THE IMPACT OF RENEWABLE ENERGY CONSUMPTION, FOREIGN DIRECT INVESTMENT, ECONOMIC GROWTH, AND CARBON DIOXIDE EMISSIONS ON SOYBEAN PRODUCTION IN SOUTH AFRICA

By

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DEDICATION

I dedicate this dissertation firstly to my gorgeous little princess, Refilwe Rakgoale, so she can grow up knowing that the only path to success is through education and hard work and that she can dream big. Secondly to my lovely siblings, for them to know that nothing comes easy, but it is through hard work and passion that we are able to achieve our goals and prosper in life. Everything seems impossible until it is done.

DECLARATION

I, Shiluva Faith Baloyi, hereby declare that the work contained in this dissertation is my own work, submitted for the degree, Master of Science in Agriculture (Agricultural Economics) at the University of South Africa, and I had never prior submitted it in full or in parts, to any other university in South Africa to receive a degree. All the references that were used in this study were accordingly recognized and acknowledged.

………………………… 07 March 2024

Ms S.F Baloyi **Date**

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ABSTRACT

Soybean is one of the most significant global crops due to its high protein content and high-quality essential oils, therefore, it is used for food, energy, and animal feed, however, climate change threatens its productivity. Climate change influences all sectors of the economy but the most vulnerable is agriculture, the main source of income and ensures food security for the majority of rural communities. Although the production of soybeans has been increasing over the years, South Africa remains a net importer. The climatic changes brought on by greenhouse gas pollution, such as carbon dioxide (CO_2) emissions have adversely affected soybean production. To reduce these emissions, the country needs to invest in the use and production of renewable energies. Renewable energy use not only reduces emissions but also creates opportunities. Currently, the South African energy sector depends largely on the burning of fossil fuels responsible for more CO_2 emissions. The agricultural sector has a chance to contribute by providing biomass feedstock for renewable energy production as farmers are the producers of these feedstocks. Developed countries have successfully increased their renewable energy mix using bioenergy but this requires investment. Energy transition is expensive for many developing countries, including South Africa, as domestic savings are not enough and to increase capital inflows to uplift economic growth, they need to attract Foreign direct investment. Africa needs climate finance from developed countries which are, also, the main contributors to climate change. In this study, the main objective was to analyse the effect of renewable energy consumption, foreign direct investment (FDI), economic growth, and carbon dioxide emissions on soybean production in South Africa between the years 1975 to 2021. This study was informed by macroeconomic theories, which are the Environmental Kuznets Curve, Pollution Haven, and Pollution Halo Effect Hypothesis. The data on key variables was collected from World Development Indicators, Food and Agriculture Organization, and British Petroleum. The Autoregressive Distributed Lag (ARDL) Model was utilized to evaluate the relationship that exists among the variables. The cointegration bounds test was conducted and found that a long-run relationship exists among the variables. The ARDL model results showed that in the short run, CO_2 emissions and FDI had a negative and favourable effect on soybean production, respectively. While, in the long run, soybean production was positively impacted by renewable energy consumption, foreign direct investment, and economic growth. These results were further validated by DOLS, FMOLS, and CCR models. The pairwise Granger causality was then carried out and the results demonstrate that there was unidirectional causality from soybean production and renewable energy consumption to FDI, from CO_2 emissions to soybean production, and FDI, and between GDP and FDI the relationship was bidirectional. The study recommended that investments should be channelled towards renewable energy use in the agricultural sector and climate-smart farming in the production of soybeans. Practically the agricultural sector should be supported and the emphasis should be on soybean production developments, and more investments should be made at the rural level. Therefore, this suggests that the government must be intentional about investment in soybean production at the rural level. This can be achieved by prioritizing land allocation for the production. The investments should not only be in production for energy but also in processing soybeans for energy to broaden the participation of farmers in the energy sector. This will open doors for rural farmers as the global demand for soybeans is also increasing for energy production and stimulate production at the local level ultimately improving farmers' livelihoods and increasing renewable energy mix and adoption in the country.

Keywords: Soybean Production, Renewable Energy, Carbon Dioxide Emissions, Foreign Direct Investment, South Africa Economy, ARDL

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ACRONYMS AND ABBREVIATIONS

2 /3 SLS	Stage Least Squares
ADF	Augmented Dickey-Fuller test
AIC	Akaike Information Criterion
APCs	Asia Pacific countries
APFER	Applied Panel Fixed Effect Regression
ARDL	Autoregressive distributed lag model
ARIMA	Autoregressive integrated moving average
ASEAN	Association of Southeast Asian Nations
BARDL	Bootstrap Autoregressive distributed Lag model
BFAP	Bureau of Food and Agricultural Policy
BIC	Bayesian Information Criterion
BP	British Petroleum
BRICS	Brazil, Russia, India, China, and South Africa
CCR	Canonical Co-integrating Regression
CEECs	Central and Eastern Europe Countries
CIPS	Cross-Sectional Augmented Panel Unit Root Test
CO_2	Carbon Dioxide
CUSUM	Cumulative Sum
CUSUMQ	Cumulative Sum of Squares
DALRRD	Department Agriculture, Land Reform, and Rural Development
DF	Dickey-Fuller Test
DOLS	Dynamic Ordinary Least Squares

ECM	Error Correction Model
ECOWAS	Economic Community of West African States
EKC	Environmental Kuznets Curve
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign Direct Investment
FMOLS	Fully Modified Ordinary Least Squares
GCT	Granger causality test
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLM	Generalized Least Model
GMM	Generalized Method of Moments
GMO	Genetically Modified Organism
ha	hectares
HQIC	Hannan-Quinn Information Criterion
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
KRLS	Kernel-based Regularized Least Squares
LAC	Latin America and the Caribbean
MCST	Monte Carlo Simulation techniques
MENA	Middle East and North Africa
Mt	Metric Tonnes
NDP	National Development Plan
ODA	Official Development Assistance
OLS	Ordinary Least Squares
PDOLS	Panel Dynamics Ordinary Least Squares

PFMOLS	Panel Fully Modified Ordinary Least Squares
PHEH	Pollution Halo Effect Hypothesis
PHH	Pollution Haven Hypothesis
PP	Phillips–Perron test
PPML	Poisson Pseudo Maximum Likelihood
PSMDID	Propensity Score Matching and Differences-In-Differences
PVECM	Panel Vector Error Correction Model
R & D	Research and Development
RE	Renewable Energy
REC	Renewable Energy Consumption
SA	South Africa
SAARC	South Asian Association for Regional Cooperation
SBM-ML	Slack-Based Measure and Malmquist-Luenberger
SDG's	Sustainable Development Goals
SOYBP	Soybean Production
SSA	Sub-Saharan African Countries
T	Tonnes
TWh	Terawatt hours
UNISA	University of South Africa
VAR	Vector Autoregression
VECM	Vector Error Correction Model
WDI	World Development Indicator

CHAPTER 1: INTRODUCTION

1.1 Background

Climate change has become a major and alarming issue around the world. The primary cause of climate change is the burning of fossil fuels to generate energy, resulting in the emission of greenhouse gases such as carbon dioxide and methane (Nica *et al*., 2019; Rajak, 2021). Countries that are severely impacted include Nigeria, Zambia, Sudan, Tanzania, Kenya, and South Africa (Tadesse *et al*., 2019). Approximately 75% of world emissions are basically due to the combustion of traditional energy utilization and to mitigate global warming, there must be investments in strategies that reduce carbon emissions with technology and innovation (Ganda, 2019). According to British Petroleum (BP, 2023), fossil fuel combustion caused South Africa to emit about 435 metric tons of carbon dioxide in 2021. South Africa is the highest emitter in Africa and the 14th largest carbon dioxide emitter globally (Adebayo and Odugbesan, 2021), with China being the number one biggest carbon emitter globally (Caineng *et al*., 2021).

Climate change influences all sectors of the economy but the most vulnerable is agriculture. Agriculture is the main source of income and ensures food security for the majority of rural communities (Chandio *et al*., 2020a). The consequences of climate change on agriculture have become visible and evident over the years (Chandio *et al*., 2020a; Chen and Gong, 2021; Malhi *et al*., 2021). The changes in atmospheric climate have caused extreme temperatures resulting in droughts, forest fires, extremely cold weather, and heavy rainfall resulting in floods and thunderstorms (Duchenne-Moutien and Neeto, 2021). These climate changes have caused crop and livestock production and quality decline, farming infrastructure damage, harm to human health, ecosystem damage, and a decline in the GDP (Ebadi *et al*., 2020; Atanga and Tankpa, 2021; Weiskopf *et al*., 2021).

The agricultural industry is one of the biggest polluters and can also contribute to renewable energy generation as the sector also produces feedstock from energy crop biomass and livestock manure. One of the most significant energy crops in the world due to its high-quality oil content and plant-based protein is soybeans and it is grown in many countries in Africa mainly in Sub-Sahara Africa (Nakei, 2022). Soybeans are used as food, energy, and animal feedstock. Humans consume them as soymilk, soy flour, soy oil, and soy meal while animals use soybeans as feed and the seeds or crop residues are used to create renewable energy (Datta *et al*., 2019; Khanal and Shah, 2021). Soy oils extracted from the soybean are mainly used as a feedstock for biofuels (Barahira *et al*., 2021). According to Fernandez-Gnecco *et al*. (2021), the world's top producers of soybeans are Brazil, Argentina, and the United States of America (USA). In South Africa, Soybeans are grown in Limpopo, Gauteng, Northwest, Eastern, and Northern Cape in low quantities while it is grown in larger quantities in Free State, Mpumalanga, and Kwazulu-Natal. Due to hotter and drier climatic conditions, the production of soybeans has been severely affected by droughts and floods (Rattis *et al*., 2021).

The rational energy source that is environmentally friendly and sustainable is renewable energy which can mitigate climate change and global warming and has gained attention in discussions of energy sustainability and solutions globally (Akintande *et al*., 2020). The different types of renewable energy (RE) that different countries use to reduce the combustion of fossil fuels and other combustions are solar, wind, geothermal, hydropower, and bioenergy (Rahman *et al*., 2022). According to our World in Data (2021), Brazil is the highest producer of renewable energy contributing 46.22% while South Africa contributed only 3.41% in 2021. Furthermore, the most renewable energy produced in South Africa is solar and wind but globally it is hydropower (BP, 2021).

Solar uses the sun to generate energy, hydroelectric uses water to generate energy, geothermal uses underground heat to generate energy and bioenergy uses crops and animal manure as a feedstock to generate energy (Tovar-Facio *et al*., 2022). The agricultural sector has an influential role in renewable energy production as it provides feedstock and has the potential to produce more renewable energy (Ardebili, 2020; Adewuyi, 2020). South Africa's recent renewable energy investments have been focused on wind and solar developed by the Renewable Independent Power Producer Programme (Tagwi, 2022). The investments in solar and wind energies have led to the negligence of modern bioenergy potential.

Bioenergy and waste management energy systems ought to be given attention in terms of renewable energy development (Akinbami *et al*., 2021). Foreign Direct Investment (FDI) directed to Africa has led to the improvement of technologies in renewable energy which has reduced long-run change-related consequences while promoting sustainable development (Ergun *et al*., 2019). However, of these investments, few have been directed to bioenergy. The reality is energy transition will be an expensive exercise for many developing countries as domestic savings in developing countries are not enough to increase capital inflows for their investment objectives to uplift economic growth, alternatively, they turn to FDI (Ahmad *et al*., 2020). It has been widely debated that Africa needs climate finance from developed countries which are the major contributors of climate change.

It was the interest of this study to assess the association between agricultural production (soybean), RE consumption, FDI, GDP, and environmental quality. The availability of investments will have a direct influence on the level of green technology adoption in the country, consequently affecting economic growth. Renewable energy needs climate finance, without it, most countries will not be capable of transition. From the perspective of climate change measured by CO_2 emissions in this study, it is important to assess how all these macroeconomic variables react and affect soybean productivity. Considering that soybean is also an energy crop used in renewable energy globally, it is key to determine the role that RE consumption plays in soybean production together with the identified macroeconomic variables.

1.2 Problem Statement

Global warming and climate change are mainly a result of greenhouse gas (GHG) pollution such as CO_2 emissions. The GHG emissions are the most harmful substances that affect the natural ecosystem and human development (Alola *et al*., 2019). Climate change causes extreme temperatures and rainfall which have resulted in droughts, floods, storms, and a rise in sea levels. These events have caused disturbing effects on the environment, agriculture, food security and nutrition, housing and infrastructure, health, and income of the people (Purba *et al*., 2022). At the centre of climate change, low-hanging fruits for solutions rest in the utilization of renewable energy. In addition, energy insecurity is growing, with frequent load shedding that has been an obstacle in South Africa, affecting the agricultural industry and ultimately affecting farmers' profits.

The energy sector in South Africa has been at the centre of policy debates because of the growing and high demand for energy. The energy sector largely (more than

70%) depends on fossil fuels for electricity generation. The challenge is, fossil combustion releases greenhouse gases into the atmosphere which has caused global warming (Bose and Saini, 2022; He *et al*., 2023). The environmental effects caused by increased temperatures and weather extremes can be observed in the loss of biodiversity and ecosystem, changes in agricultural production, and loss of land (Bouwer, 2019). Soybean production has been heavily affected by these climatic impacts, droughts and floods, which has been evident by the reduced production over the years (Meyer et al., 2018; Engelbrecht et al., 2020). The use and production of renewable energy will reduce these effects and boost soybean production.

Renewable energy has become an intuitive option for the survival of the environment and people but has not received sufficient investments. For renewable energy technologies developments, South Africa has to increase clean technologies investments to fulfil its goal of zero carbon emissions. In the context of moving towards cleaner energies, it was of interest to see how renewable energy consumption, foreign direct investment and other macroeconomic variables affect soybean production. Moreover, soybean is a global energy crop and a strategic crop for South Africa. Its performance has not been assessed with environmental quality considered at the macro level in South Africa. The production of soybeans has been increasing in South Africa over the years which could be driven by competing needs globally, however for South Africa, the role of renewable energy consumption on soybean production is not yet known.

1.3 Justification of the Study

This study was conducted to evaluate the impact of renewable energy consumption, foreign direct investment, carbon dioxide emissions, and economic growth. No literature, under the review period, was found that investigated the impact of renewable energy consumption, economic growth, FDI, and environmental quality on Soybean production in South Africa. This study was important because it contributes to the body of knowledge and informs the policymakers on renewable energy consumption prospects and carbon emissions impact on South Africa’s economic growth while factoring in foreign direct investment in the agricultural sector. This study was important as it is in line with the National Development Plan 2030 (NDP) which aspires that the energy sector in South Africa will provide efficient and reliable energy service at competitive rates, expanded access to affordable energy for social equity, and environmentally friendly by reducing emissions and pollution. This is also in line with SDGs 7 and 13 which focus on clean energy and climate change.

Agriculture is one of the key sectors that create millions of jobs in South Africa which reduces poverty and high levels of inequality (Bhorat *et al*., 2020). Bioenergy is another source of energy that is renewable, and soybean is an energy crop that significantly contributes to bioenergy as a feedstock to produce biodiesel and biofuel. This study will not only outline the macroeconomic drivers of soybean production but also its interaction with renewable energy consumption which will inform policy on agriculture and renewable energy prospects. The study will further provide valuable information for policymakers in terms of how soybean producers can position themselves in the future considering new opportunities in the energy sector.

1.4 Aim of the Study

The study aimed to contribute to the discourse of renewable energy, SDGs 7 and 13 in the agricultural sector by generating empirical economic analysis on the short and long-run impact of renewable energy consumption and other macroeconomic variables on soybean production for the past 46 years.

1.5 Objectives of the Study

1.5.1 Main Objective

To analyze the impact of renewable energy consumption, foreign direct investment, economic growth and carbon dioxide emissions on soybean production in South Africa.

1.5.2 Specific Objectives

i. To analyze soybean production trends from 1975 to 2021 in South Africa.
ii. To examine the impact of renewable energy consumption, foreign direct investment, economic growth and carbon dioxide emissions on soybean production.
iii. To analyze the causality between soybean production and macroeconomic variables.

1.6 Research Questions

i. What are the production trends of soybeans from 1975 to 2021?
ii. What is the impact of renewable energy consumption, foreign direct investment, economic growth and carbon dioxide emissions on soybean production?
iii. What is the direction of causality of macroeconomic variables on soybean production?

1.7 Hypotheses of the Study

i. **Specific objective i**: No hypothesis.
ii. **Specific objective ii**: 4 hypotheses.
   - **H_{01}:** Renewable energy consumption does not have a statistically significant and positive impact on soybean production.
   - **H_{02}:** Carbon dioxide emissions do not have a statistically significant and positive impact on soybean production.
   - **H_{03}:** Economic growth does not have a statistically significant and positive impact on soybean production.
   - **H_{04}:** Foreign direct investment does not have a statistically significant and positive impact on soybean production.

iii. **Specific objective iii:** 4 hypotheses.
   - **H_{01}:** Renewable energy consumption does not Granger Cause soybean production.
   - **H_{02}:** Carbon dioxide does not Granger Cause soybean production.
   - **H_{03}:** Economic growth does not Granger Cause soybean production.
   - **H_{04}:** Foreign direct investment does not Granger Cause soybean production.

1.8 Limitations and Delimitations of the Study

The limitation of this study was the lack of data from the potential data sources on the identified variables, specifically recent years' data (2022 and 2023). The lack of funds to purchase data from the data sources was another limitation. To mitigate this, the study only focused on readily available data in the public domain. The study was delimited to South Africa and the study was focused on soybean production, renewable energy consumption, economic growth, and carbon emissions from the year 1975 to 2021.

1.9 Ethical Consideration

The study adhered to the research ethical standards of the University of South Africa. This study used time series data which was collected over time from reputable international data sources. The ethical clearance certificate was applied for and obtained from the University of South Africa, with an ethical clearance number of 2023/CAES_HREC/1911. Available data from public sources were accordingly acknowledged. All the information used by different authors was acknowledged and referenced. The results formed part of the bigger bioenergy project where the results of the study were shared in preparation of policy briefs.

1.10 Definition of Terms

Renewable energy is energy that comes from natural sources that can be replenished and plentiful (Elavarasan, 2019). In this study, renewable energy refers to energies that do not run out from their sources and emits low carbon dioxide. The sources were bioenergy, solar, wind, geothermal, and hydroelectric which depend on the natural occurrences for their functioning (Osman *et al*., 2023).

Renewable energy consumption is the total energy used from all renewable sources (Inayat and Raza, 2019). In this study, renewable energy consumption was identified as the total energy used by South Africa from all the renewable energy sources (Baloch *et al*., 2019). This included solar, wind, geothermal, hydroelectric and bioenergy.

Soybean (Glycerine max) is an annual legume crop that is economically important providing rich in protein food to people and feeds to animals (Yuan *et al*., 2020). Currently, soybean has been seen and used as a potential feedstock to generate renewable energy. In this study, soybean was referred to as an oilseed crop used as a potential feedstock to create renewable energy such as biodiesel (Gonzalez *et al*., 2023).

Foreign direct investment is a cross-border investment whereby the investor has control of the enterprise in another economy that transfers technologies between countries and promotes international trade (Orjiakor and Onyia, 2022). In this study, the FDI referred to the investment from other countries into South Africa.

Economic growth is defined as the improvement of the economic production of goods and services over time (Magdalena and Suhatman, 2020). In this study, economic growth was the total output of South Africa's production of goods and services.

Carbon dioxide emissions are the result of environmental deterioration which is the major contributor to GHG emissions (Haseeb *et al*., 2020). This definition was adopted in this study.

1.11 Objectives Summary

Table 1.1: Summary of objectives

Objectives	**Research Questions**	**Research Hypothesis**	**Data requirement**	**Data Analysis**
To analyze soybean production trends from 1975 to 2021.	What are the production trends of soybeans from 1975 to 2021?	n/a	Soybean production	Descriptive analysis
To examine the impact of renewable energy consumption, foreign direct investment, economic growth and carbon dioxide emissions on soybean production	What is the impact of renewable energy consumption, foreign direct investment, economic growth, and carbon dioxide emissions on soybean production in South Africa.?	renewable energy consumption, foreign direct investment, economic growth, and carbon dioxide emissions does not positively impact soybean production	renewable energy consumption, foreign direct investment, economic growth, carbon dioxide emissions	ARDL Model
To analyze the causality between soybean production & macroeconomic variables	What is the direction of causality of macroeconomic variables on soybean production?	There is bidirectional causality between soybean production & macroeconomic variables	foreign direct investment, carbon dioxide emissions, economic growth, renewable energy consumption	Pairwise Granger Causality

Source: Author (2024)

1.12 Chapter Summary

The chapter emphasized the impact of carbon dioxide emissions on soybean production which is used as human food and animal feed, it also contributes to the GDP of the country and investment in soybean production, as an energy crop will help the country produce and use renewable energy. The problem statement highlighted that South Africa relies on fossil fuels for energy which further causes environmental degradation that has a negative impact on soybean production. Therefore there is a need for renewable energy production and use. The study aimed to contribute to the discourse of renewable energy in the agricultural sector by generating empirical economic analysis on the short and long-run impact of renewable energy consumption and other macroeconomic variables on soybean production for the past 46 years. The chapter further outlined the objectives, hypotheses, research questions, limitations and delimitations, justification of the study, ethical considerations, definitions of key terms, and the summary of the objectives.

1.13 Study Outline

This study is outlined as follows:

- Chapter 1: outlined the background of the study, details the research problem, the aim, objectives (main and specific), hypotheses, research questions, limitations and delimitations, justification of the study, ethical considerations, definitions of key terms used in this study, and the summary of the study.
- Chapter 2: provides the conceptual framework, review of literature linked with the variables used in this study, and analytical framework adopted by this study.
- Chapter 3: Describes the study area, research design, and the methodology used in this study.
- Chapter 4: provides soybean trends over the period 1975-2021 and trade.
- Chapter 5: presents and discusses the descriptive and inferential analysis outcomes of this study.
- Chapter 6: summarised the study objectives, conclusion, and recommendation, and further stated the study's future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discussed the conceptual framework of the study, a theoretical framework, a review of the literature for the variables used in the study, an analytical framework and then the summary.

2.2 Conceptual Framework

The study examined the existing relationship between several macroeconomic variables and agricultural production. Economic activity is crucial in poverty reduction plans. The agricultural industry is a key strategic industry in poverty alleviation in developing nations. (Gassner *et al*., 2019). However, for the sector to grow capital injection is essential. Growth in agricultural production is influenced by investments in the country. However, the ability of the agricultural sector to increase productivity is endangered by climate change which negatively affects crop yield and growth (Raza *et al*., 2019). To ensure food security and employment, South Africa's agricultural industry needs to be a flexible and active economy, thus the sector should embrace new ideas, technologies, and innovations but in a sustainable manner (Wale and Chipfupa, 2021).

The major reported challenge in economic growth discourse is the environmental quality deterioration that comes along with economic growth. This is because economic activities across the globe and in South Africa are dependent on the energy sector (Akadiri *et al*., 2019). The heavy dependence on the combustion of fossil fuels for its economic activities emits more CO_2 emissions. The agricultural sector is also energy-intensive and one of the industries that contribute to the degradation of environmental quality (Ngarava *et al*., 2019). The agricultural sector is also responsible for emissions and therefore should be taking steps to reduce emissions. Food production accounted for over 70% of total global ammonia emissions (Liu *et al*., 2022). This is mainly due to the adoption of intensive agricultural techniques to meet the demands of rapid population growth (Rasheed *et al*., 2020).

Important to note is that agriculture generates the most biomass energy and produces 140 billion metric tons of biomass annually, however, rotting agricultural biomass emits methane and leachate, while open burning by farmers to clear fields also releases CO_2

and other hazardous particles into the environment (Kumar *et al*., 2023). This shows untapped opportunities for biomass from the agricultural sector that could be used for energy. Agriculture production requires energy for mechanization, irrigation, and processing. Although these activities emit carbon emissions, livestock farming has been reported to emit more methane gases negatively affecting the environment. Feng *et al*. (2022) reported that Methane (CH_4) had a global warming potential that is 84 times higher than that of CO_2 on a 20-year basis. In South Africa, soybean is a critical crop and a means of subsistence for small-scale farmers in rural regions, and it is a crucial energy commodity utilized in the production of bioenergy worldwide and preferred for its reasonable and low-grade oil factor (Chhabra *et al*., 2017). It is imperative to understand the environment, investment, energy, and economic growth interaction with soybean output in pursuit of the bio-circular economy development within the agricultural industry policy space.

This research evaluated the impact of FDI, RE consumption, GDP, and CO_2 emissions on soybean production. Renewable energy consumption was measured as total renewable energy used in terawatts-hour, carbon dioxide emissions in million tonnes (proxied for environmental quality), and foreign direct investment measured by net cash inflows. Economic growth proxies measured by GDP per capita and soybean productivity were used. The theoretical frameworks that supported this study comprised the Environmental Kuznets Curve (EKC), Pollution Halo Effect Hypothesis (PHEH), and Pollution Haven Hypothesis (PHH). The theoretical framework was used to unpin the possible relationship between agricultural productivity and chosen macroeconomic variables.

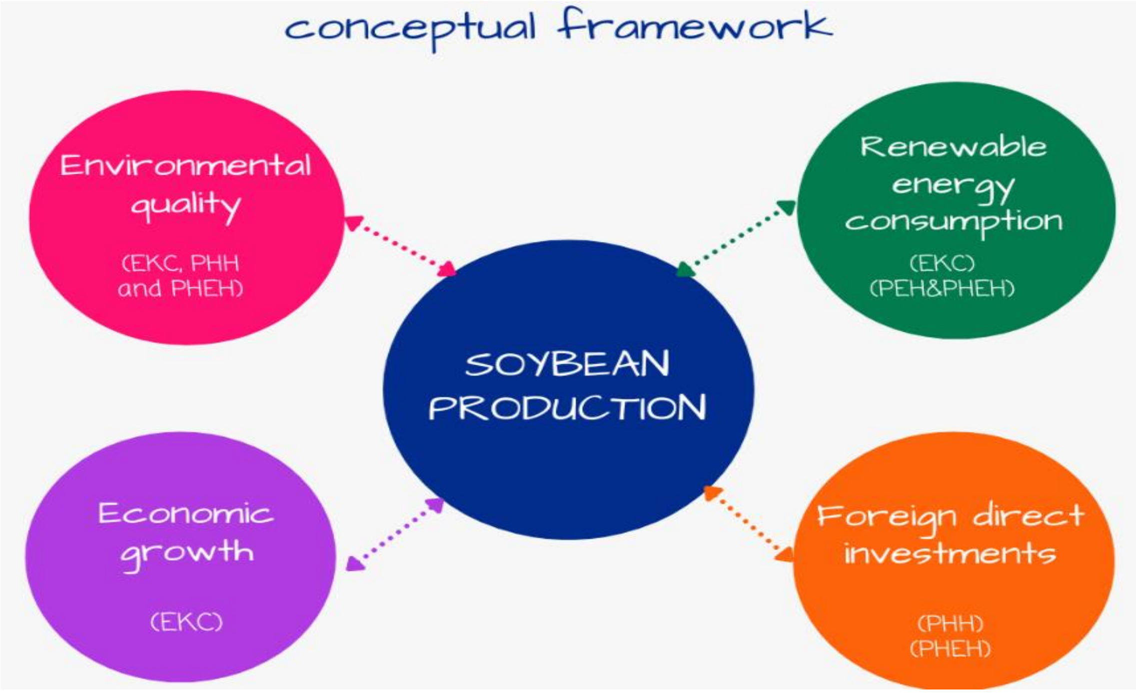

Figure 2.1 Conceptual Framework

Source: Author (2024)

Figure 2.1 illustrates how the agricultural sector (soybean production) would be affected by different explanatory variables in the study. The nexus between renewable energy consumption (explained by EKC, PHH, and PHEH theories), carbon dioxide emissions (explained by EKC, PHH, and PHEH theories), foreign direct investment (explained by PHH and PHEH theories), and economic growth (explained by EKC theory), was discussed.

Soybean production was identified as the response variable in this study. Through the lenses of the selected theories, it was hypothesized that the explanatory variables would have a positive and negative impact on the dependent variable. Demand in the renewable energy industry leads to a rise in the production of soybeans as the crop is a feedstock for bioenergy generation. *A priori* expectation was that foreign direct investment would affect soybean production positively due to the cash inflow that will be used to increase infrastructure and technology that will trickle down to improved agricultural productivity. Because the improvement in economic growth also entails an increase in agricultural economic growth, soybean output increase was anticipated to benefit from economic growth. Economic growth theories show that there will be more pollution as a result of increased agricultural activity, which will lead to environmental degradation. Using selected theories, the study variables’ expected behaviour was discussed below.

2.3 Theoretical Framework

2.3.1 The Environmental Kuznets Curve (EKC)

2.3.1.1 Economic Growth, Environmental Quality, and Renewable Energy

South Africa largely relies on the burning of coal for energy use and is one of the largest emitters of GHG in Africa (Shikwambana *et al*., 2021). The EKC hypothesis was put forth by Grossman and Krueger from their analysis of the association between environmental indicators and per capita income (Grossman and Krueger, 1995), which was inspired by Simon Kuznets's concern about the connection between income inequality and economic growth (Kuznets, 1955). The Environmental Kuznets Curve theory was adopted in this research study, which explained the relationship between renewable energy, environmental quality, and economic activity.

The relationship was explained by the three phases of the EKC, namely, *the pre-industrial* phase, determined by economic inefficiencies with less pollution, *the industrial* phase, characterised by an increase in income and more pollution, and the *post-industrial* phase, characterised by an upsurge in income but with supplementary green technologies reducing pollution (Dinda, 2004 and Tagwi, 2023). The Environmental Kuznets Curve (EKC) hypothesis suggests that it will be unlikely for poor economies to prioritize environmental quality, however with an increase in GDP per capita, the nation will be able to adopt cleaner technologies and have better financial and human capital capacities to implement environmental regulations that will curb emissions (Aydin and Turan, 2020). Ideally, the post-industrial phase is a desirable stage for every economy.

According to the EKC, in the ***pre-industrial stage*** which is the first stage of economic expansion, governments prioritize production and consumption above environmental issues, which describes the link between economic development and environmental deterioration (Aydin and Turan, 2020). In the beginning, the growth of the economy is at its lowest along with the pollution due to fewer economic activities happening (Zhang, 2021) as represented by an inverted U-shaped curve in Figure 2.2. During this phase, the hypothesis is centred on the development of the economy while experiencing an increase in pollution, primarily because at this stage, the environmental regulations and policies are relaxed (Sousa, 2015; Ziyu, 2022).

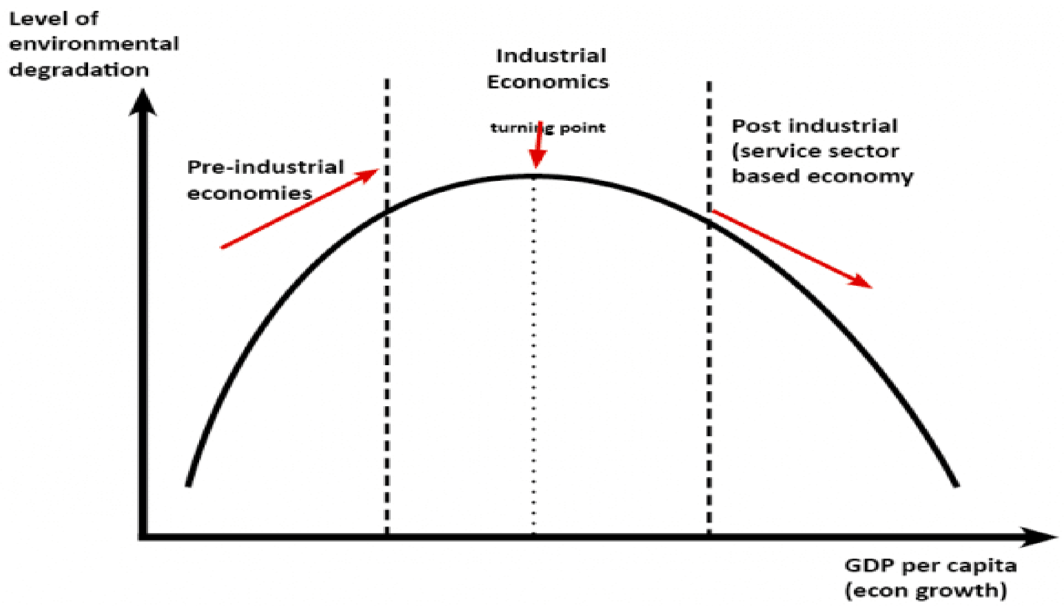

Figure 2.2: The Environmental Kuznets Curve

Source:https://www.economicshelp.org/wp-content/uploads/2015/09/kuznets-environment-600x450.png.webp

As more activities are happening in the economy, waste is produced from the additional resources being consumed, which leads to environmental damage increasing (Kasioumi, 2021). At some point, the economy passes through pre-industrialization, during which various economic development activities take-off (Ozturk *et al*., 2023), such as increasing agricultural and energy production. Agricultural production will cause pollution through the use of fertilizers and toxic farm chemicals that help to increase production, also increasing the income per capita (Tsion and Steven, 2019). Land emissions, manure management, enteric fermentation, crop cultivation, and fuel use in agricultural production have been reported to have accounted for the majority of direct agricultural greenhouse gas emissions (Hitaj *et al*., 2019), whereas indirect emissions are primarily brought on by deforestation motivated by an increase in arable land due to rising demand for agricultural products subsequently increasing pollution (Ntinyari and Gweyi-Onyango, 2021).

According to Rasheed *et al*. (2022), energy use is a significant economic activity and an essential component of economic growth. Utilizing energy contributes to enhancing standards of living, increasing productivity and efficiency, and also provides new incentives for investors and entrepreneurs to increase investments to boost production and employment in an economy. However, these economic activities drive fossil fuel energy consumption demand (Wang *et al*., 2022).

The EKC indicates that in the ***industrial phase***, which is the stage of mass production, the economy reaches a turning point, wherein the environmental quality of a nation will begin to improve (Yao *et al*., 2019). In other words, the theory suggests that there is a self-correcting connection between environmental deterioration and GDP after economic growth reaches a peak, implying that economic expansion is also key in addressing environmental deterioration in a nation (Chang *et al*., 2019). It was observed that society will appreciate environmental amenities and a clean environment at a certain point when an economy reaches a certain degree of economic growth or rather its full capacity (Balsalobre-Lorente *et al*., 2019a). This is because people will give more importance to the environment once their basic needs have been met. As affluence rises, manufacturing techniques will change from being extensively industrialized, which produces more emissions, to being more service-oriented, which produces less emissions (Tagwi, 2023).

As income improves, government spending on environmental protection and cleaner technology is also improved, resulting in more expenditure on advanced green technologies (Iqbal and Kalim, 2023). This is because high-polluting industries are gradually replaced by low-polluting ones, which results in a reduction in the overall quantity of emissions for each output unit. This way, the structural transformation in the process of economic growth can have an impact on environmental quality (Yao *et al*., 2019). At this point, the country will have enough money that will be directed or devoted to research and development (R & D) to find solutions to their environmental degradation (Ameyaw *et al*., 2020).

The EKC theory states that in the ***post-industrial phase,*** which is the post-peak economic growth point, pollution levels decrease, allowing the country to balance the trade-off between economic progress and environmental deterioration (Sinha *et al*., 2019; Wang and Lv, 2022). The adoption of energy-saving technology as a result of inventions and technical advancements, which reduces pollution is reinforced (Yao *et al*., 2019). According to Gruda *et al*. (2019), in the agricultural sector, mitigation measures will frequently rely on introducing novel agricultural techniques that boost output while lowering greenhouse gas emissions. Sustainable intensification of agricultural production, increased resource use effectiveness, conservation agriculture, better management of livestock and grazing, increased energy efficiency, crop development, and providing the funding required for implementing emissions-reducing agricultural procedures are some examples of innovative practices (Lipper *et al*., 2014; Devkota *et al*., 2022).

At this stage, the economy continues to develop and would have adopted green technologies such as creating energy through renewable sources (Haberl *et al*., 2020). Policies and regulations regarding environmental quality and supporting the use of renewable energy technologies are mostly implemented (Fu *et al*., 2021). At this point substituting fossil energy use with renewable energy consumption becomes an effective measure to alleviate carbon emissions (Kirikkaleli *et al*., 2022). However, for developing economies, the contribution of RE consumption in the energy consumption mix is still comparatively low because encouraging RE consumption is a challenge for developing economies (Dong *et al*., 2020). Given that the generation of renewable energy is cleaner, it is preferable for the environment if agricultural economic expansion coincides with the rise of the renewable energy sector, however, this requires climate finance which is mostly lacking in most developing economies (Tagwi, 2023). In this study, EKC was relevant as the interaction between the environment and economic activities in the agricultural sector is envisioned.

2.3.2 Pollution Haven and Pollution Halo Effect Hypothesis

2.3.2.1 Foreign Direct Investment, Environment and Renewable Energy

Foreign Direct Investment (FDI) inflows may have both positive and negative consequences on the environment of the host economy (Opoku *et al*., 2021). The Pollution Haven Hypothesis (PHH) is used to explain the adverse environmental consequences of FDI inflows (Gyamfi *et al*. 2022), whereas the Pollution Halo Effect Hypothesis (PHEH) is used to interpret the good benefits of FDI (Gao *et al*., 2022). Pethig (1976) introduced the PHH, as the environment was viewed as a production factor by Walter and Ugelow (1979), who also demonstrated how environmental rules might change the flow of foreign capital (Balsalobre-Lorente *et al*., 2019b). According to the pollution haven effect, investments in energy-intensive industries or economies with lax environmental regulations cause pollution in the host nation (Abbass *et al*., 2022).

PHH states that financial globalization attracts foreign investment, particularly in developing and emerging nations, where unclean industrial processes are more prevalent, leading to a predicted increase in CO_2 levels in the host economies (Demena and Bergeijk, 2019; Chishti *et al*., 2021). This sensation develops when strict environmental regulations in developed countries force investors to invest in developing nations with flexible environmental regulations (Leal *et al*., 2021). As a result, these investors take advantage of the relaxed environmental regulations in developing nations to invest in their industries that produce large amounts of pollution (Yu and Li, 2020; Dong *et al*., 2021). Therefore, the growth of polluting industries inside the economies that welcome FDI increases those countries' individual FDI inflows, but the inflows drive more CO_2 emissions in the economy (Qin and Ozturk, 2021).

As inbound FDI might increase the usage of fossil fuels and hence increase the accompanying CO_2 emissions, such FDI inflows are expected to have a detrimental effect on the environment in the host economies (Zafar *et al*., 2020). Contrarily, according to the principles of the PHEH, an increase in comparatively clean FDI can be anticipated to have a positive impact on technological advancement (Murshed, 2022), thus leading to the development of the necessary technologies to facilitate the switch to renewable energy necessary to ensure environmental sustainability (Hamid *et al*., 2021). In such an environment, carbon emissions are decreased when energy-efficient technology is introduced to the host nation (Kwakwa *et al*., 2022).

Technological innovation has been generally accepted in the literature as being essential to uncoupling CO_2 emissions from economic development (Liu and Feng, 2021). In this sense, funding research and development (R & D) initiatives using domestic or international resources might be useful in promoting technological advancement (Wang *et al*., 2020). Accordingly, the PHEH acknowledges the significance of financial globalization for promoting technical innovation in the economy of the host nations, which can be connected to the successful execution of CO_2 emissions-reduction measures through green technologies (Musah *et al*., 2022).

Therefore, the harmful environmental effects brought on by FDI inflows can then be mitigated by investing in renewable energy to promote environmental well-being (Musah *et al*., 2022; Dauda *et al*., 2021). In this study, the Pollution Haven and pollution Halo Effect Hypothesis is relevant as interactions between FDI, CO_2 emissions, and renewable energy will be studied.

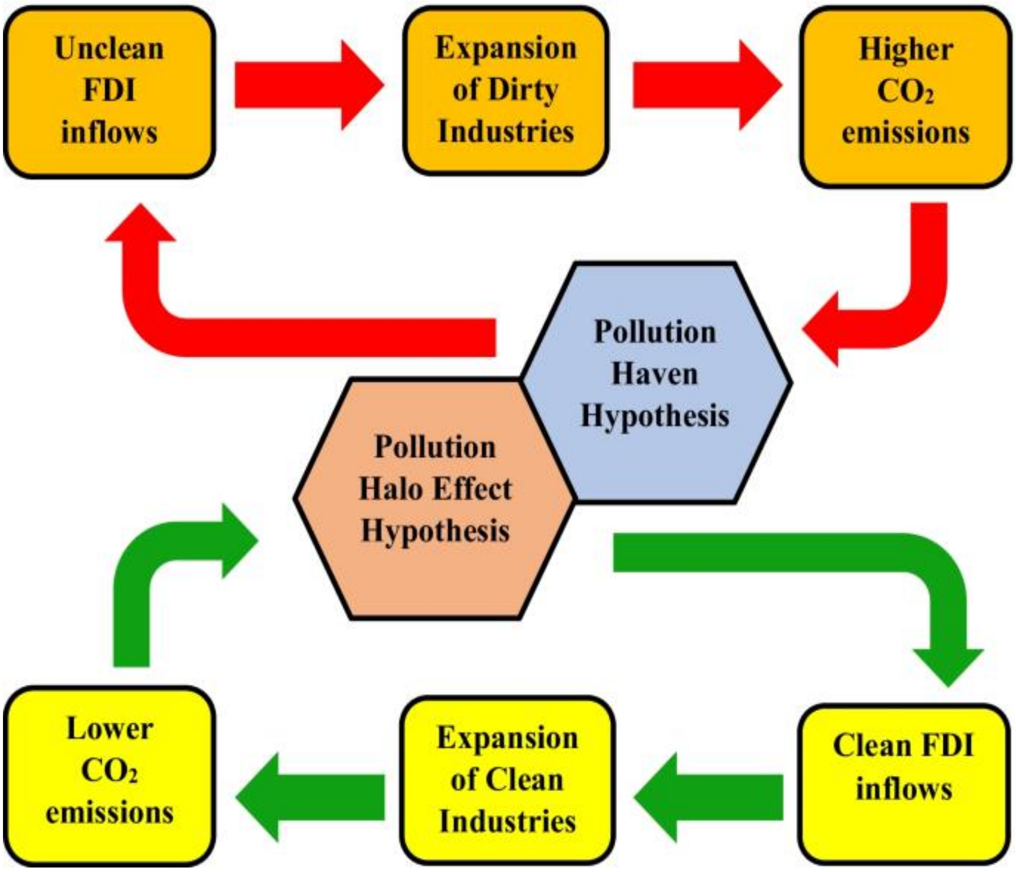

Figure 2.3: FDI Theoretical framework

Source: Musah *et al*. (2022)

Figure 2.2 illustrates the pollution haven hypothesis which shows that unclean FDI cash injected into the host nation will lead to an expansion of activities of polluting industries due to fossil fuel use leading to more CO_2 emissions. This means that some investments will be made that will degrade the environmental quality of the country. While the pollution halo effect hypothesises that FDI for clean cash inflows will increase the activities of clean industries that lower CO_2 emissions, this is entirely up to the host government to decide where to spend the inflows (i.e. more or less environmentally friendly economic activities), with the exception of some cases where the inflow will have specific instructions on where it should be spent. Depending on where the host FDI will be diverted, it is expected that FDI will either affect the environment positively or negatively.

2.4 Review of literature for the variables used in the study

2.4.1 Agricultural Production and CO_2 Emissions

Using data from 1960 to 2017, Sibanda and Ndlela (2020) applied the Autoregressive Distributed Lag (ARDL) approach and found that carbon emissions lowered agricultural production, affecting food security in South Africa. Similarly, in Pakistan, an ARDL technique was used to estimate the data from 1980 to 2018 and observed that CO_2 and agriculture value-added had an inverse relationship in the long run (Raza *et al*., 2021). Gurbuz *et al*. (2021) found a unidirectional causality link between CO_2 emissions and agricultural value-added using data from 1992 to 2014 in Azerbaijan. Using data from 1995 to 2017, Usman *et al*. (2022a) found a substantial positive association between the agricultural value chain and environmental quality through the use of a fully modified ordinary least square (FMOLS) approach in the seven South Asian countries (Pakistan, Bangladesh, India, Bhutan, Maldives, Nepal and Sri Lanka).

In Brazil, a unidirectional causality was established between CO_2 and agriculture productivity using the ARDL bounds cointegration technique and Granger causality tests from 1980 to 2013 (Jebli and Youssef, 2019). Through the application of quarterly frequency data from 1990q1 to 2018q4 using Bootstrap ARDL analysis, Alam *et al*. (2023), found a negative correlation between CO_2 and agricultural output in India. According to Kwakwa (2023), an unfavourable association was observed between agriculture productivity and CO_2 using data from the 2002–2021 period estimated by the FMOLS regression method in 32 African countries. In Pakistan, agricultural production was found to have a negative effect on CO_2 emissions between 1970-2017 using the vector ARDL method (Rehman *et al*., 2021a). Chandio *et al*. (2020b), using the ARDL estimates from 1990 to 2016 period reported a linear relationship between agricultural production and CO_2 emissions in China. Rehman *et al*. (2021b) also found a positive association between agricultural production and carbon dioxide emission from the 1988-2017 period in China through the use of the ARDL technique.

According to Ridzuan *et al*. (2020), crop production was found to significantly reduce CO_2 emissions using the ARDL approach for the period 1978 to 2016. Using canonical cointegrating regression (CCR), dynamic ordinary least squares (DOLS), and FMOLS models, agricultural production was found to reduce CO_2 emissions in Egypt from 1990 to 2019 period (Raihan *et al*., 2023). A similar study conducted by Raihan and Tuspekova (2022a), using the same techniques of data from 1990-2019 discovered that agricultural value-added reduced CO_2 emissions in Nepal. The authors conducted another study in Mexico from 1990-2019 using the DOLS model and found that agricultural value added had a significant influence in reducing CO_2 emissions (Raihan and Tuspekova, 2022c). The same results were found for Turkey (Raihan and Tuspekova, 2022b) using DOLS from 1990 to 2020 period that increasing agricultural production has reduced CO_2 emissions.

With yearly data ranging from 1980 to 2020, a short and long-run positive relationship was found between Bhutan's agriculture and CO_2 emissions (Rehman *et al*., 2022). According to Qiao *et al*. (2019), CO_2 emissions were significantly increased by agriculture from the G20 nations employing panel data from 1990 to 2014 using the FMOLS technique cointegration test. Agriculture was found to reduce CO_2 emissions using panel data during the 1970 to 2013 period from the selected ASEAN countries using ordinary least squares (OLS), FMOLS, and DOLS techniques (Liu *et al*., 2017). A policy was discovered to have reduced agricultural carbon emissions in China during the 2011 to 2020 period using the propensity score matching and differences-in-differences (PSMDID) methods (Du *et al*., 2023). Nwaka *et al*. (2020), used panel data from 15 Economic Community of West African States (ECOWAS) and reported that agricultural output increased overall CO_2 emissions, suggesting a shift towards traditional farming practices and biomass utilization. It is clear from the examined literature that there are both positive and negative relationships, depending on the location and time, between agriculture and CO_2 emissions.

2.4.2 Agricultural Production and RE Consumption

Jun *et al*. (2023) found a unidirectional relationship between agriculture and energy use in Nigeria for the period of 28 years (1990-2017) using the ARDL model and Granger causality test. Agriculture and RE consumption were observed to have been negatively associated using applied panel fixed effect regression (APFER) and Generalized Method of Moments (GMM) estimator on yearly cross-sectional data from 2000 to 2017 in the South Asian Association for Regional Cooperation (SAARC) countries (Naseem and Guang Ji, 2021). Using the Granger causality tests, a unidirectional causality running from agricultural contribution to renewable energy consumption for a balanced panel of five SAARC countries (Bangladesh, Bhutan, India, Nepal, and Pakistan) from 1990 to 2013 (Dar and Asif, 2020) was found.

In a study done in Indonesia using the ARDL technique from 1986 to 2020 period, Nendissa *et al*. (2022) indicated that RE consumption had a positive association with agricultural growth. In Africa, renewable energy had a negative influence on agricultural carbon emissions using panel FMOLS (PFMOLS) and panel DOLS (PDOLS) estimation procedures from 1990–2019 period (Zwane *et al*., 2023). Another study by Zhang *et al*. (2019), showed a unidirectional causality between agricultural energy consumption and agricultural growth in China using the ARDL technique from 1996 to 2015.

Using Data from 1990 to 2015 estimated by the ARDL bounds testing method and the Johansen cointegration approach in China, RE was observed to have a unidirectional causality association with agricultural production (Chandio *et al*., 2021). In South Africa, Tagwi (2022) found a unidirectional causality association between agricultural GDP and RE consumption from the 1972 to 2021 period by applying the ARDL approach. According to Ali (2021), using the panel cointegration methods and the Panel Vector Error Correction Model (PVECM) with data from 1990 to 2015, agricultural value-added and RE consumption had a unidirectional relationship from West Africa's 13 countries.

A bidirectional association was found between RE consumption and agricultural production using panel unit root tests, cross-sectional tests, cointegration tests, Driscoll & Kraay approach, FMOLS regressions and causality analysis with data from 1996 to 2015 for Latin America and the Caribbean (LAC), Sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), Europe, Asia and the Pacific regions (Yasmeen *et al*., 2021). The ten Association of Southeast Asian Nations (ASEAN) nations were investigated using the Mean Group (MG) class estimators and Chopra *et al*. (2022), discovered that RE use positively contributed to the agricultural sector.

Similarly, in Brazil, Russia, India, China, and South Africa (BRICS) during the period 1990–2019 using several econometric techniques such as the Westerlund cointegration test, Shah *et al*. (2023), established that renewable energy increased agricultural productivity. In Malaysia, energy consumption showed a negative and substantial impact on agriculture value added when estimated through the GMM estimator on data from 1985 to 2016 period (Akhtar and Masud, 2022). A study by Singh (2022), using the 3-stage least squares (SLS) simultaneous equation estimation from 2000 to 2019 data reported that renewable energy consumption had a linear relationship with the agricultural sector in Southern Europe and Northern Europe regions but negative in Eastern Europe and Western Europe. Aydoan and Vardar (2020), suggested that the E7 nations should maintain raising the proportion of RE uses in the agriculture sector to promote growth. The evaluation indicates that the connection between agricultural productivity and RE use is influenced by the specific location where the research is done, leading to variations across various nations and periods.

2.4.3 Agricultural Production and Economic Growth

Economic growth is the aggregate performance of various industries in an economy. Therefore, the agricultural industry's performance will equally affect the economy positively or negatively. The ARDL approach was used in the Central and Eastern Europe (CEECs) countries using data from 2000 to 2017, the findings demonstrate a bidirectional association between agriculture and GDP (Florea *et al*., 2020). Similarly, in the thirteen Asia Pacific countries (APCs), the results showed that there is a bidirectional causality connecting GDP and agriculture using the ARDL and Granger causality test from 2005-2017 data (Latif *et al*., 2020). According to Hussain *et al*. (2019), a significantly positive and bidirectional causal association existed between agriculture and GDP during the years 1978 to 2016 using the ARDL bound testing technique in the Malaysian economy.

Tampubolon (2023) showed a bidirectional association between GDP and the agriculture sector using quarterly data from Q1 2019 to Q3 2022 data. In Brazil, a positive and unidirectional causality association between agriculture and GDP using the ARDL technique during the period 1980 to 2013 period was reported (Jebli and Youssef, 2019). In Botswana, crop production and economic growth had a linear relationship from 1990 to 2017 period using the ARDL bound testing approach (Matandare *et al*., 2021). In Bangladesh, a positive association was found between agriculture and GDP when using 1990 to 2018 data estimated by the ARDL approach (Uddin *et al*., 2022). Using much wider data from 1975 to 2019, agriculture was positively influenced by economic growth in Bangladesh and India using the ARDL model (Islam *et al*., 2020). Matuka and Asafo (2021), reported a favourable relationship between GDP and agricultural growth between 2000 to 2018 using the ARDL technique.

In Nigeria, it was reported that growth in agricultural output increased economic growth during the 1981 to 2019 period using the ARDL and the Kernel-based Regularized Least Squares (KRLS) approach (Akadiri *et al*., 2022). In another study conducted in Gambia, the contrary findings showed an unfavourable relationship between GDP growth and agriculture from the 1960 to 2017 period using the Granger causality framework and the ARDL approach (Ceesay *et al*., 2022). A unidirectional association was found amongst GDP, CO_2 emissions, land under cereal crops, and agriculture value-added from the 1961 to 2014 period using the ARDL model in Pakistan (Ali *et al*., 2019). The review also suggests that the originality of the association between agricultural production and GDP is inconclusive and depends on the region and the period.

2.4.4 Agricultural Production and Foreign Direct Investment

From 1995 to 2015 period, a linear relationship between FDI and agricultural production from 50 developing nations using three step-approach was found (Dhahri and Omri., 2020a). A positive relationship was also observed between FDI and agricultural land using panel data from 1991-2018 from 46 Asian countries using the models OLS, POLS, GMM and two-stage least squares (2SLS). However, the study also reported a harmful relationship between FDI, and agriculture value added (Paul *et al*., 2021b). According to Tian (2023), FDI was found to be influenced by agriculture official development assistance (ODA), this was measured using the Poisson pseudo maximum likelihood (PPML) approach and data from 1991 to 2019 from 63 developing countries.

Using System-GMM and Nonlinear ARDL of panel data from 1985 to 2019 for lower-income, upper-income, lower-middle-income, and upper-middle-income, countries, Qamruzzaman (2022) reported a positive relationship between FDI and agricultural production. Using data for the 2004 to 2016 period from China's 24 provinces the results showed that FDI had a positive association with agriculture using the slack-based measure and malmquist-luenberger (SBM-ML) index and two-step system generalized moment method (GMM) economic techniques (Wang *et al*., 2019). The results from a study conducted by Obekpa *et al*. (2020) demonstrated that in the short run, FDI had a beneficial impact on agriculture from 1980 to 2018 period in Nigeria using a Vector Autoregressive Model.

Obekpa *et al*. (2021) used Johansen Cointegration, VECM, and Monte Carlo Simulation techniques (MCST) and found that in the short run, FDI had a harmful effect on agricultural production although, in the long run, it was positive from 1980 to 2018 period in Nigeria. In contrast, Martin-Odoom (2021) observed a positive association between FDI and the agricultural sector in the short run while in the long run, the relationship was negative from 1984 to 2019 using the ARDL model in Ghana. Agricultural output was believed to attract more FDI in India using vector autoregressive specification technique from 1995 to 2016 period (Jana *et al*., 2019). According to Chukwu *et al*. (2022), Agriculture and FDI had a positive bidirectional causality from 1990-2019 period in 23 African countries using heterogeneous panel Granger causality test, panel multivariate linear and nonlinear Granger causality test. A positive association was found between agricultural production and FDI using data from 1980 to 2014 in Djibouti. Using the ARDL technique (Elmi, 2023).

2.5 Analytical Framework

There are different vector autoregression models that different authors use to analyze time series data such as the Poisson pseudo-maximum likelihood (PPML) approach, autoregressive distributed lag (ARDL) model, System Generalized Method of Moments (GMM) model, Autoregressive Integrated Moving Average (ARIMA) model.

2.5.1 Poisson pseudo-maximum likelihood (PPML) approach

The PPML addresses overdispersion and temporal correlation in count time series data by extending the Poisson cross-sectional regression model. The PPML is suitable for counting data, where the response variable counts discrete events. According to recent research, the PPML estimate is the most popular, most effective, and accurately described technique for structural gravity models (Dadakas *et al*., 2020). Compared to other approaches, the PPML offers many benefits, including proper handling of heteroscedasticity, model misspecification, and excess zeros (Prehn *et al*., 2016; Mchani, 2022). The PPML estimator fundamentally resolves econometric consistency and effectiveness challenges that arise in the expected existence of heteroscedastic residuals (Esteve-Pérez *et al*., 2020). This approach applies to continuous data regressions. The PPML model has gained attention, and incredible success, and its appealing characteristics have expanded since it was first introduced to the trade sector (Kwon *et al*., 2022). The PPML is focused on count data with a specific distributional assumption, however, it does not have the capabilities of estimating short and long-run dynamics in a model and was therefore not appropriate based on the study's objectives.

2.5.2 System Generalized Method of Moments (GMM) model

The GMM simultaneously analyses cross-sectional and time series relationships. Its primary focus is on addressing endogeneity (difficulty in establishing a causal relationship between regressor and regressed) and bias problems in panel data. The two-step GMM approach was recommended by Arellano and Bover (1995), and Blundell and Bond (1998). The GMM system can manage bias and consistency, which lessens the likelihood of omitting the undetected time-invariant impact (Adika, 2020). The system GMM model for regression is a more reliable and effective estimation method that examines the resilience and realization of the mistakes that are associated with the past and the present (Naseem and Guang Ji, 2021). The endogenous and heteroskedasticity issues that may arise among the model variables can be managed by the system GMM (Jin *et al*., 2019). The system GMM model has limitations such as issues of instrument proliferation that arise when an excessive number of instruments are generated in the instruments set which results in biased outcomes when running the model, and the GMM estimator is very susceptible to model specifications, even when a simulated or actual dataset is used (Cheng and Bang, 2021). The GMM model captures the short-term dynamics of time series data because it disregards the stationarity of variables, therefore, it is uncertain whether the calculated models depict a spurious relationship or a structural long-run equilibrium relationship (Kwend and Chinoda, 2019). However, this study's focus was on establishing long-run dynamic relationships in time series data and this method failed to account for such and was therefore not preferred.

2.5.3 Autoregressive Integrated Moving Average (ARIMA) model

The ARIMA models are based on the parsimony principle (Simplicity) in their identification, estimation, and diagnostic procedures (Mohamed, 2022). It is a stringent statistical methodology that uses stationary and non-stationary time series past data to generalize a forecast (Nyoni and Bonga, 2019), as an ancient time series analysis technique it explains time series using previous values and stochastic error factors. It includes autoregressive, integration, and moving average processes, making it commonly known as ARIMA models (Rahman and Hasan, 2017). An enormous number of observations are needed for ARIMA estimates, although it restricts the capacity to predict when the sample size is not large (Pao *et al*., 2012; Malik *et al*., 2020). The ARIMA model is based on the assumption that time series data exhibits a linear trend, however, the presence of nonlinear elements such as unexpected occurrences disrupts the model's predictions (Liu, 2024). ARIMA is good at short to medium-term forecasting and trend analysis of univariate time series data. However, the study is multivariate and intends to analyze interactions among multiple time series variables over time. Based on these shortcomings, the method was therefore not preferred.

2.5.4 Autoregressive distributed lag (ARDL) model & Vector error correction model (VECM)

The ARDL approach is used to run and estimate the short and long-run relationship between variables at the same time (Naseem *et al*., 2021). This model can make estimates for a small data sample but is not suitable for a very large series of data (Pickup, 2022). Issues of endogeneity are removed through an appropriate section of optimal lags and the residuals are corrected by the technique. This model accounts for heteroskedasticity by conducting a robustness test (Oryani *et al*., 2021). A unit root is accounted for by making sure that data is stationary (Aydin and Pata, 2020).

The VECM is employed to estimate the long and short relationship within variables for time series while PVECM is used in panel data analysis (Alam and Sumon, 2020). The panel VECM model is a dynamic multivariate model that aims to treat several variables equally by regressing the endogenous variable on both its own lags and the lags of all other variables while taking into account a finite-order system (Apostu *et al*., 2022;

Khan and Yoon, 2021; Khan *et al*., 2022). The VECM can be run once cointegration has been detected in the series.

The ARDL was first established by Pesaran and Shin (Pesaran and Shin, 1995; Pesaran *et al*.,1996) and defined as an econometric approach suitable for analysing and estimating if variables from a certain data set have a short- and long-term association. This model was further developed by Pesaran *et al*. (2001). This approach is mostly preferred by many scholars because of its favourable advantages. Some of the advantages are that estimation of a small data set is possible (Khan *et al*., 2021) and at the same time this approach can establish the long- and short-run association amongst variables at the same time (Karimi *et al*., 2021).

Another advantage is that the ARDL approach unlike other cointegration approaches can apply a single reduced-form equation to estimate the long-run relationship among variables unlike using a system of equations (Koh *et al*., 2020). The technique can still be applied to do estimation even if the regressors are not stable or integrated in the same order, meaning that variables can be stationary at either I(0) or I(1) or a combination of both (Kripfganz and Schneider, 2018; Reda and Nourhan, 2020). ARDL method can provide estimates even though the variables are at different optimal lags (Shahzad *et al*., 2021). Regardless of the endogeneity of specific regressors, the ARDL approach provides correct t-statistics and unbiased estimates. Actually, by choosing the appropriate lag, which also prevents residual correlation, the problem of endogeneity is further mitigated (Tenaw, 2021).

Although the ARDL method has many advantages there are some limitations to it. The approach is also valid if the time series combination is stationary, that is, if it is stationary at both the first difference, I(1), and level, I(0). However, if the series is stationary at I(2), the model collapses (Menegaki, 2019). Therefore the series should not be I(2). In addition, for sample data that is very large, this method is not suitable (Alam *et al*., 2021). Another model's limitation is that it takes into account one level of relationship among the variables and anticipates a linearity between the dependent and explanatory variables (Tagwi, 2022). Based on the intuitive features of the ARDL model, this study estimated the short and long-run dynamics using the ARDL method.

2.6 Summary

This chapter introduced the variables in detail in the conceptual framework that shows the linkages amongst the dependent and the explanatory variables and the theorise that explained the links. The theoretical framework was laid out to further explain the environmental kuznets curve, which is, a theory that explains the association between GDP, environmental quality, and energy while the pollution haven and pollution halo effect hypothesis are theories used to explain FDI, environment, and renewable energy. Relevant literature was then reviewed to assess the interactions between soybean production and the independent variables reported by various authors. Then lastly the analytical framework was done whereby different VAR models were reviewed and the ARDL was chosen as the best model suitable for this research study.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter contained the study area along with the map of the area, the research design, variables, collection of data approach, and data analysis presented through descriptive and inferential statistics.

3.2 Study Area

The study focused on South Africa, with an estimated population of over 60 million (Stats SA, 2022). In Africa, it is the southernmost country, and the neighbouring countries, amongst others, are Botswana, Zimbabwe, and Mozambique (Naidoo, 2020). South Africa covers a surface area of 1 219 602 km^2 and is the world's 24th-largest nation, while in Africa with 55 states, it is the ninth-largest country (Uhunamure and Shale, 2021). Furthermore, South Africa has 11 recognized official languages, the nation is multilingual. South Africa has nine official provinces and soybean is produced in almost all of them, but the main provinces are Limpopo (4%), Gauteng (5%), KwaZulu-Natal (7%), North-West (10%), Mpumalanga (33%), and Free State (41%) as shown in the map in Figure 3.1.

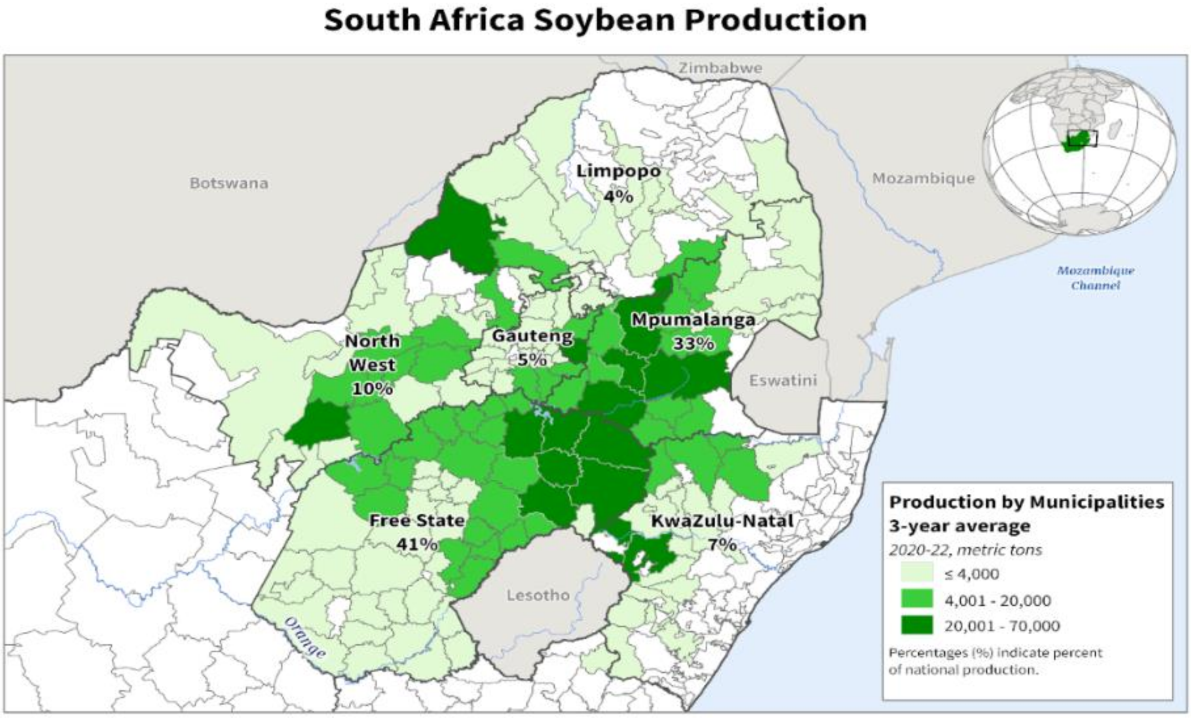

Figure 3.1. Map of South Africa

Source: Foreign Agricultural Services (2023)

In 2021, South Africa produced 1 897 000 t of soybeans and consumed 116,78 TWh of renewable energy, emitted about 43 Mt of carbon dioxide and received a cash inflow of 41 billion US$ from foreign direct investments. While the economy of the country grew by 405.87 billion Constant 2015 US$ (FAO & WDI, 2023).

3.3 Research Design

This section followed the systematic approach to designing research methodology in preparation to collect data. positivist research philosophy was used in this study which is based on the operationalization of variables and measurements in order to test hypotheses and experiments from raw data (Park *et al*., 2020), generally focuses on identifying explanatory associations or causal relationships where empirical-based findings from large sample sizes are preferred (McGregor, 2017). The deductive research approach was used as it is in line with hypothesis-driven experimental analysis whereby the hypothesis is tested for significance. A null hypothesis is made and tested whereby it can be rejected or fail to be rejected by the author after the analysis of the results (Young *et al*.,2020).

The research strategy can be experimental, mainly focusing on the association between the cause and effect of the dependent and explanatory variable(s) (Johannesson *et al*., 2021), however, this study used an exploratory strategy to model future predictions. Longitudinal research design was used in this study as it is a research design that deals with readily available data from more than one variable collected for more than one time period allowing changes in measurement and possibly explanations as this study aims to do (Menard, 2007). The quantitative research methodology was used in this research study as it deals with the collection and analysis of numerical data over the chosen period. The data is collected from the same or different source or subject regularly, such as daily, monthly, or yearly (Taherdoost, 2021).

To examine the data and forecast future events, statistical approaches like regression analysis and the Vector autoregressive (VAR) approach are frequently utilized (Docheshmeh Gorgij *et al*., 2022). With the use of the quantitative research methodology, researchers may systematically investigate the dynamics and changes in time series data, which offers important new information about the variables under investigation.

3.4 Study Variables and Data Collection

This research study desired to examine the impact of renewable energy consumption, foreign direct investment, economic growth, and carbon dioxide emissions on soybean production in South Africa utilizing the ARDL method using data from 1975 to 2021. The years 1975 to 2021 were selected because of the consistency in the availability of data between the selected variables, and the decrees of freedom associated with time series data in which at least 30 observations are required to perform an analysis. The response variable in this study was Soybean production (SOYBP) in tonnes and the data used for estimations was obtained from the Food and Agriculture Organization (FAO). In most cases, soybean production was represented by agricultural production. The selected microeconomic explanatory variables in this study were REC, GDP, CO_2 emissions, and FDI.

Renewable energy consumption (which included biomass, wind, solar, nuclear, hydroelectricity, geothermal, and other sources) in terawatt-hours (TWh) and carbon dioxide emissions in millions of tonnes (Mt) data was sourced from BP statistics. Carbon dioxide emissions were represented by environmental quality. Economic growth (represented by GDP per capita) and foreign direct investment data were sourced from the World Bank Development Index (WDI) database. The summary of the data variable description, unit of measurement, data source, and code are presented in Table 3.1.

Table 3.1. Variable description

code	Variable	Unit of measurement	Data source
SOYBP	Soybean production	Tonnes (t)	FAO
FDI	Foreign direct investment	FDI net cash inflow	WDI
CO_2	Carbon dioxide emissions	Million tonnes (Mt)	BP
GDP	Economic growth (gross domestic product)	GDP per capita (constant 2015 US$)	WDI
REC	Renewable energy consumption	Total renewable energy used in terawatts-hour (TWh)	BP

Source: Author (2024)

3.5 Data Analysis

3.5.1 Descriptive Statistics

Descriptive statistics was useful in simplifying the organization of data, making it easier to comprehend. It provides an entry point for data analysis, helping researchers arrange, reduce complexity, and synthesize data (Ansari *et al*., 2022). Moreover, descriptive statistics created a pathway to determine which advanced statistical tests are appropriate. On the other hand, descriptive statistics, do not allow the researcher to draw inferences about the population of interest, as this is left for more sophisticated, inferential statistics (Mishra *et al*., 2019). Measures of central tendency and dispersion such as the minimum, maximum, median, mean, kurtosis, standard deviation, and skewness, were used to describe the macroeconomic variables series.

Descriptive statistics was used for **objective one** which was looking at the historical trends of soybean production from 1975 to 2021 period was represented using line graphs, pie and bar charts. **Objective two** which was looking at the impact of RE consumption, FDI, GDP and CO2 emissions on soybean production was analysed using ARDL, presented in tables. **Objective three** which looked at the causality between soybean production and macroeconomic variables was performed using the Granger Causality technique, presented in a table.

3.5.2 Inferential Statistics

The inferential statistics in this study were used to analyze objective two. The econometric technique that was used for analysis was the Autoregressive Distributed Lag (ARDL) technique. The steps of the ARDL Cointegration estimation approach are shown below:

Step 1: Unit root test

Firstly, the unit root test was done to make sure that the data set does not have the presence of a unit root, that is, variables should be stationary. Variables that are not stationary give unrealistic results or estimations which will make conclusions to be false. Variables should be stationary at level I(0) and 1st difference I(1) (Sharif *et al*., 2020). There are different tests used to reveal the order of incorporation within the selected variables, which are, Augmented Dickey–Fuller (ADF), Phillips–Perron (PP), Dickey–Fuller (DF) test, and Kwiatkowski–Phillips–Schmidt–Shin (KPSS), but for the purpose of this study, the Augmented Dicky-Fuller (ADF) and the Phillips-perron (PP) test were used, to allow for cross-validation of results and increases confidence in the stationarity or non-stationarity conclusion when both tests agree on the presence or absence of a unit root of the time series data. The variables can be stationarity at I(0) or I(1) or at both levels. These tests are done to make sure that there is no integrated series of order I(2) or above (Kirikkaleli and Adebayo, 2021). If structural breaks had been identified, the Zivot-Andrews unit root test would have been conducted to capture and solve the single structural breaks (Kasasbeh, 2021). Unit root hypothesis can then be derived as follows: **H_0**: there is no presence of unit root.

Step 2: Lag selection

After determining the order in which the variables will be integrated, the next step was to select the optimal lag for the variables. The lag length can be chosen from information criteria such as the Hannan-Quinn Information Criterion (HQIC), Bayesian Information Criterion (BIC), and Akaike Information Criterion (AIC) (Wen and Huang, 2022). These criteria seek to find a balance between model fit and complexity. The ideal lag length minimizes the selected information criteria. The optimal lag selection minimizes residual correlation when endogeneity is corrected. In this study, the Akaike Information Criterion (AIC) was used to select the lag length (Khan and Yahong, 2021).

Step 3: Cointegration (bounds) test

The next step that followed was to perform a cointegration test. In the ARDL testing technique, the cointegration test was undertaken to observe if there is a long-run equilibrium association between the independent and dependent variables. This was done by conducting the ARDL bounds test (Voumik *et al*., 2022). Estimating the model and assessing the coefficients' significance linked to the lagged values of the variables are required. The Cointegration was evaluated using the limits F-test or the t-test. The bounds test yields a pair of crucial values: lower and upper bounds (Usman *et al*., 2022b). A null hypothesis was formulated that there is no cointegration among variables: **H_0**: No cointegration among variables.

When the upper bound value in the Bounds test is exceeded by the F-statistic value obtained, it does not support the rejection of the null hypothesis; instead, it indicates the presence of a long cointegration relationship. The null hypothesis of no cointegration is not rejected if the F-value is less than the lower bound. Furthermore, an F-value between the lower and higher bounds indicates that the cointegration connection is uncertain (Reda and Nourhan, 2020).

Step 4: ARDL Error correction model

When cointegration was discovered, an error correction model (ECM) was developed. The ECM captures the short-term dynamics as well as the degree of adjustment to the long-run equilibrium relationship. The short- and long-term correlations between the variables are shown by the coefficients of the lagged levels, differenced variables, and error correction terms. They provide details on the scope, importance, and modifications impacts made to the system (Martins *et al*., 2021; Ahmed and Sleem, 2023).

Step 5: ARDL short and long-run estimation

A short-run model was estimated after which a long-run model was estimated whereby both models illustrated which variables are positively and negatively significant and which variables would be insignificant (Saleem *et al*., 2020).

Step 6: Diagnostic test

To evaluate the accuracy and dependability of the estimated ARDL model, diagnostic tests were carried out for the model's stability. The stability of the coefficients was assessed using the CUSUM and CUSUM of squares graphs. The Breusch-Godfrey LM, Breusch-Pagan-Godfrey, and Jarque-Bera tests were employed for autocorrelation among other diagnostic statistical tests (Zaman *et al*., 2022). The model's dependability was assessed using these tests. The model's absence of serial correlations was shown using the Breusch-Godfrey LM test. The Jarque-Bera test demonstrated that the estimated model residuals are normal while the Breusch-Pagan-Godfrey test demonstrated that there is no heteroscedasticity issue. The rule of thumb is that the p-value should be greater than 0.05 (Abbasi *et al*., 2021a).

Step 7: Robustness test

The robustness test was done to validate the models that were selected in the analysis. The Canonical Cointegrating Regression, Dynamics Ordinary Least Squares, and Fully Modified Ordinary Least Squares, models were used to verify the

ARDL model estimate. The results from all the models should confirm some of the estimates from the ARDL model results, for the ARDL results to be valid (Tursoy, 2019).

Step 8: Causality

Finally, to determine the direction and importance of causal linkages among the variables, the Granger causality test was conducted. Causality between variables could be unidirectional or bidirectional (Shahzad *et al*., 2020).

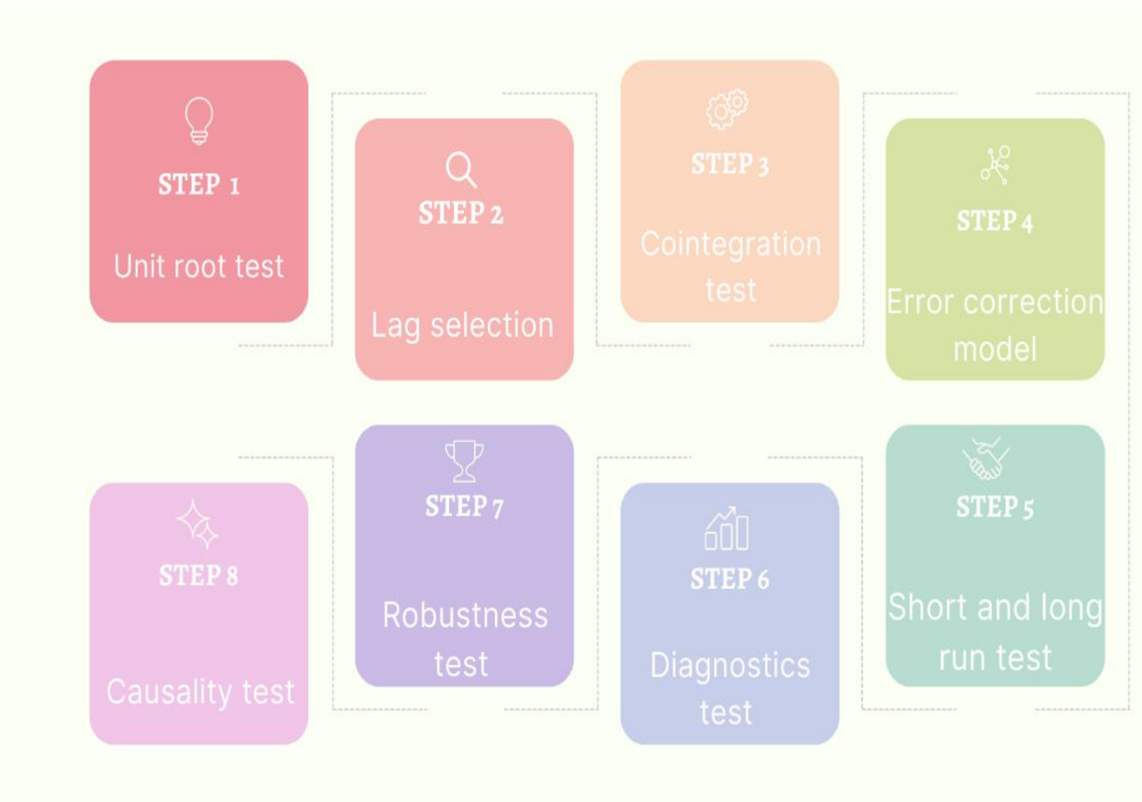

Figure 3.2: The steps of the ARDL Cointegration Approach

Source: Author (2024)

Figure 3.2 shows the steps of the ARDL Cointegration Approach that was applied. Firstly, the unit root test was done to test for stationarity and then the optimal lag was selected. After that, the cointegration bounds test was done to establish the existence of the long-run relationship. Then the error correction model was formulated. The ARDL was then used to estimate the long- and short-term relationship. The diagnostic and robustness test along with the causality test was performed.

3.5.3 Econometric Models

3.5.3.1 General Model

The relationship is represented in a generalized estimate form as follows:

$$\boldsymbol{Y_t = a_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + e_t} \quad (1)$$

3.5.3.2 Specified Model

Equation 2 illustrates how the connection in a fitting form was expressed. The variables are expressed in a log form.

$$\boldsymbol{LnSOYBP_t = f\ (LnCO2t + LnRECt + LnFDIt + LnGDPt)} \quad (2)$$

Where LnSOYBP represented the log of soybean production, LnFDI represented the log of foreign direct investment, LnREC represented the log of renewable energy consumption, LnGDP represented the log of gross domestic product, and LnCO2 represented the log of carbon dioxide emission.

Equation 3 was derived from equation 2:

$$\boldsymbol{LnSOYBP_t = a_0} + \mu_1 \boldsymbol{(LnCO2)_{t-1}} + \mu_2 \boldsymbol{(LnREC)_{t-1}} + \mu_3 \boldsymbol{(LnGDP)_{t-1}} + \mu_4 \boldsymbol{(LnFDI)_{t-1}} \quad (3)$$

The ARDL model in Equation 4 is stated, where Ø, µ, p and q represent the short-run elasticities coefficients, long-run elasticities coefficients, and the regressand and regressors lag lengths, respectively. The disturbance term is denoted by e_t.

$$\Delta \boldsymbol{LnSOYBP_t = a_0} + \mu_1 \boldsymbol{(LnCO2)_{t-1}} + \mu_2 \boldsymbol{(LnREC)_{t-1}} + \mu_3 \boldsymbol{(LnGDP)_{t-1}} + \mu_4 \boldsymbol{(LnFDI)_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{p}} Ø_1 \Delta \boldsymbol{(LnSOYBP)_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{q}} Ø_2 \Delta \boldsymbol{(LnCO2)_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{q}} Ø_3 \Delta \boldsymbol{(LnREC)_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{q}} Ø_4 \Delta \boldsymbol{(LnGDP)_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{q}} Ø_5 \Delta \boldsymbol{(LnFDI)_{t-1}} + \boldsymbol{e_t} \quad (4)$$

Equation 5 showed the long-run relationship:

$$\Delta \boldsymbol{LnSOYBP_t = a_0} + \mu_1 \boldsymbol{(LnCO2)_{t-1}} + \mu_2 \boldsymbol{(LnREC)_{t-1}} + \mu_3 \boldsymbol{(LnGDP)_{t-1}} + \mu_4 \boldsymbol{(LnFDI)_{t-1} + e_t} \quad (5)$$

Equation 6 showed the short-run relationship:

$$\Delta \boldsymbol{LnSOYBP_t} = \boldsymbol{a_0} + \sum_{i=1}^{q} \varnothing_1 \Delta(\boldsymbol{LnCO2})_{t-1} + \sum_{i=1}^{q} \varnothing_2 \Delta(\boldsymbol{LnREC})_{t-1} + \sum_{i=1}^{q} \varnothing_3 \Delta(\boldsymbol{LnGDP})_{t-1} + \sum_{i=1}^{q} \varnothing_4 \Delta(\boldsymbol{LnFDI})_{t-1} + \boldsymbol{e_t} \quad (6)$$

Equation 7 depicts the error correction model (ECM), which includes long-run and short-run associations. The error correction model is denoted by γECM.

$$\Delta \boldsymbol{LnSOYBP_t} = \boldsymbol{a_0} + \mu_1(\boldsymbol{LnCO2})_{t-1} + \mu_2(\boldsymbol{LnREC})_{t-1} + \mu_3(\boldsymbol{LnGDP})_{t-1} + \mu_4(\boldsymbol{LnFDI})_{t-1} + \sum_{i=1}^{p} \varnothing_1 \Delta(\boldsymbol{LnSOYBP})_{t-1} + \sum_{i=1}^{q} \varnothing_2 \Delta(\boldsymbol{LnCO2})_{t-1} + \sum_{i=1}^{q} \varnothing_3 \Delta(\boldsymbol{LnREC})_{t-1} + \sum_{i=1}^{q} \varnothing_4 \Delta(\boldsymbol{LnGDP})_{t-1} + \sum_{i=1}^{q} \varnothing_5 \Delta(\boldsymbol{LnFDI})_{t-1} + \boldsymbol{\gamma ECM_{t-1}} + \boldsymbol{e_t} \quad (7)$$

The ECM measured how the long-run disequilibrium was corrected within its adjusted speed. For the adjustment to be corrected and for the relationship to be established, the error term must be significantly negative.

3.6 Chapter Summary

The study is conducted in South Africa, consisting of nine provinces, in which Gauteng, Limpopo and Mpumalanga are amongst some of the provinces that produce soybeans. Positivism research philosophy, deductive research approach, experimental research strategy, longitudinal research design, and the quantitative research methodology represents the research design of the study. The data used for estimations from the variables was obtained from FAO, WDI, and BP from 1975 to 2021. The ARDL model was chosen and used for data analysis following the 8 steps of the cointegration approach from testing for unit root up to the causality test.

CHAPTER 4: DESCRIPTIVE RESULTS ON SOYBEAN PRODUCTION AND TRADE TRENDS

4.1 Introduction

This chapter revealed the trend analysis of soybean production from 1975 to 2021 to achieve objective one. This section discussed the production and trade of soybeans in South Africa.

4.2 South Africa Soybean Production

When soybeans were primarily brought in 1903 into South Africa, farmers encountered difficulties because of lack of knowledge, but the Department of Agriculture and Forestry developed potential for soybean production and created innovative methods hoping to reduce knowledge problems (Du Toit (1942) cited by Dlamini *et al*., 2014). Du Toit (1942) further showed that soybeans could be rotated with maize (and other grain crops) which significantly enhances soil fertility. Soybeans are now among the 16 top important crops in the world because of their usage as food, oils, energy, and animal feed which has made their demand increase worldwide. The top 16 crops that are largely cultivated worldwide are potato, oil palm, barley, cassava, groundnut, maize, rye, sorghum, millet, rice, rapeseed, sugar beet, sugarcane, wheat, sunflower, including soybean (Siamabele, 2021).

4.2.1 South African Soybean Production Trend

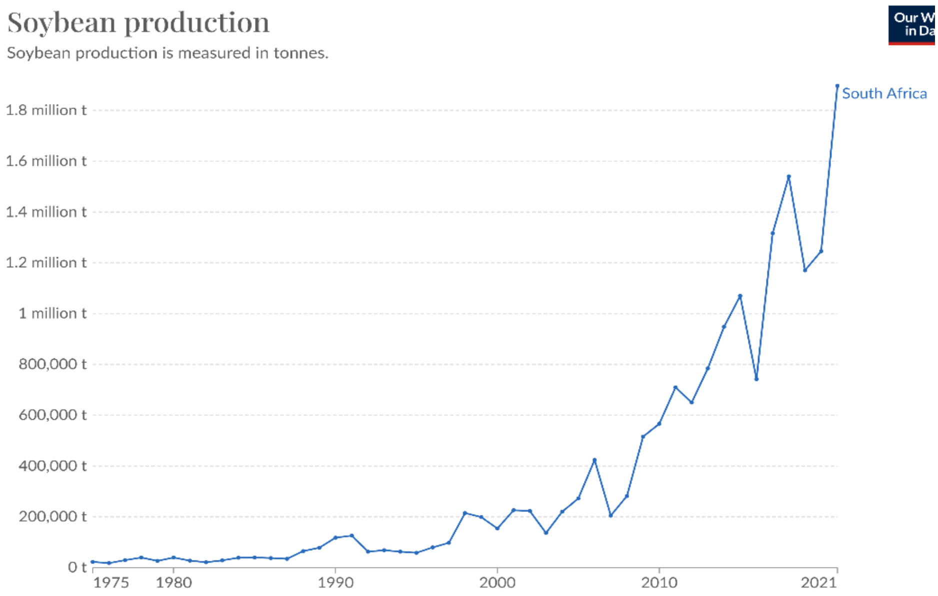

Figure 4.1: South African Soybean Production

Source: Our World in Data (2024), FAO (2024)

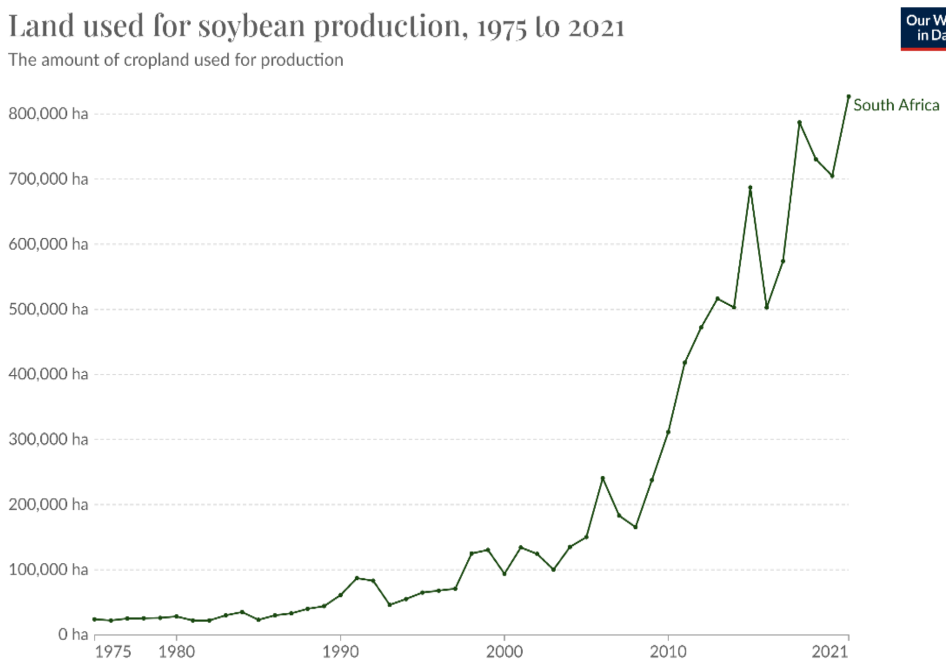

Figure 4.2: Land used for soybean production

Source: Our World in Data (2024), FAO (2024)

Soybean production data has been available for public consumption since 1961 when South Africa produced 2 631 tonnes(t) from 5,000 hectares(ha) of land. (FAO, 2023), but for this study, figure 4.1 shows soybean production from 1975 to 2021. The production increased gradually from 1975 to 1987, with 22 700 t to 34 900 t respectively, but notably gained momentum from 1988 to 1991, with a production of 65 300 t to 126 000 t respectively. The increase in production in 1991 is due to the increased land use of 87 000 ha, compared to the 40 000 ha used in 1988. In 1992 the production of soybeans decreased to 63 900 t from 83 000 ha used.

Slow production was experienced from 1993 to 1997, this was an important era for South Africa as democracy was born. An improved increase in production was experienced in 1998 of 215 000 t from 125 000 ha. Production decreased again in 2000, 2003, and 2007 with 153 925 t, 136 520 t, and 205 000 t respectively. In 2006 there was an increase from 2004 with a production of 424 000 t from 220 000 t and the area under cultivation increased to 240 570 ha from 135 000 ha. From 2008 to 2015 there was an increase from 282 000 t to 1.07 million tonnes (mt) and the land used increased from 165 400 ha to 687 300 ha and again in 2017 and 2018 with a production of 1.32 mt and 1.54 mt and the land under use was 573 950 ha and 787 200 ha respectively. Production decreased during the years 2016 and 2019 to 742 000 t and 1.17 mt and the area harvested to 502 800 ha and 730 500 ha, respectively. Production started to increase in 2020 and again in 2021 by 1.25 mt and 1.90 mt and the land used increased from 705 000 ha to 827 100 ha. This production growth indicates concerted efforts from the government to promote the production of soybeans.

South Africa's ARC-Grain Crops Institute launched a countrywide soybean cultivar assessment program in 1978/79 in response to government mandates to boost and encourage the soybean sector locally (De Beer and Prinsloo, 2013). This program resulted in an increase in production from 1980 onwards. During the 1993/4/5 growing seasons, viruses such as Soybean mosaic potyvirus were detected in the main South African soybean-producing areas which led to a slight decrease in production during those years (Pietersen *et al*., 1998). The increase in production from 1998 was due to the Genetically Modified Organism (GMO) Act of 1997. The Act made it easier for agricultural biotechnologies to be commercialized, enabling farmers to switch from growing traditional cereals to soybeans, which helped to maximize profitability for farmers by allowing them to rotate soybeans with other crops and make use of the newest agricultural technologies (Dlamini *et al*., 2014).

In 2001, soybean rust was first observed in South Africa. The majority of farmers took prompt action and sprayed their soybean crops immediately, which reduced production losses (Levy, 2005), which is why a minimized decline in production was observed from 2001 onwards. Soybean production was high in 2008 but the production for the 2012 growing season was lower than in 2011 due to poor weather conditions throughout the growing season. Due to high prices already recorded for the 2013 season, soybean hectares were expected to increase improving the yield (BFAP, 2012). Since then, soybean production increased significantly from 2013 (FAO, 2023).

The increase that occurred from 2008 to 2015 was also caused by the increased demand from the crushing plants to produce oil and meal (Sihlobo and Kapuya, 2016). However, as a result of the drought that occurred in 2016, the production of soybeans decreased (Meyer *et al*., 2018). Drought circumstances caused a substantial decline in soybean lands in South Africa's summer-producing area. The area planted for soybeans decreased by 26.8% between 2015 and 2016, but in 2017 it was projected to increase according to the Bureau of Food and Agricultural Policy (BFAP, 2016).

Soybean production has been a success because local manufacturers have been interested in using soybeans for food, animal feed, and vegetable oils, rather than relying on imports, and this can be credited to government policies that encouraged local food production (Khojely, *et al*., 2018).

The provinces with the largest soybean output, especially those in the most productive regions, were severely affected by climatic factors, especially the drought that occurred in 2018/19 (Engelbrecht *et al*., 2020). Consequently, the decrease in output experienced in 2019 can be attributed to the period of drought. However, the production started to recover from the following year (FAO, 2023). South Africa's soybean spot price locked at R9 990 per tonne in 2021. This price rise was supported by rising international soybean prices, caused by China's expanding demand, which was maintained by the country's pig industry's recovery from the destruction caused by the 2019 African swine fever outbreak (Sihlobo, 2021). This influenced soybean production to increase.

4.2.2 Production Areas

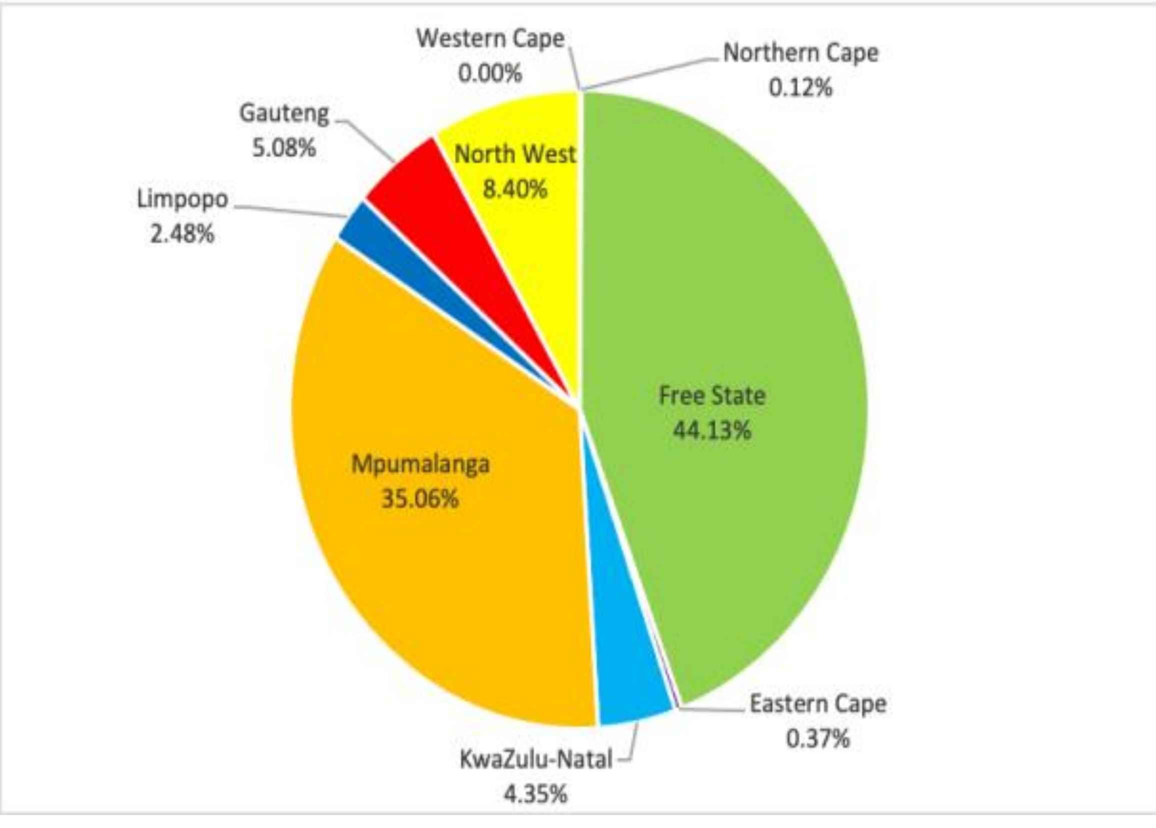

Figure 4.3: Soybean production area by province, 2020/2021

Source: Van der Linde, 2023

A study conducted by Hall (1930), saw an opportunity and suggested that soybeans should be cultivated in areas with enough rainfall like in Kwa-Zulu Natal. Currently, soybeans are cultivated in almost all the nine provinces of South Africa. Although soybeans are grown all over the nation, the provinces of the Free State, Northwest, KwaZulu Natal, and Mpumalanga produce the majority of the nation's soybeans due to the area under cultivation as shown in Figure 4.3 while 0% of the land is allocated in Western Cape (Van der Linde, 2023). KwaZulu Natal is among the top producers but due to the drought that occurred in 2018/19, its production experienced a significant decrease (Engelbrecht *et al*., 2020). The soybean production performance is not only driven by local demand but also by international trade.

4.2.3 South Africa's top 5 trading partners of soybean

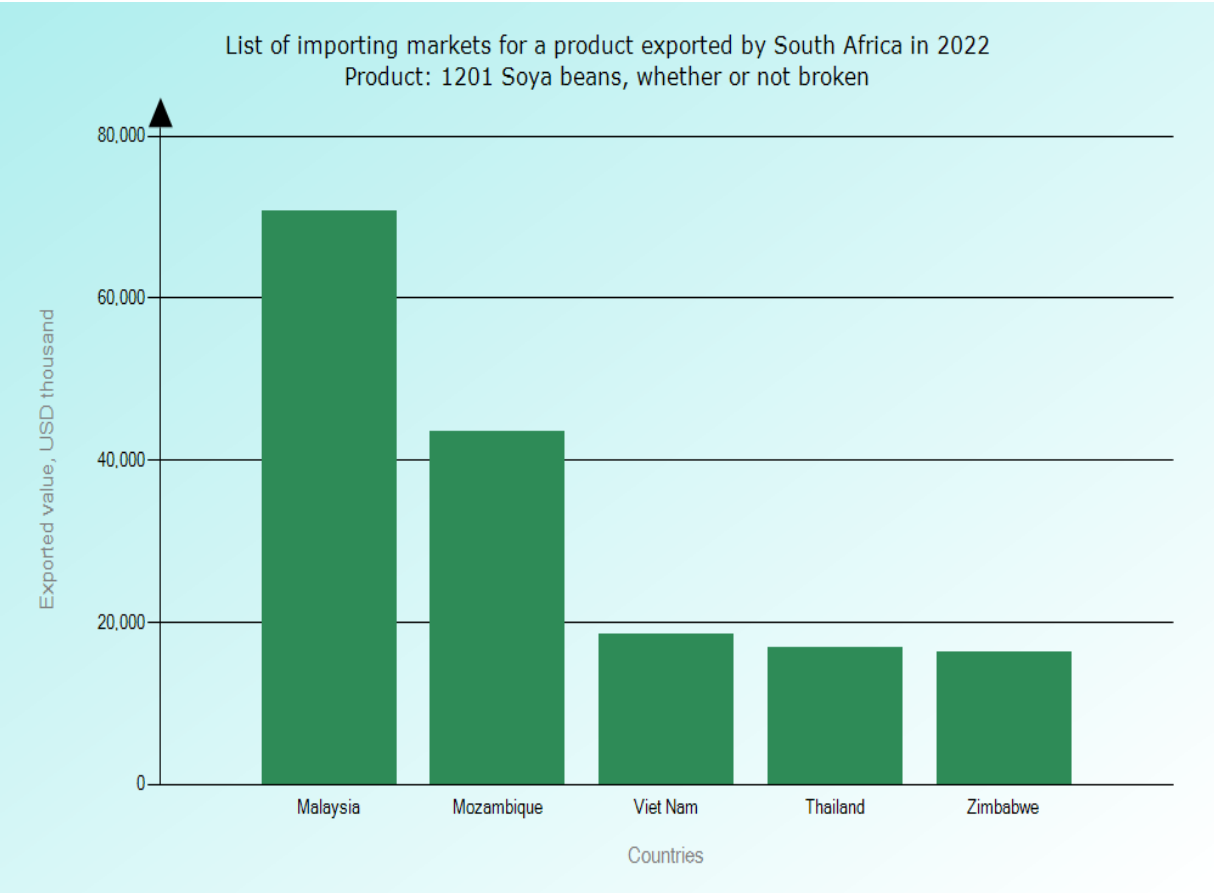

Figure 4.4: Top 5 South African Exporters

Source: Trade Map (2024)

Malaysia, Mozambique, Vietnam, Thailand, and Zimbabwe are the top 5 South African trading partners that South Africa exports Soybeans to (Trade Map, 2023). South Africa exports most of the soybeans to Malaysia as shown in figure 4.4 above. A value of 70 684 USD was imported by Malaysia from South Africa in 2022. Even with the increase in production over the years, SA exports of soybeans to other regions have been insufficient or low. A favourable trade balance was experienced between 2011 to 2013, as exports were higher than imports (DALRRD, 2019). Due to the droughts during 2016 and 2019, a decline in exports was experienced, but they picked up in 2020 (DALRRD, 2020). Although soybean exports are low, South Africa can trade with different countries, which strengthens their international trade (Trade map, 2023). According to DALRRD (2021), Gauteng Province dominates the soybean export market because of the required marketing infrastructure available.

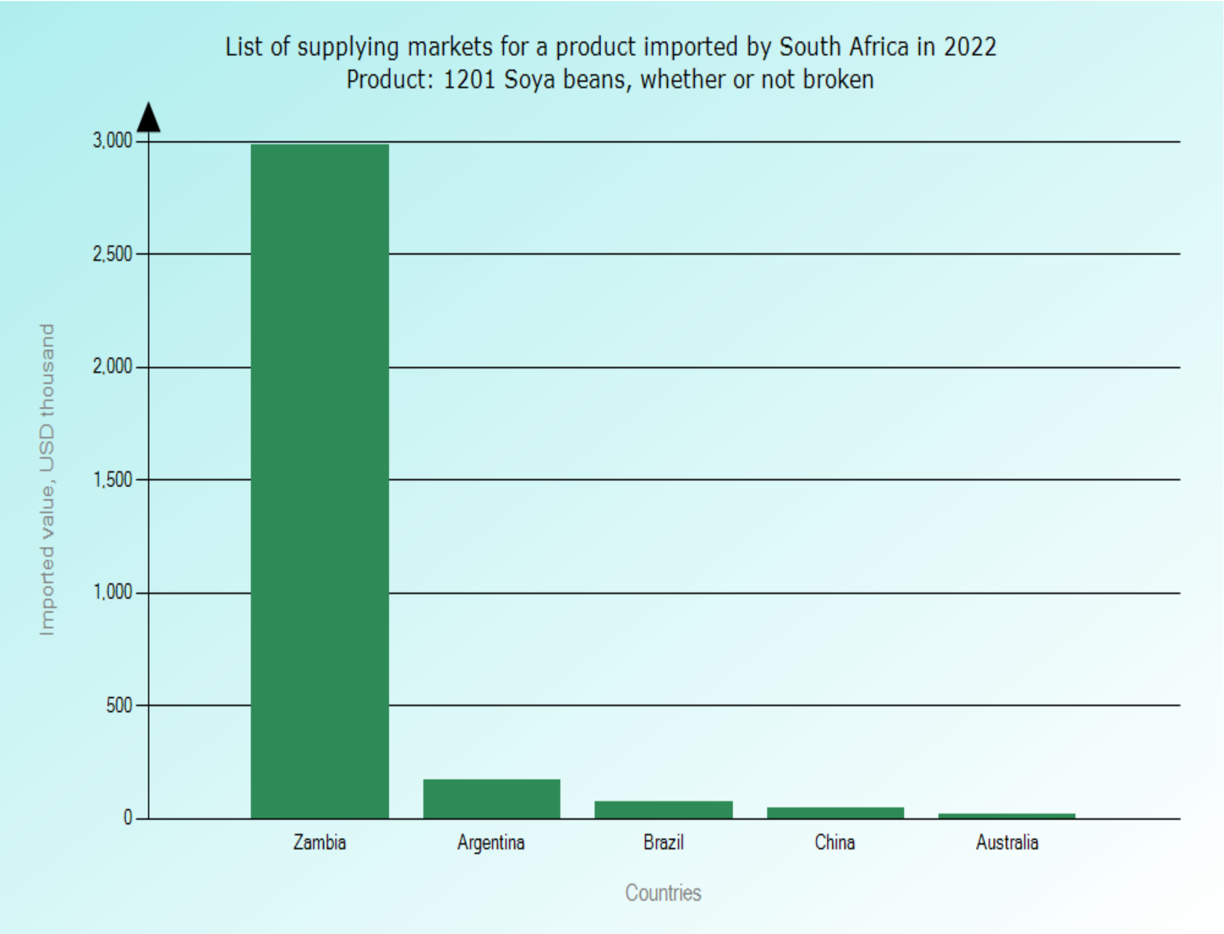

Figure 4.5: Top 5 South African importers

Source: Trade Map (2024)

South Africa imports most of its soybeans from Zambia as shown in figure 4.5. Argentina, Brazil, China, Australia, and Zambia are the top trading partners of South Africa exporting soybeans to South Africa (Trade Map, 2023). Both South Africa and Zambia are located in Africa while the other 4 countries are situated in other continents, indicating that the majority of the South African imports come from Zambia, thus promoting continental trade. Zambia has established itself as a competitive soybean producer, breaking into the South African market in 2014 and serving as a major oilcake supplier to neighbouring nations (Ncube *et al*., 2017). Exports of Zambian soybeans increased steadily starting in 2018, where surplus was traded within the African continent mostly with South Africa. Due to the strong local demands, Zambian output has also increased from a very low level and is now a net exporter (Bell *et al*., 2020).

Due to an insufficient amount of local production to meet demand, South Africa is a net importer of soybeans, meaning that imports surpass exports (Bahta and Willemse, 2016). In an attempt to boost home production, South Africa invested in soybean crushing equipment; nevertheless, even with these investments, the nation continues to import soybean oilcake and oil. This indicates the possibility of more local production eventually replacing imports (Sihlobo and Kapuya., 2016). Even so, South Africa has failed to meet the demands which is why it is still a net importer. This is not a good picture as this indicates that farmers are not producing enough. At the same time, this is a good opportunity for farmers to expand their soybean production as the market already exists mirrored by the imports.

4.3 Chapter Summary

This chapter covered South African soybean production and land use trends from 1975 to 2021, whereby there has been fluctuation over the years. Investments and improved varieties of soybean increased its production whereby climatic changes resulting in droughts and floods decreased soybean production. Mpumalanga and Free State are the major producing areas of soybeans in South Africa. Whereas, South Africa imported soybeans from Zambia and exported them to Malaysia in 2022.

CHAPTER 5: THE ARDL MODEL RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter discussed the results of the descriptive statistics for all the chosen study variables, the correlation coefficients, and the inferential statistics. The inferential statistics analysis included the unit root test, discussed the long- and short-run relationship that existed between the dependent and independent variables, and then established the causality in which objectives two and three were achieved.

5.2 Descriptive Statistical Analysis

Table 5.1 displays the descriptive statistics results for soybean production (SOYBP), renewable energy consumption (REC), Gross Domestic Product (GDP), foreign direct investment (FDI), and carbon dioxide (CO_2) emissions.

Table 5.1: Descriptive statistics results

Description	LNSOYBP	LNREC	LNGDP	LNFDI	$LNCO_2$
Mean	11.93918	3.284226	8.569369	0.215790	19.68511
Median	11.82423	3.666737	8.562906	0.214091	19.73271
Maximum	14.45578	4.787575	8.742431	2.366077	20.02007
Minimum	9.792556	0.564978	8.359299	-3.462564	19.03587
Std. Dev.	1.377426	1.075725	0.122239	0.912215	0.269327
Skewness	0.217869	-1.010319	-0.034211	-1.413318	-0.920533
Kurtosis	1.785990	3.123329	1.754493	8.326110	2.995590
Jarque-Bera	3.258059	8.025611	3.047106	71.19974	6.637855
Probability	0.196120	0.018083	0.217936	0.000000	0.036192
Sum	561.1413	154.3586	402.7603	10.14213	925.2001
Sum Sq. Dev.	87.27597	53.23050	0.687346	38.27828	3.336695
Observations	47	47	47	47	47

Source: Author (2024)
Generated from EViews 10

The mean value of the dependent variable LNSOYBP was 11.94 and the standard deviation was 1.38 as shown in table 5.1. This indicated that on average South Africa produced 11.94 tonnes of soybean each year. The explanatory variables LNREC, LNGDP, LNFDI, and LN CO_2 mean values were 3.28, 8.57, 0.22, and 19.69 respectively while the standard deviations were 1.07, 0.12, 0.91, and 0.27

respectively. The standard deviation of LNREC, LNGDP, LNSOYBP, and LN CO_2 were below the means which implies that the variables are not volatile meaning that the data was stable, which shows that the observations do not display significant fluctuations over time. While the standard deviation (0.91) of LNFDI was more than its mean (0.21) emphasizing that the data was not stable during the given period, which shows that the observations in the dataset were not steady and showed unpredictable changes. These findings are consistent with those of Ntiamoah *et al*. (2022), who reported a similar trend.

The kurtosis of LNSOYBP (1.8), LNGDP (1.8), and LNCO_2 (2.9) were less than three (3) while the kurtosis of LNREC (3.1) and LNFDI (8.3) was more than three. According to Qiu *et al*. (2020), Kurtosis measures extreme values or outliers. A kurtosis value of less than three shows a negative kurtosis called Platykurtic whereas a value of more than three represents a positive kurtosis called Leptokurtic. Platykurtic have distribution values that are widely dispersed around the mean, and leptokurtic distribution demonstrates fewer fluctuations around the mean. While a kurtosis value equal to 3 is called mesokurtic and the outliers are normally distributed (Verma, 2019). The Jarque-Bera test for normality was more than one percent (1%) for all the variables showing that all the variables were normally distributed.

5.3 Correlation Coefficient

The results from the correlation matrix in Table 5.2 show that there was a strong positive correlation between soybean production and RE consumption (0.83), and CO_2 emission (0.84) whereas it had a moderate positive correlation with gross domestic product (0.63) and foreign direct investment (0.59). The strong correlations are supported by the theories reviewed in the study. The results further demonstrate that there was a strong positive correlation between RE consumption and CO_2 emissions with a coefficient of 0.85, a weak correlation with GDP (0.23), and a moderate positive correlation with FDI (0.53). There was a weak positive correlation between GDP and FDI (0.31), and CO_2 emissions (0.43). The results further show that FDI had a moderate positive correlation with CO_2 emissions. Variables with strong positive correlations mean that as one increases the other will also increase. Additionally, the correlation coefficients on the diagonal of the table as presented were all equal to 1, as each variable demonstrates a perfect correlation with itself. Table 5.2 below shows the results from the correlation matrix test among the variables.

Table 5.2: Correlation matrix results

	LNSOYBP	LNREC	LNGDP	LNFDI	$LNCO_2$
LNSOYBP	1.000000	0.827814	0.630011	0.587922	0.837731
LNREC	0.827814	1.000000	0.230172	0.529414	0.852492
LNGDP	0.630011	0.230172	1.000000	0.306163	0.425228
LNFDI	0.587922	0.529414	0.306163	1.000000	0.575000
LNCO2	0.837731	0.852492	0.425228	0.575000	1.000000

Source: Author (2024)
Generated from EViews 10

5.4 Inferential Statistics Results

The analysis of inferential statistics results followed the steps that were aligned in Chapter 3 starting with testing the unit root for the chosen series while the causality test was conducted lastly.

5.4.1 Unit Root Test

The findings in Table 5.3 demonstrate that soybean production, foreign direct investment, and carbon dioxide emissions were integrated of order I(0) while gross domestic product and renewable energy production were integrated of order I(1). These results were concluded after running the Augmented-Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The ADF test results show that only soybean production, foreign direct investment, and carbon dioxide emissions were integrated at level I(0), whereas at 1st difference at I(1) all the variables were stationary. The PP test results showed similar results of the ADF test, where only soybean production, foreign direct investment, and carbon dioxide emissions were stationary at level I(0) while in the 1st difference I(1) all the variables were integrated of order I (1). From these results, it was evident that none of the variables were integrated of order I(2), and therefore they do not have a unit root. The null hypothesis which indicated that there is no presence of a unit root, failed to be rejected because there was no presence of a unit root as the series were stationary. Therefore, the ARDL approach was used for analysis because it accommodates variables that are stationarity at both I(0) and I(1).

Table 5.3: Unit root test

Variable	ADF		PP		Conclusion
	level	1st difference	Level	1st difference	
LNSOYBP	-4.166** (0.01)	-6.83*** (0.00)	-4.21*** (0.01)	-14.95*** (0.00)	I(0)
LNFDI	-6.47**** (0.00)	-5.80*** (0.00)	-6.56*** (0.00)	-4.43*** (0.00)	I(0)
LNGDP	-1.64 (0.75)	-4.41*** (0.00)	-1.53 (0.80)	-30.43*** (0.00)	I(1)
$LNCO_2$	-2.91* (0.05)	-6.53*** (0.00)	-3.02*** (0.04)	-7.26*** (0.00)	I(0)
LNREC	-2.26 (0.44)	-2.85* (0.06)	-2.55 (0.30)	-7.56*** (0.00)	I(1)

Source: Author (2024)
Generated from EViews 10

5.4.2 Lag selection

After concluding that the series was stationary, the next step was to establish the lag selection for the ARDL Model. The results for the lag selection are shown in Table 5.4. As presented in the table, different criteria are shown but only Akaike Information criteria (AIC) was used. According to the results of AIC, the optimal lag length was 1. However, all the other four information criteria confirm that lag 1 is the selected and the appropriate optimal lag length. The consistency across the different information criteria choosing lag 1 shows that it is the most suitable and appropriate choice for the ARDL model.

Table 5.4: Lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-29.13451	NA	0.273570	1.541140	1.704972	1.601556
1	-9.760142	34.24306*	0.116449*	0.686518*	0.891309*	0.762039*
2	-9.121708	1.098701	0.118516	0.703335	0.949084	0.793960
3	-8.374614	1.250948	0.120049	0.715098	1.001805	0.820827
4	-8.355505	0.031107	0.125837	0.760721	1.088386	0.881554

* Indicates lag order selected by the criterion

Source: Author (2024)
Generated from EViews 10

5.4.3 Cointegration (bounds) test

The variables were determined to be stationary at order I(0) and I(1), therefore an ARDL bounds testing approach was conducted to establish if the variables had a long-run association or not. Two critical values were generated from the bounds test which are the lower- and upper-bound values. A null hypothesis is that there is no cointegration meaning that there is no long-run relationship between the dependent and the independent variables. This can then be proven only if the F-statistic value is below the lower bound, then it can be established that there is no cointegration and the null hypothesis fails to be rejected (Reda and Nourhan, 2020). If the F-value is above the upper bound then there is cointegration and the null hypothesis is rejected. After running the bounds test, an F-statistical value of 6.49 was established, as shown in Table 5.5.

Table 5.5: Bounds test

Test Statistic	Value	K
F-statistic	6.491868	4
Critical Value Bounds		
Significance	I(0) Bounds	I(1) Bounds
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06
Outcome	**Cointegrated**	

Source: Author (2024)
Generated from EViews 10

The F-statistic value of 6.49 was greater than the lower-bound and upper-bound values at the significance levels of 1%, 2.5%, 5%, and 10%. An existing long-run relationship among variables is then concluded. The null hypothesis was then rejected. Now the error correction model and long-run model were estimated using the ARDL approach because there is a long-run relationship that exists between the variables.

5.4.4. The ARDL Error correction and Short-Run Estimates and Discussion

Table 5.6: The ARDL Model Short-Run Estimates and ECM

Dependent Variable: D(LNSOYBP) Model Selected: ARDL (1, 4, 4, 4, 4)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-10.41659	1.685423	-6.180403	0.0000***
ECM(-1)*	-0.923804	0.148611	-6.216274	0.0000***
D(LNFDI)	0.146942	0.060653	2.422660	0.0245**
D(LNFDI(-1))	-0.455323	0.105765	-4.305054	0.0003***
D(LNFDI(-2))	-0.327423	0.095809	-3.417457	0.0026***
D(LNFDI(-3))	-0.088093	0.061254	-1.438164	0.1651
D(LNGDP)	-0.467864	1.953973	-0.239442	0.8131
D(LNGDP(-1))	-1.391049	2.594019	-0.536252	0.5974
D(LNGDP(-2))	-0.654595	3.383245	-0.193481	0.8484
D(LNGDP(-3))	-6.975054	2.702645	-2.580826	0.0174**
D(LNREC)	0.119390	0.112334	1.062820	0.2999
D(LNREC(-1))	-0.763473	0.160870	-4.745896	0.0001***
D(LNREC(-2))	-0.462060	0.180535	-2.559401	0.0183**
D(LNREC(-3))	-0.236288	0.144967	-1.629946	0.1180
D(LNCO2)	-2.010447	0.812385	-2.474746	0.0219**
D(LNCO2(-1))	-0.025855	0.840798	-0.030750	0.9758
D(LNCO2(-2))	2.429310	0.852491	2.849661	0.0096***
D(LNCO2(-3))	2.665230	0.996474	2.674659	0.0142**
R-squared	0.703963	Mean dependent var		0.089690
Adjusted R-squared	0.502658	S.D. dependent var		0.347402
S.E. of regression	0.244996	Akaike info criterion		0.319737
Sum squared resid	1.500579	Schwarz criterion		1.056984
Log likelihood	11.12564	Hannan-Quinn criter.		0.591611
F-statistic	3.496994	Durbin-Watson stat		1.871945
Prob(F-statistic)	0.002308***			
** and *** denote 5% and 1% level of significance respectively				
Source: Author (2024) Generated from EViews 10				

The results of the short-run ARDL and ECM estimates are represented in Table 5.6 above. The error correction model was significant at a 1% level of significance. The statistically significant negative coefficient of ECM was -0.92 which is the speed of adjustment. This indicates that it will take an adjusted speed of 92% per year for soybean production to reach the long-run equilibrium alongside FDI, GDP, RE consumption, and CO_2 emissions. In other words, for these variables to attain their equilibrium position, it will take 1.08 years (1/0.92).

In the short run, Foreign direct investment was statistically significant and had a positive coefficient at a 1% level of significance. This means that with a 1% increase in foreign direct investment, soybean production will be increased by 0.14%. These results are expected as investment increases production in the agricultural sector, as supported by the Pollution Halo Effect Hypothesis. The lagged FDI were all negative and only the 1st and 2nd lagged FDI were statistically significant at a 1% level of significance. This means that a year and two years ago, FDI was statistically significant in explaining changes in soybean production. A 1% increase in FDI will decrease soybean production by 0.46% a year ago and 0.33% two years ago, respectively. A study by Dhahri and Omri (2020a), showed similar results where FDI (including and excluding foreign capital) statistically increased agricultural production. Nur's (2022) results showed that FDI significantly contributed to the increase in agricultural production. Paul *et al*. (2021a), results also demonstrated a relationship that is significantly positive between the crop production index and FDI.

International/ foreign investors aiming to maximize profits are likely to be drawn to the opportunities arising from broadened access to resources, when entering new markets, potentially reducing production costs, and improving efficiency through economies of scale is important when investing in a different economy (Hirsch *et al*., 2020). According to the results, the agricultural sector increases when FDI increases showing potential to increase its productivity when investment is injected. The Feed Africa document by the African Development Bank (2016), stated that it is necessary to enhance and accelerate investment in Africa. This is due to food insecurity and more opportunities for unused arable land available for agricultural activities. To transform the agricultural sector and increase its output, external investments are needed to enhance food security. The land is available in our country that can be used for agriculture, this means that South African farmers can engage in more agricultural activities, especially rural farmers if more investments are made.

In another study, FDI was found to significantly reduce agricultural production. The author emphasized that these results were because some technological transfers caused changes such as unsustainable practices that shift away from primary productions affecting the environment (Gupta *et al*., 2023). This means that when FDI is transferred into another economy, the focus should be on green technologies that will benefit the primary sector and not shift away from its sustainable practices. Downplaying the importance of sustainable agriculture practices contributes to climate change which in turn affects productivity negatively and African countries are more vulnerable.

For instance, the agricultural industry in West African countries is considered extremely dangerous because they do not have official insurance policies in place to mitigate the risks in the event of an unsuccessful harvest even after investment (Ali *et al*., 2020; Mamba *et al*., 2020). The implications are that agriculture would have a tough time attracting FDI, causing investments to be shifted to other industries. This shows that the agricultural sector should consider having insurance policies in place to avoid losses during uncontrollable disasters which is also key in attracting investors.

Carbon dioxide emission was negative and statistically significant at the 5% level. An increase in CO_2 emissions by 1% will reduce soybean production by 2%. Similar findings were reported by Selcuk *et al*. (2021). Who found a significant and negative relationship between agriculture and CO_2 emissions. This indicates that soybean production is affected by the environment. The second and third-lagged CO_2 emissions were positive and statistically significant. This means that CO_2 emissions two years ago were statistically significant at a 1% level, meaning soybean production increased emissions. Considering the decline that has been reported due to climate change disasters, this is expected.

Similar studies have found similar results. Abdunnur (2020) found a negative and significant impact between agricultural production and ecological footprint in the short run. In Jiang *et al*. (2021) study, the results showed that in the short run agriculture value-added contributed to a decrease in CO_2 emissions significantly. The outcome of agriculture value added was negative and significant, and increasing agriculture value addition will lead to lower carbon emissions (Prastiyo *et al*., 2020). Abbasi *et al*. (2021b), results showed that CO_2 emissions were reduced with an increase in agricultural value mainly due to the implementation of the Climate Resilient Green Economic (CRGE) plan that significantly reduced CO_2 emissions.

Some examples of green plans include Climate-smart agriculture which helps to reduce greenhouse gas emissions, by sustainably boosting production and revenue. Using clean, contemporary energy sources in agriculture, such as renewables, to diversify energy technologies may also help reduce over-reliance on fossil fuels for farming activities (Sarkodie *et al*., 2019). In addition, excess land in farms can also assist in carbon sequestration by absorbing and storing CO_2 in trees over time from their surroundings. Tree planting may absorb 5% to 10% of CO_2 emissions (Ridzuan *et al*., 2020). These are measures that can easily be planned when land is made available to farmers.

However, in other studies, CO_2 and agricultural production had a positive association. Yurtkuran (2021), study found that there was a positive and significant association between CO_2 emissions and agriculture. Udemba (2020), also found that ecological footprint and agricultural production had a positive relationship. These results were experienced because some agricultural activities contributed to the ecological footprint. Other authors also confirmed that growing agricultural output may release additional pollutants into the atmosphere, increasing CO_2 emissions (Sharma *et al*., 2021). As a result, a greater carbon footprint and an irregular climatic pattern, detrimental to agricultural productivity have been observed (Arora, 2019), negatively affecting crop growth, yield, and nutritional value (Bai *et al*., 2019). This means that it is important for farmers to practice sustainable agriculture.

Economic growth had a negative coefficient and was statistically insignificant. This implies that in the short run, GDP does not have a significant impact on soybean production. The lagged GDP was negative and statistically insignificant, while only the third lagged GDP was significant at the level of 5%. Economic growth three years ago was significant in explaining soybean production wherein an increase in economic growth would have decreased soybean production by 6,97%. This is because it takes time for economic activities to influence agricultural activities and to trickle down to the means of production such as land, technology, and capital (Bański and Mazur, 2021).

Although the renewable energy consumption coefficient was positive, it did not have a statistically significant impact on soybean production. RE is a developing sector in South Africa, thus its uptake is still slow due to the initial high costs of set-up. Thus, the agricultural industry will see RE as unaffordable and will use less renewable energy as a result. This is an indication that at this stage renewable energy use does not have an impact on soybean production. This also suggests that the demand for soybeans for renewable production might also be minimal locally. RE consumption was statistically significant at 1% and 5% levels of significance in the 1st and 2nd lag, respectively, while in the 3rd lag, it was not significant. RE was significant in explaining soybean production one year and two years ago. Whereby one year ago, as renewable consumption increased, soybean production decreased by 0.76%, and two years ago by 0.46%. This relationship simply means that RE use has not benefited soybean production in South Africa.

In summary, the **short-run** results indicate that FDI significantly increased soybean production while soybean production decreased CO_2 emissions. In contrast, RE consumption and GDP did not have a significant effect on soybean production. These results were expected as they are in line with the environmental Kuznets curve.

5.4.5 The Long-Run ARDL Results and Discussions

Table 5.7: The ARDL Model Long-Run Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNFDI	0.810786	0.276590	2.931366	0.0080***
LNGDP	5.613679	0.576288	9.741099	0.0000***
LNREC	0.963280	0.163281	5.899517	0.0000***
$LNCO_2$	-1.421162	0.939810	-1.512179	0.1454
*** represents 1% level of significance				

Source: Author (2024)
Generated from EViews 10

Results in Table 5.7 showed that the **long-run** relationship existed between the dependent and independent variables. The results show that FDI, GDP, and REC were positive and statistically significant at a 1% level of significance, while CO_2 emission was negative and statistically insignificant. A rise of 1% in CO_2 emissions will decrease soybean production by 1.42% in the long run. In comparison, a 1% increase in FDI, GDP, and REC will improve soybean production by 0.81%, 5.6%, and 0.96%, respectively.

Edeh *et al*. (2020), found that FDI had a positive and significant impact on the agricultural sector. Boucenna *et al*. (2021), results show that foreign direct investment has a notably favorable impact on the Agriculture Productivity Index. Nyiwul and Koirala's (2022), results show that in the medium and long run, FDI had a positive impact on value added in agriculture, forestry, and fishing. The authors suggested that regulations and other restrictions that raise transaction costs for foreign investors should be removed and then strengthen institutional processes that encourage foreign investments in developing nations. This will lead the agricultural sector to attract more investments and be able to boost its productivity and effectiveness by creating a conducive environment.

The outcome of the Obekpa *et al*. (2021) study demonstrated that governmental agriculture spending and FDI both gradually raised agricultural output. This leads to the most effective strategy of ensuring the sustainability of agricultural growth by boosting public agriculture spending and foreign direct investment. It is believed that FDI inflows towards agricultural output guarantee food security and, eventually, aid in the reduction of poverty (Dhahri and Omri, 2020b). Also, considering that soybean is an energy crop, FDI can help promote its use in the production of bioenergy, boosting the energy sector.

In the long run, renewable energy consumption significantly increased soybean production. These results correspond with future expectations that renewable energy use might increase energy crops such as soybeans. This will stimulate soybean production which will increase feedstock for the RE market. In agriculture, renewable energy could also assist with product drying, soil development, irrigation, heating, and cooling. However, to effectively address ecological challenges, investment in green technology will be necessary (Naqvi *et al*., 2023). The utilization of sustainable energy sources can also reshape technological innovation (Sohail *et al*., 2022). The use of RE sources may also lower energy prices and improve human health and air quality while creating jobs (Wang *et al*., 2024). Shah *et al*. (2023), discovered that the use of RE increases agricultural output.

In the long run economic growth statistically significantly increased soybean production. This will be due to the trickle effects of the promotion of economic activities that encourage soybean production in the future when production increases, the economy grows and more jobs can be created (Ulucak, and Erdogan, 2022). Carbon dioxide emissions, in this study, did not have a considerable impact on soybean output in the long run. These findings are reliable as supported by other studies. The observation by Warsame *et al*. (2021), revealed that CO_2 had an inverse effect on crop production and the results were statistically insignificant. Results presented by Balogh (2019), showed that there was a negative association between carbon footprint and agricultural development, this was because of the use of technologies that are environmentally friendly which reduces carbon emissions in the long run.

The long-run results illustrate that FDI, GDP, and REC had a statistical and positive relationship with soybean production. This means that an increase in any of these three variables will cause an increase or improve the production of soybeans in South Africa. While CO_2 emissions did not have a significant impact on the production of soybeans.

5.4.6 Diagnostics Test

A procedure known as a diagnostic test was carried out after the model of the ARDL was established to ensure the stability of the model and estimations are accurate. To determine whether the model had a serial correlation, the Breusch-Godfrey Serial Correlation LM Test was performed. We are unable to reject the null hypothesis, which says there is no serial correlation in the series since the impact was not significant. Serial correlation occurs when errors in one period are correlated with errors in another period or future periods and this is a problem that mainly occurs in time series analysis. It can lead to incorrect estimations and reduce the reliability of statistical findings if it is not accounted for (Burlig *et al*., 2020).

To confirm that heteroscedasticity was not present in the model, the ARCH test was conducted. Because the p-value (0.21) in Table 5.9 was more than 0.05, it was considered not significant. Consequently, the research was unable to reject the null hypothesis of no heteroscedasticity issue in the series. Heteroscedasticity refers to data having a varying (hetero) variation (scedasticity) of random errors across different explanatory variable values (Das, 2019). Jarque-Bera test was carried out to ensure a normal distribution of residuals. The normality test is necessary as it determines the distribution of the data set in the model (Edeh *et al*., 2020). The results from Figure 5.1, show a p-value of 0.24 that was insignificant because it was more than 0.05. The null hypothesis is rejected because of the no presence of normal residuals. Therefore, the variables are normally distributed.

Table 5.8: Breusch-Godfrey Serial Correlation LM Test

F-statistic	0.113004	**Obs*R-squared**	1.113720
Prob. F (4,17)	0.9762	**Prob. Chi-Square (4)**	0.8921
Source: Author (2024) **Generated from EViews 10**			

Table 5.9: ARCH test

F-statistic	1.499125	**Obs*R-squared**	5.847098
Prob. F (4,34)	0.2243	**Prob. Chi-Square (4)**	0.2109
Source: Author (2024) **Generated from EViews 10**			

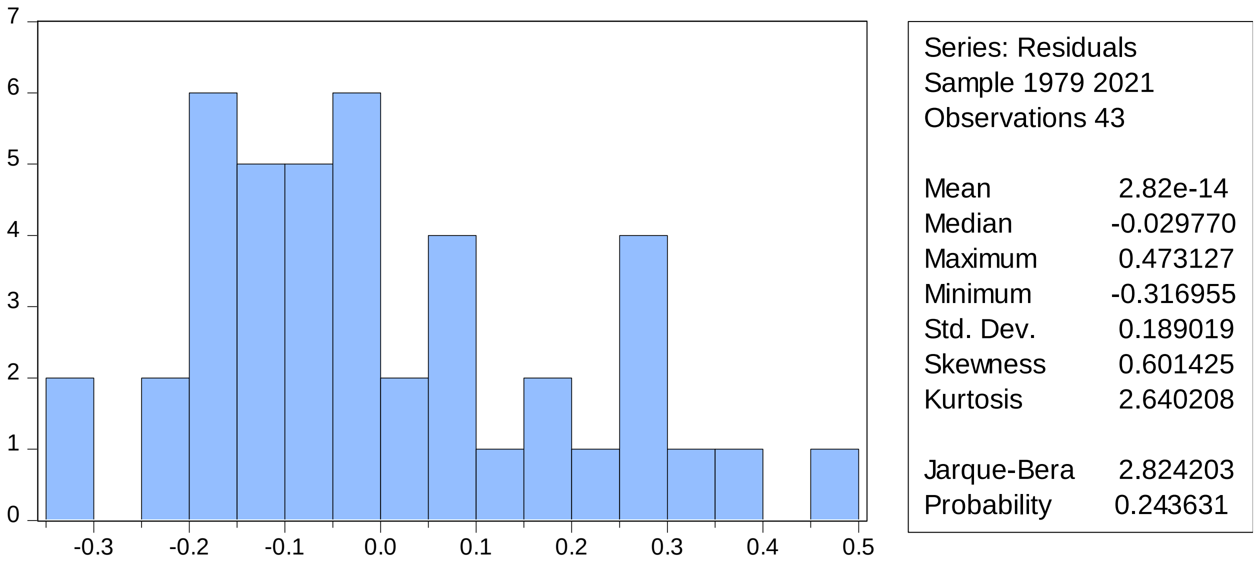

Figure 5.1: Jarque-Bera test

Source: Author (2024); Generated from EViews 10

The diagnostics test summary is presented in Table 5.10 below. It was then concluded that the residuals were normally distributed and that neither serial correlation nor heteroscedasticity existed in the model.

Table 5.10: Summary of the Diagnostics test

Diagnostic statics	p-value	Outcome
Breusch-Godfrey LM Test	0.89	No Serial Correlation
ARCH test	0.21	No Heteroskedasticity
Jarque-Bera test	0.24	Normal residuals

Source: Author (2024)
Generated from EViews 10

The diagnostic test was carried out through the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests to confirm the model stability. For the model to be stable, the middle blue solid lines must be in between the red dotted lines, if the blue solid lines cross the red dotted lines or are found outside, the model will not be stable. In this study, the middle blue solid lines are in between the red dotted lines as shown in Figure 5.2, which indicated that at a 5% level of significance, the model was stable.

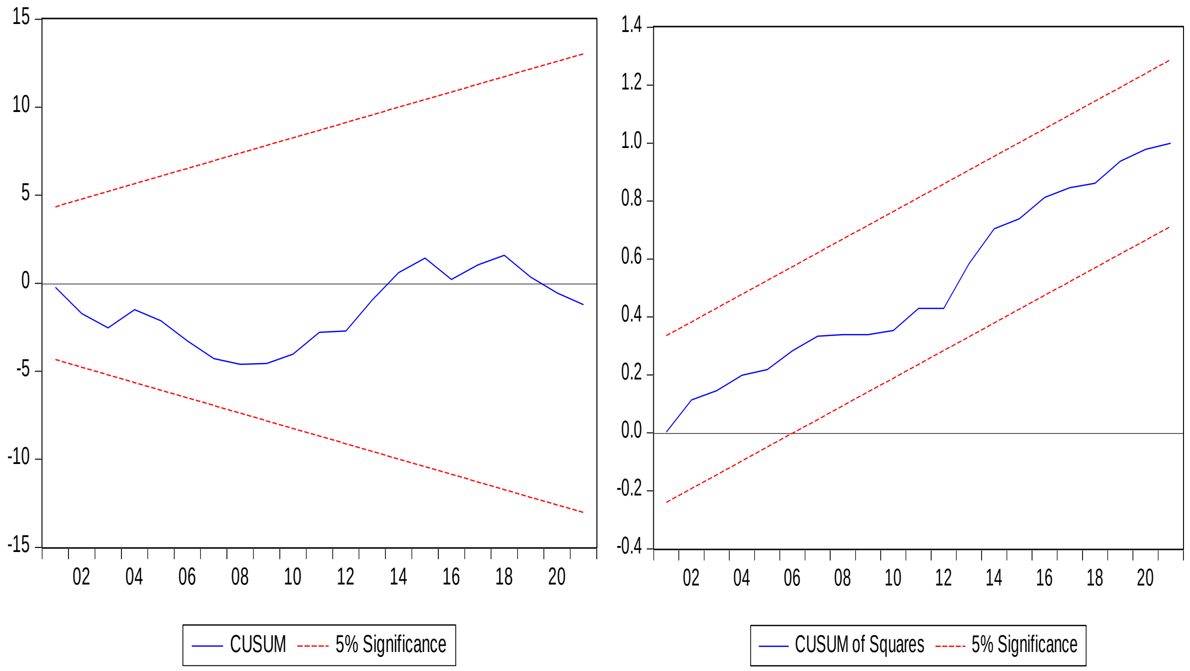

Figure 5.2: Cusum and Cusum Squares

Source: Author (2024); Generated from EViews 10

5.4.7 Robustness Test

After confirming that there was a long-term relationship between variables and that the model was stable, it is important to carry out the robustness test and check for sensitivity. FMOLS, DOLS, and CCR were used as presented in Tables 5.11, 5.12, and 5.13, respectively. FMOLS results show that FDI was significant at a 10% level of significance while GDP and RE consumption were positive and significant at a 1% level of significance. CO_2 emissions were found to be negative and statistically insignificant.

Table 5.11: Fully Modified Least Squares (FMOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNGDP	5.185209	0.709235	7.310984	0.0000***
LNREC	0.878309	0.137450	6.390022	0.0000***
LNCO2	-0.054628	0.635964	-0.085898	0.9320
LNFDI	0.199733	0.102861	1.941773	0.0591*
C	-34.26585	10.89003	-3.146536	0.0031
R-squared	0.885057			
Adjusted R-squared	0.873844			
*** and * denotes 1% and 10% level of significance				
Source: Author (2024) **Generated from EViews 10**				

DOLS results show similar results as FMOLS, but the only difference is that CO_2 emissions were negative but significant at a 1% level of significance. This is the case due to the different assumptions and estimation procedures of the models.

Table 5.12: Dynamic Least Squares (DOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNGDP	6.805951	0.923873	7.366765	0.0000***
LNREC	1.346019	0.254691	5.284917	0.0002***
LNCO2	-4.344088	1.294775	-3.355092	0.0057***
LNFDI	0.828389	0.399296	2.074623	0.0602*
C	35.02949	19.64166	1.783428	0.0998
R-squared	0.987527			
Adjusted R-squared	0.958424			
*** and * denotes 1% and 10% level of significance				
Source: Author (2024) **Generated from EViews 10**				

CCR results are also similar to the results from DOLS and FMOLS. The singular difference in results is that FDI was negative and statistically insignificant. The variation in the results must be because of the different assumptions and estimation procedures of the models.

Table 5.13: Canonical Cointegrating Regression (CCR)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNGDP	5.205236	0.693856	7.501897	0.0000***
LNREC	0.270090	0.137136	1.969507	0.0557**
LNCO2	0.884883	0.143040	6.186254	0.0000***
LNFDI	-0.163020	0.650971	-0.250426	0.8035
C	-32.34408	11.18971	-2.890519	0.0061
R-squared	0.879917			
Adjusted R-squared	0.868202			
*** and ** denotes 1% and 5% level of significance				
Source: Author (2024) **Generated from EViews 10**				

The findings of the long-run analysis show that FDI, GDP, and REC were all positive and significant at a 1% level of significance. The results for GDP and REC are similar to the results of FMOLS and DOLS and for CCR, although REC was significant at a 5% level of significance. These results of the ARDL model are confirmed by all three cointegration models. It can then be concluded that CCR, DOLS, and FMOLS models have validated the ARDL long-run models. This validation shows that the results can be trusted and used for conclusions and recommendations.

5.4.8 Causality Analysis

After determining that there is a long-run relationship amongst the variables, further analysis was conducted to find the nature of the causality linkages among variables. The findings of the pairwise Granger causality tests are outlined in Table 5.14 below. The results show that soybean production granger caused FDI, and the null hypothesis was rejected at a 1% level of significance. A unidirectional causality was then detected, where a one-directional relationship existed going from soybean production into FDI, but the reverse relationship was not observed. This means that a successful agricultural sector will attract investment while investments would not be made to an agricultural sector that is not striving. As mentioned before, soybean is an energy crop, and the involvement of soybean in the creation of bioenergy will also attract FDI in the energy sector. These findings are in support of Selcuk *et al*. (2021), who found the causality results show that there is unidirectional causality from agriculture to FDI, and Agboola and Bekuna (2019), concluded that agriculture causes FDI. Other studies show that there exists a bidirectional causality between FDI and agriculture, forestry, and value-added (Nyiwul and Koirala, 2022). A substantial long-run unidirectional causal relationship between FDI and agricultural value-added demonstrates that any change in the agricultural sector's contribution to the GDP considerably impacts changes in the inflow of agricultural FDI in the long term (Jana *et al*., 2019).

Carbon dioxide emission causes soybean production at a level of significance of 5%, observing a unidirectional causality. This observation tells us that CO_2 emissions have an impact on soybean production, meaning that it can either increase or decrease soybean production at any given point, but soybean production does not have an impact on CO_2 emissions because it does not increase or decrease it. This is true as per the short-run results whereby CO_2 emissions had a significant negative impact on soybean production. Several studies are in line with these results from this study. Ramzan *et al*., 2021, found that CO_2 emissions cause agricultural production, and the nature of the relationship was a unidirectional causality. Ntiamoah *et al*. (2022), found that CO_2 emissions caused maize and soybean production in the long run. Other results from a study conducted by Balsalobre-Lorente *et al*. (2019c), show from agricultural activities to CO_2 emission there exists a unidirectional relation, reinforcing the link that exists between agricultural practices and environmental quality. The results show that agriculture has a unidirectional causality to CO_2 (Ali *et al*., 2021).

However, in other studies, agriculture was found to have a significantly bidirectional causality with ecological footprint (representing environmental degradation), which means that CO_2 emissions caused agricultural production while vice versa is possible/true (Olanipekun *et al*., 2019). Ahsan *et al*. (2020), concluded a bidirectional causality between CO_2 emission and agricultural (cereal crop) production. Carbon dioxide emission caused changes in agricultural value-added, while on the other hand, agricultural activities (crop and animal farming) caused CO_2 emission resulting in a bidirectional relationship (Adedoyin *et al*., 2020). This bidirectional relationship could be caused by the use of unsustainable practices in the agricultural sector that lead to emissions contribution to Carbon dioxide. The causality between agricultural GDP and CO_2 emission was bidirectional, the results further illustrated that the causality of agricultural GDP to CH4 emissions is unidirectional (Uddin, 2020).

RE consumption granger causes FDI at a 5% level of significance. A unidirectional causality is observed. It is more likely that RE consumption will attract FDI as it is a growing sector and has the potential to excel but FDI does not cause RE consumption. These results are supported by Ibrahim *et al*., 2021, who found that renewable energy attracts foreign investors, stimulates economic growth, and further creates green jobs. Fan and Hao (2020), Found that RE consumption causes FDI and enhances its growth. This means that an increase in the use of renewable energy is going to demonstrate to international investors that the market is favourable for investments.

Furthermore, carbon dioxide emission granger causes foreign direct investment at a 1% level of significance, showing a unidirectional relationship. CO_2 emissions have the ability to increase or decrease FDI in host nations, while in this case, FDI does not cause CO_2 emissions. Karimov (2020), the causality test findings showed that there is a unidirectional causal link between CO_2 and FDI. A bidirectional causal relationship between foreign direct investment and economic growth, at a 10% level of significance was observed. FDI impacts and stimulates economic growth and economic development has the potential to attract FDI. The agricultural sector FDI had a bidirectional causality relationship with economic growth because agricultural investments are considered to be a key factor in the economy that promotes growth in the country due to its ability to create job opportunities (Chandio *et al*., 2019).

Table 5.14: Pairwise Granger Causality Tests

Null Hypothesis:	Causality	F-Statistic	Prob.
LNREC does not Granger Cause LNSOYBP	-	0.93946	0.4530
LNSOYBP does not Granger Cause LNREC		1.21429	0.3228
LNGDP does not Granger Cause LNSOYBP	-	0.26875	0.8960
LNSOYBP does not Granger Cause LNGDP		0.91795	0.4648
LNFDI does not Granger Cause LNSOYBP	Unidirectional	0.58656	0.6745
LNSOYBP does not Granger Cause LNFDI		4.23901	0.0069***
LNCO2 does not Granger Cause LNSOYBP	Unidirectional	3.29191	0.0220**
LNSOYBP does not Granger Cause LNCO2		1.78017	0.1556
LNGDP does not Granger Cause LNREC	-	0.64861	0.6317
LNREC does not Granger Cause LNGDP		1.88467	0.1357
LNFDI does not Granger Cause LNREC	Unidirectional	0.84307	0.5077
LNREC does not Granger Cause LNFDI		3.57619	0.0154**
LNCO2 does not Granger Cause LNREC	-	2.08127	0.1049
LNREC does not Granger Cause LNCO2		0.65718	0.6259
LNFDI does not Granger Cause LNGDP	Bidirectional	2.20315	0.0894*
LNGDP does not Granger Cause LNFDI		2.37241	0.0717*
LNCO2 does not Granger Cause LNGDP	-	0.82209	0.5202
LNGDP does not Granger Cause LNCO2		1.62175	0.1913
LNCO2 does not Granger Cause LNFDI	Unidirectional	4.27185	0.0066***
LNFDI does not Granger Cause LNCO2		0.31107	0.8686
***, ** and * represents 1%, 5% and 10% level of significance			
Source: Author (2024) **Generated from EViews 10**			

5.5 Summary

This chapter described the data and explained the mean, standard deviation, kurtosis, and Jarque-Bera values and discussed the correlation between the variables. The inferential statistics results show that the variables are stationary, and the bounds test shows that the long-run relationship exists. The results show that FDI significantly increased and CO_2 emission significantly decreased soybean production but renewable energy consumption and economic growth did not have a significant effect on soybean production in the short-run. Whereas, in the long run, the results show that FDI, GDP, and REC significantly increased soybean production. The model had no presence of heteroscedasticity and serial correlation and the residues were normally distributed. The causality results show both unidirectional and bidirectional relationships between variables.

CHAPTER 6: CONCLUSION AND POLICY RECOMMENDATIONS

6.1 Introduction

This chapter presented the summary of the objectives, the conclusion, recommendations of the study, and further stated areas of future research from the study findings. The main objective of the study was to analyze the impact of renewable energy consumption, foreign direct investment, economic growth and carbon dioxide emissions on soybean production in South Africa.

6.2 Study Objectives Summary

Based on the time series dataset of South Africa from 1975 to 2021, this study aimed to analyze the short and long-run impact of renewable energy consumption, foreign direct investment, economic growth, and carbon dioxide emissions on soybean production using the ARDL approach. This type of study is very crucial as it links key macroeconomic variables together, and the results are of the essence to the economy of South Africa and can inform policymakers. the climate changes such as heavy rains and high temperatures causing floods and droughts have a huge impact on the production of soybeans. These changes in the climate are a result of the country's heavy reliance on fossil fuels for energy. Renewable energy is a suitable solution because its use does not have negative effects on the environment, but rather produces clean energy.

The objectives achieved by this study were: to firstly analyze soybean production trends from 1975 to 2021 in South Africa through a review, secondly to examine the short and long-run impact of renewable energy consumption, carbon dioxide emissions, economic growth, and foreign direct investment on soybean production through ARDL approach, and lastly to analyze the causality between soybean production and RE consumption, CO_2 emissions, GDP, and FDI using the pairwise granger causality test of the ARDL approach. The study tested two major hypotheses: firstly, the study hypothesized that renewable energy consumption, carbon dioxide emissions, economic growth, and foreign direct investment do not have a statistically significant and positive impact on soybean production; then secondly the study hypothesized that renewable energy consumption, carbon dioxide emissions, economic growth, and foreign direct investment does not Granger Cause soybean production.

6.2 Conclusion

The following conclusions were made from the results of each of made on each of the study objectives:

6.2.1 Objective 1: To analyze soybean production trends from 1975 to 2021.

Since the introduction of soybeans in South Africa, it has made significant contributions to the agricultural sector and the economy, with production increasing over the years. The increase was caused by improved soybean products and its uses. The increased demand for animal feeds and human consumption as soybean is high in protein has made its supply to increase. The industry has also seen an improved demand for soybean products such as soymilk and oils, which means that the country had to increase its production so that the supply could meet these demands. Investments have been made towards the crushing facilities in other to make an adequate supply of soybean products. This shows that soybeans are the most preferred beans to be consumed and used due to their health and other benefits. Although the production of soybeans has been increasing in the country, it remains the net importer because the demand exceeds the local supply/production. Despite this, the country is still able to export some of its soybeans to other countries.

6.2.2 Objective 2: To examine the impact of foreign direct investment, renewable energy consumption, economic growth, and carbon dioxide emissions on soybean production in South Africa.

Foreign direct investment, renewable energy consumption, economic growth, and carbon dioxide emissions significantly had an impact on soybean production.

FDI increases soybean production both in the short and long run. This means that FDI creates opportunities for farmers and emerging farmers. The industry benefits from skills and technologies, in the form of FDI, that assist farmers to improve their production. The increased soybean production through investment means that the industry will contribute towards food security and poverty reduction in the country. This will also create jobs and households will have a source of income. This suggests that investments coming into the country have a crucial influence on the agricultural sector and enhance its contributions to the economy. These results show that some of the investments coming into the country could be trickling down to the agricultural sector.

Carbon dioxide emissions decrease soybean production in the short run. Supporting the EKC. Environmental degradation has negative effects on production, which shows that more production is done in an unsustainable way negatively impacting agricultural outputs. Carbon dioxide has become a global threat because of its impact on the environment, production, and people. These results show that it is still a threat to the production of soybeans as it reduces soybean output. The decrease in soybean production also results in a low contribution towards agricultural GDP, which means that jobs will be lost, and communities can also experience food insecurity. Therefore, it is very crucial that mitigation techniques should be put in place to reduce CO_2 emissions.

Renewable energy consumption increases soybean production in the long run. This means that using clean energy helps increase production. The use of soybeans for energy generation can also play a huge role as feedstock in renewable energy production, specifically bioenergy. The increased use of bioenergy will increase soybean production and alternatively create jobs in both the energy and agricultural sectors. From this result, an increase in renewable energy consumption will increase soybean production.

Economic growth increases soybean production in the long run. When there is growth in the economy, it means that the household's income will improve which increases the demand for food. The increased demand for food means soybean supply should also increase, resulting in the rise of soybean production. Economic growth leads to improved infrastructures and technologies in the agricultural sector. Thus, leading to improved production of soybeans.

6.2.3 Objective 3: To analyze the causality between soybean production and foreign direct investment, renewable energy consumption, economic growth, and carbon dioxide emissions.

The results have shown that the variables have unidirectional and bidirectional causality relationships. A unidirectional causality from soybean production and renewable energy consumption to FDI, from CO_2 emissions to soybean production, and FDI, and a bidirectional relationship between GDP and FDI. This means that the success in the production of soybeans will attract investment while CO_2 emissions can cause an increase or decrease in FDI in host nations. The reduction of CO_2 emissions will attract foreign investors with them knowing that their investment in the agricultural sector won't be influenced by environmental degradation. This shows that the quality of the environment is enhanced by FDI while it further stimulates economic growth. This suggests that the investment made could be stimulating the development of clean industries.

Clean FDI inflows involve the transfer of technologies that are environmentally friendly and management approaches. As a result of developing clean industries, the use of fossil fuels will be reduced, and CO_2 emissions will be lowered. Therefore, the pollution halo effect hypothesis for South Africa is validated through this study. An essential healthy and clean environment is needed for many of the 17 sustainable development goals to be achieved. One of the many goals that need to be met by 2030 is reducing pollution which many countries have pledged to achieve, thus this study is very important as it informs South Africa on which path to take or area of focus.

6.3 Recommendations

The study makes the following recommendations in light of the conclusions it drew from the results of each objective:

6.3.1 To analyze soybean production trends from 1975 to 2021

The local production still can’t meet the demand and yet the soybean market is available, and farmers can sell their produce as the country still largely imports. Given the significant local and global market opportunities, the government should dedicate more land to boost soybean production. The government and private sector should invest more in the production of soybean production. This cash injection will benefit both the farmers and the economy, as farmers will be able to produce more and sell more in the markets which will increase its contribution towards the GDP. A clear plan for training rural farmers on soybean production technologies, processing, and management strategies should be made as part of the Agriculture and Agro-processing Master Plan of South Africa.

6.3.2 Objective 2: To examine the impact of foreign direct investment, renewable energy consumption, economic growth, and carbon dioxide emissions on soybean production in South Africa

FDI

Foreign direct investment increases the output of food which helps towards the improvement of food security, reduces poverty, and creates jobs. Therefore, this study recommends that the government should focus on increasing FDI towards the production of soybeans by making sure that this sector attracts investors with simple investment regulations. The government should target green inflow investments that prioritize emission reduction practices in the general economy and the agricultural sector.

CO_2 emissions

Carbon dioxide emissions reduce soybean production which influences the profitability by decreasing its profits. This study recommends that the government should focus on climate-smart farming practices that will help decrease CO_2 emissions and lower their impact on soybean production through the implementation of policy and regulations. Most importantly it is recommended that government invests in soybean research and development that uses technology to curb emissions in production. Programmes that educate the agricultural sector about emission reduction should be initiated especially in rural areas.

REC

Renewable energy consumption increases soybean production. The government should encourage and train farmers to use renewable energy to conduct agricultural activities at the farm level. The government should implement bioenergy programs or policies that promote the use of soybean residues as feedstock and the development of green technologies specifically for bioenergy production from soybeans. The government of South Africa should encourage the efficient use of renewable energy by the farmers and the economy as a whole through training and raising awareness. Farmers' incentives for supplying soybean feedstock in the energy market should be initiated to encourage uptake. Therefore, the government should facilitate a market for soybean residues. The energy fund should be implemented for soybean farmers, for training purposes.

GDP

Economic growth improves soybean production. The agricultural sector is one of the key sectors that contributes to the country's economy as it provides for most of the livelihoods in the communities. This study recommends that the government should focus on economic activities that enhance the production of soybeans, especially in rural areas as it also helps towards the development of the economy and its activities. Improve the infrastructures for the transportation of produce to the market to reduce losses because of damaged roads and storage facilities. This improves the market access for farmers. The economy should encourage the development and research of advanced technologies that will help increase soybean production sustainably.

6.3.3 Objective 3: To analyze the causality between soybean production and foreign direct investment, renewable energy consumption, economic growth, and carbon dioxide emissions.

This study recommends that the government should implement a policy that promotes the use of renewable energy mostly bioenergy in the agricultural industry, as this will accommodate soybean farmer participation in the energy sector. The increased use of REC and soybean production and reduced CO_2 emissions promote FDI. Therefore, the government and farmers should focus on attracting foreign investments which in turn will promote economic development. Investment opportunities in global climate finance from the just energy transition funds should be targeted at the bioenergy sector.

6.4 Areas for Future Research

This study focused on soybean production and how it has been influenced by macroeconomic variables such as renewable energy consumption, foreign direct investment, economic growth, and carbon dioxide emissions. Due to sample size limitations and degrees of freedom, the study was limited to only these chosen variables and was not able to include other variables that might have helped explain soybean production. Other variables that could have been used that would have helped to explain or have an impact on soybean production are:

- ❖ The use of other investment variables such as domestic, private, and green technology investments that may have a negative or positive impact on the production of soybeans.
- ❖ Use renewable energy production instead of consumption to understand its wide influence on soybean production.
- ❖ The use of greenhouse gases and/or climate change to understand how soybean production will react when affected by these variables.
- ❖ Do comparison research on how different energy crops will be influenced by the same variables compared to soybean production to choose the best crop that will benefit South Africa more when using it to produce energy.

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