Renewable Power Generation and the Environmental Kuznets Curve in South Africa

Motsei Modise

0604132e

A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in Energy Leadership

Johannesburg, 2021

ABSTRACT

The Environmental Kuznets Curve (EKC) hypothesis states that there is an inverted U-shape relationship between economic growth and environmental degradation. South Africa is currently in the initial phase of renewed economic growth. Due to its historical reliance on coal for power generation, the country is also among the highest carbon dioxide emitters globally. There is a wide range of existing literature investigating the presence of the EKC in South Africa with other independent explanatory variables such as energy consumption, financial development, and globalisation added to the investigation. However, few studies have included total renewable power generation for South Africa in their assessments. This paper sought to investigate the causal relationship between carbon dioxide emissions, economic growth, and total renewable power generation for South Africa within the EKC framework. Time series data for the period 1997-2018, collected from secondary public sources, was analysed for this study. From the regression model, it was deduced that there is no presence of the EKC theory for the period under study. A unit root test was performed using the Augmented Dickey Fuller test, and it was found that all variables were integrated at the order of 1, GDP was also found to be stationary at level. The results from the Autoregressive Distributed Lag (ARDL) approach proved that there is co-integration between carbon dioxide emissions, economic growth, and total renewable power generation. The Granger Causality test showed a unidirectional relationship from carbon dioxide emissions, no causal relationship from economic growth to total renewable power generation and total renewable power generation and CO_2 emissions. The results indicated that total renewable power generation had a low significant direct impact on carbon dioxide emissions reduction. The current low proportion of renewable energy sources in the total energy mix led to the finding that there was no meaningful reduction in carbon dioxide emissions. This paper proposed the implementation of efficient and powerful policies geared towards reducing South Africa's carbon footprint without causing a negative impact on economic growth in the process.

KEY WORDS – Environmental Kuznets Curve, South Africa, Economic growth, Total renewable power generation, Carbon dioxide emissions

DECLARATION

I, ________**Motsei Modise**_________________, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in Energy Leadership at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Name:Motsei Modise Signature: 

Signed at: Ferndale, Johannesburg…………………………………………

On the ……14th………………….. day of …June……………… 2021

DEDICATION

I dedicate this thesis to my parents, Boikanyo and Miliswa Modise, who stressed the importance of education and sacrificed a lot to ensure I received a good education.

This thesis is also dedicated to young black girls, everything is possible.

ACKNOWLEDGEMENTS

I give praise and glory to God Almighty, for without Him I would not be here.

To my mother. I would not have finished this journey had it not been for your prayers, encouragement, frequent calls to check if I am alright and food packages. I am truly grateful.

A big thank you to Khwezi Tiya, a boss many wish to have, for encouraging me to further my studies, listening to my frustrations, offering support and guidance and mostly for allowing me to bounce my ideas off you.

To my supervisor, Tsele Moloi. You took me under your wing when I was lost and guaranteed I fly in the right direction. Your dedication to producing high quality work and achieving black excellence is commendable, you really inspire me. Thank you for walking this journey with me.

To Anesu Kuhudzai, thank you for teaching me data statistics and for your patience during the process. A big thank you to Thabang Tsotesi from WBS, your hard work in ensuring the academic year ran smooth is appreciated.

To my Mamkhulu, I am truly grateful for the encouragement and love you continuously show me. To Sifiso Skenjana, you made me believe that this is possible even during the darkest moments. Enkosi Sbal'khulu. To my friends, you make me want to be and do better. Your contribution to my life does not go unnoticed, thank you.

Lastly, to my late grandparents, I am who I am today because of your prayers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AIC – Akaike Information Criterion

ARDL – Autoregressive Distributed Lag

CO_2 – Carbon Dioxide

CO – Coal Consumption

DMRE – Department of Mineral Resources and Energy

DoE – Department of Energy

E – Energy Consumption

ECM – Error Correction Model

EKC – Environmental Kuznets Curve

ENE – Energy Efficiency

ENINT – Energy Intensity

EU – Energy Use

FD – Financial Development

GDP – Gross Domestic Product

GHG – Greenhouse Gas

GI – Globalisation Index

GWh – Giga Watt per hour

IRP – Integrated Resource Plan

MW – Mega Watt

REIPPPP – Renewable Energy Independent Power Producer Procurement Programme

REN – Renewable Energy

TR – Trade Openness

CHAPTER 1. INTRODUCTION

1.1 Purpose of the Study

This research investigated the causal relationship between carbon dioxide (CO_2) emissions, economic growth and total renewable power generation (electricity generated from renewable fuel sources) within the framework of the Environmental Kuznets Curve (EKC) for South Africa for the period 1997-2018.

1.2 Context of the Study

Over the last two decades, climate change, and the negative impact that human activity has had on the environment and on the acceleration of global warming have become a global concern, resulting in the call to address the increasing greenhouse gas (GHG) emissions (Pegels, 2010). In December 2015, 196 State Parties at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change signed an Agreement (referred to as the Paris Agreement) to combat climate change (United Nations, 2015). The landmark Paris Agreement requires participating States to introduce economic and social transformation measures to ensure that the global temperature rise this century is maintained below 2 degrees Celsius above pre- industrial levels and with greater effort for the temperature increase to not increase above 1.5 degrees Celsius (United Nations, 2015). Coal is observed as one of the highest GHG emitting fuels (Asafu-Adjaye & Mahadevan, 2013). South Africa has abundant coal reserves, and utilises coal mostly for power generation. Over 70% of the CO_2 emitted in South Africa stems from the power sector, which results in the country being among the highest carbon emitters globally (Mostert & van der Berg, 2018). Eskom, a wholly-owned state enterprise and the majority power producer in South Africa, reported that 92% of the total power generated during the financial year period ending 2019 used coal as a fuel source (Eskom, 2019).

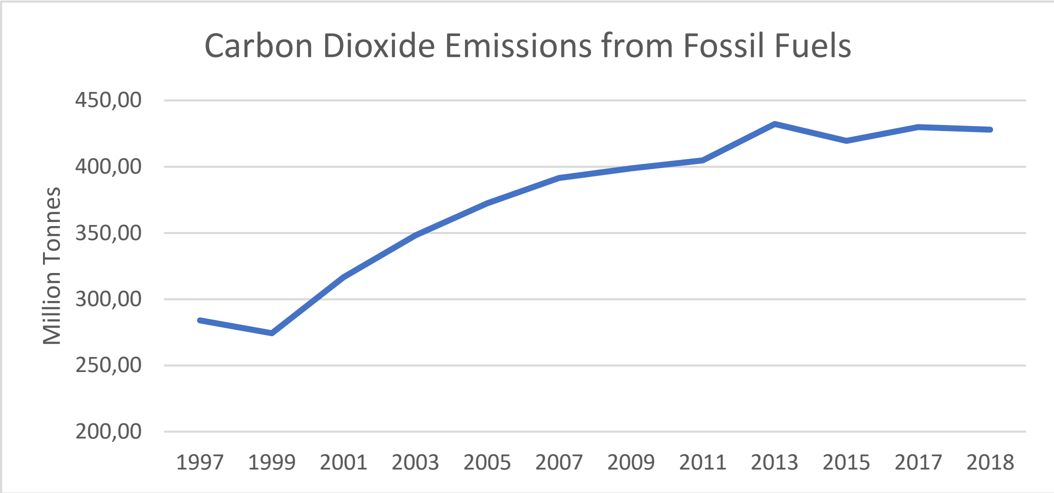

Figure 1: CO_2 emissions in South Africa 1997-2018

Source: (International Energy Agency, 2020)

Figure 1 illustrates South Africa's CO_2 emissions in million tonnes for the period 1997-2018 . The figure illustrates an overall increase of CO_2 emitted over the period. CO_2 emissions are expected to increase further as more coal generating power plants are commissioned leading up to 2030, as highlighted in the Integrated Resource Plan 2019 (IRP, 2019) issued by the Department of Mineral Resources and Energy (DMRE) in 2019 (Republic of South Africa, 2019). An Integrated Resource Plan (IRP) is a electricity capacity plan issued out by the Government of South Africa periodically giving an indication of the country's long term electricity demand and how it will be supplied considering factors such as generating capacity, type, timing and cost (Republic of South Africa, 2010). To date four IRP documents have been released: IRP 2010, IRP Update Assumptions, IRP Update Draft Report 2018 and IRP 2019. The IRP 2019 forecasts new power generation coming from the following sources: 1 000 MW generated from coal (this is in addition to the already contracted capacity of 5 732 MW, which is not yet commissioned), 22 900 MW generated from renewable energy and 3 000 MW generated from gas (Republic of South Africa, 2019).

In 2003, the DMRE released the White Paper on Renewable Energy. According to Aliyu, Modu, and Tan (2018), the paper had set a target of 10 000 GWh of power generated from renewable energy by 2013. In 2011, the Department of Energy (DoE) launched the Renewable Energy Independent Power Producer

Procurement Programme (REIPPPP) to facilitate the introduction of private sector investment in power generation, which would use renewable energy as a fuel source (Eberhard & Naude, 2016). The DMRE describes renewable energy as either one of the following: wind, solar PV, concentrated solar power (CSP), small hydro, biomass, biogas or landfill gas projects (Republic of South Africa, 2019). Prior to the launching of the REIPPPP, renewable energy as a fuel source was utilised for power generation but the Programme introduced this at a large scale. As of October 2019, however, only 7 714 MW of power generated in South Africa is from renewable energy (Republic of South Africa, 2019), a significant shortfall, particularly when measured against the target set for 2013.

The Environmental Kuznets Curve (EKC) illustrates the relationship between economic growth and environmental degradation. The EKC hypothesis according to Stern (1998) suggests that an inverted U-shape relationship is present between economic growth and environmental degradation. Dinda (2004) explained the hypothesis of such relationship as stating that in the early stages of economic development, countries are more concerned about development and less about the impact on the environment; therefore, there is an increase in environmental pollution during the early growth and development phases, but as income increases, mitigating environmental degradation becomes a key focus area with measures and laws being implemented.

Roca, Padilla, Farré, and Galletto (2001) argued that economic growth cannot be the only factor that leads to environmental degradation as suggested by the EKC hypothesis; other independent variables need to be included to test the hypothesis. In their study, the authors further expanded the model to include environmental quality and technology process to the already existing variables: economic growth and CO_2 emissions, in order to investigate the EKC hypothesis. In his study on *Economic Growth and Carbon Emissions in South Africa: An Empirical Investigation,* Odhiambo (2012) investigates the presence of the EKC hypothesis by adding energy consumption as an additional independent variable. Over the years, other authors have included other explanatory variables in testing for the presence of the EKC.

Table 1 summarises existing literature investigating the presence of the EKC in South Africa.

1.3 Research Problem

South Africa has approximately 50 billion tonnes of recoverable coal reserves, and the easily accessible coal is used for power generation (Pegels, 2010). As a result of the country's heavy reliance on coal, South Africa is among the top carbon emitters in the world. Energy has a causal relationship with economic growth (Stern, 1993) and is therefore needed to grow the South African economy. The South African economy is currently in the initial phases of renewed growth and development and therefore, requires sufficient power generation to grow its economy (Inglesi-Lotz & Bohlmann, 2014).

In 2018, the Department of Environmental Affairs of South Africa released a strategy document listing key initiatives planned in eight selected sectors to reduce CO_2 emissions in South Africa leading up to the year 2050 (Republic of South Africa, 2018). The introduction of renewable energy for power generation and other energy efficient measures are some of the initiatives the energy sector in South Africa plans to introduce to reduce its carbon footprint. Noting that currently, over 70% of the carbon emissions in South Africa are emitted from the power sector (Mostert & van der Berg, 2018) with more power plants expected to be commissioned over the next decade, it will be imperative to consider the negative impact that a growing economy will have on the environment because of rising CO_2 emissions. The topic of increasing environmental degradation has become a major concern for most countries across the globe, and as a result, measures to ensure the sustainability of environments have to be implemented, while still growing economies – also to be able to fund such mitigating measures. Taking note of the environmental concerns for South Africa, it is important to investigate the causal relationship between CO_2 emissions, economic growth, and total renewable power generation. In understanding the relationship between the three factors, policy-makers will be able to draft and implement policies that reduce environmental degradation, while not causing additional barriers for economic growth.

Therefore, the main aim was to investigate the presence of the EKC in South Africa by examining if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation between the years 1997 and 2018.

The period selected for analysis in this study (1997 – 2018) is due to data illustrating significant renewable energy power generation only available from 1996 in South Africa. The period under study also captures the renewable energy power generation procured under the REIPPPP coming online from 2013.

1.4 Research Objectives

Objective 1:

To investigate the presence of the EKC in South Africa for the period 1997-2018;

Objective 2:

To establish if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation for the period 1997-2018.

1.5 Significance of the Study

Table 1 illustrates some of the existing literature that tested for the presence of the EKC in South Africa. Several of the listed authors included additional independent variables in their studies. The table highlights the Autoregressive Distributed Lag (ARDL) method as the most frequently used method among the authors. It is also evident that few authors included total renewable power generation as an additional independent variable. This could be as a result of the topic of power generation from renewable energy and climate change only having become more prominent in the past few decades.

This research paper aimed to contribute significantly to existing literature by testing the EKC hypothesis, and including total renewable power generation as an independent variable in the case of a single country, South Africa. The period under investigation referred to the years between 1997 and 2018, this period captures the start of significant power being generated from renewable energies as well as the commencement of independent power generated under the REIPPPP in South Africa. The recommendations from this study may benefit policy-makers in drafting policies that promote economic growth, while still reducing the country’s carbon footprint at the same time.

Table 1 Previous Studies on EKC for South Africa					
Authors	Period	Variables	Methodology	Causality	EKC Hypothesis
Menyah & Wolde-Rufael(2010)	1965-2006	CO_2, real GDP, E, K, L	ARDL Toda- Yamamoto Granger Causality	Real GDP→CO_2 E→CO_2 K→CO_2 L→CO_2	Yes
Odhiambo (2012)	1970- 2007	CO_2, E, real GDP	ARDL Granger Causality	Real GDP→CO_2 E→CO_2	Yes
Shahbaz et al.(2013)	1965- 2008	CO_2, real GDP, FD, CO, TR	ARDL ECM Granger Causality	Real GDP →CO_2 FD→CO_2 TR→CO_2 CO→CO_2	Yes
Kohler (2013)	1960-2009	CO_2, E, real GDP, TR	ARDL Engel Granger Causality	E→CO_2 TR→CO_2 Real GDP →CO_2 (conditional)	Mixed results
Inglesi-Lotz & Bohlmann (2014)	1960-2010	CO_2, real GDP, ENINT, REN	ARDL	N/A	No
Nasr et al. (2015)	1911-2010	CO_2, real GDP	Co-summability	N/A	No
Rafindadi & Usman (2019)	1971-2014	CO_2, real GDP, EU, GI	Maki Toda- Yamamoto Granger Causality	Real GDP→CO_2 GI→CO_2 EU→CO_2 Real GDP ↔EU	Yes

1.6 Delimitations of the Study

a. The study was focused only on South Africa;
b. CO_2 emissions is a proxy for environmental degradation / pollution;
c. CO_2 emissions is emissions from fuel combustion;
d. GDP was used as a proxy for economic growth per capita;
e. The study only concentrated on environmental degradation in the context of the EKC theory;
f. Total renewable power generation and economic growth are the only variables whose impact on CO_2 emissions were analysed in this study;
g. Identifying and correcting for structural breaks in the data had been ignored.

1.7 Definition of Terms

Renewable Energy: Renewable energy consists of the following fuel sources: biomass, solar, wind, and small-scale hydro (The Republic of South Africa, 2003);

CO_2 emissions: CO_2 emitted from fuel combustion, fuel category includes: coal, oil, natural gas and other (industrial waste and non- renewable municipal waste) (International Energy Agency, 2020).

1.8 Structure of the Report

The report is structured in six chapters. Chapter 2 details previously published literature on the Environmental Kuznets Curve, the causal relationship between environmental degradation and economic growth. The literature review of Chapter 2 also assisted the author in formulating the hypothesis that was tested in the study. Chapter 3 documents the research methodology, highlighting the research design, research instruments, data collection and analysis, the reliability, validity, and limitations of the methodology. Chapter 4 presents the results from the data analysis, while Chapter 5 discusses the results in relation to the hypothesis formed under Chapter 2. The study concludes in Chapter 6 by summarising the results in relation to the objectives as set in Chapter 1; it provides suggestions for future studies to be conducted on the EKC for South Africa, and concludes with recommendations for policy-makers.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the existing literature to be used in the study to formulate the hypotheses. The chapter reviews the literature in three segments. The first segment provides theoretical background on the EKC hypothesis. The second segment focuses on the empirical relationship between economic growth and environmental degradation (the basis of the EKC hypothesis). The third segment focuses on the relationship between environmental degradation, economic growth and renewable power generation. In conclusion, the chapter states the hypothesis formulated from the literature reviews.

2.2 Environmental Kuznets Curve

The EKC hypothesis captures the relationship between economic growth and environmental degradation (Stern, 1998). The hypothesis explains that an inverted U-shaped relationship is present between economic growth and environmental degradation, because environmental pollutants increase faster during the early stages of economic development, and then tend to reduce over time(Stern, Common, & Barbier, 1996). This relationship is similar to that of income inequality and economic development as described by Simon Kuznets (1955). Kuznets concluded in his study that in the early stages of economic development, income inequality is wide between skilled and unskilled workers, but this narrows in the later stages of economic development. Figure 2 is an illustration of the long-term inverted U-shaped relationship between economic growth and environmental degradation *ceteris paribus* (Dinda (2004).

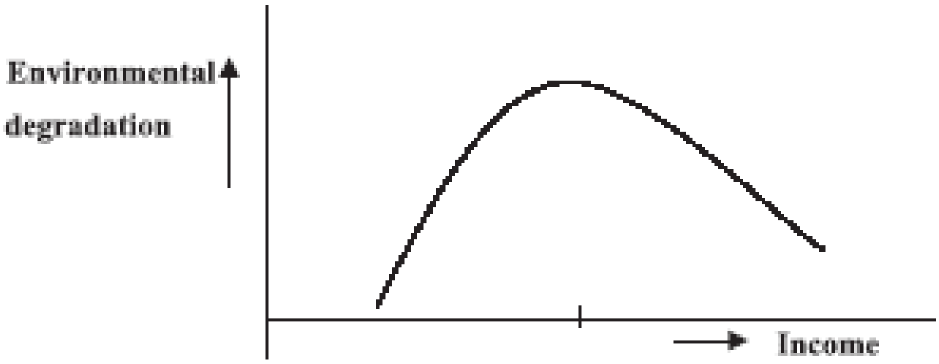

Figure 2 Environmental Kuznets Curve

Source: (Dinda, 2004)

Studies on the relationship between economic growth and environmental pollution first emerged in the 1990s, post the working paper by Grossman and Krueger (1991). According to Grossman and Krueger (1991), the shape of the curve is explained by three different channels:

- Scale effect: As economic growth increases *ceteris paribus,* environmental degradation will most likely increase due to the absence of pollution mitigants (Saboori, Sulaiman, & Mohd, 2012). Industrialised countries whose growth is ear-marked on the production and exporting of manufactured goods operate on the upward slope of the inverted U-shaped curve (Suri & Chapman, 1998);
- Composition effect: In the beginning phases of economic development, the emphasis is on production in the resource extractive / heavy industries that emit more pollution (Stern, 2004). As economies grow, the emphasis shifts more towards agriculture and light manufacturing industries with less emissions or pollution;
- Technique effect: According to Stern (2004), at higher levels of development and income, structural changes − including improvement in technology – occur, leading to a decline in environmental degradation as the economy further develops. McConnell (1997) attested that as income increases, households are most likely to value the environment and the protection of its quality more, and therefore demand energy efficient

technologies and goods / services with less pollutants. Carson et al. (1997) expanded that over time, the wealthy and influential members of society can also influence policy-makers to enforce regulations that reduce carbon dioxide emissions. This is observed in the downward slope of the U-shape.

In 2015, the energy sector was responsible for about 75% of the total GHG emissions globally (Zaidi, Hou, & Mirza, 2018). Stern (1993) stated that energy production was needed to grow an economy. Therefore, one can summarise that if energy production were to increase, this should also boost economic growth; and if the EKC null hypothesis were to be rejected, then the result should be a constant increase in carbon dioxide emissions.

South Africa is classified as a developing country needing significant economic growth to address the increasing poverty levels. As a method to increase economic growth, the South African Government has committed to increasing power generation as stipulated under the IRP 2019 (Republic of South Africa, 2019). In the past, South Africa predominantly relied on coal for electricity generation due to the abundance of the natural resource. However, the IRP 2019 introduced other fuel sources and technologies for electricity generation, which are considered energy efficient and produce fewer GHG emissions than coal-fired power plants.

2.3 Economic Growth and the Environmental Degradation

Grossman and Krueger (1991) investigated the relationship between air quality and economic growth in urban areas across 42 countries. The empirical results from the study evidenced that environmental pollutants increase per capita GDP at low levels of national income, but subsequently increase as levels of national income surpass a particular point (Grossman & Krueger, 1991). Studies by Shafik and Bandyopadhyay (1992) and Panayotou (1997) also corroborated the relationship between GDP and environmental pollutants. The relationship was termed the Environment Kuznets Curve, named after Simons Kuznets, who in his research discovered the inverted U-shape relationship between income inequality and economic growth (Kuznets, 1955).

The initial critiques of the EKC hypothesis were raised by Arrow et al. (1995) and Stern et al. (1996), they attributed the decline in environmental pollutants once income increases to an increase in legislation and reforms that initially ignored the impact, which environmental degradation will have on future generations. Stern et al. (1996) identified several major errors in the EKC model. These errors included the assumption of a unidirectional causality from economic growth to environmental pollution; the assumption that effects of other economic factors have no influence on the environmental pollution; and the quality of data used to test the hypothesis. Despite the criticism, several studies were conducted over the years for countries across the globe, with varying conclusions on the presence of the EKC and the causal direction flow between economic growth and environmental pollutants.

In their empirical testing of the EKC for Tunisia, using time series data, Fodha and Zaghdoud (2010) confirmed that there is a unidirectional causal relationship between economic growth and resulting pollutant emissions (CO_2 and SO_2) in the short and long run. The study confirmed the EKC hypothesis for Tunisia for the period 1961-2004. Saboori et al. (2012) tested the EKC hypothesis for Malaysia for the years between 1980 and 2009, and confirmed the presence of an inverted U-shape relationship between economic growth and CO_2 emissions. The authors utilised the ARDL method to test for co-integration among the variables. However, the results do not show any direct causality between economic growth and CO_2 emissions in the short-run, but unidirectional causality in the long-run. Saudi (2019) conducted the same test for Malaysia over the period 1980-2017, where the results confirm the presence of the EKC hypothesis with a bi-directional causal flow between economic growth and CO_2 emissions. The author utilised the ARDL method to test for co-integration among the variables. In 2012, Odhiambo (2012) in his study verifies the presence of the EKC in South Africa on data collected between 1970-2007. The results also detected unidirectional causality between economic growth and CO_2 emissions in the short and long-run.

The author utilised the ARDL method to test for co-integration among the variables. Using data of the years between 1970 and 2014, Rafindadi and Usman (2019) tested the existence of the EKC in South Africa, with no causal relationship established between economic growth and carbon dioxide emissions. The authors utilised the Maki Co-integration method to test for co-integration among the variables; this method is best utilised where structured breaks within the data are factored into the study.

Dogan and Turkekul (2016b) discovered no presence of the EKC for the period 1960 -2010 in the United States of America. The results conclude that as real output increases, environment degradation declines, while gas emissions increase as GDP^2 increases, therefore the EKC hypothesis is not true for that study. A bi-directional causality was detected between real output and CO_2 emissions (Dogan & Turkekul, 2016b). Inglesi-Lotz and Bohlmann (2014) reject the presence of EKC in their study conducted in South Africa, covering the years 1960 -2010, with the authors reasoning that the result could be that policy-makers have not yet enforced legislation to mitigate pollutants. The authors utilised the ARDL method to test for co-integration among the variables, and did not conduct a test to determine causality. The test results of a study by Kohler (2013) regarding the presence of the EKC in South Africa between 1960 and 2009 were found to be inconclusive, while Kohler discovered a bi-directional causality between economic growth and carbon emissions. The author utilised the ARDL method to test for co-integration among the variables.

Various other authors have tested for the EKC hypothesis in South Africa with varying results. According to Dogan and Turkekul (2016b), Inglesi-Lotz and Bohlmann (2014), the reasons for the discrepancies in the results (even if the same method were used to test for co-integration) could be attributed to data characteristics, functional form, length of the period under analysis, and the techniques used to conduct the studies.

2.3.1 *Hypothesis 1*

a. $H_{0:}$ there is no presence of the EKC in South Africa for the period 1996-2018;
b. $H_{1:}$ there is presence of the EKC in South Africa for the period 1996-2018 .

2.4 Environmental Degradation, Economic Growth and Renewal Power Generation

Given that the electricity sector in South Africa is responsible for causing the largest carbon dioxide emissions in the country, according to Menyah and Wolde-Rufael (2010), South Africa can generate electricity by using alternative and renewable (sustainable) fuel sources, which are proven to cause fewer emissions. South Africa currently procures just over 5% of its power from renewable energy sources, but plans to increase this percentage share in future as part of its REIPPPP (Eberhard & Naude, 2016).

A few studies, though few studying the South African context, have investigated the causal relationship between economic growth, total renewable power generation, and carbon dioxide emitted, and these studies have concluded different results. Wu, Liu, Liu, Fang, and Xu (2015) confirm in their study a relationship between energy consumption, urban population, economic growth and CO_2 emissions in their panel study conducted for Brazil, Russia, India, China, and South Africa over the period 1985-2016. Wu et al. (2015) also confirm the presence of the EKC hypothesis for the nations tested using a multi- variable grey model. Pata (2018) confirmed in the study conducted in Turkey the existence of the EKC hypothesis and cointegration among the variables used in the study: renewable consumption, urbanization, financial development, income and CO_2 emissions using the ARDL method. The study also concluded that total renewable power generation has no impact on the level of CO_2 emitted. The author attributes this finding to the fact that total renewable power generation in

Turkey only accounts for 6.79% of the total energy consumed; therefore, the contribution is too small to make an impact (Pata, 2018). The study conducted by Al-Mulali, Solarin, and Ozturk (2016) for the period 1980- 2010 also confirms that total renewable power generation has no significant effect on the CO_2 emissions in the Middle East and Sub-Saharan Africa because of their small percentage contribution to the total energy sector. The study conducted by Al-Mulali et al. (2016) rejects the presence of the EKC in the Middle East and Sub-Saharan Africa, stating that the EKC will be present only if total renewable power generation were to show a significant effect on CO_2 emission reduction. The authors utilised the Pedroni and Fisher method to test for co-integration among the variables and concluded that there was co-integration among the variables.

Bölük and Mert (2015) conducted a study to determine the relationship between renewable energy, economic growth and CO_2 emissions in the presence of the EKC framework utilising the ARDL method to test for cointegration. The results proved the presence of the EKC in Italy for the period 1961- 2010 and cointegration among the variables in the long-run. The results also highlighted that the relationship between renewable electricity production and CO_2 emissions is only significant in the long-run, therefore renewable electricity production results in a reduction in carbon dioxide emissions in the long-run (Bölük & Mert, 2015).

The test conducted in Pakistan for the EKC hypothesis proved true in the study by Zhang, Wang, Wang, and Danish (2017) with the study confirming co-integration among the variables using the ARDL method for the period 1970-2012. The results evidence that renewable energy plays a significant role in the reduction of CO_2 emissions, and that there is bi-directional causality between the two variables in the short and long-run. These results are synonymous with those obtained by Saudi (2019) in the study for Malaysia. The ARDL method employed by the author to test for co-integration among the variables: renewable energy, non- renewable energy, technology innovation, economic growth and carbon dioxide emissions yielded a positive result with the study also confirming the presence of the EKC during the period 1980- 2017 . The results from the study indicated that renewable energy consumed had a significant and negative effect on CO_2 emissions.

2.4.1 *Hypothesis 2*

a. $H_{0:}$ there is no causal relationship between CO_2 emissions, economic growth and total renewable power generation;
b. $H_{1:}$ there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation for the period 1997-2018

2.5 Research Knowledge Gap Analysis

The theoretical literature on the EKC hypothesis states that in the initial phase of economic development, the government of a country will rarely focus on implementing policies aimed at reducing the country's carbon footprint at the expense of economic growth. It is only once the economy is no longer in the initial developmental phase that governments then consider environmental degradation caused by pollutants and emissions, and put in place policies focused on environmental sustainability. This explains why over the long run an inverted U shape relationship exists between economic growth and environmental degradation. Assessing the impact of cleaner fuel sources on carbon dioxide emissions can assist policy-makers in creating policies focused on reducing GHG emissions, while still growing the economy.

Empirical literature investigating the presence of the EKC in South Africa (in some cases including other independent variables) is presented in table 1. In their recommendations for future studies on the EKC in South Africa, Inglesi-Lotz and Bohlmann (2014) suggested that future researches should include other independent variables to confirm if these would influence the presence of the EKC.

With the launch of the REIPPPP in 2010, South Africa has seen a significant increase in power generated from renewable energies to date. With further significant power to be generated from renewable energies as highlighted under the IRP 2019, it is evident that the Government of South Africa is committed to reducing the carbon dioxide emissions as per its commitment under the Paris Agreement.

Studies such as (Bölük & Mert, 2015), Zhang et al. (2017) and (Saudi, 2019) have indicated that renewable energy plays a significant role in the reduction of carbon dioxide emissions. It is therefore imperative to analyse in the South African context the impact which the introduction of renewable energies has had on carbon dioxide emissions since its introduction for power generation in 1997.

In line with the recommendation by Inglesi-Lotz and Bohlmann (2014) to include other independent variables to further expand the study on the EKC in South South Africa and the introduction of renewable power generation into the power grid, this study identified and sought to address the research gap. The study addressed a theoretical literature gap by investigating the relationship between CO_2 emissions, economic growth and total renewable power generation in the framework of the EKC in South Africa for the period 1997- 2018.

2.6 Conclusion of the Literature Review

Chapter 2 analysed the existing literature on the EKC framework as well as that studying the causal relationship between CO_2 emissions, economic growth and environmental degradation.

According to Suri and Chapman (1998), the hypothesis was based on the notion that environmental pollution has an inverted U-shaped relationship with economic growth. Dogan and Turkekul (2016a) also mention in their study that there are other factors that contribute to CO_2 emissions; therefore, economic growth cannot be the only variable included in the analysis, but other explanatory variables should be included. The South African Government introduced the REIPPPP in 2010 to encourage further investment into power plants fired by renewable energy (Eberhard & Naude, 2016). Emanating from the literature review is the absence of total renewable power generation as an additional variable in studies testing for the EKC in South Africa. Therefore, the following hypotheses investigated in this research arose from the literature review.

Hypothesis 1

a. $H_{0:}$ there is no presence of the EKC in South Africa for the period 1997- 2018;
b. $H_{1:}$ there is presence of the EKC in South Africa for the period 1997- 2018.

Hypothesis 2

a. $H_{0:}$ there is no causal relationship between CO_2 emissions, economic growth and total renewable power generation;
b. $H_{1:}$ there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation

Table 2 Consistency matrix: research objectives

Objective	Research Objective	Hypothesis
1	To investigate the presence of the EKC in South Africa for the period 1997- 2018.	• $H_{0:}$ there is no presence of the EKC in South Africa for the period 1997- 2018; • $H_{1:}$ there is presence of the EKC in South Africa for the period 1997- 2018.
2	To establish if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation.	• $H_{0:}$ there is no causal relationship between CO_2 emissions, economic growth and total renewable power generation; • $H_{1:}$ there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation.

CHAPTER 3. RESEARCH METHODOLOGY

Chapter 3 describes the methodology used in the study to test for the hypotheses formulated under Chapter 2. The chapter details the research design and instruments, data collection methods, limitations, validity and reliability of the methodology.

3.1 Research Approach

The focus of the study was to investigate the causal relationship between CO_2 emissions, economic growth, and total renewable power generation (electricity generated from renewable fuel sources) in South Africa within the EKC framework for the period 1997- 2018. This was a quantitative study.

According to Tewksbury, Dabney, and Copes (2010), quantitative studies rely on the collection of data, usually from secondary sources, and that data is then used in solving a specific problem.

The study was conducted using the following steps:

1. Collection of the dataset;
2. Testing the series for a unit root;
3. Computing of a regression model;
4. Testing the long-run and short-run relationship between the variables using a co-integration approach;
5. Determining the causal direction flow between the three variables.

3.2 Research Design

Following from the study by (Stern, 2004) an earlier scholar of the EKC hypothesis, the EKC model is presented in its natural logarithm form as follows:

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln GDP_t^{\,2} + \varepsilon_t \qquad \textbf{Equation 1}$$

The relationship between economic growth and CO_2 emissions formulates the EKC hypothesis. According to (Rafindadi & Usman, 2019) the squared term of the GDP is to test the shape of the relationship between economic growth and CO_2 emissions. According to Bilgili, Koçak, and Bulut (2016) , the null hypothesis that there is no EKC present is rejected if α_1 is positive and α_2 negative, which demonstrates the inverted U-shaped relationship therefore the presence of the EKC.

The following scholars: Kohler (2013), Menyah and Wolde-Rufael (2010), Bento and Moutinho (2016)have in their studies added other independent variables to the EKC model to determine the effects of those variables on CO_2 emissions. Following the existing literature, this study constructed the following model to investigate the effects of economic growth and total renewable power generation on CO_2 emissions for the period 1990- 2018:

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln GDP_t^2 + \alpha_3 \ln REN_t + \varepsilon_t \quad \textbf{Equation 2}$$

In this study, CO_2 emissions were denoted as carbon dioxide emissions (metric tonnes per capita), GDP referred to economic gross domestic product per capita (with constant 2010 ZAR) and REN reflected total renewable power generation per capita (ktoe), with ε being the error term.

According to Zhang et al. (2017), the addition of power generated from renewable energy was expected to have a negative relationship on CO_2 emissions as renewable energies are considered to emit fewer carbon dioxide emissions; therefore, α_3 was expected to be negative.

Further to the investigation of the presence of the EKC in South Africa. The causal relationship was investigated using the research instruments listed in section 3.5.

3.3 Data Collection Methods

Time series data for the period 1997-2018 was used for the analysis. The data on CO_2 emissions per capita was collected from the International Energy

Agency's CO_2 Emissions from fuel Combustion: Overview (International Energy Agency, 2020). The data on total renewable power generation was collected from BP's Statistical Review of World Energy. The data on GDP per capita was collected from the South African Reserve Bank (South African Reserve Bank, 2020).

3.4 Population and Sample

The data collected was for the period 1997-2018. The specific period is selected due to data illustrating significant renewable energy power generation only available from 1997 in South Africa. The period under study also captures the renewable energy power generation procured under the REIPPPP coming online from 2013.

In line with the definition by The Republic of South Africa (2003), renewable energy consists of the following fuel sources: biomass, solar, wind, and small-scale hydro.

3.5 The Research Instrument

The literature review was a guide for the researcher to determine the dataset and methodologies to be used in this research. The testing process involved the following steps:

1. Determining if each variable contained a unit root;
2. Performing a regression model;
3. If the variables did not contain a unit root, determining if there was a co-integration relationship between the variables;
4. Testing for causality between the variables.

3.5.1 *Unit root tests*

According to Pata (2018), a unit root test is run to check if the series is stationary in order to avoid spurious regression problems with the data. The study applied the Augmented Dickey- Fuller (ADF) Model to test stationarity first at level and then on first differential for each variable.

Hypothesis

H_0: time series has a unit root;

H_1: time series does not have a unit root.

3.5.2 *Testing for co-integration*

In the existing literature, the authors used different co-integration test to determine the relationship between the variables and this was mostly driven by the dataset. The most used test is the Autoregressive Distributed Lag (ARDL) bounds testing approach. The ARDL approach was developed by Pesaran, Shin, and Smith (2001) and is commonly used to test for co-integration between variables mostly because the variables can have a mixed order of integration. The other co-integration model frequently used is the Johansen Co-integration model but the disadvantage of this model is that it requires all the variables to be integrated at order of one *I(1)* (Johansen & Juselius, 1990). According to Saboori et al. (2012) other benefits of using the ADRL approach include: the short and long run impact of the independent variables on the dependent variables are assessed simultaneously. The approach can also be used for small sample sizes which makes this approach appropriate for the sample size analysed under this study. Therefore, for the purpose of this study, the ARDL approach was used.

Hypothesis

H_0: there is no co-integration between CO_2 emissions, economic growth and total renewable power generation;

H_1: there is a co-integration between CO_2 emissions, economic growth and total renewable power generation.

3.5.3 *Testing for causality*

While the results from the co-integration test proved the existence of a relationship, the test did not provide for the direction of causality; therefore, a causality test needed to be performed. The Engle and Granger test was used to determine the short-run direction of the causal relationship between the variables. Kohler (2013) explains that a Granger Causality test determines the effect that a change in lags of *x* has on the current *y* value, given sufficient information. According to Engle and Granger (1987), the Vector Autoregressive (VAR) test is utilised when there is no co-integration between the variables and is used to detect dynamic interrelationships among the variables. Under the VAR model, all variables are endogenous. The VAR model can be written as follows:

$$y_t = \beta_0 + \sum \beta_i \Delta y_{t-I} + \sum \delta \Delta X_{t-I} + \mu t \quad \textbf{Equation 3}$$

However, should the results of the co-integration test produce positive results of co-integration between the variables, then the Vector Error Correction Model (VECM) is applied. According to Saboori et al. (2012), the VECM allows for the capturing of both the short-run and long-run causal relationships at first difference, with the long-run causal relationship being established through the significance of the lagged error term (ε_{t-1}). Therefore, the long-run model, also referred to as the cointegrating equation can be written as follows:

$$\varepsilon_{t-1} = y_{t-1} - \beta_0 - \beta_1 x_{t-1} \quad \textbf{Equation 4}$$

While the short-run model, also referred to as the conventional error correction model for co-integrated series, is written as follows:

$$\Delta y_t = \beta_0 + \sum \beta_i \Delta y_{t-I} + \sum \delta \Delta X_{t-i} + \Phi\ \varepsilon_{t-1} + \mu_t \quad \textbf{Equation 5}$$

The Φ is the coefficient of the error correction, which measures the speed at which in the short-run, Y returns to long-run equilibrium after a change in X.

The Granger Causality test is used to determine short-run causality between the variables. The Granger Causality test determines if the lagged values of one variable can predict the value of another variable in the short-run.

Hypothesis

H_0: no causal flow is present between the variables;

H_1: causal flow is present between the variables.

3.6 Data Analysis and Interpretation

The data collected from secondary sources covering the period 1997-2018 was analysed and run through the statistical tests. The results from the co-integration and causality tests were interpreted as follows:

Co-integration: To test the cointegration of the variables, the F- statistics categorised into two bounds as prescribed under Pesaran et al. (2001) will be used. “These lower critical bound (LCB) and upper critical bound (UCB) are used to test whether cointegration between the variables exists or not. The decision is in favour of cointegration if the F-statistic is more than the upper critical value. There is no cointegration found between the variables, if lower critical bound exceeds the F-statistic. The inference would be inconclusive, if the F-statistic is between lower and upper critical bounds” (Shahbaz et al., 2013, p. 1455). The two critical bounds as stated by Pesaran et al. (2001) are only for large sample sizes. In the study by Narayan (2005), new critical bounds values are derived for small samples sizes. The critical bounds derived from Narayan (2005) at a 5% level of significance will be used to analyse the results in this study.

Causality: To determine the short-run causal relationship (both for VAR and VECM), the Granger Causality test was performed by analysing the significance of the p-value under the Wald test for the lagged independent variable (Saboori et al., 2012). For the purpose of this study, the 5% critical value was utilised to test the significance level.

3.7 Limitations of the Study

The small sample size was a restriction on the co-integration approach/ analysis which can be used in the study.

3.8 Validity and Reliability

According to Heale and Twycross (2015), validity assesses if a particular concept is accurately measured. To ensure accuracy of the data collected from the secondary sources (as listed in section 3.3), the researcher compared the data with that from other secondary sources to determine if there were any large discrepancies, and that construct validity was achieved. No large discrepancies were detected. Through the literature review, it was evident that other authors utilised the same secondary sources to acquire their data, with others using the same statistical methodologies to test for the EKC hypothesis (Shahbaz et al., 2013) (Zhang et al., 2017) (Xu & Lin, 2019).

Reliability assesses if a particular concept has been consistently measured (Bollen, 1989); implying that the same results could be obtained by other authors if they were to use the same dataset and methods. The researcher collected the data from secondary sources that had previously been used by other scholars, and tested this data by using methodologies popularly used to test for co-integration and causality.

3.8.1 *External validity (generalisability)*

The research met the generalisability criteria. Regarding the data collected for the period 1997-2018, the size of the sample was small in comparison to sample sizes of other studies (Nasr et al. (2015) who utilised data ranging over a century. The small sample size utilised in this research paper was the result of renewable energy being largely utilised for power generation only during this period. Peer reviews conducted using the same statistical methods proved the presence of the EKC for South Africa and that in other regions, while the introduction of renewable energy for power generation resulted in the reduction of total CO_2 emission. Therefore, one can assume that the findings of this research are generalisable to other regions.

3.8.2 *Internal validity*

South Africa is one of the world's highest carbon dioxide emitters as a result of the country's reliance on coal power generating plants. An increase in energy is set to support and even increase economic growth. This would also mean for South Africa, that such economic growth will lead to an increase in CO_2 emissions and other pollutants. Such increase in carbon emissions can lead to inconclusive results on the presence of the EKC in South Africa. Therefore, the internal validity of the study can only be decided once testing has occurred and the results analysed.

3.8.3 *Objectivity*

The research was based on a dataset collected from a secondary source to be tested in a statistical method previously used by other authors. The researcher took all necessary steps to ensure that the findings were clear of any bias from the researcher.

3.9 Ethical Considerations

Post the submission of the research proposal to the proposal committee, the researcher received permission from the Witwatersrand's Research Ethics Committee to commence with the data collection. The data analysed for this research was collected from publicly available databases, and no human contact was involved in the data collection.

Table 3 Consistency matrix: research objectives, hypothesis, data collection and data analysis

Objective #	Research Objective	Hypothesis	Data Collection Detail	Data Analysis Method
1	To investigate the presence of the EKC in South Africa for the period 1997- 2018.	• $H_{0:}$ there is no presence of the EKC in South Africa for the period 1997- 2018; • $H_{1:}$ there is presence of the EKC in South Africa for the period 1997- 2018.	• Independent Energy Agency • South African Reserve Bank • BP Statistical Review of World Energy	Regression Model
2	To establish if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation.	• $H_{0:}$ there is no causal relationship between CO_2 emissions, economic growth and total renewable power generation; • $H_{1:}$ there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation.	• Independent Energy Agency • South African Reserve Bank • BP Statistical Review of World Energy	ADF ARDL VECM Engle and Granger

CHAPTER 4. PRESENTATION OF RESEARCH RESULTS

4.1 Introduction

This chapter presents the results from the data analysis conducted using the methodology as described in Chapter 3.

4.2 Descriptive Statistics

The results presented in this chapter form the basis on which the research objectives are answered.

4.2.1 *Data sample*

The sample data was collected for the period 1997-2018 for South Africa using publicly available datasets. The data on CO_2 emissions per capita was extracted from the Independent Energy Agency; data on total renewable power generation from BP's Statistical Review of World Energy; and that of GDP per capita from the South African Reserve Bank. The data on renewable power generation is presented in the original source in terawatts per hour (Twh). For the purpose of this study, the data was converted to kilotonnes of oil equivalent (ktoe) using the conversion 1Twh= 85,985 ktoe (International Energy Agency, 2020)

Table 4 is the sample data, which was utilised in running the econometric models.

Table 4 Sample data of input variable

Year	CO2 Emissions (metric tonnes per capita)	Renewable Power Generation (ktoe)	GDP per Capita (2010 ZAR)
1997	6,608	12,5537	44 420,00
1998	6,684	19,8624	43 720,00
1999	6,186	16,9389	43 826,00
2000	6,238	41,8573	44 735,00
2001	6,945	37,3087	45 075,00
2002	7,082	40,6449	45 798,00
2003	7,455	36,8272	46 287,00
2004	7,936	35,2021	47 605,00
2005	7,776	39,0628	49 335,00
2006	7,716	37,4978	51 331,00
2007	7,97	39,7764	53 334,00
2008	8,469	42,8891	54 322,00
2009	7,896	43,1986	52 838,00
2010	8,206	39,3723	53 823,00
2011	7,782	45,5116	54 968,00
2012	7,993	46,9131	55 543,00
2013	8,05	65,1505	56 232,00
2014	8,125	225,3740	56 549,00
2015	7,575	536,3627	56 470,00
2016	7,471	681,0230	55 914,00
2017	7,541	913,7109	55 930,00
2018	7,407	1053,8474	55 595,00

As per Table 4, the data was collected for the period 1997- 2018 due to data availability. Even though data on GDP per capita and CO_2 emissions per capita is available before 1997, data on renewable power generated is only available from 1996. This is due to significant power generation from renewable energy only coming on to the power grid at that time.

In running the model, the data was changed to logarithmic format.

4.3 Unit Root Test

Table 5 Unit Root Test

Variables (logarithm format)	**ADF unit root test**			
	I (0)		I (1)	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
CO_2 emissions per capita	-1.1328	-1.5187	-5,2804*	-5,2634*
GDP per capita	-4,6987*	-4,9922*	-8,5981*	-8,4325*
Total renewable power generation	-0,2056	-1,2215	-3,6727*	-3,7719*

** Statistical significance at 5%*

The unit root test was performed to determine if the series is non-stationary and possesses a unit root. The presence of a unit root implies a systematic pattern with the data that is unpredictable and has spurious regression. Time series, which is stationary, is preferred as it means the statistical properties do not change over time.

The Augmented Dickey Fuller test was used to test the data for stationarity. The test was run at stationary level and then at first difference. The results of the unit root test were used to assist the researcher on the co-integration model, as some models can only use series at a particular integrated level.

Table 5 displays at the 5% significance level that the null hypothesis is rejected for GDP both at intercept, and intercept and trend when tested at *I(0)*. The variable is stationary at level.

All the variables were then tested at first difference. The results from the first difference unit root test indicate that the null hypothesis is rejected for all the variables at the 5% significance level at intercept, and intercept and trend: CO_2 emissions, GDP, and total renewable power generation. The variables do not possess a unit root and are stationary. The statistical properties of the variables do not change over time.

From the results, all the variables are stationary implying that the data has a systematic pattern, which is predictable, and that there is no presence of spurious regression. The results of the unit root test play a significant role in determining the co-integration model to be used, as some models require that all variables be stationary either at level or first difference, while other models are not prescriptive on the level of stationarity. From the results GDP is the only variable stationary at both level and first difference, whilst CO_2 emissions and renewable power generated are only stationary at first difference. Therefore, the ARDL approach was used to determine co-integration among the variables as it is not prescriptive on the level which all the variables should be stationary at.

4.4 Results Pertaining to Hypothesis 1

The results presented in this section are in relation to the first research objective: To investigate the presence of the EKC in South Africa for the period 1997- 2018.

Table 6 Long-run Results

Dependent Variable = lnCO2 emmisions

Variable	**Coefficient**	**Standard error**	**t- statistics (p- value)**
Constant	17.489	2,793	6,263 (0.000)*
lnGDP per capita$_t$	-8,078	1,346	-6,000 (0.000)*
lnGDP per capita^2_t	0,9684	0,161	6,028 (0,000)*
lnRenewable power generation$_t$	-0,029	0,012	-2,445 (0,024)*
Diagnostic test			
R-squared	0,714	Prob (F-stat)	0,000021
Adjusted R-squared	0,669	DW	0,923
F-stat	15,796	Sum squared residual	0,001

Table 6 displays the statistical results of the long-run relationship between the variables used to formulate the regression model to determine the presence of the EKC. The p-values and coefficients of the variables (in logarithm format) were analysed in this study to determine the statistical significance of the relationship, and the nature of the relationship between the dependent variable

(CO_2 emissions) and the other independent variables (GDP and total renewable power generation).

The p-values indicate the statistical significance of the relationship between the dependent and independent variables. If the p-value is less than the specified significance level, then the null hypothesis is rejected.

Using a statistical significance level of 5%, and analysing the results from table 5, the p-value of GDP, GDP squared and renewable power generation are all below the 5% statistical significance level. Therefore, the null hypothesis that there is no correlation between CO_2 emissions and each of the independent variables: GDP, GDP squared and total renewable power generation can be rejected. A conclusion can be reached that changes to each of the independent variables will lead to a change in the dependent variable *ceteris paribus*.

The value of the coefficient indicates how much the mean of the dependent variable changes, given a 1% shift in the independent variable *ceteris paribus.* The sign of the coefficient variable determines whether the correlation between the dependent variable and independent variable is positive or negative. From table 5, the coefficient of GDP is -8.07, the negative sign signals that a 1% augmentation to GDP in the long-run will decrease CO_2 emissions by 8.071% *ceteris paribus.* The coefficient of GDP squared is 0.96, a 1% increase in GDP squared is set to increase CO_2 emissions by 0.96% *ceteris paribus*. The coefficient of total renewable power generation is -0.023, the negative sign signals that a 1% increase in total renewable power generation will decrease CO_2 emissions by 0.023% *ceteris paribus.*

4.5 Results Pertaining to Hypothesis 2

The results presented in this section are in relation to the second research objective: To establish if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation.

To determine if a causal relationship exists between CO_2 emissions, economic growth and total renewable power generation, post testing for stationarity of the variables, a co-integration test had to be modelled before determining the causal direction.

4.5.1 *Co-integration results*

Table 7 Results of the ARDL bounds testing co-integration approach

Estimated equation $lnCO2t = \alpha0 + \alpha1\ lnGDPt + \alpha2\ lnGDPt2 + \alpha3\ lnRENt + \varepsilon t$

F- Stat	14.13459		
Significance level	1%	5%	10%
Lower Bounds *I(0)*	5,856	4,154	3,43
Upper Bounds *I(1)*	7,578	5,54	4,624

Diagnostic test

R-squared	0,769	DW	2,171
Adjusted R-squared	0,714	Sum squared residual	0,007
Prob (F-stat)	0,000003		

A co-integration test determines if there is a relationship between the three variables. For the purpose of this study, the ARDL approach method was used to determine the relationship between CO_2 emissions, economic growth and total renewable power generation. The ARDL approach is not prescriptive on the order of integration, the variables can be stationary at *I(0) or I(1) or mixed order.* As per the results of the unit Root test, all the variables are stationary at first difference with only GDP stationary at level. Therefore, the stationarity requirement to use the ARDL method has been achieved.

An optimal lag length of 4, using the Akaike Information Criterion (AIC), was selected. According to Lütkepohl (2006), the AIC criterion is more suitable for small size samples. The critical bounds follow those given by Narayan (2005) following unrestricted intercept and unrestricted trend with a sample size of 30. The null hypothesis that the is no co-integration among the variables is rejected if the lower critical bound exceeds the F-statistic. The result is inconclusive if the F-statistic is between the lower and upper critical bounds.

Using the 5% level of significance, table 7 illustrates that the F-statistic of 14.13 is larger than the upper critical bounds of 5,54. Therefore we reject the null hypothesis and conclude that there is co-integration among the variables. This result also confirms the existence of a long-run relationship between CO_2 emissions, economic growth and total renewable power generation in South Africa during the period 1997- 2018. This result is aligned with that demonstrated in table 5.

A Vector Error Correction Model (VECM) was modelled to establish the long-run and short-run co-integration models.

4.5.2 *Vector Error Correction Model*

Table 8 Estimated coefficients from VECM model

Long Run estimate

Variable	**Coefficient**	**Standard error**	**t- statistics**
Constant	1,428		
lnGDP per capita (-1)	-0,487	0,089	-5,464
lnRenewable power generation (-1)	-0,02	0,03	-0,664

Short Run estimate Dependent Variable = lnCO2 emmisions

Variable	**Coefficient**	**Standard error**	**t- statistics**
Constant	0,004	0,006	0,662
lnCO2 Emissions (-1)	-0,206	0,251	-0,819
lnGDP per capita (-1)	0,021	0,022	0,916
lnRenewable power generation (-1)	-0,008	0,03	-0,277
E (-1)	0,071	0,066	1,088

Diagnostic test

R-squared	0,103
Adjusted R-squared	-0,121
F-stat	0,461

The VECM allows for the examination of the long-run and short-run dynamics of the co-integrated series. Table 8 illustrates the results from the VECM. The results can be applied to the co-integrating equation (long-run model) as shown in equation 4 and be presented as:

$$\varepsilon_{t-1} = 1.000lnCO_2emissions_{t-1} - 0.487lnGDP_{t-1} - 0.02lnREN - 1.428$$

Equation 6

The conventional error correction model (short-run) can be written as follows, with CO_2 emissions as the target variables:

$$\Delta lnCO_2\ emissions_t = 0,004 - 0,206\Delta lnCO_2emissions_{t-1} + 0,021\Delta lnGDP_{t-1} - 0,008\Delta lnREN\ 0.071\varepsilon_{t-1}$$

Equation 7

Equation 6 signifies long-run relationship among the variables. A 1% increase in GDP will result in an 0,48%% decline in CO_2 emissions in the long-run. A 1% increase total renewable power generated will result in a 0,02%.

In interpreting equation 7, the conventional error correction model, ε_{t-1} represents the adjustment coefficient. The adjustment coefficient illustrates that the previous period's deviation from long-run equilibrium is corrected in the current period at an adjustment speed of 7.1%. The past realisation of CO_2 emissions is associated with a 0,2% increase in CO_2 emissions on average *ceteris paribus* in the short-run. The past realisation of economic growth and total renewable power generated is associated with 0,02 increase and 0,008 decline in CO_2 emissions on average *ceteris paribus* in the short-run, respectively.

4.5.3 *Granger Causality test*

The Granger Causality test was performed to understand the direction of the causality between the three variables. The Granger Causality test indicates that there is a correlation between the past values of one variable and the present value of another.

Table 9 Granger Causality test between the variables

Granger Causality Test

Null Hypothesis	Chi-square	Prob
GDP does not Granger cause CO_2 emissions	0,838	0,36
Renewable Power does not Granger cause CO_2 emissions	0,071	0,781
CO_2 emissions does not Granger cause GDP	9,99	0,0016
Renewable Power does not Granger cause GDP	2,359	0,125
CO_2 emissions does not Granger cause Renewable Power	0,115	0,734
GDP does not Granger cause Renewable Power	0,166	0,684

The results listed in Table 9 are those from the Granger Causality test conducted between CO_2 emissions, GDP and total renewable power generation. To test for the presence of Granger causality between the variables, if the p-value is greater than 0.05 level of significance, the null hypothesis stating that X does not Granger cause Y is not rejected and the conclusion is reached that there is no causality between the variables. The results in table 9 indicate the p-value of CO_2 emissions does not Granger cause GDP is 0,0016, this figure is below the significant level of 0,005. Therefore, the null hypothesis is rejected and a conclusion that CO_2 emissions Granger causes GDP holds. However, the results show that GDP does not Granger cause CO_2 emissions. Therefore, there is unidirectional causality from CO_2 emissions to GDP.

Furthermore, no causal flow is detected between total renewable power generation and GDP. There is also no causal flow is detected between total renewable power generation and CO_2 emissions.

4.6 Conclusion of Presentation of Research Results

Chapter 4 presents the results of the analysis of the study. The long-run regression model was formulated to ascertain if the EKC hypothesis was present for South Africa during the period 1997-2018. This was to respond to the first objective:

Objective 1: To investigate the presence of the EKC in South Africa for the period 1997- 2018.

Post the determination of the presence of the EKC, a statistical analysis was performed to respond to the second objective:

Objective 2: To establish if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation

A unit root test was initially performed on the dataset to confirm stationarity of the variables. The ARDL approach was then employed to determine co-integration among the variables: CO_2 emissions, economic growth and total renewable power generation. The results also confirmed that there is a long-run relationship among the variables.

Once co-integration was established, the causal flow direction needed to be ascertained. The Granger Causality method was utilised. The results proved a unidirectional causal flow exists from CO_2 emissions to GDP. Furthermore, no causal flow was found between total renewable power generation and GDP. There is also no causal relationship found between total renewable power generation and CO_2 emissions.

CHAPTER 5. DISCUSSION OF RESEARCH FINDINGS

5.1 Introduction

The aim of this chapter is to discuss the results as presented in Chapter 4. The results will be applied to the purpose of the study, research objectives, and the hypotheses, and linked with previous studies that had been conducted on the topic as outlined under the literature review in Chapter 2.

5.2 Unit Root Test

While the unit root test was conducted to ensure that the time series was stationary in order to avoid spurious regression within the analysis, the results of the test were also used in selecting the co-integration model to be used. The findings as per section 4.3 indicated that at the 5% significance level, at first difference at intercept, the null hypothesis that the time series was not stationary could be rejected. GDP was the only variable which was stationary at level at a 5% significance level.

In the study by Zhang et al. (2017), at the 5% significance level, none of the series were stationary at level, but all were integrated at first difference. This result is synonymous to that of Bölük and Mert (2015), Al-Mulali et al. (2016) and Baek (2016).

The ARDL approach allows for the testing of co-integration when variables are either *I(0)* or *I(1),* mixed order of integration. The order of integration of the series must only be at first difference for the Johansen Co-integration approach to be used, Hossain (2011) employed this method of co-integration as the series was only stationary at first difference. In this study, the series was stationary at first difference, with GDP the only variable stationary at level, the author elected to use the ARDL approach to test for co-integration. This is the same approach used by Kohler (2013), Shahbaz et al. (2013), Baek (2016) and Inglesi-Lotz and

Bohlmann (2014) where the series used in their respective studies was either all integrated at first difference or mixed order of integration was present.

5.3 Discussion Pertaining to Hypothesis 1

One of the key objectives of this study was to determine the presence of the EKC between the period 1997-2018 in South Africa. According to Stern (1998), the EKC hypothesis states that there is an inverted U-shaped relationship between environmental degradation and economic growth. In order to determine the presence of the EKC, a regression model had to be formulated and the signs of the coefficients analysed. When inputted into equation 2, the quantitative results from section 4.3 produced the following regression model:

$$\mathbf{lnCO_2 = 17{,}49 - 8{,}08lnGDP + 0{,}97(lnGDP)^2 - 0.03lnREN} \qquad \textbf{Equation 8}$$

According to the literature by Stern et al. (1996), and in an effort to prove the presence of the EKC by analysing a regression model, the coefficient of GDP should be positive, while the coefficient of GDP squared should be negative. The explanation of the coefficients of the regression model by Stern et al. (1996) is based on the initial literature of the EKC, which did not take into account any other independent explanatory variables. In later studies, scholars such as Zhang et al. (2017) extend the regression model to include total renewable energy. In their study, the coefficient of total renewable energy is concluded to be negative for the presence of the EKC to prove true.

The regression model for discussion in this study is given as equation 8. The coefficient of GDP is negative; the coefficient of GDP squared is positive; and that of REN is negative. In comparison with the interpretation of the results by Stern et al. (1996) and Zhang et al. (2017). As per equation 9, the coefficient of GDP is negative when it should be positive; the coefficient of GDP squared is positive when it should be negative; and the coefficient of REN is negative and as per literature should be so. Therefore, based on the results, which differ from the literature review, there is no presence of the EKC in South Africa between the years 1997-2018.

The findings of the absence of the EKC but the presence of a long-run relationship between the variables in this study are synonymous with the study by Inglesi-Lotz and Bohlmann (2014) for their study on South Africa, adding energy intensity and renewable energy use as additional independent variables. The study by Nasr et al. (2015) also concluded that there was no EKC presence for South Africa, using the co-summability concept, with no additional explanatory variables added to the regression model. The two findings from the two studies are aligned with the current study's findings and prove no presence of the EKC in South Africa but long-run relationship among the varables.

Other studies that have confirmed no presence of the EKC include: Dogan and Turkekul (2016a) for the USA with energy consumption, trade urbanisation and financial development as additional independent variables; Hossain (2011) in their panel estimation finding no presence of the EKC for China, the Philippines and Thailand, using energy consumption, trade openness and urbanisation as additional variables.

The study by Pata (2018) for the period 1974-2014 including renewable energy consumption, urbanization and financial development as independent variables to the EKC framework supported the presence of the EKC hypothesis in Turkey. The study found the presence of a long-run relationship among the variables, however the renewable energy consumption was not significant to reduce CO_2 emissions. Renewable energy accounted for 6.79% of total power generation in Turkey during the period under study, this could be attributed to the insignificant impact on reducing CO_2 emissions.

As per our results, in the long-run, a 1% change in renewable energy power generated decreases carbon dioxide emissions by 0,023%. The not significant contribution to reducing CO_2 emissions is as a result of during the period under study, renewable energy only contributed approximately 7% to total power generation.

5.4 Discussion Pertaining to Hypothesis 2

The discussion of the results pertains to the second objective of this study: To establish if there is a causal relationship between CO_2 emissions, economic growth and total renewable power generation. The results have been discussed in three segments: co-integration, VECM model and the Granger causality test.

5.4.1 *Co-integration Results*

In Chapter 1, the study explained that South Africa is one of the highest carbon emitters in the world because of the high usage of coal for power generation. To reduce the carbon dioxide emissions, the South African Government initiated the REIPPPP, a programme that will see the introduction of renewable energy as a fuel source in power generation. Total renewable power generation was included as an explanatory variable in this study to assess its relationship with carbon dioxide emissions and economic growth in the context of the EKC framework for South Africa.

The null hypothesis states that there is no presence of co-integration between CO_2 emissions, economic growth and renewable power generation. At the 5% significance level, as per the results is rejected as the F-statistics is greater than the upper critical bounds value. Therefore, there is a co-integration relationship between CO_2 emissions, economic growth and GDP. The presence of a relationship implies that a change in one variable affects the other variable in the long-run.

Bölük and Mert (2015) used the ARDL approach in their study to determine co-integration among CO_2 emissions, economic growth and electricity generated using renewables in Turkey. The results of the study concluded that there is co-integration among the variables and presence of a long-run relationship. This method used by the authors and results achieved as the same as those of this paper.

Al-Mulali et al. (2016) investigated the presence of co-integration between renewable energy consumption, economic growth and GDP across seven regions. The study found that there is co-integration between the variables across the seven regions using the Fisher type co-integration test. The results also confirmed a long-run relationship between the variables. Even though this study utilised the ARDL approach, the results of co-integration and presence of a long-run relationship among the variables is the same.

5.4.2 *VECM Results*

The presence of a long-run relationship among the variables enables the use of the VECM to analyse the long-run and short-run dynamics.

The co-integration equation as illustrated in equation 4 is the long-run equation. The negative sign of the coefficients of GDP and renewable power generation indicate the ability of the data to revert to long-run equilibrium should a shock arise in the short-run. Had the coefficients displayed a positive sign, this could have indicated specification issues with the dataset.

The co-integration equation as illustrated in equation 5 is the short-run equation. The coefficient of the error correction term is measures the speed at which in the short-run, CO_2 emissions return to long-run equilibrium after a change in GDP and renewable energy power generation. When CO_2 emissions are not at their equilibrium level, they adjust by approximately 7% within the first year to revert to the equilibrium level.

5.4.3 *Granger Causality test*

The Granger Causality test was used to test for a short-run causal relationship between the variables: CO_2 emissions, GDP and renewable energy power generation following the VECM. The null hypothesis states that there is no causal flow between the variables. The results show a unidirectional causal direction from CO_2 emissions to GDP and no causality between CO_2 emissions and total renewable power generation and total renewable power generation and GDP the other variables. This result is different to that reached by Al-Mulali et al. (2016) who in their study confirmed a bidirectional causal flow between CO_2 emissions and GDP and a unidirectional causal direction from renewable energy consumption to CO_2 emissions for Eastern and Central Europe. The study by Saudi (2019) proposes a bidirectional causal flow between the variables: renewable energy, non-renewable energy and technology,CO_2 emissions and GDP. The study by Hossain (2011) proposes that there is a unidirectional causal flow between GDP to CO_2 emissions .

5.5 Conclusion of Research Findings

In summary, the chapter discussed the results from Chapter 4 and put them in context with the hypotheses, the findings from the literature review, and the objectives of this study. The main findings included:

1. The time series was stationary at first difference with GDP being the only variable stationery at level. The ARDL approach was selected to test for co-integration;
2. The long-run relationship among the variables was determined. From the results, the presence of the EKC in South Africa for the period 1997-2018 was not detected;;
3. The ARDL approach proved that there is co-integration between the three variables: CO_2 emissions, GDP and total renewable power generation and reconfirmed a long- run relationship between the variables.
4. The Granger causality test proposed that in the short run, there is a unidirectional causal flow from CO_2 emissions to GDP. There is a no causal flow between CO_2 emissions and total renewable power generation and total renewable power generation and GDP.

CHAPTER 6. CONCLUSION & RECOMMENDATIONS

6.1 Introduction

This study sought to investigate the causal relationship between economic growth, total renewable power generation, and carbon dioxide emissions through the Environmental Kuznets Curve (EKC) framework for the period 1997-2018 in South Africa. Time series data on GDP growth, CO_2 emissions, and total renewable power generation was used for the analysis. The data was collected from secondary and publicly available sources, and run through statistical software to determine the long- run relationship, co-integration, and causality among the variables.

The ARDL approach was used to investigate the presence of co-integration between the variables. The Granger Causality test was applied to examine the direction of causality between the variables.

6.2 Summary

The Environmental Kuznets Curve (EKC) hypothesis states that there is an inverted U-shaped relationship between economic growth and environmental degradation. South Africa is one of the largest carbon dioxide emitters in the world, as over 90% of the electricity generated in South Africa uses coal as a fuel source (Pegels, 2010). With energy being one of the essential catalysts in driving economic growth, this study sought to evaluate if the EKC was present in South Africa for the analysed period 1997-2018, and to investigate the causal relationship between CO_2 emissions, GDP and renewable power generation.

Using the coefficients of the variables from the regression model to determine the presence of the EKC during the specified period, the findings from the study indicated that there was no presence of the EKC hypothesis in South Africa for the period 1997-2018. According to previous studies on the topic, the coefficient of total renewable power generation must be negative to illustrate its impact on reducing carbon dioxide emissions. The findings from the regression model produced a negative coefficient sign for total renewable power generation, although the statistical significance was low. The study by Al-Mulali et al. (2016) proposed that the existence of the EKC in a particular region is determined by the significance of the renewable energy consumption. In their study, regions where renewable energy had a low significant influence on CO_2 emissions, the presence of the EKC was not detected (Al-Mulali et al., 2016).

One of the reasons the presence of the EKC could not be detected in this study could be due to the short period of analysis selected. The period of study is 1997-2018. During this time, the country was transitioning and largely focused on economic growth and development, and it had few environmental policies in place to curb greenhouse gases. It was only during the later years (of this specified period) that environmental policies were initiated and introduced. During this period, in an effort to procure more energy to assist in economic growth, while also adhering to the international treaties that the country was now a party to, the South African Government introduced the REIPPPP, which was set to see renewable energy used for power generation. However, by the end of 2018, power generated from renewable energies accounted for approximately 7%% of the total power generated in South Africa, with coal generation still accounting for over 90%. This unbalanced energy mix explains why total renewable power generation has such a low impact on carbon dioxide emissions. This also implies that the higher the proportion of renewable energy in the total mix of energy, the more renewable energy will have an impact on the reduction of CO_2 emissions.

The results produced in this study regarding the lack of the EKC presence validates the findings by Kohler (2013). In his study, Kohler (2013) used the period 1960 to 2009 as his analytical period, and concluded that the endogeneity between CO_2 emissions and economic growth dataset explains the lacking presence of the EKC. Inglesi-Lotz and Bohlmann (2014) provide the same findings of no EKC presence in their study regarding the period 1960 to 2010. They suggested that due to South Africa still being in the initial stages of its economic development, and very limited use of renewable energy sources, the country has not yet reached the point of creating forceful policies aimed at environmental quality. Nasr et al. (2015) also confirmed no EKC presence in South Africa for the period 1911-2010, and attributed this finding to the lack of policies aimed at promoting environmental quality and renewable energy sources leading to energy efficiency. The three studies were aligned to this study and indicated the need for efficient and more powerful policies aimed at increasing energy efficiency, and minimising environmental degradation, while focusing on economic growth.

Even though the results in this study confirmed no EKC presence in South Africa during the time under observation, the findings using the ARDL approach confirmed co-integration between CO_2 emissions, economic growth and total renewable power generation. Notably, the results from the Granger causality test indicate a unidirectional causal relationship between CO_2 emissions and economic growth. Rafindadi and Usman (2019) in their study confirmed the presence of a co-integration relationship between CO_2 emissions and economic growth. However, their study indicates a bi-directional causal flow between the two variables, which differs from the current study. The difference between the two studies could be the result of the utilisation of two different methodologies to determine the causal flow. Rafindadi and Usman (2019) utilised the Toda and Yamamoto method, while this study utilised the Granger Causality test. Odhiambo (2012) also confirmed the presence of a relationship between the two variables; however, the study produced a unidirectional causal flow from economic growth to CO_2 emissions, utilising the same statistical test as in this study. This study confirms no causality between total renewable energy power generation and GDP as well as total renewable power generation and CO_2 emissions. Even though the results regarding causal flow between CO_2 emissions and economic growth in this study and the two other studies mentioned above differ, the same conclusions are reached of the need for government to implement effective and powerful policies focused on reducing the country's carbon footprint and increasing the utilisation of renewable energies, while aiming for economic growth.

This was similar to the conclusion and recommendation reached by Inglesi-Lotz and Bohlmann (2014), Kohler (2013), and Nasr et al. (2015) who − unlike Rafindadi and Usman (2019) and Odhiambo (2012) − did not find the presence of the EKC in their respective studies.

6.3 Contribution to Literature

Chapter 1 highlighted that South Africa, a developing country, is one of the highest carbon emitting countries in the world, and this is largely as a result of over 90% of the power being generated by utilising coal, a resource that is still heavily mined in South Africa. Energy is one of the greatest catalysts to economic growth; thus, it was imperative to analyse the impact economic growth has on the environment, and whether government's mitigating measures had resulted in curbing environmental degradation. This study sought to investigate the causal relationship between CO_2 emissions, economic growth, and total renewable power generation in the context of the EKC framework.

There is a wide range of literature already in existence looking at investigating the presence of the EKC in South Africa, but using different statistical methods and the inclusion of different other independent variables. In the analysis of the literature, the ARDL method seemed to be commonly used to determine the presence of co-integration among the variables with the Granger Causality test used to determine the causal flow. The author of this study elected to continue with the precedence set by other scholars who have studied the EKC for South Africa and used the ARDL approach and Granger Causality test.

In the existing literature, other independent variables were included with the two main variables, economic growth and CO_2 emissions, to investigate the presence of the EKC. In their study, Dogan and Turkekul (2016a) included energy consumption, trade urbanisation, and financial development as additional independent variables, while Inglesi-Lotz and Bohlmann (2014) utilised energy intensity and renewable energy as additional variables. Bölük and Mert (2015) elected to include electricity generated from renewables as an additional variable in their study. With the introduction of the REIPPPP in South Africa, it became imperative to analyse the impact of this programme on CO_2 emissions in South Africa. This study sought to fill the theoretical gap by exploring the relationship between CO_2 emissions and total renewable power generation in South Africa.

The findings of this study indicated that the utilisation of renewable energies for power generation between the years 1997 to 2018 did not significantly aid in the reduction of CO_2 emissions. This can be attributed to the low percentage of power generated from renewable energy, thus not reducing the potential CO_2 emission caused by the use of coal.

6.4 Recommendations

South Africa is signatory to various international treaties focused on climate change initiatives, and the reduction of CO_2 emissions and other pollutants by 2030. South Africa has implemented policies in various sectors to reduce the emission of greenhouse gases. The results from the study infer that carbon dioxide emissions are continuing to increase in line with economic growth, and the current renewable energy projects in the power sector are not meaningful enough to curb the emissions. Based on the results from this study, the following recommendations are suggested to policy-makers:

I. Invest into research & development centres with a focus on clean energy technologies;
II. Promote investment in green technology power projects;
III. Pass policies geared towards the promotion of energy efficiency and controlled, low levels of pollutants and CO_2;
IV. Offer subsidies to power generating projects that use renewable energy or other fuel sources, which emit less carbon dioxide than carbon plants;
V. Replace decommissioned coal power plants with power plants that utilise cleaner fuel sources.

6.5 Limitations

The period of analysis under this study was only for 1997-2018; and during this time, data for total power generation was only available from 1996. This could therefore potentially have had an impact on the findings and the conclusion.

Due to the REIPPPP having only been initiated in the last decade, there was a lack of literature regarding the impact renewable power generation has had on CO_2 emissions in South Africa. The research had to rely on literature available in other countries.

The study did not take into consideration structural breaks present in the data as a result of policies changes. The incorporation of structural breaks in the dataset would require the utilisation of a co-integration model that factors this in.

6.6 Suggestions for Further Research

Continuous research and investigation of the EKC in South Africa will be required in future to ascertain the environmental impact economic growth has, and the impact renewable energy has as a fuel source in power generation on the reduction of emissions. The following factors can be considered for future research:

I. Different proxy for environmental degradation, this study used CO_2 emissions;
II. Addition of other independent explanatory variables, which have an impact on carbon dioxide emissions;
III. Non-linear functional form analysis of the relationship between the variables;
IV. The endogeneity between the variables, CO_2 emissions and economic growth, which had been attributed as a reason for the lack of EKC presence. Future research could consider testing for endogeneity between the variable prior to running the models;

V. Performing the same research as more data for total renewable power generation becomes available;

VI. Using a co-integration method, which considers structural breaks.

REFERENCES

Al-Mulali, U., Solarin, S. A., & Ozturk, I. (2016). Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. *Natural Hazards, 80*(3), 1729-1747.

Aliyu, A. K., Modu, B., & Tan, C. W. (2018). A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews, 81*(2), 2502-2518.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., . . . Perrings, C. (1995). Economic growth, carrying capacity, and the environment. *Ecological Economics, 15*(2), 91-95.

Asafu-Adjaye, J., & Mahadevan, R. (2013). Implications of CO2 reduction policies for a high carbon emitting economy. *Energy Economics, 38*(1), 32-41.

Baek, J. (2016). Do nuclear and renewable energy improve the environment? Empirical evidence from the United States. *Ecological Indicators, 66*, 352-356.

Bento, J. P. C., & Moutinho, V. (2016). CO2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. *Renewable and Sustainable Energy Reviews, 55*, 142-155.

Bilgili, F., Koçak, E., & Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews, 54*, 838-845.

Bollen, K. A. (1989). *Structural equations with latent variables* New York: John Wiley & Sons.

Bölük, G., & Mert, M. (2015). The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach. *Renewable and Sustainable Energy Reviews, 52*, 587-595.

Carson, R. T., Jeon, Y., & McCubbin, D. R. (1997). The relationship between air pollution emissions and income: US data. *Environment and Development Economics, 2*(4), 433-450.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecological Economics, 49*(4), 431-455.

Dogan, E., & Turkekul, B. (2016a). CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research, 23*(1), 1203-1213.

Dogan, E., & Turkekul, B. (2016b). CO 2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research, 23*(2), 1203-1213.

Eberhard, A., & Naude, R. (2016). The South African renewable energy independent power producer procurement programme: A review and lessons learned. *Journal of Energy in Southern Africa, 27*(4), 1-14.

Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society, 55*(2), 251-276.

Eskom. (2019). Integrated Report 31 March 2019. *Eskom*. Retrieved from http://www.eskom.co.za/IR2019/Documents/Eskom_2019_integrated_report.pdf

Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement* (0898-2937). Retrieved from Cambridge:

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-based nursing, 18*(3), 66-67.

Hossain, M. S. (2011). Panel estimation for CO2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy, 39*(11), 6991-6999.

Inglesi-Lotz, R., & Bohlmann, J. (2014, 3 July). Environmental Kuznets curve in South Africa: To confirm or not to confirm? Retrieved from http://ecomod.net/system/files/Ecomod%202014%20-%20full%20paper-%20Inglesi-Lotz%20and%20Bohlmann.pdf

International Energy Agency. (2020). CO2 emission statistics. Retrieved from https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics. Available from IEA Retrieved 10 April 2021 https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with appucations to the demand for money. *Oxford Bulletin of Economics and statistics, 52*(2), 169-210.

Kohler, M. (2013). CO2 emissions, energy consumption, income and foreign trade: A South African perspective. *Energy Policy, 63*, 1042-1050.

Kuznets, S. (1955). Economic growth and income inequality. *The American economic review, 45*(1), 1-28.

Lütkepohl, H. (2006). Structural vector autoregressive analysis for cointegrated variables. *Allgemeines Statistisches Archiv, 90*(1), 75-88.

McConnell, K. E. (1997). Income and the demand for environmental quality. *Environment and Development Economics, 2*(4), 383-399.

Menyah, K., & Wolde-Rufael, Y. (2010). Energy consumption, pollutant emissions and economic growth in South Africa. *Energy Economics, 32*(6), 1374-1382.

Mostert, H., & van der Berg, H. M. (2018). *Challenges to Regulating Hydraulic Fracturing*. United Kingdom: Oxford University Press.

Narayan, P. K. (2005). The saving and investment nexus for China: evidence from cointegration tests. *Applied economics, 37*(17), 1979-1990.

Nasr, A. B., Gupta, R., & Sato, J. R. (2015). Is there an environmental Kuznets curve for South Africa? A co-summability approach using a century of data. *Energy Economics, 52*, 136-141.

Odhiambo, N. M. (2012). Economic growth and carbon emissions in South Africa: an empirical investigation. *Journal of Applied Business Research (JABR), 28*(1), 37-46.

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: turning a black box into a policy tool. *Environment and Development Economics, 2*(4), 465-484.

Pata, U. K. (2018). The effect of urbanization and industrialization on carbon emissions in Turkey: evidence from ARDL bounds testing procedure. *Environmental Science and Pollution Research, 25*(35), 7740-7747.

Pegels, A. (2010). Renewable energy in South Africa: Potentials, barriers and options for support. *Energy Policy, 38*(9), 4945-4954.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics, 16*(3), 289-326.

Rafindadi, A. A., & Usman, O. (2019). Globalization, energy use, and environmental degradation in South Africa: Startling empirical evidence from the Maki-cointegration test. *Journal of Environmental Management, 244*(1), 265-275.

Republic of South Africa. (2010). *Executive Summary of the Draft Integrated Electricity Resource Plan for South Africa - 2010 to 2030 IRP 2010*. Pretoria Retrieved from http://www.energy.gov.za/IRP/irp%20files/Executive_Summary_Draft_IRP2010_22Oct2010.pdf

Republic of South Africa. (2018). *South Africa's Low-Emission Development Strategy 2050*.

Republic of South Africa. (2019). *Integrated Resource Plan 2019*. Pretoria Retrieved from http://www.energy.gov.za/files/docs/IRP%202019.pdf

Roca, J., Padilla, E., Farré, M., & Galletto, V. (2001). Economic growth and atmospheric pollution in Spain: discussing the environmental Kuznets curve hypothesis. *Ecological Economics, 39*(1), 85-99.

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. *Energy Policy, 51*, 184-191.

Saudi, M. H. M. (2019). The role of renewable, non-renewable energy consumption and technology innovation in testing environmental Kuznets curve in Malaysia. *International Journal of Energy Economics and Policy, 9*(1), 299-307.

Shafik, N., & Bandyopadhyay, S. (1992). *Economic growth and environmental quality: time-series and cross-country evidence* (Vol. 904): World Bank Publications.

Shahbaz, M., Tiwari, A. K., & Nasir, M. (2013). The effects of financial development, economic growth, coal consumption and trade openness on CO2 emissions in South Africa. *Energy Policy, 61*, 1452-1459.

South African Reserve Bank. (2020). Online Statistical Query. Retrieved from https://www.resbank.co.za/Research/Statistics/Pages/OnlineDownloadFacility.aspx

Stern, D. I. (1993). Energy and economic growth in the USA: a multivariate approach. *Energy Economics, 15*(2), 137-150.

Stern, D. I. (1998). Progress on the environmental Kuznets curve? *Environment and Development Economics, 3*(2), 173-196.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development, 32*(8), 1419-1439.

Stern, D. I., Common, M. S., & Barbier, E. B. (1996). Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. *World Development, 24*(7), 1151-1160.

Suri, V., & Chapman, D. (1998). Economic growth, trade and energy: implications for the environmental Kuznets curve. *Ecological Economics, 25*(2), 195-208.

Tewksbury, R., Dabney, D. A., & Copes, H. (2010). The prominence of qualitative research in criminology and criminal justice scholarship. *Journal of Criminal Justice Education, 21*(4), 391-411.

The Republic of South Africa. (2003). *White Paper on renewable energy*. Pretoria: Government Printer

United Nations. (2015). *Paris agreement*. Retrieved from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Wu, L., Liu, S., Liu, D., Fang, Z., & Xu, H. (2015). Modelling and forecasting CO2 emissions in the BRICS (Brazil, Russia, India, China, and South Africa) countries using a novel multi-variable grey model. *Energy, 79*(1), 489-495.

Xu, B., & Lin, B. (2019). Can expanding natural gas consumption reduce China's CO2 emissions? *Energy Economics, 81*, 393-407.

Zaidi, S. A. H., Hou, F., & Mirza, F. M. (2018). The role of renewable and non-renewable energy consumption in CO 2 emissions: a disaggregate analysis of Pakistan. *Environmental Science and Pollution Research, 25*(31), 31616-31629.

Zhang, B., Wang, B., Wang, Z., & Danish. (2017). Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. *Journal of Cleaner Production, 156*(1), 855-864.