UNIVERSITY OF WITWATERSRAND

PhD RESEARCH THESIS

PERSPECTIVES ON CLIMATE CHANGE AND ENERGY SECURITY IN SOUTH AFRICA: A STUDY OF ESKOM

BY

KHULISO JAMES RASIMPHI (Student number: 1699084)

SUPERVISED BY

PROFESSOR MULALA DANNY SIMATELE

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DECLARATION 1: PLAGIARISM

I, Khuliso James Rasimphi, hereby make a declaration that this Thesis Report is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy (Geography) at the University of the Witwatersrand, Johannesburg. This work has not been submitted before for any degree or examination at any other University.

_______________________________ (Signature of candidate) ___2nd____day

of_____June______20 23_______________in____Pretoria_________

DECLARATION 2: PUBLICATIONS

I, Khuliso James Rasimphi, declare that I undertook all the data collection, analysis, development and writing of the manuscript mentioned below. This work has been submitted as manuscript for publication to the peer reviewed journal with the following details:

1. Rasimphi, K.J. and Simatele, M.D. (Under Review) '*Reflections on South Africa's Energy Security Crisis': Is Climate Change the Problem?* Journal of Energy in Southern Africa. ISSN 2413-3051.

Khuliso James Rasimphi Signature:________________ Date: 02 June 2023

ABSTRACT

Global changes in climatic conditions have both direct and indirect implications on various energy sources and systems, particularly in terms of energy generation vis-à-vis security for sustainable social-economic development. This study examined the relationship between climate change and energy security in South Africa, focusing on energy production, accessibility, and affordability as key determinants. The investigation also explored measures to minimise Eskom's carbon footprint and opportunities for transitioning the energy sector to cleaner energy sources. A mixed research method, including structured questionnaire surveys, semi-structured interviews, observations, and existing records, was used for data collection. The data was mainly analysed by use of the Microsoft Excel package to generate statistical correlations and relationships to draw the key conclusions contained in this paper.

Eskom coal power plants' ten-year (2010 to 2020) carbon footprint was found to be constantly above 200 million per year. The power utility's ten-year CO_2e trend was primarily influenced by production activities. This is because all Eskom's coal power plants (except for Medupi) do not have CO_2e abatement technology, and the available technologies in the market are too expensive. The study also found that Waterberg (LP) and Nkangala (MP) regions, where most coal power plants are located, have been receiving inconsistent and insufficient rainfall from 2010 to 2021; and projections are suggesting a further decline in precipitation distribution and incline in average temperatures in these regions. Despite all these glaring climate change implications, the current study found that water consumption (2020 to 2021 trend) at coal power plants remained high even in periods wherein energy availability factor had dropped, and therefore indicative of thermal inefficiency. The study also found that South Africa's slow approach in building a climate change resilient and adaptive energy system was caused by a slow and ineffective implementation of IRP. Thus, South Africa must embark on a decisive transition programme to cleaner energy sources mix as a critical and urgent measure to decarbonize and enhance the energy sector's resilience against climate change effects, and ensure energy availability, reliability and affordability.

The study concludes that Eskom coal power plants should focus their efforts on resolving maintenance problems, operational inefficiencies, and developing adaptation strategies to decarbonize and build resilience against climate change vulnerabilities such as irregular precipitation and high temperature, while ensuring energy security. The energy policy and IRP should be adaptive and continuously informed by regional research to determine the most suitable energy sources for specific regions to ensure an effective transition to cleaner energy systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASSAF	Academy of Science of South Africa
AU	African Union
BP	British multinational oil and gas company headquartered in London, England
CCAM	Conformal-Cubic Atmospheric Model
CCES	Climate Change and Energy Security Nexus
CFPS	Eskom's Coal-Fired Power Stations
CIGI	The Centre for International Governance Innovation
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Emissions
CoE	Centre of Excellence
COP	Conference of Parties
COVID-19	Coronavirus disease is an infectious disease caused by the SARS-CoV-2 virus
CSIR	Council for Scientific and Industrial Research (South Africa)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DE	South Africa's National Department of Energy
DFFE	Department of Forestry, Fisheries and the Environment
DWS	Department of Water and Sanitation
EAF	Energy Availability
USEPA	United States' Environmental Protection Agency
EU	European Union
FGD	Flue Gas Desulphurisation
GHG	Green House Gases
GWh SO	Gigawatt Hour Sent Out
Gx	Eskom Generation Division
HARP	Heightening Awareness of Research Philosophy
IEA	The International Energy Agency
IPPs	Independent Power Producers
IRP	Integrated Energy Resource Plan
JMU	James Madison University
KZN	KwaZulu-Natal Province of South Africa

LP	Limpopo Province
Ml	Megalitre
MP	Mpumalanga Province
NEMA	National Environmental Management Act
NGOs	Non-Governmental Organisations
Pers.com	Personal Communication
R&S	Eskom's Risk and Sustainability
RCM	Regional Climate model
RT&D	Eskom's Research, Testing and Development Division
SA	South Africa
SAWS	South African Weather Services
SDGs	Sustainable Development Goals
SWP	Stiftung Wissenschaft und Politik (German think tank in international relations and security studies)
TWh	Terawatt hour
UN	United Nations
USA	United States of America
USUCS	United States' Union of Concerned Scientists
WEF	Water-Energy-Food Nexus
WFC	Water-Food-Climate
WUL	Water Use Licence
WWF	Worldwide Fund for Nature

CHAPTER ONE

FRAMES OF REFERENCE

1.1 INTRODUCTION

Climate change, which was once considered a myth in the 19th and 20th centuries (Kozarcanin et al., 2019), is now increasingly evident (Kozarcanin et al., 2019). The early years of the 21st century have already seen a significant global change in regional weather patterns, with 2014 to 2018 being recorded as the warmest five years on record (Reddy, 2019). Boqiang (2012) argues that climate change and energy security are interlinked subjects that require a joint policy to address. Developing countries require reliable and sufficient energy to sustain their economies, but also need to invest in energy-generating technologies to augment their climate change mitigation and adaptation strategies (Boqiang, 2012).

Between 2008 and 2018, the world's GDP rose by 28%, while electricity generation increased from 20 433 TWh to 26 615 TWh (BP Energy Outlook, 2019). 40% of this electricity was generated from coal (BP Energy Outlook, 2019). Coal-generated electricity increased by 18% between 2008 and 2018, while global CO_2 emissions rose by 10% (from 30 337 to 33 891 million tonnes) during the same period (BP Energy Outlook, 2019). These figures suggest that countries around the world continue to contribute to climate change through the use of coal-generated energy. The increase in coal-generated electricity and CO_2 emissions highlights the need for countries to include climate change reduction measures and adaptation strategies into the energy policy. The climate change effects on the energy sector are already evident in Africa, as energy-generating and transmitting infrastructure continues to be damaged by severe climate variability, such as storms and violent winds (Chapman & Whande, 2013). Predictions indicate that changes in rainfall distribution patterns will result in Southern African countries receiving less rainfall, while East African countries will receive more rainfall later in the 21st century (Serdeczny et al., 2016, p. 12). This decrease in precipitation distribution will significantly affect Southern African countries such as Lesotho, Malawi, Mozambique, Namibia, and Zambia, whose 85% to 100% of their electricity is generated from hydropower (Chapman & Whande, 2013, p. 34).

In 2011, South Africa established a national climate change response white paper to guide the country's response strategy to climate change (DEA, 2011). The white paper acknowledged that

South Africa’s energy sector is contributing to global carbon emissions, while also being highly vulnerable to the climate change effects. This is because South Africa relies heavily on coal-fired power stations to generate electricity, which require water for cooling processes. It is thus, no exaggeration to argue that the current projections in climatic changes, and more specifically in relation to precipitation and temperatures variabilities over the whole of Southern Africa, have the potential to adversely affect Eskom’s reliability and accessibility, because of its heavy reliance on coal, water resource and ambient temperatures (Mathetsa et al., 2022; Serdeczny et al., 2016). Although it is widely understood that South Africa’s energy sector is at risk of climate change effects, there are limited studies that specifically assess the way climate change will possibly impact the Eskom’s ability to create and preserve the availability, reliability, and affordability of South Africa’s energy supply. This study therefore investigated the extent of Eskom’s exposure to climate change risks as well as the potential opportunities that can be harnessed to build climate change resilience and adaptation at the power utility. The study used mixed research methods (qualitative and quantitative), with data instrumentation comprising of the collection of both primary data and a rapid appraisal of existing information on climate change and the energy security nexus at Eskom Generation Division’s operational units as the study area.

1.2 THEMATIC CONSIDERATIONS

The primary supplier of electricity in South Africa is Eskom, which produces around 90% of the country’s electricity (Department of Energy, 2020). Eskom produces some of this electricity in partnership with Independent Power Producers (IPP), who only produce renewable energy for the state-owned entity. Other power producers, such as municipalities and self-generators like Sasol, contribute the remaining 10% of electricity (Department of Energy, 2020). Eskom’s mandate is to generate, transmit, and distribute electricity across South Africa and ensure the security of electricity supply in the country. Eskom has a total of 29 power stations with a minimum capacity of 44 134 Megawatts (Department of Energy, 2019). Coal-generated electricity contribute around 83% of Eskom’s generated power, while other power stations such as nuclear, gas-fired, hydro and pumped storage schemes contribute around 17% to the energy grid (Department of Energy, 2019). Additionally, wind energy source currently generates less than 1% of energy to the grid (Department of Energy, 2019). In 2019 alone, Eskom’s coal-fired power stations emitted a combined total of 214 888 856.12 tons of carbon dioxide (CO_2) into the atmosphere (Eskom, 2020a). This was a slight increase from the 2018 figure of 213 851 218.5 tons of CO_2 emitted by all Eskom powered power stations (Eskom, 2019). These figures demonstrate that Eskom power stations are, to some extent, contributing to carbon emissions and climate change.

Risk assessments conducted on some of Eskom's coal power plants suggest that an increase in ambient temperatures over 35°C will lead to an increase in the cooling water temperatures of generators, resulting in an increase in evaporation, chemical excursions due to cycles of concentrations and production load losses (Moatshe, 2016). High ambient temperatures resulting from changes in climatic conditions will also adversely affect most of the power stations' transformers, which are designed to operate within a specific temperature range, leading to operational inefficiencies and load losses (Moatshe, 2016). Some of the effects of climate change on the coal-fired power stations include frequent and unpredictable flash floods, which can result in wet coal and combustion challenges (Moatshe, 2016). For example, combustion of wet coal can result in excessive use of coal and fuel oil, while producing less energy output. This can lead to an inadequate energy supply to the grid and load-shedding (Moatshe, 2016).

According to the Eskom Risk and Sustainability (R&S) report of January 2018, Eskom's coal-fired, nuclear, and new-build power stations consumed 320 000 Ml of raw water per annum between 2008 and 2018 (Eskom R&S, 2018). A significant portion of this water was used for air pollution control, washing, steam generation, and cooling processes, with Eskom using 2-3% of South Africa's freshwater (Eskom R&S, 2018). Climate change projections indicate that southern Africa will receive less rainfall in the 21st century, which will affect Eskom's energy generation fleet that relies heavily on water for energy production (Serdeczny et al., 2016). The potential for water scarcity and drought due to climate change will likely slow down energy production rates and pose a significant risk to South Africa's energy security (Serdeczny et al., 2016). The risk assessment also found that most coal power plants do not have adequate clean water containment dams to contain water during flash floods for future use, resulting in storm water contamination in the dirty water systems (Moatshe, 2016).

Climate change could not have occurred at a worse time for South Africa, as most of Eskom's coal plants, which provide the utility's baseload, are ageing and therefore less robust and resilient. Four of the 15 Eskom's coal energy plants, including Kriel, Hendrina, Arnot, and Grootvlei, are within the last ten years of their 50-year design lifespan, while two of those 15 power stations, Camden and Komati, have already exceeded their 50-year lifespan (De la Rue du Can, 2013). The ageing infrastructure also contributes to water wastage, with leaks of freshwater into pollution control dams increasing (Eskom, 2020b). Most of these power stations do not have water treatment facilities that could aid in treating and recycling water back into the process. The water scarcity challenge presented by the effects of climate change will require these power stations to optimise their energy-generating infrastructure to be more efficient in saving water resources.

Eskom power stations such as Ingula, Palmiet, and Drakensberg are pumped storage schemes that rely on freshwater from running streams, while Gariep and Van Der Kloof are hydroelectric power stations that also rely on water from running streams to generate energy (Eskom, 2020). Together, these power stations have an installed capacity to generate 3 332 Megawatts (Eskom, 2020b). Precipitation variability in the Southern Africa due to climate change is likely to affect the operation of these hydro power stations and put the country's energy supply at risk of losing a significant number of peaking megawatts. In the General Overview for Peaking Environmental Management System Manual, Nelson (2019) argues that the recent severe drought season experienced in Cape Town and surrounding areas is a cause for concern, which will likely affect Eskom's strategic direction as water resource is critical to all of Eskom's hydroelectric power stations. The climate change and energy security relationship is not a myth, but a reality that is already affecting South Africa's energy generation sector.

Serdeczny et al., 2016 found that the potential for water scarcity and drought due to climate change will likely slow down energy production rates and pose a significant risk to South Africa's energy security. Mathetsa et al. (2022), and Reid and Simatele (2021) argued that South Africa's energy system, in its current form, will continue to suffer the implications of climate change induced energy production interruptions resulting to escalating costs of energy usage for residents and industries. The existing studies do not, however, determine at length the extent of climate change impacts on South Africa's energy production, accessibility, reliability, and affordability. Neither do the existing studies identify any transformative approaches that South Africa can adopt to improve innovations within the energy sector to build adaptive capacity and resilience to the challenges that climate change possess. Furthermore, the existing studies do not expansively identify and discuss the opportunities that exist for South Africa's energy sector to expeditiously transition its coal-based energy baseload to cleaner energy mix, with a purpose of ensuring a reliable, accessible, and affordable energy system in the wake of climate change risks.

In light of these observations, this study aimed at investigating the relationship between climate change and energy security in South Africa. Specifically, the study focused on understanding how changes in climatic conditions impact energy security in terms of energy production, accessibility, and affordability. The study also aimed at understanding the contemporary carbon footprint from South Africa's only power utility (Eskom) and investigate the ideal approach for South Africa to transition its energy sector from being primarily coal-dependent to a clean energy mix within the context of the country's Integrated Energy Resource Plan (IRP).

1.2.1 RESEARCH QUESTIONS

The current study was guided by the following two broad questions formulated from the research problem:

Firstly, what is South African energy sector's contribution to climate change, and what are the impacts of climate change on the country's energy security? In line with this broad question, the following research questions were developed:

I. To what extent does South Africa's power utility (Eskom) contribute to climate change inducing carbon emissions?

II. What are the implications of climate change on South Africa's energy production process, accessibility, and affordability?

Secondly, is South Africa's IRP comprehensive enough to facilitate a transition towards an adaptive, robust, and resilient energy sector in the face of climate change? In line with this second broad research question, the following research questions were formulated:

III. What policy framework exists to guide South Africa to an effective transition to cleaner energy mix and climate change adaptive energy system?

IV. In what ways would a transition to cleaner energy mix ensure a climate change resilient and adaptive energy system in South Africa?

V. Are there any technological innovations that can be implemented to reduce Eskom's carbon emissions and South Africa's contribution to climate change?

1.2.2 RESEARCH AIM AND OBJECTIVES

The aim of this study was twofold:

Firstly, to investigate South African energy sector's contribution to climate change as well as the impacts of climate change on the country's energy security. In line with this aim, the objectives of this study were to:

I. Investigate the respondents' perspective on Eskom's contribution to South Africa's carbon footprint, and challenges resulting into Eskom's carbon emissions.

II. Investigate the potential implications of climate change on energy security in South Africa.

Secondly, to evaluate the comprehensiveness of South Africa's IRP in facilitating a transition towards an adaptive, robust, and resilient energy sector in the face of climate change. In accord with this research aim, the objectives of this study were to:

III. Determine the effectiveness of South Africa's policy framework in guiding a transition to cleaner energy systems.
IV. Assess how a comprehensive energy transition can ensure a sustainable energy system in South Africa.
V. Identify technological measures that can be implemented to reduce carbon emissions from existing coal energy sources in South Africa.

1.2.3 THEORETICAL CONSIDERATIONS

Climate change and energy security are interconnected concepts. According to Brown and Huntington (2008), climate change mitigation strategies and energy security policies should be integrated into a unified policy. They argue that an integrated approach would ensure that countries around the world safeguard the sustainability and sufficiency of their energy generation capacities while utilising technologies with minimal emissions of greenhouse gases. Klare (2015) also concurs with Brown and Huntington (2008) that focusing solely on the energy sector's contribution to climate change without considering the effects of climate change on energy security could result in countries' energy systems being affected by the changes in climatic conditions.

Klare (2015) further warns that the effects of climate change, such as high temperatures, disrupted precipitation patterns, and droughts, will likely interrupt the production of most hydroelectricity stations, which are the leading renewable energy generators worldwide. Although Brown and Huntington (2008) concur with Klare (2015) that climate change response strategies and energy security policies should be integrated, neither study provides a suitable approach for developing countries to adopt in order to balance the development of climate change-resilient energy sectors.
A study conducted by United States' Environmental Protection Agency (USEPA) (2017) also highlighted the impact of the climate change and energy security nexus in the United States, specifically the projected rise in temperatures and heat in the 21st century, which will likely result into the increased demand for electricity for air conditioning. Predictions suggest that a temperature increase of 9.0°F will lead to a 22% increase in electricity demand in the USA (USEPA, 2017). This increase in demand will put pressure on USA's energy grid and will also have a direct impact

on the amount of greenhouse gas emissions, depending on the technology used to generate the additional electricity (USEPA, 2017). The climate change adaptation strategies for the USA's energy sector need to be in place and aligned with the effects of climate change to ensure that energy security is sustained (USEPA, 2017)

The effects of changes in climatic conditions on energy security will have a global impact, and African countries are not immune to these effects. Approximately eleven Sub-Saharan African countries depend on hydropower to generate 85% to 100% of their electricity, while six countries also generate 70% to 84% of their electricity from hydropower (Chapman & Whande, 2013). Over 20 African countries rely on hydropower to generate some portion of their electricity (Chapman & Whande, 2013). Climate change has been threatening the stable and reliable supply of energy in some parts of Africa. East Africa has been suffering from frequent droughts from 1999 to 2010, resulting in the interruption of hydropower energy generation and supply in countries such as Kenya, Tanzania, and Ethiopia (Chapman & Whande, 2013).

The government of South Africa has developed a climate change response strategy which requires that individual institutions, such as Eskom, coordinate efforts in researching, developing, and innovating new ideas to mitigate and adapt to the climate change effects (DEA, 2018). The country's industrial sectors, including the energy sector, whose key input materials for production include water, may face challenges in the future as projections suggest that South Africa's water demand will surpass the supply by 17% in 2030, with the potential to worsen due to escalating climate change effects (WWF, 2017). Eskom's internal research division has already warned that climate change will have negative impacts on the organisation's operations and thus there is a need to proactively adapt to climate change effects, manage associated risks, and build a resilient organisation (Eskom Research, Technology & Development, 2016).

Chapter two provides an in-depth review, comparison, contrast, correlation, synthesis, and integration of various literature and theories to gain comprehensive insights and observations related to the connection between climate change and energy security, which is the core focus of this study.

1.2.4 METHODOLOGICAL CONSIDERATIONS

The current study employed a mixed research method. Eskom's Generation division was used as the primary case study, while five of Eskom's power-generating stations were selected and studied as embedded case studies. The study population included participants within and outside of Eskom with experience in climate change and energy security issues. Purposive and snowball sampling procedures were used to select the research participants. Instruments such as structured questionnaires, semi-structured interviews, participant observations, and existing records review were used for data collection. A computer system was used for storage of all collected field data. Microsoft Excel was used to generate statistical data from both surveys and interviews. The data was then analysed to establish correlation and conclusions in terms of research findings. A detailed methodological discussion and a step-by-step process of the methodology and implementation of the study is discussed in Chapter Three of this thesis.

1.2.5 SCOPE OF THE STUDY

This study aimed at investigating the effects of climate change on energy security in South Africa. Within this context, the study examined changes in climatic conditions such as temperatures, precipitation distribution, etc, and how these changes affect energy production and distribution in South Africa. The research primarily focused on coal-generated energy as the basis for investigation; however, the study also examined the effects of changes climatic conditions on other energy sources such as hydropower, solar, and wind. The study aimed at understanding how climate change variability may negatively or positively impact the production of various energy sources. Existing scientific weather projections were used to project possible changes in weather distribution in relation to future energy production. The research did not develop any new data modelling for climate change severity in South Africa, it only relied on existing modelled data to project future implications of climate change on South Africa's energy sector. The study was executed within a period of 36 months, the duration of the study was significantly reduced by the fact that all the research data was electronically collected from both human participants and existing records.

1.2.6 ETHICAL CONSIDERATIONS

Ethics are defined as moral values that guide one's behaviour, while research ethics refers to measures that are legally and morally truthful when conducting a study (Parveen & Showkat, 2017). Research ethics are not limited to the planning phase, but apply throughout all the phases of the research, and are critical in distinguishing between unacceptable and acceptable behaviour. Ethics serve as a research code of conduct and assist in validating the overall research activity. This study was guided by four key principles of ethics, which included respect for participants' independence, non-maleficence towards participants, beneficence, and justice. Respect for participants' independence refers to using a research approach that does not undermine participants' right to make a free choice when participating in the study. Participants were fully informed about the research problem, aim, and their rights before participating in the study; and this was achieved through administering consent forms and participant information sheets. Non-maleficence towards participants, another principle of ethical research, refers to conducting research in a manner that does not result in risk of harm (physical, mental, emotional harm). This study did not involve any physical contact with human participants and did not include any line of questioning that negatively affected the emotional well-being of participants. Beneficence principle of ethical research refers to conducting research that is worth the effort, considering all the trouble the researcher and research participants may go through to successfully conclude the research. Justice as an ethical principle refers to giving participants similar and just treatment within their full rights.

Before initiating the study, ethical issues surrounding authorisation for the study to be conducted at Eskom and obtaining permission from the University of Witwatersrand's Ethics Committee needed to be addressed. To address these issues, clearance and consent letters were obtained from the University of Witwatersrand's Ethics Committee and Eskom management, respectively. At the beginning of the study, ethical considerations to ensure participants' autonomy were identified. These were addressed by providing participant information sheets and consent forms, outlining participants' rights prior to participating in the study. All key information related to the study was disclosed to participants beforehand. During data collection, two key ethical issues were identified and effectively managed, including avoiding misleading participants and addressing potential power inequities and mistreatment. In accordance with the ethical principle of justice, the purpose of the research and the manner in which data would be used was discussed with participants. Efforts were made to avoid disclosing participants' personal information, and individual impressions were not shared. Participants were involved in the study as undercover agents.

During the data analysis phase, three ethical issues were identified as posing ethical risks, including the temptation to align with participants' views, reporting only positive findings, and failing to uphold the privacy and anonymity of participants. To manage these issues, the study reported all views, including those that were negative or contrary to the hypothesis, and fabricated names of participants were used to ensure their anonymity and privacy. It is important to note that participants' privacy was respected throughout the research process. Participants' responses were kept confidential, and no information that could divulge their identity was included in the report. Additionally, participants' details and information were not disclosed to anyone except the researcher, and the interviews, observations, and questionnaire survey material were viewed by the researcher and the principal supervisor only (Creswell, 2014). Participants were not deceived into participating in the study, and they were informed of their right to refuse answering any question and to withdraw their participation at any point in the process without a penalty or loss of benefit (Creswell, 2014). One of the key ethical issues during research is avoiding falsifying authorship, data, evidence, results, and deductions. To address this issue, honest reporting principles were upheld, and all written work was submitted to a plagiarism detection software to ensure that any incidental plagiarism was identified and rectified.

Potential conflicts of interest were also identified, particularly between the researcher and the organisation (Eskom) where the research was conducted. To manage these issues, compliance with Eskom's Conflict of Interest Policy (32-173) was ensured. The research was declared in Eskom's online conflict management system to ensure that research activities were managed within the organisation's policy guidelines. This declaration was made before the fieldwork or research activities commenced, and it ensured that matters related to conflicting interests were effectively managed throughout the study. It is imperative to note that although this study was considered to be of low risk in terms of creating conflicts of interest between the investigator and participants and/or Eskom, the researcher implemented necessary measures to effectively manage any conflicts of interest on an ongoing basis.

CHAPTER TWO

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

2.1 INTRODUCTION

This chapter aligns with the aim and objectives of the study by exploring various theories and literature related to the nexus between climate change and energy security, from a global to a South African context. Literature review is a crucial step in the research process, as it is conducted before proceeding to the main study. It also helps to gain an extensive understanding and knowledge of the topic being researched, and to identify gaps in existing literature, learn various techniques, and gain insights from existing theoretical evidence and application of concepts (Rowland, 2021; Western Sydney University, 2017). In short, literature review helps to compare and contrast, critically evaluate, correlate, and integrate existing theories and literature into the research argument (Rowland, 2021; Western Sydney University, 2017).

The chapter is divided into three sections: global, African, and South African contexts. It evaluates, dissects, and discusses various literatures related to the connection between climate change and energy security, with a special focus on views related to climate change impact on energy production, accessibility, and affordability, and how this impacts energy security. The chapter also assess energy sectors' contribution to the carbon footprint and ultimate climate change, as well as available decarbonization opportunities. Observations on the effective climate change and energy security policies, and how policies should be implemented are also reviewed. The energy systems transition to cleaner energy mix as an effective approach to build institutional climate change resilience, adaptation and security is also discussed. The conclusion of the chapter assesses the gaps in knowledge based on reviewed theories and literature and highlights the importance of this research.

2.2 CLIMATE CHANGE AND THE ENERGY SECURITY NEXUS: A GLOBAL CONTEXT

The connection between climate change and energy security has been a growing topic of interest amongst corporate and academic circles in recent years. While climate change is generally understood as a major change in weather patterns such as rain and temperatures (Reddy, 2019), the concept of energy security is not consistently defined across academic literature. Chapman &

Whande (2013), Cherp et al. (2015), Böhringer & Keller (2011), and the UN (2008) have defined energy security as a country's ability to reliably supply energy at low cost while also taking care of the environment. This definition aligns with one of the commitments made in the United Nations' 2030 Agenda for Sustainable Development, which pledges to ensure access to reliable, affordable, sustainable, and modern energy for all (UN, 2015). Although the definition of energy security is not consistent, all definitions point to affordability, reliability, and responsible investment as key determinants of a secure energy system.

In recent years, there has been an increasing awareness, amongst the global community, of the connection between climate change and energy security. Historically, the connection was understood to be only about the impact of energy generation on climate change (IEA, 2014). However, the focus has shifted from just minimising greenhouse gas emissions to also ensuring that energy systems adapt to the climate change effects in relation to productivity, affordability, accessibility and sustainability (IEA, 2014). While the focus of most national governments and associated power utilities are swiftly shifting towards climate change adaptation, the world cannot afford to adopt a lackadaisical approach in curbing carbon emissions (RE, 2021). Investments on decarbonization technologies are required while also transforming institutions and upskilling employees to be ready for low carbon future that is dominated by cleaner energy mix (RE, 2021). Studies by Nik and Perera (2020) and Kabeyi and Olanrewaju (2022) highlighted that decarbonization programmes serves a double materiality as they reduce the pace of global warming and climate change while also accelerating energy sectors' transition towards diverse clean energy systems that have much needed robustness and resilience against climate change effects.

Nik and Perera (2020) also identified renewable energy sources being amongst the typical decarbonization programmes that serves the double materiality of reducing carbon emissions while ensuring energy sources transition and climate change resilience. Nik and Perera (2020), RE (2021), and Cevik (2022) also highlighted that in order to effectively respond to climate change risk, two key measures need to be implemented; and these include intensifying the decarbonization programmes to mitigate climate change acceleration and also investing on climate change adaptation measures to ensure institutional resilience. While a study by Wang et al. (2021) acknowledged that transitioning fossil fuel energy sources to renewables will be critical towards achieving carbon neutrality and climate change mitigation, the study also acknowledged that the global energy demand surpasses the renewable energy sources' supplies; and therefore, triggering the need to also invest on carbon sequestration areas which include terrestrial and marine environments. Although, somehow helpful in pointing out some decarbonization and climate change mitigation initiatives, the above studies do not take into account certain socio-economic challenges that developing countries such as South Africa are faced with while trying to fund these decarbonization initiatives. The studies do not acknowledge fragile energy generation context of emerging markets such as of South Africa that which have to careful strike a balance between decarbonization and maintaining the national security of energy supply.

Although the studies reviewed above suggest the existence of a climate change-energy security linkage, the question remains whether this connection is significant enough to disrupt energy production and ultimately result into unreliable and high cost of electricity in most countries. A study by the German Institute for International and Security Affairs argues that climate change is a universal issue that is not fully understood (Stiftung Wissenschaft and Politik (SWP), 2021). They further argue that projections used to predict climate change have limitations and that countries such as Germany, India, Brazil, and South Africa should not be pressured to immediately align with pervasive climate change policy, but rather be afforded an unpressured opportunity to reform their energy systems towards climate change-resilient energy systems. The conversation above indicates an existence of inconsistent views amongst academics and organisational think tanks, with regard to the urgency with which countries should address the climate change-energy security nexus.

There is a general consensus that there is a link between climate change and energy security, but individual countries have different definitions of this link (Cherp et al., 2015; Toke & Vezirgiannidou, 2013). Studies by Cherp et al. (2015) and Toke and Vezirgiannidou (2013) further highlighted that the definition of this link is similar across the world, but its breakdown and finer detail is left to individual countries to expand upon. They also note that this definition is influenced by how individual countries coordinate their climate change and energy security policies. King and Gulledge (2013) suggest that climate change mitigation policies will have a direct impact on energy security by 2040, but do not specify if it will be negative or positive.

Several studies suggest that climate change policies and energy security policies are compatible, even though they cannot be integrated into one policy (King & Gulledge, 2013; Stang, 2015; SWP, 2021). As energy security is an immediate objective, compared to climate change mitigation which is a long-term objective, it is unrealistic for countries to fully integrate the two policies (King & Gulledge, 2013; SWP, 2021). In contrast, Brown and Huntington (2008) argue that climate change mitigation strategies and energy security policies should be incorporated into a single policy. They assert that this approach would ensure that countries safeguard the sustainability and sufficiency of their energy availability, reliability and affordability capacities while using technology with minimal emissions of greenhouse gases. The literature shows contrasting views on how climate change and energy policies should be managed, which may be indicative of the different perspectives of the authors.

Stiftung Wissenschaft and Politik (2021) maintains that countries should not be pressured to implement climate change impacts mitigation policies at the expense of their energy security and economic ambitions. In contrast, Klare (2015) and Brown and Huntington (2008) warn that only focusing on the energy sector’s contribution to climate change, while overlooking the effects of climate change, may result in climate change blowback. Although there is a consensus that there is a strong relationship between climate change and energy security, there are contrasting perceptions on which aspect should be prioritised, as highlighted by the SWP (2021) study.

The climate change and energy security discourses are closely linked, with studies indicating that climate change can have a number of adverse impacts on energy systems (King & Gulledge, 2013; Sudan, 2021). Brown and Huntington (2008) and Klare (2015) have found that energy systems worldwide are particularly vulnerable to interruptions caused by high temperatures, inconsistent precipitation, and droughts, among other effects of climate change. These interruptions can have a knock-on effect on energy generation, making energy systems less robust, resilient and reliable, and ultimately forcing an increase of electricity tariff. A study by Cherp et al. (2015) found that the energy security of most countries assessed was in one way or more vulnerable on matters relating to durability, sovereignty, and resilience (Figure 2.1). This is particularly true for countries that generate a significant proportion of their hydroelectricity from shared sources, such as water from shared rivers, which may become stressed due to climate change.

In the United States of America, it is anticipated that frequent floods and droughts will significantly impact the reliability of energy supply (Organization of American States, 2020). To mitigate this vulnerability, it is essential to ensure that electricity is generated from various sources, such as coal, hydro, solar, oil, gas, and nuclear. However, in Latin America, the energy system is less diverse, with 47% of power generated from fossil fuels, 49% from hydro, and only 4% from other alternatives such as solar and wind (Organization of American States, 2020; O’Keefe, 2021). While O’Keefe (2021) suggests that hydroelectricity could be expanded as an energy source in America, the study also warns that hydroelectricity generation may be under threat due to the climate change effects on energy systems.

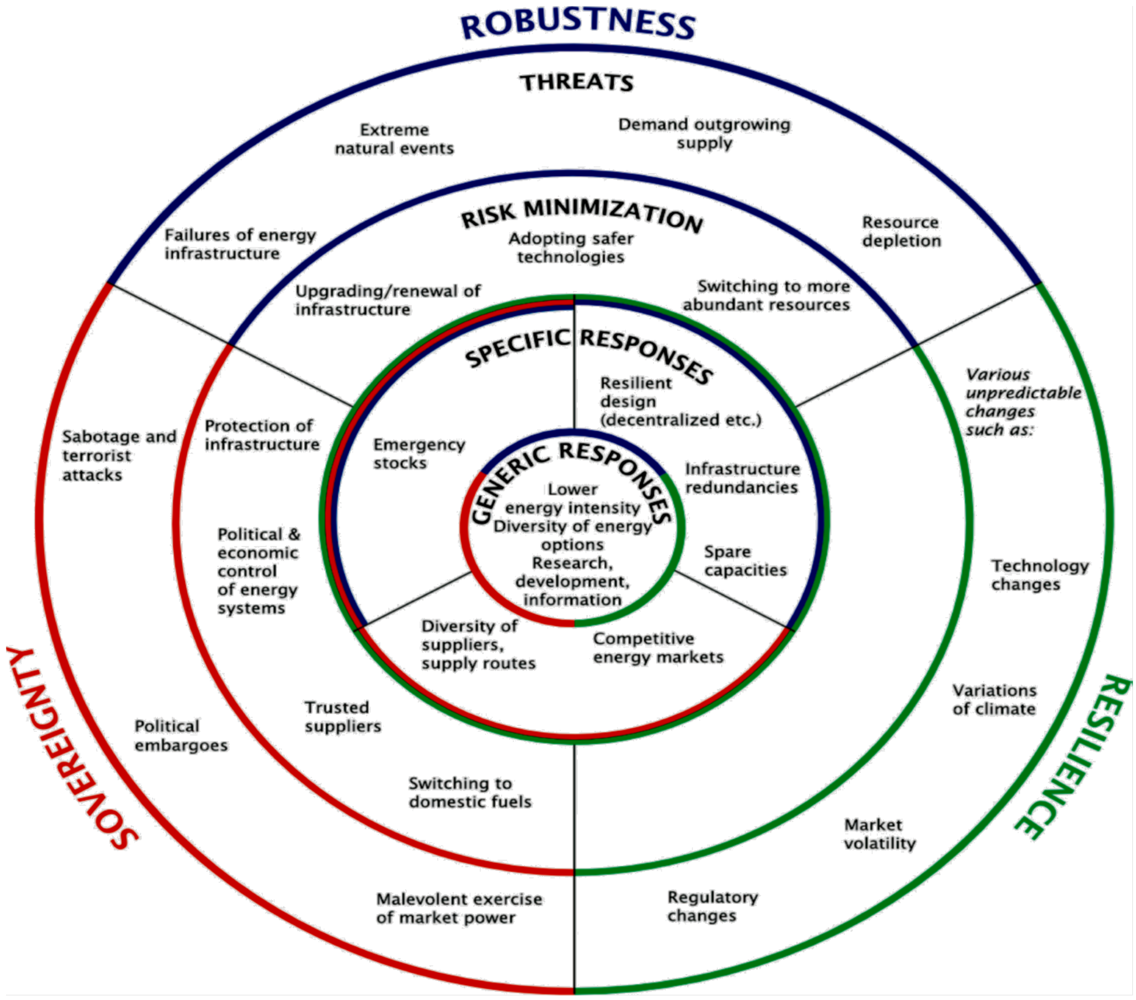


Figure 2.1 Elements affecting energy security in over 130 countries
Source: Cherp et al. (2015)

One of the positive and critical finding from Cherp et al.'s (2015) study is that the link between climate change and energy security may also result in positive effects on energy security as some countries may experience changes in weather patterns favourable to sustain new energy sources such as solar, wind and hydroelectricity, and therefore ensuring that electricity remains available and affordable for consumers. Projections by O'Keefe (2021) suggest that Latin America may experience water scarcity in the coming years, resulting in a dwindling water resource for hydroelectricity. This highlights the findings of Cherp et al. (2015) and SWP (2021) that the connection between climate change and energy security will cause fortunes for some countries and misfortunes for others. Therefore, countries need to invest in scientific research to understand the projected impacts in their respective regions. The link between climate change and energy security in Latin America, as indicated by O'Keefe (2021), is also apparent in the USA. The United States' Union of Concerned Scientists (USUCS) estimates that the United States could experience a rise in the hottest daily temperatures by about 10 °Fahrenheit in the 21st century compared to the 20th century due to climate change resulting in high energy demand and possible shortfall in energy supply (USUCS, 2020). Most power stations in the USA rely heavily on water; high ambient temperatures and high evaporation rate will likely result in disruption of various power plants' operations (USEPA, 2017). The sea level rise caused by increased temperatures threatens the infrastructure of some of the USA's power stations located in coastal regions which could potentially affect the national energy availability factor (USEPA, 2017).

The International Energy Agency (IEA) projects that by the 2040s, a warming of 1°C in Europe will result in a 19% reduction in energy generation capacity during the summer season (IEA, 2014). European countries have acknowledged the link between energy security and climate change and EU countries have started playing an influential role in sensitising other countries outside Europe to also grasp and act on measures to manage the connection (EU, 2019; Stang, 2015). In this regard, the European Union has established a plan to ensure that the connection between climate change and energy security is managed across EU countries through the establishment and implementation of a strategic energy framework aimed at ensuring a resilient energy-generating system against climate change effects. This framework was also developed in synchronisation with the EU's climate change policy (EU, 2019). The energy strategy plan for Turkey, one of the countries under the EU, primarily focuses on ensuring future energy security through implementing energy systems that reduce the effects of climate change (Colantoni et al., 2017). The European Union's objective to diversify their energy systems in response to the link between climate change and energy security, while commendable, does not necessarily mean that the global challenge of energy systems' impact on climate change will be curbed as many countries are still emitting significant amounts of greenhouse gases in pursuit of economic ambitions. However, it does place European countries in a better position to build energy systems that can adapt and resist the effects of climate change and therefore ensuring stable and cheap energy supply (Criqui & Mima, 2011; IEA, 2014).

The effects of the link between climate change and energy security are already being felt in some parts of Asia. Inconsistent rainfall and increased temperatures are interrupting hydropower generation in Nepal and Sri Lanka, painting an undesirable future for hydropower energy in both countries (Sudan, 2021). Climate change projections show a greater than 2°C increase in ambient temperature by 2050 and an estimated increase of 4.8°C by 2100 in South Asian countries such as Bangladesh, Bhutan, India, and Nepal (Sudan, 2021). Given the predicaments that some South Asian countries are facing in relation to water resource availability, a question arises as to whether an investment in energy sources heavily linked with climate change variables is worth pursuing. An analysis conducted by India's Centre for Policy Research in 2015 suggests that by 2030, India's coal use for energy production will double 2015 usage regardless of any changes to climate change-energy policy (Dubash et al., 2015). Dubash's analysis also suggests a passive engagement by India's policymakers in developing predictive models and mitigation measures in response to the nexus of climate change and energy security.

China, with its rapidly growing economy, is among the countries struggling to balance climate change and energy security (Nyman, 2018). Nyman (2018) argues that China's national energy policy is not aligned with the Paris Agreement, as it heavily relies on abundant fossil fuels such as coal and fuel oil to achieve energy security. China's approach would not make a significant progress in mitigating the drivers of climate change and its potential long-term effects on economic growth (Nyman, 2018). In contrast, a study by SWP (2021) argues that countries should prioritise securing their energy generation capacity (through renewable or non-renewable sources) while gradually diversifying their energy systems to be adaptive and resilient to climate change effects.

Schaeffer et al. (2011) presented a practical example of the link between climate change and energy security in a South American case study. High temperatures caused by climate change are already melting and reducing glaciers in places such as Chacaltaya in Bolivia, which may negatively impact hydro power production and energy tariffs as water supply becomes scarce. Additionally, Schaeffer et al. (2011) found a decline in incoming solar radiation that will negatively affect solar energy production in Canada. The study also shared a detailed model to highlight the impact of climate change on various energy-generating technologies across the world using various scenarios (refer to Table 2.1).

Table 2.1 Synopsis: Climate Change and Energy Security Nexus - Causes and Effects

Energy source & Demand	Climate variables (causes)	Related impacts on energy security (effects)
Thermoelectric (coal, nuclear and natural gas)	• Water and ambient temperature, humidity and wind, as well as extreme weather events	• Impact on quality and quantity of cooling water system as well as efficiency of turbine operation and cooling
Oil and Gas	• Extreme climate-related occurrences, water and ambient temperature, floods, etc.	• Disturbances of onshore and offshore extraction. • The quantity and quality of cooling water in the oil refineries affected.
Biomass	• Extreme climate-related events, water and ambient temperature, flooding • Carbon dioxide levels	• Access to land with suitable edaphoclimatic environments (agrarian zoning) • Desertification • Bioenergy crop yield
Hydropower	• Ambient temperature, precipitation and other extreme climate-related events.	• Water availability in the power stations' reservoirs as well as droughts • Fluctuations in hydropower system vaporisation from water storage ponds/reservoirs
Wind Power	• Wind and other extreme weather events	• Vicissitudes in wind resource distribution (duration and intensity). • Increased wind shear and wind hubs damage from extreme weather.
Solar Energy	• Extreme climate-related events and wind	• Changes in Insolation (formation of clouds) • Decline in efficacy due to decline in radioactivity • Decline in efficacy due to ambient conditions
Geothermal Wave Energy	• Extreme climate-related occurrences, water and ambient temperature	• Cooling efficacy • Changes in wave resource
Demand	• Ambient temperature, precipitation, extreme climate-related events	• Upsurge in demand for air conditioning in hot seasons and decline in energy demand for heating during cold seasons • Rise in demand for irrigating energy

Source: Schaeffer et al. (2011)

While the data presented in Table 2.1 above aligns with most of the reviewed literature in that climate change has the crippling effects on energy production, availability and affordability, studies by Nik and Perera (2020), Cevik (2022), Kabeyi, and Olanrewaju (2022) identified that the transition to renewable energy mix is critical for countries to establish climate change resilient and adaptive energy systems. In accord with this view, Cherp et al. (2015) also found that most African countries should transition to a diversified energy sources in order to stand a good chance to withstand the climate change effects. Cherp et al. further argued that low diversity of energy sources significantly reduces the adaptability of energy sectors resulting into climate change related interruptions of energy generation processes. For instance, Cherp et al. (2015) also argues that countries that rely mainly on hydro generated power, faces serious interruptions of energy production processes particularly when such countries are going through dry spells; however, countries that invest on diverse energy sources strives during various climate change related variabilities because when one energy source is adversely impacted by drought (e.g., hydropower) the other energy source strives (e.g., solar). While these observations project a positive story about the benefits of transitioning to cleaner energy mix to ensure climate change adaptability by energy sectors across the world, these studies failed to acknowledge that renewable energy sources do not provide adequate energy to meet the immediate demand particularly in the developing countries such as South Africa. Therefore, there is a need to conduct further studies in the context of South Africa's energy distribution landscape to be able to make suitable recommendations on ideal transitional investments which will ensure that the country's energy sector is resilient and robust enough to survive climate change implications.

In the global context, the relationship between climate change and energy security is well-established, particularly in respect of its impact on energy availability, affordability, and accessibility aspects (IEA, 2014; King & Gulledge, 2013; Schaeffer et al., 2011). While there is consensus that policies for climate change and energy security are compatible, there is also a view that countries should not be forced to prioritise climate change reduction measures over energy security. Literature on the subject presents detailed perspectives from various authors around the world, highlighting the existence and the significance of the link between climate change and energy security. This highlights the need for further studies to explore the significance of this relationship in the South African context.

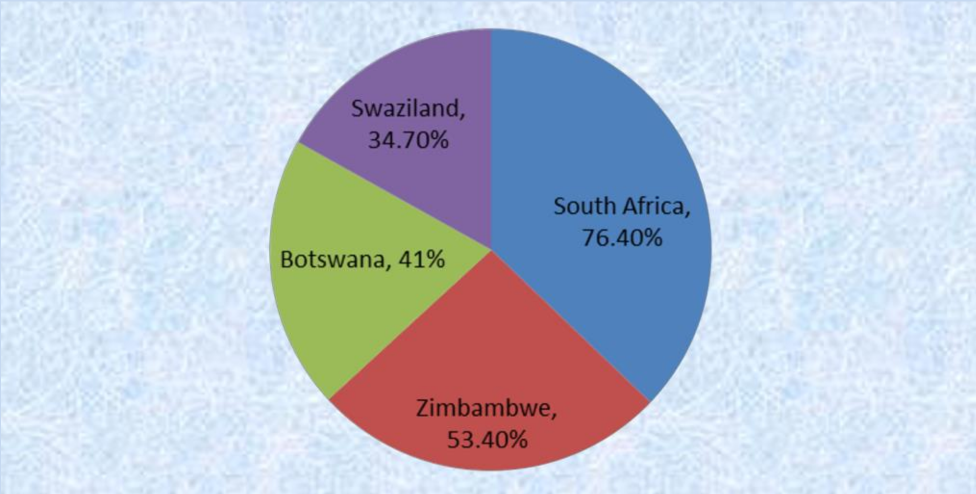
2.3 CLIMATE CHANGE AND THE ENERGY SECURITY NEXUS: A SUB-SAHARAN AFRICAN CONTEXT

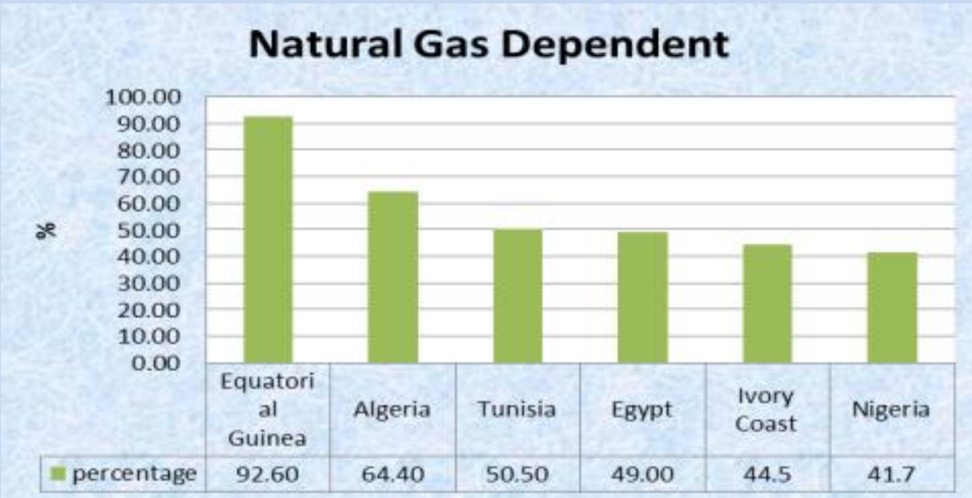
The African Union (AU, 2015) has established a pathway for African countries to address the link between climate change and energy security. The AU's 2063 Agenda encourages African nations to develop industrial systems, including energy systems, that can mitigate and adapt to the effects of climate change in pursuit of reliable, affordable and accessible energy systems. However, it remains uncertain if Africa has enough resources to diversify and achieve an energy mix. Stiftung

(2016) urged African countries, particularly those near the equator with ample solar energy, to invest in solar energy as a means of diversifying their energy systems. Similarly, Addaney (2018) found that African countries have been slow to make use of alternative energy sources as a means of building resilient energy systems (in terms of energy availability, accessibility, and affordability) that are also adaptive to the undesirable consequences of the climate change-energy security connection.

Addaney (2018) and Dyke et al. (2021) argued that the main problem with Africa's climate change adaptation measures is the reactive approach, and it places the continent's energy security at great vulnerability of failing to sustain adequate energy availability, affordable energy tariffs and accessible electricity. While a study by Stiftung (2016) identifies untapped opportunities for African countries near the equator to expand their energy sources through solar energy, Isingoma (2009) warns of the potential for dwindling energy production capacity for many African countries in the equatorial region due to climate variability. Based on these findings, it is clear that African countries, particularly those in the equatorial region, have adopted a reactive approach in addressing the climate change-energy security connection, which may result in these countries being unable to meet projected increases in energy demand as climate change effects further disrupt and destabilise the supply security of existing energy sources. This may also trigger an increase in the cost of energy unit sent out.

In the context of the climate change-energy security connection, data depicted in Figure 2.2 highlights a significant issue of a lack of energy source diversity in Africa, making many African countries' energy systems highly vulnerable to the effects of climate change (Cherp et al., 2015). Failing to tap into the diverse energy sources that are available in most African countries may also contribute to energy insecurity as a result of climate change impacts (Cherp et al., 2015). Stiftung (2016) and Cherp et al. (2015) concur that African countries near the equator are failing to explore other suitable energy sources such as solar energy (refer to Figure 2.2).

<table>
<tr><th>ENERGY SOURCES</th><th>COUNTRIES IN AFRICA & PERCENTAGE OF RELIANCE ON PARTICULAR ENERGY SOURCE</th></tr>
<tr><td>Significant Coal-dependent countries in Africa</td><td>


</td></tr>
<tr><td>Significant Hydroelectricity-dependent countries in Africa</td><td>
<table>
<tr><th>Country</th><th>Reliance (%)</th></tr>
<tr><td>Mozambique</td><td>82.10%</td></tr>
<tr><td>Zambia</td><td>75.20%</td></tr>
<tr><td>Congo Kinshasa</td><td>68.20%</td></tr>
<tr><td>Malawi</td><td>45.30%</td></tr>
<tr><td>Cameroon</td><td>41.60%</td></tr>
</table>
</td></tr>
<tr><td>Significant Natural Gas-dependent countries in Africa</td><td>


</td></tr>
</table>

Figure 2.2 Significant sources of energy in selected African countries
Source: Cherp et al. (2015)

Climate change and energy security are closely linked, with each affecting the other. Failure to recognise this connection by African countries can lead to significant energy insecurity in the long term (Chapman & Whande, 2013). A study by Chapman and Whande (2013) raises energy security concerns related to dwindling energy availability, affordability and accessibility for more than 20 African countries that rely heavily on hydropower (over 50%). Chapman and Whande (2013) call for an urgent need to review and align energy policies to promote diverse, adaptive and resilient energy systems that can withstand the effects of climate change, therefore ensuring that energy supply remain reliable, affordable and accessible in Africa. Climate change and energy security also impact other critical natural resources, such as water, which availability is dependent on climate variables. This poses a new risk of water scarcity, particularly for countries sharing common rivers, which can result into major challenges related to energy availability, affordability and accessibility for African countries that rely heavily on hydropower (Chapman & Whande, 2013).

In a special report on Africa's Climate Change Adaptation, Mitigation and Governance Challenges, CIGI (2009) identified case studies in Ghana, Uganda, and Ethiopia to highlight the significance of the climate change and energy security link in Sub-Saharan Africa. During the period from 2004 to 2007, Ghana's Akosombo dam, Uganda's Lake Victoria and some raw water dams in Ethiopia experienced a significant reduction in water capacity due to inadequate rainfall, high temperatures, and dry spells. This resulted in serious interruptions to hydropower generation in Ghana, Uganda, and Ethiopia, leading to load-shedding and blackouts, which negatively impacted their energy security and socio-economic activities (CIGI, 2009).

The nexus between climate change and energy security is a critical issue in the Sub-Saharan African context. Studies have shown that Africa possesses a wealth of underutilised renewable energy sources, which should be harnessed to diversify energy systems, stabilize the electricity tariffs, and increase resilience against the effects of climate change on energy security (Chapman & Whande, 2013; Cherp et al., 2015; Fiott, 2010; Stiftung, 2016). For example, the Republic of Congo has a range of potential energy sources, that include solar, wind, hydropower, and biomass, yet less than 20% of homes have access to power (Fiott, 2010). Similarly, despite being drought-prone, Kenya still relies heavily on hydropower for over 60% of its national energy, putting the drought-prone Tana River under further strain while also placing the country under serious energy insecurity risk (Fiott, 2010). Energy diversification is critical to reduce dependence on single sources of energy and increase energy security. This does not only ensure better management of the relationship between climate change and energy security, but it also creates job opportunities and economic stimulation for local communities, and provides relief to stressed environmental resources, such as rivers (Fiott, 2010).

The southern Africa region is not spared from the effects of climate change on energy security, as temperatures are projected to rise by more than 4°C by 2080, with the exception of South Africa's eastern and southern coastal regions (DEA, 2018). African countries are urged to reform their energy policies to diversify energy sources to ensure adequate availability, affordability and accessibility which would attract positive investments and growth (Hafner et al., 2018). Overall, the relationship between climate change and energy security is a national security matter that requires each African country to understand their own energy landscape, potential risks associated with climate change, and align policies to establish a diverse range of energy sources and technologies to adapt and resist projected effects.

2.4 CLIMATE CHANGE AND THE ENERGY SECURITY NEXUS: A SOUTH AFRICAN CONTEXT

Climate change and energy security are closely linked, and South Africa has long acknowledged this connection. The country's initial National Climate Change Response Strategy, dating back to 2004, recognised the need for energy diversification to ensure energy security (availability, affordability, and accessibility) in the face of climate change. However, a study by Cherp (2015) found that South Africa's heavy reliance on single energy source (coal) left the country vulnerable to the effects of climate change on energy security. Core to South Africa's initial National Climate Change Response Strategy was to reduce the country's carbon footprint as part of greenhouse gas effect and climate change mitigation (DEAT, 2004). Thus, South Africa has always acknowledged its contribution towards Africa's carbon footprint as it is the only African country that largely relies on fossil fuel combustion to generate electricity. According to Eskom RT & D (2021), the carbon footprint by South Africa's energy sector remained relatively significant for several years, i.e., Eskom's coal power plants have emitted a combined CO_2e figure of over 200 million tons per year from 2010 to 2020 (refer to Table 2.2 below).

Table 2.2 Decade inventory of Eskom's carbon footprint

Eskom Fiscal Years	Eskom CO_2 Emissions (Tons)
April 2010 to March 2011	230 313 101.7
April 2011 to March 2012	231 930 682.0
April 2012 to March 2013	228 116 934.6
April 2013 to March 2014	233 341 022.8
April 2014 to March 2015	223 560 494.5
April 2015 to March 2016	218 841 946.4
April 2016 to March 2017	211 100 102.4
April 2017 to Mach 2018	205 555 463.7
April 2018 to March 2019	220 909 237.1
April 2019 to March 2020	213 209 999.7

Source: Eskom RT&D (2021)

To reduce this significant carbon footprint (refer to Table 2.2), Eskom has been trying to gradually retire some of its old coal power plants over the years, however, these efforts have been largely futile because of the sustained pressure on South Africa's energy grid that has even resulted into the country experiencing unprecedented load shedding in the recent past (Sloss, 2021; Trollip et al., 2014). Since the major phasing out of most of these coal power plants is not feasible under the current era of high energy demand and regular shortfall in energy supply by Eskom, another opportunity for South Africa's power utility to decarbonize include the installation of carbon emission abatement technology at the coal power plants (McCourt, 2020). This view is also aligned with the observations made by Pretorius et al. (2015) who also added that Eskom's carbon emissions increase during plant breakdowns and emergency power generation periods because all its coal power generators lack CO_2e abatement technology. Eskom's power stations were commissioned from the late 1960s to the early 1990s and were not designed with gaseous emissions' abatement technology as the connection between carbon emissions and climate change effects was not widely researched, projected, and understood at the time (JMU, 2021). Although there are some technologies in the market that Eskom can invest on to decarbonize its coal power plants to mitigate climate change phenomenon, such abatement technologies are found to be quite expensive considering South Africa's economic status (McCourt, 2020). Furthermore, the Carbon Tax Act that has been recently promulgated in South Africa to encourage decarbonization does not seem to have enough bite to force the main contributors to carbon emissions to scale down their carbon footprint. It is in this context that Hanto et al. (2021) has argued that South Africa must transition to clean energy mix (renewables) as a main avenue towards decarbonization. Hanto et al. also added that investment on cleaner energy mix will also enhance the competitiveness of renewable energy mix. These observations harmonize on the significance of South Africa's carbon footprint and the need to scale it down in line with climate change mitigation ambitions, however, the same literatures do not deeply deal with Eskom's institutional challenges and how those can be turned into opportunities to intensify South Africa's decarbonization programme.

A Governance of Climate Change Policy report by Averchenkova et al. (2019) noted that South Africa's climate change-energy security policy had called for cleaner energy sources mix as early as 2011, but lack of political interest had hindered progress until 2018. Kiratu (2010) also alluded to South Africa's lack of policies that would promote the establishment and utilization of clean energy technologies as part of the policy stagnations. Conway et al. (2015) warned that South Africa's energy generation sector is at high risk of underproduction, unreliability and high cost of energy unit sent out during droughts and extreme floods due to its heavy dependence on coal-fired power stations, which consume large amounts of water and are vulnerable to irregular rainfall and constrained water supply. Donnenfeld et al. (2018) argued that South Africa should invest in a shift away from coal-dependent energy systems towards renewables in order to preserve the country's already-scarce water resource while also ensuring energy security. In contrast, SWP (2021) argued that while climate change and energy security link should be addressed, this should be done without overstating the effects of climate change. They argue that South Africa should not be pressured to overspend in order to transition to cleaner energy sources.

Climate change projections indicate that water demand for cooling activity at the coal energy plants will increase significantly in the coming years due to increased temperatures (Donnenfeld et al., 2018). The efficient use of water resource by coal energy plants will be critical to secure South Africa's energy system against climate change effects; and this can only materialise when most Eskom power stations start using dry cooling instead of wet cooling systems (Conway et al., 2015; Donnenfeld et al., 2018; Thopil & Pouris, 2016). In this regard, Conway et al. (2015) study identified and commended South Africa's new builds (Medupi and Kusile Coal-Fired Power Stations) which are using dry cooling systems and therefore ensuring a significant reduction of water usage as a great path to follow in order to ensure clean coal technologies that would also ensure productivity, reliability and affordability (i.e., energy security) of such power plants amidst climate change induced precipitation variability.

According to Eskom R&S (2018), eleven of Eskom's coal power plants (Arnot, Camden, Duvha, Hendrina, Kendal, Komati, Kriel, Kusile, Majuba, Matla and Tutuka coal power plants), which are all located in the Mpumalanga Province, receives their raw water resource for energy production purposes from the Vaal River Eastern Sub-System (VRESS); while the two coal power plants (Medupi and Matimba power plants), which are located in the Limpopo Province, receives their production water from Mokolo Crocodile Water Augmentation Project. As depicted in the water consumption inventory in Table 2.3 below, most of these eleven coal power plants receiving their raw water from the common VRESS water source consume over 10 billion litres of water resource annually (Eskom R&S, 2018). These observations, together with water consumption inventory in Table 2.3 below, clearly highlight Eskom coal power plants' significant reliance on raw water resource for energy production. Based on the observations above, there was therefore a gap in knowledge that the current study had to close-up in relation to the deep understanding of climate change related risks, and opportunities associated with Eskom's significant reliance on raw water resource for energy production.

Table 2.3 An annual (April 2020 to March 2021) Water Consumption Inventory by Eskom Coal Power Plants

Eskom Coal-fired power stations	Annual Water Consumption (Ml)
Arnot	25 624.2
Hendrina	15 187.3
Komati	3 674.1
Duvha	29 007.5
Camden	8 151.4
Kriel	29 485.2
Matla	43 638.3
Kendal	6 188.9
Kusile	4 196.1
Tutuka	34 152.0
Grootvlei	10 214.8
Lethabo	41 001.4
Matimba	6 217.9
Medupi	3 721.3
Majuba	26 556.7
Total	287 017.1

Source: Eskom Water Management Centre of Excellence (EWMCE) (2021)

The nexus between climate change and energy security in the South African context is complex, with energy production processes contributing to climate change while projected changes in climate are affecting energy systems. Studies have noted South Africa's over-dependence on coal as a source of vulnerability in terms of adapting to the effects of climate change on energy security (Averchenkova et al., 2019; Cherp, et al., 2015). Concerns have been raised about the potential for decreased energy productivity, cost, and reliability during droughts and extreme floods, particularly because of the effects of climate change on water resources necessary for energy production (Conway et al., 2015; DEA, 2018; Donnenfeld et al., 2018). In accord with this view, Steele et al. (2012) and Mambo and Faccer (2017) also found that South Africa's energy sector is one of the most at-risk sectors against changes in climatic conditions due to its dependence on water resources and inadequate infrastructure. In response, South Africa's National Department of Environmental Affairs has developed flagship programmes aimed at promoting energy efficiency, investing in renewable energy, and conserving and managing water resources (DEA, 2018). However, some argue that the risks associated with climate change and energy security in South Africa should not be over-dramatized and that care should be taken to avoid risking financial instability in the pursuit of cleaner energy sources mix (SWP, 2021).

Studies by DEA (2018), Mukheibir (2007), Mambo and Faccer (2017), Conway et al. (2015) and Donnenfeld et al. (2018) have all identified the connection between climate change and its effects on South Africa's energy security. The question now is how South Africa should manage this connection. The National Department of Environmental Affairs developed a National Climate Change Response Policy in 2011 as a framework to start working on measures to curb the continuous emissions of greenhouse gases and also to manage the effects of climate change on South Africa's industries and economy, including the energy sector (Averchenkova et al., 2019; DEA, 2011). In the second draft of South Africa's National Climate Change Adaptation Strategy issued in October 2017, more detail on the effects of the climate change and energy security link in the South African context was articulated (Averchenkova et al., 2019). The adaptation strategy identified the state-owned entity (Eskom), which is responsible for electricity supply across the country, as being critically vulnerable to climate change effects. Some of the issues identified included projected drought spells and high temperatures which would respectively interrupt hydropower plants' generation activities and coal power plants' cooling activities and therefore adversely affecting South Africa's energy availability, affordability, and reliability (Gilfillan and Pittock, 2022; Averchenkova et al., 2019; DEA, 2017). The draft National Climate Change Adaptation Strategy also directed that a climate change response strategy must be developed for the energy sector and that Eskom's climate change-resilient strategy had to be supported to ensure that the effects of the 'connection' are well managed (Averchenkova et al., 2019; DEA, 2017).

Eskom, South Africa's main energy supplier, is aware of its vulnerability to the effects of the climate change-energy security nexus, hence the development of an Eskom Climate Change Strategy which is mainly focused on mitigating the causes, and also adapting against the effects of climate change while ensuring energy security. In the strategy, Eskom identifies the diversification of the energy sources to include more of nuclear energy, clean coal, gas, imports, wind, hydro, and pumped storage as one of the six critical points for the organisation to achieve its climate change strategy and security of energy supply (Eskom, 2013). Eskom further highlighted the importance of planning for climate change effects such as droughts, flooding, fires, etc., as another important point for an organisation to survive the adverse effects associated with climate change and its impact on the energy security (Eskom, 2013).

Taken together, these studies support the notion that South Africa should look into transitioning to cleaner energy sources mix in order to stand a fair chance of adapting against and resisting the effects of climate change, and therefore ensuring energy security (Cherp et al., 2015; Eskom, 2013; Conway et al., 2015; Donnenfeld et al., 2018). Investigations by ASSAF (2017) and DE (2019) indicate that South Africa is globally rated number 12 in the list of the most attractive renewable energy investment site due to the abundance of sunshine and wind ideal for generating electricity, and therefore the country should make use of the opportunity to strengthen its energy security. ASSAF (2017) further advises that South Africa should actively consider partnering with other countries with abundant renewable energy sources and also invest in energy infrastructure to support the inclusion of renewable energy sources into the national energy mix. It also advises that the availability of only few rivers suitable to support major hydroelectricity power generation plants, together with the projected constrain of water resource availability makes hydropower investment an unideal option for most regions in South Africa.

2.5 IDENTIFYING THE GAPS IN KNOWLEDGE

The literature reviewed provided evidence that there is a strong linkage between climate change and energy security. Several studies have identified climate change effects such as irregular precipitation, high temperatures, flooding, droughts, etc., as well as the risks and opportunities presented by these effects to various energy systems across the world. Together, these studies provided critical insights into the compatibility of climate change and energy security policies, although they may not be combined into one policy (IEA, 2014; King & Gulledge, 2013; Schaeffer et al., 2011). In all the studies reviewed here, climate change and energy security are recognised as global issues and therefore African countries are equally impacted.

The studies reviewed did not propose a model for developing countries such as China, South Africa, and India to manage the risks of their reliance on fossil fuels in an era of climate change. There is little information on the implications of the choices made by these countries for their energy sectors in the future (Chapman & Whande, 2013; Cherp et al., 2015; Conway et al., 2015; Donnenfeld et al., 2018; Eskom, 2013). This study was necessary to provide a better understanding of South Africa's response to climate change inducing carbon emissions. Studies by Sloss (2021), Hanto et al. (2021), and Gustafsson (2021) acknowledged the significance of South Africa's carbon footprint and the need to transition the country's coal-based energy system to cleaner energy sources mix in order to achieve decarbonization ambitions. These studies do not, however, deal with the institutional and socio-economic challenges that South Africa's power utility is faced with while trying to achieve an effective decarbonization programme. This study, therefore, investigates some of Eskom's institutional challenges with an aim of identifying operational issues that could be addressed to effectively improve decarbonization ambitions.

Reviewed literature also supported the notion that the relationship between climate change and energy security must be addressed as a national security matter, requiring each African country to understand its own energy landscape, potential risks associated with climate change, and align climate change-energy security policies in order to establish a diversity of energy sources and technologies to adapt and resist against projected climate change effects (Nik and Perera, 2020; Cevik, 2022; Kabeyi, and Olanrewaju, 2022; Chapman & Whande, 2013; Cherp et al., 2015). All of the studies reviewed in relation to the climate change-energy security nexus in the South African context support the hypothesis that the country needs to transition its largely coal-dependent energy sector into various energy sources (Nik and Perera, 2020; Cevik, 2022; Kabeyi, and Olanrewaju, 2022; Cherp et al., 2015; Eskom, 2013; Conway et al., 2015; Donnenfeld et al., 2018). Reviewed studies also maintained a general view that South Africa has abundant natural energy sources such as wind and sunshine, which can be utilised to expand the energy mix programme. While these studies show the benefits of transitioning energy sectors to cleaner energy mix as another means of achieving climate change adaptation, they do not acknowledge the reality that renewable energy sources cannot provide adequate energy to meet the immediate high energy demand, particularly in the developing countries such as South Africa. Therefore, this research thoroughly assesses South Africa's energy demand context to be able to recommend informed solutions that will be suitable in resolving the country's challenges.

Academic literatures on the connection between climate change and energy security are limited. Many theories have been developed by think tanks and non-academic organisations, which often lack rigorous methodology (King & Gulledge, 2013). There is limited research work undertaken on the policy linkage between climate change and energy security (Toke & Vezirgiannidou, 2013). King and Gulledge (2013) and Toke and Vezirgiannidou (2013) called for more studies at the international, national and organisational level to better understand the link and associated bottlenecks. In the South African context, the majority of research focuses on the Water-Energy-Food (WEF) or Water-Food-Climate (WFC) nexus, leaving a gap in understanding the Climate Change and Energy Security (CCES) link.

The review of various studies suggests that diversifying energy systems and enhancing energy security is influenced by a country's energy system set-up, national energy policies, economic status, and political influences (Chapman & Whande, 2013; Cherp et al., 2015; Conway et al., 2015; Donnenfeld et al., 2018; Eskom, 2013). This observation basically suggests that, 'it is not a one size fits all situation', and therefore, developed countries' solutions may not be applicable to developing countries, and different countries may require different adaptations and resilience mechanisms. The reviewed literature leaves a gap for individual countries' power utilities to undertake a detailed review and assessment of energy policy and energy sector landscape in relation to climate change to develop relevant policy recommendations. Furthermore, the reviewed studies did not provide modelled solutions for various energy sectors across the world to mitigate and adapt to climate change effects. Therefore, the current study was needed to assess South Africa's situation and possible measures to deal with issues related to the climate change-energy security nexus at the institutional (Eskom) level.

CHAPTER THREE

METHODOLOGICAL CONSIDERATIONS

3.1 INTRODUCTION

This chapter outlines the methodological steps employed in this study. Research methodology is a systematic approach to gather data in response to research questions, and offers various approaches, models, and processes (Kumar, 2011). The methodology used in this study aimed at describing, explaining, and predicting the research hypothesis or topic (Goundar, 2019). Effective research methodology is essential to obtain research knowledge (Goundar, 2019). It explains the justification for the study, the nature of data to be collected, the instruments used to collect the data, and the criteria for data analysis (Goundar, 2019). This chapter is crucial as it details the research plan followed to obtain comprehensive data to describe, explain and predict the themes associated with the research topic.

In light of this, Chapter Three begins by outlining the researcher's positionality in terms of the philosophy used to investigate the research problem. After outlining the philosophy adopted by the research, the aims and objectives of the research are recapped to ensure their alignment with the selected research methodology. Chapter 3 also outlines the design of the study, along with the connected elements such as the description of the study area, population of interest, sampling procedure and data collection tools. The chapter also explains the data analysis methodology used, taking into account the reliability and accuracy of the method; qualitative and quantitative data analysis methods are also explained. Before concluding, Chapter Three includes a methodological reflection section to assess the weaknesses and strength of the overall methodological package used in the study.

3.2 RESEARCH POSITIONALITY

Conducting research is a complex activity that involves various facets, particularly when interpreting research findings. To gain justifiable solutions, thorough debates, negotiations, and interpretations of the reality within the context under investigation are necessary. The reality can change with the vicissitudes of contextual issues. The outward appearance of a situation can be misleading, so a thorough interrogation and reasoning with circumstances is crucial to better understand the real position of circumstances and possible alternatives for improvement.

Understanding the interconnectedness of activities, products, and services in relation to the environmental issues is critical, as problems that become more prominent downstream are often caused by poor decision-making upstream, such as poor designs, unjustifiable costs, and inadequate research. Science is a valuable tool for breaking impractical traditional practices and promoting a strong sustainability framework. Scientists should investigate and provide pragmatic and contemporary solutions to ensure that economic development activities are executed with strong consideration for natural capital.

Based on this discussion, the study adopted to use the pragmatism approach as its research positionality. Research positionality is an important procedure through which a researcher reflects on and assesses their personal concepts, individualities, transparency, impartiality, and partiality in relation to the perspectives assumed in the study (Throne et al., 2017). Pragmatism is a research approach that is rooted in understanding the research problem, questions, and aim to establish applied solutions to inform future activities (Saunders, 2016). The pragmatism research approach consists of four positional elements: an understanding of the nature of being (ontology), the attributes of suitable knowledge (epistemology), the role of standards and morals in research (axiology), and the research methods to be used. All of these elements were assessed in line with the philosophy of the current research (refer to Table 3.1 below).

Ontologically, the current study aligns with the pragmatism research approach as it is multifaceted and loaded, assuming that the reality that is outwardly visible is a result of the fluidity of philosophies, developments, knowledge, and applications. The epistemological assumption of pragmatism is that information in real-world settings is precise, and that philosophies and knowledge should lead to some form of action. Therefore, it is oriented and focused on problems, processes, and outcomes. In terms of axiology, pragmatism aligns with the current study as it is value-driven and based on reflexive instinct. Additionally, research conducted under this approach is initiated based on its philosophies and uncertainties. The main methodological elements associated with pragmatism include qualitative and quantitative methods, mixed and multiple methods, and action research. The mixed or multiple research approach is also aligned with the current study (Saunders et al., 2009). The Heightening Awareness of Research Philosophy (HARP) quiz was also completed to that ensure a suitable philosophical approach was selected for the current research (Saunders et al., 2009). As depicted in Table 3.1 below, the HARP quiz demonstrates that the theories and assumptions used in this study are strongly aligned with the pragmatism research approach.

Table 3.1 Research philosophy and assumptions – HARP quiz assessment outcome

DETERMINING THE RESEARCH PHILOSOPHY					
Elements	**Positivism**	**Postmodernism**	**Critical Realism**	**Pragmatism**	**Interpretivism**
Ontology	-Actual -Autonomous -Well-ordered	-Nominal complex -Interpretations -Flux of process	-Layered (empirical, actual, etc) - Autonomous -Objective structures	-Complex and rich -Reality is practical consequences of ideas -Experience and practices	-Complex -Multiple interpretations -Flux of process
Epistemology	-Scientific -Measurable -Causal explanation	-Decided by dominant Ideologies -Focus on absences	-Relativism -Historical causal explanations	-Practical meaning -True theories enable successful action -Problem oriented	-Too simplistic -Focus on interpretations -New understanding
Axiology	-Value free -Researcher detached -Objective	-Value-driven -Embedded in power relations -Radically reflexive	-Value-driven -Bias acknowledged -Objective	-Value-driven -Researcher reflexive	-Value-driven -Subjective -Reflexive
Methods	-Typically, quantitative	-Typically, qualitative methods	-Mixed methods	-Mixed research methods	-Mostly qualitative
Research's Alignment with the Philosophy	**Weak** - slightly agree/disagree with the philosophy.	**Slightly Weak** - slightly agree with the philosophy.	**Slightly Strong** - slightly agree with the philosophy.	**Very Strong** - researcher strongly agree with the philosophy.	**Strong** - generally agrees with the philosophy.

Source: Saunders et al., (2009)

This study has adopted a pragmatic research approach to unpack the features associated with the nexus of climate change and energy security in South Africa. This approach facilitates the understanding of external factors and their linkages to the real-world consequences of theories, practices, and knowledge. Furthermore, it promotes the development of actionable theories to address identified problems, inefficient practices, and processes within the context of the study. The use of a mixed research method, within the pragmatic approach, furthers the objective of the study as it employs various data collection techniques, such as participant observations, interviews, and surveys.

3.3 RECAPPING THE RESEARCH AIM AND OBJECTIVES

The suitability, adequacy, and effectiveness of South Africa's Integrated Energy Resource Plan (IRP) is critical as it directs actions towards the implementation of energy sector transformation. Therefore, the current study aimed at exploring changes of climatic conditions on South Africa's (SA) energy security as well as assessing the suitability, adequacy, and effectiveness of SA's current IRP in transitioning the energy sector to become adaptive and resilient to adverse climatic conditions changes. There was also a need to determine adequate measures to reduce South Africa's contribution into climate change as well as the effects of climate change into South Africa's energy sector. Consequently, the initial two objectives of this study respectively included investigating the influence of South Africa's energy sector into global carbon emissions as well as exploring the potential effects of climate change on South Africa's energy security.

Energy policy is critical in guiding the transition process of energy sector; its misalignment may directly result into ineffective transition process. In this regard, the study also included two objectives which intended to measure the efficacy of South Africa's policy agenda in guiding the energy sector to transition into cleaner energy systems; and also determining if transitioning the energy sector is an ideal solution for South Africa in responding to climate change threat. Lastly, the other objective for this study was to identify practicable measures which may be applied to counterbalance the current carbon emissions from coal power plants; this objective was included to assess opportunities which may be implemented to ensure that existing coal-based power plants can continue being used while emitting lesser CO_2.

3.4 RESEARCH DESIGN

The research design, as outlined hereunder, is an overall strategy used by the current study to obtain all the answers to the research questions (Saunders et al., 2019). It was developed in line with the research problem, questions, objectives, and positionality. The research methods, sampling procedure and data collection tools used in this study are outlined in this section. According to Saunders et al. (2019), a case study is a research approach that pragmatically explores a specific contemporary phenomenon within its original context. This study has therefore used an embedded case study to gain comprehensive viewpoints and insights of the research problem and obtain a desired range of data to address the research aim and objectives. An embedded case study refers to a situation where the examination level is not limited to the main organisation, but also extends into relevant sub-units (Saunders et al., 2019). Although the study focuses on investigating

Eskom's energy Generation Division as the main case study, five Eskom Business Units (power stations) have been selected to make up embedded case studies. Singh (2019) and Saunders et al. (2019) classify research purpose as exploratory, descriptive, and explanatory. This study has used an exploratory research purpose as it is flexible and allows the use of mixed research methods such as interviews, questionnaires, and participant observations. In line with the pragmatism research approach, the exploratory research purpose used in this study assisted in acquiring relevant insights using various data collection methods to better assess the climate change and energy security nexus in the South African context.

3.4.1 DESCRIPTION OF THE RESEARCH SITE

This study was conducted at Eskom Generation Division as the main case study area. Eskom Generation Division has a total of 29 power plants consisting of technologies such as coal-based, hydroelectric, pumped storage scheme, gas turbines, nuclear, and renewable energy. Fifteen (15) of the 29 power stations are coal-based power plants and they form the baseload for Eskom Generation fleet (Department of Energy, 2019). To obtain an in-depth understanding and analysis of the research problem, this study selected five of the 29 Eskom power stations as the embedded case studies for detailed exploration. The five power stations were selected through purposive sampling procedure, considering their diversity in terms of energy generation technology (hydropower, hydro-pumped storage scheme, coal-based power plants), diversity in terms of geographical locations and ultimate regional weather distribution (Mpumalanga, Limpopo, Northern Cape, KwaZulu-Natal, and Western Cape Provinces), and lastly their diversity in terms of age of the plant (some are new builds while others are old). The above range presented a rare opportunity for this study to collect extensive data to understand the impact of climate change on both new and old power-generating plants located at significantly different geographical areas with different energy generation technologies. For example, the newly built Medupi Power Station is considered a new technology with better climate change adaptation techniques compared to the old Kriel Power Station. Similarly, the new Ingula Hydro Pumped Storage Scheme is a better station when compared with the old Gariep Hydro Power Station. These sites have certainly helped the study to collect diverse data to advance rich correlations and arguments in relation to the climate change and energy security nexus. Additional details associated with the embedded case studies (power stations) are briefly discussed below:

Embedded Case Study 1: Kriel Power Station is an old coal power plant located within the Mpumalanga highveld area. The power station has been operating for over 40 years. Kriel emits a significant amount of CO_2 as its technology does not have mitigation measures to reduce gaseous emissions. Kriel Power Station consumes a significant amount of water for cooling, steam generation, and ashing. This station was selected as one of the five embedded case studies to understand the effects of changes in climatic conditions on coal energy production; it was used as a representative case for several old Eskom power stations operating in Mpumalanga and other regions in South Africa. Kriel as a case study provided an in-depth analysis of existing coal power stations' climate change-resilient mechanisms. Refer to Figure 3.1 below to view Kriel Power Station's location and generating capacity.

Embedded Case Study 2: Medupi Power Station is one of Eskom's two new coal power plants. It is in a very hot region of Lephalale, Limpopo Province. It uses a significant amount of water for gaseous emission control and steaming. As newly built, it was included in the study to provide an in-depth understanding of the contribution and vulnerability level of new built plants to climate change effects. Refer to Figure 3.1 below to view Medupi's location and generating capacity.

Embedded Case Study 3: Ingula Pumped Storage Scheme is Eskom's largest power station among the hydroelectric and pumped storage scheme stations. It is located in the Drakensburg area, in the KwaZulu-Natal Province. Ingula is a newly built clean energy technology station that relies on water flow from the feeder stream to generate power. The inclusion of Ingula in the study was to understand the effects of climate change on clean energy technologies in KZN and other regions, and the ideal adaptation strategies. Refer to Figure 3.1 below to view Ingula's location and generating capacity.

Embedded Case Study 4: Gariep Hydroelectric is a station located in a province that has recently been experiencing drought, Northern Cape. It also relies on running streams to generate energy. The reason for its inclusion in the study was to understand the effect of climate change in Northern Cape and other regions, and to determine if hydroelectric technology will still be viable in the future. Refer to Figure 3.1 below to view Gariep's location and generating capacity.

Embedded Case Study 5: Palmiet Pumped Storage Scheme is located in the Western Cape Province. Palmiet also relies on running streams to generate power. Palmiet is an old power station that has been providing energy to the grid for years. The inclusion of Palmiet in the study was to gain an in-depth analysis of the climate change effects on hydropower systems in Western Cape and other regions. Refer to Figure 3.1 below to view Palmiet's location and generating capacity.

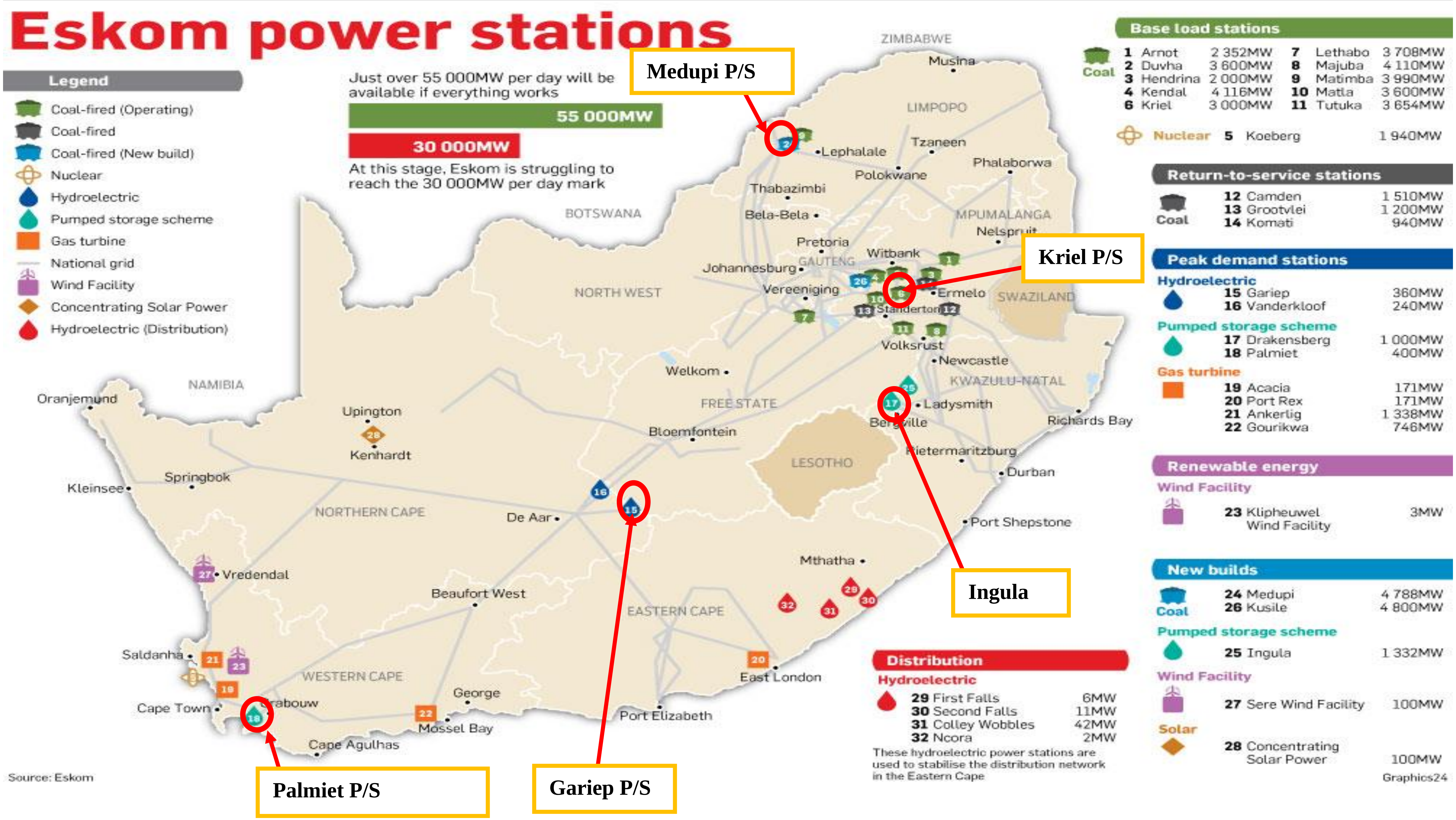


Figure 3.1 Locations and generating capacity of Eskom power stations

Source: Eskom (2013)

3.4.2 STUDY POPULATION AND SAMPLING PROCEDURE

(i) *Study population*

According to Majid (2018), a study population is a subcategory of a target population comprising individuals with common characteristics. The sample of the current study was selected from the study population as it is often impractical to include every person within the target population (Majid, 2018). The perceptions on the climate change and energy security nexus gathered from the sampled participants were then used for generalisation of the research findings. The study population for this research primarily included all the employees working at five embedded case studies: Eskom power stations such as Kriel, Medupi, Ingula, Palmiet and Gariep. The estimated number of employees working at these power stations is approximately 1500, most of whom are technical personnel working in departments such as Operating, Engineering, Maintenance and other supporting departments. In addition to these, the researcher also identified other personnel who formed part of the study population, such as relevant environmental practitioners from other Eskom business units, officials from the Department of Forestry, Fisheries and the Environment (DFFE), Department of Water and Sanitation (DWS), Nkangala District Municipality, environmental activists (NGOs), knowledgeable environmental practitioners from other industries, e.g. mines, SASOL, subject matter experts from professional societies, academia, environmental consultancy, and any other personnel from institutions not mentioned above (refer to Table 3.2).

(ii) *Sampling procedure for human participants*

Purposive sampling was used as the primary sampling procedure to identify participants for this study. Purposive sampling is a procedure in which the investigator uses own judgement to sample relevant participants deemed knowledgeable to share in-depth information about a particular phenomenon under study (Teddlie & Yu, 2007 and Etikan, et al., 2016). A multi-stage strategy of purposeful sampling involving criterion, expert and snowball sampling techniques was used for data collection from a range of sources, including people, webinars, and existing records, to ensure that a broad spectrum and different angles were explored (Palinkas et al., 2015). Taking into account the challenges and dynamics of the climate change and energy security nexus, it was important for this study to use multi-stage sampling to obtain an in-depth understanding of the dynamic perspectives relating to the characteristics, actions, practices, occurrences, qualities, and circumstances of the climate change-energy security nexus. The purposive sampling method was also in accord with the researcher’s positionality (pragmatism) and the adopted research method (mixed research method). A total of 220 participants from various organisations, as identified in Table 3.2, were selected through purposive sampling. As a secondary sampling procedure, snowball sampling was also used to identify participants for this study. Snowball sampling is a technique in which participants recruit others from their network, and this process is repeated until the desired sample size is reached.

Participants of the study were purposefully selected using the following eligibility criteria: all race and genders from the age of 18 and above, with a minimum of three (3) years' experience on South Africa's climate change and energy security nexus topic. An experience filtering database was established to ensure the effectiveness of the eligibility criteria for potential research participants within and outside of Eskom. For Eskom participants, internal inventories of Generation and Sustainability environmental practitioners/specialists, technical managers, plant engineers, plant maintainers and operators were sourced from HR and meetings' distribution lists. Participants with adequate experience and knowledge were then selected using their job profiles and experience on the topic. Some participants, whose knowledge of the topic was unknown, were contacted to verify their eligibility and level of knowledge before inclusion in the sample.

This process also led to the identification of additional participants with in-depth knowledge and experience via snowball sampling. For participants outside Eskom, relevant meetings' distribution lists were requested from the convenors/organisers of such meetings, leading to the identification and selection of participants from other industries, regulatory institutions, expert consultancies, and environmental consultancies. The study also utilised existing work and academic-related networks to purposefully identify a significant number of participants from other industries (environmental practitioners, regulators, engineers, subject matter experts, academic professionals, etc.) and environmental consultancies for inclusion in the research sample. All participants were asked to share their years of experience on the topic, and all had more than three years of experience.

Using purposive sampling procedure, the following sample size was selected from the study population; refer to Table 3.2 below for detailed description of the sample size, characteristics and techniques.

Table 3.2 Sample size and sample selection justification

Sampled participants' industry	Research objectives applicable	Data collection instrument used	Justification of a sample frame	Sample Size
Participants from five case studies (include Environmental Practitioners and Engineers)	*iii,iii,iv and v*	Interview guide & Questionnaire surveys	**Characteristics:** Environmental practitioners and engineers from Kriel Power Station, Medupi Power Station as well as Peaking Power Stations (Ingula, Gariep, and Palmiet) were included in the study for their perspectives and experiences on the actual and potential climate change effects in their respective power stations. All the sampled participants had vast experience on the influence of climate change on the energy generation processes as they have been involved in the development of the climate change risk assessment and adaptation strategy at their respective stations. **Technique:** Purposive sampling's *criterion technique* was used to select participants in this segment. While the five case studies have over 100 engineers working under different engineering sections, about 15 engineers who were involved in Auxiliary and Process engineering activities were purposefully sampled. The five case studies had a total of 15 environmental practitioners who were all included in the sample. Therefore, a total of 30 participants were identified from the five case studies under this segment. All the 30 participants selected to participate in the study were then assessed through employer's experience inventory and found to be meeting the eligibility criteria (i.e. residing in South Africa with three years' experience related to the research topic).	**30** participants
Environmental Practitioners (other Eskom coal Power Stations)	*i,ii,iii,iv and v*	Interview guide & Questionnaire surveys	**Characteristics:** Environmental practitioners are responsible for monitoring the climate variabilities together with their direct and indirect impact on energy production processes at the coal-fired power stations. They have also been involved in the development of Eskom's climate change risk assessment and adaptation strategy over the years. **Technique:** Purposive sampling's *criterion technique* was used to select participants in this segment. The selection technique was simple and straightforward as all the identified 50 (out of a total of 50)	***50*** *participants*

			environmental practitioners from other generation plants were included in the sample. The experience threshold of 3 years and more on the research topic and their residence in South Africa was a key eligibility criterion used for participants' selection.	
Sustainability Centre of Excellence (CoE)	*i,ii,iii,iv and v*	Interview guide, participant observation & Questionnaire surveys	**Characteristics:** Eskom's Sustainability Centre of Excellence comprises of professionals with in-depth knowledge related Air Quality, Water Management, Coal Management, Environmental Impact Assessments, etc. The aforementioned professionals have been part of the development and implementation of Eskom's climate change and energy security adaptation strategy. They have very rich views related to Eskom's contribution towards climate change as well as the impact of climate change on Eskom's energy system and energy security. They were purposefully selected to share their rich experience gained over the years of being involved in the programme. **Technique:** *Criterion sampling technique* was utilised to select and include all 30 identified participants to form part of the sample. The experience inventory of the CoE personnel was requested from Human Resource to assess their participation eligibility. All 30 participants were found to be positively matching the eligibility criteria and were therefore included in the sample.	***30*** *participants*
Eskom RT&D & Climate Change Research Team	i,ii,iii,iv and v	Interview guide, participant observation & Questionnaire surveys	**Characteristics:** Professionals working at Eskom's Research, Testing and Development (RT&D) as well as professionals who have been directly working at Eskom's Climate Change Research programme were also purposefully selected to take part in this study. The selection of professionals from R, T&D was guided by the participants' involvement in Eskom's climate change adaptation strategy development. The selected participants also possessed knowledge on potential technologies which can be used to abate high emissions of carbon from the coal power plants as well as the measures that the stations may implement to minimise the effects of climate change at Eskom's 29 power-generating plants. Having been directly involved in the process of identifying aspects related to climate change of Eskom's energy production and security, the participants from climate change research team were included to get their insights on the	***15*** *participants*

			feasibility of the adaptation plan developed and also the progress made by Eskom to implement the strategy so far. **Technique:** *Purposeful expert technique* was used to select participants in this segment. RT&D has over 50 employees responsible for various environmental management disciplines. Eskom's database of climate change experts was therefore used to identify the participants in this category. In line with the eligibility criterion, only 15 participants were identified as experts and therefore included in the sample.	
Authorities /Government	i,ii,iii,iv and v	Questionnaire surveys	**Characteristics:** These professionals are based at the national government (DWS & DFFE) and they possess the knowledge of the government's policies and regulations with regard to climate change and energy security nexus. Participants in this segment also understand the challenges experienced by energy generators and regulators in relation to policy implementation dilemmas as well as the pressure exerted to the regulators and energy generators by environmental activists to effectively respond to climate change effects. Their climate change and energy security policy perspective was critical to the study. **Technique:** *Purposeful criterion technique* were used to select participants in this segment. Combined, DWS & DFFE have over 30 personnel working with energy generators. However, only 10 participants were purposefully selected based on their involvement and knowledge on climate change – energy security topic. Suitable personnel from both the departments were selected from their climate change webinars/commissions' attendance registers. Eligibility criteria was then used to qualify all the selected participants.	***10 participants***
Environmental Practitioners from other Industries outside Eskom	*iii,iii,iv and v*	Questionnaire surveys	**Characteristics:** The study also purposefully selected environmental practitioners from organisations such as the coal mines, SASOL, Petroleum refineries, etc., who have knowledge and interest on climate change effects on energy security. As most coal mines supply coal to Eskom power plants, the practitioners from those organisations were asked to share their views on the current primary source of	***20 participants***

			electricity generation in South Africa. The variety perspectives received through mixed research methods provide a diversity of data to the research which in turn increases the data reliability. **Technique:** *Criterion and snowball techniques* were used to select participants in this segment. The researcher selected 15 participants from the regional and national air quality meetings' attendance registers whose defined roles suggested that they were knowledgeable on climate change and energy security risk. The participants were then contacted via email to verify their interest and eligibility to participate in the study. Five other participants were snowballed to the study by other participants; this was then followed by a successful eligibility test.	
Subject Matter Experts from Environmental Professional Societies, Academia, Environmental Consultancy, etc.	i,ii,iii,iv and v	Interview guide & Questionnaire surveys	**Characteristics**: Subject matter experts from South African Council for Natural Scientists, environmental consulting firms, academia, etc., whose work and experience is aligned with the research topic were purposefully included in the study to get their well-researched views on the energy security and climate change nexus. Some of the aforementioned experts are personnel who have been undertaking their research within Eskom coal-fired power stations on climate change and energy generation processes. **Technique:** E*xpert and snowball sampling techniques* were used to select participants in this segment. A total of forty (40) experts (include: professors, Doctor of Philosophies, lectures, tutors, etc.,) known to the researcher were selected based on their years of experience on matters related to the climate change and energy security. Eskom library's record register was used to identify some of these experts who historically worked on the subject. A total of five (5) expert participants were snowballed to the study through referrals. A total of 45 participants were sampled.	***45*** *participants*
Other – Eskom	i,ii,iii,iv and v	Interview guide, participant observation	**Characteristics:** There were also other professionals working for various Eskom sections such as Water Management, Operating and Coal Management Sections were also included in the study based on their knowledge of energy generation aspects that are significant threatened by climate change variabilities.	***20*** *participants*

		& Questionnaire surveys	These participants had vast knowledge on key input materials (water, coal, fuel oil, etc.) and influencers (temperatures, precipitation, etc.) on the coal energy production process. **Technique:** All the participants under this segment were snowballed to the study by other participants based on their rich knowledge of the research topic. All the 20 participants were screened for eligibility before being accepted as part of the sample.	
TOTAL				***220***

(iii) *Sampling procedure for existing records/data*

This section outlines the process of collecting the existing data used in the study.

a) Carbon Emissions Data from Eskom Power Stations (Eskom RT&D, 2020):

To evaluate the impact of Eskom's coal-based power plants towards greenhouse gas emissions and climate change, data on carbon dioxide (CO_2) emissions was purposely selected for inclusion in the study. The R, T & D department of Eskom generated this CO_2 emissions data over a 10-year period for each coal power plant. The data covers the period from the 2009/2010 financial year to the 2019/2020 financial year. The CO_2 emissions were calculated using a mass balance, taking into account unburnt carbon in the ash produced from pulverised fuel boilers. This unburnt carbon was obtained from ash analysis for combustible matter. The emission factor calculation for coal power plants is shown in the following equation (Eskom RT&D, 2020):

$$CO_{2COAL}\ \mathrm{EF}\frac{kg}{ton} = \left(C_{AF} - \frac{C_{ASH} * A_{COAL}}{100 - C_{ASH}}\right) * 3.67 * 10$$

Where,

$CO_{2COAL}\ \mathrm{EF}\frac{kg}{ton}$ is the Carbon Dioxide emission factor for coal;
C_{AF} is the percentage total carbon by mass in the coal as fired.
C_{ASH} is the percentage unburnt carbon by mass in the ash; and
A_{COAL} is the percentage ash by mass in the coal.

The 10 in the formula converts emissions from kg per 100 kg of coal to kg per 1 ton of coal.

The above equation was integrated into a Microsoft Excel spreadsheet to automatically calculate CO_2 emissions from the monthly coal tonnages burnt in the boilers.

A mass balance method was employed to determine CO_2 emissions from fuel oil combustion at coal power plants, with a carbon conversion assumption of 100%. The CO_2 emission factor from fuel oil combustion was calculated using the following formula (Eskom RT&D, 2020):

$$CO_{2LIQUID\ FUEL}\ \mathrm{EF}\frac{kg}{ton} = C_{LIQUID\ FUEL} * 3.67 * 10$$

Where,

$C_{LIQUID\ FUEL}$ is the percentage carbon by mass in the liquid fuel (diesel/kerosene/fuel oil
The 10 in the formula is to convert the emissions from kg per 100kg of fuel to kg per 1 ton of fuel.

The equation above was integrated into a Microsoft Excel spreadsheet to automatically calculate and convert monthly fuel oil tonnages into CO_2 emissions figures, based on the manually entered data.

b) <u>Climate change projections data for South Africa (Eskom RT&D, 2014)</u>

The study used existing climate change projection data which predicted climate variabilities in various regions of South Africa. The data collected by Eskom RT&D in partnership with the Council for Scientific and Industrial Research (CSIR) was utilised; this data included the period from 1971 to 2000 as the baseline/reference data and the period from 2021 to 2050 as the climate variabilities projection data. The data reflects the expected impact of climate change variability on different regions of South Africa. The inclusion of the climate variability data aimed to depict potential weather patterns that could result in energy generation disruptions, leading to energy insecurity in South Africa. The methodology for collecting the data is outlined below.

A high-resolution regional climate model (RCM), the conformal-cubic atmospheric model (CCAM) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (McGregor, 2005), was applied in order to obtain simulations of present-day and future climate over southern Africa. CCAM is a variable-resolution global model - rather than a limited-area model as in the case of most RCMs. The variable-resolution approach avoids the problems that limited-area models experience with the reflection of atmospheric waves at their lateral boundaries. In order to obtain the high-resolution projections of future climate change over southern Africa, the model was first integrated at quasi-uniform resolution of about 2° (about 200 km) in latitude and longitude. These simulations were forced with the bias-corrected sea-surface temperatures (SSTs) and sea-ice fields of the six different CGCMs used in AR4 of the IPCC, for the period 1961-2100, and for the A2 emission scenario of the Special Report on Emission Scenarios (SRES) of the IPCC. The model was subsequently integrated in stretched-grid variable resolution mode over southern Africa and tropical Africa, with the spatial resolution over these regions being about 0.5° (about 50 km). The high-resolution simulations were nudged within the 2° simulations, applying the digital filter at a length scale of about 4000 km. All the simulations have been performed using the computer clusters of the Centre for High Performance Computing (CHPC) in South Africa (Eskom RT&D, 2014).

c) Water consumption figures across Eskom power stations (Eskom, 2021)

Data on water consumption at Eskom power stations was used in this study to shed light on the scale of water usage at Eskom's coal power plants. The data was collected to provide an insight into the significance of water resources in energy production and to understand the relationship between climate change, water, and energy security. The most recent data on water consumption from various power stations was collected and analysed for the period from April 2020 to March 2021, covering a 12-month span. This data was chosen as it provides valuable perspectives on the relationship between water and energy security in the context of climate change.

In terms of data collection methodology, each power station has raw water reservoirs, that receive water from various water resource schemes, such as Usuthu, Vaal, and Komati, among others. The water is measured through a flow meter before it is stored in the reservoirs. On a monthly basis, the power stations submit their water measurement figures to Eskom's Water Management Centre of Excellence for consolidation. The consolidated report was the data source used in this study.

d) Rainfall and Temperature data from 2010 to 2021 (SAWS, 2023)

Raw monthly rainfall and temperature data, dating from year 2010 to 2021, was purposefully included in the study to depict a precipitation and temperature distribution trend within regions wherein most of Eskom's coal power plants are located. The sampled data was mainly for Nkangala district municipality (Witbank SAWS monitoring station) wherein Duvha, Arnot, Hendrina, Komati, Kendal, Kusile, Kriel and Matla coal power plants are located, and Waterberg district municipality (Lephalale SAWS monitoring station) wherein Medupi and Matimba coal power plants are located (also refer to Figure 3.1 above for geographical location of these plants).

SAWS rainfall data is measured at 08:00 SAST. The rain accumulated in the bucket of the rain gauge is poured into a specially calibrated measuring glass and the millimetre reading is recorded, whereafter the water is discarded. The rainfall measured between 08:00 SAST yesterday and 08:00 SAST today is recorded against yesterday's date on the database. On the other hand, thermometers embedded in the weather monitoring stations' dataloggers are used to read and record ambient temperature (SAWS, 2023).

3.4.3 DATA INSTRUMENTATION

This section outlines the tools utilised to collect data during the study. Quantitative and qualitative data collection approaches, which included interviews, questionnaires, participant observations, and existing records, were employed in this study.

(i) *Questionnaire surveys*

Close-ended questionnaire surveys constituted the primary data collection method, as many knowledgeable participants selected for the study preferred this approach over interviews. Closed-ended questionnaire were used, taking into account that, the sampled participants were well knowledgeable on the topic and could easily and forthrightly provide informed and reliable answers to the survey statements. The questionnaire survey also made it possible for the researcher to reach as many knowledgeable participants as possible. The questionnaire was designed with an open space at the bottom which invited any additional qualitative insights; and most of the participants added qualitative views on this space, making the tool to even be more effective in gathering both quantitative and qualitative data. Furthermore, the closed-ended questionnaire also made it convenient for the researcher to quantify and analyse collected data with ease. Considering the large sample selected to participate in the research, closed-ended questions were useful in ensuring that participants' responses are generated and analysed quickly. Additionally, the timing of the fieldwork during the peak of the COVID19 pandemic (August 2020 to March 2021) encouraged the use of questionnaires, which could easily be administered through electronic channels such as email and file-sharing platforms (e.g., Drop-box, ZendTo).

Participants were invited to complete a structured, closed-ended questionnaire survey. The introductory section of the questionnaire included an information sheet outlining the study, the participants' rights, and the ethical requirements for handling their completed survey. Section A of the questionnaire required the participants to provide information on their institutional association, experience related to the topic, and optional demographic data. Section B comprised 25 Likert-style rating scale statements and questions developed with consideration of the research objectives and informed by literature review, supervisor guidance, and personal experience. A five-point Likert-Scale for the 25 items was used. The questionnaire was structured to gather in-depth perspectives from participants on the nexus between climate change and energy security. Some 180 questionnaires were administered to the sampled personnel via email, with automatic reminders and monthly follow-up emails for outstanding responses. The email channel proved to be an efficient method of administering the questionnaires, with a number of participants also completing the survey through snowball sampling as indicated in Table 3.2. These participants who participated through snowball sampling met the eligibility criteria.

(ii) *<u>Individual participants interviews</u>*

In order to gather qualitative data for triangulation, semi-structured interviews were conducted with selected participants. The development of the interview guides involved the creation of themes and questions by the researcher, which varied between participants (Saunders, 2009). The interview questions/guide were designed by the researcher in accordance with the research objectives. A participant observation sheet and consent forms were developed to accompany the interview questions/guide. Interview guide was created, consisting of two sections: A for demographic information and B for the semi-structured interview questions. The guide included 15 questions, with 12 of them being open-ended and three being close-ended dichotomous questions, allowing for additional comments. The guide was submitted to five quality assessors for review before administration to the participants, all of whom endorsed it as a comprehensive tool.

To comply with social distancing measures during the COVID-19 pandemic, all interviews were conducted electronically through email. Monthly follow-ups were made with participants who did not respond within the first four weeks. A total of 40 participants were invited to participate in the semi-structured interview. The 40 interview participants also formed part of the 220-sample size presented in Table 3.2 above. The reason for selecting the interview participants from the 220-sample size was to triangulate and validate the data received from the questionnaire survey participants to ensure data certainty. All participants were comfortable with the electronic format and returned their responses to the researcher via email.

(iii) *<u>Participant observations</u>*

From June to September 2020, the researcher participated as an observer in a series of weekly Sustainable Development Goals webinars hosted by Eskom's Climate Change Department. Participants from various industries were included in the webinars. The researcher was granted permission to observe the participants' views, with certain conditions in place, including not recording the proceedings or participant names. Instead, pseudonyms were used to protect the identities of the participants and their organisations. The researcher captured the views of the participants regarding climate change and energy security during the observations.

(iv) *Existing records*

The study utilised three sets of pre-existing records as the data sources needed to achieve its objectives. Firstly, the carbon dioxide emissions data generated by Eskom RT&D (2020) for all coal power stations was employed to assess the impact of Eskom's power stations on greenhouse emissions over a decade, from 2009/2010 to 2019/2020. Secondly, the data relating to climate change variables (rainfall and temperatures) generated by Eskom RT&D for the period from 1971 to 2000 as a baseline and 2021 to 2050 for projection was utilised to calculate the potential impact of climate change in different regions of South Africa. The research also relied on the pre-existing data regarding water consumption in various Eskom power stations to evaluate the potential impacts of reduced precipitation on energy production as a result of climate change; the water usage data was sourced from the recent 12-month period (April 2020 to March 2021). Lastly, the study also relied on the raw monthly rainfall and temperature data, dating from 2010 to 2021, which was procedurally requested from SAWS.

3.4.4 DATA ANALYSIS

The procedure for data analysis, as outlined by Marshall and Rossman (1990), involves organising, structuring, and making sense of research data that has been collected. Both qualitative and quantitative data analysis methods are used in this process. Qualitative data analysis involves describing data in order to gain insight into their meaning, while quantitative data analysis utilises statistics to convert data for interpretation and decision-making purposes (The Open University, 2021). The sections below describe the data analysis methods used in this study.

(i) *Questionnaire survey data analysis*

The electronically received questionnaire surveys were assigned unique numbers and stored in a computer hardware folder named Survey Responses. A quality check was then conducted to identify any problematic questionnaires, including those that were incomplete or had errors in completion, such as multiple ticks for the same statement. The quality check also verified the participants' eligibility to participate in the study. All the questionnaires were found to have passed the quality check and were transferred to another folder named Checked Questionnaire Survey Responses. After the quality check, the next step involved coding each questionnaire and saving it in the computer. The questionnaires were coded in accordance with the relevant research objectives and/or themes to allow for generalisation. Participants were also categorised based on their industries for triangulation purposes.

Following the quality assurance of the responses and their storage in the computer folder, the process of transferring the data from the questionnaires into Microsoft Excel (2016) began. A field with 148 rows was established in an Excel spreadsheet to document the pseudonyms of the 148 participants who submitted completed questionnaires. An additional 25 fields were added to capture participants' responses to all 25 statements, resulting in a total of 26 fields. The final field captured any additional comments from the participants. The first field, containing the reference codes or unique identifiers for the participants, was colour-coded according to the industry of each participant. This was a useful aspect of the data analysis, providing insight into perspectives per industry. This computerised method was deemed useful for promoting accuracy in data capturing and ease of automation. The 148 rows under 25 columns captured participants' responses in a Likert scale format (1 to 5), with Section B of the questionnaire containing 25 Likert-style rating scale statements. **The scale was structured as follows: 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; and 5 = Strongly Agree.** A spot-check of 25 randomly selected participants' responses was conducted to verify the accuracy of the data transfer from the questionnaires to the Microsoft Excel spreadsheet, and all was found to be accurately recorded.

The subsequent step involved the generation of statistical data. The data captured in the Excel spreadsheet was analysed by sorting and filtering to understand the responses to the 25 statements from each of the 148 participants. The overall responses for each questionnaire statement were recorded into 25 mini data tables using the same Excel spreadsheet, showing the number of participants who agreed, disagreed, or were neutral on each statement. The researcher used these mini tables to generate fieldwork evidence and findings by means of charts, graphs, and other visual aids. Qualitative inferences were also derived from the survey data. The qualitative data captured by participants in the additional comments column was quoted in the empirical evidence chapter, while some was summarised into text tables.

As a competent user of Microsoft Excel for statistical data generation, the researcher utilised the programme to accurately and efficiently analyse the data. The use of computer hardware and Microsoft Excel allowed for adequate data storage and automation. The analysis methodology was reliable and easily verifiable.

(ii) *Analysis of semi-structured interview data*

All interview participants preferred documenting their perceptions instead of undergoing oral interviews. The responses of all participants were stored in a computer system under the folder

Semi-Structured Interview Responses. The completed interview guides were assigned unique identifiers and coded by the participant's industry. A total of 23 completed semi-structured interviews were returned to the researcher electronically. After the responses were stored, they were evaluated for quality and compliance with eligibility criteria. All the interview responses received were found to be compliant and contained a rich dataset. After quality control was completed, the interview data was entered into a Microsoft Excel spreadsheet, containing 17 fields (columns). The first field captured the participant's unique identifier; the next 15 fields captured the participant's responses to the 15 interview questions, and the last field captured any additional comments from the participants. The unique identifiers were also colour-coded to represent the participant's industries.

In line with the researcher's pragmatism research approach, a thematic network data analysis was adopted to examine and interpret the data collected through semi-structured interviews. The researcher coded all the data to uncover diverse perceptions in the findings. The qualitative data was also interpreted into statistical inferences and used for triangulation. Patterns and themes from the interview data were analysed and transformed into statistical packages. The interview data, both in text and statistical format, was then used to generate citations, tables, graphs, charts, and the like.

(iii) <u>Analysis of participants' observation data</u>

Data collected from participants observed during Eskom's Sustainable Development Webinars was recorded as text or qualitative data in a Microsoft Word document. The transcript was saved in a computer system under the folder, Participants Observations Record. The recorded text was cited in the findings section to triangulate data from other sources.

(iv) <u>Data analysis of existing records</u>

This study utilised three sets of existing data, comprising Eskom's carbon dioxide emissions data, water consumption data, and weather projection data. The carbon dioxide emissions data was sourced from Eskom's RT&D division and was already captured in Microsoft Excel spreadsheets. The quantitative data, which was recorded in tonnages for the period of 10 years (from 2009 to 2020), was obtained for each Eskom business unit (i.e. individual power stations). The data was saved under the project folder named Existing Records_CO_2 Data and was consolidated into a single Microsoft Excel spreadsheet in order to facilitate interpretation. The CO_2 data was then coded by power station names to evaluate the impact of technological advancements on carbon emissions.

The second dataset employed in the study was the 2020/2021 financial year water consumption data, covering a 12-month period. This data was received from Eskom's Sustainability Division in Microsoft Excel format and was saved under the folder named Existing Records: Water Consumption Data. The water consumption data was saved and analysed by power station name over a one-year period to understand water usage and its potential impacts from climate change. The data was presented in a quantitative format and was used to generate tables, graphs, charts, and make qualitative inferences.

Thirdly, the study utilised existing climate change projection data, which comprised of maps and quantitative data related to temperature and rainfall changes. This data was saved in its original PDF file format under the folder named Existing Records: Climate Change Project Change data. The data was used to interpret the effects of climate variability on energy processes and was presented in the form of tables, graphs, and charts. Some of the existing data, such as the climate projection maps, was used unaltered in the study to ensure that an adequate quantity of data was collected for meaningful triangulation and generalisation. ANOVA and Regression Models are other statistical packages used by the current study to generate the correlation and co-efficiency between CO_2e, water consumption and Gigawatt Hour Sent Out (GWh SO) data. Finally, the study used monthly historical rainfall and temperature distribution data that was provisioned by SAWS, dating from 2010 to 2021. The two sets of weather data were synthesized to annual figures which were then used to generate the eleven-year graph line trend for analysis; and was then further interrogated in line with energy production output.

3.5 METHODOLOGICAL CONSIDERATIONS

Methodology is a vital aspect of any study, as it can significantly impact the quality of gathered data and ultimately the validity of the research findings, discussions, and conclusions. In this section, the methodology used in this study is evaluated in terms of its robustness and its relevance to the research conclusions. The researcher adopted a pragmatist research method, which emphasises a practical approach to data collection. This was deemed appropriate given the exploratory nature of the study, as it allows for a flexible approach to data collection, using various means to achieve the research goals and objectives. To further validate this choice, the researcher completed the Heightening Awareness of Research Philosophy (HARP) quiz, which confirmed that the pragmatist methodology was most aligned with the researcher's positionality. This served to strengthen the methodology from the outset and ensure that the researcher was on the right track.

The methodology used in the research was strengthened through the selection of Eskom Generation Division as the main case study and five Eskom business units as embedded case studies. The uniqueness of these case studies, in terms of geography and type of operation, among other factors, facilitated the collection of a diverse range of perceptions. The use of a mixed research method, incorporating both quantitative and qualitative research approach, allowed the researcher to gather data from multiple sources, such as participant responses, existing records, and the administration of a questionnaire survey. The quantitative data (questionnaire surveys data) was triangulated with qualitative data obtained from semi-structured interviews and participant observations. The researcher ensured the validity of the data by having the data collection instruments reviewed by five experienced personnel before administering them to participants. A purposive sampling approach was used to select eligible participants, which was evident in the high response rate of 148 survey participants, with over 50% of them adding qualitative comments to elaborate on their responses.

A total of 29 participants were interviewed and observed, adding to the responses received from the questionnaire survey, resulting in a robust data triangulation. The participants represented various industries and roles, including the energy sector, academia, regulators, environmental consultancy, environmental professional bodies, and environmental practitioners, engineers, and consultants. The instruments used for data collection were well-suited for most participants and were administered through electronic means, considering the COVID-19 pandemic. The methodology used in the research was successful in gathering a sufficient amount of data from multiple sources, including surveys, interviews, participant observations, and existing records. The data triangulation ensured the validity of the collected data and the results were positive, yielding more than enough data for a detailed analysis.

One of the most critical aspects of research methodology is data analysis. It is essential that raw field data is analysed properly, otherwise, it could prove meaningless to the research findings. To ensure data accuracy, the researcher conducted quality checks on all the data received, including eligibility criteria and response completeness. The researcher employed Microsoft Excel software to analyse the quantitative data obtained from surveys. This software proved useful in generating statistical data, providing a simple and understandable interpretation of the field data. Additionally, Microsoft Excel was utilised to analyse qualitative data received from interviews as well as quantitative data from existing records. The researcher’s proficiency in using Microsoft Excel for data generation and interpretation further contributed to the level of accuracy and diligence during the data analysis phase.

CHAPTER FOUR

EMPIRICAL EVIDENCE

4.1 INTRODUCTION

This chapter presents the results of the study. It is an essential component of the research process, as it provides empirical evidence that enables the analysis and conclusions of the study to be tested. The findings presented in this chapter are derived from the data gathered during the fieldwork and are aligned with the strategic themes identified in the research problem and questions. As noted by JMU (2021), the results of a study should provide answers to research questions, be in line with the study's hypothesis, and highlight any surprising or relevant patterns in the collected data. In keeping with this understanding, Chapter Four is structured around the research questions presented in Chapter One.

The chapter begins by presenting the results of the investigation into the contribution of South Africa's energy sector to global carbon emissions. It then continues to explore the effects of climate change on South Africa's energy sector and energy security. In order to address the research question about the suitability and adequacy of South Africa's energy policy framework, the chapter also presents the results of the assessment on the effectiveness of the policy framework in guiding the transition to cleaner energy systems. The perceptions on the energy transition programme as a solution to dealing with the effects of climate change in South Africa are also presented in this chapter. The chapter concludes by presenting the participants' perceptions on the feasible measures that could be implemented to reduce carbon emissions from coal-based power plants.

The data presented in this chapter was gathered through exploratory research methods, including semi-structured interviews, close-ended questionnaires, participant observations, and existing records. The participants in the sample met the eligibility criteria as stated in Chapter Three, particularly with regards to their experience in the field of climate change and energy security. The average years of experience among the participants was 12.5 years. The results presented below represent a range of views from knowledgeable environmental practitioners, engineers, operators, etc., from power generation plants, professional experts from consulting firms, environmental practitioners from other industries such as the mines, experienced personnel from academia, and others.

4.2 ESKOM COAL-FIRED POWER STATIONS' CARBON FOOTPRINT AND INHERENT CHALLENGES RESULTING TO CARBON EMISSIONS

At the outset, the aim of the present study was to comprehend the extent of South Africa's energy sector's contribution to global carbon emissions. It was deemed necessary to gather perspectives on the presence and importance of carbon emissions from South Africa's energy sector, so as to establish a baseline reference dataset for the study. To this end, the research participants were solicited for their opinions on whether coal-generated energy is South Africa's main source of carbon emissions; see Figure 4.1.

	No, CFPS are not the main source of carbon emissions	I do not know	Yes, CFPS are the primary source of carbon emissions
%	7	5	88

Figure 4.1 Perceptions on the contribution of Eskom's coal-fired power stations (CFPS) into South Africa's carbon footprint
Source: Based on field survey (2021) – refer to Annexure A1 for raw data

Figure 4.1 indicates that approximately 88% of respondents identified coal-fired power stations (CFPS) as the main contributor to carbon emissions, whereas 7% were uncertain. An engineer from a CFPS provided further insight into the issue, explaining that *"coal, being predominantly carbon, reacts with oxygen in the air upon combustion to generate carbon dioxide, a greenhouse gas"* (Pers.com 2021a). The data displayed in Figure 4.1 supports the notion that Eskom's coal power plants do contribute to the greenhouse effect. During the Eskom's Sustainable Development Goals (SDGs) Webinar, a Senior Environmental Practitioner added a slightly different but relevant viewpoint, stating, "*carbon emission from coal burnt in households should not be underestimated. Most of the people in SA depend on road transport and vehicles produces lots of carbon that is contributing to climate change. When alternative energy is being considered, households and transport industry must also be considered*"- (Pers.com 2021Ag). In addition to the views provided in Figure 4.1, participants were also asked to share their perceptions on some of the inherent challenges that contribute to Eskom's carbon emissions; and these views are presented in Figure 4.2 below.

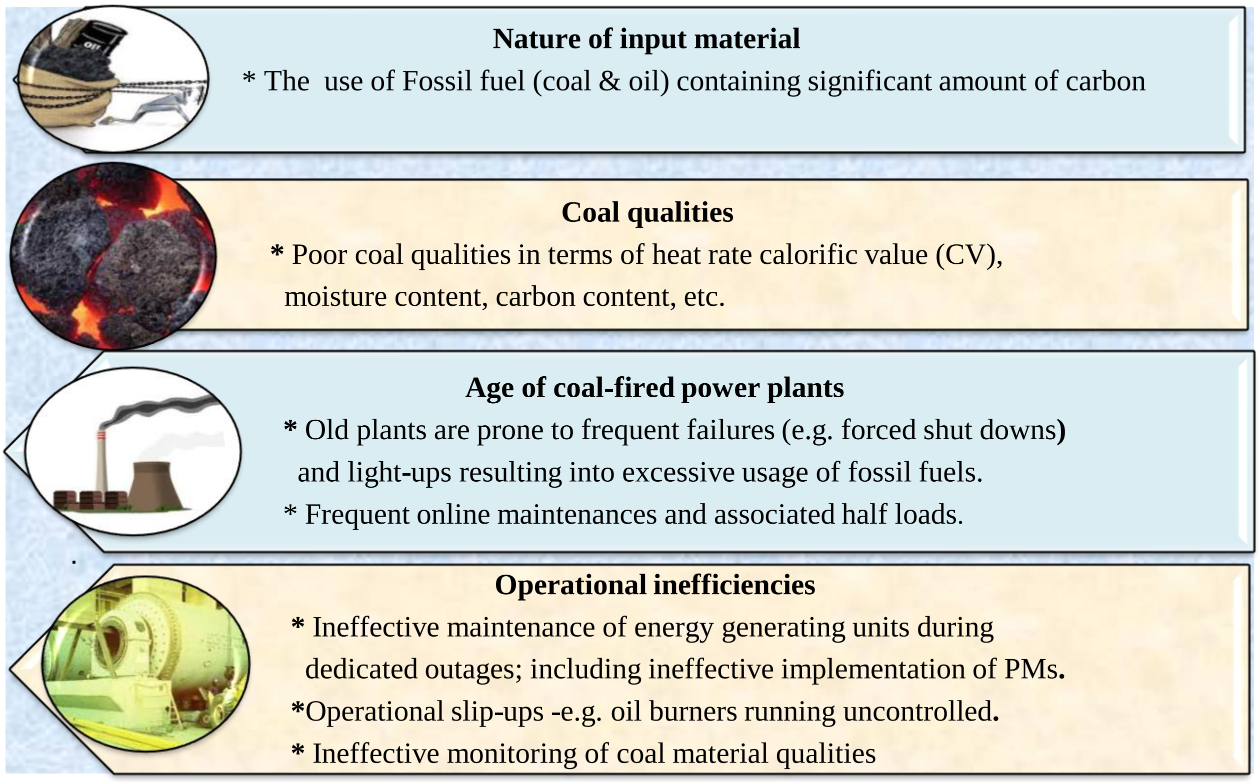


Figure 4.2 Perceptions on Eskom's inherent challenges contributing to carbon emissions
Source: Based on field survey (2021)

Based on Figure 4.2 above, key challenges to Eskom coal power plants that are significantly contributing to the power utility's carbon footprint include the nature of the input material (i.e., coal and fuel oil) which comprises of a large percentage of carbon. Participants also identified the old age of most Eskom's coal power plants as another challenge that result into frequent breakages and online maintenances, and therefore triggering high carbon emissions. Lastly, the issue of operational inefficiency was also identified as one of Eskom's issues contributing to high carbon emissions.

The participants' perspectives as depicted in Figure 4.1, were supplemented by an examination of existing records to assess the extent of Eskom's contribution to carbon emissions. The relative Carbon dioxide (CO_2) emissions vis-à-vis gigawatt hour sent out (GWh SO) data was used as a benchmark to evaluate Eskom's production process efficiency in the period of ten fiscal years. The empirical evidence of Eskom's relative CO_{2e} vis-à-vis GWh SO for a ten-year period is presented in Figure 4.3 below.

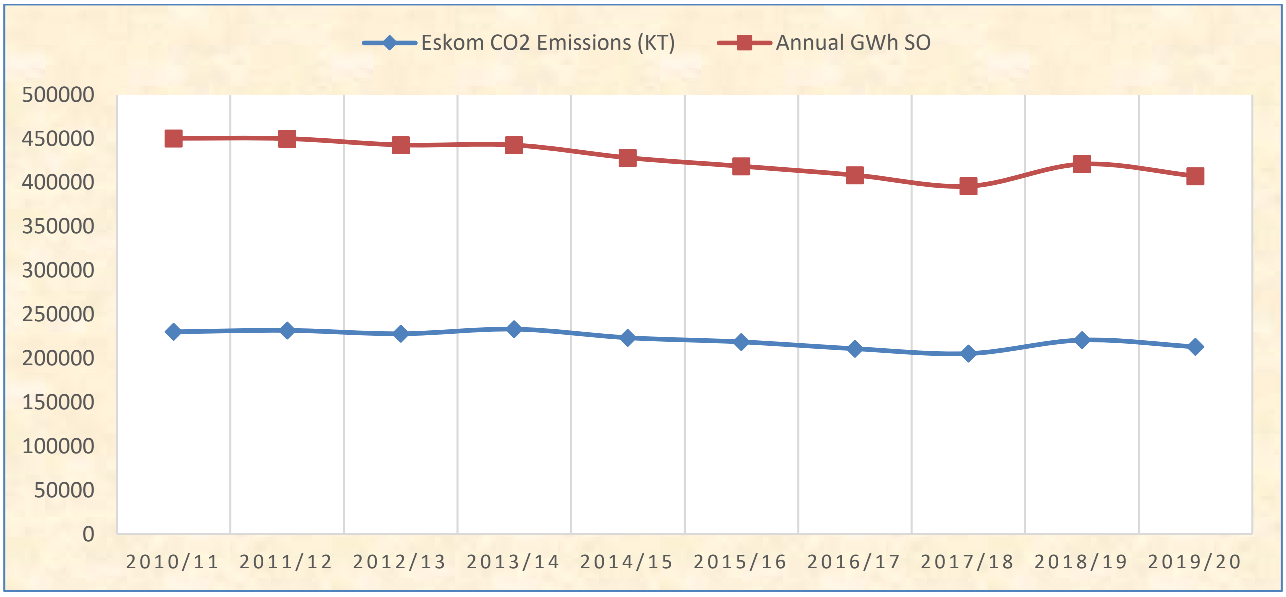


Figure 4.3 Eskom's coal power plants' CO2e vis-à-vis GWh SO for a ten-year period (2010/2011 to 2019/2020 financial years)
Source: Eskom RT&D (2021)

According to Figure 4.3, Eskom power generation plants emitted a total of **2 216 878 985** tonnes of CO_2 gas between April 1st, 2010 and March 31st, 2020 (120 months). Figure 4.3 also indicates that, in the ten-year period under scrutiny, carbon emissions in Eskom have increased as power production output increases and decreased as energy production decreases. The data presented in Figure 4.3 does not suggest that Eskom coal power plants have any effective decarbonization measure except for taking production load reduction; this is evident in Figure 4.3 wherein a drop in CO2e can only be witnessed when there is a drop in production of GWh SO. The Figure further illustrates a decline in CO_2 gas emissions from Eskom during the financial years 2014/2015 to 2017/2018, however, a sudden increase was noted in 2018/2019; the CO2e pattern also matches that of GWh SO. Over the 10-year period covered in this study, the total annual CO_2 gas emissions from Eskom never fell below 205 million tonnes. Figure 4.3 concurs with the participants' perceptions presented in Figure 4.1, demonstrating that Eskom's coal-fired power plants contribute significantly to South Africa's carbon footprint.

Table 4.1 below present the statistical correlations data to assure the strength of the linear relationship between GWh SO vis-à-vis CO2 Emissions as presented in Figure 4.3 above.

Table 4.1 Correlations of Eskom's energy production (GWh SO) vis-à-vis CO_2 Emissions (2010/11 to 2019/20 fiscal years)

		Eskom CO_2 Emissions (KT)	Annual GWh SO
Eskom CO_2 Emissions (KT)	Pearson Correlation	1	.914**
	Significance (2-tailed)		<.001
	No. of Years	10	10
Eskom's Annual GWh SO	Pearson Correlation	.914**	1
	Significance (2-tailed)	<.001	
	No. of Years	10	10

**Correlation is significant at the 0.01 level (2-tailed).

Source: Based on fieldwork data (2021)

Based on Table 4.1 above, the correlation significance (2-tailed value) is = 0.01. This statistical analysis implies that there has been a strong association between Eskom's Annual GWh SO and CO_2 emissions for the period from 2010/11 to 2019/20 fiscal years. Furthermore, a Pearson correlation coefficient of 0.914 implies that there is a positive strong association between GWh SO and CO_2 emissions during the period under scrutiny. The results in Table 4.1 and 4.2 are indicative of an energy system that is highly dependent on coal energy sources, and therefore associated with significant carbon emissions.

In addition to the correlation data depicted in Table 4.1 above, Table 4.2 below provides a deeper statistical performance co-efficiency analysis to describe the significance of correlation between CO_2e and electricity production (GWh SO).

Table 4.2 Performance Co-efficiency of Eskom's energy production (GWh SO) vis-à-vis CO_2 Emissions (2010/11 to 2019/20 fiscal years)

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T-test	Significance
1	(Constant)	48742.390	27190.223		1.793	.111
	GWh SO	.844	.132	.914	6.368	<.001

a. Dependent Variable: Eskom CO_2 Emissions (KT)

Source: Based on fieldwork data (2021)

The regression model results depicted in Table 4.2 above suggest that there was a linear relationship between CO_2 emissions and annual energy production output (GWh SO) in the period from 2010/11 to 2019/20 fiscal years (10 years). The GWh SO coefficient is at 0.914, which implies a positive strong relationship. Therefore, as Eskom's Annual GWh SO increases by one unit, CO_2 emissions also increases by 91.4%. As evident in Table 4.2, the regression model is statistically significant at

0.01. Being statistically significant at 0.01 (1%) means that there is a 99% assurance that this statistical test is true.

Additionally, participants were asked to express their views on the significance of South Africa's (Eskom) contribution to the greenhouse effect. The survey results are shown in Figure 4.4 below.

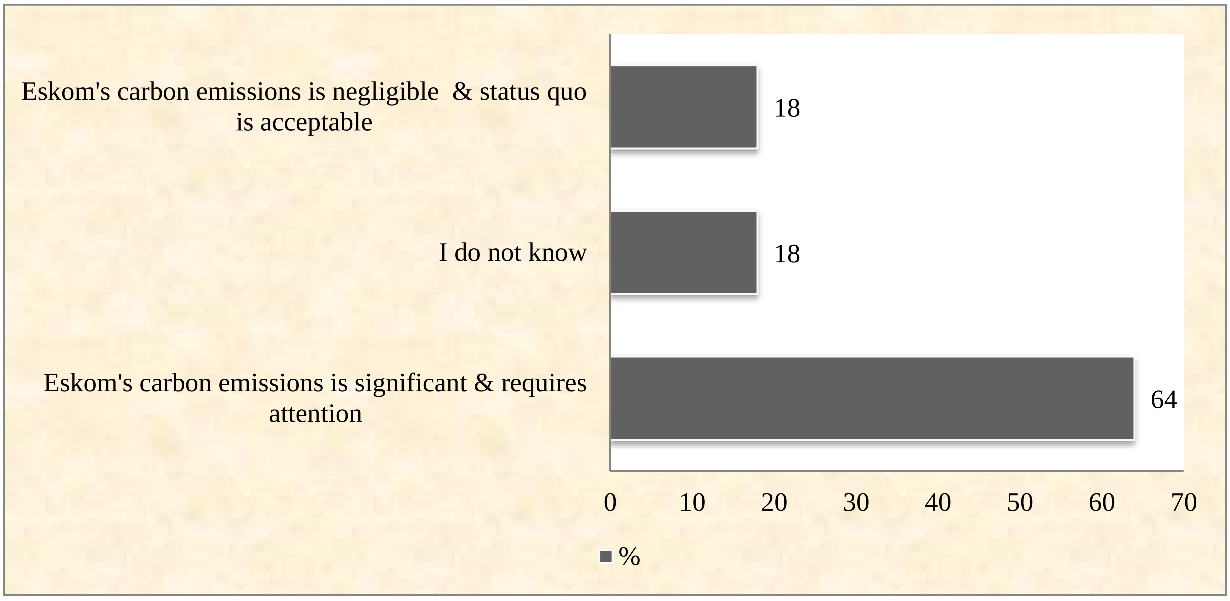


Figure 4.4 Views on the acceptableness of Eskom's contemporary carbon footprint
Source: Based on field survey (2021) – refer to Annexure A2 for raw data

Figure 4.4 displays data indicating that 64% of participants believe Eskom's carbon emissions are unacceptable and merit attention. Conversely, only 18% of respondents view Eskom's contribution as negligible, with the remaining 18% unsure. This data suggests that a nearly two-thirds majority of respondents believe South Africa's carbon emissions are too significant to ignore. A professional from an environmental consulting firm specialising in climate change causes and effects stated, *"Humans do have an impact on this planet through pollution, deforestation, etc., however, to blame humans for 100% of climate change may not be totally accurate"* (Pers.com 2021b). This view suggests that climate variability has existed for millions of years prior to the 21st century, and therefore, industries cannot be solely blamed for the greenhouse effect and climate variability. A Geographic Information Scientist from the regulatory office stated:

> "Greenhouse gases are the main cause of climate change, but one could also argue that there is a small percentage of contribution from South Africa's energy sector or even the internal energy sectors to this climate change. The earth's magnetic behaviour is influential to the functioning of Van-Allen radiation belt responsible for blocking violent cosmic rays. For

billions of years the sun keeps swelling due to the burning of its helium content and swelling into a giant supernova which has a capability of turning Earth into a global desert and might likely leads to sun's explosion and turning into black hole" – (Pers.com 2021c).

The survey participants' perceptions, as depicted in Figure 4.1, were in accordance with the views of interview participants regarding the major carbon emitter in South Africa, as presented in Figure 4.5. Both sources of data indicated that the energy sector, specifically Eskom's coal power plants, is the primary contributor to carbon emissions in the country.

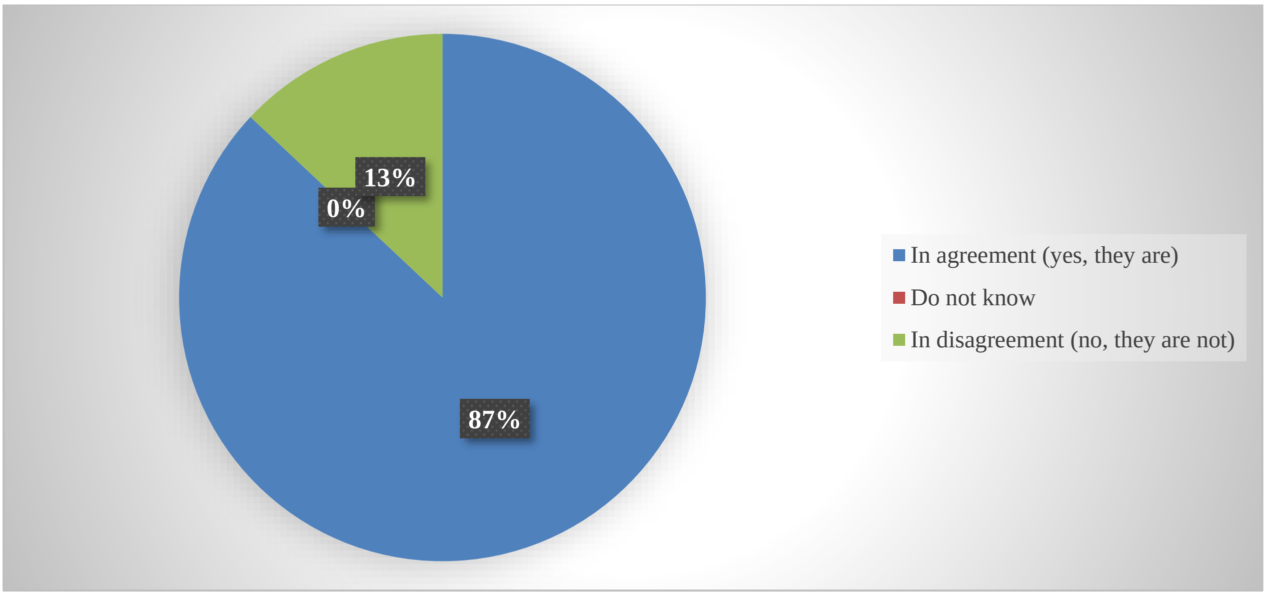


Figure 4.5 Participants views on Eskom's coal-fired power stations being the major emitters of carbon in South Africa (N.23)
Source: Based on field survey (2021)

The data presented in Figure 4.5 indicates that 87% of the participants regarded Eskom as a major contributor to carbon emissions in South Africa, while only 13% held a different opinion. An experienced climate change and energy expert from an environmental consultancy concurred with this perspective, stating that *"Eskom accounts for two-fifths of greenhouse gas emissions in South Africa"* (Pers.com 2021d). In contrast, a practitioner from the power generation sector expressed a contrary viewpoint.

"I disagree because greenhouse gases are as a result of a natural processes. Greenhouse gases have always been in the atmosphere. Other agricultural practices that include livestock manure have been the source of greenhouse gases such as methane. Natural processes that include respiration are other sources of greenhouse gases. Deforestation is also the process in which CO_2 is released to the atmosphere. Based on my biological knowledge, cutting of trees for various uses result into the release of carbon that is naturally retained in each tree for photosynthesis process. Deforestation alone result into the release of nearly a billion tons of carbon to the air" – (Pers.com 2021e).

4.3 CLIMATE CHANGE AND SOUTH AFRICAN ENERGY SECURITY

This study also aimed at investigating the relationship between climate change and energy security in the South African context. In order to fully understand the implications of climate change on energy security in South Africa, it was necessary to gather empirical evidence in this regard. Thus, the views of the respondents were sought regarding the potential direct link between climate change and energy production process, affordability, and reliability (as depicted in Figure 4.6).

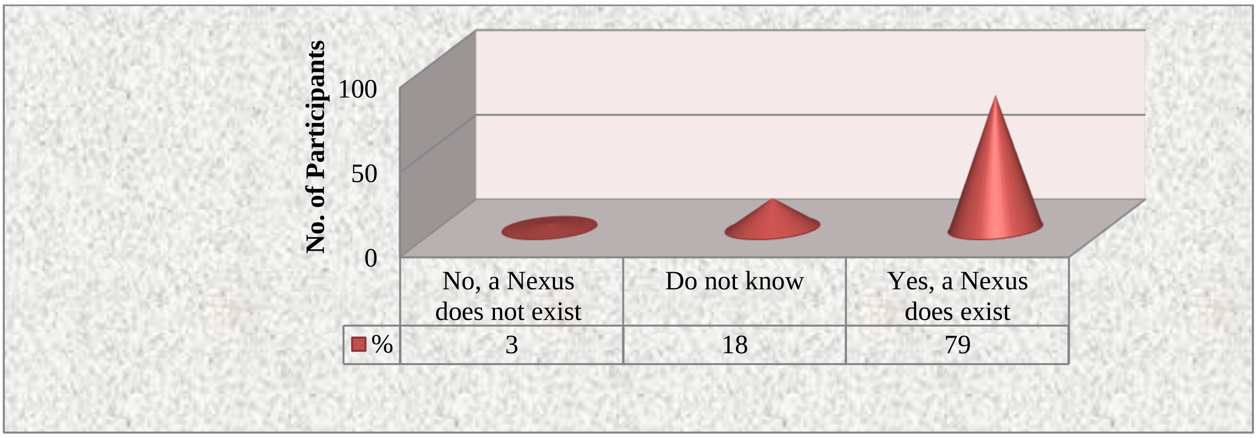


Figure 4.6 Views on climate change effects' direct link with energy production processes, affordability, and reliability (energy security) (N.148)
Source: Based on field survey (2021)

From the data presented in Figure 4.6, it is evident that a substantial number of the participants, 79%, hold the belief that there is a link between climate change variability and energy security. Conversely, only 3% of respondents disagreed with this notion. One respondent from a regulatory background further emphasised that, *"climate change effects may impact regions that are not the sources of greenhouse gases (GHGs). Hence, it is imperative that all states across the world make an equitable contribution towards reducing GHGs"* (Pers.com 2021a).

Having established the existence of a connection between climate change and energy security as depicted in Figure 4.6, it was deemed necessary to assess the significance of such connection. To this end, participants were asked to share their perspectives on the impact of climate change on South Africa's energy security. Refer to Figure 4.7 for related information.

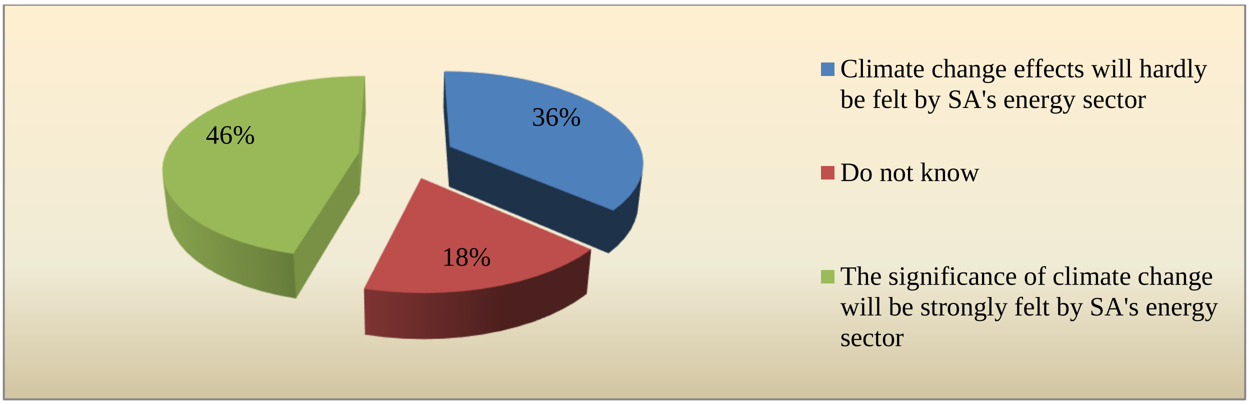


Figure 4.7 The significance of Climate change effects on SA's energy sector in terms of energy availability, affordability, and reliability

Source: Based on field survey (2021) – refer to Annexure A3 raw data

The data depicted in Figure 4.7 reveals that 46% of participants considered the impact of climate change on South Africa's energy sector, in terms of energy availability, affordability and reliability, to be substantial. On the contrary, 36% of participants did not perceive the relationship between climate change and energy security in South Africa to be of significant importance. A small proportion of participants, 18%, were not knowledgeable on the subject. Despite the fact that the perspective held by 36% of participants is not in the majority, it merits further examination and discussion to determine the reasons behind it.

Furthermore, it is crucial to acknowledge that the significance of the effect of climate change on South Africa's energy security will depend on the energy systems' capacity to adapt and withstand such impact. In this regard, participants were also queried about their views on the robustness and resilience of South Africa's energy systems in the face of climate change, as illustrated in Figure 4.8.

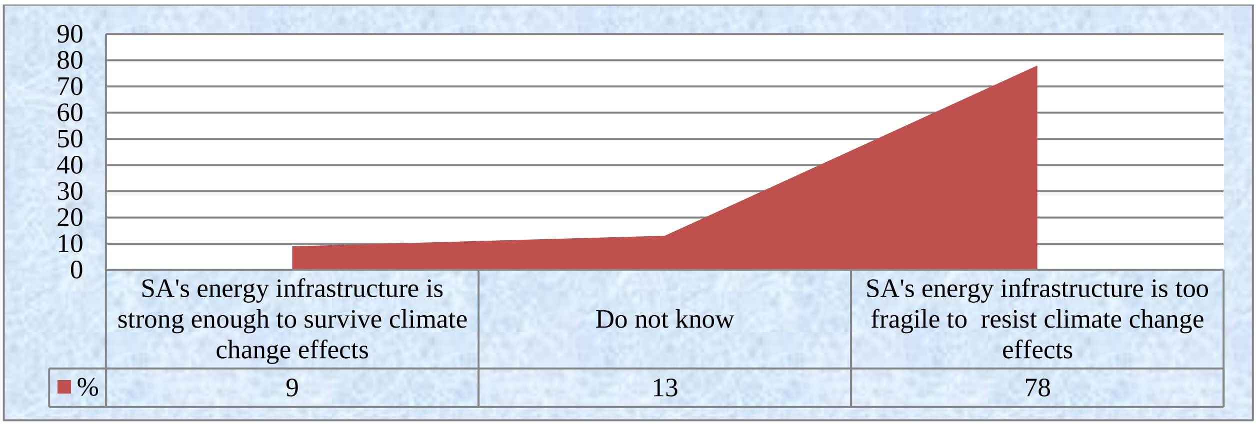


Figure 4.8 Robustness and resilience of South Africa's energy-generating infrastructure against climate change effects (N.148)

Source: Based on field survey (2021)

The results indicated in Figure 4.8 suggest that a significant majority (78%) of the respondents were of the view that South Africa's energy infrastructure is not robust or resilient enough to withstand the effects of extreme climate change. A limited number of participants (9%) held the view that South Africa's energy sector is strong enough to overcome these impacts. A small proportion (13%) of the respondents stated that they were unable to rate the preparedness of the energy sector in the face of extreme weather patterns resulting from climate change. A specialist from Eskom's Centre of Excellence reported:

> "I do not believe that the country has implemented responsive strategies to ensure that the power system withstand climate change impacts. Thus, there is a risk that the existing infrastructure will not sustain when the dire impacts of climate change are felt. While there is a lot of research done on this matter (resilience, in particular), I do not have confidence that it has been transferred to power plants" - (Pers.com 2021f).

In order to gain insights into the potential impacts of climate change on the robustness and resilience of energy systems, the participants were asked to express their views on the effects of precipitation variability and water shortage on Eskom's coal-fired and hydro power stations. Table 4.3 illustrates the participants' views in this regard.

Table 4.3 Views on water resource adequacy amidst irregular precipitation (N.148)

Participants' Perceptions	No. of Participants	%
Irregular precipitation and lack of water resource will definitely interrupt coal and hydro energy production.	113	76
Do not know	19	13
Coal and hydro energy production will remain uninterrupted despite irregular precipitation and lack of water.	16	11
Total	**148**	**100**

Source: Based on field survey (2021)

Table 4.3 reveals that 76% of participants believed that irregular precipitation and inadequate water resources would significantly disrupt production processes for coal and hydro energy generation. Only 13% of respondents were uncertain, while a mere 11% felt that these power generation sources would still maintain production despite variations in precipitation and water shortages. The findings of Table 4.3 align with the views expressed in Figure 4.8, suggesting that South Africa's energy sector could be susceptible to the impacts of climate change. According to Pers.com (2021l), a seasoned Chief Environmental Advisor in the power generation sector:

> "The climate change effects will be multiple, and these will include extreme weather patterns, such as droughts. South Africa is a water-scarce country, and therefore drought will have an effect on power-generating plants, as most of these plants require water for plant cooling while generating electricity. Therefore, energy security will be affected."

In accord with the findings of Pers.com (2021l), another Environmental Advisor from the power generation sector has indicated that:

> "Water is vital for power generation business. Therefore, changes in climate would reduce water availability which affects power generation and other users. Also, infrastructure such power lines and transformers are likely to face risks of physical damage by heavy storms and flooding." - (Pers.com 2021m)

The perspectives presented by participants in Table 4.3 and the supplementary views shared by Pers.com (2021l) and Pers.com (2021m) concur that the inadequate availability of water, due to the impacts of climate change, will lead to the interruption of coal-fired and hydro power generators. To obtain a deeper understanding of this issue, the existing data regarding raw water consumption at baseload power stations (coal-fired) was reviewed vis-à-vis Gigawatt Hour Sent Out (GWh SO). The review results are depicted in Figure 4.9.

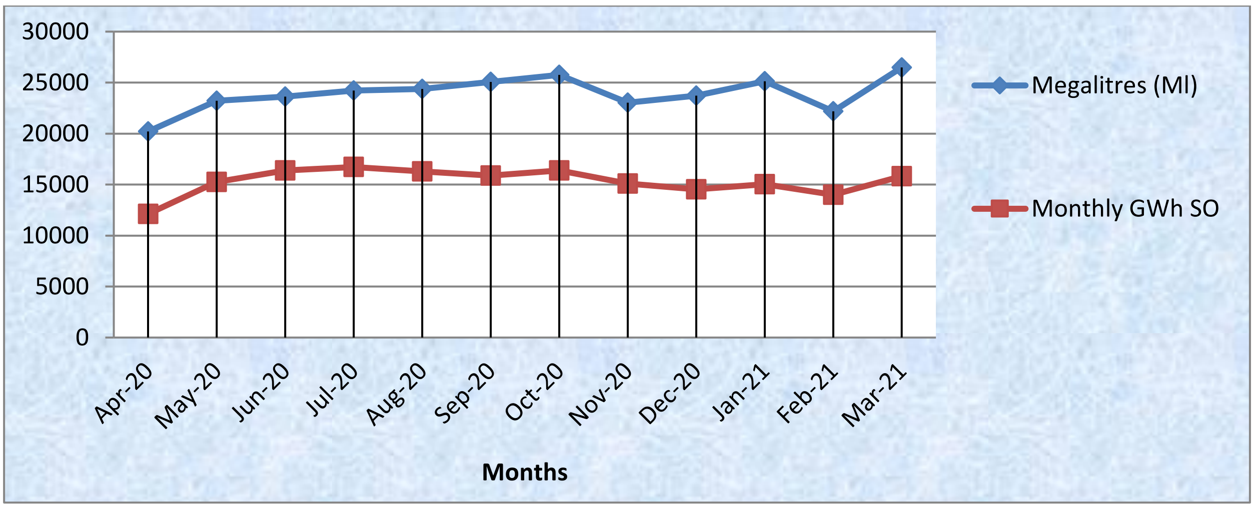


Figure 4.9 Eskom coal power plants' water consumption vis-à-vis GWh SO for 12-months period (April 2020 to March 2021)
Source: Eskom Water Management Centre of Excellence (EWMCE) (2021)

As depicted in Figure 4.9, Eskom's coal power stations consumed over 20 000 million litres of water on a monthly basis during the 2020/2021 financial year. A close analysis of Figure 4.9 suggests that there was a slight increase in water consumption from August to October 2020, then a drop in November 2020, thereafter a rise until January 2021. Figure 4.9 also suggests a decline in Eskom's GWh SO over the period from July 2020 (around 17 000 GWh) to January 2021 (around 15 000 GWh), with the exclusion of October 2020 wherein it momentarily increased to about 17 000 GWh. Water consumption increased relatively strongly from December 2020 to January 2021, and again from February 2021 to March 2021, but electricity output only increased marginally. Figure 4.9 also shows that water consumption gradually increased from autumn season to winter season. The consumption slightly dropped towards the end of spring season (November) and increased again in the first month of summer season. Generally, Eskom coal power plants' water consumption pattern, as depicted on Figure 4.9 above is not stable. In addition to figure 4.9 above, Table 4.4 below present the statistical correlations data to assure the strength of the linear relationship between monthly GWh SO data vis-à-vis monthly megalitres of water consumed data.

Table 4.4 Correlations of Eskom's energy production (GWh SO) vis-à-vis Megaliters of Water Consumed data (April 2020 to March 2021)

		Megaliters (Ml)	GWh SO
Megaliters (Ml)	Pearson Correlation	1	.778**
	Significance (2-tailed)		.003
	Number of Months (Apr 20 -Mar 21)	12	12
Monthly GWh SO	Pearson Correlation	.778**	1
	Significance (2-tailed)	.003	
	Number of Months (Apr 20 -Mar 21)	12	12

**. Correlation is significant at the 0.01 level (2-tailed).
Source: Based on fieldwork data (2021)

As presented in Table 4.4 above, the significance (2-tailed value) = 0.03, which is less than 0.05, thus confirming the statistically significant at 0.05(5%). This statistical analysis results implies that there is an association between Eskom's energy production rate (GWh SO) and monthly megalitres of water consumed in these twelve months period under scrutiny. A Pearson correlation coefficient as depicted in table 4.4 is at 0.778 (77.8%), which implies that there is a positive strong association between Monthly GWh and Megalitres (Ml) of water consumed.

In addition to correlation data depicted in Table 4.4, Table 4.5 below further present the performance co-efficiency statistics between GWh SO vis-à-vis megalitres of water consumed at Eskom coal power plants from April 2020 to March 2021 for deeper analysis.

Table 4.5 Performance Co-efficiency of Eskom's energy production (GWh SO) vis-à-vis Megaliters of Water Consumed (April 2020 to March 2021)

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T-test	Significance
1	(Constant)	8449.386	3961.199		2.133	.059
	GWh SO	1.011	.258	.778	3.918	.003

a. Dependent Variable: Megaliters (Ml)

Source: Based on fieldwork data (2021)

The statistical data presented in Table 4.5 implies that there is a linear relationship between Eskom's Megalitres used, and monthly GWh SO from April 2020 to March 2021. The monthly GWh SO coefficient was at 0.778, thus implying a positive strong relationship. It can also be further deduced that as the monthly energy production (GWh SO) increases by one unit, the megalitres (Ml) usage also increases by 77.8%. The regression model used to generate data in Table 4.5 is statistically significant at 0.05. Being statistically significant at 0.05 (5%) means that there is a 95% assurance that this statistical test is true.

To further understand the significance of water consumption in the energy production processes, Figure 4.10 presents empirical data on the water consumption rate per Eskom's coal power plant during the 2020/2021 financial year.

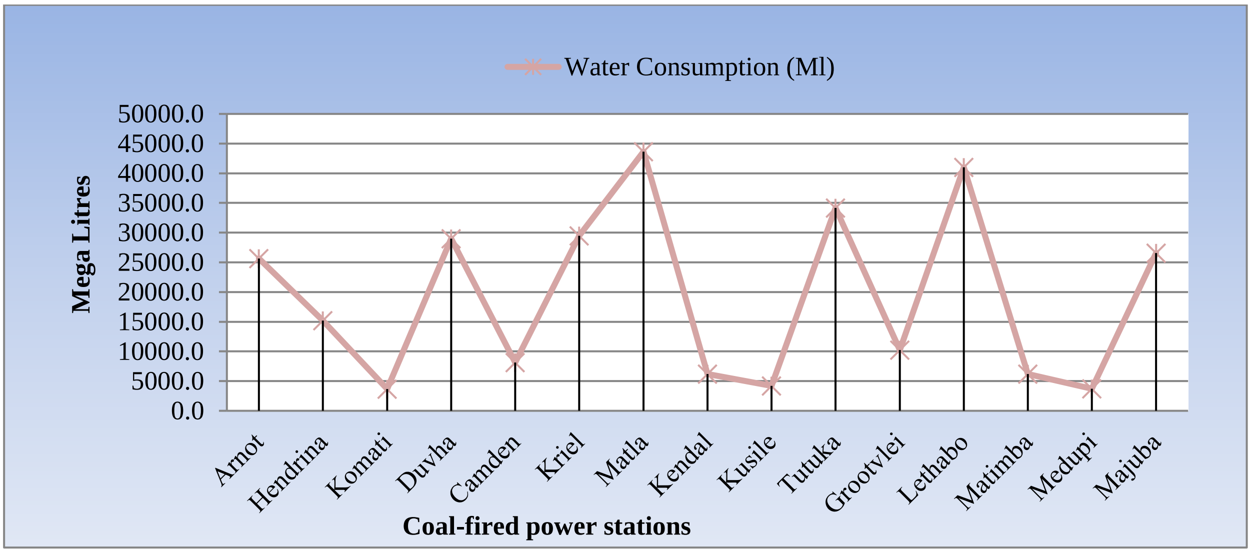


Figure 4.10 Comparative Annual raw water consumption data per Eskom coal power plant for 2020/2021 financial year

Source: Eskom Water Management Centre of Excellence (EWMCE) (2021)

Figure 4.10 demonstrates that combined, Eskom's coal power plants consumed 287 017.1 million litres of water during April 2020 to March 2021 for energy production purposes. The average raw water consumption across the fleet was approximately 19 134.5 million litres. Amongst the stations, those that consumed more than the average amount of water included Arnot Power Station (9%), Duvha Power Station (9%), Kriel Power Station (10%), Matla Power Station (15%), Tutuka Power Station (12%), Lethabo Power Station (14%), and Majuba Power Station (9%). The newly built power stations, Kusile and Medupi, consumed a significantly lower amount of raw water compared to the rest of the stations, at 1% each, although it should be noted that these stations were not yet fully operational at the time of data collection. Kriel and Matla Power Stations, located roughly 4 kilometres apart, consumed 25% of the overall raw water recorded for all 15 coal power stations.

In addition to inquiring about the implications of irregular precipitation and water shortage on energy production, participants were also asked to share their perspectives on the impact of temperature increases on thermal efficiency at coal power plants. The results are presented in Figure 4.11 below.

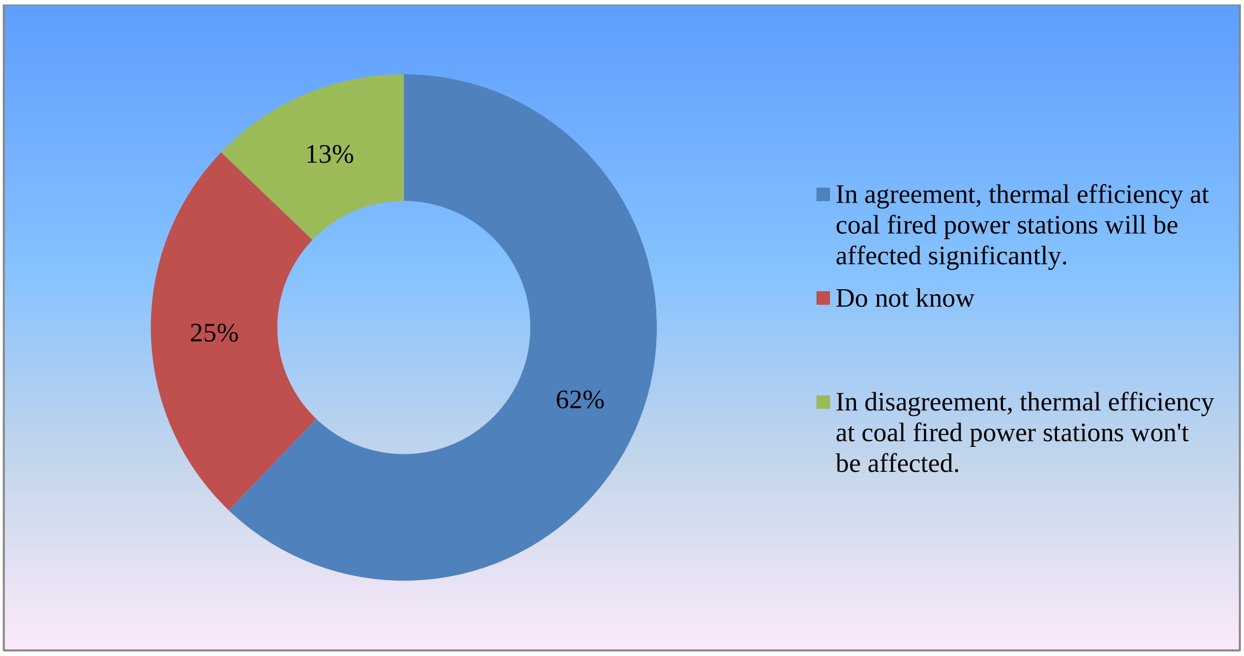


Figure 4.11 High temperatures' effect on the thermal efficiency at coal-fired-power stations
Source: Based on field survey (2021) – refer to Annexure A4 for raw data

Figure 4.11 reveals that 25% of participants were unable to answer the question, which may be attributed to the technical nature of the topic of thermal efficiency. This subject may be better understood by individuals who have been exposed to coal-based energy sources. The majority of participants, constituting 62% and primarily based in the power generation industry, concurred that elevated temperatures have an impact on the thermal efficiency process at the coal power plants. Conversely, only 13% of participants held a contrasting perspective. A participant from a coal power plant provided the following comment: *"Coal power stations experience load losses due to elevated ambient temperatures, particularly in the summer, which poses a significant risk for energy security"* – (Pers.com 2021Aa).

In order to contextualize the issue of temperature variability and the risk to Eskom coal power plants' operations, it was necessary for the current study to assess the temperature distribution aspect paying a particular attention to areas such as eMalahleni (Witbank, Mpumalanga Province) and Lephalale (Ellisrus, Limpopo Province) as the key regions wherein Eskom's coal power plants are located. The ambient temperature distribution pattern (from 2010 to 2021 – 11 years) is presented in Figure 4.12 below.

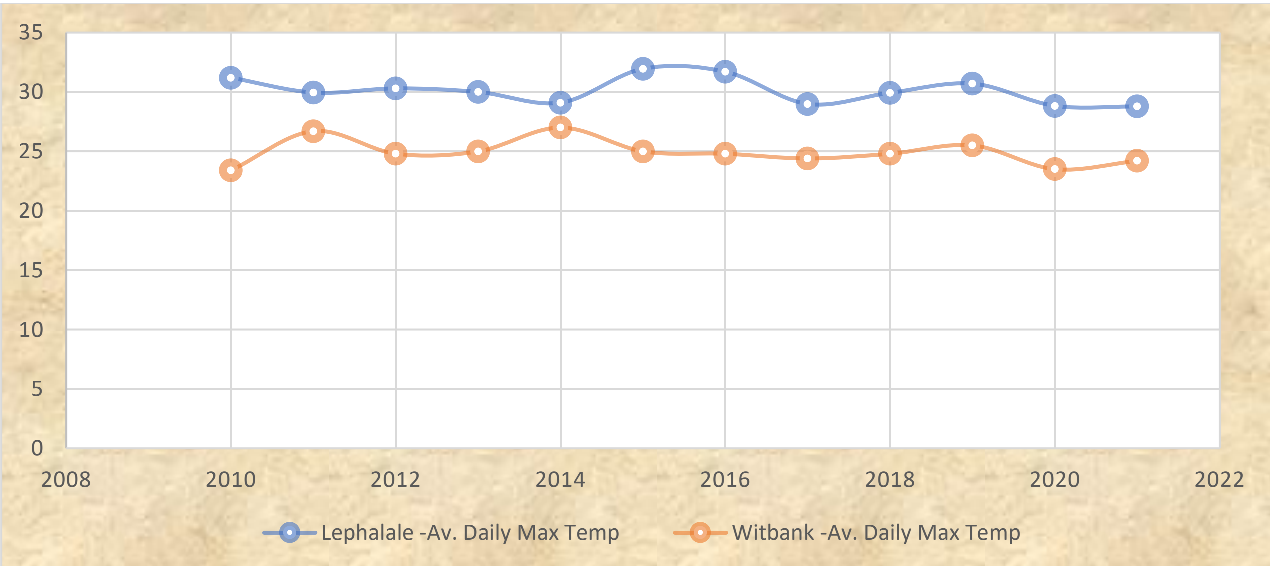


Figure 4.12 Average Annual Maximum Temperature for Lephalale & Witbank Areas (°C) (2010 to 2021 period)
Source: SAWS (2023)

Figure 4.12 depicts a varying average annual maximum temperature at the Lephalale region in the period from 2010 to 2021, with the 2013 average maximum temperature recorded at 30°C, 2014 at 29°C, and 2015 at 32°C. It was only in the five of the eleven trended years wherein the average annual maximum temperatures were below 30°C in the Lephalale region. Conversely, eMalahleni region experienced limited temperature variation in the eleven years period, with the average annual maximum temperature remaining below 30°C mark. Although eMalahleni region has experienced some sharp variabilities in regional temperature in the period from 2010 to 2015, the period from 2016 to 2019 has been calm. Generally, Figure 4.12 indicates a picture of unpredictable temperature distribution over the eleven-year period, particularly in the Lephalale region. In order to obtain the comprehensive data for triangulation purposes, interview participants were also asked to express their views on the effects of climate change on energy sector. The participants' views on this matter are summarised in Box 4.1.

Box 4.1 Various perceptions by interview participants on the significance of climate change effects on energy sector (N.23)

- Climate change will compel South Africa to shift away from coal power plants to renewable energy sources that have low carbon footprint (Pers.com 2021g).
- Changes in climate will mean a decrease in water availability which will in turn affecting the energy security negatively because there will be no water for production and cooling purposes (Pers.com 2021h, Pers.com 2021k & Pers.com 2021w).
- Increased natural disasters affecting energy sector infrastructure (floods/ strong winds/ storms) (Pers.com 2021k).
- The entire energy supply system (coal and renewable energy systems) will be affected by extreme weather events (e.g., heat, floods, droughts and storms) – (Pers.com 2021l, Pers.com 2021m, Pers.com 2021n).
- The demand of electricity may increase due to the requirements of cooling in summer time. The energy sector is reliant mostly on water for cooling as well as electricity generation – (Pers.com 2021p).
- It will have minimal effect. Current climate change interventions will assist in mitigating the effects – (Pers.com 2021o & Pers.com 2021q).
- A change to a cleaner energy generation will affect the energy sector due to technological transformation; financially this will harm the energy sector on a long term. in a short term the impact will not be felt – (Pers.com 2021r, Pers.com 2021s & Pers.com 2021u).
- The impacts will be negatively severe as are exacerbated by hydrological linkages; the eastern part of the country has a number of small hydro-power stations and due to low rainfall, the efficiency of the power stations is compromised – (Pers.com 2021x & Pers.com 2021y).

Source: Based on field survey (2021)

Perceptions as captured in Box 4.1 indicate that most respondents hold the view that climate change will result in a broad range of significant adverse impacts on South Africa's energy sector and production. Most participants emphasised that extreme weather events such as high temperatures, droughts, strong winds and floods pose a significant risk to the energy sector. However, there were two participants who did not consider climate change to have serious adverse effects on the energy sector (Pers.com 2021o & Pers.com 2021q). Some participants also indicated that the impacts of climate change will compel South Africa to move away from fossil fuels, which will have severe financial implications for the country (Pers.com 2021g, Pers.com 2021r, Pers.com 2021s & Pers.com 2021u).

According to the survey, 76% of participants indicated that irregular precipitation would disrupt production in coal-fired and hydro power stations (as indicated in Table 4.3 above). To triangulate the views of the survey participants on the impacts of irregular precipitation on energy production (hydro and coal-fired), interview participants were also asked to share their perspectives on the matter. The results are presented in Figure 4.13 below.

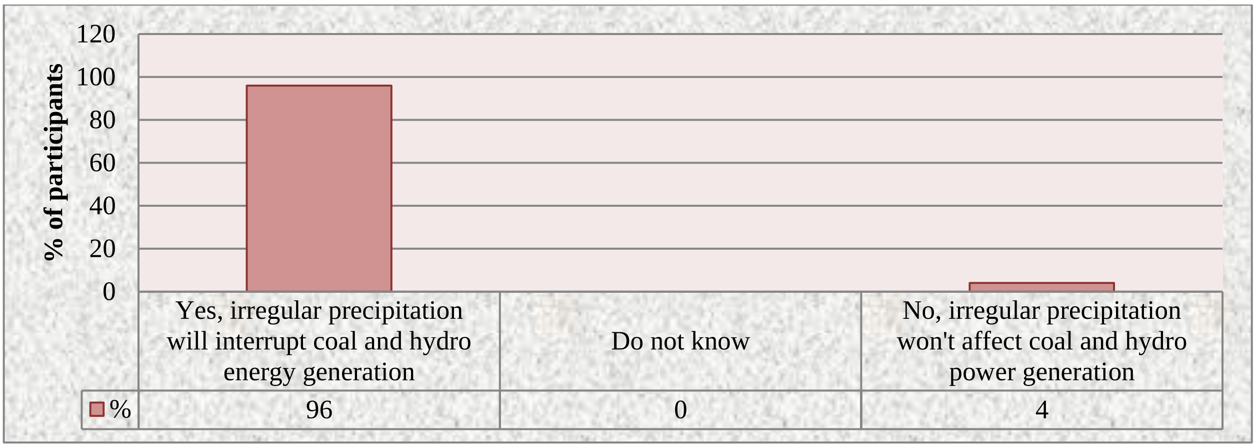


Figure 4.13 Irregular precipitation and interruption of energy production at Eskom's coal-fired and hydro power stations (N.23)
Source: Based on field survey (2021)

The results depicted in Figure 4.13 demonstrate a correlation between the views of interview and survey participants (Table 4.3). An overwhelming 96% of participants indicated that irregular precipitation would result in disruptions to both coal and hydro power generation plants. Only 4% of participants believed that irregular precipitation would have no impact on these energy sources. It is evident that all participants were well-informed on the subject as none chose not to respond to the question. The participants' views presented in this section mostly indicate that the effects of climate change will have a detrimental impact on energy systems in South Africa.

In addition to Figure 4.13 above, it was also important for the current study to understand the extent of precipitation variability risks for operational regions wherein coal fired power plants are located by means of reviewing historical annual rainfall patterns in line with raw water needed for energy production. In line with this view, Figure 4.14 below provide annual rainfall recorded for the period from 2010 to 2021 for eMalahleni (Witbank, Mpumalanga Province) and Lephalale (Ellisrus, Limpopo Province).

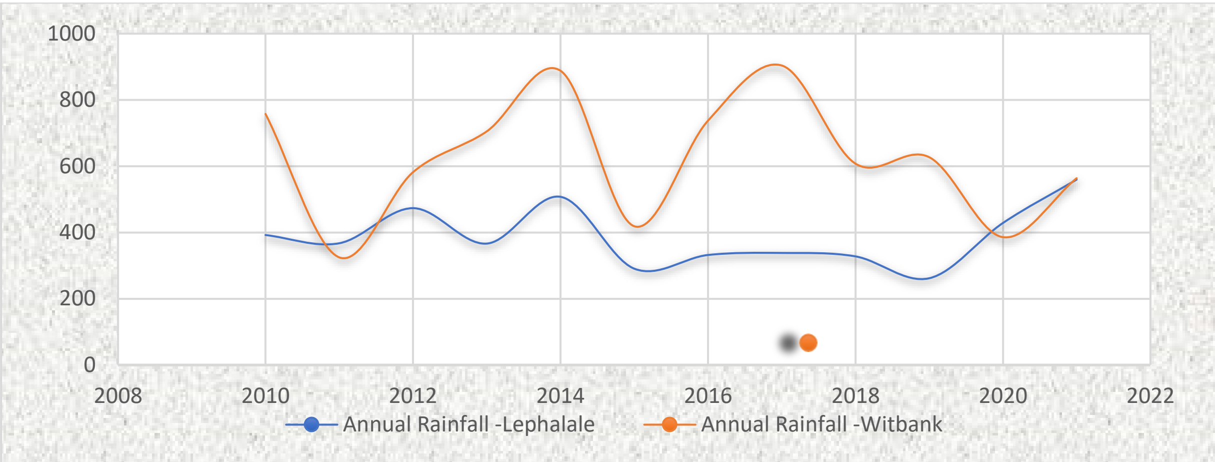


Figure 4.14 Annual Rainfall Pattern for Lephalale & Witbank Areas (mm) (2010 to 2021 period)
Source: SAWS (2023)

A scrutiny of Figure 4.14 indicates that precipitation distribution at eMalahleni region has been significantly inconsistent, with yearly rainfall distribution varying by the margin of 100mm to 350mm on a year-to-year basis (from 2010 to 2021). eMalahleni region received more rainfall than Lephalale region that has received rainfall exceeding 550mm only in 2021, during the period from 2010 to 2021. Rainfall distribution at eMalahleni region has been declining from 2017 to 2020. Additionally, survey participants were asked to provide their opinions on whether the aforementioned effects of climate change would result in a reduction in energy production and energy insecurity in South Africa. This question was posed in order to determine whether an immediate response to climate change is necessary to ensure energy security in the country. The participants' views in this regard are presented in Figure 4.15 below.

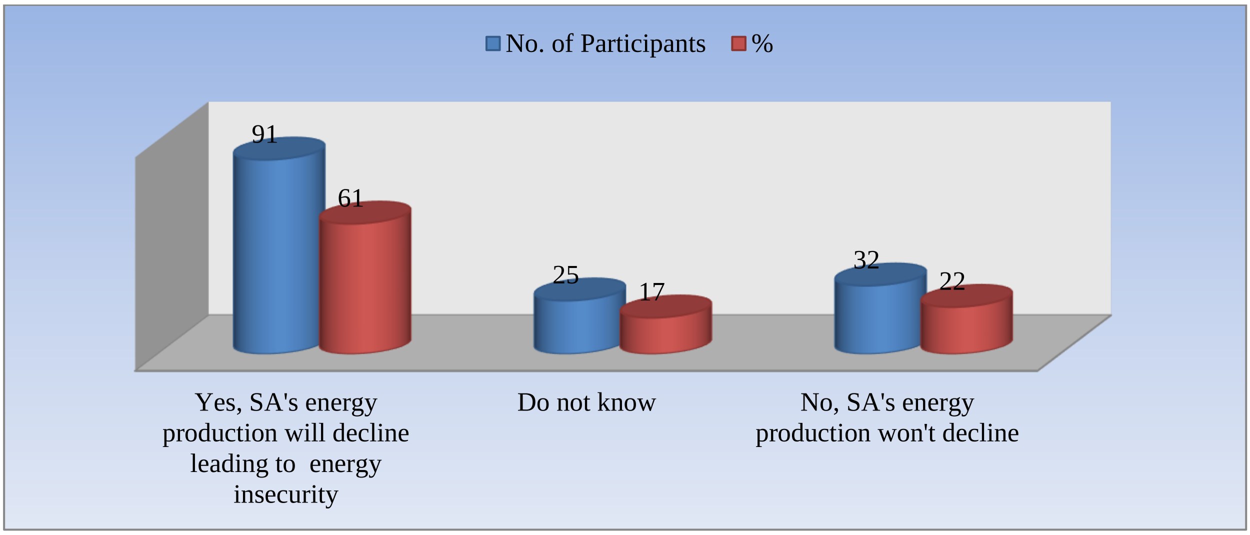


Figure 4.15 Perceptions on whether climate change effects may result in a reduction in energy production (N.148)
Source: Based on field survey (2021)

The results presented in Figure 4.15 indicate that 61% of participants hold the view that South Africa's energy production will decrease due to the impacts of climate change. Approximately 22% of participants did not believe that climate change would result in a reduction in energy production, while 17% of participants were unsure about the potential impact on energy production. One power station operator stated that:

> "South Africa needs to balance the power generation to avoid what happened recently in California wherein they experienced blackout due to high temperatures (heat wave) which led to high demand; and when sun sets, solar energy drops, removing megawatts of solar power from the grid while demand was going up due to high heat temperatures" – (Pers.com 2021Ac).

To support the argument that the impacts of climate change will lead to a reduction in energy production, a participant based at a hydro power plant argued that:

> "Climate change will exacerbate extreme weather conditions i.e. storms/floods and drought which are projected to affect inland areas more but coastal areas are not immune. Floods and storms will potentially flood the mines supplying the coal-fired power stations, and the issue of wet coal will become more prominent. Drought will seriously impact hydropower and pumped storage plants as their generating fuel is water; thus, with drought, the station's output will be restricted. If the drought persists for longer duration, the hydropower and pumped storage stations will shut down because of lack of water. Importantly, the pumped storage schemes like Ingula and Drakensberg provide a black start capability. For Ingula, where Eskom owns the dams, there is a legal requirement to meet set ecological water releases irrespective of the drought; and this will have a bearing on the generation capacity" – (Pers.com 2021n).

Contrary to the perspective shared by Pers.com (2021n), another participant from a coal-based power station dismissed the significance of climate change, characterising it as an overstated subject. This participant also commented that:

> "Like any extreme weather changes that have been happening for years, there will be periods where the country will experience extreme dry and wet seasons alike. All these weather patterns will have some sort of impact on the energy sector, e.g. Koeberg's lack of water due to drought in the Western Cape province some years ago" – (Pers.com 2021e).

Despite this dismissive view of the impact of climate change on the energy sector, Pers.com's (2021e) view is still consistent with the perspective shared by Pers.com (2021n) that the sector will be affected by the consequences of climate change. Participants were also asked to express their opinions on the survival chances of South Africa's current electricity baseload, which is predominantly composed of coal power plants, in the face of weather variability, including dry spells, heat waves, and floods. The views of the participants are presented in Figure 4.16 below.

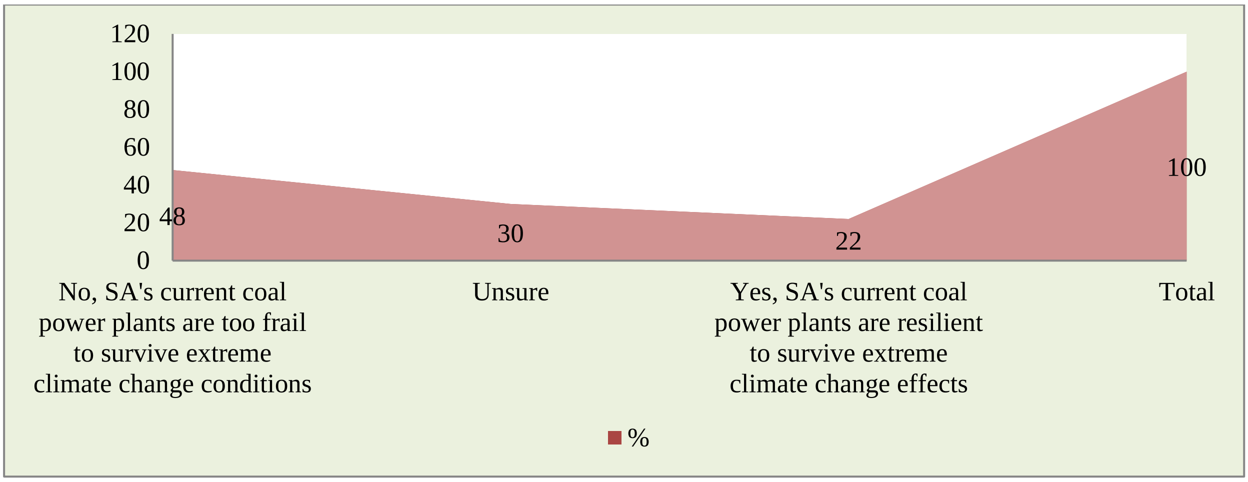


Figure 4.16 Participants' views on the resilience and robustness of SA's energy baseload against climate change effects such as high temperatures, drought, and floods (N.23)
Source: Based on field survey (2021)

Findings of the interviews, depicted in Figure 4.16, suggest that 48% of participants do not believe that South Africa's coal energy plants can endure the impacts of climate change, such as increased temperatures and irregular precipitation patterns. These perceptions were influenced by several factors, including South Africa's water-scarcity challenge coupled with Eskom's coal power plants that were not constructed or designed to withstand extreme weather events brought about by climate change. Moreover, there is a risk of wet coal affecting the generation units.

The views of Pers.com 2021d, Pers.com 2021x, Pers.com 2021s, Pers.com 2021p, and Pers.com 2021h concurred in that South Africa is already a water-scarce country and that, with the potential for even less precipitation, the impacts on the heavily water-reliant coal power plants would be significant. Some coal power plants are equipped with flue gas desulfurization plants that consume large amounts of water to scrub SO2. Another expert from the Environmental consulting firm argued that *"South Africa cannot survive the effects of climate change"* and that *"load-shedding has already occurred multiple times due to extreme wet weather events."* - (Pers.com 2021v).

The views of Pers.com 2021t, Pers.com 2021n, Pers.com 2021j, Pers.com 2021k, and Pers.com 2021f were in agreement that the infrastructure of older coal power stations is not equipped to withstand extreme weather events, and that South Africa's energy baseload is primarily composed of these older power stations. However, 22% of participants, as depicted in Figure 4.16, believe that South Africa's energy sector will endure harsh climate conditions, as it has in the past, and that adaptation measures currently being implemented will further assist in this regard (Pers.com 2021y, Pers.com 2021z, Pers.com 2021u, Pers.com 2021q, Pers.com 2021o). Approximately 30% of participants were uncertain about the survival of South Africa's energy sector in the face of harsh conditions associated with climate change. Views shared by Pers.com 2021g, Pers.com 2021i, and Pers.com 2021r suggest that, while the coal power plants may seem to be surviving in the present, this trend may prove to be unsustainable in the long run. To triangulate views regarding the impacts of climate change on South Africa, including increased temperatures and potential interruptions of operations in coal power plants, a projection map has been included in the findings. This map compares projected changes in climate from 2021 to 2050 (future) to the recorded historical weather patterns (baseline/reference data) from 1971 to 2000 (historical). Figure 4.17 below illustrates the projected increase in average temperature for South Africa from 2021 to 2050.

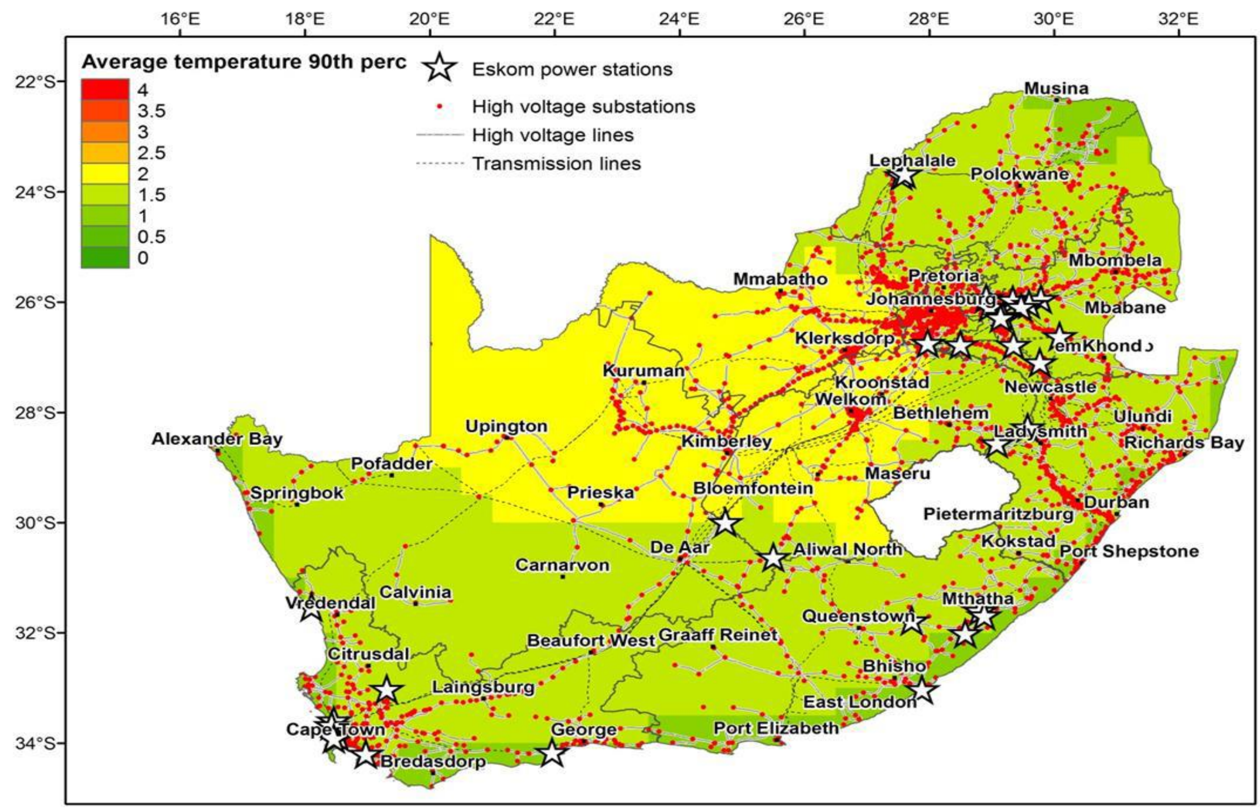


Figure 4.17 **Projected increase in average temperatures in SA (2021-2050 projection)**
Source: Eskom RT&D (2015)

According to Figure 4.17, it is projected that various regions in South Africa will experience an increase in average temperatures ranging from 0.5 to 2.5°C in the 30-year period between 2021 and 2050. An increase of 1.5°C is projected for the majority of the country, including the provinces of Mpumalanga, KwaZulu-Natal, Eastern Cape, Limpopo, Gauteng, and Western Cape. Coastal regions in the Cape and KZN provinces will experience a temperature increase of 0.5 to 1°C, while large portions of the Northern Cape, Free State, and North West provinces are projected to experience a temperature increase of up to 2.5°C. Interestingly, the Vhembe district municipality in the northeast of Limpopo Province is projected to experience a lesser increase in temperatures (0.5 to 1°C).

The study also included a projection of rainfall dynamics as depicted in Figure 4.18, which provides insight into this important weather component. Figure 4.18 presents projected variabilities in rainfall distribution from 2021 to 2050 around South Africa.

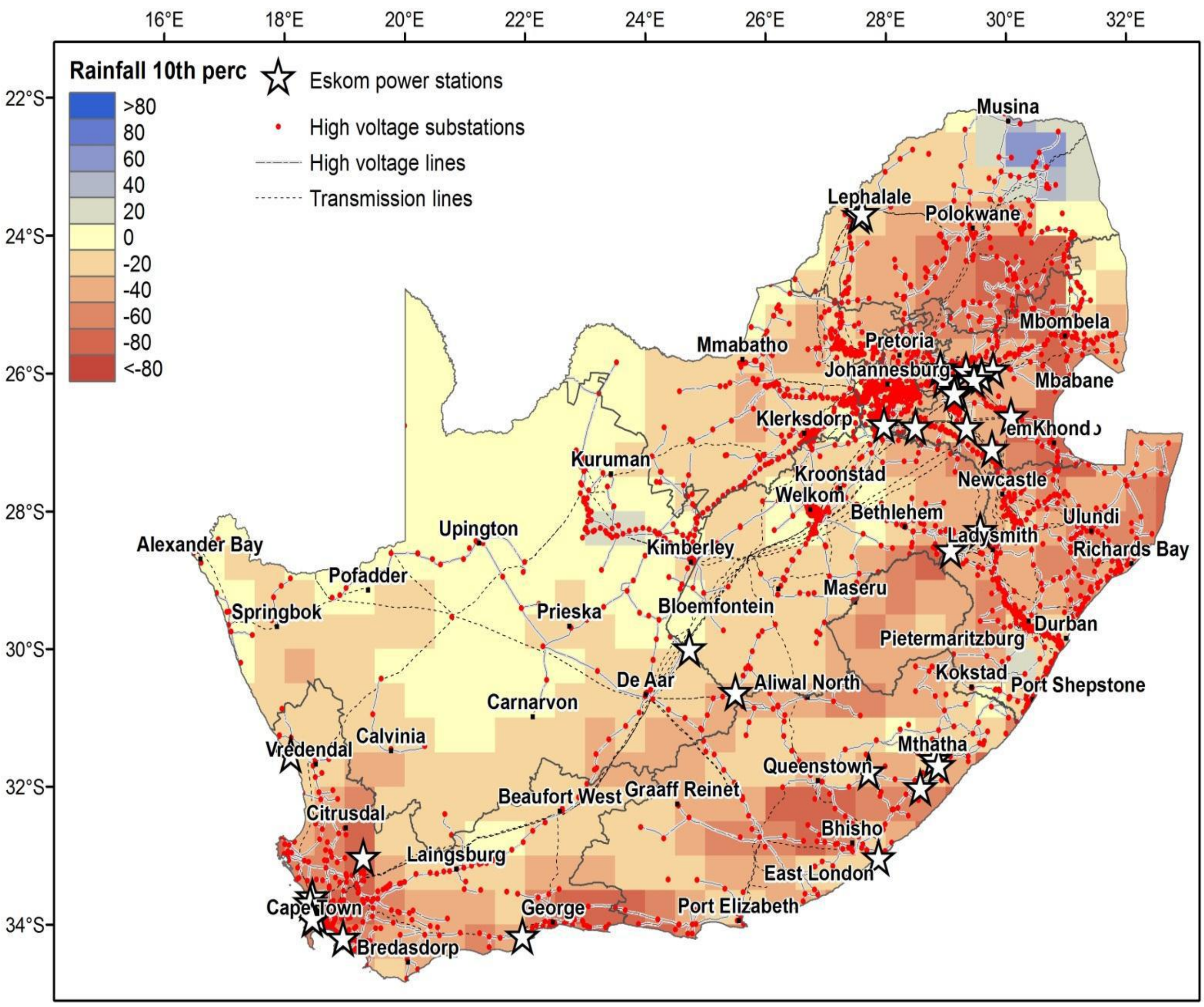


Figure 4.18 Projected vicissitudes in rainfall totals in South Africa (2021-2050 projection)
Source: Eskom RT&D (2015)

As demonstrated in Figure 4.18, projections suggest that most regions in South Africa will experience a decrease in rainfall ranging from -20 to -80 mm in the period from 2021 to 2050. The projections also indicate that a large portion of the Northern Cape Province's rainfall will remain unchanged in comparison to the 1971-2000 period. Meanwhile, significant reductions in rainfall are expected in large parts of the KwaZulu-Natal, Mpumalanga, Gauteng, and Limpopo Provinces during the same period. Conversely, the projections indicate that the northeast of Limpopo Province (Vhembe District Municipality) will experience rainfall increase in the 2021-2050 period.

While climate variables such as precipitation and temperature distribution have been presented above as directly linked with energy security determinants such as energy accessibility, affordability and reliability, there are other climate variables that poses a significant risk to energy generation process. A schematic presentation of the chain of impacts, as shown in Figure 4.19, was devised to provide participants' views on how other climate variables such as severe storms, flash floods, and strong winds, affect energy production processes.

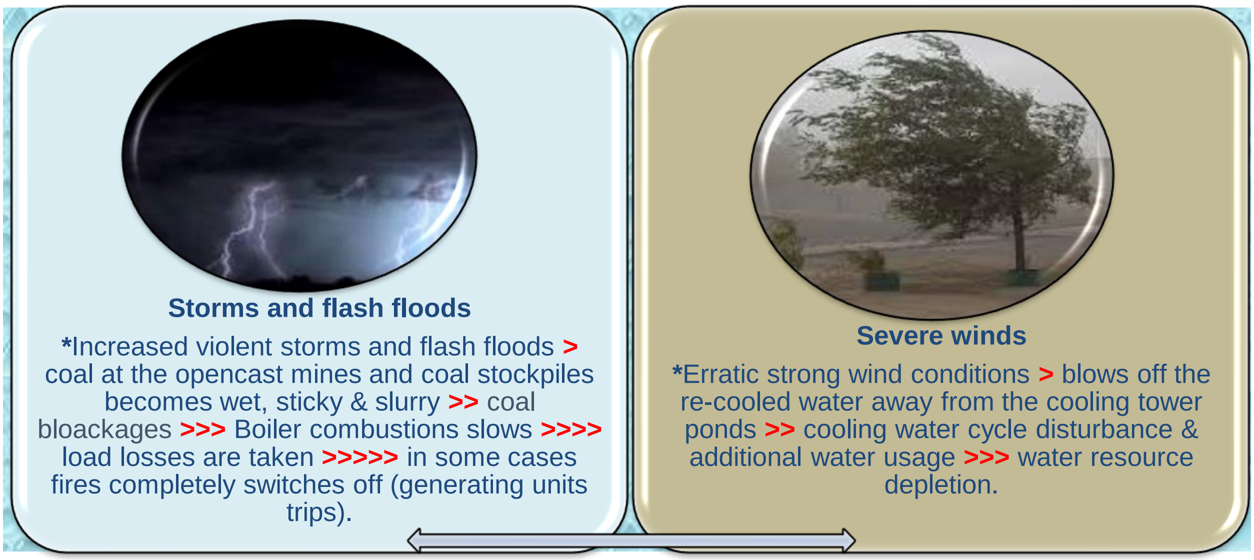


Figure 4.19 Other effects of climate change variables on South Africa's energy baseload
Source: Based on field survey (2021)

A close look at Figure 4.19 above indicates participants' diverse views in respect of the climate change impacts that present risks to South Africa's energy sector. Participants identified climate change effects such as storms and severe winds, amongst the additional risks that could adversely affect coal conditioning and cooling system performance, resulting into interruption of energy generation process.

4.4 POLICY FRAMEWORK FOR SOUTH AFRICA'S TRANSITION TO CLEAN ENERGY SYSTEMS

The findings of this section pertain to the participants' perspectives on the suitability, adequacy, and effectiveness of South Africa's energy policy framework to successfully transition the country's energy sector to cleaner energy systems. Additionally, this section presents the participants' views on the level of development for South Africa's energy policy framework in promoting the robustness, resilience, and adaptation of the country's energy generation sector, as well as ensuring energy security. A prerequisite for the effective transition of energy systems to clean energy mix is for the energy policy to align with such transition. Therefore, participants were asked for their opinions on whether South Africa has an effective energy policy that can facilitate the desired transition to cleaner energy systems, as depicted in Figure 4.20.

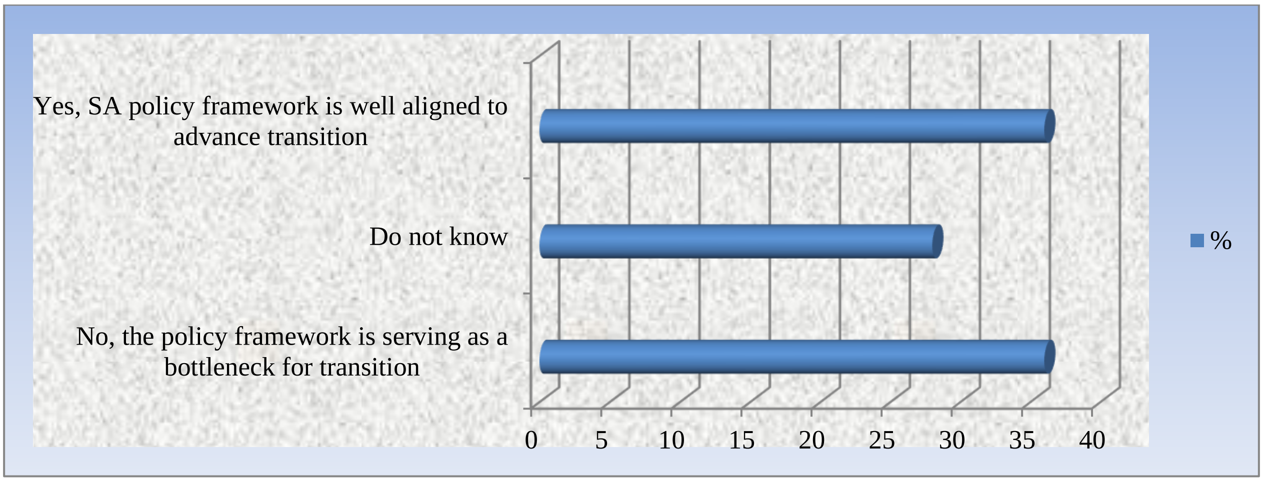


Figure 4.20 Participants' assessment of SA's energy policy framework
Source: Based on field survey (2021) – refer to Annexure A5 for raw data

The data presented in Figure 4.20 reveals that 36% of the respondents perceived South Africa's policy framework as adequate and capable of promoting the transition towards cleaner energy systems. Conversely, 36% of the respondents perceived the policy as being misaligned and serving as an impediment to rapid transition. These opposing views among the participants indicate a clear division in the interpretation of South Africa's energy policy, with half of the respondents in support and half against. Additionally, a substantial proportion of participants (28%) were uncertain of their response in this regard. An environmental specialist based at a coal energy plant noted that:

> "Any development must take into account the socio-economic and environmental factors prevailing at any given point. South Africa's policy framework to transition the current

energy sector to cleaner energy system in my view is one sided in favour of the environmental protection while the socio-economic factors are disregarded. There are many South Africans today that are still waiting for the promises of a better life, and the move towards the "cleaner energy" is not going to assist many to come out of poverty and the inequality that the country still faces" – (Pers.com 2021d).

For the purpose of triangulation, interview participants were solicited to express their opinions on the appropriateness, sufficiency, and efficacy of South Africa's energy policy in promoting the transition towards cleaner energy systems. Refer to Box 4.2.

Box 4.2 Suitability, adequacy, and effectiveness of SA's energy policy to transition the energy sector

- The country has good policy provision to transition, especially in consideration of the need to balance the economic needs, and the potential for optimal utilization of the existing energy system – (Pers.com 2021f).
- The transition to a cleaner energy system will come at a cost. Ultimately the consumer will have to carry the cost. This fact is not adequately addressed by the current policy framework – (Pers.com 2021g).
- The policy is suitable and adequate, yet not being effectively implemented. This could be as a result of both funds and the short span of some of the plant remaining operation life – (Pers.com 2021j, Pers.com 2021o and Pers.com 2021r).
- The policy is in place however is very slow, lacks implementation or urgency drive from the government to support and create a suitable environment for the private sector (renewable energy) to play a role, and connecting to the national grid – (Pers.com 2021l)
- The policy framework is currently in-adequate. As a developing country mining is considered a high employment creator as it able to absorb a large number of low skilled personnel. In this regard current policy framework seeks to protect these jobs as they will be lost by a transition from coal fired power stations to renewables – (Pers.com 2021v).
- The policy framework is currently not suitable and adequate enough to transit to a cleaner system. It is limited by, amongst others, lack of institutional systems and integrated approach in policy development – (Pers.com 2021x and Pers.com 2021z)
- Interplay between policy, technological innovation and market forces will determine whether a transition towards decarbonisation will be a positive influence on SA's future growth and development – (Pers.com 2021d)

Source: Based on field survey (2021)

Participants' perspectives, as recorded in Box 4.2, generally concur that the existing energy policy framework in South Africa is adequate, however, the challenge lies in its implementation rather than the policy's design. Participants expressed a lack of confidence in the efficacy of the policy, particularly with regards to its implementation and enforcement. There were, nonetheless, a few interviewees who had doubts about the policy's suitability. An Environmental Advisory participant with extensive experience in power generation stated during a webinar that:

> "An effective renewable energy policy should be expedited in South Africa to ensure policy certainty, sustainable investments associated with renewable energy projects should be increased, the implementation of the Just Transition and Sustainable Development Goals (SDGs) should be facilitated, reduce energy poverty and accomplish the country's international climate change obligations/commitments" – (Pers.com 2021Aq).

One of the critical components emerging from the energy policy framework is the IRP. Participants were thus asked to express their views on whether South Africa's Integrated Energy Resource Plan is backed by a progressive implementation plan (see Figure 4.21).

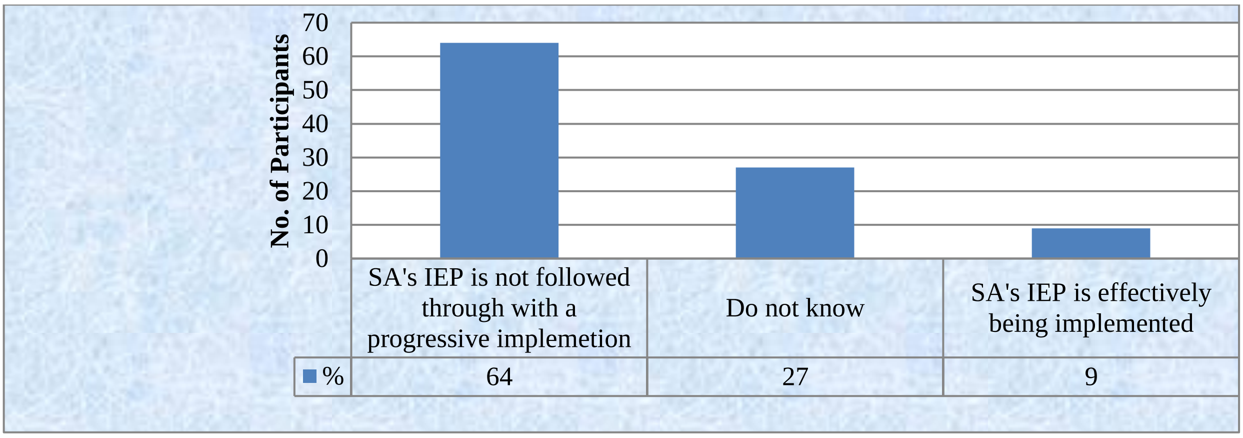


Figure 4.21 Views by participants regarding the implementation of South Africa's Integrated Energy Resource Plan by government (N.148)
Source: Based on field survey (2021)

The results of the fieldwork, presented in Figure 4.21, indicate that 64% of participants did not believe that the implementation of South Africa's Integrated Energy Resource Plan (IRP) was progressive. A significant number of participants (27%) were unsure of their answer to the question. Only 9% of participants felt that the IRP was being effectively implemented. Despite a considerable number of participants considering South Africa's energy policy framework to be suitable, as indicated by Figure 4.20 and Box 4.2, a substantial number of participants felt that the policy's implementation was inadequate, particularly regarding the IRP (refer to Figure 4.21).

The implementation of South Africa's Integrated Energy Resource Plan aims to fulfil the energy transition commitments outlined in the same energy policy. Participants were therefore asked to share their views on South Africa's efforts to transition to cleaner energy systems. The participants' views are presented in Figure 4.22 below.

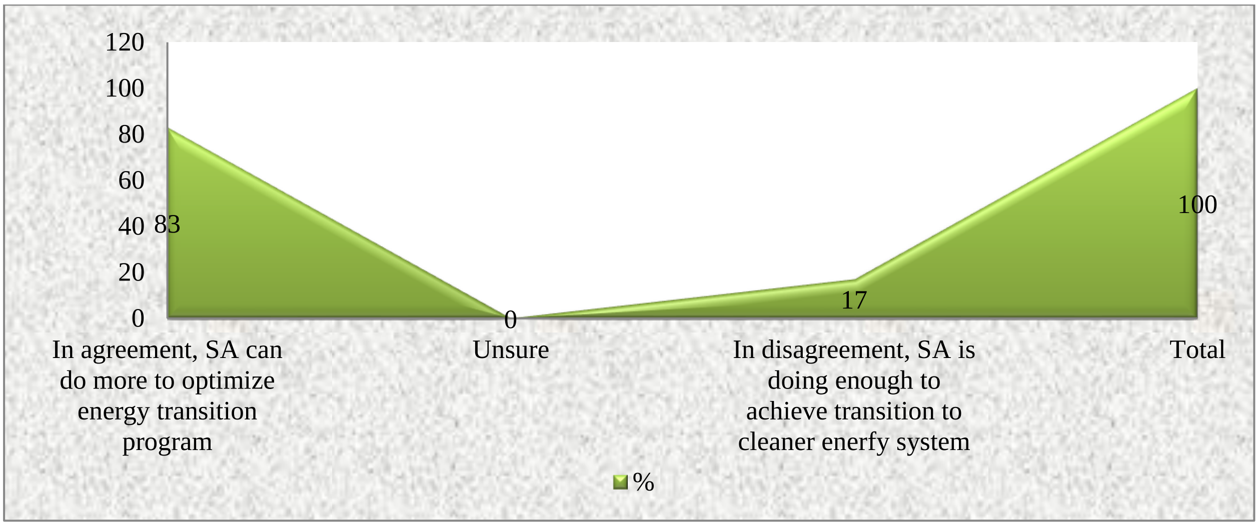


Figure 4.22 Perceptions on SA's progress towards the implementation of a transition to cleaner energy (N.23)
Source: Based on field survey (2021)

The results in Figure 4.22 suggest that 83% of interview participants felt that South Africa could do better in transitioning to clean energy systems. Only 17% of participants believed that the country was doing enough to transition to cleaner energy technologies. To expand the data collection on this perspective, survey participants were also asked to provide their views on the same issue, the results of which are presented in Figure 4.23 below.

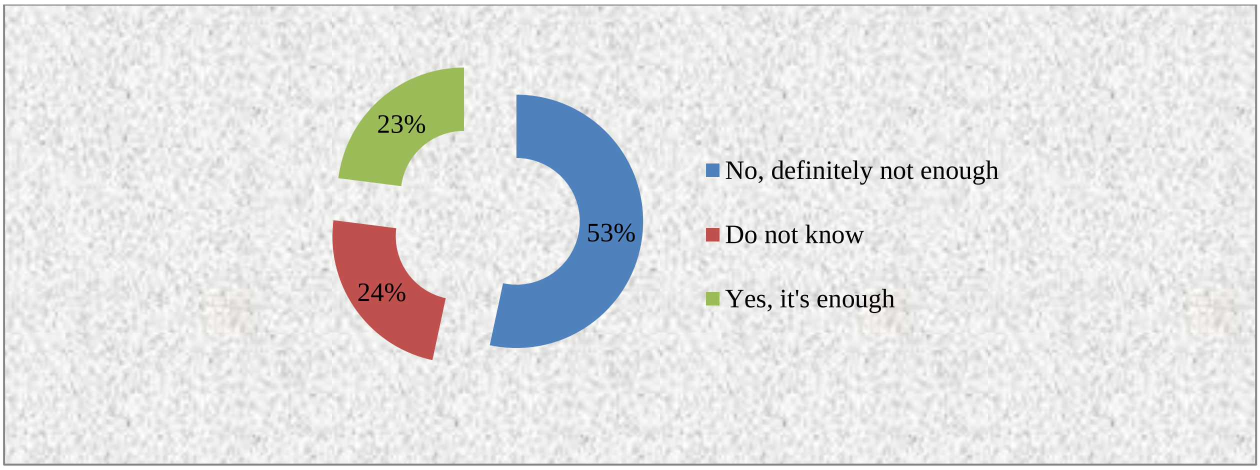


Figure 4.23 Perceptions on whether South Africa is doing enough to ensure that transition to cleaner energy is achieved
Source: Based on field survey (2021) – refer to Annexure A6 for raw data

In accord with the majority views of the interview participants recorded in Figure 4.22, the data as presented in Figure 4.23 also shows that 53% of the survey participants believe that South Africa is not doing enough to facilitate a transition to cleaner energy systems. Conversely, 23% of participants hold the view that the country is taking adequate steps towards this transition, while 24% of participants were unsure of their response to the question. The Figures reinforce the strong opinions expressed by experienced participants regarding their dissatisfaction with South Africa's efforts to promote energy source transition and mix. Building on the views expressed in Figures 4.22 and 4.23, participants were also asked for their perspectives on the possibility of transitioning 50% of South Africa's energy sector to cleaner systems by 2050. These views are documented in Table 4.6 below.

Table 4.6 Insights on whether 50% of South Africa's current energy sector can be transitioned to cleaner energy system by year 2050 (N.148)

Participants' Perceptions	No. of Participants	%
In agreement, the milestone can be achieved	31	21
Do not know	42	28
In disagreement, it's easier said than done	75	51
Total	**148**	**100**

Source: Based on field survey (2021)

As shown in Table 4.6 above, 28% of participants were unable to provide a response to the question. Meanwhile, 51% of participants expressed the belief that it would not be possible for 50% of South Africa's current energy sector to transition to cleaner systems by 2050, compared to the 21% who held the opposite view. The results in Table 4.6 align with those recorded in Figures 4.22 and 4.23, indicating that South Africa is making insufficient efforts towards transitioning its energy system.

Subsequently, in order to gain insights into participants' views on the incorporation of climate change mitigation and adaptation strategies into South Africa's energy policy, as opposed to them being managed separately, participants were asked to share their perspectives. These views are documented in Table 4.7 below.

Table 4.7 Observations on whether South Africa's climate change mitigations and adaptation strategies need to be integrated into the energy policy (N.148)

Participants' Perceptions	No. of Participants	%
Yes, integration is key to project success	140	95
Do not know	7	4
No, they need to be managed separately	1	1
Total	**148**	**100**

Source: Based on field survey (2021)

Table 4.7 displays the results of a survey on the opinion of participants regarding the integration of climate change mitigation and adaptation strategies into a comprehensive energy policy. It is evident that there is a strong consensus among the participants, with 95% stating that such integration is strongly required, while only 1% disagreed with this approach. A mere 4% of participants were unable to respond to the question.

South Africa's efforts to transition to a clean energy system are reflected in the investment decisions made to increase the power capacity of the grid. In line with this, the survey participants were asked to express their views on South Africa and Eskom's recent investments in the coal-fired power plants of Medupi and Kusile. The results of this inquiry are presented in Figure 4.24.

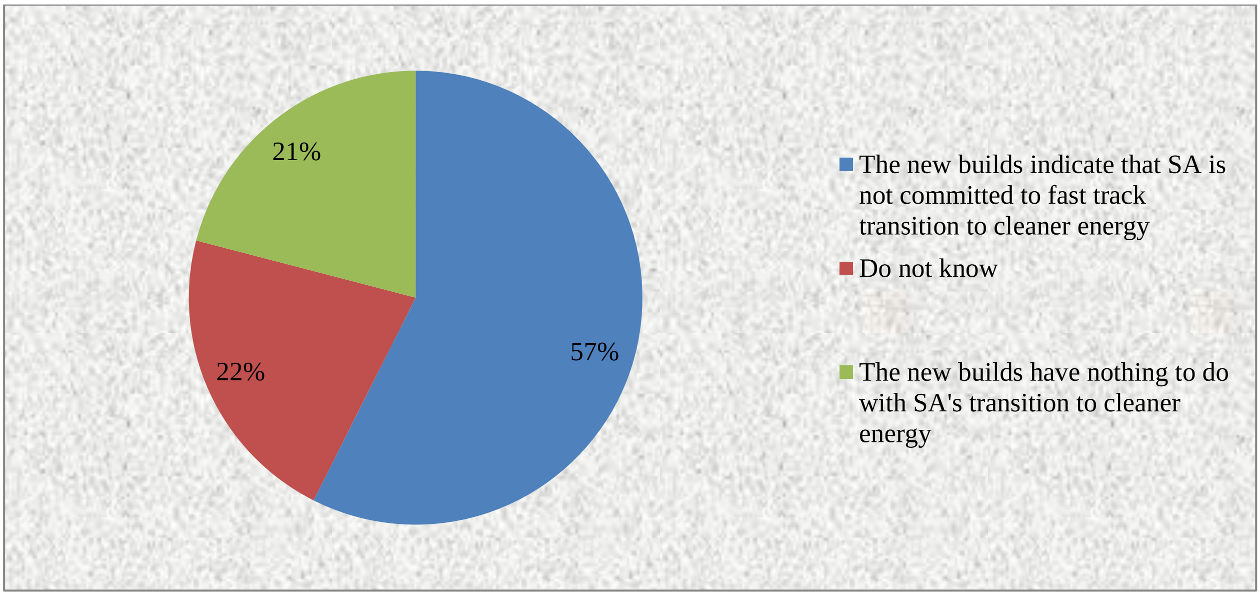


Figure 4.24 Viewpoints on the construction of Medupi and Kusile coal power plants in line with SA's energy policy (N.148)

Source: Based on field survey (2021)

Figure 4.24 presents the results on participants' views regarding South Africa's investment in the new build coal-based energy sources, Medupi and Kusile. The data shows that 57% of the participants perceived this investment as a lack of commitment by South Africa to rapidly transition to cleaner energy systems. Only 21% of the participants considered the new build programme as a necessary step separate from the energy transition programme, while 22% were unable to respond to the question. Table 4.8 below presents the results of additional interviews conducted on the same subject, offering further insights into the views of the participants.

Table 4.8 Views on Eskom's recent large spending on constructing Medupi and Kusile coal power stations (N.23)

Participants' Perceptions	No. of Participants	%
Despite the challenges associated with abnormal cost escalations, Medupi and Kusile plants were absolutely necessary to achieve short-medium term energy security.	19	83
Do not know	1	4
The project was a pure waste of money; definitely misaligned with SA's energy transition plan.	3	13
Total	23	100

Source: Based on field survey (2021)

Table 4.8 presents the views of interview participants on the new builds, which contrast with the perspectives of survey participants depicted in Figure 4.24. The majority of survey participants (83%) believed that the new builds were necessary to address immediate energy demands, whereas a minority of 13% felt that they were a waste of money and misaligned with the country's energy transition plan. Survey participants largely viewed the new builds as misaligned with transition objective while interview participants believed that new builds were absolutely necessary to address immediate energy need. In highlighting why the new builds were needed then, a specialist from coal power plant argued that:

> "Medupi and Kusile are RSA's "cleanest" coal-fired power stations. Medupi is also relatively "water smart". From this perspective, they are the best coal fired power station in the fleet (from a GHG emissions point of view). Having said that, no further investments should be made into coal fired power stations unless they come along with carbon capture upon initial commissioning (net zero GHGs) and other relevant abatement technology to reduce emissions of GHGs as well as primary pollutants" – (Pers.com 2021k).

Adding perspectives in support of why the new builds were required, Pers.com 2021s from hydro power station indicated that:

> "Medupi and Kusile are a strategic power stations which will add almost 10 000 MW's into the national grid, which South Africa needs as it will help to end load shedding which is crippling the South African economy. The country still needs coal-fired power stations in order to ensure the sustainability or continuous supply of electricity to its citizens".

4.5 COMPREHENSIVE ENERGY TRANSITION AND SUSTAINABLE ENERGY SYSTEM IN SOUTH AFRICA

This section presents the views of participants regarding the role of comprehensive energy transition in ensuring a sustainable energy system in South Africa. It also showcases fieldwork data that highlights the link between the effects of climate change, energy transition, and a sustainable energy system in the country. Energy transition has a significant socio-economic impact on South Africa, and thus, participants were asked to express their opinions on the significance of transitioning South Africa's energy sector towards cleaner energy systems in ensuring energy security. Participants' views on this matter are depicted in Figure 4.25.

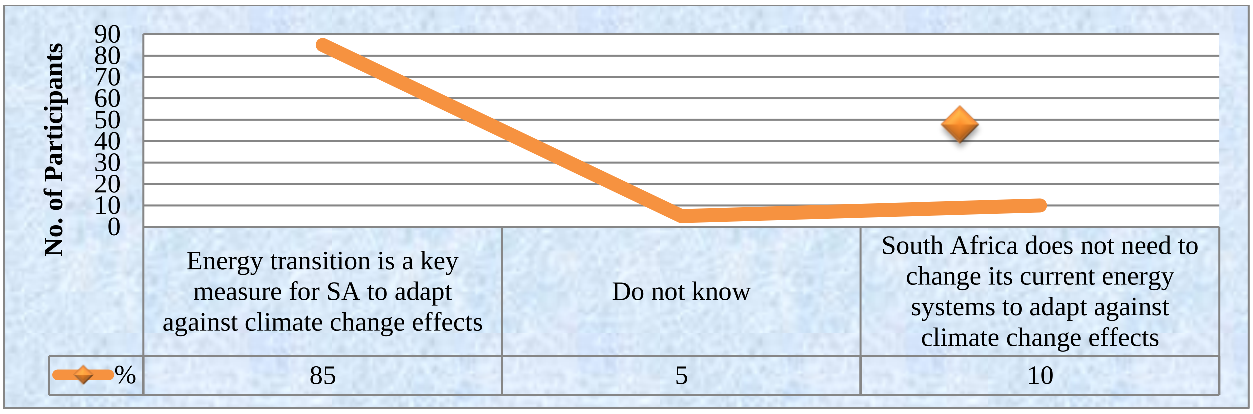


Figure 4.25 The importance of a transition to cleaner energy sources in South Africa
Source: Based on field survey (2021) – refer to Annexure A7 for raw data

The perceptions depicted in Figure 4.25 reveal that a substantial majority (85%) of survey participants hold the view that transitioning to cleaner energy systems is a crucial step for South Africa to establish a diverse energy system that is adaptive and resilient to climate change. Conversely, a minority (10%) of participants did not consider energy transition to be necessary in order to mitigate the effects of climate change in the country. The remaining 5% of participants were unable to provide a response to the statement. To complement the data obtained from the survey, interview participants were also asked to provide their thoughts on the potential benefits of a comprehensive energy transition and energy mix for South Africa. The results of these interviews are summarized in Box 4.3.

Box 4.3 Views on the long-term benefits of transitioning to cleaner energy systems (N.23)

- Reduction in emissions of pollutants (GHG, PM10, etc.,), improved air quality and improve health for communities living within pollutants' receiving environment – (Pers.com 2021z, Pers.com 2021y, Pers.com 2021x, Pers.com 2021v, Pers.com 2021u, Pers.com 2021t, Pers.com 2021r, Pers.com 2021p, Pers.com 2021o, Pers.com 2021n, Pers.com 2021j, Pers.com 2021f).
- Ensure energy security through sustainable clean energy technologies – (Pers.com 2021d Pers.com 2021s, Pers.com 2021m, Pers.com 2021l)
- Conserve the scarce water resource – (Pers.com 2021x and Pers.com 2021i)
- A diversified energy mix is more flexible – (Pers.com 2021k)
- There are three potential benefits of the cleaner transition: (1) Lower carbon footprint (2) Cheaper energy (renewable are getting cheaper) (3) Energy democracy (ability for self-generation) – (Pers.com 2021g)

Source: Based on field survey (2021)

According to Box 4.3, a majority of participants (57%) hold the belief that transitioning to alternative energy sources will mitigate air pollution, thus enhancing the health of individuals negatively impacted by high emissions. In addition to energy security through the adoption of cleaner technologies, participants also identified water conservation and energy diversification as benefits of energy transition. The views of both interview participants (Box 4.3) and survey participants (Figure 4.4) align in that energy transition will not only help reduce carbon footprint and slow down climate change, but also ensure the establishment of flexible energy-generating plants.

The current energy baseload of South Africa heavily relies on coal source, and therefore, a comprehensive energy transition necessitates the integration of a greater proportion of renewable energy sources to attain diversity. This is why survey participants were asked to share their perspectives on the benefits of renewable energy systems, with the results depicted in Figure 4.26.

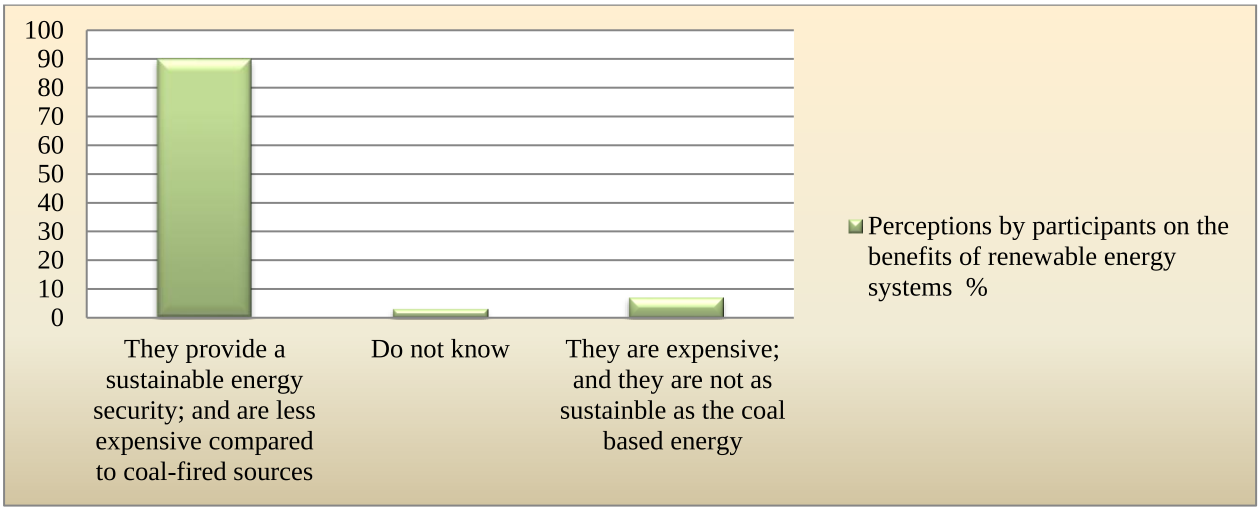


Figure 4.26 Insights on the advantages of renewable energy systems in terms of affordability, reliability, and sustainability (N.148)
Source: Based on field survey (2021)

The findings presented in Figure 4.26 demonstrate that majority of participants, 90%, viewed renewable energy systems as affordable, reliable, sustainable, and providing energy security. In addition, the majority of participants considered renewables to be less costly compared to coal energy sources. Conversely, a minimal number of respondents, 7%, believed that renewables were expensive and unsustainable. A small number of participants, 3%, expressed their lack of knowledge on the matter. Furthermore, a practitioner within the environmental sector and a participant working at a coal energy source expressed the views as follows:

> "The problem in South Africa is not necessarily the willingness, but inability to secure the funds that are required to fund renewable energy. Renewable energy projects are high risk due to availability. Sources are dependent on natural factors such as temperature, availability of water and wind, which are not a guaranteed. The risk factor is also considered in the repayments of the loans that SA gets from the World Bank. This will significantly increase the cost of electricity. SA needs to open the energy market and allow small energy producers to generate renewables and sell the electricity to Eskom" – (Pers.com 2021An).

Pers.com (2021Ao), whose views were observed from a webinar, commented that *"the bottom line is that investment will be eliminated by poor investor certainty"*. In contrast to this view, another participant observed from a webinar argued that *"there are many green funders out there, willing to provide loans for renewable energy projects at a really good interest rate"* (Pers.com 2021Ap).

Furthermore, to acquire a deeper understanding of the long-term impact of coal-based energy sources in relation to cost, participants were asked to share their perceptions. This information was gathered to determine the cost-justifiability of transitioning from coal energy baseload. The participants' views are shared in Table 4.9.

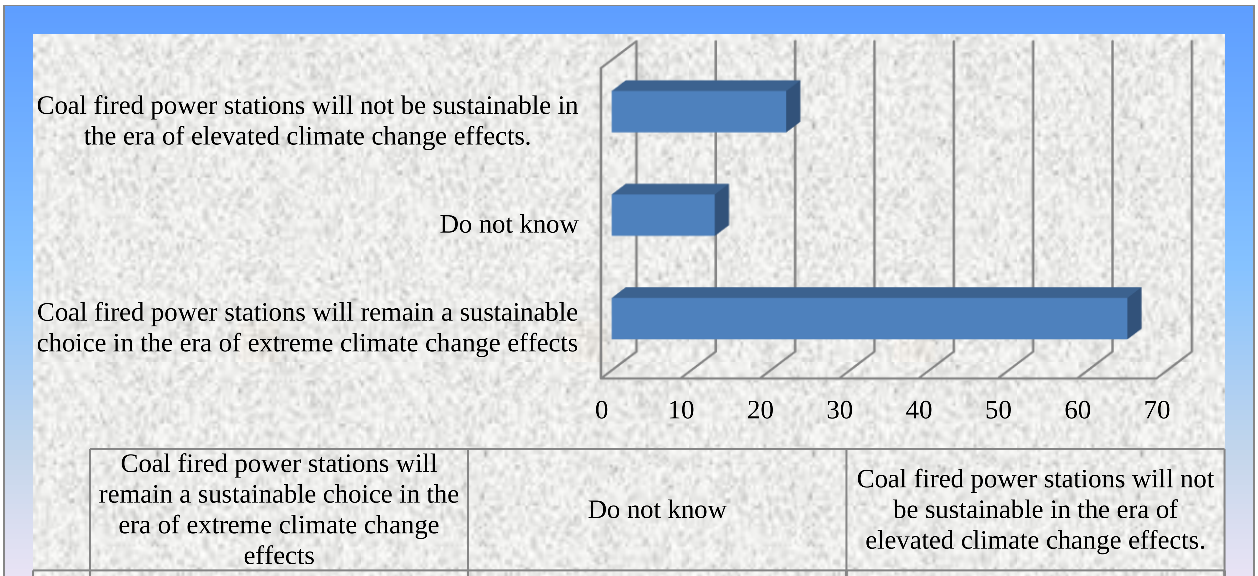
Table 4.9 Long-term cost implications for operating coal-fired power stations

Participants' Perceptions	No. of Participants	%
Coal-fired power stations may prove to be highly costly for SA as they will need to be overhauled or shut- down due to lack of coal	84	57
Do not know	21	14
Coal-fired power stations will always remain a cheaper energy-generating source in SA	43	29
Total	**148**	**100**

Source: Based on field survey (2021)

Table 4.9 indicates that the majority of participants (86%) held the view that coal energy sources was a liability in terms of operating costs over time, while only 14% were uncertain in their response. Of those who responded, 57% believed that coal energy sources would become increasingly expensive to operate in the long term, while 29% argued that they would remain a more cost-effective energy source in South Africa. The results from Figure 4.26 and Table 4.9 are aligned in their suggestion that renewable energy sources are more economically viable and that coal power plants are likely to become increasingly costly over time.

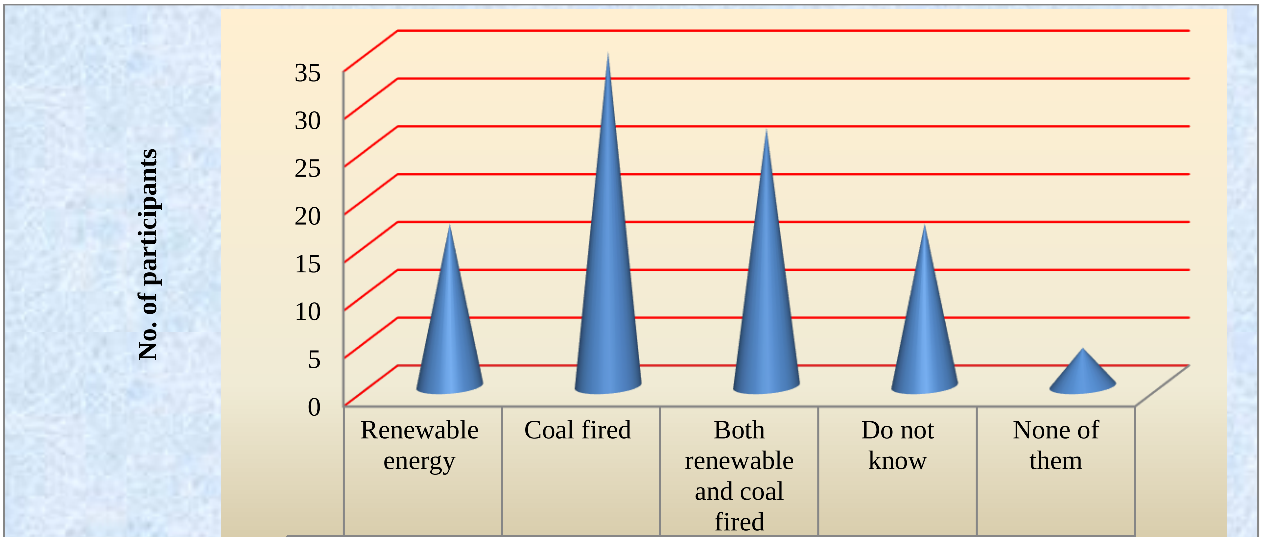
The questionnaire survey also sought to gauge participants' views on the resilience of coal energy sources in the face of the impacts of climate change. Figure 4.27 presents the participants' views on this matter, aimed at determining whether the high cost of operating these power stations would be offset by their ability to withstand the challenges posed by a changing climate.



	Coal fired power stations will remain a sustainable choice in the era of extreme climate change effects	Do not know	Coal fired power stations will not be sustainable in the era of elevated climate change effects.
%	65	13	22

Figure 4.27 Observations on the robustness of Eskom coal-fired power stations to withstand climate change effects
Source: Based on field survey (2021) – refer to Annexure A8 for raw data

Interestingly, findings indicate that 65% of participants believed that coal power plants have the resilience to withstand the impacts of climate change (Figure 4.27). Conversely, only 22% were of the view that Eskom's coal power generators are not robust enough to endure the consequences of climate change, while 13% were uncertain of their response. To acquire additional data for triangulation purposes, participants were queried regarding the energy source most prone to the effects of climate change between coal and renewable energy sources (refer to Figure 4.28).



	Renewable energy	Coal fired	Both renewable and coal fired	Do not know	None of them
%	17	35	27	17	4

Figure 4.28 The most vulnerable energy source to climate change effects (N.23)
Source: Based on field survey (2021)

According to Figure 4.28, a mere 4% of the participants believed that none of the energy sources would be immune to the impacts of climate change. On the other hand, 26% of the participants held the perspective that both renewable and coal energy sources would experience adverse effects of climate change. This viewpoint is supported by an expert from an environmental consultancy who argued that:

> "Climate change has caused changes in weather patterns with frequent incidents of extreme weather events. Both renewable and coal-fired energy systems are equally affected by these changes depending on the nature of the extreme weather event. Unusual wet weather will make the coal too wet and will affect energy generation from coal. High wind speeds associated with some weather events will affect power generation from wind farms. It is reported that at a wind speed of above 25 km/h, some wind turbines shut down on auto-protection as they are unable to produce wind energy. It is also reported that the efficiency of solar panels is also affected by extreme heat"- (Pers.com 2021v).

Figure 4.28 indicates that 35% of the participants considered that coal-fired power generators would be more susceptible to the impacts of climate change, compared to only 17% of participants who viewed renewables as more vulnerable. This view differs from that of the majority of participants in the survey shown in Figure 4.27, as a substantial proportion of interview participants (35%) perceived coal energy sources to be more vulnerable to the effects of climate change. Additionally, Pers.com (2021f) stated that:

> "Coal plants would be more susceptible because their functioning processes have a temperature-related regulation, especially high temperatures. With respect to renewables, I believe they can be retrofitted for resilience relatively easier than coal stations, particularly due to their lower levels of complexity when compared to coal."

Interview participants were queried about the measures that Eskom power generation plants may adopt in order to establish a climate change adaptive and resilient sector. The objective of this line of inquiry was to determine if a transition to cleaner energy systems should be considered among the measures Eskom could invest in, in order to adapt to the impacts of climate change and establish a sustainable energy system. The insights obtained from the interview participants are presented in Figure 4.29 below, which highlights the various measures that Eskom should consider as adaptive measures.

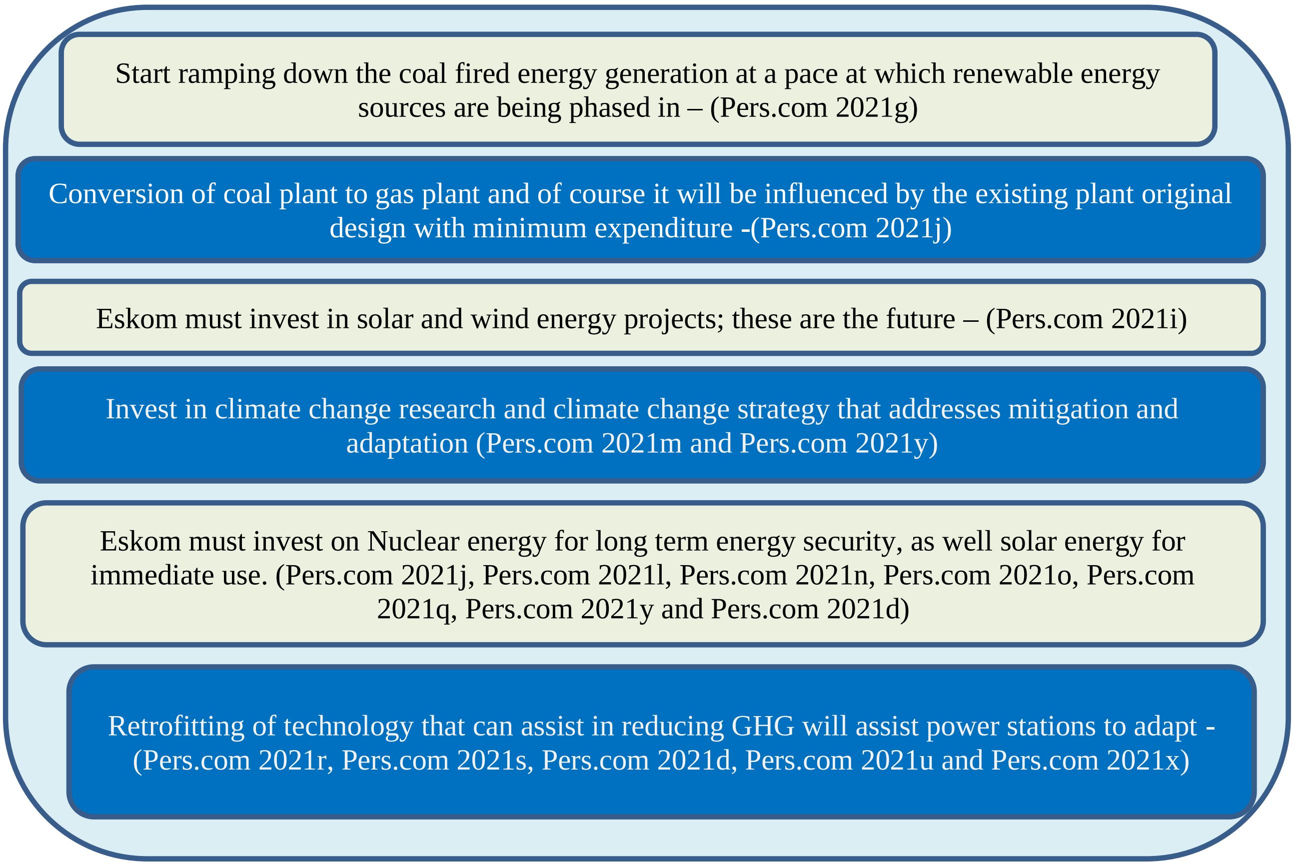


Figure 4.29 Suggestions for Eskom to adapt against climate change effects (N.23)
Source: Based on field survey (2021)

As shown in Figure 4.29, 30% of participants proposed that investing in nuclear energy sources constitutes a suitable long-term strategy, while an investment in solar energy represents an immediate action that Eskom should consider in order to cope with the impacts of climate change. One practitioner in the field of the environment, working in a coal power plant, also expressed the opinion that:

> "It is critical for Eskom coal-fired stations to invest on technologies that will enable the use of less water for cooling. Hydro power plant should consider the use of methods such as those in the pumped storage schemes (Ingula)"– (Pers.com 2021p).

A practitioner in the field of the environment from a pumped storage scheme, Pers.com (2021s), also contributed the following statement:

> "Coal-fired power stations should invest on the installation of high-frequency transformers and fabric filter plants that will assist in reducing the emission of noxious gases into the atmosphere. Hydropower station can invest on alien vegetation removal projects along their

catchment areas and dam verges since alien vegetation consume lot water and threaten the long-term sustainability of hydropower stations, and reuse water such as at pumped storage schemes (e.g. Palmiet, Ingula and Drakensberg Pumped Storage Scheme).

In addition to the viewpoints of participants captured in Figure 4.25 above, the participants were further asked to express their opinions on the current level of concern within South Africa's energy sector regarding climate change adaptation measures. The purpose of including this question in the study was to elicit views on the urgency of implementing the energy transition and adaptation strategy in the country. The results of this inquiry are depicted in Figure 4.30.

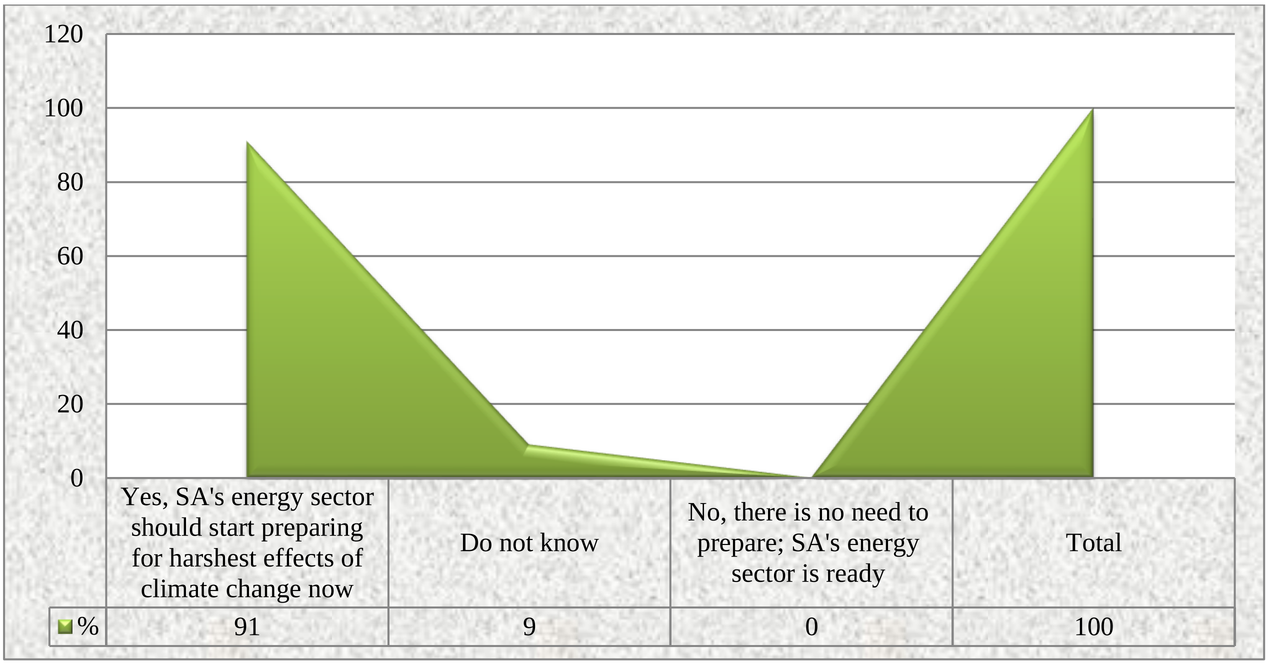


Figure 4.30 Insights on whether South Africa's energy sector should immediately start to work on the climate change adaptation strategy (N.23)
Source: Based on field survey (2021)

The findings of the fieldwork, depicted in Figure 4.30, reveal that 91% of the participants who responded to the question concurred that South Africa's energy sector should immediately commence work on the adaptation measures for climate change. Only 9% of the participants were unable to provide a response. Supplementing the views presented in Figure 4.30, an environmental specialist from an environmental consultancy stated that:

"South Africa should concern itself with climate change and the adaptation ability because it is very vulnerable to the effects of climate change. South Africa is likely to experience hotter weather, less rain and erratic climate conditions. It is likely to impact the hydrological

> yield and food security. The effect might be intense in 20-30 year but there is no denying that we have already started experiencing them" – (Pers.com 2021g).

In accordance with the findings reported by Pers.com (2021g), a participant from the power generation industry also emphasised that:

> "Southern Africa is predicted to be disproportionately affected by climate change. The number of hot days will increase, and models predict increased severe weather events (e.g. flooding). The elevated levels of inequality and poverty in South Africa places the country at high vulnerability to the effects of climate change, and women, children, the elderly and the sick are most affected. We are already feeling the impacts of climate change; it is not 20-30 years away. If we wait that long to do something, it will be too late (it already may be). Governments, the private sector, investors, and small businesses, the public… all should make adaptation plans a priority. Climate change is everyone's business and will affect everyone" – (Pers.com 2021k).

A participant whose perspective was recorded during a webinar expressed the following:

> "South Africa need to undertake vast measures in response to climate change risks and impacts. The country also needs to intensify its education and awareness on the impacts of climate change and strengthen the capacity of key stakeholders from all sectors of society to ensure effective implementation and inclusive actions towards climate change"- (Pers.com 2021Ar).

A comprehensive energy transition in South Africa requires a shift from the current baseload, which primarily consists of coal-fired energy sources, to a mixture of energy sources. To acquire a deeper understanding of this issue, participants were asked to share their perspectives regarding the significance of energy mix in the energy system transition process. The results are displayed in Box 4.4 below.

Box 4.4 The importance of energy mix as an integral part of the solution to climate change and energy security nexus (N.23)

- Different energy sources offer different characteristic, which make the grid more resilient. It also offers an opportunity to participant in the energy transition so that the country can build the necessary capacity in a new world energy order (Pers.com 2021g, Pers.com 2021f and Pers.com 2021y).
- By ensuring that the country avoid relying on one energy source which cannot be able to meet the demand and sustain economy (Pers.com 2021l and Pers.com 2021q).
- The energy generation mix in our country will enable a smooth transition and gradual phasing out of GHG emitting plants contributing to climate change (Pers.com 2021l, Pers.com 2021i, Pers.com 2021j, Pers.com 2021m, Pers.com 2021p, Pers.com 2021r, Pers.com 2021v and Pers.com 2021x).
- Flexibility, Resilience, Back-up and peaking station options for quick start-up (Pers.com 2021k and Pers.com 2021t).
- It will optimise the use of natural resource such as the solar radiation, Wind and Oceans (Pers.com 2021o)
- It will ease the pressure from the coal energy sources, and promote the usage of green energy, which will benefit the current and future generations (Pers.com 2021s).
- It is important to ensure energy supply security in case coal energy supply fails due to effects of climate change (Pers.com 2021u and Pers.com 2021z).

Source: Based on field survey (2021)

The views expressed in Box 4.4 suggest that an energy mix will bring diversity, resilience, and flexibility to South Africa’s energy sector. Participants also believe that an energy mix will lower greenhouse gas emissions and hasten the transition programme in South Africa’s energy sector. Pers.com (2021n), an environmental specialist in coal power plant, made the following statement:

> “Climate change is an existential threat to the country so ensuring energy mix allows SA to decommission old coal stations which are major source of greenhouse gases. Failure to achieve the energy mix will have severe consequences on the economy, human health, and disasters such as extreme floods/storms and drought”.

Contrary to the perspective expressed by Pers.com (2021n), another participant from a coal-fired power station offered a differing viewpoint, stating that:

> "There needs to be a good balance of energy mix in SA. You cannot rely only on renewables in a water-scarce country or wind and solar which also have other negative effects. The current need of electricity which is a necessity in a third world country outweighs the climate change effects. Farming, burning of fires in rural areas etc. also contributes significantly to gaseous emissions and has a great contribution to climate change. Wind and solar are not cheap and vast areas of land will need to be made available to supply the current demand of electricity. Adoption of stricter legislation and the COP requirements has gotten SA on the move towards meeting first world standards, but there are a lot of issues that need to be addressed with the coal fleet before we can fully comply. Retrofitting technology is expensive and funding may not be freely available and so while the government can have these controls in place and monitor from their perspective, providing a basic need to the people of the country allows for exemptions and postponements. There needs to be proper investigation into South Africa's energy needs, the diversification of energy and how it can be provided (be it nuclear, coal and supported by other renewables). Granted, the new stations should have had abatement technologies already fitted and not after the fact, look at FGD for Medupi as an example" – (Pers.com 2021Ad).

In accordance with the views of the survey participants presented in Figure 4.26, the issue of the cheaper and sustainable energy source between coal and renewable energy sources was also addressed with the interview participants. Their perspectives are illustrated in Figure 4.31 below.

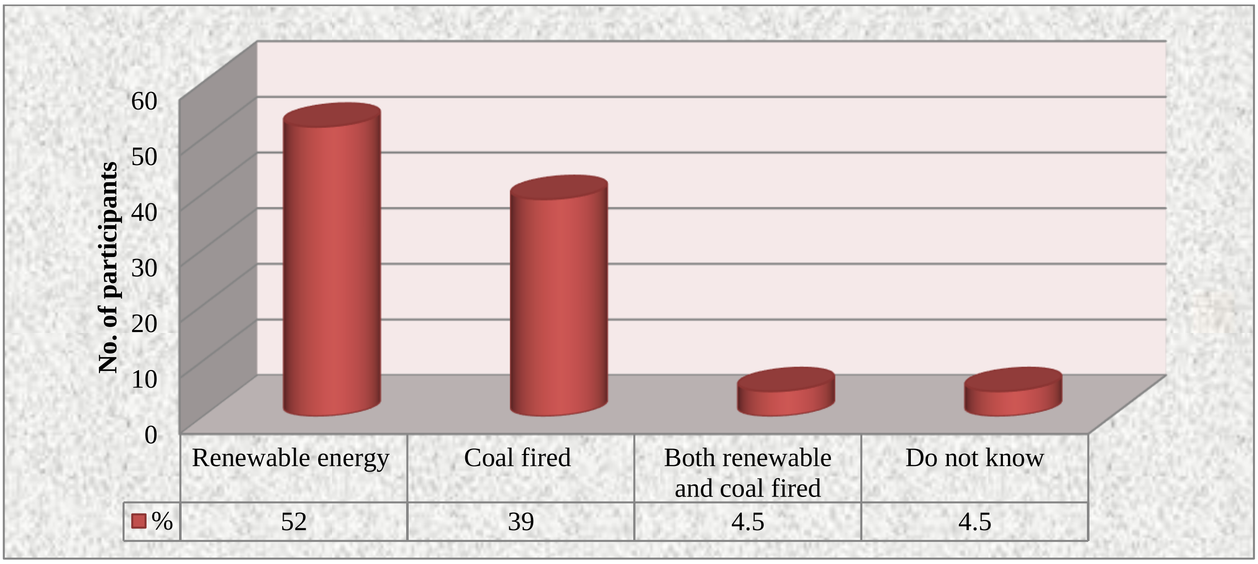


Figure 4.31 Views on the cheaper energy-generating source (N.23)
Source: Based on field survey (2021)

Figure 4.31 indicates that 52% of interview participants perceived renewable energy sources to be more cost-effective than coal energy sources. These perspectives are in line with the findings of the survey, which suggested that renewable energy is a more cost-effective investment option compared to coal energy sources (Pers.com 2021f). It was further noted by Pers.com (2021f) that:

> "Capital and operation costs are much higher for the coal plant than a renewable plant. Also, from sustainability principles, coal-fired generation has a great impact to society at large than renewables. However, in the context of South Africa, renewable energy is not nearly sufficient to service the developmental needs of the country."

Pers.com 2021g resonated with Pers.com 2021f's view in that, "*currently the cost of renewable energy might be high, but it is dropping very fast. As input cost increase, the cost of coal technology will increase. The future is renewable, distributed energy*"; similar view was also shared by Pers.com 2021Am. As indicated in Figure 4.31 above, 39% of participants viewed coal generated energy as cheaper than renewable energy. Pers.com 2021e, who also viewed coal generated energy as cheaper, argued that:

> "South African has enough coal resources and this must be used as a catalyst to address poverty and inequalities. It them becomes obvious that coal-fired is cheaper at the moment. Renewable technologies can only be afforded by the middle class and the elite due to the price tag attached to renewables."

Another participant also added that, "*coal fired energy generating technology is the cheapest, but due to the aging technology used when power stations were constructed, it is difficult to sustain the fleet to its maximum load. Renewable are environmental friendly but too expensive for developing countries*" – (Pers.com 2021r). An experienced engineer who participated from coal power plant added that:

> "There is abundance of coal in South Africa, and therefore we cannot completely turn our backs on it. I feel that Eskom, with the support from government, can focus on improving the thermal efficiency of our coal-fired power stations while running cleaner initiatives in parallel and also start burning better quality coal. Once this is done, post combustion emission control technologies can be considered as an additional measure. Renewable energies are far more expensive and not reliable as compared to coal. Even if renewables are brought in, they will still need coal as back up, so why not invest in coal right from the

> beginning. A proper strategy is required"- (Pers.com 2021Ah). Similar view was also shared by Pers.com 2021Af, Pers.com 2021Ai, Pers.com 2021Ak and Pers.com 2021Aj who participated in the survey.

In support of a perception by Pers.com 2021Ah, another participant from coal power station highlighted that:

> "As much as we appreciate the adverse consequences of climate change due to emissions from coal powered stations, we must note the massive initial cost required to build renewable energy sources. The problem is that the most probable renewable energy source, which is solar, cannot sustain a country as big as South Africa in severe summer conditions let alone winter/rainy seasons when they are less efficient. It is cheaper for South Africa to build coal plants as energy sourced, and this must be greater source since we have the coal resource on our side. To reduce the overall environmental damages, 1st world countries should be the ones investing on renewables and let the poorer countries like South Africa stick to coal. This is however not the case as we can see even the rich countries like China and USA are building more coal power plants"- (Pers.com 2021Al).

Interview participants were also asked to share their views on other energy sources that South Africa and Eskom could look into to achieve a balanced energy mix. Generally, interview participants identified solar energy, wind energy, hydro, and nuclear power generation as well as battery storage as the best technologies which should be further investigated as potential sources to achieve energy mix in South Africa. Pers.com 2021k from hydro power generation sector raised an argument that: "*South Africa is a water scarce country, so pumped storage is not sustainable as a main energy source. More base-load options including solar and wind and battery storage should be investigated in time".* Pers.com 2021q from environmental consultancy also added that:

> "Wind and solar are already proven to be a viable source, but nuclear energy is totally under exploited. New technologies devised by TerraPower should be looked at. This technology can use depleted or used Uranium which is basically an unlimited source. Why not get South Africa involved? An integrated energy mix is required rather than one source as each energy technology has separate advantage and disadvantages. (i.e. solar without storage cannot supply electricity at night)".

The study also solicited the opinions of interview participants on the key stakeholders that are crucial to the success of an energy transition programme. The participants' identification of these stakeholders is presented in Table 4.10 below.

Table 4.10 Suggestions on who should play a part to achieve South Africa's comprehensive transition to cleaner and sustainable energy systems (N.23)

Government	**Department of Energy**	**Private Sectors**
Financial Institutions	**Consumers**	**NERSA**
Research Institutions	**Investors**	**Energy Generators (e.g. IPPs, Eskom, etc.)**
Public	**Industries**	**Public-private partnerships**
Civil Society	**Authorities/Regulators**	**NGOs**

Source: Based on field survey (2021)

In addition to the role players identified in Table 4.10, Pers.com 2021f further added that:

> "Any achievement of this transition must start with government policy being aligned to the cause, and then strict focus on implementation is a critical success factor. South Africa prides itself with good sunshine in the Northern Cape, in particular – those should be harnessed for this drive".

4.6 TECHNOLOGICAL MEASURES TO MITIGATE CARBON EMISSIONS FROM COAL POWER PLANTS

Section 4.2 presented empirical evidence demonstrating the significant contribution of coal power plants to climate change via GHG emissions. Participants' views, as presented in sections 4.3 to 4.5 of this chapter, have emphasised the criticality of an energy mix in South Africa. However, participants have generally concurred that energy produced by coal, while still needed for energy security, needs to be phased out in an orderly transition. Hence, this study has also investigated other measures that may be implemented by Eskom's coal power plants to reduce or offset current GHG emissions, as highlighted in Section 4.2 above. To triangulate the survey participants' views on the significance of Eskom's GHG emissions, as depicted in Figure 4.4 above, participants were further asked about the need to act on mitigating the GHG emissions from Eskom's power plants. Figure 4.32 presents the survey participants' perceptions on this matter.

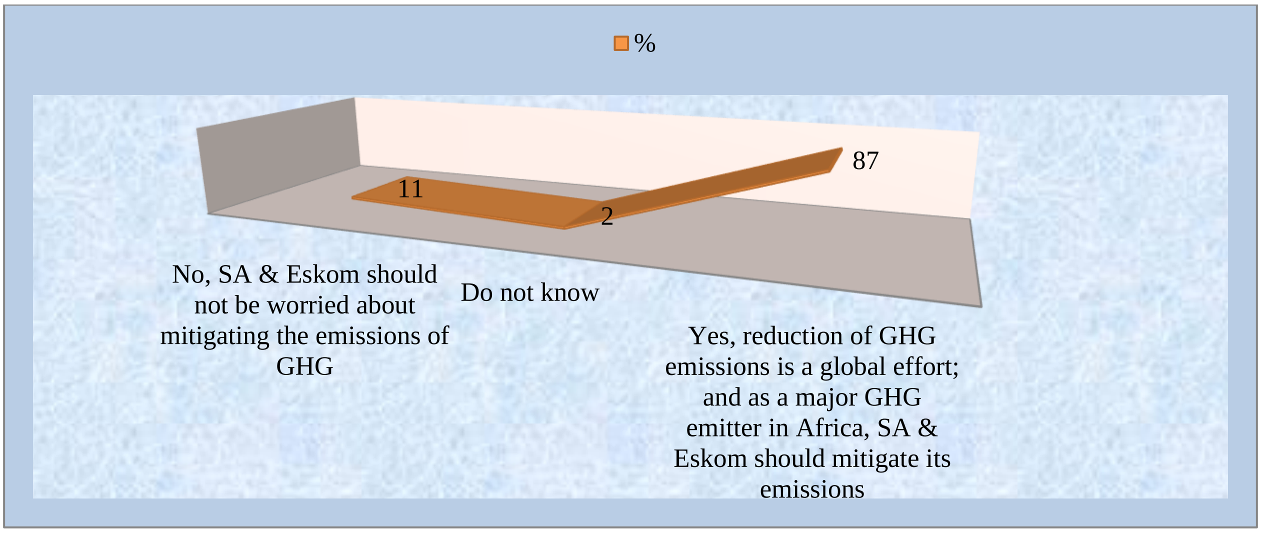


Figure 4.32 Assessment by participants on the need for SA and Eskom to mitigate GHG emissions (N.148)
Source: Based on field survey (2021)

Based on Figure 4.32, a substantial majority of participants (87%) expressed the view that South Africa should take measures to mitigate its high GHG emissions. These views are consistent with those presented in Figure 4.4, which highlights the significant contribution of South Africa's coal power plants to GHG emissions. Conversely, only 11% of participants held the view that South Africa should not invest in technology or programmes to mitigate GHG emissions, while 2% were unsure. While the participants' views depicted in Figure 4.32 indicate a clear need for measures to mitigate GHG emissions, it was necessary to determine if such measures were available. In this regard, participants were also asked about the availability of technology for abating GHG emissions. Participants' views on this issue are captured in Figure 4.33 below.

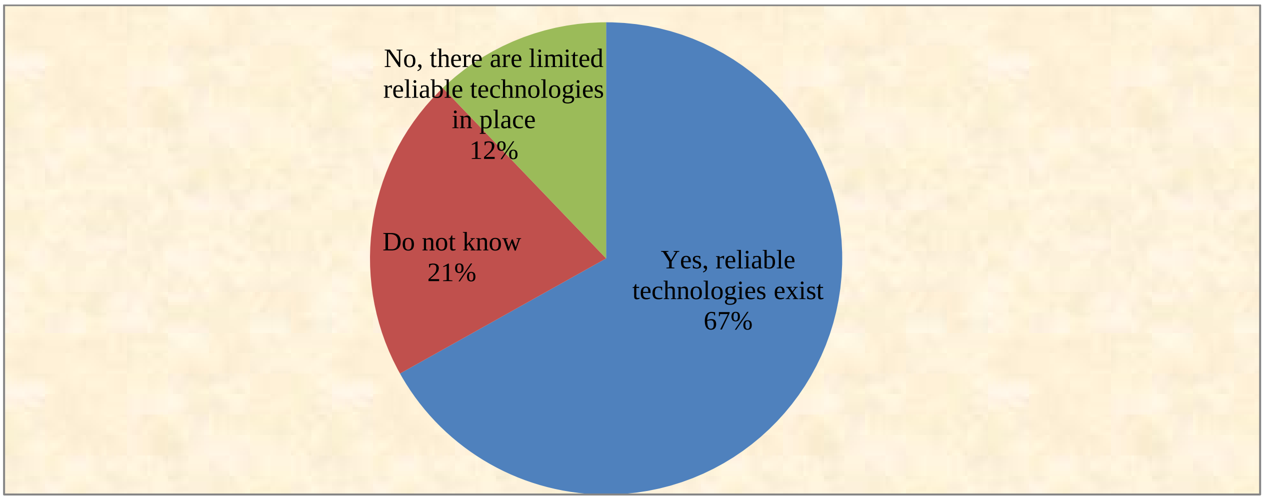


Figure 4.33 Insights regarding the existence of technologies to mitigate and offset GHG from Eskom power plants
Source: Based on field survey (2021) – refer to Annexure A9 for raw data

According to Figure 4.33, a majority (67%) of the participants were of the opinion that technologies capable of reducing GHG emissions from Eskom's coal power plants are available. Conversely, only 12% of the participants held the view that such technologies do not exist, while 21% of the participants were uncertain of their existence. A participant from a hydro power station provided insight by stating that, *"The installation of a Fabric Filter Plant and a high-frequency transformer can aid in reducing the emission of harmful gases into the atmosphere"* (Pers.com 2021o).

In addition to the survey participants' views on the availability of technology to mitigate GHG emissions, interview participants were also asked to share their perspectives on the most ideal mitigation measures to address GHG emissions from coal-fired power plants. These views are depicted in Figure 4.34 below.

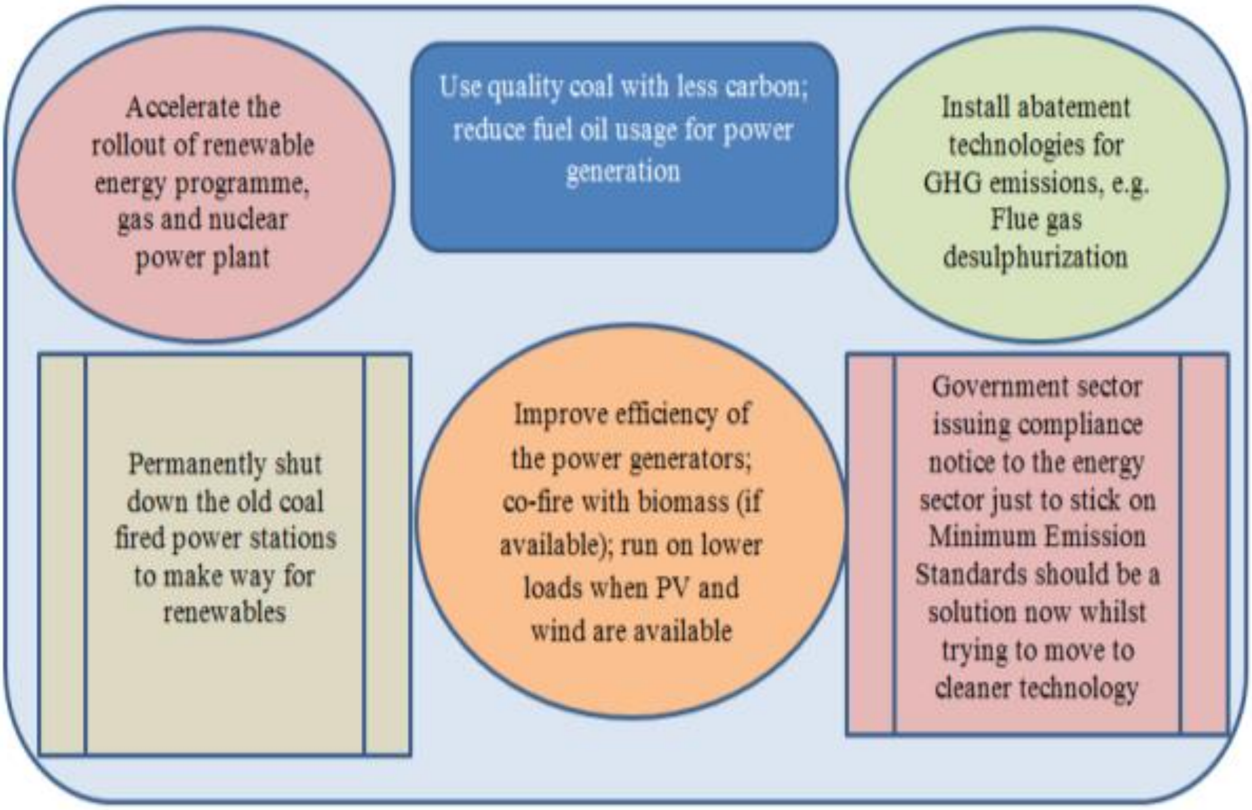


Figure 4.34 Summarised participants' perceptions on short-term measures to abate GHG emissions (N.23)
Source: Based on field survey (2021)

According to the data presented in Figure 4.34, it can be inferred that participants believe there are various measures that can be employed to mitigate high emissions of GHGs from Eskom's coal energy sources. Improving the operational efficiency of these plants was identified as one of the measures that could contribute towards GHG emissions reduction. The views expressed by the interview participants depicted in Figure 4.34 are consistent with the results of the survey participants as depicted in Figure 4.33, in that the existence of technologies to reduce GHG emissions has been acknowledged. Furthermore, one participant from a coal energy plant shared the following observation:

> “Low hanging fruit: Many of Eskom’s coal power plants are old and they require a lot of maintenance, if these are maintained properly, inefficiencies which contribute to emissions can be improved. Include more flexible independent power producers to the grid so that coal-fired power stations do not have to run when they are exceeding emission limits or are not working efficiently, or when they need to be maintained. Increase energy efficiency campaigns for the end-user”- (Pers.com 2021k).

The viewpoints expressed by participants in Figures 4.33 and 4.34 concur in the notion that there are viable measures that can be implemented to reduce high greenhouse gas (GHG) emissions. Nonetheless, it remains uncertain if such measures to mitigate GHG emissions from coal energy generators are economically feasible. In an effort to gather insight on this issue, participants were asked to share their views on the affordability of these technologies and their investment viability, as captured in Figure 4.35.

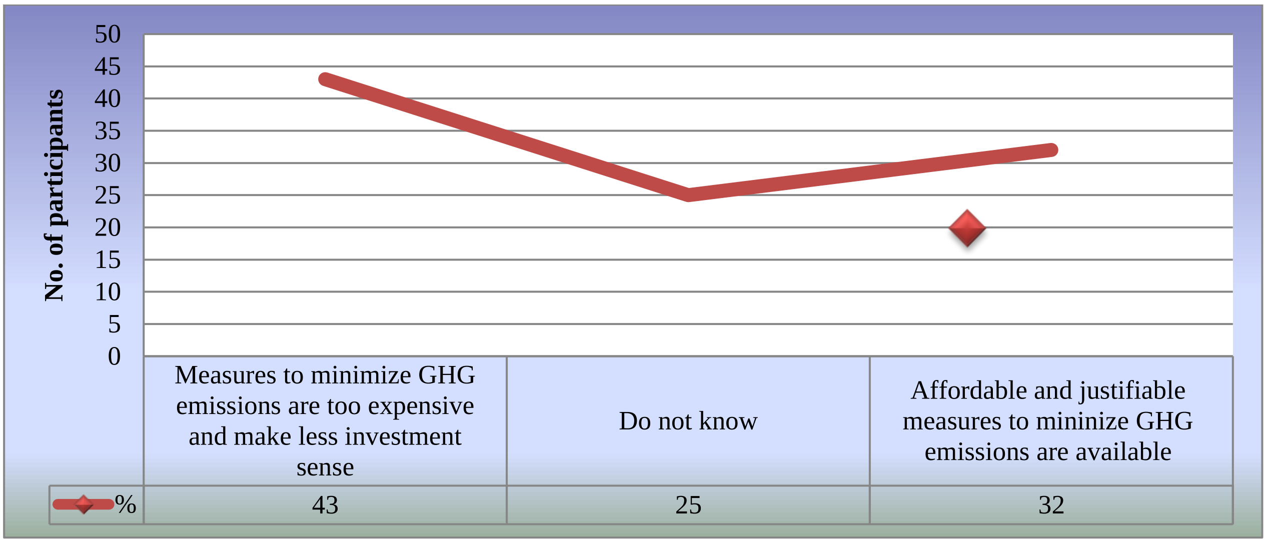


Figure 4.35 Cost of measures to abate GHG emissions from Eskom’s coal power plants
Source: Based on field survey (2021) – refer to Annexure A10 for raw data

The results presented in Figure 4.35 reveal that a considerable portion of participants (43%) hold the belief that measures aimed at mitigating GHG emissions are too costly and do not make sound investment sense. This perspective appears to contradict the stance expressed in Figure 4.32, which highlights the need for action to minimize GHG emissions. However, there were also 32% of participants who considered such measures as affordable and worthwhile investments. A quarter of the participants (25%) did not provide an opinion on the matter. With regards to the cost-effectiveness of GHG emissions reduction measures, a representative from the power generation industry, Pers.com (2021Ae), expressed the following viewpoint:

> "There are technologies that could assist Eskom to curb their impact on climate change; however, they come at a huge cost. Considering that some of the power stations that would require the implementation of these technologies are nearing their lifespan, it would not make a good business case to spend all this money and not be able to reap the benefits. South Africa needs to look at using natural renewable resources such as wind and solar as a form of power generation."

In conclusion to Section 4.6, the survey participants were asked to provide their perspectives on South Africa's Carbon Tax Act. The objective of this particular questionnaire was to determine if the participants viewed the Act as an added measure that would incentivize emitting companies, including Eskom, to enforce stricter control measures to reduce carbon emissions in light of potential penalties. The participants' views are presented in Table 4.11.

Table 4.11 Participants' expressions on the recent gazette of Carbon Tax Act (N.148)

Participants' Perceptions	No. of Participants	%
The Act will result in a significant reduction in CO_2 emissions from most emitter companies in South Africa including Eskom	64	43
Do not know	38	26
Not much should be expected; big companies will still budget for penalties caused by their operations	46	31
Total	148	100

Source: Based on field survey (2021)

As indicated by Table 4.11, only 110 out of 148 survey participants were knowledgeable about the Carbon Tax Act. Of these participants, 43% believed that the Act would help South Africa to control CO_2 emissions from industries, while 31% saw it as having limited impact on reducing CO_2 emissions. A quarter of the participants (26%) were unable to respond to the statement. This majority view was supported by Pers.com (2021f), who noted that:

“This is a good position for the environment, however, the fact that climate change issues are non-committal (at Conference of Parties, COP) and the fact that developing states may be deprived of the opportunity to grow best, may present an unfavorable taste. However, considering that the environment is a provider of natural resources, it is important that principles of sustainability are implemented. There are social and health aspects related to any emissions, which creates a gap between people who can afford and those who cannot – and a balance must be maintained, especially because our country has high unemployment levels. Therefore, provision of jobs should not be presented as a trade-off for people’s health (long life).”

In addition to the views expressed by survey participants in Table 4.11, interview participants were also asked about the impact of the Carbon Tax Act on carbon emissions reduction from South Africa’s major emitting industries. These participants’ views are depicted in Figure 4.36 below.

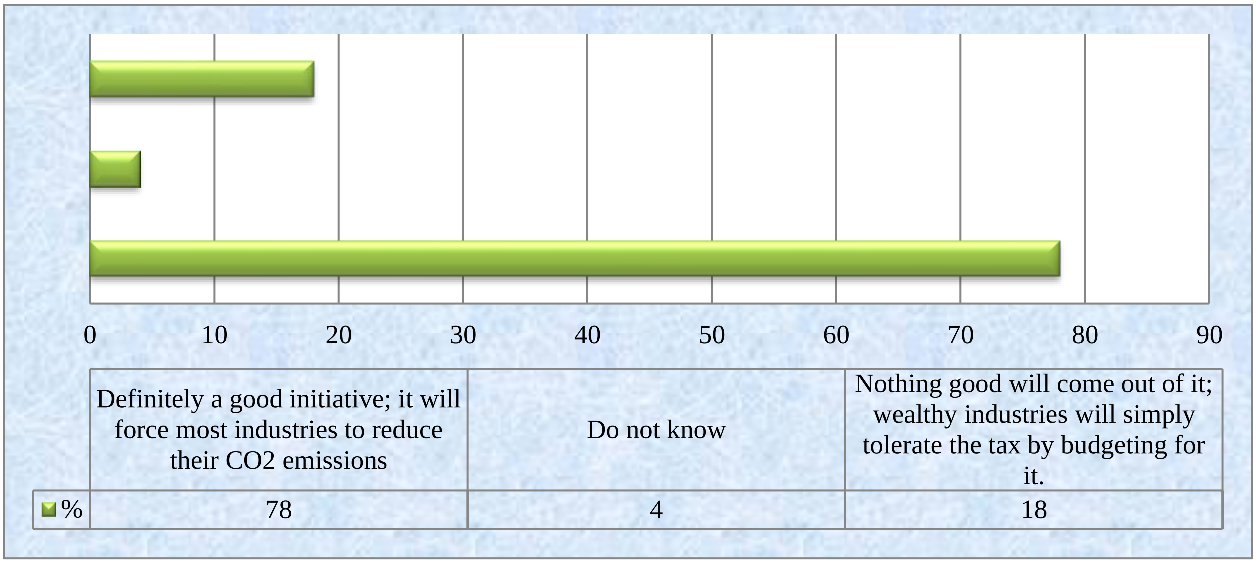


Figure 4.36 Viewpoints on the recently gazetted Carbon Tax Act in South Africa (N.23)
Source: Based on field survey (2021)

Figure 4.36 reveals that a considerable proportion of interview participants, 78%, hold a positive perspective regarding the Carbon Tax Act as a means of encouraging emission reduction in emitting industries. In contrast, 18% of participants expressed a dissenting viewpoint, while a small proportion of participants, 4%, were unable to provide a response to the question. The observation by Pers.com (2021i) from a coal-fired power station showed a less optimistic outlook towards the Act, with the following statement:

"Although the Carbon Tax has been implemented, human health which is being deteriorated as a result of air pollution from the plants can't be replaced". Another participant further added that, "while on paper it is noble, but it must be part of the comprehensive strategy to deal with climate change" - (Pers.com 2021n).

4.7 SUMMARY

Chapter 4 provides a comprehensive examination of the participants' perceptions on the link between climate change and energy security, focusing on South Africa's energy sector, i.e. Eskom power plants. The research methodology involved a questionnaire survey, interviews, participant observations, and an analysis of existing records. The findings presented in Section 4.2 as well as in Section 4.6, demonstrate that Eskom is a significant contributor to carbon emissions. Participants' views in Section 4.6 also stress the importance of reducing emissions from coal-fired power plants. Section 4.3 presented participants' views on the extent to which South Africa's energy sector is vulnerable to the impacts of climate change, indicating that the country's energy production and security will be affected. Section 4.3 also provided scientific projections indicating that South Africa may experience adverse weather conditions, such as temperature and rainfall fluctuations, which will further impact energy production. Participants' perceptions in Section 4.4 highlighted that, while South Africa's energy policy framework is suitable, it is not being implemented effectively. In Section 4.5, participants' views emphasized the need for increased energy diversity and a transition towards cleaner energy systems as a crucial step towards adapting to the effects of climate change. The detailed findings presented in this chapter effectively address the research problem, questions, aims, and objectives.

CHAPTER FIVE

ANALYSIS AND DISCUSSION

5.1 INTRODUCTION

This chapter presents the analysis and discussion of the findings of the current study, with a focus on describing, analysing, discussing, and interpreting the implications of the results. The discussion chapter brings together all the previous chapters and their relationships, enabling the reader to comprehend the significance of the research outcome. The chapter describes and interprets the importance of the findings within the context of the research problem and questions, and outlines the significance of the current research findings, the academic value added to existing literature, and areas that fell short of expectations (Dunton, 2021).

With this understanding, Chapter Five begins by examining the contribution of South Africa's energy sector to climate change through carbon emissions. This is followed by the discussion of climate change implications on the country's energy sector, an analysis of the adequacy and effectiveness of South Africa's current energy policy, and an evaluation of the guarantees associated with the energy transition programme in achieving climate change adaptation and resilience of the country's energy sector. The chapter also explores the possible technological options for reducing the high emissions from existing coal power plants. This is presented in a methodical manner, aligned with the objectives of the research.

5.2 AN ASSESSMENT OF ESKOM'S CARBON FOOTPRINT AND CHALLENGES INDUCING CARBON EMISSIONS

The current study has found that Eskom's coal-fired power plants are the significant contributors to South Africa's carbon footprint, and this issue need to be urgently mitigated. The results also showed that Eskom's carbon footprint has been steadily fluctuating in line with the energy production pattern (GWh SO). This basically shows that Eskom's carbon emissions will remain significantly high for as long as coal power plants remain South Africa's primary source of electricity. This is because Eskom's old coal power plants are not fitted with any CO_2e abatement technology. South Africa and Eskom are faced with a real dilemma of having to meet the decarbonization commitment made as part of Paris Agreement, while also trying to manage Eskom's fragile power generation fleet which cannot afford to reduce energy production load for purposes of decarbonization, and still be able to supply the required baseload to the grid. It can therefore be argued that South Africa need to look at other innovative ideas to decarbonize while not interrupting the energy grid. The field work results made a recommendation for an urgent action in this regard, and this can only be realised if there is a political will to urgently look at available decarbonization quick wins. What is further concerning is that, in the 10 years period scrutinized by the current study, Eskom's carbon footprint does not appear to be gradually declining, however, it has been fluctuating up and down indicating that the power utility has no control on carbon emission reduction at all. What was noted as another issue of concern is that there were certain instances where a sharp decline in energy production (GWh SO) was evident between 2010 and 2020, however carbon emissions decline was relatively insignificant. This could be indicative of other operational issues such as coal qualities, that are contributing to Eskom's significant carbon footprint. There is a need to thoroughly study Eskom's carbon emissions in relation to operational and maintenance philosophy, in order to find out if the coal power plants cannot be optimized to promote decarbonization. The study also found that most of South Africa's coal-fired power stations are old and do not have carbon emissions abatement technologies. These power stations were commissioned from the late 1960s to the early 1990s, and were not designed with gaseous emissions' abatement technology as the connection between carbon emissions and climate change effects was not widely researched, projected, and understood at the time (JMU, 2021). Only two newly constructed power stations, Medupi and Kusile, are equipped with a flue gas desulphurisation (FGD) system to reduce gaseous emissions. Figure 5.1 below was developed by the current study to contextualise the age of the existing coal-fired power stations.

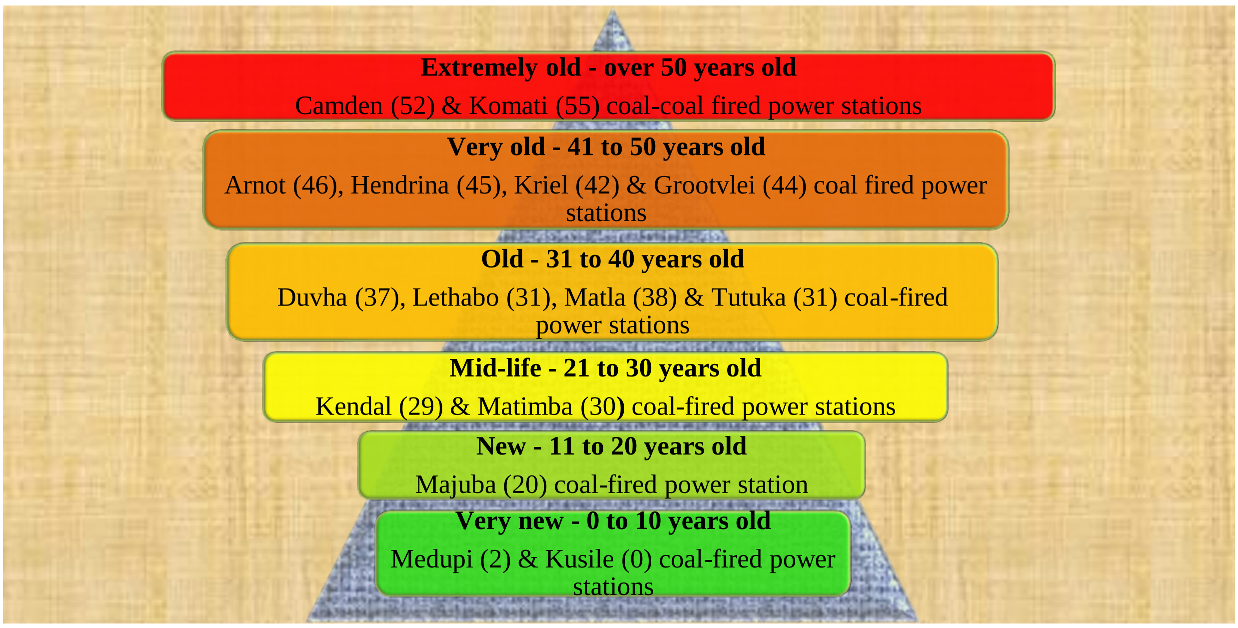


Figure 5.1 Age of Eskom's coal-fired power stations
Source: Based on Field survey notes (2021)

Figure 5.1 depicts that Eskom's coal energy plants are generally old and, as a result, are susceptible to frequent unit trips and breakdowns. These trips result in frequent unit start-ups, which leads to severe CO_2 emissions. The fact that 10 out of 15 of Eskom's coal-fired power stations were over 30 years of age in June 2021 is a matter of national concern as it implies that these power stations have less than 20 years of operational life remaining, with a design lifespan of 50 years. These old power stations are likely to consume more fossil fuel and emit more carbon compared to newer stations. The South African political leaders responsible for implementing the country's carbon emissions reduction targets seem to be unaware of this fact. Jakob et al. (2020) found that old coal-fired power stations are less efficient and should be phased out as they are associated with air pollution, including carbon emissions. This highlights a disconnect between the carbon emissions reduction targets agreed upon in boardrooms and the operational realities at most of these coal power plants. Eskom power plants are generally known for being deprived of major maintenance. It can therefore be argued that Eskom's carbon footprint is aggravated by old-aged power plants that are deprived of major maintenance. It is critical to regularly maintain these old power plants to ensure that the replacements of worn-out components (e.g. milling plant) is done to lessen the rate of carbon emissions.

Urgent attention needs to be directed towards addressing operational issues to improve performance (thermal efficiency) and reduce high carbon emissions. Eskom's Generation division faces the challenge of balancing the prioritisation of plant maintenance of its old coal power generating plants while avoiding load-shedding. Pretorius et al. (2015) added that insufficient energy availability factor (EAF) from Eskom's coal energy plants resulted in high carbon emissions as maintenance practices were compromised in pursuit of improved EAF. Best operational practices also tend to be overlooked when energy demand is at peak, resulting in excessive combustion of fuel oil and poor-quality coal, leading to high CO_2 emissions. Eskom needs to demonstrate strong leadership and establish clear operational philosophies to ensure that the energy grid is protected while reducing carbon emissions. The pressure to sustain the national energy grid often results in Eskom's coal power generators being the major emitters of CO_2 in South Africa.

The position presented above is echoed by Sloss (2021), who posits that South Africa's attempts to reduce its carbon emissions are impeded by the inabilities of its power supply baseload system to decrease load and thus lower its GHG emissions. This suggests that the goal of reducing carbon emissions from South Africa's energy sector may not be achieved if its current coal energy sources are not adapted or transformed. This argument is supported by the fact that between 2010 and 2020, the combined CO_2 emissions from Eskom's coal power generators remained above 200 million tonnes annually. This trend may indicate a lack of investment or ineffective measures to reduce CO_2 emissions from Eskom's power generation activities. The observations above are indicative of an energy sector that is failing to meet the expectations with regard to decarbonization, especially under the current constraints in the national energy grid. Questions need then to be asked if South Africa can bank on Eskom alone to realise a meaningful decarbonization programme and 2050's Net Zero target. Political leaders need to look at how South Africa's Integrated Energy Resource Plan can be adapted to integrate decarbonization ambitions while also transitioning the energy system to cleaner energy mix system. What is also of concern with South Africa's integrated energy resource plan is the political indecisiveness resulting into decommissioning and recommissioning of certain old and out of lifespan coal power plants. This result into intangible decarbonization progress and stagnation of South Africa's climate mitigation ambitions.

This discussion is noteworthy as it highlights the possible presence of ineffective control measures and unfavourable contextual factors in reducing carbon emissions from Eskom's coal energy plants. In light of this, the current study developed Figure 5.2 to highlight some of the existing issues at the outdated coal power generators that are contributing to CO_2e.

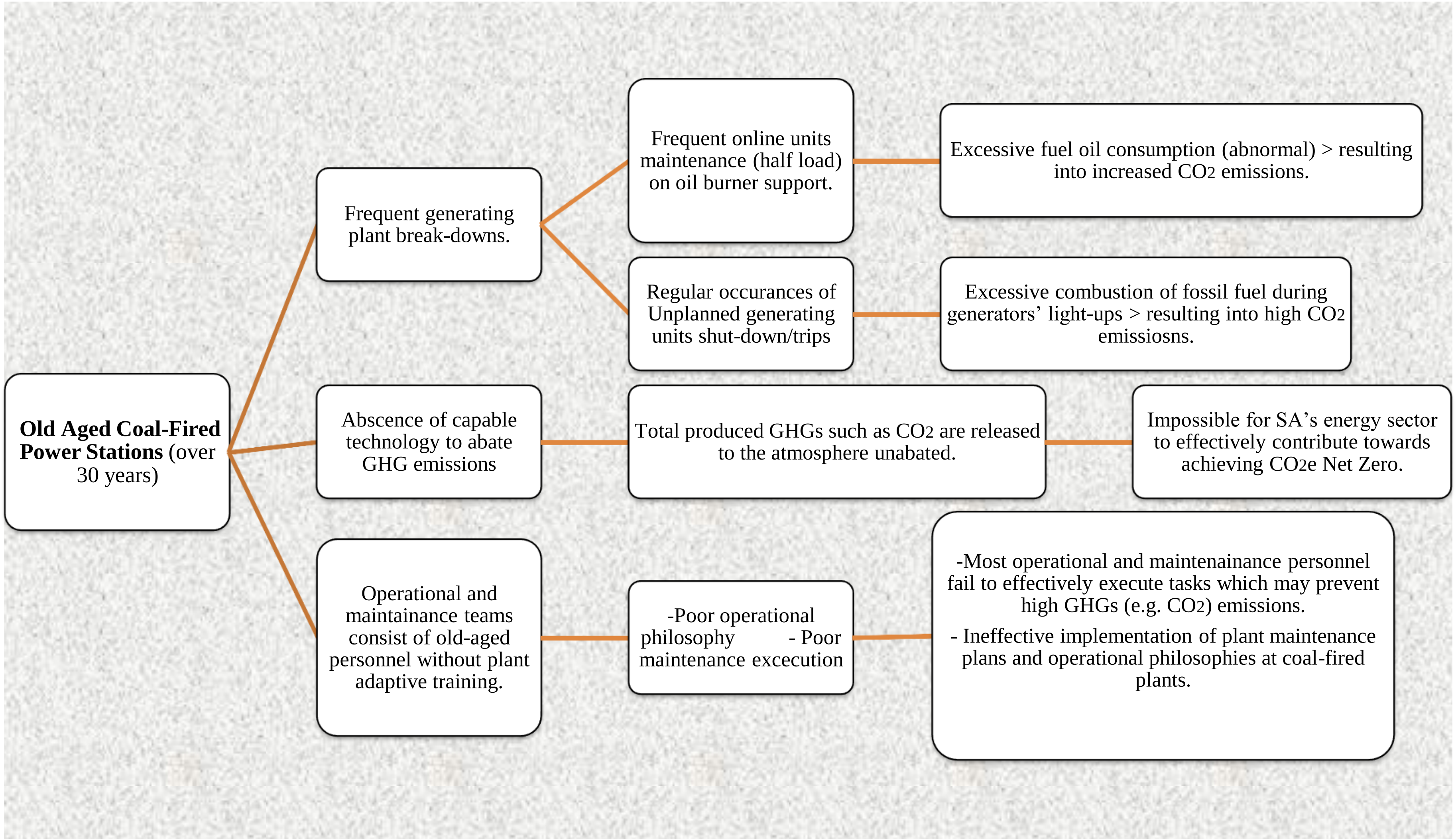


Figure 5.2 Challenges identified at Eskom's coal-fired power stations

Source: Based on field survey (2021)

Figure 5.2 highlights various challenges faced by most of the Eskom's coal power stations in their current state. These challenges encompass plant design issues, plant fragility due to ageing, and issues with operational personnel in terms of adequate training. The combination of frequent plant breakdowns and the lack of greenhouse gas (GHG) emissions abatement technology is a significant challenge, and one that cannot be easily resolved given the financial constraints faced by the power utility. The relationship between plant breakdowns and CO_2e emissions is such that when coal power plants' units' trip and remain off for more than 24 hours, they have to be brought back online through a process known as a cold start-up. Cold start-ups typically consume excessive amounts of coal and fuel oil during the fires-in process to generate enough heat and steam to begin producing megawatts and synchronise with the energy grid. As a result, frequent unplanned unit breakdowns and start-ups result in high fossil fuel consumption and high CO_2e emissions. Pretorius et al. (2015) suggested that carbon emissions increase during plant breakdowns and emergency power generation periods because all of Eskom's coal power generators lack CO_2e abatement technology. Furthermore, frequent online plant maintenance results in generating units being operated at half capacity in terms of combustion, which leads to excessive fuel oil usage to compensate for inadequate coal feed into the boilers. This, in turn, results in increased GHG emissions.

At present, South Africa's efforts to decarbonise the energy sector have been largely unsuccessful, as improvements in the coal energy plants have been limited. It can be argued that the approach adopted by the country over the past decade has been largely ineffective and may need to be revised. The high CO_2e emissions from existing coal plants, as shown in Chapter Four, suggest a persistent emissions challenge in South Africa's energy sector that can only be addressed through the substitution of some of the coal power plants and the reconstitution of the overall energy system. This argument was echoed by a study undertaken by GE (2021), which indicated that for South Africa to achieve an accelerated energy transition and its decarbonisation programme, the country will have to invest in alternative energy sources such as a mix of gas power and renewable energy.

5.3 IMPLICATIONS OF CLIMATE CHANGE ON ENERGY SECURITY IN SOUTH AFRICA

This study revealed that climate change has a direct impact on South Africa's energy production and security. High temperatures and precipitation variabilities due to climate change have far reaching adverse effects on the country's coal energy production system (Mathetsa et al, 2022). Given that coal energy source is the sole baseload for the country's energy supply, the findings portend an unfavourable future outlook for South Africa's energy security. This conclusion concurs with Chapman and Whande's (2013) study, which posits that climate change and energy security are closely intertwined with a cause-and-effect relationship. Chapman and Whande (2013) also warn that failure to recognise this connection could lead to energy insecurity. Based on these observations, it can be argued that climate change effects may result into the affordability of South Africa's electricity supply becoming unattainable and therefore worsening the country socio-economic status. This risk cannot be undermined as it can also destabilize peace in the country as electricity has become a basic need to the lives of many. These observations should also raise an alarm to the political principals as they are expected to develop watertight climate change adaptation policy that should look at safeguarding the country's energy system to ensure its reliability, affordability, and availability for all. South Africa should look at the climate change implications on energy security in context with the country's recent investments drive. This will ensure that new investors are conscious to the country's energy supply constraints, and therefore would invest on their own (private) clean energy sources to sustain their investments. This is one of the most critical adaptation approaches that could also relieve Eskom from power supply burden.

The anticipated irregular precipitation due to climate change in various parts of South Africa should be the cause for serious concern and prompt action from the relevant political authorities. This is because water is a critical resource for the production of coal and hydro power. The study revealed that South Africa is already experiencing rainfall irregularities due to climate change, highlighting the need for immediate implementation of climate change mitigation and adaptation measures. This view is echoed by Conway et al. (2015) and Donnenfeld et al. (2018), who argue that coal-fired power stations, with their heavy use of water for wet cooling activities, are at a higher risk of being impacted by rainfall variability and therefore require adaptation or complement with other water-independent energy sources. Schaeffer et al. (2011), Sudan (2021), and Klare (2015) also argue that interruption of precipitation will cause fluctuations in hydropower systems due to the evaporation of water storage ponds/reservoirs. Based on these discussions, it therefore can be argued that water resource shortage due to climate change effects will have adverse implications to both coal-fired and hydro power plants, and as a result, Eskom will face an arduous challenge with respect to generating the minimum baseload and peaking power to sustain the national energy grid.

Findings in this study indicate that the majority of Eskom's coal power stations are situated in the highveld region of Mpumalanga, and they draw water resource from shared water sources. For instance, the Arnot, Komati, Duvha, and Hendrina coal power plants rely on the Komati GWS/Komati River scheme for their raw water needs. Sharing common water resources can become problematic in instances of irregular precipitation, as these conditions can result in stress on the shared water scheme and a subsequent shortage of steaming and cooling water for energy production. This lack of water can disrupt energy production, potentially leading to a scenario where energy demand exceeds supply capacity, thereby hindering South Africa's economic growth prospects. Cherp et al. (2015) also raised similar concerns in their study, suggesting that African countries ought to invest in a diverse range of energy sources and avoid reliance on energy generated from common water sources shared by multiple power generators.

The current study's finding on Eskom coal power plants relying on common water sources is particularly concerning when one considers that both Waterberg (Limpopo Province) and Nkangala (Mpumalanga Province) regions, where most coal power plants are located, have been receiving inconsistent rainfall from 2010 to 2021. Rainfall distribution in both these regions already project a worrying trend, and therefore triggering the need for Eskom to effectively practice the water efficiency habits. South Africa is a water scarce country with an annual rainfall average which falls short of that of the global average (860mm/year). Severe regional water resource constraints are not new to South Africa, with Cape Town and Port Elisabeth being two of the recent cities to experience a day zero water scare. Eskom, as a strategic water user, need to thoroughly assess its operational activities and identify those activities that can be maximized for water efficiency. Most of Eskom's coal power plants in the Mpumalanga region uses wet cooling systems that heavily rely on water resource. Investments need to be made on refurbishing such power plants with dry cooling systems to save more water; particularly those power plants that still have the lifespan of over 20 years. These discussions highlight the possibility of Eskom power plants having to shed some load due to water scarcity if the status quo can continue unabated.

It is also crucial for Eskom's coal power plants to address process gaps that contribute to significant water loss and to identify opportunities to improve their resilience to the impacts of climate change. The emphasis on proper maintenance is considered crucial in addressing the issues related to abnormal water resource usage. For instance, if the energy-generating unit(s) is put back into operation after maintenance with many issues, frequent breakdowns may occur, leading to excessive and abnormal water consumption during start-up activities. The start-up process of the units consumes a large amount of water to stabilise the steam generation process. Thus, frequent shutdowns and start-ups due to inadequate maintenance result in excessive water resource consumption and increased operational costs. Operational inefficiencies caused by the inadequate execution of standard operating procedures are also contributing factors to high water consumption at the coal energy plants. This viewpoint is supported by Steele et al. (2012), who warned about Eskom's excessive and unnecessary use of freshwater resource as unsustainable and a major threat to Eskom's survival. This finding may also indicate a lack of proper training for operational staff at the power stations. Some examples of operational inefficiencies include the failure to identify and report defective plant areas, leading to massive water leaks and overflows, and the failure to control input materials in line with thermal efficiency demands. For example, a defective water-cooling tower pond automation system can result in a massive overflow and wastage of water resources until the issue is reported and repaired.

The observations above, that are suggesting operational inefficiencies amongst Eskom issues resulting to poor water governance are justified. There were instances between December 2020 and March 2021 wherein water consumption increased relatively strongly while GWh SO only increased slightly. In a true definition of thermal efficiency, input material such as water must increase with production increase. In this case, water consumption remains high while GWh SO reduced. This basically mean that coal power plants are inefficiently consuming a lot water which could be indicative of Eskom's operational inefficiencies. A thorough assessment of Eskom's water use streams must be undertaken to identify and address areas of inefficiency. If this pattern of careless consumption continues unabated, in times of constrained rainfall distribution, the common water sources supplying Eskom, particularly in Mpumalanga region could be severely stressed to an extent of failing to sustain Eskom's water demands. Water resource is like Eskom's bloodstream, and therefore Eskom need to pull all stops to build institutional water efficiency systems for its own survival.

These discussions illustrate that a combination of effective maintenance and operational philosophy is critical in ensuring efficient water resource usage at coal power plants. This viewpoint is also supported by Steele et al. (2012), who emphasised that the allocation of freshwater resources must be guided by efficiency, sustainability, and equity, or Eskom and South Africa may rapidly reach a point of no return that could threaten the country's water and energy security. A water consumption programme based on efficiency, sustainability, and equity will position Eskom's coal power generators in a strong position to adapt and withstand climate change-induced rainfall variability.

With regard to temperature variability, this study discovered that elevated temperature occurrences brought about by climate change impacts will result in thermal inefficiency. The findings of the current study are aligned with the risk assessment carried out by Moatshe (2016) at Eskom's coal power plants, which determined that a rise in ambient temperatures of over 35°C may result in increased cooling water temperatures of energy generators. As a result, evaporation will occur, along with chemical excursions due to concentration cycles, and it may be necessary to take megawatt load losses in order to manage the risk. This argument is supported by the studies of Brown and Huntington (2008) and Klare (2015), which also found that energy systems globally are susceptible to major disruptions due to climate change impacts such as elevated temperatures, inconsistent precipitation, and droughts. Based on these observations, it can be further added that ambient temperatures affect Eskom's cooling abilities and the water resource evaporation rate from power plants' water storage dams. Therefore, high temperatures have both a significant implication on Eskom coal power plants' optimal functionality as well as on the water dams' storage abilities.

To illustrate the systematic effect of increased ambient temperatures on coal power stations' thermal efficiency, the current study has developed Figure 5.3.

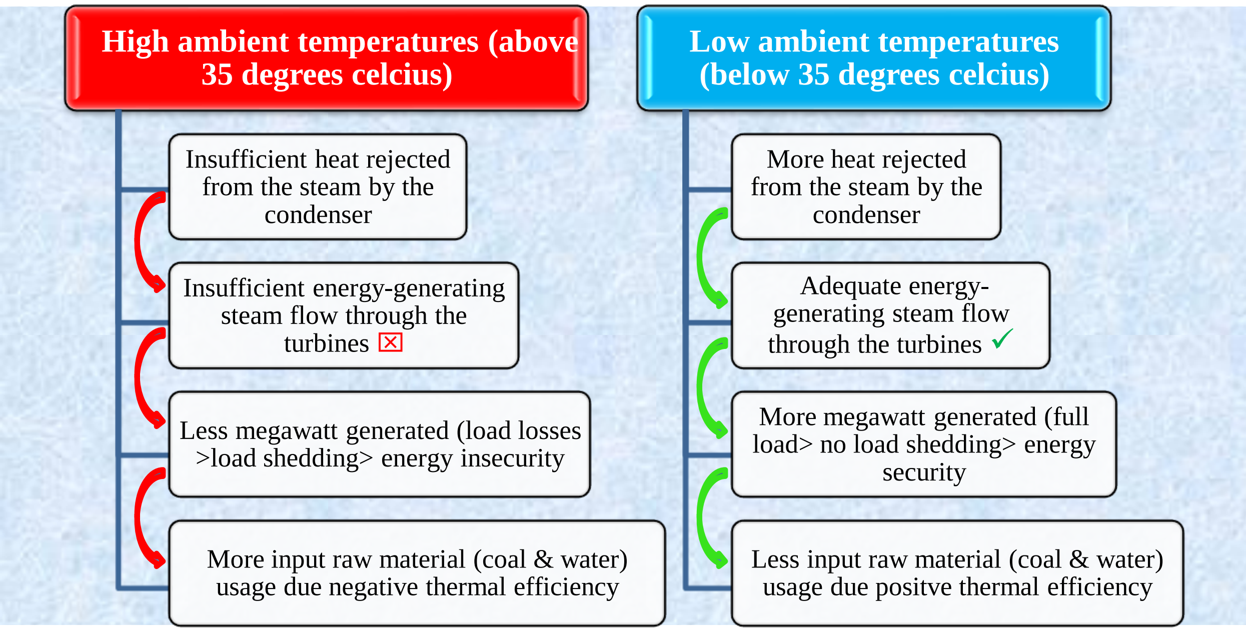


Figure 5.3 Effects of temperature variability on coal power stations' thermal efficiency and energy production (effects on turbines)
Source: Based on field survey (2021)

Figure 5.3 demonstrates the ambient temperatures' effects on the thermal efficiency and energy generation process at coal power plants. The configuration of the power station's turbine process involves condensation of steam from low-pressure turbines, which then flows into the condenser section, where the heat transfer medium is either water-cooled (wet cooling) or air-cooled (dry cooling). The inlet temperature of the heat transfer medium is contingent upon the ambient temperature; thus, a lower heat transfer medium inlet temperature (lower ambient temperature) results in more heat being rejected from the steam by the condenser, leading to greater steam flow through the turbines and electricity generation. The opposite occurs when ambient temperatures are high. The illustration in Figure 5.3 implies that, as temperatures increase and power stations age, they may experience difficulties generating megawatts at full load in regions within the Mpumalanga and Limpopo provinces, where average temperatures are projected to increase between 2021 and 2050 (Thopil & Pouris, 2016). Furthermore, projections indicate that there will be a significant decrease in rainfall distribution and an increase in average temperature in South Africa between 2021 and 2050, which presents concerns not only for coal energy sources but also for hydro power plants. However, these changes may present an opportunity to invest in alternative energy sources, such as wind and solar, which may thrive under such conditions. There is a need, therefore, to conduct regional research initiatives to determine the most feasible energy sources per region. Eskom may also need to review its operational philosophy and adaptation capability in response to the expected changes in ambient temperatures and rainfall distribution (Thopil & Pouris, 2016).

The observations above are particularly concerning after learning in the current research that both Waterberg and Nkangala regions have been experiencing an inconsistent but gradually increasing regional temperatures in the period from 2010 to 2021. Even more worrying is the annual average temperature in the Lephalale area (Waterberg) which has been averaging above 30 degrees Celsius. This is concerning because the region has a very scarce water resource and this rise in ambient temperatures could result into further water scarcity as it promotes quick evaporation. The rise in ambient temperatures also lead to a decrease in cooling towers efficiency, and ultimately resulting into poor cycle of efficiency during electricity production. Consequently, more coal and water are utilized, and the loading rate of fly ash in the precipitators also increases resulting into high particulate matter emissions to the atmosphere. High temperature events also reduce the efficiency rate of compressors. This goes to show the extent that the issue of temperature rising has in coal power plants' operations.

The effects of climate change on coal energy sources primarily involve high temperatures and variations in precipitation, however, it is essential to acknowledge that there are other climatic conditions that significantly impact coal energy production. These conditions include droughts and strong winds, among others, which pose a substantial interruption to the energy production process. In order to mitigate the risk, significant and costly reconfigurations of power stations may be required. Most of the Eskom's coal power plants did not have the necessary mitigation measures to prevent or cope through the wet coal occurrences during the storm events experienced in Mpumalanga Province's highveld region in December 2019; this is a good example of an energy system that lacks robustness and resilience towards harsh changes to climatic conditions (Eskom, 2019). Urgent research is necessary to determine the extent and severity of the energy sector's exposure to climate change effects. South Africa's lack of progress in ensuring an energy mix may suggest complacency and an underestimation of climate change impacts by those responsible for driving the country towards meaningful implementation of mitigation and adaptation measures. This could result in complete unpreparedness or poor planning for the potential severe effects of climate change on the energy sector and potentially limit the country's energy baseload capacity to only half of its current level. Addaney (2018) also raised this concern, noting that the main problem with Africa's climate change adaptation measures is a reactive approach that is common in the continent.

The aforementioned discussions indicate a lack of robustness and resilience in South Africa's energy-generating infrastructure to withstand the effects of climate change. For example, the recent flash floods in the Mpumalanga Province's highveld region, which caught most of the coal power plants without necessary mitigation measures to prevent wet coal events, exemplifies the lack of resilience. Hence, it can be argued that when flooding events become dominant, the energy sector will be operating at the brink of collapse. An urgent action is therefore necessary to curb the foreseeable effects of climate change on the energy sector, including measures to protect coal stockpiles from prolonged heavy rains and a review of energy source locations and investments in new, robust, and resilient energy sources. This view is consistent with the findings of Cherp et al. (2015), who highlighted that South Africa's dependency on coal-generated energy directly affects the energy sector's resilience to climate change effects. Additionally, the studies of Chapman and Whande (2013) and Cherp et al. (2015) further emphasised the issue of low diversity as a major adverse factor affecting South Africa's chances of survival against climate change effects. South Africa has struggled to make a significant transition to cleaner energy mix despite identifying such need as far back as 2004. This is a classic example of South Africa's lackadaisical approach in dealing with climate change mitigation and adaptation measures. It is therefore important that those entrusted with authority to ensure energy diversity in the country start acting because climate effects will continue to expose Eskom's weak energy system to the expense of the country's energy security.

In addition to the efforts to enhance the diversity of South Africa's energy sources, as noted by Chapman and Whande (2013) and Cherp et al. (2015), further research is necessary to identify additional measures that may be put in place to improve the reliability and resilience of existing energy sources in the face of climate change. Taking into consideration that it is not feasible for South Africa to immediately transition from its sole coal-based energy system, it is imperative to conduct investigations to determine which operational activities are most vulnerable to the impacts of climate change, followed by the development of a plan to improve their resilience.

The observations presented support the notion that climate change will have a profound and adverse impact on Eskom's baseload power generators, which rely on coal as the primary energy source. High temperatures, decreased rainfall, floods, droughts, among other factors, will significantly affect coal energy sources. These findings highlight the need to transform South Africa's current energy baseload system to become more adaptable to the impacts of climate change.

5.4 EFFECTIVENESS OF SOUTH AFRICA'S POLICY FRAMEWORK TO FACILITATE A TRANSITION TO CLEANER ENERGY SYSTEMS

The findings of this study suggest that South Africa's existing energy policy is appropriate and adequate for transitioning the country's reliance on coal energy to a cleaner energy mix. However, the study also revealed that despite its suitability and adequacy, the policy is not being effectively implemented. Thus, it can be argued that the challenge facing South Africa is not a lack of a climate change-energy policy, but rather an issue of policy implementation. South Africa established an energy evolution strategy, also referred to as a climate change adaptation strategy, as early as 2004. However, to date, the country has not made significant progress in translating the policy framework into implementation. This strategy placed a strong emphasis on diversifying energy sources to reduce the high levels of carbon emissions from coal energy sources. If implemented promptly, this policy could position South Africa's energy generation sector to be better equipped to adapt to and resist the effects of climate change. Similar concerns were raised by Trollip et al. (2014), who highlighted that despite South Africa's white paper on energy policy being established in 1998, the policy has not been effectively implemented, resulting in significant delays in implementing the energy mix. Kiratu (2010) also alluded to South Africa's lack of policies that would promote the establishment and utilization of clean energy technologies as part of the policy stagnations.

South African government's partnership with Independent Power Producer to facilitate the renewable energy programme was a good idea from the inception, however, it was muddled with political interferences resulting into a very minimal progress. The 'so called' regulatory red tapes resulted into many big industry players not seeing the value of investing in electricity generation activity that was capped at a threshold of one megawatt. It was only until recently that the South African government decided to lift the threshold for embedded energy generation to 100 megawatt, and therefore triggering more interest from private power producers to invest on renewable energy sources. This goes to show that political buy-in is critical, in terms of policy perspective, to achieve an effective energy transition programme.

The sluggish progress towards implementing an energy diversity policy in South Africa raises important questions. Is it due to a lack of practical approach or an insufficient implementation programme and monitoring mechanism? To fast track the implementation of an energy policy aimed at addressing the low energy source diversity and resultant vulnerability to the impacts of climate change in South Africa, it is crucial to undertake academic research on the bottlenecks in executing energy policy. The reasons behind the slow transfer of energy transition programmes into implementable Integrated Energy Resource Plans must be clearly understood. Although energy policy implementation may not be solely dependent on political office, political administration must also be held accountable, as the policy constitutes part of the social contract to be executed by them.

However, this view contrasts with the findings of SWP (2021), who argued that countries, including South Africa, should not prioritise the immediate implementation of climate change mitigation policies and objectives over energy security and economic objectives. In accord with this view, Böhringer & Keller (2011) also highlighted that the objective of energy security should be underpinned on the provision of reliable, affordable and adequate energy while not risking the country's values and economic ambitions. While this argument may be valid for many countries, it may not be appropriate for South Africa as the coal power plants in the country are already experiencing some of the impacts of climate change, as discussed in Section 5.3. In December 2019, Eskom's coal power plants, located in Mpumalanga region suffered widespread energy load losses due to wet coal resulting from flash flooding that had taken place in the area. In contrast with SWP (2021), it can therefore be argued that South Africa's energy sector is already caught-up with climate change effects and can no longer afford to postpone its investment on climate change adaptation. In South African context, the lackadaisical approach in terms of policy implementation, particularly regarding climate change adaptation, may result into serious unreliability of energy system, and therefore adversely affecting the availability and affordability of electricity in the country. This highlights the importance of prioritising the implementation of energy policy and Integrated Energy Resource Plan in South Africa.

Quite interesting, this study also discovered that by year 2050, 50% of South Africa's overall energy system may not be transitioned to cleaner energy mix. This may also be suggestive that South Africa's energy sector will not be able to assist the country towards achieving its Net Zero (carbon neutrality) decarbonisation target by year 2050. Considering the fact that Kusile and Medupi coal power stations are considered clean technologies, it would be a massive setback if South Africa fails to transition at least 50% of energy baseload into cleaner energy systems by 2050. In support of this view, Dyke et al. (2021) also highlighted that the year 2050 Net Zero concept has actually slowed down efforts by power generators to immediately do away with fossil fuel usage as they believe that they still have time before they can effectively start working towards the year 2050 ambition of net zero. In contrast with this view, it can be argued that the recent regulations which lifted South Africa's embedded energy generation threshold for licensing will promote the development of cleaner energy sources and multiple microgrids driven by private sector. This will then ease some pressure off Eskom to start ramping down some of its old coal energy generators while phasing in renewable energy sources in the grid. The energy policy and IRP should promote more research to align Eskom with private energy evolution, as it blends its energy sources to become more robust and resilient to climate change effects.

Based on the above observations, it can be further added that the current Integrated Energy Resource Plan need to address the issue of establishing public and private micro electricity grids that would link up with Eskom's main energy supply grid. Some countries around the world (e.g., Alaska) are adopting a micro electricity grid system as another way of building a robust and resilience energy supply infrastructure that would withstand various effects of climate change. It is also important to note that investing in various clean energy sources is one aspect towards ensuring cleaner energy transition, however, there is still a need to invest on energy transmission infrastructure which would be easily manageable if there are effective micro grids established across the country. This viewpoint was also lamented by Hicks's (2017) study that found that microgrids that are managed by private power producers are another way of ensuring energy security. It is therefore important for South Africa's energy sector, guided by energy policy, to invest on the studies that investigate the feasibility of establishing various effective energy microgrids, taking into account the country complex energy generation and distribution landscape.

The current results also suggest that South Africa's climate change mitigations and adaptation strategies need to be incorporated into an energy policy. These results contradict the findings by SWP (2021) and King and Gulledge's (2013) studies. These studies argued that climate change and energy security are only related subjects which need to be addressed through completely different timeframes. They further maintained that energy security is a matter that needs to be addressed immediately, while climate change mitigations and adaptation measures may only have to be implemented at a later stage. Arguments by SWP (2021) and King and Gulledge's (2013) are not sustainable in terms of South Africa's context. South Africa operates coal energy sources which were mostly built during the apartheid era (before 1994). These power stations were built with very limited capabilities to minimise carbon emissions as well as adapt to the effects of climate change. It therefore can be argued that in South Africa's context, energy production and security is directly threatened by climate change effects necessitating the need to address the two subjects now through one policy.

In light of the argument presented, it must be emphasised that the separation of energy and climate change policies will not protect the energy sector from the effects of climate change that are already being observed in South Africa's energy generation fleet. The integration of these policies will also encourage a unified planning process, which will enhance the adaptation and resilience of energy systems in response to the climate change effects. The fact that most energy sources, including coal-fired, hydro, wind, and solar power, are vulnerable to weather variability such as high temperatures, irregular rainfall, floods, inconsistent wind resource, and fluctuating solar radiation, highlights the need for a comprehensive policy that considers climate change risks as part of an IRP. This view is supported by the study of Brown and Huntington (2008), who assert that climate change mitigation strategies and energy security policies must be integrated into a single policy.

Moreover, it can be argued that the funds invested in the new coal power plants (Medupi and Kusile) could have been allocated to cleaner energy systems that yield results more quickly, rather than investing in expensive and inefficient plants that do not significantly advance the transition to a more sustainable energy mix, as stated in the energy policy. While some may argue that the new builds were necessary to address the impending energy crisis, this stance is not well-founded, as the new builds project would not have been implemented in the short term. Moreover, a comprehensive assessment of the potential risks posed by climate change was lacking, as evidenced by the high-water consumption requirements of the Medupi coal power plant's flue-gas desulfurization (FGD) plant. Given the water scarcity in the region where Medupi Power Station is located, the choice to use water-intensive technology in the 21st century was not well-advised. These concerns align with the warnings of Bazilian et al. (2011), who pointed out that the construction of new coal power plants may prove to be a poor decision due to their high energy intensity and the need to restructure the technology in response to climate change impacts.

Furthermore, Medupi case study also shows that certain energy policies are misaligned with realities on the ground, particularly climate change-related realities in this regard. It can therefore be further argued that the energy policy that informed the construction of a water intensive Medupi coal power plant in a semi-arid region like Lephalale was not based on effective materiality assessment and due diligence, climate change-related impacts and risk management, and clear strategy to deal with the risk. Consequently, Eskom regularly finds itself in a shared value related disputes, wherein the power utility has to compete with local communities with regard to water demand and supply. These issues could have been anticipated through comprehensive research and planning. Thus, the energy policy and Integrated Resource Plan (IRP) should be adaptive, and their frameworks should be informed by a regional focused research to determine the most suitable energy sources for each region.

5.5 ASSESSMENT OF WHETHER COMPREHENSIVE ENERGY TRANSITION WILL GUARANTEE SUSTAINABLE ENERGY SYSTEM IN SOUTH AFRICA

This study suggests that energy transition is a crucial step for South Africa to mitigate the impacts of climate change and achieve a sustainable energy system. Furthermore, it highlights the need for the South African energy sector to diversify its energy sources. This supports previous research that also advocates for energy source diversification as a way to ensure energy systems availability, reliability and affordability amid climate change risks (Cherp et al., 2015; Conway et al., 2015; Donnenfeld et al., 2018). The energy transition programme will not only enhance South Africa's energy security but also promote energy democracy by providing private energy generators with the opportunity to generate their own power using clean energy systems. This would also allow Eskom Generation to concentrate on plant maintenance, reduce the use of expensive gas turbines, and invest in renewable energy sources as there would be less energy demand. In addition, the energy mix will enable old coal power plants to be rested through 'cold reserve' programmes and only be brought online during periods of high energy demand, such as winter seasons. It can be concluded that energy democracy, through the promotion of clean energy sources, will have a positive impact on South Africa's climate change mitigation and adaptation strategy by reducing carbon emissions and diversifying the country's energy baseload.

This study found that renewable energy sources are beneficial due to their sustainability and cost-effectiveness compared to coal energy sources (refer to Table 5.1 below). The widespread use of renewable energy technologies in the recent history and the improved understanding of these technologies by local manufacturers have made this possible. Furthermore, the study found that coal energy sources are more susceptible to the impacts of climate change, unlike most popular renewable energy sources such as solar and wind (refer to Table 5.1 below). Contrary to this finding, Schaeffer et al. (2011) argued that wind energy is unpredictable to forecast, particularly at the 50-metre altitude where wind turbine hubs are usually located. They also identified excess atmospheric moisture and high ambient temperatures as limitations to the effectiveness of solar photovoltaic energy generation. The study by Schaeffer et al. (2011) highlighted that Sub-Saharan Africa may receive reduced solar radiation in the future. Based on these observations, it is quite clear that almost all energy sources have their own advantages and disadvantages. Therefore, it is important to conduct necessary science-based feasibility studies to be able to invest on the right energy source, at the right geographical location in terms of weather, landscape, input material, etc.

While renewable energy sources offer diversification and sustainable energy security, there is still a knowledge gap regarding the appropriate technology to be invested in, considering regional weather forces. Therefore, careful assessments of sustainable wind resource availability in a specific area and the reliability of solar energy panels with different regional temperature ranges are necessary to ensure the compatibility and effectiveness of the technology in relation to weather dynamics. A more in-depth, 50-kilometre by 50-kilometre projection of the ideal site for establishing a new renewable energy source should be carried out to understand the projected local variability in weather forces, to ensure its productivity and sustainability in the area. Mukheibir (2007) warned that investment in any energy-generating source should only be made after conducting a thorough investigation to determine regional climate change variables. This argument supports the idea that not every area in South Africa, which is considered among the top 12 sites for investment in renewable energy technology, is suitable for solar or wind energy technology. Failure to undertake necessary feasibility assessments as recommended above may result into some of these investments in renewable energy sources not bearing positive returns. South Africa's central government has to devise an approach that can assist the small-medium enterprises and other private players who would like to invest in the renewable energy space to choose ideal technology for their geographical areas.

Coal energy sources' operational costs are quite high as they are linked with the cost of more than one input material. In China, fossil fuel-generated energy is considered cheaper due to low input material costs. However, in South Africa, the high cost of input materials such as coal, water, fuel oil, and sulphur make coal-generated energy unsustainable. When evaluating the affordability of energy-generating technology, various issues must be taken into account. Climate change-induced weather variability increases the uncertainty of efficient operation for coal energy plants, highlighting the need for a balanced and sustainable energy mix. For instance, reduced water supply due to irregular precipitation may result in increased tariffs for water use imposed by catchment agencies. The cost of operating coal power plants should therefore not only consider the escalating cost of fossil fuels but also the cost of other natural resources under stress (dynamic materiality), such as water. Trollip et al. (2014) found that South Africa's coal energy plants are too expensive to operate due to a failure to modernise them and poorly coordinated coal contracts with escalating costs.

A typical example of Eskom's failure to modernize coal power plants is on the issue of wet-cooling technology that most power stations use. While the dry cooling technology has been known to Eskom for many years, Eskom's plant modification team never saw the need to adapt the power utility's wet-cooled system to dry cooling. This measure would not only benefit Eskom by means of reducing its over dependence on water resource and enhancing its climate change adaptation, but it would also save Eskom a lot of money that is lost on water tariffs. Consequently, a large amount of Eskom's water allocation can also be re-allocated to communities that are water starved. Therefore, the current research strongly advocates for Eskom to invest on water efficiency programmes as a means of climate change resilience and adaptation mechanism. This aligns with Addaney's (2018) study, which suggests that African countries should shift from a slow implementation of adaptation measures against climate change effects to a more proactive approach.

The study identified energy mix (nuclear, solar, gas, wind, etc.) as a vital approach for adapting the energy sector to withstand climate change effects. However, it is important to note that some energy sources, such as nuclear power, are expensive to invest in. A social, economic, and environmental assessment is necessary to determine the overall cost and sustainability outlook of each energy source. Expanding investment in hydro power technology is imperative, as it proves to be a desirable clean energy alternative. A careful decision must be made on whether a pumped storage scheme or hydroelectricity is the ideal investment for a specific region. Factors such as projected temperatures and rainfall variabilities must be taken into account. The pumped storage scheme, such as the Ingula Power Station, features upper and lower containment dams, which enables the recycling of water resource for energy generation. Conversely, the hydroelectricity power plant, such as the Palmiet Power Station, uses water from an instream dam, which is fed by a stream or river. For contextualisation purposes, Figure 5.4 provides an illustration of a typical configuration of a less explored pumped storage scheme hydro power plant in South Africa.

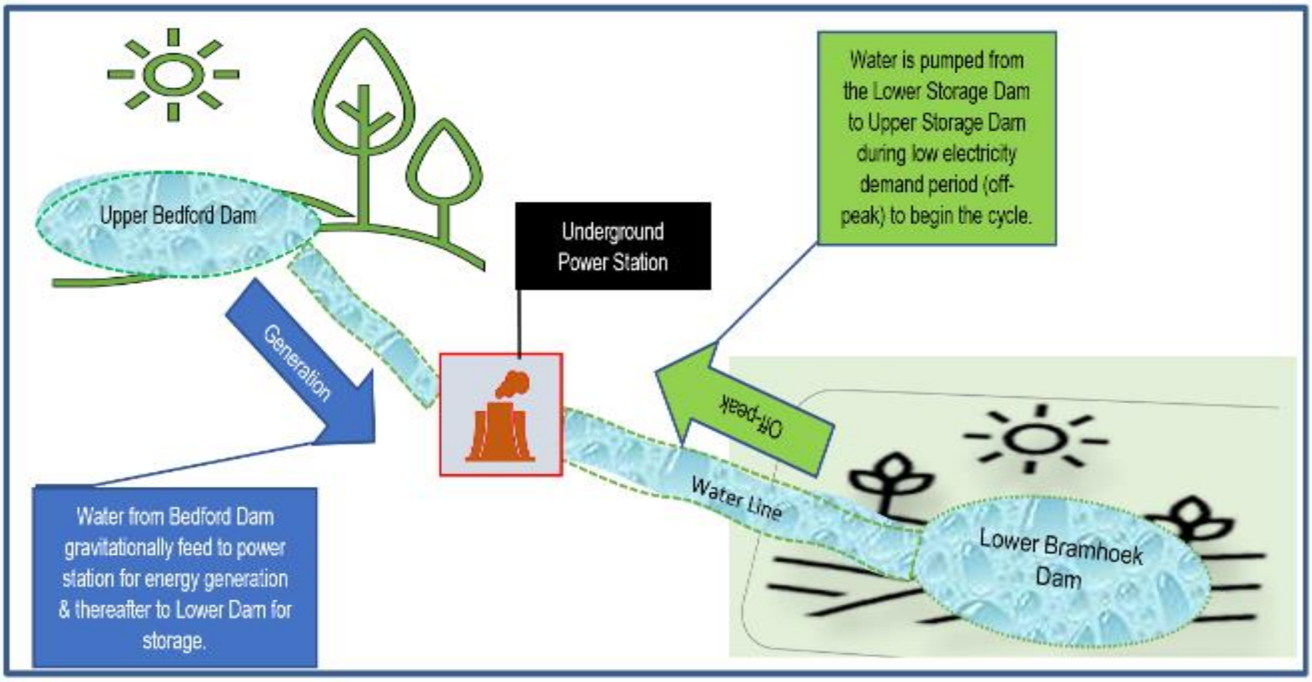


Figure 5.4 Ingula Pumped Storage Scheme water circulation design
Source: Based on field survey (2021)

Figure 5.4 depicts the two-way water flow at the Ingula pumped storage scheme. The scheme comprises an upper Bedford dam, which supplies water to the underground power station during peak demand, and a lower Bramhoek Dam. During off-peak periods, water is pumped from the lower dam back to the upper dam, completing the cycle. Further research is required to identify areas suitable for pumped storage hydropower generation systems. The advantage of these systems is that they can operate using water from small rivers and have water recycling capabilities. However, the impact of climate change variability on potential locations for pumped storage schemes, including long dry spells and droughts, must also be researched. Pumped storage schemes, such as Ingula, have a storage capacity that allows for water recycling and thus can survive dry spells better than hydroelectricity systems that rely on real-time water supply from running rivers. Gilfillan and Pittock (2022) similarly noted the limited impact of pumped storage hydropower on natural hydrology, due to its closed loop water cycle system. However, further research is needed to determine the duration of survival during dry spells and the impact of temperature increases and floods on energy production.

The current study found that energy transition programmes have positive impacts on energy security. These findings align with Cherp et al. (2015), who found that diversifying energy sources strengthens the resilience of a country's energy sector. Table 5.1 summarises the study's assessment of various energy sources and their characteristics and climate-related risks.

Table 5.1 Assessment of various characteristics of common energy sources

Energy Source	Establishment Footprint & Nature of Activities	Type of Key Input Material	Operational & Maintenance Expenses	Level of Vulnerability to Climate Change Effects
Coal	**Footprint**: Largescale (includes coal mines, ash disposal facilities, power stations, other auxiliary services); coal energy sources footprint also include massive emissions of GHG, particulate matter, oxides of nitrogen, Sulphur dioxide, etc. **Nature**: Mostly dirty activities	* Coal * Fuel oil * Water	**High** * All key input material (water, fuel oil, coal) are costly procured. * Power plants involve huge manpower to run including the coal mines. * Due to their sophisticated configuration, they require intensive maintenance.	**High** *temperature variability affects thermal efficiency. *interrupted rainfall affects water availability and energy production. *Flash floods result into wet coal in the stockpiles & combustion problems. *Excessive rainfall influences coal qualities (underground and opencast)
Hydro	**Footprint**: Small-scale (power stations mostly built instream or underground with less auxiliary services); No emissions footprint. **Nature**: Largely clean activities	* Water	**Low to medium** * Water resource is less costly. *Very minimal workforce *Low maintenance	**Low to Medium** *interrupted rainfall affects water availability and energy production
Solar	**Footprint**: Largescale (but footprint does not always involve breaking of new grounds); No emissions footprint. **Nature**: Mostly clean activities)	*Solar radiation	**Low** * Key input material is an unregulated natural gift (sunshine) * Skeleton maintenance and operational staff	**Low to medium** *extremely high or low temperature may impact on energy production. * Storms, high temps may damage the solar panels. * Increased atmospheric moisture may reduce generation capacity.
Wind	**Footprint**: Largescale (wind farms generally cover huge areas); No emissions footprint. **Nature**: Clean activities	*Wind resource	**Low** * Key input material is an unregulated natural gift (wind resource) * Skeleton maintenance and operational staff	**Low** *changes in wind speed and patterns may affect production. *Not easy to predict changes in wind patterns at the generation hight.

Source: Based on field survey (2021)

Table 5.1 compares coal energy sources with hydropower, solar, and wind energy sources in terms of their contextual issues. It highlights that coal energy sources are associated with significant negative impacts, including a large footprint, operational and maintenance costs, and vulnerability to climate change effects. Conversely, hydropower, solar, and wind energy sources are linked to fewer contextual issues and operational costs. Table 5.1 notes that these renewable energy sources each require a single input material and have a smaller environmental footprint. In comparison, coal energy sources have a large footprint that encompasses coal mining activities and the disposal of by-products (ash) and emissions. Coal energy sources also require bulk amounts of water, fuel oil, and coal as input materials and are sustained through high maintenance and operational costs. Moreover, they are vulnerable to the effects of climate change. The conclusion drawn from Table 5.1 is that coal energy sources are not an ideal energy-generating technology for the future. Their large and dirty environmental footprint, expensive input materials, and excessive operational and maintenance costs make them an unattractive investment. Studies by Conway et al. (2015) and Donnenfeld et al. (2018) support this view and recommend investment in a variety of renewable energy sources.

It is believed that South Africa's investment in coal as an energy source was due to a lack of understanding of other energy-generating technologies during the apartheid era. Today, with the climate change risks and the availability of battery storage opportunities, it is time to blend South Africa's energy system with other sources to ensure the sustainability of the system. Most of the old coal power plants should be downgraded to peaking power stations that only synchronise with the grid during peak hours or in emergency energy demand, and more renewable energy sources should be brought into South Africa's baseload. While renewable energy sources are for the future, it is also important to understand that renewable energy sources alone cannot be able to meet South Africa's immediate to medium energy demand. It is therefore also important for the country to invest on the optimization of some of the coal power plants to improve their thermal efficiency, particularly in relation to the consumption rate of the input material (water, coal & fuel oil). In this regard, technologies to enhance water efficiency and water recycling should be invested on to ensure that most of the coal power plants, that still have a lifespan of more than 20 years, achieve the desired water consumption performance coefficient; this will also be a key measure towards climate change sustainability.

This study highlights the critical role that public-private partnerships must play in South Africa's transition to a cleaner energy system. There is a need for regulators to conduct more community awareness to educate the public on the importance of energy diversity in light of projected climate change effects. Small and medium enterprises and households are increasingly generating their own energy, making it necessary to provide weather variability projections for informed investment decisions. The recent amendment to the electricity Act regulation, lifting the private power generation threshold, calls for private generators to be viewed as extensions and enablers to Eskom's climate change adaptation and resilience strategy. This viewpoint is supported by Nel

(2018), who found that the hybrid public-private-partnership model demonstrated through the IPPs programme is crucial for the energy sector transition and serves the public interest. Hicks (2017) also alluded to the importance of establishing renewable energy microgrids by small independent power producers as critical in ensuring energy security. The issue of microgrids establishment should be informed by thorough research that should focus on the feasibility of establishing the grid, and how the microgrid systems will affect South Africa's energy system in terms of availability, reliability, and affordability of electricity tariffs for the consumers. Most importantly, microgrids should be able to promote effective transition to cleaner energy systems instead of serving as the bottleneck.

This study argues that South Africa's energy sector requires a significant transition to a cleaner energy mix to achieve sustainability. The cost, pollution, and climate change threat associated with the current coal energy sources make coal an unsustainable energy source. The uncertainties associated with renewable energy sources such as solar, wind, and hydro power are manageable through thorough regional research. Solar energy, with its suitability for urban roof-tops, is an ideal option in terms of land preservation. South Africa's recent experience of load-shedding highlights the need to blend the ageing coal energy plants with cleaner energy sources to secure the country's energy supply. There is an urgent need to blend and sustain the energy system with more renewable energy sources for social, economic, and environmental sustainability.

5.6 FEASIBLE TECHNOLOGICAL MEASURES TO ABATE CURRENT CARBON EMISSIONS FROM COAL POWER PLANTS

The study's findings indicate that South Africa, being the largest CO_2 emitter in Africa, should play a proactive role in the global drive to decrease carbon emissions. This implies that South Africa's efforts to tackle climate change should serve as a model for the rest of the African continent, given its leading position in terms of carbon emissions. In line with this finding, Klare (2015) and Brown and Huntington (2008) also stressed the importance of countries investing in both mitigation strategies, such as greenhouse gas reduction plans, and adaptation strategies to mitigate the impacts of climate change. While it is expected that South Africa should demonstrate leadership in addressing carbon reduction and climate change, it is important to set realistic financial limits for investment in meeting climate change reduction goals. Investments that negatively affect the country's financial stability cannot be sustained as they may trigger other socio-economic challenges and instability. Therefore, any investment towards reducing high CO_2 emissions from power-generating plants must be realistic and sustainable. Tough decisions may need to be taken, such as choosing between installing carbon abatement technology and reducing or phasing out some coal power plants. Based on the observations above, it can be further argued that Investments in decarbonization drive should be anchored on innovation, affordability, and sustainability. Thus, Eskom need to undertake an investigation on the most innovative but affordable means to deal with its carbon footprint. That being said, a decarbonization approach that is based on shedding the load is not cheap or sustainable as it would cost South Africa's economy billions of rands per day. Example of some simple but innovative ideas may include the adaptation of some of Eskom's operational and maintenance designs and philosophy to contemporary approaches as another way of trimming down the carbon emissions. In other words, innovation should not only consider farfetched and expensive new technological designs that may completely destabilize Eskom's financial standing.

There remains a challenge in determining enforceable carbon reduction targets for countries like South Africa under the Paris Agreement (2015). Developing countries like South Africa are disproportionately affected by historical greenhouse gas emissions from developed countries, who now promote clean energy systems. This calls for a fair and balanced approach in implementing the Paris Agreement. It is unrealistic to expect South Africa to match the reduction efforts of the USA and European Union, given the difference in modernisation and socio-economic sustainability. SWP (2021) also supported this view and advised developing countries like South Africa not to compromise their economic growth by slowing down their use of fossil fuels to meet global climate change commitments. Moreover, South Africa's investments in climate change mitigation should be commended, but they will not make a significant impact on global climate recovery if countries like China continue to make large investments in coal-based energy systems. As already alluded above, it is critical for Eskom to invest on decarbonization projects that are realistic to the power utility's financial standing and the country's wealth. South Africa is one of the countries with unequal societies in the world. Therefore, it would not make sense for South Africa to channel all its financial resources towards decarbonization and climate change mitigation while the main contributor countries to climate change, through their historical and current pollution, such as the USA, Europe and China continue to direct their wealth towards their countries' socio-economic needs. The legacy polluters need to fund South Africa's decarbonization programme in order to strike the balance.

The study also found that technologies exist to reduce carbon emissions from Eskom's coal power plants. However, the cost of these technologies makes them unattractive for investment. The Flue Gas Desulphurisation (FGD) plant was identified as the most effective technology for reducing carbon emissions by Eskom's air quality report (McCourt, 2020). However, its estimated installation cost of R39 billion raises investment concerns. In the absence of a broad range of cost-effective technological options, the available technology (FGD) becomes too expensive for developing countries like South Africa. Fitting all coal power plants with FGD would result in financial hardship and socio-economic distress (McCourt, 2020). McCourt (2020) and Sloss (2021) argue that FGD systems are ideal for decarbonising Eskom's coal-based power plants, but their high procurement cost makes them an undesirable option. Thus, FGD technology should be installed only on new builds such as Medupi and Kusile coal-fired power stations, which have many years of operation ahead and are likely to achieve investment return. Eskom should review its business model and phase out older coal power plants over 40 years of age, replacing them with renewable or other clean energy sources. This would be the best measure to reduce the country's climate change effects. Investment in engineering solutions and cheaper technological measures to minimise carbon emissions in coal energy plants is also necessary. Given South Africa's limited budget for investing in expensive technologies to mitigate high carbon emissions from its coal power plants, improving operational efficiency and focusing on the quality of the input material used in the coal combustion process is a critical abatement measure to reduce Eskom's carbon emissions. Diversifying the current energy source mix is also essential to reduce carbon emissions, allowing a blend of energy sources such as wind, solar, hydro, battery storage, gas, and nuclear. Hanto et al. (2021) suggest that restructuring South Africa's energy sector to include more renewable energy sources will support its decarbonisation project and enhance the competitiveness of renewable energy sources. Further research on operational philosophies for the existing coal power plants is advisable to identify and adapt current operational philosophies, since operational inefficiencies significantly contribute to carbon emissions (Section 5.2).

The findings of the current study indicate that the Carbon Tax Act (15 of 2019) is a positive initiative that will result in a significant reduction in CO_2 emissions from most emitting companies, including Eskom. However, some industries could choose to budget for the carbon tax and not feel compelled to comply with carbon reduction programmes, but a few small industries may participate in carbon reduction measures and energy efficiency programmes for incentives. Gustafsson (2021) found that the current rate of the Carbon Tax in South Africa is too low to trigger large-scale carbon reduction by significant emitters, who still find it cheaper to pay the tax than to reduce their carbon footprint. For the Act to be effective, the playing field must be levelled, with the regulator conducting assessments for each industry and imposing phased targets. The money collected from polluting industries can be directed towards the government's climate change mitigation and adaptation drive. The success of the initiative will depend on the government's effective implementation.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter concludes the current study by summarising key research findings in relation to the research aim and questions outlined in Chapter One. Key findings are highlighted, considering their significance and contribution to the wider topic of climate change and energy security, as well as academia. Policy recommendations and suggested future research are also discussed within the context of the research topic.

6.2 SUMMARY OF KEY FINDINGS

The aim of this study was to understand the material impact of changes in climatic conditions on South Africa's energy security, as well as the ability of the country's energy policy to guide the transition towards a cleaner energy mix. The study also investigated the carbon footprint of South Africa's energy sector (Eskom) and the feasible measures to mitigate it. In this regard, hereunder are the key findings of this research.

Key Findings under Objective 1: The current study has found that Eskom's coal power plants emit more than 200 million tons of CO_2 per year, and therefore are the most significant contributor to South Africa's carbon footprint. Eskom's carbon emissions are stimulated by a number of challenges that include the old age of most of the coal power plants resulting into regular breakages and maintenance, the nature of input material which include coal and fuel oil that contains high percentage of carbon, poor quality of coal combusted in the boilers, and operational inefficiency that include old, and irrelevant plant maintenance, operational and training philosophies. Thus, operational inefficiencies at coal power plants need to be addressed to at least reduce certain portion of carbon footprint that is attributed by these inefficiencies. Nonetheless, it is also the finding of the current study that Eskom's carbon emissions will remain significantly high for as long as the coal power plants remain South Africa's primary source of electricity. This is because Eskom's old coal power plants are not fitted with any CO_2e abatement technology. In the 10 years period scrutinized by this study, it was found that CO_2 emissions trend shadowed the energy production pattern. Therefore, most of CO_2 emissions challenge in South Africa's power utility can only be addressed through the substitution of some of the coal power plants and the reconstitution of the overall energy system to cleaner energy system. South Africa and Eskom are faced with a real dilemma of having to meet the decarbonization commitment made as part of Paris Agreement, while also trying to manage Eskom's fragile power generation fleet which cannot afford to reduce energy production.

Key Findings under Objective 2: Although there is a growing interest on the relationship between climate change and energy security, the extent of the implication of this link on South Africa's energy production process seems to be underplayed. This is because this study has found that most of South Africa's coal power plants' infrastructure as well as operational and maintenance philosophies remain unmodified to adapt with climate change risks. This paper has found that temperatures and precipitation variabilities have a direct effect on coal power stations' thermal efficiency and production thereof. In this context, the current study has found that both Waterberg and Nkangala regions have been experiencing inconsistent and gradually increasing regional temperatures in the period from 2010 to 2021. High temperatures are already interrupting some of the coal power plants' regulated turbine thermodynamics resulting into megawatt load losses and reduced Energy Availability Factor (EAF). Compounding to this challenge, the coal power plants' reliance on common water sources or schemes elevates the energy production risk in cases wherein such shared water sources are under stress due to climate change induced temperature and precipitation variabilities. The findings of the study also paint an unfavourable picture in that both Waterberg (Limpopo Province) and Nkangala (Mpumalanga Province) regions, where most coal power plants are located, have been receiving inconsistent and insufficient rainfall from 2010 to 2021. Despite all these glaring implications of climate change on coal power plants, the current study found that water consumption (2020 to 2021 trend) at coal power plants remained high even when the energy availability factor had dropped. Taken together, these findings are indicative of South Africa's energy system that lacks robustness and resilience to withstand current and projected climate variabilities, and therefore, highlights to a looming energy crisis which may adversely affect the production, availability and affordability of electricity in South Africa.

Key Findings under Objective 3: The current study investigated the suitability and adequacy of South Africa's energy policy, which is based on the Integrated Resource Plan. The results indicate that while the policy is suitable, it lacks effective implementation. This is indicative of a lack of political will to expedite the policy execution. The slow implementation is projected to result in less than 50% of South Africa's energy system transitioned to a cleaner energy mix by 2050, and potentially undermining the country's goal of carbon neutrality by that year. This study also found that South Africa's policy decision regarding government partnering with Independent Power Producer, to facilitate the renewable energy programme implementation, was a good idea from the inception, however, it was muddled with political interferences resulting into a very minimal progress. The 'so called' regulatory red tapes resulted into many big industry players not seeing the value of investing in electricity generation activity that was capped at a threshold of one megawatt. It is also the finding of this study that South Africa's energy policy should investigate the feasibility, and also direct the establishment of micro electricity grids that would link up with Eskom's main energy supply grid.

Key Findings under Objective 4: This study found that South Africa must embark on a decisive energy transition programme into a cleaner energy source mix as a critical and urgent measure to enhance the resilience of the energy sector against climate change effects. The study suggests that transitioning Eskom's current coal-dominated energy baseload system to a mixture of clean energy sources will ensure the robustness and resilience of the country's energy system. The transition will also provide Eskom with an opportunity to retire some of its old coal power plants, and time to adequately maintain its current coal power plants, and thus reducing its carbon footprint. The study found that the costs of establishing renewable energy sources have significantly decreased as the technologies have become more common, and therefore reaching cost parity with coal energy sources globally. Local manufacturers are also becoming more familiar with renewable energy technologies. Hydro power, solar power, and wind power were found to be more desirable than coal energy sources in terms of their establishment footprint, type of key input material, operational and maintenance expenses, and vulnerability to climate change effects. This is because renewable energy sources rely only on one key input material (water for hydropower, sunlight for solar power, and wind resource for wind power), while coal energy source requires fuel oil, coal, and water as key inputs. Solar and wind energy are also cheaper in terms of production input material as sunlight and wind resources are naturally occurring and freely available. The study emphasised the importance of public-private partnerships for a successful transition to a blended energy system in South Africa. South Africa's recent experience of load-shedding highlights the urgent need to blend the ageing coal energy plants with cleaner energy sources to secure the country's energy supply.

Key Findings under Objective 5: The study also reveals that Eskom's coal energy sources are the significant carbon emitters in South Africa because they lack carbon emissions' abatement technologies. This, combined with frequent breakdowns, poor maintenance, and poor coal quality, perpetuates high carbon emissions. The study also found that technologies exist to reduce carbon emissions from Eskom's coal power plants. However, the cost of these technologies makes them unattractive for investment. For instance, the Flue Gas Desulphurisation (FGD) plant was identified as the most effective technology for reducing carbon emissions. However, its estimated installation cost of R39 billion raises investment concerns. In the absence of a broad range of cost-effective technological options, the available technology (FGD) becomes too expensive for developing countries like South Africa. The current study also found that Investments in Eskom's decarbonization drive should be anchored on innovation, affordability, and sustainability. Therefore, a decarbonization approach that is based on shedding the load will not be affordable or sustainable as it will cost South Africa's economy billions of rands per day. Given the high cost of procuring the suitable carbon emissions abatement technologies, the study suggests that more renewable energy sources should be incorporated into the energy system as an alternate cost-effective decarbonization measure, than investing billions in CO_2e abatement technologies for coal power stations which are fast approaching the end of their lifespan.

Summary: The findings of this study suggest that climate change has a direct impact on energy production and security. A faster transition to an energy system that is able to withstand the effects of climate change is critical. This study investigated one of the major energy-generating utilities in the Southern Hemisphere, Eskom, which has a large fleet of coal-based plants. Despite being a crucial topic, academic studies on the resilience and robustness of South Africa's energy sector, particularly with regards to energy security, are scarce. This study will contribute to the existing academic literature on climate change and energy security and prompt future research on the subject. Chapter Two highlights that existing literature and theories often do not include South African case studies in the area of climate change and energy security. This study aimed at addressing this gap by focusing specifically on the energy sector in South Africa. The study's use of climate change projections, historical weather data, water resource consumption data, emissions data, and analysis of the power plants' age, maintenance, and operational philosophy in relation to Eskom's case studies provided a comprehensive understanding of the impact of climate change on South Africa's energy sector. Chapter Five provided insights into the current state of South Africa's energy policy and its lack of implementation to transition the energy system. The discussions presented in this chapter can be applied and tested for their potential to address the challenges posed by the nexus of climate change and energy security. The findings of this study can be used to understand the vulnerability of different energy sources to climatic change, and provide ideas for energy sector transition. Furthermore, the findings on the policy implementation gaps can assist in improving the effectiveness of the Integrated Resource Plan for South Africa's energy policy.

6.3 POLICY RECOMMENDATIONS

Policy Recommendation for Objective 1 & 5: While South Africa's current energy policy advocates for decarbonization, it fails to embrace the dilemma that Eskom is facing with regard to the pursuance of decarbonization programme while ensuring the security of energy supply. Thus, the integrated energy resource plan should include directives and solutions to manoeuvre decarbonization-energy security dilemma for Eskom to implement without confusion. The current energy policy should ideally recommend innovative opportunities that existing coal fired power plants can adopt to mitigate current carbon footprint. Eskom should also review and adapt its institutional policies to evolve its operational capabilities as another means of enhancing coal power plants' performance coefficiency and carbon emissions reduction.

Policy Recommendation for Objective 2: In order to build a climate change resilient and adaptive organization, Eskom should develop its water management policy and strategies strictly aligned with and measured against coal power plants' thermal efficiency. Thus, quantity of GWh SO should be relative to the amount of water used, as guided by design consumption rates. The policy and the strategy should be drafted in a way that is linked with every role player's (e.g., operator, maintainer, lab analyst, water leak spotter, etc.) key performance indicator. Figure 6.1 provides a systematic approach that Eskom's water-energy-climate change strategies may consider to achieve desired water efficiency outcome, and ensure climate-adaptive coal power plants.

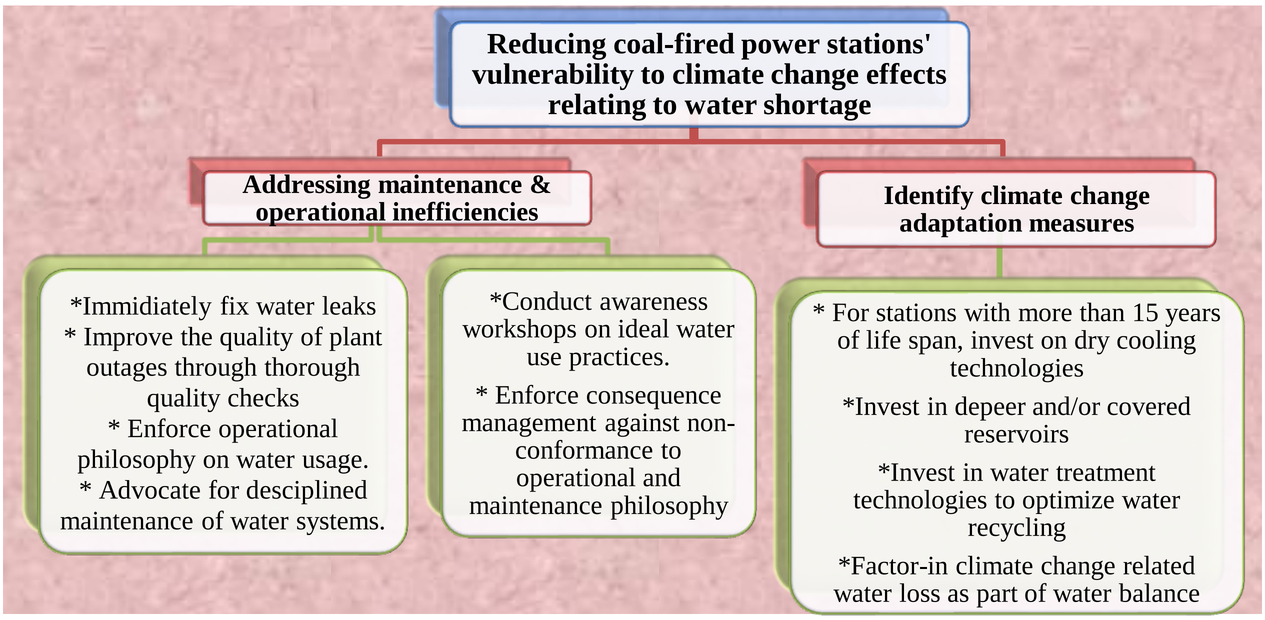


Figure 6.1 Some focus areas for strategy to ready coal-fired power plants for climate change-induced water shortages
Source: Based on field survey (2021)

As depicted in Figure 6.1 above, it is recommended that Eskom coal power plants should focus their efforts on resolving maintenance problems, operational inefficiencies, and developing adaptation strategies to cope with irregular precipitation caused by the effects of climate change while ensuring energy security.

Policy Recommendation for Objective 3: South Africa's energy policy should be adapted to enable the establishment of micro electricity grids that would link up with Eskom's main energy supply grid. Microgrids could help to stabilize the national grid against the risks of collapse and would further ensure South Africa's energy security. The energy policy and IRP should be adaptive and continuously informed by regional research to determine the most suitable energy sources for specific regions. Incorporating a unified policy for managing the connection between climate change and energy security in South Africa's IRP will ensure that risks associated with climatic change and their impacts on the energy sector are well understood and addressed. A unified climate change-energy security policy would ensure that a Medupi case study (wherein a water intensive technology was installed in a water scarce area) is avoided. It is also recommended that a root cause analysis should be undertaken to identify the challenges in fast-tracking the execution of clean energy mix projects by Eskom and Independent Power Producers (IPPs). These lessons would provide valuable insights for new IPPs to learn from and better prepare for their projects. The procurement policies and timelines should be aligned with the energy policy and IRP execution timelines to ensure a seamless implementation of policy commitments. This will also facilitate for the effective implementation of the energy mix programme and contribute to the successful transition to a clean energy mix.

Policy Recommendation for Objective 4: The current energy policy of South Africa fails to explicitly acknowledge the impact of climate change on energy security as a key driver for transitioning the energy system to a clean energy mix. This oversight could result in a reactive approach when dealing with climate change adaptation and resilience measures, for instance, in response to major weather events such as floods or droughts affecting the energy sector. To address this, it is recommended that the Integrated Resource Plan (IRP) be amended to include a unified policy for managing the link between climate change and energy security. By managing these issues through separate policies, the interdependence between them may be overlooked. A unified policy will ensure that risks related to climatic change and their impact on the energy sector are well understood and integrated into the overall energy policy implementation. This will also aid in the effective implementation of the energy mix programme. At an organisational level, Eskom needs to develop a comprehensive energy system transition policy that would outline the organizational commitments towards increasing the use of clean energy sources, maintaining excellence, and enhancing the adaptability and resilience of the energy sector.

6.4 FUTURE RESEARCH

This study used Eskom Generation Division as the main case study and employed five power stations as embedded case studies, each situated in a unique geographical context. It is believed that future regional-focused studies will be necessary to evaluate and propose feasible clean energy technologies that take into account projected changes in climatic conditions, natural resource distribution, and area or region suitability. These studies will also aid in providing less resourced Independent Power Producers with informed investment decisions.

The weather projection model used in this study was developed over five years ago and projects weather variability from 2021 to 2050. Future research that employs updated weather projections could improve the estimation of the potential impacts of climate change on energy systems. Given South Africa's reliance on coal-based energy, thorough research is required to be conducted at all existing coal power station, particularly focused on their adaptability and resilience to changes in climatic conditions. The future studies could also consider other measures to improve the robustness of coal-based energy sources.

Further research is necessary to identify suitable geographical locations for investment in various energy sources. Potential hydropower energy sites must be thoroughly evaluated in terms of potential effects of climatic conditions such as dry spells, rainfall distribution, and average temperatures. Hydro energy sources rely on water for energy production and water availability is dependent on rainfall distribution and average temperatures. Studies should be carried out to determine the rate of water reduction and loss from rivers and water storage dams at different temperature levels, taking into account the input water required to generate electricity. Similar studies should be conducted for other clean energy sources before investment decisions can be made.

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LIST OF PERSONAL COMMUNICATIONS

Personal communication 2021A, comments received through email from an experienced engineer from coal-fired power station in Mpumalanga, on the 25th of January 2021.

Personal communication 2021B, additional remarks gathered through survey instrument (via email) from Climate Change Expert from environmental consulting firm on the 14th of January 2021.

Personal communication 2021C, observations obtained from a Geographic Information Scientist based at the regulator's office (via email) on the 16th of January 2021.

Personal communication 2021D, remarks gathered during an interview (via email) conducted with a Geohydrologist and Climate Change Expert on 22rd of January 2021.

Personal communication 2021E, comments received through email from Senior Environmental Advisor (Interview) based at a coal-fired power station in Mpumalanga, on the 28th of February 2021.

Personal communication 2021F, views received through email from a veteran Environmental Impact Assessment Specialist based at Eskom's Sustainability Division, on the 23rd of March 2021.

Personal communication 2021G, interview responses received through email from a Senior Environmental Advisor and Water Specialist from Eskom Corporate Office, on the 12th of January 2021.

Personal communication 2021H, views received from an experienced Environmental Advisor from coal-fired power station based in Mpumalanga Province, on the 26th of January 2021.

Personal communication 2021I, interview perceptions received through email from Environmental Officer based at a coal-fired power station on the 30th of March 2021.

P**ersonal communication 2021J**, interview observations received through email from a senior

Civil Engineer based at a coal-fired power station in Mpumalanga, on the 3rd of February 2021.

Personal communication 2021K, insights received through email from an Air Quality Specialist based at Eskom's Sustainability Division, on the 31st of January 2021.

Personal communication 2021L, comments received through email from an experienced Senior Environmental Advisor based at Eskom's coal-fired power station, on the 22nd of January 2021.

Personal communication 2021M, interview input received from an Environmental Specialist based at Eskom's Research, Testing and Development Division, on the 13th of February 2021.

Personal communication 2021N, observations gathered during an interview (via email) conducted with an Environmental Manager based at a Hydro Power Station on the 23rd of March 2021.

Personal communication 2021O, interview views received through email from a veteran Environmental Manager based at coal-fired power station, on the 4th of February 2021.

Personal communication 2021P, observations collected through interview (email) from a Senior Environmental Advisor based at a coal-fired power station in Limpopo Province, on the 8th of February 2021.

Personal communication 2021Q, observations gathered during an interview (via email) conducted with a veteran Groundwater and Climate Change specialist based at Environmental Consulting Firm on the 19th of March 2021.

Personal communication 2021R, comments gathered during an interview (via email) conducted with a Senior Environmental Advisor based at coal-fired power station in Mpumalanga on the 19th of January 2021.

Personal communication 2021S, views gathered during an interview (via email) conducted with an environmental officer based at a Hydro Power Station based in Kwazulu-Natal on the 15th of January 2021.

Personal communication 2021T, observations collected during an interview (via email)

conducted with an Environmental Advisor from Eskom on the 13th of March 2021.

Personal communication 2021U, insights collected during an interview (via email) conducted with an environmental officer based at a coal-fired power station in Mpumalanga on the 23rd of January 2021.

Personal communication 2021V, comments gathered during an interview (via email) conducted with an environmental specialist based at an environmental consulting firm on the 14th of February 2021.

Personal communication 2021W, perceptions gathered during an interview (via email) conducted with an Eskom's Environmental Officer on the 30th of January 2021.

Personal communication 2021X, interview views gathered on the 20th of February 2021 via email from a Senior Environmental Advisor based at Eskom's Research, Testing and Development Division.

Personal communication 2021Y, observations gathered on the 5th of February 2021 via email from Eskom's Senior Environmental Advisor based at Eskom's Group Capital Division.

Personal communication 2021Z, perceptions received from an academic via email on the 4th of February 2021.

Personal communication 2021Aa, comments gathered on the 15th of January 2021 via email, as additional comments to questionnaire survey views, from Eskom's Process Engineer base at coal-fired power station.

Personal communication 2021Ab, input received through email from an Environmental Practitioner based at the regulator's office on the 23rd of March 2021.

Personal communication 2021Ac, observations received through email from a Senior Plant Operator based at the coal-fired power station on the 2nd of February 2021.

Personal communication 2021Ad, comments gathered on the 22nd of March 2021 via email from Environmental Practitioner based at coal-fired power station.

Personal communication 2021Ae, observations received through email from a senior environmental specialist based at Eskom's power generation division, on the 22nd of March 2021.

Personal communication 2021Af, comments received through email from a senior environmental specialist based at environmental consulting firm, on the 13th of February 2021.

Personal communication 2021Ag, observations received during webinar participation from a renewable energy expert, on the 13th of February 2021.

Personal communication 2021Ah, comments gathered on the 22nd of February 2021 via email from Environmental Practitioner based at coal-fired power station.

Personal communication 2021Ai, comments gathered on the 15th of February 2021 via email from Environmental Practitioner based at coal-fired power station.

Personal communication 2021Aj, comments received through email from an environmental specialist based at environmental consulting firm, on the 22nd of February 2021.

Personal communication 2021Ak, observations received from an Environmental Officer on the 17th of February 2021 from based at coal-fired power station.

Personal communication 2021Al, views shared by an Environmental Practitioner based at coal-fired power station on the 24th of February 2022.

Personal communication 2021Am, additional views received through email from a Senior Environmental Consultant based at environmental consulting firm, on the 17th of February 2021.

Personal communication 2021An, comments received through email from an Environmental Practitioner from coal-fired power station, on the 20th of February 2021.

Personal communication 2021Ao, observations received during webinar participation from a Climate Change expert, on the 13th of February 2021.

Personal communication 2021Aq, observations received during webinar participation from an

Environmental Specialist based at Eskom's climate change office, on the 13th of February 2021.

Personal communication 2021Ap, observations received during webinar participation from a Climate Change and Energy expert, on the 13th of February 2021.

Personal communication 2021Ar, observations received during webinar participation from a Environmental Practitioner, on the 13th of February 2021.

ANNEXURE A: FIELD BASED MATERIAL (A1 to A10)

Annexure A1: Participants' perceptions on whether coal-fired power stations are a South Africa's primary source of carbon emissions		
Participants' Perceptions	**No. of Participants**	**%**
No, CFPS are not the main source of carbon emissions	10	7
I do not know	7	5
Yes, CFPS are the primary source of carbon emissions	131	88

Annexure A2: Participants' perceptions on whether Eskom's contribution on carbon emissions and climate change is negligible or not		
Participants' Perceptions	**No. of Participants**	**%**
Eskom's carbon emissions is significant & requires attention	95	64
I do not know	27	18
Eskom's carbon emissions is negligible & status quo is acceptable	26	18

Annexure A3: Participants perceptions on the significance of Climate change effects on South Africa's energy sector and energy security		
Participants' Perceptions	**No. of Participants**	**%**
Climate change effects will hardly be felt by SA's energy sector	54	36
Do not know	26	18
The significance of climate change will be strongly felt by SA's energy sector	68	46

Annexure A4: Participants' views on whether high temperatures caused by climate changes will significantly affect thermal efficiency at coal-fired-power stations		
Participants' Perceptions	**No. of Participants**	**%**
In agreement, thermal efficiency at coal-fired power stations will be affected significantly.	92	62
Do not know.	37	25
In disagreement, thermal efficiency at coal-fired power stations won't be affected.	19	13

Annexure A5: Participants' perceptions on whether South Africa has an effective policy framework to transition the current energy sector to cleaner energy systems		
Participants' Perceptions	**No. of Participants**	**%**
No, the policy framework is serving as a bottleneck for transition	54	36
Do not know	41	28
Yes, SA policy framework is well aligned to advance transition	53	36

Annexure A6: Perceptions of survey participants on whether South Africa is doing way less to ensure that transition to cleaner energy is achieved		
Participants' Perceptions	**No. of Participants**	**%**
No, definitely not enough	79	53
Do not know	35	24
Yes, it's enough	34	23

Annexure A7: Viewpoints by survey participants on the significance of transition to cleaner energy mix in South Africa		
Participants' Perceptions	**No. of Participants**	**%**
Energy transition is a key measure for SA to adapt against climate change effects	126	85
Do not know	8	5
South Africa does not need to change its current energy systems to adapt against climate change effects	14	10

Annexure A8: Participants' views on the sustainability of coal-fired power stations in the era of elevated climate change effects		
Participants' Perceptions	**No. of Participants**	**%**
Coal-fired power stations will remain a sustainable choice in the era of extreme climate change effects	96	65
Do not know	19	13
Coal-fired power stations will not be sustainable in the era of elevated climate change effects.	33	22

Annexure A9: Participants' perceptions regarding the existence of technologies to mitigate and offset carbon for Eskom power plants		
Participants' Perceptions	**No. of Participants**	**%**
Yes, reliable technologies exist	99	67
Do not know	31	21
No, there are limited reliable technologies in place	18	12

Annexure A10: Participants' views on the affordability of measures to minimise carbon emissions		
Participants' Perceptions	**No. of Participants**	**%**
Measures to minimise GHG emissions are too expensive and make less investment sense	63	43
Do not know	37	25
Affordable and justifiable measures to minimise GHG emissions are available	48	32

ANNEXURE B: PARTICIPANT INFORMATION SHEET (INTERVIEWS)

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies

University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: (011) 717-6516

RE: Participant Information Sheet (Interview Questions)
Date: 10 August 2020

Good day,

My name is Khuliso James Rasimphi and I am a Doctor of Philosophy (PhD) student in the school of Geography, Archaeology and environmental Studies at the University of the Witwatersrand (Wits), Johannesburg. As part of my studies, I have to undertake a research project, and I am investigating the **Perspectives on Climate Change and Energy Security in South Africa: A Study of Eskom, South Africa** under the supervision of Professor Mulala Danny Simatele. The aim of this research project is to explore the potential impacts of climate change on South Africa's energy security; and also to assess the suitability, adequacy and effectiveness of SA's current Integrated Energy Plan (IEP) in transitioning the energy sector to become adaptive and resilient to climate change effects.

As part of this project, I would like to invite you to take part in an interview session. In order to comply with social distancing measures to minimize the spread of Coronavirus (Covid19), this activity will involve answering semi-structured qualitative interview questions through virtual means or telephonic sessions; and will take around 30 minutes. Alternatively, semi-structured interview questions will be made available to you through electronic means such as email and internet; you can then complete the interview questions and thereafter scan and send completed questions back to me using your preferred electronic means. With your permission, I would like to also record the interview using a digital device.

There will be no personal costs to you if you participate in this project. You will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. You may withdraw at any time or not answer any question if you do not want to. The interview will be confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else. I will be using false name to represent your participation in my final research report. If you experience any distress or discomfort at any point in this process, we will stop the interview or resume another time.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to see a summary of this report, I will be happy to send it to you. The data collected from this research project will be stored in the computer system with a controlled password for future secondary analysis; and it will be kept for five years. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email: hrecnon-medical@wits.ac.za.

Yours sincerely,

Researcher: Khuliso James Rasimphi
Student No: 1699084
Cell: 076 250 2002 / Tel: 017 615 2634
Email: 1699084@students.wits.ac.za

Supervisor: Professor Mulala Simatele

Cell: 083 383 6884 / Tel: 011 717 6516
Email: Danny.Simatele@wits.ac.za

ANNEXURE C: CONSENT FORMS (INTERVIEWS)

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies

University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: +27(0) 11 717 1408

RE: Consent Form

Title of Project: Perspectives on Climate Change and Energy Security in South Africa: A Study of Eskom, South Africa.

Name of researcher: Khuliso James Rasimphi

I ……………………………………………………., agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I therefore agree to the following:

Please tick the relevant options below:

DESCRIPTION OF THE OPTIONS	YES	NO
I agree that my participation will remain anonymous.	☐	☐
I agree that the researcher may use anonymous quotes in his / her research report.	☐	☐
I agree that the interview may be audio recorded.	☐	☐
I agree that the information I provide may be used anonymously after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	☐	☐

Signatures:

Participant Signature: …………………………….....

Name of Participant: ………………………………

Date:………………………………..

Signature:

Khuliso Rasimphi: Researcher

Cell: 076 250 2002 / Tel: 017 615 2634

Email: RasimpKJ@eskom.co.za

Student No: 1699084

Professor Danny Simatele: Supervisor

Cell: 083 383 6884 / Tel: +2711-717-6602

Email: Danny.Simatele@wits.ac.za

ANNEXURE D: INTERVIEW QUESTIONS INSTRUMENT

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies
University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: +27(0) 11 717 1408

Thank you for taking time to complete this research interview questions. There are two sections to be completed which are section 1 (demographic information) and section 2 (questions). Kindly complete all the questions carefully. The following interview questions should take you about 30 minutes to answer.

SECTION 1: Demographic Information

Kindly complete demographic information in the table below:

Participant's Institutional Association (e.g. Government/Authority, Power Generation, Climate Change Expert, Private Section, NGO, Local Resident)	
Designation/Position	
Related Experience (Years and months)	
Contact Details (Optional)	
Gender (Optional)	

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies
University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: +27(0) 11 717 1408

SECTION 2: Questionnaire

1. Eskom's coal-fired power stations are the major emitters of greenhouse gases in South Africa? (tick in the correct box on the right)	Agree	☐	Disagree	☐
Additional Comments:				
2. What effects do you think climate change will have on South Africa's energy sector and energy security on a medium to long term?				
Response:				
3. What is your view on the suitability, adequacy and effectiveness of South Africa's policy framework to transition the current energy sector to cleaner energy system?				
Response:				
4. Based on your knowledge, which energy generating technology between coal-fired and renewable energy systems would you say is more susceptible to climate change effects, and why?				
Response:				
5. South Africa is currently doing way less to ensure that transition to cleaner energy is achieved (tick in the correct box on the right)	Agree, more effort is needed	☐	Disagree, more has been done.	☐
Additional Comments:				
6. Considering that South Africa is seeking to achieve more energy mix in the grid, what is your view on the Eskom's recent large spending on Medupi and Kusile coal-fired power stations?				
Response:				
7. In your view, what measures would you suggest that Eskom power stations (coal-fired and hydropower) should invest on now in order to adapt against climate change effects?				
Response:				
8. South Africa has recently gazetted Carbon Tax Act which legally binds CO2 emitters to pay tax				

for their emissions, what is your opinion about this development?				
Response:				
9. Inadequate availability of water due to irregular precipitation may result into the interruption of energy production at Eskom's coal-fired and hydro power stations. (tick in the correct box on the right)	Yes, I agree	☐	No, I disagree	☐
Additional Comments:				
10. What do you think are the long term benefits of transitioning to cleaner energy systems?				
Response:				
11. Do you think a developing country such as South Africa should concern itself about adaptation strategy for climate change effects considering that the said effects may only be experienced in some 20-30 years to come? Please elaborate				
Response:				
12. In your opinion, what would you say are some of the measures which can be implemented in a short-term to minimize greenhouse emissions from Eskom coal-fired power stations?				
Response:				
13. With a motivation, would you say that the current coal-fired energy base load in South Africa can survive climate change effects such as high temperatures, irregular precipitation, etc.?				
Response:				
14. In your opinion, why is it so important to ensure that there is energy generation mix in South Africa's energy sector particularly in nexus with climate change effects?				
Response:				
15. Who do you think needs to play a role to ensure that transition to cleaner energy is swiftly achieved in South Africa? Which cleaner (renewable) energy systems/technology are ideal for South Africa?				
Response:				
16. Based on your knowledge, what is the cheaper and sustainable energy generating technology (between coal fired and renewable)? Please elaborate on your answer.				

Response:
ADDITIONAL GENERAL COMMENTS:

ANNEXURE E: QUESTIONNAIRE SURVEY INSTRUMENT

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies
University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: +27(0) 11 717 1408

RE: Participant Information Sheet (Questionnaire Survey)
Date: 14 October 2020

Good day,

My name is Khuliso James Rasimphi and I am a Doctor of Philosophy (PhD) student in the school of Geography, Archaeology and environmental Studies at the University of the Witwatersrand (Wits), Johannesburg. As part of my studies, I have to undertake a research project, and I am investigating the **Perspectives on Climate Change and Energy Security in South Africa: A Study of Eskom, South** Africa under the supervision of Professor Mulala Danny Simatele. The aim of this research project is to explore the potential impacts of climate change on South Africa's energy security; and also to assess the suitability, adequacy and effectiveness of SA's current Integrated Energy Plan (IEP) in transitioning the energy sector to become adaptive and resilient to climate change effects.

As part of this project, I would like to invite you to take part in a questionnaire survey. In order to comply with social distancing measures to minimize the spread of Coronavirus, this activity will involve answering questionnaire survey made available to you though electronic means such as email and internet; you may then complete the questionnaire and thereafter relay a completed questionnaire back to me using your preferred electronic means. It is estimated that the questionnaire will take about 15 - 20 minutes of your time. There will be no personal costs to you if you participate in this project. You will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. You may withdraw at any time or not answer any question if you do not want to. The survey will be confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else. I will be using false name to represent your participation in my final research report. If you experience any distress or discomfort at any point in this process, you can stop completing the survey or resume another time.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to see a summary of this report, I will be happy to send it to you. The data collected from this research project will be stored in the computer system with a controlled password for future secondary analysis; and it will be kept for five years. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email: hrecnon-medical@wits.ac.za.

Yours sincerely,

Researcher: Khuliso James Rasimphi
Student No: 1699084
Cell: 076 250 2002 / Tel: 017 615 2634
Email: 1699084@students.wits.ac.za

Supervisor: Professor Mulala Simatele
Cell: 083 383 6884 / Tel: 011 717 6516
Email: Danny.Simatele@wits.ac.za

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies
University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: +27(0) 11 717 1408

Thank you for taking time to complete this survey. Before you start, kindly take time to read the instructions below:

- There are 2 sections to be completed which are section 1 (demographic information) and section 2 (questionnaire).
- Kindly complete all the questions carefully
- Completion of all the questionnaire should take you about 15-20 minutes to answer
- After completing the survey, kindly submit it to the researcher (email: RasimpKJ@eskom.co.za)

SECTION 1: Demographic Information

Kindly complete demographic information in the table below:

Participant's Institutional Association (e.g. Government/Authority, Power Generation, Climate Change Expert, Private Section, NGO, Local Resident)	
Designation/Position	
Related Experience (Years and months)	
Contact Details (Optional)	
Gender (Optional)	

SECTION 2: Questionnaire

Your views are critical; there are no wrong or right answers. Tick in the ☒ box which strongly represent your views.

Participants Response Criteria:

1. Strongly Disagree	2. Disagree	3. Do Not Know (Neutral)	4. Agree	5. Strongly Agree

N0	Link to Obj.	Statement	S disagree ◄—► S agree				
1	(iv)	A significant transition to cleaner energy mix is South Africa's key measure to survive climate change effects.	1☐	2☐	3☐	4☐	5☐
2	(i)	Coal generated energy is South Africa's primary source of emissions for greenhouse gases such as CO2, Methane,etc.	1☐	2☐	3☐	4☐	5☐
3	(ii)	Climate change effects may largely result into an insignificant effect on South Africa's energy sector and energy security.	1☐	2☐	3☐	4☐	5☐
4	(iii)	South Africa has an effective policy framework to transition the current energy sector to cleaner energy systems.	1☐	2☐	3☐	4☐	5☐
5	(i)	South Africa's energy sector does contribute to emissions of greenhouse gases and climate change effects.	1☐	2☐	3☐	4☐	5☐
6	(iv)	Investment in cleaner energy and energy efficiency is critical in minimizing the adverse economic, social and environmental impacts of energy generation in South Africa.	1☐	2☐	3☐	4☐	5☐
7	(iii)	South Africa's integrated energy plan is not followed-up with a progressive implementation by government.	1☐	2☐	3☐	4☐	5☐
8	(ii)	South Africa's energy generating infrastructure and generating processes are too robust to be affected by climate change phenomenon.	1☐	2☐	3☐	4☐	5☐
9	(i)	As a developing country, South Africa should not be worried about mitigating the emissions of greenhouse gases.	1☐	2☐	3☐	4☐	5☐
10	(ii)	Effects of climate change may result in reduction of energy production and eventual energy insecurity for South Africa.	1☐	2☐	3☐	4☐	5☐
11	(iii)	50% of South Africa's current energy sector founded on coal as primary energy can be transitioned to cleaner energy system by year 2050.	1☐	2☐	3☐	4☐	5☐
12	(iv)	South Africa does not need to change its current energy systems to adapt against climate change threat.	1☐	2☐	3☐	4☐	5☐
13	(v)	Technologies exist which Eskom can adopt to offset current greenhouse gas emissions from coal fired power stations.	1☐	2☐	3☐	4☐	5☐
14	(v)	Measures which can be implemented to minimize greenhouse gases emission from Eskom coal-fired power stations are too expensive and make less investment sense.	1☐	2☐	3☐	4☐	5☐

15	(vi)	In a long term, South Africa's current investment on coal-fired power stations may prove to be highly costly as the technology will need to be overhauled or shut- down due to lack of coal.	1☐	2☐	3☐	4☐	5☐
16	(iii)	South Africa is doing way less to ensure that transition to cleaner energy is achieved.	1☐	2☐	3☐	4☐	5☐
17	(ii)	Inadequate availability of water due to irregular precipitation may result into the interruption of energy production at Eskom's coal-fired and hydro power stations.	1☐	2☐	3☐	4☐	5☐
18	(i)	South Africa's energy sector has implemented strict measures which are effectively curbing high emissions of greenhouse gases.	1☐	2☐	3☐	4☐	5☐
19	(v)	The recent gazette of Carbon Tax Act will result in a significant reduction of CO2 emissions from most emitter companies in South Africa.	1☐	2☐	3☐	4☐	5☐
20	(i)	The contribution of South Africa's energy sector on greenhouse effect and climate change is negligible.	1☐	2☐	3☐	4☐	5☐
21	(iv)	Renewable energy sources such as solar and wind offers cheaper long-term energy alternatives for South Africa.	1☐	2☐	3☐	4☐	5☐
22	(ii)	Climate change effects have a direct link with energy production processes and energy security.	1☐	2☐	3☐	4☐	5☐
23	(iii)	South Africa's climate change mitigations and adaptation strategies need to be integrated into the energy policy.	1☐	2☐	3☐	4☐	5☐
24	(ii)	High temperatures caused by climate change will significantly affect thermal efficiency at coal fired-power stations.	1☐	2☐	3☐	4☐	5☐
25	(iii)	The construction of Medupi and Kusile coal-fired power stations (new-builds) is a good indicator that South Africa is not committed to fast track transition to cleaner energy.	1☐	2☐	3☐	4☐	5☐

ANY ADDITIONAL COMMENTS:

ANNEXURE F: ETHICS CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Rasimphi

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H20/07/39**
PROJECT TITLE	Perspectives on climate change and energy security in South Africa: A study of Eskom, South Africa
INVESTIGATOR(S)	Mr K Rasimphi
SCHOOL/DEPARTMENT	Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	24 July 2020
DECISION OF THE COMMITTEE	Approved Risk Level: Low
EXPIRY DATE	16 August 2023

DATE 17 August 2020 **CHAIRPERSON** J Knight

(Professor J Knight)

cc: Supervisor : Professor M Simatele

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature Date 31 / 08 / 2020

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

ANNEXURE G: CONSENT FORMS (PARTICIPANT OBSERVATIONS)

School of Geography, Archaeology and Environmental Studies
Department of Geography and Environmental Studies
University of Witwatersrand/ Private Bag 3, WITS, 2050
Enquiries: Tel: (011) 717-6516

RE: Consent Form (Participants Observations)

Title of Project: Perspectives on Climate Change and Energy Security in South Africa: A Study of Eskom, South Africa.

Name of researcher: Khuliso James Rasimphi

I ………………………………………………….., give permission to the abovementioned researcher to be a participants' observer in the event as identified in the participant information sheet for which I am the moderator. The research project has been explained to me and I understand what the researcher's participants observations will involve. I therefore agree to the following:

Please tick the relevant options below:

DESCRIPTION OF THE OPTIONS	YES	NO
I agree to that the researcher will keep all the participants anonymous.	☐	☐
I agree that the researcher may not use any quotes from the participants in his / her research report.	☐	☐
I agree that the event (webinar, conference,etc.) may be audio recorded.	☐	☐
I agree that the information provided by participants may be used anonymously after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	☐	☐

Signatures:

Participant Signature: ……………………………....

Name of Participant: ………………………………..

Date:…………………………………….

Signature:

Khuliso Rasimphi: Researcher

Cell: 076 250 2002 / Tel: 017 615 2634

Email: RasimpKJ@eskom.co.za

Student No: 1699084

Professor Danny Simatele: Supervisor

Cell: 083 383 6884 / Tel: 011 717 6516

Email: Danny.Simatele@wits.ac.za