to raise sugarcane output. Higher sugarcane production is linked to getting enough rain, using green energy, having a strong economy, and having released carbon dioxide in the past. Temperature, GDP, carbon dioxide, and population growth don't seem to have much of an effect on short-term changes in sugarcane output. This suggests that these factors may not have an instant or direct effect on changes in sugarcane production. There are other things or longer time frames that might have a bigger effect on short-term changes in return. The fact that population growth doesn't explain changes in sugarcane yield means that it doesn't have a direct effect on sugarcane production in the model that was looked at. There may be better links between other things and changes in yield.

Overall, these results show that climate, energy use, economic measures, and past carbon dioxide emissions are some of the most important factors that affect sugarcane growth. The results show how important it is to think about these things when controlling and evaluating sugarcane production, especially when it comes to climate change and environmentally friendly farming methods.

6.2.3 Causality between sugarcane production and variables of interest

The found causal linkages offer valuable insights into the direction of impact among variables. For instance, the one-way relationship where rainfall affects sugarcane production indicates that changes in rainfall impact the productivity of sugarcane. Likewise, there is a two-way link between temperature and renewable energy consumption, carbon dioxide emissions and renewable energy consumption, and rainfall and population increase, indicating that these factors affect each other in a reciprocal manner.

6.3 Recommendations

Based on the study conclusions drawn from the results, the study recommends the following:

6.3.1 Sugarcane production trends from the 1972-2021 period

The findings revealed a positive correlation between output (volumes [produced) and land allocation, and a negative correlation between productivity (yield) and land allocation. Consolidating fragmented land parcels for sugarcane cultivation is advisable to achieve economies of scale and improve productivity. Encouragement is given to the facilitation of land redistribution programmes that seeks to allot land to smallholder farmers and marginalised groups. Establish and guarantee farmers' solid land tenure rights to encourage their long-term investments in land enhancement and agricultural cultivation. Well-defined land tenure regimes instil farmers with assurance to invest in sustainable land management methods. To promote production in remote locations, it is advisable to allocate resources towards the development of rural infrastructure, including roads, irrigation systems, and storage facilities, which would improve access to agricultural land.

Facilitation of farmers' access to agricultural research, extension services, and technology transfer to implement optimal methods for enhancing crop yields and land productivity is also recommended. It is also important to enhance market entry opportunities for small-scale farmers by enhancing transportation infrastructure, implementing market intelligence systems, and promoting efforts for the development of value chains. This allows farmers to gain revenue from their crops and encourages increased production of the land. Promote the use of climate-smart agricultural techniques, such as cultivating drought-resistant crops, utilising water-saving technology, and adopting agroecological methods, to reduce the negative effects of climate change on crop yields and land resources. Additionally, offer training and capacity-building initiatives to farmers on sustainable land management, soil conservation, and crop production practices, with the aim of enhancing land productivity in the long run.

6.2.2 Short run and possible long run relationships between sugarcane yield and variables of interest

a) *Climate Change Mitigation: reducing carbon emissions*

Given the significant negative relationship between carbon dioxide emissions and sugarcane yield, stakeholders should prioritize reducing carbon dioxide emissions. This can be achieved through implementing cleaner energy sources and adopting sustainable practices in industries and transportation.

b) *Promote renewable energy consumption*

The positive impact of renewable energy consumption on sugarcane yield suggests that stakeholders should encourage the use of renewable energy sources. This can be done by promoting investments in renewable energy infrastructure, offering incentives for renewable energy projects, and implementing policies that support renewable energy adoption.

c) *Water Management: Improve water availability*

Since rainfall has a significant positive impact on sugarcane yield, stakeholders should focus on improving water availability through effective water management practices. This may include investing in irrigation systems, promoting water conservation techniques, and implementing policies that ensure equitable water distribution.

d) *Economic Development: Foster GDP growth*

The positive relationship between GDP and sugarcane yield implies that stakeholders should prioritize economic development to support the sugarcane industry. This can be achieved by implementing policies that promote investment, innovation, and entrepreneurship, as well as providing support to small-scale farmers.

e) *Long-term Planning: accounts for lag effects*

The findings suggest that lagged values of renewable energy consumption, rainfall, and carbon dioxide emissions have a significant impact on sugarcane yield. Stakeholders should consider these lag effects in their planning processes to ensure effective decision-making and resource allocation.

f) *Population Growth: Monitor population growth*

Although population growth was found to be insignificant in explaining sugarcane yield changes, stakeholders should still monitor population trends as they can have indirect effects on the industry. Population growth may lead to increased demand for agricultural products and put pressure on resources, such as water and land. By monitoring population growth, stakeholders can anticipate and plan for potential challenges and opportunities.

6.2.3 Causality between sugarcane production and macroeconomic variables

Stakeholders should take into account the identified causality relationships among variables. For instance, the unidirectional causality from rainfall to sugarcane yield and renewable energy consumption suggests that improving water availability can positively impact sugarcane yield and renewable energy consumption. Understanding these causal relationships can inform policy and investment decisions.

Overall, these recommendations highlight the importance of addressing climate change, promoting sustainable practices, improving water management, fostering economic development, and considering long-term planning in order to bring about positive change in the South African sugarcane industry. Robust programmes that can be driven include:

a) *Renewable Energy Incentive Programs (DEMR)*

   Implement financial incentives, such as tax breaks or subsidies, for individuals, businesses, and industries to invest in renewable energy technologies. This can help make renewable energy more economically viable and encourage its adoption.

b) *Capacity Building and Training (AGRI-SETA)*

   Establish training programs and workshops to educate local communities, engineers, technicians, and policymakers about renewable energy technologies. This can help build a skilled workforce capable of designing, installing, and maintaining renewable energy systems.

c) *Research and Development (CSIR, ARC, Academia)*

   Invest in research and development initiatives focused on renewable energy technologies specific to the country's resources and needs. This can include studying the feasibility of different renewable energy sources, developing innovative technologies, and improving the efficiency and affordability of existing renewable energy systems.

d) *Public-Private Partnerships (SA Government and Private entities)*

Foster collaborations between the government, private sector, and research institutions to accelerate the development and deployment of renewable energy projects. This can involve joint ventures, knowledge sharing, and resource pooling to overcome barriers and promote sustainable energy solutions.

e) *Regulatory Framework (SA Government)*

Establish clear and supportive policies and regulations that facilitate the integration of renewable energy into the country's energy mix. This may include setting renewable energy targets, streamlining permitting processes, and implementing feed-in tariffs or power purchase agreements to incentivize renewable energy producers.

f) *Rural Electrification (SA Government, communities, industry associations, private sector, NGOs)*

Prioritize rural electrification using renewable energy sources. Implement off-grid and mini-grid systems to provide electricity to remote communities that are not connected to the main grid. This can improve access to clean energy and contribute to socio-economic development in rural areas.

g) *Public Awareness and Education (DOE, Media, NGOs)*

Launch public awareness campaigns to inform citizens about the benefits of renewable energy and the importance of transitioning to sustainable energy sources. Educate the public about energy conservation practices and encourage behavioural changes to reduce energy consumption.

h) *International Cooperation (the DTI, Government entities like TIKZN, Trade partners, Academia)*

Seek partnerships and collaborations with international organizations and other countries with advanced renewable energy sectors. This can facilitate knowledge sharing, technology transfer, and financial support to accelerate the country's renewable energy development.

These programs can help create an enabling environment for the growth of renewable energy in a country where it is still in its early stages.

By combining financial incentives, capacity building, research and development, supportive policies, and public awareness, stakeholders can work towards a sustainable and clean energy future.

6.4 Recommendations for further research

Future research initiatives may further seek to assess the impact of other factors such as technological advancement and trade on sugarcane production. The focus may also be on quantifying the potential of bioenergy production given the resources that the country currently has. This can either be done at a commercial or small-scale level. More bioenergy crops may be explored for their potential as well, such as maize, sunflower, soyabean and other non-food plants like Algae. Of course, this should consider food security concerns. The country needs to invest in research and development as much as possible, to realise the full potential that it has and help provide alternative sources of energy. Priority, in this regard, should be given to the agricultural sector and its contribution. This will likely have a positive impact in the economy of South Africa, and agriculture can contribute to revenue generation for the country in other ways.

REFERENCES

Abbas, S., 2022. Climate change and major crop production: evidence from Pakistan. *Environmental Science and Pollution Research*, 29(4), pp.5406-5414. https://doi.org/10.1007/s11356-021-16041-4

Abbasi, K.R., Adedoyin, F.F., Abbas, J. and Hussain, K., 2021. The impact of energy depletion and renewable energy on CO2 emissions in Thailand: fresh evidence from the novel dynamic ARDL simulation. *Renewable Energy*, *180*, pp.1439-1450. https://doi.org/10.1016/j.renene.2021.08.078

Abbasi, K.R., Shahbaz, M., Zhang, J., Irfan, M. and Alvarado, R., 2022. Analyze the environmental sustainability factors of China: The role of fossil fuel energy and renewable energy. *Renewable Energy*, 187, pp.390-402 https://doi.org/10.1016/j.renene.2022.01.066

Acaroğlu, H. and Güllü, M., 2022. Climate change caused by renewable and non-renewable energy consumption and economic growth: A time series ARDL analysis for Turkey. *Renewable Energy*, 193, pp.434-447. https://doi.org/10.1016/j.renene.2022.04.138

Adu, D.T. and Denkyirah, E.K., 2019. Economic growth and environmental pollution in West Africa: Testing the Environmental Kuznets Curve hypothesis. *Kasetsart Journal of Social Sciences*, 40(2), pp.281-288. https://doi.org/10.1016/j.kjss.2017.12.008

Affoh, R., Zheng, H., Dangui, K. and Dissani, B.M., 2022. The impact of climate variability and change on food security in sub-saharan africa: Perspective from panel data analysis. *Sustainability*, 14(2), p.759. https://doi.org/10.3390/su14020759

Ahmad, M., Shuai, J. and Ali, H., 2023. The effects of climate change on food production in India: evidence from the ARDL model. *Environment, Development and Sustainability*, pp.1-19. DOI: https://doi.org/10.1007/s10668-023-03209-w

Ahmed, A. ed., 2019. *Making Science, Innovation and Research Work for the Sustainable Development Goals*. World Association for Sustainable Development (WASD). Making Science, Innovation And Research Work For The Sustainable Development ... - Google Books

Ahmed, M., Shuai, J. and Ali, H., 2023. The effects of climate change on food production in India: evidence from the ARDL model. *Environment, Development and Sustainability*, pp.1-19.https://link.springer.com/article/10.1007/s10668-023-03209-w

Alam, K.M., Li, X., Baig, S., Ghanem, O. and Hanif, S., 2021. Causality between transportation infrastructure and economic development in Pakistan: An ARDL analysis. *Research in Transportation Economics*, *88*, p.100974. https://doi.org/10.1016/j.retrec.2020.100974

Alam, R. and Adil, M.H., 2019. Validating the environmental Kuznets curve in India: ARDL bounds testing framework. *OPEC Energy Review*, *43*(3), pp.277-300. https://doi.org/10.1111/opec.12156

Alamanda, A., 2021. The effect of economic growth on income inequality: Panel data analysis from fifty countries. *Info Artha*, *5*(1), pp.1-10. https://doi.org/10.31092/jia.v5i1.1176

Alhassan, H., 2021. The effect of agricultural total factor productivity on environmental degradation in sub-Saharan Africa. *Scientific African*, 12, p.e00740. https://doi.org/10.1016/j.sciaf.2021.e00740

Ali, A., Usman, M., Usman, O. and Sarkodie, S.A., 2021. Modeling the effects of agricultural innovation and biocapacity on carbon dioxide emissions in an agrarian-based economy: evidence from the dynamic ARDL simulations. *Frontiers in Energy Research*, 8, p.592061. https://doi.org/10.3389/fenrg.2020.592061

Ali, A.A., Ali, A.Y.S. and Dalmar, M.S., 2018. The impact of imports and exports performance on the economic growth of Somalia. *International journal of economics and Finance*, *10*(1), pp.110-119. https://doi.org/10.5539/ijef.v10n1p110

Aliyu, A.K., Modu, B. and Tan, C.W., 2018. A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, *81*, pp.2502-2518.https://doi.org/10.1016/j.rser.2017.06.055 .

Amin, M., Shah, H.H., Fareed, A.G., Khan, W.U., Chung, E., Zia, A., Farooqi, Z.U.R. and Lee, C., 2022. Hydrogen production through renewable and non-renewable energy processes and their impact on climate change. *International journal of hydrogen energy*, *47*(77), pp.33112-33134. https://doi.org/10.1016/j.ijhydene.2022.07.172.

An, J. and Mikhaylov, A., 2020. Russian energy projects in South Africa. *Journal of Energy in Southern Africa*, *31*(3), pp.58-64. https://hdl.handle.net/10520/ejc-jesa-v31-n3-a4

Anderson, K., 2023. What Was the Industrial Revolution's Environmental Impact? Greenly Earth. https://greenly.earth/en-gb/blog/ecology-news/what-was-the-industrial-revolutions-environmental-impact. Accessed-25 January 2023.

Ankomah, E.K., 2020. A comparison of population growth rate and the rate of increase in food crop production in Africa. In *Handbook of Research on Sustainable Supply Chain Management for the Global Economy* (pp. 260-280). IGI Global. DOI: 10.4018/978-1-7998-4601-7.ch014.

Appiah, K., Du, J. and Poku, J., 2018. Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. *Environmental Science and Pollution Research*, *25*, pp.24764-24777. https://doi.org/10.1007/s11356-018-2523-z

Archer, E.R.M., Landman, W.A., Tadross, M.A., Malherbe, J., Weepener, H., Maluleke, P. and Marumbwa, F.M., 2017. Understanding the evolution of the 2014–2016 summer rainfall seasons in southern Africa: Key lessons. *Climate Risk Management*, *16*, pp.22-28. https://doi.org/10.1016/j.crm.2017.03.006.

Arnaut, J. and Lidman, J., 2021. Environmental sustainability and economic growth in Greenland: testing the environmental Kuznets curve. *Sustainability*, *13*(3), p.1228. https://doi.org/10.3390/su13031228

Asfew, M. and Bedemo, A., 2022. Impact of climate change on cereal crops production in Ethiopia. *Advances in Agriculture*, 2022, pp.1-8. https://doi.org/10.1155/2022/2208694

Assefa, S., Kessler, A. and Fleskens, L., 2018. Assessing farmers' willingness to participate in campaign-based watershed management: experiences from Boset district, Ethiopia. *Sustainability*, *10*(12), p.4460. https://doi.org/10.3390/su10124460

Baker, L., 2022. *The Political Economy of South Africa's Carbon Tax*. Institute of Development Studies.DOI: 10.19088/ICTD.2022.017.

Banjare, J. and Bhalerao, S., 2016. Obesity associated noncommunicable disease burden. *International Journal of Health & Allied Sciences*, *5*(2), pp.81-81. Obesity associated noncommunicable disease burden - Document - Gale Academic OneFile

Basheer, M., Nechifor, V., Calzadilla, A., Ringler, C., Hulme, D. and Harou, J.J., 2022. Balancing national economic policy outcomes for sustainable development. *Nature Communications*, *13*(1), p.5041. https://doi.org/10.1038/s41467-022-32415-9

Bordonal, R.D.O., Carvalho, J.L.N., Lal, R., de Figueiredo, E.B., de Oliveira, B.G. and La Scala, N., 2018. Sustainability of sugarcane production in Brazil. A review. *Agronomy for Sustainable Development*, *38*, pp.1-23. https://doi.org/10.1007/s13593-018-0490-x

Botai, C.M., Botai, J.O. and Adeola, A.M., 2018. Spatial distribution of temporal precipitation contrasts in South Africa. *South African Journal of Science*, *114*(7-8), pp.70-78. http://dx.doi.org/10.17159/sajs.2018/20170391

BP Statistics, 2022. Data on renewable energy and CO2 emission from energy. Data Catalog | Climate Change Knowledge Portal (worldbank.org). Accessed-November 2022.

Cardoso, T.F., Watanabe, M.D., Souza, A., Chagas, M.F., Cavalett, O., Morais, E.R., Nogueira, L.A., Leal, M.R.L., Braunbeck, O.A., Cortez, L.A. and Bonomi, A., 2018. Economic, environmental, and social impacts of different sugarcane production systems. *Biofuels, Bioproducts and Biorefining*, *12*(1), pp.68-82. https://doi.org/10.1016/j.rser.2020.110518

Ceesay, E.K., Francis, P.C., Jawneh, S., Njie, M., Belford, C. and Fanneh, M.M., 2022. Climate change, growth in agriculture value added, food availability and economic growth nexus in the Gambia: a Granger causality and ARDL modeling approach. In *Food Security and Safety Volume 2: African Perspectives* (pp. 435-468). Cham: Springer International Publishing. DOI: 10.1007/978-3-031-09614-3_20

Central Intelligence Agency, 2023. The World Fact Book: Population Growth Rate. Population growth rate - The World Factbook (cia.gov).

Chandio, A.A., Gokmenoglu, K.K. and Ahmad, F., 2021. Addressing the long-and short run effects of climate change on major food crops production in Turkey. Environmental Science and Pollution Research, 28(37), pp.51657-51673. *Science and Pollution Research*, 27, pp.11944-11957. DOI: 10.1007/s11356-020-07739-y

Chandio, A.A., Jiang, Y., Fatima, T., Ahmad, F., Ahmad, M. and Li, J., 2022a. Assessing the impacts of climate change on cereal production in Bangladesh: evidence from ARDL modeling approach. *International Journal of Climate Change Strategies and Management*, *14*(2), pp.125-147. DOI: 10.1108/IJCCSM-10-2020-0111

Chandio, A.A., Jiang, Y., Rehman, A. and Rauf, A., 2020a. Short and long run impacts of climate change on agriculture: an empirical evidence from China. *International Journal of Climate Change Strategies and Management*, 12(2), pp.201-221. https://www.emerald.com/insight/content/doi/10.1108/IJCCSM-05-2019-0026/full/html.

Chandio, A.A., Ozturk, I., Akram, W., Ahmad, F. and Mirani, A.A., 2020b. Empirical analysis of climate change factors affecting cereal yield: evidence from Turkey. *Environmental Science and Pollution Research*, *27*, pp.11944-11957. https://link.springer.com/article/10.1007/s11356-020-07739-y.

Chandio, A.A., Shah, M.I., Sethi, N. and Mushtaq, Z., 2022b. Assessing the effect of climate change and financial development on agricultural production in ASEAN-4: the role of renewable energy, institutional quality, and human capital as moderators. *Environmental Science and Pollution Research*, pp.1-15. DOI: 10.1007/s11356-021-16670-9

Chen, X., Huang, B. and Lin, C.T., 2019. Environmental awareness and environmental Kuznets curve. *Economic Modelling*, *77*, pp.2-11. https://doi.org/10.1016/j.econmod.2019.02.003

Chen, X., Wang, Q., Cui, B., Chen, G., Xie, T. and Yang, W., 2023. Ecological time lags in biodiversity response to habitat changes. *Journal of Environmental Management*, *346*, p.118965. https://doi.org/10.1016/j.jenvman.2023.118965.

Chien, F., Kamran, H.W., Albashar, G. and Iqbal, W., 2021. Dynamic planning, conversion, and management strategy of different renewable energy sources: a sustainable solution for severe energy crises in emerging economies. *International Journal of Hydrogen Energy*, *46*(11), pp.7745-7758. https://doi.org/10.1016/j.ijhydene.2020.12.004

Child, K.P., 2004. Raising cane: small grower contract production in the South African sugar industry. Item – Theses Canada

Chopra, R., Magazzino, C., Shah, M.I., Sharma, G.D., Rao, A. and Shahzaaffect agriculture productivity?. Resources Policy, 76, p.102578. https://doi.org/10.1016/j.resourpol.2022.102578

Climate Action Tracker (CAT), 2023. South Africa's Climate Action. Policies & action | Climate Action Tracker. Accessed-04 December 2023.

Climate Change Knowledge Portal, 2021. South Africa: Climatology. South Africa - Climatology | Climate Change Knowledge Portal (worldbank.org). Accessed-27 July 2023.

Climate Watch, 2023. Has South Africa enhanced its NDC compared to the previous submission? https://www.climatewatchdata.org/countries/ZAF?end_year=2020&start_year=1990. Accessed-15 November 2023.

CNN, 2023. South Africa's energy crisis poses 'existential threat' to its economy. https://edition.cnn.com/2023/02/10/economy/south-africa-economy-energy-crisis-president/index.html. Accessed-15 April 2023.

CNN, 2024. As climate chaos accelerates, which countries are polluting the most? Which countries are contributing the most to climate change? (cnn.com). Accessed-28 January 2024.

Coelho S. and Goldermberg J., 2019. Sustainability and Environmental Impacts of Sugarcane Biofuels. DOI:10.1007/978-3-030-18597-8_18.

Department of Environment, Forestry, and Fisheries. (2021). South Africa's third national communication and first biennial update report to the United Nations framework convention on climate change. https://www.environment.gov.za/sites/default/files/docs/south_africas_3rd_national_communication_bur1_unfccc.pdf . Accessed-10 April 2023.

de Matos, M., Santos, F. and Eichler, P., 2020. Sugarcane world scenario. In *Sugarcane biorefinery, technology and perspectives* (pp. 1-19). Academic Press. https://doi.org/10.1016/B978-0-12-814236-3.00001-9.

DeCarlo, L.T., 1997. On the meaning and use of kurtosis. *Psychological methods*, *2*(3), p.292. https://doi.org/10.1037/1082-989X.2.3.292

Dilanchiev, A., Nuta, F., Khan, I. and Khan, H., 2023. Urbanization, renewable energy production, and carbon dioxide emission in BSEC member states: implications for climate change mitigation and energy markets. *Environmental Science and Pollution Research*, pp.1-13. https://doi.org/10.1007/s11356-023-27221-9

Dogan, N., 2016. Agriculture and Environmental Kuznets Curves in the case of Turkey: evidence from the ARDL and bounds test. *Agricultural Economics/Zemedelska Ekonomika*, *62*(12). https://agricecon.agriculturejournals.cz/pdfs/age/2016/12/06.pdf

Dong, J., He, J., Li, X., Mou, X. and Dong, Z., 2020. The Effect of Industrial Structure Change on Carbon Dioxide Emissions: A Cross-Country Panel Analysis. Journal of Systems Science and Information, Vol. 8 (Issue 1), pp. 1-16. https://doi.org/10.21078/JSSI-2020-001-16

Donner, L.J. and Large, W.G., 2008. Climate modeling. *Annual Review of Environment and Resources*, *33*, pp.1-17 https://www.annualreviews.org/doi/full/10.1146/annurev.environ.33.020707.160752 .

Doss, C.R., 2018. Women and agricultural productivity: Reframing the Issues. *Development policy review*, *36*(1), pp.35-50. https://doi.org/10.1111/dpr.12243

Du Bois, D.L., 2015. *Sugar and Settlers: A history of the Natal South Coast, 1850-1910*. UJ Press.

Dubb, S., 2016. Community wealth building forms: What they are and how to use them at the local level. *Academy of Management Perspectives*, *30*(2), pp.141-152. https://doi.org/10.1111/joac.12107

Dube, L.T. and Jury, M.R., 2000. The nature of climate variability and impacts of drought over KwaZulu-Natal, South Africa. *South African Geographical Journal*, *82*(2), pp.44-53. https://doi.org/10.1080/03736245.2000.9713692

DW, 2022. South Africa reels from floods. South Africa reels from floods – DW – 04/20/2022. Accessed-10 November 2023.

Ehrlich, R., Geller, H.A. and Cressman, J.R., 2022. *Renewable energy: a first course*. CRC press. https://doi.org/10.1201/9781003172673T.

Energy Information Administration, 2016.Energy-related CO2 emissions. Chapter 9 - Energy-related CO2 emission (eia.gov)

Epaphra, M., 2018. The impact of macroeconomic variables on stock prices in Tanzania. *Journal of Economics Library*, *5*(1), pp.12-41. The impact of macroeconomic variables on stock prices in Tanzania | EPAPHRA | Journal of Economics Library (kspjournals.org)

Espoir, D.K. and Sunge, R., 2021. Co2 emissions and economic development in Africa: Evidence from a dynamic spatial panel model. *Journal of Environmental Management*, *300*, p.113617. https://doi.org/10.1016/j.renene.2022.05.065

Evenson, R., 1976. International transmission of technology in the production of sugarcane. *The Journal of Development Studies*, *12*(2), pp.208-231.https://doi.org/10.1080/00220387608421569

FAO, 2021a. Climate change and food systems: Global assessments and implications for food security and trade, Food and Agriculture Organization of the United Nations. http://www.fao.org/3/cb4478en/cb4478en.pdf. Accessed-30 April 2023.

FAO, 2021b. 'Sugarcane', Food and Agriculture Organization of the United Nations. http://www.fao.org/sugarcane/en/. Accessed-30 April 2023.

Food and Agriculture Organization (FAO), 2023. Sugarcane yield data. https://www.fao.org/faostat/en/#data/QCL . Accessed-10 May 2023.

Food and Agriculture Organization (FAO), 2020. Climate Change and Food Safety Impacts. Climate change and food safety impacts (fao.org). Accessed-12 April 2023.

Farmer's Weekly, 2023. Sugar tax the main threat to the industry in 2023. Sugar tax the main threat to the industry in 2023 (farmersweekly.co.za). Accessed-24 January 2023.

Fawzy, S., Osman, A.I., Doran, J. and Rooney, D.W., 2020. Strategies for mitigation of climate change: a review. Environmental Chemistry Letters, 18, pp.2069-2094. https://link.springer.com/article/10.1007/s10311-020-01059-w

Food and Agriculture Organization of the United Nations (FAO), 2023. Land used for sugarcane farming in South Africa. https://www.fao.org/faostat/en/#data/QCL. Accessed-20 January 2024.

Food and Agriculture Organization Statistics, 2021. World Sugarcane Production by Country. World Sugarcane Production by Country - AtlasBig.com. Accessed-04 January 2024.

Future Growth Insights, 2021. https://www.futuregrowth.co.za/insights/sa-s-agriculture sector-a-key-driver-of-economic-growth/#:~:text=1.,in%20volumes%20and%20crop%20prices. Accessed- 27 April 2023.

Galloway, J.H., 2005. *The sugar cane industry: an historical geography from its origins to 1914* (Vol. 12). Cambridge University Press. ISBN 10: 0521022193 ISBN 13: 9780521022194.

Global Climate & Health Aliance, 2023. Healthy NDCs Scorecard: South Africa Leads Big Emitters on Climate-Health Action Ahead of COP26. https://climateandhealthalliance.org/press-releases/healthy-ndcs-scorecard-south-africa-leads-big-emitters-on-climate-health-action-ahead-of-cop26/. Accessed-24 January 2024.

Godfray, H.C.J., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Nisbett, N., Pretty, J., Robinson, S., Toulmin, C. and Whiteley, R., 2010. The future of the global food system. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), pp.2769-2777. https://doi.org/10.1098/rstb.2010.0180.

Goh, S.K., Sam, C.Y. and McNown, R., 2017. Re-examining foreign direct investment, exports, and economic growth in Asian economies using a bootstrap ARDL test for cointegration. *Journal of Asian Economics*, *51*, pp.12-22. https://doi.org/10.1016/j.asieco.2017.06.001

Gokmen, O., 2021. The relationship between foreign direct investment and economic growth: A case of Turkey. *arXiv preprint arXiv:2106.08144*. https://doi.org/10.48550/arXiv.2106.08144.

Gokmenoglu, K.K. and Sadeghieh, M., 2019. Financial development, CO2 emissions, fossil fuel consumption and economic growth: the case of Turkey. Strategic Planning for Energy and the Environment, 38(4), pp.7-28. https://doi.org/10.1080/10485236.2019.12054409

Goldar, B., Das, D.K., Das, P.C. and Gupta, N., 2020. Domestic versus imported contents in exports: the case of India’s merchandise trade. *Journal of South Asian Development*, *15*(1), pp.62-96. https://doi.org/10.1177/0973174120922451.

Gonçalves, F., Perna, R., Lopes, E., Maciel, R., Tovar, L. and Lopes, M., 2021. Strategies to improve the environmental efficiency and the profitability of sugarcane mills. *Biomass and Bioenergy*, *148*, p.106052. https://doi.org/10.1016/j.biombioe.2021.106052.

Gordon Institute of Business Science (GIBS), 2023. South Africa's Energy Crisis – Is 2023 the year of long-lasting solutions, or empty promises? South Africa's Energy Crisis – Is 2023 the year of long-lasting solutions, or empty promises? | GIBS. Accessed-15 April 2023.

Gouvêa, AF, Barbosa, RG, Beltrão, NEM, Gomes, LGL, Cruz, H, Souza, MD & Oliboni, B 2021, 'Sugarcane as a bioenergy crop', in Plant Biotechnology and Agriculture, Academic Press, pp. 237-259. DOI: 10.1007/978-3-030-18597-8_1

Government Gazette, 1978. Sugar Act 9 of 1978. Publication No.: 5907. Sugar Act 9 of 1978 | South African Government (www.gov.za). Accessed-12 January 2024.

Government Gazette, 1984. Publication No.: 9085. Sugar Amendment Act (www.gov.za). Accessed-12 January 2024.

Government Gazette, 1987. Publication No.: 10942. Sugar Amendment Act (www.gov.za). Accessed-12 January 2024.

Government Gazette, 1992. Publication No.: 14029. Sugar Amendment Act 71 of 1992 (www.gov.za). Accessed-12 January 2024.

Government Gazette, 2019. Publication No.: 42483. Carbon Tax Act 15 of 2019 (www.gov.za). Accessed- 8 November 2023.

Greenberg, S., Thow, A.M. and Hara, M., 2017. Trade, food and nutrition security in South Africa: The cases of sugar and poultry.

GroundUp, 2021. South Africa's carbon emission targets not nearly ambitious enough. South Africa's carbon emission targets not nearly ambitious enough | GroundUp. Accessed-30 July 2023.

Greenwood-Nimmo, M., Cho, J. and Shin, Y., 2021. Recent Developments of the Autoregressive Distributed Lag Modelling Framework. Journal of Economic Surveys. ISSN 0950-0804 https://doi.org/10.1111/joes.12450.

Gul, A., Xiumin, W., Chandio, A.A., Rehman, A., Siyal, S.A. and Asare, I., 2022. Tracking the effect of climatic and non-climatic elements on rice production in Pakistan using the ARDL approach. *Environmental Science and Pollution Research*, pp.1-15. DOI: 10.1007/s11356-022-18541-3

Guntukula, R., 2020. Assessing the impact of climate change on Indian agriculture: Evidence from major crop yields. *Journal of Public Affairs*, 20(1), p.e2040. https://doi.org/10.1002/pa.2040

Hochstetler, K., 2020. *Political economies of energy transition: wind and solar power in Brazil and South Africa*. Cambridge University Press.

Horstkötter, D. and de Wert, G., 2020. *Ethical considerations* (pp. 145-159). Springer International Publishing. Ethical Considerations | SpringerLink

Husnain, M.I.U., Subramanian, A. and Haider, A., 2018. Robustness of geography as an instrument to assess impact of climate change on agriculture. *International journal of climate change strategies and management*, *10*(5), pp.654-669. DOI 10.1108/IJCCSM-03-2017-0049

Hussain, I. and Rehman, A., 2021. Exploring the dynamic interaction of CO2 emission on population growth, foreign investment, and renewable energy by employing ARDL bounds testing approach. *Environmental Science and Pollution Research*, 28, pp.39387-39397. https://link.springer.com/article/10.1007/s11356-021-13502-8

Hussain, S., Khaliq, A., Mehmood, U., Qadir, T., Saqib, M., Iqbal, M.A. and Hussain, S., 2018. Sugarcane production under changing climate: Effects of environmental vulnerabilities on sugarcane diseases, insects and weeds. Climate Change and Agriculture, pp.1-17.

ICLG, 2023. Renewable Energy Laws and Regulations South Africa. Renewable Energy Laws and Regulations Report 2024 South Africa (iclg.com). Accessed- 09 December 2023.

International Monetary Fund, 2010. What Caused the Global Financial Crisis? — Evidence on the Drivers of Financial Imbalances 1999–2007 https://www.imf.org/external/pubs/ft/wp/2010/wp10265.pdf. Accessed-09 January 2024.

International Renewable Energy Agency, 2019. Sugarcane bioenergy in Southern Africa: Economic potential for sustainable scale-up. Sugarcane bioenergy in Southern Africa Economic potential for sustainable scale-up (irena.org). Accessed 30 April 2023.

International Renewable Energy Agency (IRENA), 2021. The Renewable Energy Transition in Africa.The Renewable Energy Transition in Africa (irena.org). Accessed-16 August 2023.

International Trade Centre (ITC), 2022a. Trade statistics for international business statistics. List of importing markets for a product exported by South Africa in 2022 | Product: 121293 Sugar cane, fresh, chilled, frozen or dried, whether or not ground (trademap.org). Accessed-21 January 2024.

International Trade Centre (ITC), 2022b. Trade statistics for international business statistics. List of supplying markets for a product imported by South Africa in 2022 | Product: 121293 Sugar cane, fresh, chilled, frozen or dried, whether or not ground (trademap.org)

Intergovernmental Panel on Climate Change (IPCC), 2018. Global Warming of 1.5°C. SR15_SPM_version_stand_alone_LR.pdf (ipcc.ch). Accessed-12 April 2023.

Intergovernmental Panel on Climate Change (IPCC), 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/report/ar6/wg2/. Accessed-12 April 2023.

Jayne, T.S., Chamberlin, J. and Benfica, R., 2018. Africa's unfolding economic transformation. *The Journal of Development Studies*, *54*(5), pp.777-787. https://doi.org/10.1080/00220388.2018.1430774

Jean-Paul, F. and Martine, D., 2018. Beyond GDP: measuring what counts for economic and social performance. OECD Publishing. https://doi.org/10.1787/9789264307292-en.

Jena, P.K., 2021. Nexus between Climate Change and Agricultural Production in Odisha, India: An ARDL Approach. *Int. J. Environ. Agric. Biotechnol*, *6*, pp.136-144. https://dx.doi.org/10.22161/ijeab.62.15.

Jones, M.R. and Singels, A., 2018. Refining the Canegro model for improved simulation of climate change impacts on sugarcane. *European Journal of Agronomy*, *100*, pp.76-86. https://doi.org/10.1016/j.eja.2017.12.009.

Johnsson, F., Kjärstad, J. and Rootzén, J., 2019. The threat to climate change mitigation posed by the abundance of fossil fuels. *Climate Policy*, *19*(2), pp.258-274. https://doi.org/10.1080/14693062.2018.1483885.

Jun, Z., Franca, U.A. and Iwuozor, K.O., 2023. Relationship Between Agricultural Production, Energy Consumption, and Climate Change in Nigeria. In Climate Change Impacts on Nigeria: *Environment and Sustainable Development* (pp. 563-580). Cham: Springer International Publishing. https://link.springer.com/chapter/10.1007/978-3-031-21007-5_27.

Kahia, M., Ben Jebli, M. and Belloumi, M., 2019. Analysis of the impact of renewable energy consumption and economic growth on carbon dioxide emissions in 12 MENA countries. *Clean Technologies and Environmental Policy*, 21, pp.871-885. https://link.springer.com/article/10.1007/s10098-019-01676-2.

Ketema, A.M., 2020. Determinants of agricultural output in Ethiopia: ARDL approach to co-integration. *International Journal of Business and Social Research*, *10*(3), pp.1-10. https://dx.doi.org/10.18533/ijbsr.v10i3.1293.

Khan, M.K., Khan, M.I. and Rehan, M., 2020. The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. Financial Innovation, 6, pp.1-13.https://link.springer.com/article/10.1186/s40854-019-0162-0.

Khan, N., Ma, J., Zhang, H. and Zhang, S., 2023. Climate Change Impact on Sustainable Agricultural Growth: Insights from Rural Areas. *Atmosphere*, *14*(8), p.1194. https://doi.org/10.3390/atmos14081194

Khanna, S. and Tan, V.Y., 2019. Economy statistical recurrent units for inferring nonlinear granger causality. *arXiv preprint arXiv:1911.09879*. https://doi.org/10.48550/arXiv.1911.09879

Kohler, M., 2016. An economic assessment of bioethanol production from sugar cane: The case of South Africa. *Economic Research Southern Africa-ERSA. Working paper*, *630*. SAEF_Bioethanol-Production_MK-.pdf (ukzn.ac.za)

Koondhar, M.A., Aziz, N., Tan, Z., Yang, S., Abbasi, K.R. and Kong, R., 2021. Green growth of cereal food production under the constraints of agricultural carbon emissions: A new insights from ARDL and VECM models. *Sustainable Energy Technologies and Assessments*, *47*, p.101452. https://doi.org/10.1016/j.seta.2021.101452.

Kovacs, J., 1998. *Trade barriers and processed exports from developing countries: Sugar and tobacco*. The University of Manchester (United Kingdom).

Kripfganz, S. and Schneider, D.C., 2018. ardl: Estimating autoregressive distributed lag and equilibrium correction models. In *Proceedings of the 2018 London Stata conference* (Vol. 9, pp. 1-33). TUPD-2022-006.pdf (tohoku.ac.jp)

Kuznets, S., 1955. Economic growth iy7xand income inequality. The American economic review, 45(1), pp.1-28. https://www.jstor.org/stable/1811579.

Landman, W.A., Malherbe, J. and Engelbrecht, F., 2017. South Africa's present-day climate. *Understanding the social and environmental implication of global change, African Sun Media: Stellenbosch*. Chapter 3.pdf (saeon.ac.za)

Lee, JW & Kim, C 2020. Renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality test. *Sustainability*, vol. 12, no. 7, pp. 2785.

Leggett, J.A., 2020. The United Nations Framework Convention on Climate Change, the Kyoto protocol, and the Paris agreement: a summary. *UNFCC, New York*, *2*. https://www.everycrsreport.com/files/20200129_R46204_d496a7f6b79412253cfb14eb1e7c21c3124dfcf4.pdf. Accessed-14 September 2023.

Letcher, T.M., 2020. Introduction with a focus on atmospheric carbon dioxide and climate change. In *Future energy* (pp. 3-17). Elsevier. https://doi.org/10.1016/B978-0-08-102886-5.00001-3

Li, Y.R. and Wei, Y.A., 2006. Sugar industry in China: R & D and policy initiatives to meet sugar and biofuel demand of future. Sugar Tech, 8, pp.203-216. Sugar industry in China: R & D and policy initiatives to meet sugar and biofuel demand of future | Sugar Tech (springer.com)

Li, Y.R. and Yang, L.T., 2015a. Research and development priorities for sugar industry of China: recent research highlights. *Sugar Tech*, *17*, pp.9-12. Research and Development Priorities for Sugar Industry of China: Recent Research Highlights | Sugar Tech (springer.com)

Li, YR., Yang, LT., 2015b. Sugarcane Agriculture and Sugar Industry in China. Sugar Tech 17, 1–8. https://doi.org/10.1007/s12355-014-0342-1

Linnenluecke, M.K., Zhou, C., Smith, T., Thompson, N. and Nucifora, N., 2020. The impact of climate change on the Australian sugarcane industry. *Journal of Cleaner Production*, *246*, p.118974. https://doi.org/10.1016/j.jclepro.2019.118974

Little, B., 2023. Industrial Revolution and Climate Change. https://www.history.com/news/industrial-revolution-climate-change. Accessed- 25 January 2023.

Liu, P.R. and Raftery, A.E., 2021. Country-based rate of emissions reductions should increase by 80% beyond nationally determined contributions to meet the 2 C target. *Communications earth & environment*, *2*(1), p.29. https://doi.org/10.1038/s43247-021-00097-8.

Liu, X., Kwon, H., Wang, M. and O'Connor, D., 2023. Life Cycle Greenhouse Gas Emissions of Brazilian Sugar Cane Ethanol Evaluated with the GREET Model Using Data Submitted to RenovaBio. Environmental Science & Technology.

MacKellar, N., New, M. and Jack, C., 2014. Observed and modelled trends in rainfall and temperature for South Africa: 1960-2010. *South African Journal of Science*, *110*(7-8), pp.1-13. https://doi.org/10.1590/sajs.2014/20130353

Makin, M., 1997. South Africa's departure from the commonwealth in 1961: postmortems and consequences. *African Historical Review*, *29*(1), pp.156-171. https://doi.org/10.1080/00232089785380081

Mandela, 1995.Address by President Nelson Mandela at launch of Siyakha Project, Groutville.http://www.mandela.gov.za/mandela_speeches/1995/950617_siyakha.htm

Mashwani, Z.U.R., 2020. Environment, climate change and biodiversity. Environment, climate, plant and vegetation growth, pp.473-501. https://link.springer.com/chapter/10.1007/978-3-030-49732-3_19

Masood, E., 2016. *The great invention: The story of GDP and the making and unmaking of the modern world*. Simon and Schuster. Masood, E., 2016. *The great invention: The story of GDP and the making and unmaking of the modern world*. Simon and Schuster. ISBN 1681771810, 9781681771816.

Matthew, O., Osabohien, R., Fasina, F. and Fasina, A., 2018. Greenhouse gas emissions and health outcomes in Nigeria: Empirical insight from ARDL technique. *International Journal of Energy Economics and Policy*, *8*(3), pp.43-50. 1EVANS_Gas_Emissions_and_Health_Outcome_1220200211-37702-15em4o2-libre.pdf (d1wqtxts1xzle7.cloudfront.net).

Merchant, C.J., Minnett, P.J., Beggs, H., Corlett, G.K., Gentemann, C., Harris, A.R., Hoyer, J. and Maturi, E., 2019. Global sea surface temperature. In *Taking the Temperature of the Earth* (pp. 5-55). Elsevier. https://doi.org/10.1016/B978-0-12-814458-9.00002-2.

Minnaar, A.D.V., 1991. The growth and development of small cane growers in Zululand (1950s-1980s). *Africanus*, *20*(1), pp.18-30. The growth and development of small cane growers in Zululand (1950s-1980s) (journals.co.za)

Mohamed, J., 2020. Time series modelling and forecasting of Somaliland consumer price index: a comparison of ARIMA and regression with ARIMA errors. *American Journal of Theoretical and Applied Statistics*, *9*(4), pp.143-53. http://www.sciencepublishinggroup.com/j/ajtas

Moyo, S., 2014. Land ownership patterns and income inequality in Southern Africa. *Background paper prepared for World Economic and Social Survey*, pp.1-50. https://www.un.org/en/development/desa/policy/wess/wess_bg_papers/bp_wess2014_moyo.pdf.

Msimanga, B. and Sebitosi, A.B., 2014. South Africa's non-policy driven options for renewable energy development. *Renewable Energy*, *69*, pp.420-427. https://doi.org/10.1016/j.renene.2014.03.041

Muthuramu, P. and Maheswari, T.U., 2019. Tests for structural breaks in time series analysis: A review of recent development. *Shanlax International Journal of Economics*, *7*(4), pp.66-79. https://ssrn.com/abstract=3473137

Narayan, P.K. and Smyth, R., 2006. What determines migration flows from low-income to high-income countries? An empirical investigation of Fiji–Us migration 1972–2001. *Contemporary economic policy*, *24*(2), pp.332-342.https://doi.org/10.1093/cep/byj019

Naseem, S., Guang Ji, T. and Kashif, U., 2020. Asymmetrical ARDL correlation between fossil fuel energy, food security, and carbon emission: providing fresh information from Pakistan. Environmental Science and Pollution Research, 27, pp.31369-31382.

National Agricultural Marketing Council, 2013. Growing the Sugar Industry in South Africa. National Agricultural Marketing Council (NAMC).

National Oceanic and Atmospheric Administration, 2023. International report confirms record-high greenhouse gases, global sea levels in 2022. https://www.noaa.gov/news-release/international-report-confirms-record-high-greenhouse-gases-global-sea-levels-in-2022. Accessed-22 September 2023.

National Planning Commission, 2012. National Development Plan 2030 Our Future-make it work. ISBN: 978-0-621-41180-5. prelims (nationalplanningcommission.org.za). Accessed-15 August 2024.

News24, 2022. KwaZulu-Natal Floods. https://www.news24.com/news24/SpecialReports/ImpactReport/2022/the-stories-that-made-2022-kwazulu-natal-floods-20221213. Accessed-15 August 2023.

Ngarava, S., Zhou, L., Ayuk, J. and Tatsvarei, S., 2019. Achieving food security in a climate change environment: considerations for environmental Kuznets curve use in the South African agricultural sector. *Climate*, *7*(9), p.108. https://doi.org/10.3390/cli7090108.

Ngepah, N., Tchuinkam Djemo, C.R. and Saba, C.S., 2022. Forecasting the Economic Growth Impacts of Climate Change in South Africa in the 2030 and 2050 Horizons. *Sustainability*, *14*(14), p.8299. https://doi.org/10.3390/su14148299.

Nguyen, K.H. and Kakinaka, M., 2019. Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. Renewable Energy, 132, pp.1049-1057. https://doi.org/10.1016/j.renene.2018.08.069.

Nhamo, L., Matchaya, G., Mabhaudhi, T., Nhlengethwa, S., Nhemachena, C. and Mpandeli, S., 2019. Cereal production trends under climate change: Impacts and adaptation strategies in southern Africa. *Agriculture*, *9*(2), p.30. https://hdl.handle.net/10520/EJC-13bd851ecf.

Nigusse, T., Tadesse, T. and Melaku, T., 2019. Supply and demand side determinants of inflation in Ethiopia: Auto-regressive distributed lag model (ARDL). *International Journal of Commerce and Finance*, *5*(2), pp.8-21. Supply and Demand Side Determinants of Inflation in Ethiopia: Auto-Regressive Distributed Lag Model (ARDL) | Nigusse | International Journal of Commerce and Finance (ticaret.edu.tr)

Nordhaus, W., 2019. Climate change: The ultimate challenge for economics. *American Economic Review*, *109*(6), pp.1991-2014. DOI: 10.1257/aer.109.6.1991.

NPR, 2023. South Africa's power grid is collapsing and outages are disrupting the economy. https://www.npr.org/2023/02/07/1155014891/south-africas-power-grid-is-collapsing-and-outages-are-disrupting-the-economy. Accessed-15 April 2023.

OECD, 2023. Crop production (indicator). doi: 10.1787/49a4e677-en. Accessed-10 April 2023.

Ogundari, K. and Awokuse, T., 2018. Human capital contribution to economic growth in Sub-Saharan Africa: does health status matter more than education?. *Economic Analysis and Policy*, *58*, pp.131-140. https://doi.org/10.1016/j.eap.2018.02.001.

Ouessar, M., Sghaier, A., Frija, A., Sghaier, M. and Baig, M.B., 2021. Impacts of climate change on agriculture and food security in Tunisia: challenges, existing policies, and way forward. *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa: Climate Risks and Resource Scarcity*, pp.65-99.https://link.springer.com/chapter/10.1007/978-3-030-72987-5_3.

Ozdemir, D., 2022. The impact of climate change on agricultural productivity in Asian countries: a heterogeneous panel data approach. Environmental Science and Pollution Research, pp.1-13. https://doi.org/10.1007/s11356-021-16291-2.

Paraschiv, L.S. and Paraschiv, S., 2023. Contribution of renewable energy (hydro, wind, solar and biomass) to decarbonization and transformation of the electricity generation sector for sustainable development. *Energy Reports*, *9*, pp.535-544. https://doi.org/10.1016/j.egyr.2023.07.024.

Pata, U.K., 2021. Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in BRIC countries: A sustainability perspective. Renewable Energy, 173, pp.197-208. https://doi.org/10.1016/j.renene.2021.03.125.

Peacock, S.D. and Schorn, P.M., 2002. Crystal recovery efficiency as an overall measure of sugar mill performance. In *Proc S Afr Sug Technol Ass* (Vol. 76, pp. 544-560). Crystal Recovery Efficiency as an Overall Measure of Sugar Mill Performance (researchgate.net).

Peçe, M.A., Ceyhan, S., Kamacı, A. and Cengiz, V., 2023. The effects of renewable energy sources on Turkiye's economic growth: ARDL estimation. *Environmental Science and Pollution Research*, *30*(15), pp.45112-45122. https://link.springer.com/article/10.1007/s11356-023-25479-7.

Pegkas, P., 2020. The impact of renewable and non-renewable energy consumption on economic growth: the case of Greece. *International Journal of Sustainable Energy*, 39(4), pp.380-395. https://doi.org/10.1080/14786451.2019.1700261.

Pettinger T., 2019. Environmental Kuznets Curve. Economics Help. Environmental Kuznets curve - Economics Help

Pipitpukdee, S., Attavanich, W. and Bejranonda, S., 2020. Climate change impacts on sugarcane production in Thailand. *Atmosphere*, *11*(4), p.408. https://doi.org/10.3390/atmos11040408.

Polity, 2021. South Africa the 12th biggest source of greenhouse gases? Yes, but that's not the only measure that matters. https://www.polity.org.za/article/south-africa-the-12th-biggest-source-of-greenhouse-gases-yes-but-thats-not-the-only-measure-that-matters-2021-04-19 Accessed- 12 March 2023.

Pwc, 2023. South Africa Economic Outlook - January 2023. South Africa Economic Outlook - January 2023 | Press release (pwc.co.za). Accessed-24 July 2023.

Qiao, H., Zheng, F., Jiang, H. and Dong, K., 2019. The greenhouse effect of the agriculture-economic growth-renewable energy nexus: evidence from G20 countries. *Science of the Total Environment*, *671*, pp.722-731. https://doi.org/10.1016/j.scitotenv.2019.03.336.

Rada, N.E. and Fuglie, K.O., 2019. New perspectives on farm size and productivity. *Food Policy*, *84*, pp.147-152. https://doi.org/10.1016/j.foodpol.2018.03.015.

Raheem, I.D. and Ogebe, J.O., 2017. CO2 emissions, urbanization and industrialization: evidence from a direct and indirect heterogeneous panel analysis. *Management of Environmental Quality: An International Journal*, *28*(6), pp.851-867. https://doi.org/10.1108/MEQ-09-2015-0177

Raihan, A. and Tuspekova, A., 2022a. Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan. *World Development Sustainability*, 1, p.100019. https://doi.org/10.1016/j.wds.2022.100019.

Raihan, A. and Tuspekova, A., 2022b. Dynamic impacts of economic growth, energy use, urbanization, tourism, agricultural value-added, and forested area on carbon dioxide emissions in Brazil. *Journal of Environmental Studies and Sciences*, 12(4), pp.794-814. https://doi.org/10.1007/s13412-022-00782-w.

Raihan, A. and Tuspekova, A., 2022c. Nexus between economic growth, energy use, agricultural productivity, and carbon dioxide emissions: new evidence from Nepal. *Energy Nexus*, *7*, p.100113. https://doi.org/10.1016/j.nexus.2022.100113.

Raihan, A. and Tuspekova, A., 2022d. Nexus between energy use, industrialization, forest area, and carbon dioxide emissions: New insights from Russia. *Journal of Environmental Science and Economics*, 1(4), pp.1-11. DOI:10.56556/jescae.v1i4.269.

Raihan, A. and Tuspekova, A., 2022d. The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: new insights from Peru. *Energy Nexus*, 6, p.100067. https://doi.org/10.1016/j.nexus.2022.100067.

Raihan, A., 2023a. An econometric evaluation of the effects of economic growth, energy use, and agricultural value added on carbon dioxide emissions in Vietnam. *Asia-Pacific Journal of Regional Science*, pp.1-32. https://doi.org/10.1007/s41685-023-00278-7.

Raihan, A., 2023b. The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. *Energy Nexus*, 9, p.100180. https://doi.org/10.1016/j.nexus.2023.100180.

Raihan, A., Ibrahim, S. and Muhtasim, D.A., 2023. Dynamic impacts of economic growth, energy use, tourism, and agricultural productivity on carbon dioxide emissions in Egypt. *World Development Sustainability*, 2, p.100059. https://doi.org/10.1016/j.wds.2023.100059.

Raihan, A., Muhtasim, D.A., Farhana, S., Hasan, M.A.U., Pavel, M.I., Faruk, O., Rahman, M. and Mahmood, A., 2022a. Nexus between economic growth, energy use, urbanization, agricultural productivity, and carbon dioxide emissions: New insights from Bangladesh. *Energy Nexus*, *8*, p.100144. https://doi.org/10.1016/j.nexus.2022.100144

Raihan, A., Muhtasim, D.A., Pavel, M.I., Faruk, O. and Rahman, M., 2022b. Dynamic impacts of economic growth, renewable energy use, urbanization, and tourism on carbon dioxide emissions in Argentina. *Environmental Processes*, 9(2), p.38. https://doi.org/10.1007/s40710-022-00590-y.

Ramírez-Gil, J.G., Henao-Rojas, J.C. and Morales-Osorio, J.G., 2020. Mitigation of the adverse effects of the El Niño (El Niño, La Niña) southern oscillation (ENSO) phenomenon and the most important diseases in avocado cv. Hass crops. Plants, 9(6), p.790. https://doi.org/10.3390/plants9060790

Rasool, H., Malik, M.A. and Tarique, M., 2020. The curvilinear relationship between environmental pollution and economic growth: Evidence from India. *International Journal of Energy Sector Management*, *14*(5), pp.891-910. https://doi.org/10.1108/IJESM-04-2019-0017.

Rastogi, M., Singh, S. and Pathak, H., 2002. Emission of carbon dioxide from soil. *Current science*, *82*(5), pp.510-517. https://www.jstor.org/stable/24105957

Raza, G., Ali, K., Hassan, M.A., Ashraf, M., Khan, M.T. and Khan, I.A., 2019. Sugarcane as a bioenergy source. *Sugarcane biofuels: status, potential, and prospects of the sweet crop to fuel the world*, pp.3-19.

Reason, C.J.C., Hachigonta, S. and Phaladi, R.F., 2005. Interannual variability in rainy season characteristics over the Limpopo region of southern Africa. *International Journal Of Climatology: A Journal Of The Royal Meteorological Society*, *25*(14), pp.1835-1853.https://doi.org/10.1002/joc.1228

Regmi, K. and Rehman, A., 2021. Do carbon emissions impact Nepal's population growth, energy utilization, and economic progress? Evidence from long-and short run analyses. *Environmental Science and Pollution Research*, 28(39), pp.55465-55475.https://doi.org/10.1007/s11356-021-14546-6.

Rehman, A., Ma, H. and Ozturk, I., 2020. Decoupling the climatic and carbon dioxide emission influence to maize crop production in Pakistan. *Air Quality, Atmosphere & Health*, 13, pp.695-707. https://doi.org/10.1007/s40710-022-00590-y.

Rehman, A., Ma, H., Ahmad, M., Ozturk, I. and Işık, C., 2021. An asymmetrical analysis to explore the dynamic impacts of CO 2 emission to renewable energy, expenditures, foreign direct investment, and trade in Pakistan. *Environmental Science and Pollution Research*, *28*, pp.53520-53532. https://doi.org/10.1007/s11356-021-14537-7.

Rehman, A., Rauf, A., Ahmad, M., Chandio, A.A. and Deyuan, Z., 2019. The effect of carbon dioxide emission and the consumption of electrical energy, fossil fuel energy, and renewable energy, on economic performance: evidence from Pakistan. *Environmental Science and Pollution Research*, 26, pp.21760-21773. https://doi.org/10.1007/s11356-019-05550-y.

Rena, R. and Msoni, M., 2014. Global financial crises and its impact on the South African economy: A further update. *Journal of Economics*, *5*(1), pp.17-25. https://doi.org/10.1080/09765239.2014.11884980.

Ridzuan, N.H.A.M., Marwan, N.F., Khalid, N., Ali, M.H. and Tseng, M.L., 2020. Effects of agriculture, renewable energy, and economic growth on carbon dioxide emissions: Evidence of the environmental Kuznets curve. *Resources, Conservation and Recycling*, 160, p.104879. https://doi.org/10.1016/j.resconrec.2020.104879t.

Rodríguez-Morales, J.E., 2018. Convergence, conflict and the historical transition of bioenergy for transport in Brazil: The political economy of governance and institutional change. *Energy research & social science*, *44*, pp.324-335. https://doi.org/10.1016/j.erss.2018.05.031.

Rohrer, J.M., 2018. Thinking clearly about correlations and causation: Graphical causal models for observational data. *Advances in methods and practices in psychological science*, *1*(1), pp.27-42.https://doi.org/10.1177/2515245917745629

Rossi Neto, J., De Souza, Z.M., Kölln, O.T., Carvalho, J.L.N., Ferreira, D.A., Castioni, G.A.F., Barbosa, L.C., de Castro, S.G.Q., Braunbeck, O.A., Garside, A.L. and Franco, H.C.J., 2018. The arrangement and spacing of sugarcane planting influence root distribution and crop yield. Bioenergy Research, 11, pp.291-304. https://doi.org/10.1007/s12155-018-9896-1

SA Cane Growers, 2020. Sa Canegrowers' Small-Scale Farmer Grows Diversity. SA Canegrowers' small-scale farmer grows diversity - SA Canegrowers. Accessed-23 July 2023.

Saint Akadiri, S., Alola, A.A., Olasehinde-Williams, G. and Etokakpan, M.U., 2020. The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. *Science of The Total Environment*, 708, p.134653. https://doi.org/10.1016/j.scitotenv.2019.134653.

Sakanko, M.A. and David, J., 2018. An Econometric Validation of Malthusian Theory: Evidence in Nigeria. *Signifikan*, *7*(1), pp.77-90.http//dx.doi.org/10.15408/sjie.v7i1.6461.

Salim, R., Hassan, K. and Rahman, S., 2020. Impact of R&D expenditures, rainfall and temperature variations in agricultural productivity: empirical evidence from Bangladesh. *Applied Economics*, 52(27), pp.2977-2990. https://doi.org/10.1080/00036846.2019.1697422.

Salim, R.A. & Yao, Y., 2019. The effects of renewable energy and environmental technology on the price of fossil fuel. *Energy Economics*, vol. 78, pp. 620-634.

Samour, A., Moyo, D. and Tursoy, T., 2022. Renewable energy, banking sector development, and carbon dioxide emissions nexus: A path toward sustainable development in South Africa. *Renewable Energy*, 193, pp.1032-1040. https://doi.org/10.1016/j.renene.2022.05.013.

Sánchez, M.V., Cicowiez, M. and Ortega, A., 2022. Prioritizing public investment in agriculture for post-COVID-19 recovery: A sectoral ranking for Mexico. *Food Policy*, *109*, p.102251. https://doi.org/10.1016/j.foodpol.2022.102251

Schober, P., Boer, C. and Schwarte, L.A., 2018. Correlation coefficients: appropriate use and interpretation. *Anesthesia & analgesia*, *126*(5), pp.1763-1768. https://doi.org/10.1213/ANE.0000000000002864

Segoni, S., Piciullo, L. and Gariano, S.L., 2018. A review of the recent literature on rainfall thresholds for landslide occurrence. Landslides, 15(8), pp.1483-1501. https://doi.org/10.1007/s10346-018-0966-4

Shafiq, M.N., Gillani, S. and Shafiq, S., 2021. Climate Change and Agricultural Production in Pakistan. *IRASD Journal of Energy & Environment*, *2*(2), pp.47-54. https://doi.org/10.52131/jee.2021.0202.0016.

Shah, S.A.A. and Solangi, Y.A., 2019. A sustainable solution for electricity crisis in Pakistan: opportunities, barriers, and policy implications for 100% renewable energy. *Environmental Science and Pollution Research*, 26, pp.29687-29703. https://doi.org/10.1007/s11356-019-06102-0.

Shahbaz, M., Haouas, I. and Van Hoang, T.H., 2019. Economic growth and environmental degradation in Vietnam: is the environmental Kuznets curve a complete picture?. *Emerging Markets Review*, 38, pp.197-218. https://doi.org/10.1016/j.ememar.2018.12.006.

Shita, A., Kumar, N. and Singh, S., 2018. Determinants of agricultural productivity in Ethiopia: ARDL approach. *The Indian Economic Journal*, *66*(3-4), pp.365-374. https://doi.org/10.1177/0019466220941418.

Shrestha, M., 2014. Evaluation of Water Supply and Demand under Climate Change Scenarios in Kathmandu Valley, Nepal. *Thailand: Asian Institute of Technology*. https://www.researchgate.net/profile/Manish-Shrestha-2/publication/301788570_Evaluation_of_Water_Supply_and_Demand_under_Climate_Change_Scenarios_in_Kathmandu_Valley_Nepal/links/5728635108aee491cb41ff68/Evaluation-of-Water-Supply-and-Demand-under-Climate-Change-Scenarios-in-Kathmandu-Valley-Nepal.pdf.

Shrestha, M.B. and Bhatta, G.R., 2018. Selecting appropriate methodological framework for time series data analysis. *The Journal of Finance and Data Science*, *4*(2), pp.71-89. https://doi.org/10.1016/j.jfds.2017.11.001.

Silalertruksa, T. and Gheewala, S.H., 2018. Land-water-energy nexus of sugarcane production in Thailand. *Journal of Cleaner Production*, *182*, pp.521-528. https://doi.org/10.1016/j.jclepro.2018.02.085.

Sims, E. and Wolff, J., 2018. The output and welfare effects of government spending shocks over the business cycle. *International Economic Review*, *59*(3), pp.1403-1435. https://doi.org/10.1111/iere.12308.

Solomon, S. and Swapna, M., 2022. Indian Sugar Industry: Towards Self-reliance for Sustainability. Sugar Tech, 24(3), pp.630-650. https://doi.org/10.1007/s12355-022-01123-5.

South African History Online, 2014. Land Restitution in South Africa since 1994. Land Restitution in South Africa since 1994 | South African History Online (sahistory.org.za). Accessed-26 January 2024.

South African Revenue Services, 2021. Health Promotion Levy on Sugary Beverages. Health Promotion Levy on Sugary Beverages | South African Revenue Service (sars.gov.za). Accessed-08 April 2023.

South African Sugar Association (SASA), 2019. South African sugar industry challenges. https://www.sasa.org.za/sugar-industry/sugar-industry-challenges. Accessed-20 June 2023.

South African Sugar Association, 2020a. South African Sugarcane Value Chain Master Plan to 2030. South African Sugarcane Value Chain Master Plan (sasa.org.za). Accessed-10 August 2023.

South African Sugar Association, 2020b. South African Sugarcane Master Plan. Cane Growing In South Africa | The South African Sugar Assocciation (sasa.org.za). Accessed-15 June 2023.

South African Sugar Association, 2021. The South African sugar industry at a glance. https://www.sasa.org.za/sugar-industry/sugar-industry-at-a-glance. Accessed-08 September 2023.

South African Sugar Association, 2023. An overview of the South African Sugar Industry. The Sugar Industry | The South African Sugar Assocciation (sasa.org.za). Accessed-14 May 2023.

Statista, 2024a. South Africa: Distribution of gross domestic product (GDP) across economic sectors from 2012 to 2022. https://www.statista.com/statistics/371233/south-africa-gdp-distribution-across-economic-sectors/. Accessed-20 January 2024.

Statista, 2024b. South Africa: Urbanization from 2012 to 2022. https://www.statista.com/statistics/455931/urbanization-in-south-africa/. Accessed- 23 January 2024.

Statistics South Africa, 2023. Quarterly Labour Force Survey. Beyond unemployment – Time-Related Underemployment in the SA labour market | Statistics South Africa (statssa.gov.za). Accessed-10 June 2023.

Statistics South Africa, 2023a. GDP weakens in the third quarter. GDP weakens in the third quarter | Statistics South Africa (statssa.gov.za). Accessed-20 January 2024.

Statistics South Africa. (2019). Gross domestic product (GDP). https://www.statssa.gov.za/topics/gross-domestic-product-gdp. Accessed-10 June 2023.

Stern, D.I., 2018. The environmental Kuznets curve. *Companion to Environmental Studies*, *49*(54), pp.49-54. ISBN-9781315640051.

Stone, G.D., 2021. Malthusian Thought. In *Oxford Research Encyclopedia of Anthropology*. https://doi.org/10.1093/acrefore/9780190854584.013.312.

Tagwi, A., 2022. The Impacts of Climate Change, Carbon Dioxide Emissions (CO2) and Renewable Energy Consumption on Agricultural Economic Growth in South Africa: ARDL Approach. Sustainability, 14(24), p.16468. https://doi.org/10.3390/su142416468.

Tahir, T., Luni, T., Majeed, M.T. and Zafar, A., 2021. The impact of financial development and globalization on environmental quality: evidence from South Asian economies. *Environmental Science and Pollution Research*, *28*, pp.8088-8101. https://link.springer.com/article/10.1007/s11356-020-11198-w.

Tawiri, N., 2011. *Determinants of Domestic Investment in the Libyan Manufacturing Sector and its Impact* (Doctoral dissertation, University of Gloucestershire). https://eprints.glos.ac.uk/3245/.

Tenaw, D. and Beyene, A.D., 2021. Environmental sustainability and economic development in sub-Saharan Africa: A modified EKC hypothesis. Renewable and Sustainable Energy Reviews, 143, p.110897.https://doi.org/10.1016/j.rser.2021.110897.

The Department of Trade and Industry (the Dti), 2021. The Sugar Master Plan. https://www.thedtic.gov.za/wp-content/uploads/sugar_masterplan.pdf. Accessed-15 November 2023.

Tun, M.M., Juchelkova, D., Win, M.M., Thu, A.M. and Puchor, T., 2019. Biomass energy: An overview of biomass sources, energy potential, and management in Southeast Asian countries. Resources, 8(2), p.81. https://doi.org/10.3390/resources8020081.

Udemba, E.N., 2020. A sustainable study of economic growth and development amidst ecological footprint: New insight from Nigerian Perspective. Science of the total environment, 732, p.139270. https://doi.org/10.1016/j.scitotenv.2020.139270.

United Nations Conference on Trade and Development (UNCTAD), 2022. African Continental Free Trade Area: Challenges and Opportunities of Tariff Reductions. African Continental Free Trade Area: Challenges and Opportunities of Tariff Reductions | UNCTAD. Accessed-25 January 2024.

United Nations Framework Convention on Climate Change (UNFCCC), 2020. What is the United Nations Framework Convention on Climate Change? Available at: https://unfccc.int/processand-meetings/the-convention/what-is-the-united-nations-framework-convention-onclimate-change. Accessed-18 March 2023.

United Nations Population Fund (UNPFA), 2023. World Population Dashboard: South Africa. World Population Dashboard -South Africa | United Nations Population Fund (unfpa.org). Accessed-16 August 2023

Van den Berg, M., Singels, A., Armitage, R.M., Way, M.J. and McFarlane, S.A., 2008. South African Sugarcane Production and Quality In The 2007-2008 Milling Season: An Unfulfilled Promise?. In *Proc S Afr Sug Technol Ass* (Vol. 81, pp. 51-67). South African sugarcane production and quality in the 2007-2008 milling season: an unfulfilled promise? (researchgate.net).

Van Zyl, H., Lewis, Y., Kinghorn, J. and Reeler, J., 2018. The cost of achieving South Africa's 'fair share'of global climate change mitigation. *Climate Policy*, *18*(10), pp.1327-1339.

Verschuur, J., Koks, E.E. and Hall, J.W., 2021. Observed impacts of the COVID-19 pandemic on global trade. *Nature Human Behaviour*, *5*(3), pp.305-307. https://doi.org/10.1038/s41562-020-0896-8.

Vollset, S.E., Goren, E., Yuan, C.W., Cao, J., Smith, A.E., Hsiao, T., Bisignano, C., Azhar, G.S., Castro, E., Chalek, J. and Dolgert, A.J., 2020. Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. The Lancet, 396(10258), pp.1285-1306. https://doi.org/10.1016/S0140-6736(20)30677-2.

Wani, A.K., Rahayu, F., Fauziah, L. and Suhara, C., 2023. Advances in safe processing of sugarcane and bagasse for the generation of biofuels and bioactive compounds. *Journal of Agriculture and Food Research*, *12*, p.100549. https://doi.org/10.1016/j.jafr.2023.100549.

Warsame, A.A., Sheik-Ali, I.A., Ali, A.O. and Sarkodie, S.A., 2021. Climate change and crop production nexus in Somalia: an empirical evidence from ARDL technique. *Environmental Science and Pollution Research*, 28(16), pp.19838-19850. https://doi.org/10.1007/s11356-020-11739-3.

Wealleans, A.L., Bierinckx, K., Witters, E., di Benedetto, M. and Wiseman, J., 2021. Assessment of the quality, oxidative status and dietary energy value of lipids used in non-ruminant animal nutrition. *Journal of the Science of Food and Agriculture*, *101*(10), pp.4266-4277. https://doi.org/10.1002/jsfa.11066.

Winkler, H. and Marquand, A., 2009. Changing development paths: From an energy-intensive to low-carbon economy in South Africa. *Climate and development*, *1*(1), pp.47-65.https://doi.org/10.3763/cdev.2009.0003.

Witthohn, R., 2022. Agricultural and Forestry Products, Animals, Feedingstuffs. In *International Shipping: The Role of Sea Transport in the Global Economy* (pp. 3-133). Wiesbaden: Springer Fachmedien Wiesbaden. https://link.springer.com/chapter/10.1007/978-3-658-34273-9_1.

World Atlas, 2018. Which countries border South Africa? Which Countries Border South Africa? - WorldAtlas. Accessed-17 July 2023.

World Bank Group, Climate Change Knowledge Portal (CCKP) (2023). https://climateknowledgeportal.worldbank.org/. Accessed:-15 March 2023.

World Development Indicators (WDI), 2023. Total population size for South Africa. World Development Indicators | DataBank (worldbank.org). Accessed-12 December 2023.

World Development Indicators. Gross Domestic Product and population growth data data. World Development Indicators | DataBank (worldbank.org). Accessed-13 November 2022.

World Economic Forum, 2021. Rising demand for agricultural products adds to competing pressures on tropical forest landscapes. Rising demand for agricultural products adds to competing pressures on tropical forest landscapes > Press releases | World Economic Forum (weforum.org). Accessed-15 August 2023.

World Economic Forum, 2023. Sugar prices are at their highest level since 2011. Here's what's causing the surge. Why are global sugar prices skyrocketing? Is El Nino to blame? | World Economic Forum (weforum.org). Accessed-8 January 2024.

World Resources Institute (WRI), 2020. Tracking Progress of Countries' Nationally Determined Contributions. Tracking Progress of Countries' Nationally Determined Contributions | World Resources Institute (wri.org). Accessed-17 May 2023.

World Resources Institute, 2023. 10 Big Findings from the 2023 IPCC Report on Climate Change. Top Findings from the IPCC Climate Change Report 2023 | World Resources Institute (wri.org). Accessed-20 May 2023.

Worlddata, 2023. Population Growth in South Africa. Population growth in South Africa (worlddata.info). Accessed-24 January 2024.

Worldometer, 2016. Carbon emissions by country. CO2 Emissions by Country - Worldometer (worldometers.info). Accessed-30 March 2023.

Xi-Liu, Y.U.E. and Qing-Xian, G.A.O., 2018. Contributions of natural systems and human activity to greenhouse gas emissions. *Advances in Climate Change Research*, *9*(4), pp.243-252. https://doi.org/10.1016/j.accre.2018.12.003.

Yanagi, M., 2024. Climate change impacts on wheat production: Reviewing challenges and adaptation strategies. *Advances in Resources Research*, *4*(1), pp.89-107. https://doi.org/10.50908/arr.4.1_89.

Yaseen, M., Abbas, F., Shakoor, M.B., Farooque, A.A. and Rizwan, M., 2020. Biomass for renewable energy production in Pakistan: current state and prospects. *Arabian Journal of Geosciences*, *13*, pp.1-13. https://doi.org/10.1007/s12517-019-5049-x.

Yurtkuran, S., 2021. The effect of agriculture, renewable energy production, and globalization on CO2 emissions in Turkey: A bootstrap ARDL approach. *Renewable Energy*, 171, pp.1236-1245. https://doi.org/10.1016/j.renene.2021.03.009.

Zabed, H., Sahu, J.N., Suely, A., Boyce, A.N. and Faruq, G., 2017. Bioethanol production from renewable sources: Current perspectives and technological progress. *Renewable and Sustainable Energy Reviews*, *71*, pp.475-501. https://doi.org/10.1016/j.rser.2016.12.076.

Zahoor, Z., Shahzad, K. and Mustafa, A.U., 2022. Do Climate Changes influence the Agriculture Productivity in Pakistan? Empirical Evidence from ARDL Technique. *Forman Journal of Economic Studiezas*, 18(1). DOI: 10.32368/FJES.20221805

Zakaria, M., Jun, W. and Khan, M.F., 2019. Impact of financial development on agricultural productivity in South Asia. *Agricultural Economics*, 65(5), pp.232-239. https://doi.org/10.17221/199/2018-AGRICECON.

Zhang, M. and Govindaraju, M., 2018. Sugarcane production in China. Sugarcane-technology and research, 49, pp.50-66. http://dx.doi.org//10.5772/intechopen.73113.

Zhang, W.B., 2018. *Economic growth theory: capital, knowledge, and economic structures*. Routledge. ISBN: 9780754645207.

APPENDICES

Appendix A: Raw Data

Year	Sugarcane Yield (tons/ha)	Mean Temperature (°C)	Rainfall (mm)	Gross Domestic Product (Constant 2015 $)	Renewable Energy Consumption (TWh)	Carbon Dioxide Emissions (Mt)	Population Growth (%)
1972	93,149994	17,62	465,26	5209,741	2,466129032	146	2,8551768
1973	85,5288	17,57	495,03	5304,0413	2,912634409	157	2,8454145
1974	90,180595	17,11	662	5481,5966	3,347311828	162	2,8085534
1975	90,1197	17,1	589,13	5432,346	3,311827957	172	2,7568289
1976	95,435	16,92	686,36	5416,6085	5,547311828	180	2,6881042
1977	87,569695	17,61	563,55	5279,908	5,748387097	185	2,6809957
1978	89,2436	17,41	502,47	5307,1861	5,638978495	182	2,6971629
1979	84,4196	17,79	427,38	5372,0969	3,382795699	190	2,6610429
1980	66,1356	17,61	450,04	5581,4528	2,933333333	206	2,6360797
1981	75,8347	17,1	547,98	5725,0263	4,887903226	240	2,576565
1982	72,6259	17,71	397,04	5548,47	3,004301075	264	2,579055
1983	57,8505	18,22	432,68	5297,8328	1,759408602	270	2,680368
1984	81,885895	18,07	406,94	5419,7223	12,7931601	290	2,7944994
1985	70,5713	18,14	511,61	5216,8801	16,92655317	297	2,9609489
1986	66,1959	18,09	433,97	5090,5312	29,77783751	299	3,2783263
1987	76,647995	18,16	479,6	5075,9692	22,28040621	307	3,4976764
1988	71,67	17,67	599,81	5168,139	39,12404421	331	3,467807
1989	71,9047	17,49	519,72	5169,785	39,65191159	313	3,3523741
1990	68,3203	17,73	394,62	5031,4639	26,96072282	325	3,0783937
1991	72,7423	17,76	516,51	4858,9642	31,80107527	319	2,5583963
1992	48,2868	18,32	318,82	4637,866	28,57849548	327	2,055905
1993	41,696	18,26	458,59	4581,2183	21,01789154	330	1,8145462
1994	55,1768	17,58	395	4619,3882	30,69118809	340	1,7310431
1995	61,197098	17,89	512,72	4662,3969	33,63100185	351	1,6460395
1996	69,916695	17,33	580,53	4770,1782	37,69507152	357	1,5240828
1997	74,7019	17,68	497,61	4809,2182	43,00419628	365	1,3862773
1998	72,4824	18,15	503,51	4756,3872	44,78423538	358	1,2445527
1999	67,7418	18,51	446,46	4798,4475	39,8296813	370	1,1115545
2000	73,9525	17,55	638,57	4930,0255	43,27526944	372	0,962864
2001	64,9563	17,81	547,08	4996,0785	38,03845208	376	0,8856604
2002	71,638	17,85	422,1	5115,881	42,67959402	367	0,9101009
2003	62,6432	18,22	377,19	5202,6877	40,36287515	400	0,9242094
2004	60,4245	18,5	477,67	5373,807	42,29161563	439	0,9352902
2005	66,0244	18,48	401,17	5587,7934	37,72431615	422	0,9450942
2006	66,3567	17,97	575,61	5826,8262	38,38329645	431	0,9635935

Year	Sugarcane Yield (tons/ha)	Mean Temperature (°C)	Rainfall (mm)	Gross Domestic Product (Constant 2015 $)	Renewable Energy Consumption (TWh)	Carbon Dioxide Emissions (Mt)	Population Growth (%)
2007	64,1679	18,29	429,44	6060,3942	41,74015713	441	1,0138772
2008	67,003296	18,41	445,8	6170,9053	41,75706311	476	1,1330813
2009	67,072495	18,33	482,78	5992,0273	41,53737796	474	1,1892951
2010	59,0809	18,59	483,9	6084,968	42,07257597	475	1,193036
2011	66,455696	17,89	551,97	6182,7939	45,883684	466	1,2634056
2012	67,205	18,14	468,45	6231,6208	40,28452192	462	1,3291585
2013	75,3292	18,21	427,9	6284,8602	44,476114	463	1,3616211
2014	65,0553	18,42	456,32	6273,5663	54,64783658	467	1,5762942
2015	57,4931	18,88	373,61	6259,8397	64,69719007	455	2,0740169
2016	60,3177	18,99	433,48	6209,3659	83,88511806	474	0,972004
2017	68,4811	18,52	431,76	6192,8924	102,0797583	470	0,3872785
2018	70,8409	18,65	389,73	6199,8917	102,0252644	452	1,22553
2019	65,1254	19,27	390,05	6125,7353	110,6286399	474	1,2950739
2020	64,5348	18,47	468,19	5659,2069	120,0100357	437	1,223179
2021	64,497696	18,06	526,6	5864,8205	116,7838108	439	0,99892

Source: FAO Statistics (Accessed-March 2023), Word Development Indicators (Accessed-November 2022); BP Statistics Requested and Accessed-November 2022); CCKP (Accessed-March 2023)

Appendix B: Output (EViews V.10)

DESCRIPTIVE STATISTICS

	SUG	TMP	RNF	RNC	GDP	CO2	POP
Mean	70.15775	18.00200	479.8862	37.57505	5448.977	347.2950	1.894607
Median	68.03105	18.06500	468.3200	38.21087	5372.952	357.4287	1.611167
Maximum	95.43500	19.27000	686.3600	120.0100	6284.860	475.9547	3.497676
Minimum	41.69600	16.92000	318.8200	1.759409	4581.218	145.6931	0.387279
Std. Dev.	11.01500	0.505553	78.03951	30.61388	529.1497	104.1163	0.875537
Skewness	0.291870	0.061854	0.603327	1.155260	0.159849	-0.448546	0.273578
Kurtosis	3.375599	2.796205	3.107491	4.039955	1.838395	2.035378	1.634146
Jarque-Bera	1.003806	0.118409	3.057438	13.37502	3.024026	3.615147	4.510283
Probability	0.605378	0.942514	0.216813	0.001246	0.220466	0.164052	0.104859
Sum	3507.888	900.1000	23994.31	1878.752	272448.8	17364.75	94.73035
Sum Sq. Dev.	5945.178	12.52360	298418.1	45923.27	13719972	531169.6	37.56167
Observations	50	50	50	50	50	50	50

INFERENTIAL ANALYSIS

Correlation Matrix

	LNSUG	LNTMP	LNRNF	LNRNC	LNGDP	LNCO2	LNPOP
LNSUG	1.000000	-0.585660	0.487282	-0.494107	0.066119	-0.633236	0.366596
LNTMP	-0.585660	1.000000	-0.634210	0.630659	0.415330	0.726479	-0.508413
LNRNF	0.487282	-0.634210	1.000000	-0.215919	-0.114759	-0.328131	0.148065
LNRNC	-0.494107	0.630659	-0.215919	1.000000	0.217459	0.900472	-0.667471
LNGDP	0.066119	0.415330	-0.114759	0.217459	1.000000	0.364687	-0.315020
LNCO2	-0.633236	0.726479	-0.328131	0.900472	0.364687	1.000000	-0.718216
LNPOP	0.366596	-0.508413	0.148065	-0.667471	-0.315020	-0.718216	1.000000

Unit Root Tests

UNIT ROOT TEST TABLE (PP)

		LNSUG	LNTMP	LNRNF	LNRNC	LNGDP	LNCO2	LNPOP
At Level								
With Constant	t-Statistic	-3.3131	-2.8940	-5.3260	-1.5502	-1.0592	-3.6735	-1.6110
	Prob.	***0.0196***	***0.0533***	***0.0000***	***0.5001***	***0.7245***	***0.0076***	***0.4695***
		**	*	***	n0	n0	***	n0
With Constant & Trend	t-Statistic	-3.7104	-4.6139	-5.7638	-2.5201	-1.4032	-1.1302	-2.9181
	Prob.	***0.0309***	***0.0028***	***0.0001***	***0.3176***	***0.8478***	***0.9132***	***0.1660***
		**	***	***	n0	n0	n0	n0
Without Constant & Trend	t-Statistic	-0.6381	0.5624	0.3596	0.8560	0.5133	2.7998	-1.5447
	Prob.	***0.4357***	***0.8343***	***0.7847***	***0.8918***	***0.8231***	***0.9984***	***0.1139***
		n0	n0	n0	n0	n0	n0	n0
At First Difference								
		d(LNSUG)	d(LNTMP)	d(LNRNF)	d(LNRNC)	d(LNGDP)	d(LNCO2)	d(LNPOP)
With Constant	t-Statistic	-9.3188	-20.2961	-20.2583	-7.8305	-4.9255	-6.0900	-13.4256
	Prob.	***0.0000***	***0.0001***	***0.0001***	***0.0000***	***0.0002***	***0.0000***	***0.0000***
		***	***	***	***	***	***	***
With Constant & Trend	t-Statistic	-9.8704	-21.0705	-20.2808	-7.7733	-4.8846	-7.2307	-13.3557
	Prob.	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0013***	***0.0000***	***0.0000***
		***	***	***	***	***	***	***
Without Constant & Trend	t-Statistic	-9.3557	-14.1110	-20.7057	-7.5561	-4.9506	-5.2251	-8.6420
	Prob.	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
		***	***	***	***	***	***	***

UNIT ROOT TEST TABLE (ADF)

At Level

		LNSUG	LNTMP	LNRNF	LNRNC	LNGDP	LNCO2	LNPOP
With Constant	t-Statistic	-3.4185	-2.9987	-5.3560	-1.5502	-1.0720	-3.1848	-0.8887
	Prob.	***0.0150***	***0.0420***	***0.0000***	***0.5001***	***0.7194***	***0.0271***	***0.7816***
		**	**	***	n0	n0	**	n0
With Constant & Trend	t-Statistic	-3.7587	-4.8329	-5.7754	-2.5598	-1.6003	-0.9680	-3.5382
	Prob.	***0.0275***	***0.0015***	***0.0001***	***0.2997***	***0.7782***	***0.9389***	***0.0487***
		**	***	***	n0	n0	n0	**
Without Constant & Trend	t-Statistic	-0.6514	1.5934	-0.0105	0.8560	0.4196	3.3755	-1.3781
	Prob.	***0.4297***	***0.9710***	***0.6743***	***0.8918***	***0.8002***	***0.9997***	***0.1536***
		n0	n0	n0	n0	n0	n0	n0

At First Difference

		d(LNSUG)	d(LNTMP)	d(LNRNF)	d(LNRNC)	d(LNGDP)	d(LNCO2)	d(LNPOP)
With Constant	t-Statistic	-4.7448	-5.3860	-11.5773	-7.8305	-4.9255	-6.0696	-1.8274
	Prob.	***0.0004***	***0.0000***	***0.0000***	***0.0000***	***0.0002***	***0.0000***	***0.3623***
		***	***	***	***	***	***	n0
With Constant & Trend	t-Statistic	-4.8652	-5.3177	-11.4544	-4.0495	-4.8905	-7.2315	-1.7896
	Prob.	***0.0015***	***0.0004***	***0.0000***	***0.0144***	***0.0013***	***0.0000***	***0.6910***
		***	***	***	**	***	***	n0
Without Constant & Trend	t-Statistic	-4.7072	-5.0572	-11.7021	-7.5411	-4.9506	-2.0324	-1.5383
	Prob.	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0415***	***0.1150***
		***	***	***	***	***	**	n0

Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant
*MacKinnon (1996) one-sided p-values.

This Result is The Out-Put of Program Has Developed By:
Dr. Imadeddin AlMosabbeh
College of Business and Economics
Qassim University-KSA

Optimal Lag Order Selection

VAR Lag Order Selection Criteria
Endogenous variables: LNSUG LNTMP LNRNF LNRNC LNGDP LNCO2 LNPOP
Exogenous variables: C
Date: 11/13/23Time: 13:44
Sample: 1972 2021
Included observations: 46

Lag	LogL	LR	FPE	AIC	SC	HQ
0	184.2944	NA	1.06e-12	-7.708454	-7.430182	-7.604212
1	419.3236	388.3090	3.34e-16*	-15.79668	-13.57050*	-14.96274*
2	465.0923	61.68831	4.45e-16	-15.65619	-11.48211	-14.09255
3	499.1829	35.57277	1.30e-15	-15.00795	-8.885978	-12.71462
4	596.8782	72.20962*	4.12e-16	-17.12514*	-9.055267	-14.10212

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

ARDL SR/ECM results

ARDL Error Correction Regression
Dependent Variable: D(LNSUG)
Selected Model: ARDL(4, 0, 3, 4, 0, 4, 0)
Case 3: Unrestricted Constant and No Trend
Date: 11/13/23Time: 13:47
Sample: 1972 2021
Included observations: 46

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.528579	0.558880	8.102959	0.0000
D(LNSUG(-1))	0.439769	0.112959	3.893158	0.0007
D(LNSUG(-2))	0.119360	0.108693	1.098142	0.2830
D(LNSUG(-3))	0.204959	0.094549	2.167748	0.0403
D(LNRNF)	-0.047162	0.062782	-0.751207	0.4598
D(LNRNF(-1))	-0.413218	0.111128	-3.718385	0.0011
D(LNRNF(-2))	-0.144658	0.085628	-1.689383	0.1041
D(LNRNC)	0.169341	0.029904	5.662909	0.0000
D(LNRNC(-1))	0.011661	0.034210	0.340861	0.7362
D(LNRNC(-2))	0.055521	0.029640	1.873201	0.0733
D(LNRNC(-3))	0.091662	0.030253	3.029867	0.0058
D(LNCO2)	-0.229650	0.239248	-0.959884	0.3467
D(LNCO2(-1))	0.969697	0.249022	3.894019	0.0007
D(LNCO2(-2))	0.573622	0.291069	1.970746	0.0604
D(LNCO2(-3))	0.536452	0.268562	1.997493	0.0572
CointEq(-1)*	-1.120580	0.137753	-8.134681	0.0000

R-squared	0.861134	Mean dependent var	-0.007272
Adjusted R-squared	0.791701	S.D. dependent var	0.133352
S.E. of regression	0.060862	Akaike info criterion	-2.492222
Sum squared resid	0.111124	Schwarz criterion	-1.856173
Log likelihood	73.32111	Hannan-Quinn criter.	-2.253954
F-statistic	12.40238	Durbin-Watson stat	1.879746
Prob(F-statistic)	0.000000		

* p-value incompatible with t-Bounds distribution.

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	7.562633	10%	2.12	3.23
k	6	5%	2.45	3.61
		2.5%	2.75	3.99
		1%	3.15	4.43

t-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-8.134681	10%	-2.57	-4.04
		5%	-2.86	-4.38
		2.5%	-3.13	-4.66
		1%	-3.43	-4.99

LR results (ARDL)

ARDL Long run Form and Bounds Test
Dependent Variable: D(LNSUG)
Selected Model: ARDL(4, 0, 3, 4, 0, 4, 0)
Case 3: Unrestricted Constant and No Trend
Date: 11/13/23Time: 13:48
Sample: 1972 2021
Included observations: 46

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.528579	3.580635	1.264742	0.2181
LNSUG(-1)*	-1.120580	0.221567	-5.057520	0.0000
LNTMP**	-2.350783	1.046310	-2.246736	0.0341
LNRNF(-1)	0.386666	0.241894	1.598493	0.1230
LNRNC(-1)	0.100468	0.051021	1.969167	0.0606
LNGDP**	0.798656	0.183947	4.341762	0.0002
LNCO2(-1)	-0.447462	0.174610	-2.562632	0.0171
LNPOP**	-0.062913	0.035686	-1.762943	0.0906
D(LNSUG(-1))	0.439769	0.166117	2.647346	0.0141
D(LNSUG(-2))	0.119360	0.134028	0.890559	0.3820
D(LNSUG(-3))	0.204959	0.121429	1.687891	0.1044
D(LNRNF)	-0.047162	0.112860	-0.417883	0.6797
D(LNRNF(-1))	-0.413218	0.157009	-2.631807	0.0146
D(LNRNF(-2))	-0.144658	0.108348	-1.335130	0.1944
D(LNRNC)	0.169341	0.037821	4.477431	0.0002
D(LNRNC(-1))	0.011661	0.046280	0.251961	0.8032
D(LNRNC(-2))	0.055521	0.037211	1.492084	0.1487
D(LNRNC(-3))	0.091662	0.038378	2.388386	0.0251
D(LNCO2)	-0.229650	0.323993	-0.708813	0.4853
D(LNCO2(-1))	0.969697	0.367037	2.641958	0.0143
D(LNCO2(-2))	0.573622	0.400312	1.432937	0.1648
D(LNCO2(-3))	0.536452	0.372526	1.440038	0.1628

* p-value incompatible with t-Bounds distribution.
** Variable interpreted as Z = Z(-1) + D(Z).

Levels Equation
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTMP	-2.097827	1.150545	-1.823334	0.0807
LNRNF	0.345059	0.183899	1.876350	0.0728
LNRNC	0.089657	0.043872	2.043630	0.0521
LNGDP	0.712716	0.132575	5.375966	0.0000
LNCO2	-0.399313	0.121437	-3.288222	0.0031
LNPOP	-0.056143	0.035762	-1.569911	0.1295

EC = LNSUG - (-2.0978*LNTMP + 0.3451*LNRNF + 0.0897*LNRNC + 0.7127
*LNGDP-0.3993*LNCO2-0.0561*LNPOP)

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	7.562633	10%	2.12	3.23
k	6	5%	2.45	3.61
		2.5%	2.75	3.99
		1%	3.15	4.43
			Finite Sample: n=50	
Actual Sample Size	46			
		10%	2.309	3.507
		5%	2.726	4.057
		1%	3.656	5.331
			Finite Sample: n=45	
		10%	2.327	3.541
		5%	2.764	4.123
		1%	3.79	5.411

t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-5.057520	10%	-2.57	-4.04
		5%	-2.86	-4.38
		2.5%	-3.13	-4.66
		1%	-3.43	-4.99

Diagnostics

Serial Correlation Breusch-Pagan Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.001852	Prob. F(2,22)	0.3833
Obs*R-squared	3.839842	Prob. Chi-Square(2)	0.1466

Test Equation:
Dependent Variable: RESID
Method: ARDL
Date: 11/13/23Time: 13:51
Sample: 1976 2021
Included observations: 46
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNSUG(-1)	0.064681	0.252682	0.255980	0.8003
LNSUG(-2)	0.192758	0.202344	0.952623	0.3511
LNSUG(-3)	-0.052170	0.161974	-0.322092	0.7504
LNSUG(-4)	0.038965	0.126729	0.307471	0.7614
LNTMP	-0.458210	1.218025	-0.376191	0.7104
LNRNF	-0.019180	0.117188	-0.163669	0.8715
LNRNF(-1)	-0.009797	0.123589	-0.079273	0.9375
LNRNF(-2)	-0.057453	0.122551	-0.468811	0.6438
LNRNF(-3)	-0.069245	0.137036	-0.505307	0.6184
LNRNC	-0.002939	0.039595	-0.074222	0.9415
LNRNC(-1)	-0.015588	0.067236	-0.231843	0.8188
LNRNC(-2)	-0.020334	0.057708	-0.352356	0.7279
LNRNC(-3)	0.021183	0.051068	0.414796	0.6823
LNRNC(-4)	-0.015816	0.040615	-0.389405	0.7007
LNGDP	-0.162346	0.257565	-0.630308	0.5350
LNCO2	0.130140	0.339800	0.382988	0.7054
LNCO2(-1)	-0.177020	0.423763	-0.417732	0.6802
LNCO2(-2)	0.118629	0.448175	0.264694	0.7937
LNCO2(-3)	0.015550	0.483663	0.032150	0.9746
LNCO2(-4)	0.078366	0.385164	0.203461	0.8406
LNPOP	-0.014970	0.041274	-0.362703	0.7203
C	1.800204	4.517606	0.398486	0.6941
RESID(-1)	-0.049964	0.361908	-0.138056	0.8915
RESID(-2)	-0.446373	0.320797	-1.391450	0.1780

R-squared	0.083475	Mean dependent var	1.39E-15
Adjusted R-squared	-0.874711	S.D. dependent var	0.049693
S.E. of regression	0.068040	Akaike info criterion	-2.231562
Sum squared resid	0.101848	Schwarz criterion	-1.277488
Log likelihood	75.32592	Hannan-Quinn criter.	-1.874160
F-statistic	0.087118	Durbin-Watson stat	1.956459
Prob(F-statistic)	1.000000		

Heteroskedasticity Test

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.826671	Prob. F(21,24)	0.6681
Obs*R-squared	19.30760	Prob. Chi-Square(21)	0.5654
Scaled explained SS	4.288156	Prob. Chi-Square(21)	1.0000

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 11/13/23Time: 13:52
Sample: 1976 2021
Included observations: 46

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.147293	0.171251	0.860099	0.3982
LNSUG(-1)	0.004729	0.007128	0.663463	0.5134
LNSUG(-2)	0.006495	0.007155	0.907821	0.3730
LNSUG(-3)	-0.006252	0.007164	-0.872762	0.3914
LNSUG(-4)	0.003234	0.005808	0.556909	0.5827
LNTMP	-0.028633	0.050042	-0.572181	0.5725
LNRNF	-0.006060	0.005398	-1.122648	0.2727
LNRNF(-1)	-0.004642	0.005159	-0.899773	0.3772
LNRNF(-2)	0.001476	0.004539	0.325171	0.7479
LNRNF(-3)	0.003760	0.005182	0.725569	0.4751
LNRNC	-0.001464	0.001809	-0.809198	0.4264
LNRNC(-1)	0.000497	0.002839	0.174888	0.8626
LNRNC(-2)	-0.002796	0.002560	-1.092305	0.2855
LNRNC(-3)	0.002394	0.002323	1.030579	0.3130
LNRNC(-4)	-0.001415	0.001836	-0.770855	0.4483
LNGDP	-0.011363	0.008798	-1.291628	0.2088
LNCO2	0.007673	0.015496	0.495181	0.6250
LNCO2(-1)	-0.027965	0.019331	-1.446629	0.1609
LNCO2(-2)	0.012687	0.021058	0.602448	0.5525
LNCO2(-3)	-0.000234	0.022784	-0.010267	0.9919
LNCO2(-4)	0.015689	0.017817	0.880564	0.3873
LNPOP	-0.002281	0.001707	-1.336563	0.1939

R-squared	0.419730	Mean dependent var	0.002416
Adjusted R-squared	-0.088006	S.D. dependent var	0.003120
S.E. of regression	0.003254	Akaike info criterion	-8.311686
Sum squared resid	0.000254	Schwarz criterion	-7.437118
Log likelihood	213.1688	Hannan-Quinn criter.	-7.984067
F-statistic	0.826671	Durbin-Watson stat	2.453786
Prob(F-statistic)	0.668128		

Heteroskedasticity Test: ARCH

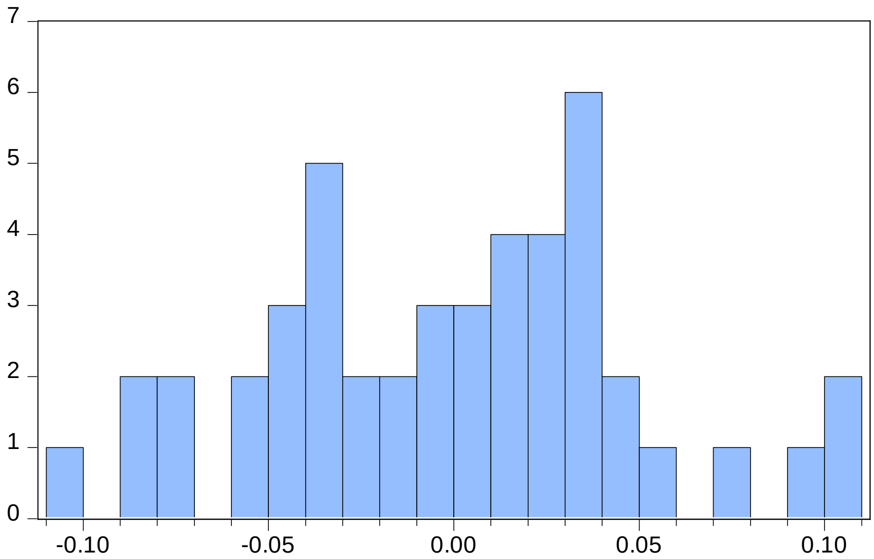
F-statistic	0.019302	Prob. F(1,43)	0.8902
Obs*R-squared	0.020191	Prob. Chi-Square(1)	0.8870

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 11/13/23Time: 13:54
Sample (adjusted): 1977 2021
Included observations: 45 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.002303	0.000599	3.845582	0.0004
RESID^2(-1)	0.021027	0.151349	0.138933	0.8902

R-squared	0.000449	Mean dependent var	0.002355
Adjusted R-squared	-0.022797	S.D. dependent var	0.003127
S.E. of regression	0.003163	Akaike info criterion	-8.631227
Sum squared resid	0.000430	Schwarz criterion	-8.550931
Log likelihood	196.2026	Hannan-Quinn criter.	-8.601294
F-statistic	0.019302	Durbin-Watson stat	1.966813
Prob(F-statistic)	0.890152		

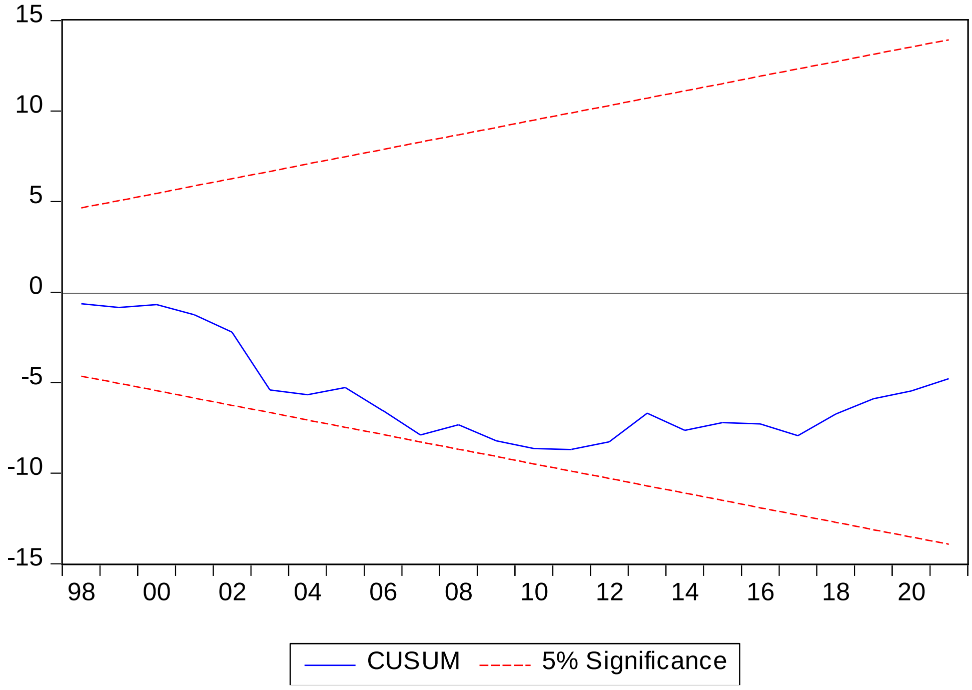
Normality Jaque-Bera Test

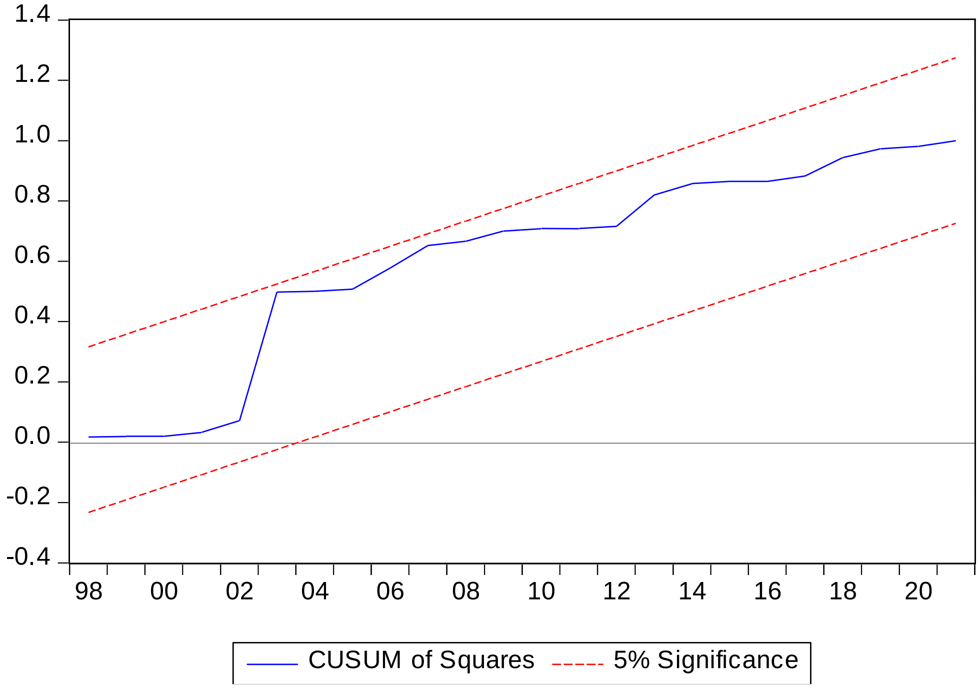


Series: Residuals
Sample 1976 2021
Observations 46

Mean	1.39e-15
Median	0.008642
Maximum	0.107362
Minimum	-0.101149
Std. Dev.	0.049693
Skewness	0.102864
Kurtosis	2.631795
Jarque-Bera	0.340973
Probability	0.843254

CUSUM Plots


15
10
5
0
-5
-10
-15
98
00
02
04
06
08
10
12
14
16
18
20
CUSUM
5% Significance


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
98
00
02
04
06
08
10
12
14
16
18
20
CUSUM of Squares
5% Significance

Robustness Tests

Dependent Variable: LNSUG
Method: Fully Modified Least Squares (FMOLS)
Date: 11/13/23Time: 14:03
Sample (adjusted): 1973 2021
Included observations: 49 after adjustments
Cointegrating equation deterministics: C
Long run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTMP	-1.261733	0.974504	-1.294744	0.2025
LNRNF	0.186368	0.123902	1.504153	0.1400
LNRNC	0.071371	0.029571	2.413552	0.0202
LNGDP	0.605353	0.171036	3.539337	0.0010
LNCO2	-0.503394	0.119885	-4.198965	0.0001
LNPOP	-0.024912	0.040732	-0.611594	0.5441
C	4.233343	3.044307	1.390577	0.1717

R-squared	0.626557	Mean dependent var	4.232472
Adjusted R-squared	0.573208	S.D. dependent var	0.155099
S.E. of regression	0.101325	Sum squared resid	0.431203
Long run variance	0.009528		

Dependent Variable: LNSUG
Method: Dynamic Least Squares (DOLS)
Date: 11/13/23Time: 14:06
Sample (adjusted): 1974 2020
Included observations: 47 after adjustments
Cointegrating equation deterministics: C
Fixed leads and lags specification (lead=1, lag=1)
Long run variance estimate (Bartlett kernel, Newey-West fixed bandwidth =
4.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTMP	4.248117	2.968236	1.431193	0.1664
LNRNF	1.046863	0.324575	3.225339	0.0039
LNRNC	0.038850	0.053330	0.728496	0.4740
LNGDP	0.190814	0.284475	0.670759	0.5094
LNCO2	-0.467546	0.153584	-3.044233	0.0060
LNPOP	0.055689	0.064704	0.860681	0.3987
C	-13.57389	8.337718	-1.628010	0.1178

R-squared	0.824792	Mean dependent var	4.229269
Adjusted R-squared	0.633657	S.D. dependent var	0.154851
S.E. of regression	0.093726	Sum squared resid	0.193259
Long run variance	0.006970		

Dependent Variable: LNSUG
Method: Canonical Cointegrating Regression (CCR)
Date: 11/13/23Time: 14:07
Sample (adjusted): 1973 2021
Included observations: 49 after adjustments
Cointegrating equation deterministics: C
Long run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTMP	-0.668131	1.487469	-0.449173	0.6556
LNRNF	0.272011	0.199065	1.366438	0.1791
LNRNC	0.064111	0.033408	1.919043	0.0618
LNGDP	0.566009	0.189493	2.986959	0.0047
LNCO2	-0.490065	0.116620	-4.202250	0.0001
LNPOP	-0.017827	0.044622	-0.399505	0.6915
C	2.269627	4.595759	0.493852	0.6240

R-squared	0.617413	Mean dependent var	4.232472
Adjusted R-squared	0.562757	S.D. dependent var	0.155099
S.E. of regression	0.102558	Sum squared resid	0.441761
Long run variance	0.009528		

Granger Causality Test

Pairwise Granger Causality Tests
Date: 11/13/23Time: 14:19
Sample: 1972 2021
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
LNTMP does not Granger Cause LNSUG	48	0.52131	0.5974
LNSUG does not Granger Cause LNTMP		1.18410	0.3158
LNRNF does not Granger Cause LNSUG	48	2.53233	0.0913
LNSUG does not Granger Cause LNRNF		0.54841	0.5819
LNRNC does not Granger Cause LNSUG	48	1.99658	0.1482
LNSUG does not Granger Cause LNRNC		2.36703	0.1059
LNGDP does not Granger Cause LNSUG	48	0.85341	0.4330
LNSUG does not Granger Cause LNGDP		1.70696	0.1935
LNCO2 does not Granger Cause LNSUG	48	1.95509	0.1539
LNSUG does not Granger Cause LNCO2		1.22671	0.3033
LNPOP does not Granger Cause LNSUG	48	0.22286	0.8011
LNSUG does not Granger Cause LNPOP		1.58977	0.2157

LNRNF does not Granger Cause LNTMP	48	1.01004	0.3727
LNTMP does not Granger Cause LNRNF		0.17443	0.8405
LNRNC does not Granger Cause LNTMP	48	4.19581	0.0216
LNTMP does not Granger Cause LNRNC		4.75466	0.0136
LNGDP does not Granger Cause LNTMP	48	1.94059	0.1560
LNTMP does not Granger Cause LNGDP		1.35139	0.2697
LNCO2 does not Granger Cause LNTMP	48	7.33053	0.0018
LNTMP does not Granger Cause LNCO2		0.09573	0.9089
LNPOP does not Granger Cause LNTMP	48	4.16879	0.0221
LNTMP does not Granger Cause LNPOP		1.60972	0.2118
LNRNC does not Granger Cause LNRNF	48	0.88248	0.4211
LNRNF does not Granger Cause LNRNC		3.68404	0.0334
LNGDP does not Granger Cause LNRNF	48	0.91814	0.4069
LNRNF does not Granger Cause LNGDP		0.18773	0.8295
LNCO2 does not Granger Cause LNRNF	48	1.87408	0.1658
LNRNF does not Granger Cause LNCO2		2.31420	0.1110
LNPOP does not Granger Cause LNRNF	48	0.48294	0.6203
LNRNF does not Granger Cause LNPOP		0.48829	0.6170
LNGDP does not Granger Cause LNRNC	48	0.67617	0.5139
LNRNC does not Granger Cause LNGDP		3.65508	0.0342
LNCO2 does not Granger Cause LNRNC	48	4.43907	0.0177
LNRNC does not Granger Cause LNCO2		2.73937	0.0759
LNPOP does not Granger Cause LNRNC	48	0.07263	0.9301
LNRNC does not Granger Cause LNPOP		2.33632	0.1088
LNCO2 does not Granger Cause LNGDP	48	2.24093	0.1186
LNGDP does not Granger Cause LNCO2		1.82290	0.1738
LNPOP does not Granger Cause LNGDP	48	2.82208	0.0705
LNGDP does not Granger Cause LNPOP		0.21238	0.8095
LNPOP does not Granger Cause LNCO2	48	1.84150	0.1709
LNCO2 does not Granger Cause LNPOP		1.57278	0.2192