Renewable energy and its implications on Fossil Fuel:
A Stranded Assets scenario in South Africa?

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Declaration

I declare that this research report is my own unaided work. It is submitted for the degree of Master of Architecture (Sustainable Energy and Efficient Cities) at the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any other degree or examination at any other university, nor has it been prepared under the auspices or assistance of any organization or person outside of the University of the Witwatersrand, Johannesburg.

Signature of Candidate

_26th__day of_August___year_2019____

Dedication

In memory of my dearly departed mother,

Mrs. Ajibola, Florence Omoboni

1946 -2004.

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Glory be to God almighty for giving me the knowledge, wisdom and strength to finish this research report. However, the completion of this report would not have been possible without some people and funders, whom I wish to acknowledge and thank.

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Abstract

The energy transition is gaining momentum globally and new sustainable energy practices are developing fast. Increasing attention is being given internationally to the risk associated with unburnable carbon which often results in stranded assets. International organizations, renewable energy lobby groups/advocates, policymakers and various government structures are influencing and establishing regulations in order to change the 'normal' practices and adopt a sustainable energy transition trending globally. However, these global energy transition trends are currently invigorated and orchestrated at various scales often by multi-national climate change imperatives, energy efficiency innovators, inventors, investors and other renewable energy lobby groups.

The call for a change in 'normal' practices, i.e. a change in 'business as usual', is essential, obligatory and invigorated in order to promote more sustainable choices and outcomes in many countries. Nevertheless, this change often puts many countries energy sector under pressure and poses huge economic disruption with various repercussions particularly to a country like South Africa.

South Africa amid other economic challenges is faced with changing its energy generation pattern. The country is highly dependent on energy generated from fossil fuel - coal. A change in the energy generation pattern with alternative renewable energy option might have an adverse effect on the economy if not strategically implemented. A move towards the global energy trend is important, however, it comes with various forms of economic disruptions one of which is the possibilities of stranded assets.

With relevant academic reports, literature and statistical analysis drawn from secondary sources, this research report examines South Africa's energy transition within a global energy debate. The report adopts the concept and ideology of "Stranded Assets" in order to query the future of South Africa's energy landscape. The report considers the country's recent investment on fossil fuel infrastructure – the Medipe and Kusile coal power stations to evaluate the possibilities of these infrastructures becoming worthless i.e. stranded assets before its due investment return period.

Anchoring on related topics associated with South Africa's commitment to renewable energy, this report presents rigorous discussions on possible implications that come with unprepared or unplanned energy transitions and concludes with possible scenarios facing a developing country like South Africa.

List of Abbreviations & Acronyms

BP	British Petroleum
CAIT	Climate Analysis Indicators Tool
CCPA	Climate Change Paris Agreement
CDM	Clean Development Mechanism
CIMS	Capital Investment Management System
CO_2	Carbon dioxide
CSIR	Council of Scientific and Industrial Research
CSP	Concentrating Solar Power
DC	Developing Countries
DoE	Department of Energy
DoM	Department of Minerals
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Green House Gas
HFC	Hydro Fluoro Carbon
IDB	Infrastructural Development Banks
IEA	International Energy Agency
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPs	Independent Power Producers
LTMS	Long-Term Mitigation Scenario
MW	MegaWatt
NERSA	National Energy Regulator of South Africa
NIRP	National Integrated Resource Plan
PV	PhotoVoltaic
RE	Renewable Energy
REFIT	Renewable Energy Feed-In-Tariff

REIPPPP/REI4P	Renewable Energy Independent Power Producer Procurement Programme
REWP	Renewable Energy White Paper
S.A.	South Africa
SER	Systematic Evaluative Review
TEPs	Techno-Economic Paradigms
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework on Climate Change
USA	United States of America

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CHAPTER 1: RESEARCH OVERVIEW

1.0 Introduction

For many decades, fossil fuels such as oil and coal have fuelled the bulk of global energy production. These products were plentiful and inexpensive at the beginning of the industrial revolution and were widely adopted in industry, commerce, and transportation (Beiser, 2016). In many ways, fossil fuels have provided simple, easy to use energy sources that powered the industrialization of most modern nations (Carbon Tracker, 2014). The issues associated with the widespread use of fossil fuels for generating energy are now numerous, consisting of some of the world's most difficult and large-scale global political, economic, health and environmental problems(*ibid*).

Staniskis *et al.* (2014) highlight that the looming energy crisis results from consuming fossil fuels resources at a rate which is unsustainable, with the global demand for fossil fuels increasing every year since the last decade has compounded fossil fuel associated problems. Currently, the utilization of these fossil fuel resources to produce energy is becoming a critical topic of discussion due to some of the global concerns such as economic, health and environmental problems highlighted above.

Jackson (2014) classifies these concerns into two - the first being the steady decline and depletion in the global supplies of various fossil fuel resources. The second is the increasing planetary temperatures due to the release of carbon dioxide and other greenhouse gasses (GHG) accumulate in the atmosphere largely due to the combustion of fossil fuel for energy purpose.

Although, there has been continuous advocacy on the need to mitigate carbon dioxide emission from burning fossil fuel since the early late '80s

(Stiglitz, 2007; Allen *et al*, 2014; Coady *et al*, 2015). Unfortunately, Coady *et al,* (2015) argue that many countries are still dependent on fossil fuel, with approximately 72% of the world's energy being generated by fossil fuel. A report by Carbon tracker initiative (2018) also agrees that vast majority of the world's energy (particularly in developing countries) are produced by burning fossil fuels because energy is pinned with economic growth in these countries. For instance, about 85% of South Africa's energy was supplied by fossil fuels until the end of 2015 (CSIR, 2015). However, a recent report by CSIR (2017) now shows a surge in the use of alternative sources of energy.

Empirically, economic growth and energy consumption are closely linked. The Center for International Development (2014) report argue that every sector of the economy requires energy and even the most basic needs of humanity cannot be supplied without access to energy. Our modern society also depends on transportation and information processing, which makes access to energy paramount. According to Cloete (2016), energy is necessary to produce food and in the provision of clean water. Whilst it would be difficult to simply stop burning these fuels in order to stop causing climate change, Coady *et al,* (2015) argue that fossil fuels remain important to develop most economy, as they are used to power heavy equipment in industries and to generate electricity for offices and households.

Nonetheless, the prevailing global consensus is that something must be done to adjust to the adverse climatic conditions and find solutions that will stabilize or decrease Green House Gas (GHG) emissions, without crippling economic development or growth. According to Dana (2014), the presence of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere which results in a change in regional and often global climate patterns known as climate change. Despite detraction, climate change is an accepted reality, the effects of which are being experienced worldwide due to the enormous strain it places on the health sector, agricultural production, plant and animal biodiversity and water resources (Carney, 2016).

According to Stern (2006: 2), climate change is "one of this century's most transnational issues, with a global effect such as increasing global temperatures that have led to various consequences". These consequences are "increase in sea levels due to glacial ice shelves melting, increase in intense weather phenomena - such as hurricanes, typhoons and flooding, as well as droughts, inconsistencies of environmental seasons, and increased levels of methane in the atmosphere due to melting ice shelves". The emission of CO_2 and other GHG gases into the atmosphere not only has hazardous health effect on people but also on the environment, contaminating water and soil which leads to their degradation (Davenport, 2016).

According to Boden *et al,* (2016), the Climate Change Paris Agreement (CCPA) serves as a global consensus and aims to find alternative renewable energy sources with little or no consequences on the environment including the earth's ecological system. The CCPA of 2015 also aims to ensure that average global temperatures do not go beyond 2°C in comparison to pre-industrial levels, and if possible, can be significantly lower (Boden *et al*, 2016). With a 50% probability of keeping global temperature rise below 2°C, Barros *et al,* (2016) argue that worldwide energy use predictions still point to a steady increase of fossil fuel for energy purpose indicating a possible increase of carbon dioxide and other greenhouse gases that contribute to global temperature rise.

However, due to increased concern about global climate change, as well as the uncertainties surrounding the use of fossil fuel as a finite resource, Jackson (2016), argues that most countries are now faced with the choice of either continuing with the 'business as usual' i.e. using fossil fuel-based energy or developing new technologies through renewable energy sources that can reduce or eliminate the need to use fossil fuel. According to Carbon Tracker (2014), there is a need for urgent intervention to mitigate the emission of carbon dioxide and other GHG gasses into the atmosphere which may lead to a disastrous transformation of the planet due to its hazardous effect.

According to Carbon Tracker (2014), the challenge of transforming the entire economy and its energy system is enormous; especially if a country is fossil fuel-based and emission-intensive as South Africa is. South Africa has one of the highest global emissions per capita of GHGs, due to its heavy dependence on coal for generating its electricity and other industrial output which has been attributed as one of the major causes of anthropogenic climate condition (*ibid*).

1.1 Background

In an increasingly carbon-constrained world that is currently experiencing various climate change impacts, If the environmental constraints on fossil energy resources cannot be overcome, the increasing shortfall in energy would very likely precipitate a crisis of unprecedented proportions. Even without the added concerns of climate change, the world's energy systems are in a precarious state. Rapid population and economic growth are constantly putting pressure on the existing infrastructure and the demands for energy are rapidly increasing. According to Nakhooda (2014), increasing demand for energy has resulted in the construction of new power stations in South Africa in order to meet its increasing energy demand.

The government of South Africa under the Mbeki administration declared mass electrification of the entire country in 2004 calling it the "Universal Access goal" (Robert, 2014: 50). This mass electrification involved connecting various areas that had no access to the electricity grid and granting them access to the national grid. The universal access goal resulted in strong economic growth with constantly increasing household demand for electricity in various parts of the country(*ibid*).

According to Michael (2011), at the end of 2007, the demand for electricity in South Africa had doubled, with an unanticipated increase in demand and inadequate electricity load planning that began to outstrip supply. This unanticipated demand for electricity resulted in rolling power outages in 2008, many of which lasted for several hours and spread across the country. According to Fell (2009), this was due to deficient coal production systems and coal delivery coordination which could not keep up with the demand. From factories to restaurants, financial banking centers to private homes, individuals were forced to endure lengthy power outages and electricity rationing.

Stats SÁ (2015), the 2007/2008 electricity crisis had a great impact on South Africa's economy and mitigating this crisis became a high priority to the Government. Building new coal-fired station seemed to be the only possible solution at that time. In reactive measures, the government embarked on commissioning two additional coal-fired stations which cost billions of Rands – Medupi and Kusile in 2007 and 2008 respectively. With the construction of these two coal-fired stations on the way, the country also increased its coal output from 124.1 to 161.2 million tonnes per year at the end of 2008, particularly to stabilize energy consumption at that time (Myllyvirta, 2014). According to British Petroleum (BP, 2011) report, during 2008 and 2010, South Africa became the fourth largest user of coal to generate electricity and the second-largest miner of coal in the world.

According to Nakhooda (2014), it is often difficult to provide enough energy for rapid world economic growth while at the same time phasing out fossil energy for environmental reasons. If fossil fuel is phased out due to various concerns, it implies that at least 33% of all oil, 49% of all gas and 82% of all coal reserves would remain underground (Mason, 2013). With an 80% probability of staying within the temperature goal, ICAP (2014) argues that the carbon budget, –which is the amount of cumulative greenhouse gas (GHG) emissions allowed over a given time frame – would be around 565 Gt CO_2 (for 2010–2050), implying that only 20% of global fossil-fuel reserves can be extracted for use. Pursuing 1.5°C and 2°C target translates into a carbon budget of around 365 Gt CO_2 from 2011 to 2100, under a 50% probability scenario (*ibid*). Thus, meeting the Climate Change Paris Agreement (CCPA, 2015) objective earlier mentioned will require leaving fossil fuel reserves untouched, not-extracted and unused, turning them into stranded resources and existing infrastructural investments into stranded assets.

While it may be necessary to accept the use of alternative renewable energy, this report presents discussions on the possibility of stranded assets as one of the major implications that may occur with unprepared or unplanned energy transition. Highlighting experiences from other countries, this report examines South Africa's quest to energy transition within the global energy dilemma. The report examines, South Africa's commitment to renewable energy while considering its recent investment on fossil fuel infrastructures, i.e. Medipe and Kusile coal-fired stations and the possibility of these costly built infrastructure becoming worthless i.e. stranded before their due investment return period.

1.2 Definition of Stranded Assets

There are several definitions of stranded assets in the energy context. Several organizations that work in the field of energy and climate have already examined what stranded assets could mean from their own perspective. The most commonly applied definitions are briefly discussed below:

According to the International Energy Agency (IEA, 2013: 98) stranded assets are "those investments which have already been made but which, at some time prior to the end of their economic life (as assumed at the investment decision point), are no longer able to earn an economic return as a result of changes in the market and regulatory environment brought about by climate policy".

Similarly, the Carbon Tracker Initiative also defines stranded assets as "assets which lose economic value well ahead of its anticipated useful life, whether that is a result of changes in legislation, regulation, market forces, disruptive innovation, societal norms, or environmental shocks associated with the transition to a low-carbon economy" (Carbon Tracker Initiative, n. d.).

The Generation Foundation (2013: 21) explains stranded assets in relation to 'stranded carbon assets' and defines it as those "assets which would likely absorb most losses associated with carbon risks given the intensity of their CO_2 emissions". This term includes fossil fuels as well as those assets which, given their dependence on fossil fuels and subsequent carbon-emissions intensity, would be stranded in the event that fossil fuel valuations plummeted.

The Smith School of Enterprise and the Environment at the University of Oxford employs a 'meta' definition to encompass these (and other) definitions. It states that stranded assets are assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities over a short period of time.

Given the above definitions and for the purpose of this study, I have attempted to explain stranded assets at the simplest level with the following example. Companies purchase assets with a view that such assets will support generation of profits over a certain time frame. These assets may help increase revenues, reduce costs or both. If these assets values reduce precipitously over a short period of time, it can have a negative impact on the company's valuation. In some instances, as is the case with utilities, oil and gas production companies, most companies' valuation can be attributed to it assets, which in turn can be particularly prone to carbon stranding scenarios.

1.3 Problem Statement

The Climate Change Paris Agreement (CCPA, 2015) being a global consensual agreement signed by many countries including South Africa, aims to ensure that average global temperatures should not rise more than 2°C in comparison to pre-industrial levels. According to Yang and Cui (2012), most developed countries are already divesting their fossil fuel assets (e.g. Germany, Sweden and Costa-Rica amongst others). However, the development of basic transportation infrastructures, a decent housing stock with the attendant need for heating and cooling, the development of basic food supplies and basic manufactured goods all depend on fossil fuel energy infrastructure in developing countries.

The idea of stranded assets, created by physical climate change impacts and the transition to a low carbon economy, has risen considerably on the agenda in recent years. If fossil fuels are destined to become stranded assets, it is important to understand the lessons learned from the literature on stranded assets, at least in the context of the debate on the right to development versus the right to (promote) sustainable development. While global fossil fuel reserves in most developing countries are calculated in excess, the pressure to neglect the exploration of these resources for their economic development is increasing. Developing countries such as South Africa, Nigeria, Ghana and Kenya are blessed with abundant fossil fuel resources. These countries hope to become economically and structurally developed and rich like Russia, Canada, Saudi Arabia amongst others through their fossil fuel-based resources and better their economies through these resources.

South Africa is under pressure from the international community to reduce its relatively high anthropogenic emissions of greenhouse gases due to the combustion of fossil fuel i.e coal for electricity purposes (Surridge, 2000). There is no doubt that the South African electricity sector plays a crucial role in the economy by generating internal revenue for local government, creating employment opportunities and empowering local businesses, yet its practices are currently being questioned by international organizations, renewable energy lobby group, alternative energy inventors, and renewable energy technologies investor amongst others.

Policymakers in South Africa are also cognizant of the possible impact a large-scale commitment to renewable energy might have on various public investments (Counterpunch, 2015). Unprepared or unplanned commitment to renewable energy may trigger the possibility of a stranded asset in the economy. Therefore, the protection of public investments has led to a proliferation of private and public-sector funding for more profitable, heavily polluting energy generation technologies, and the delay of rapid energy transition in South Africa.

Presently, the South African government, through the Department of Energy (Previously known as Department of Minerals and Energy) is being persuaded into embracing the global energy transition trend. Various influential investors of alternative renewable energy solutions are currently encouraging the South African government to accept the use of renewable energy, in order to keep up with global trends and accept the anticipated energy disruption. The government is in the process of committing to the pressure from the global energy transition trends with its development, reviewing and adapting various renewable energy strategies. The Renewable Energy White Paper (REWP) was promulgated on November 2003 and the Integrated Resource Plan (IRP) as a policy document was published recently in August 2018. These policies intend to give much-needed trust to the renewable energy lobby groups and the global energy economy.

1.4 Rationale for the Study

The understanding that energy industries can do harm to the environment is not new and environmental concerns over the use of fossil fuels in power generation have already shaped the way these industries operate. Carbon dioxide concerns simply broaden the agenda with the release of CO_2 adding to the long list of environmental impacts as a result of using fossil energy resources. Fossil fuels are not just a large source of greenhouse gases, but they are also a source of many different streams of pollutants ranging from thermal pollution of rivers to acid rain. The extraction of fossil fuel from the ground also adds to their environmental impact which has shaped a large part of the environmental agenda of the twentieth century.

Therefore, attempts to address the environmental consequences of fossil fuel use have resulted in technological advances. Technology innovations have led to alternative ways of generating renewable energy which has led to a drastic reduction in the pollution from fossil fuel-based power. While there is still a gap between what can be done and what is done, it is clear that current technology can eliminate many of the major concerns over fossil fuel-based energy sources. However, the large-scale production of CO_2 has not yet been addressed.

Today, the primary obstacle to the use of fossil fuels is the carbon dioxide emissions associated with it when it burnt or processed. Given the huge scale of energy generation in modern society, it is unsurprising that all modern and renewable energy systems have some impact on the local and global environment (Dana & Caulton, 2014). The specifics differ for each case, but a few general themes emerge most energy systems cause changes in the system from which they harvest the energy (*ibid*). According to Caldecott and Mitchell (2015), coal mining impacts are large, but there are also concerns about the sheer size of the windmill parks necessary to replace fossil fuels. Many of the alternative energy systems also have varying concerns such as environmental concerns and socio-economic growth and inclusivity(*ibid*).

The need for economic growth makes it unlikely that the world will give up on readily available fossil fuels. Therefore, the highest priority should be given to developing energy solutions that can provide plentiful energy particularly for developing countries where they are readily available for everyone in decades to come. Unfortunately, it is very difficult to achieve economic growth in developing countries while phasing out fossil fuels.

1.5 Aim of Research

The study examines South Africa's quest for energy transition within the global energy transition debate. It explores the possibility of stranded assets as one of the major implications that may occur if South Africa's energy transition is not well planned.

1.6 Research Question

To what extent can fossil fuel assets become stranded due to renewable energy transition in South Africa?

1.6.1 Sub-questions

- To what extent can the global energy transition affect the South African energy industry?
- What are the risk factors facing fossil fuel assets in South Africa?

1.7 Objective of the research

The objectives of this research are listed below as follows:

1. To examine the global energy transition debate and contextualize South Africa's energy situation.
2. To examine the possible impacts renewable energy may have on traditional modes of generating energy – coal-fired stations in South Africa.
3. To examine the possibility of stranded carbon assets as one of the major implications that may occur if South Africa's energy transition is not well planned.

1.8 Outline of the Research Report

The research report has been structured into four chapters. These chapters comprise various rigorous academic narratives and literature reviews which have been organized as follows:

Chapter 1: This chapter gives an overview of the research work, it introduces, identifies and defines the research problem, the rationale for the research, questions to be addressed in the research, and outlines the scope in its aim and objectives.

Chapter 2: This chapter reviews the global debate on energy transition. It analyses various literature and debates that are relevant to the research problem. It also provides a global perspective to the anticipated energy disruption while contextualizing South Africa's current energy situation to support the rationale for embarking on the research work and its novelty. It further discusses the concept and evolution of stranded assets, its relationship to the energy industry, particularly how it affects fossil fuel. These reviews were relevant to understand and determine the viability of stranded assets in South Africa.

Chapter 3: This chapter explains the processes adopted in gathering various information. It describes the theoretical methods that underpin the search and describes how data was sorted, analyzed and archived from various published and unpublished literature in order to provide a coherent debate. It also describes other research techniques that influenced the comprehensive compilation of this research report.

Chapter 4: This chapter pulls together relevant debates, anchoring on related theme and topic from various literature. It highlights the author's informed opinion on the possible implications that come with unprepared energy transition. Highlighting South Africa's energy and socio-economic status quo as a key consideration, the report concludes with various scenarios. It examines South Africa's commitment to renewable energy while exploring and reflecting on the country's recent Billion Rand investment on Medupi and Kusile coal-fired stations.

CHAPTER 2: LITERATURE REVIEW OF RELEVANT DEBATES

2.0 Introduction

This chapter presents systematic facts, rigorous findings and relevant information from different academic publications, institutional research and other non-academic, but relevant literature. The chapter begins with the definition of various terms; contextualization of stranded assets and continues with the amalgamation of various debates around global energy transition. Also presented in this chapter are the economic benefits of alternative renewable energy, the death spiral of utility companies and stranded carbon assets amongst other debates.

This chapter sheds light on the discourses and assumptions of different strands of grey literature highlighting related findings and analysis relating to the shift in global energy generating sources and the possibility of asset stranding. Some of the findings presented here are extracts from International Energy Agency (IEA) reports, Carbon Tracker Initiative reports, International Renewable Energy Agency (IRENA)reports and very few articles from Smit School of Enterprise; University of Oxford.

This chapter tries to create an understanding of the global energy transition dilemma by highlighting experiences from various countries. The chapter discusses some of the challenges faced by various countries during their energy transition periods. The chapter concludes with briefly contextualizing South Africa's energy transition process, the country's urge for an energy transition, recent energy infrastructure development and socio-economic status-quo.

2.1 Definition of Terms

Various terms used in the context of this report are explained below.

Renewable Energy: these are energy from sources that cannot be exhausted when used (UNEP, 2015). Theoretically, this energy does not emit any form of carbon-dioxide in contrast to fossil fuels, which are derived from a finite source. A few examples of RE include solar energy (power from the sun), wind energy and tidal energy (power from the seas).

Fossil Fuels: These are geologically formed remains of living organisms (fossils) that formed over millions of years by natural processes, such as anaerobic decomposition from the remains of dead animals and plants that were buried under dirt and rock (IEA, 2012a). Fossils are moulded by heat from inside the earth and pressure from the dirt and rock, which changes these buried dead organisms into fuel - oil, natural gas and coal. These fuels are then converted to energy through the process of combusting (burning) which emits carbon dioxide that is harmful to the environment (*ibid*). Because it takes millions of years to make, fossil fuels are referred to as non-renewable or finite fuels.

Unburnable carbon: These are fossil fuel energy sources that are expected to remain underground and cannot be extracted for use if the world is to adhere to a given carbon budget (Climate Policy initiative 2014).

Coal-fired Plant/Station: This is defined as a thermal power station that generates electricity by burning of coal (SolarEze, 2018). Coal-fired plants are energy generating stations designed on a large scale for continuous operation because they provide most of the electricity in many countries.

2.2 Contextualization of the term – Stranded Assets

The environmental discourse appropriated the term 'Stranded Assets' in 2010. The term stranded assets, as used then, was focused on the environmental-related risk factors that can strand assets. Asset stranding within the environmental discourse occurs regularly as part and parcel of economic development. Neo-Schumpeterians have attempted to understand the dynamics of creative destruction, particularly how and why technological innovation and diffusion results in technological revolutions. This gave rise to the idea of 'Techno-Economic Paradigms' (TEPs), a term coined by Perez (1985), which captures the idea of overlapping technological innovations that are strongly interrelated and interdependent resulting in technological revolutions. Perez (2002) finds five such TEPs; the Industrial Revolution (1771–1829); the Age of Steam and Railways (1829–1875); the Age of Steel, Electricity, and Heavy Engineering (1875–1908); the Age of Oil, the Automobile, and Mass Production (1908–1971); and the Age of Information and Telecommunications (1971– early 2000).

In addition to the above mentioned TEPs, Schwab (2016) identifies the TEP as the age of cyber-physical systems also known as the Fourth Industrial Revolution (4IR). The 4IR is a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres, which is characterized by emerging technology breakthroughs in a number of fields. These fields are robotics, artificial intelligence (AI), nanotechnology, quantum computing, biotechnology, the industrial internet of things (IIoT), decentralized consensus, fifth-generation wireless technology (5G), customized/additive manufacturing, 3D printing and fully autonomous vehicles.

Each TEP was accompanied by the emergence of new sectors and stranded assets in redundant ones. For example, the Industrial Revolution ushered in mechanized cotton production in England that eclipsed India's cottage textile industry (Broadberry and Gupta 2005). The Age of Steam and Railways introduced railway networks that replaced canals and waterways (Bagwell and Lyth 2002). The Age of Steel, Electricity, and Heavy Engineering saw the end of sailing ships and the dominance of steamships (Grübler and Nakićenović 1991). The Age of Oil, the Automobile, and Mass Production resulted in the rise of the automobile and the decline of railways (Wolf 1996), and our Age of Information and Telecommunications has seen the widespread adoption of digital communication and an information revolution, making analog communication redundant and technologies from typewriters to telegraphs entirely obsolete. Within each TEP specific companies and brands, physical infrastructure, plant and machinery, and human capital, among other things, have become stranded.

The term 'stranded assets' has various contexts depending on the professional field. To economist, stranded assets is referred to as ('economic loss'), accountants ('impairments'), regulators ('stranded cost'), and investors ('financial loss'). These varying perspective views make it difficult for different disciplines and professions to communicate with each other about very similar and overlapping concepts. However, in the context of upstream energy production and from an energy economist's perspective, this research report contextualizes stranded assets as those energy investments (particularly infrastructural assets) which lose economic value and are made redundant or worthless well ahead of their anticipated useful life with no possibility of earning any economic returns. This means a huge economic loss as a result of "changes in legislation, regulation, market forces, disruptive innovation, societal norms, environmental regulation associated with the transition to a low-carbon economy" (IEA, 2013: 98). Clearly then, stranded assets can be caused by many factors related to innovation and commercialization, and these are part of the process of creative destruction articulated in Perez's TEPs and conceived by Neo-Schumpeterians.

Recent research on stranded assets has, however, sought to explore the idea that some of the causes of asset stranding are increasingly environment-related. In other words, a combination of physical environmental change and societal responses to this environmental change might be qualitatively and quantitatively different from previous drivers of creative destruction such as those we have seen in TEPs. However, environment-related factors such as the adverse effect of greenhouse gases due to the burning of fossil fuels for energy purpose appear to be stranded assets across all sectors, geographies, and asset classes simultaneously. Perhaps more quickly than in previous TEPs, and that this trend is accelerating, something that could be unprecedented.

2.2.1 Stranded Carbon Assets

The extraction and burning of fossil fuels for energy purpose is an immense contributor to global climate change (World Energy Outlook, 2013). According to Carbon Tracker Initiative (2015), the burning of coal, oil and natural gas is responsible for two–thirds of humanity's emissions of greenhouse gases which are a major cause of increasing earth's temperature. Although, we cannot turn back the clock and prevent the earth's temperature from rising. That is already happening. But if we move to dramatically cut carbon emissions with a wartime sense of urgency, we may be able to stop the rising temperature and mitigate climate change entirely. However, according to Gulati and Scholtz (2017), dramatically cutting carbon emission means a reduction in fossil fuel extraction particularly for generating energy. This means that vast quantities of recoverable fossil fuels will need to remain underground 'unburnable' in order to mitigate the global climate change concern (*ibid*).

According to Generation Foundation (2013), public and private business including governments utility companies that depend on fossil fuel to generate income or provide services have found themselves in an intensifying survival predicament. The growing consensus of research concludes that most remaining fossil fuel reserves need to remain underground if humanity is to have a reasonable chance of weakening the advance of climate change (*ibid*). World Energy Outlook (2013) report allude that rendering carbon as "unburnable" endangers various scales of the economy and business models. Some of these business models include the world's largest firms such as Chevron, ExxonMobil, BP and Shell including the economy of various countries where exports of coal, oil or gas comprised more than 50% of their GDP.

However, Carbon Tracker Initiative (2014) argues that recent discussions on stranded assets have moved beyond the "unburnable carbon" and focusing more on how a wider range of fiscal, social and political factors can affect asset values which can result in asset stranding. The ongoing discussions on stranded carbon assets are currently driven by changes in the real-world economy as a result of a change in government policies, new technologies and social preferences which alter the way energy is produced and consumed (*ibid*). In addition, the Paris Agreement (COP 21) on climate change mitigation strategies that were voluntarily signed by most countries is also putting increasing pressure on various countries to address greenhouse gas emission before the agreed year 2020 (Generation Foundation, 2013). This means that various fossil fuel infrastructural equipment used to generate electricity including fossil fuel-dependent economic activities will have to be retired before the year 2020 and at an accelerated pace to make space for less carbon-intensive technologies and practices (*ibid*).

According to the Carbon Tracker Initiative (2015), there is a high possibility of assets becoming stranded as climate policies and falling cost of renewables drives and directs the global energy transition. A change in the normative practice of generating energy from fossil fuel means that the investment cost of carbon assets will become unrecoverable, with a loss of value for carbon dependent utility companies. According to Watson (2015), stranded carbon assets will affect various scale of carbon investment sectors and economy including the entire fossil fuel industry such as the fossil fuel extracting industry (oil and coal miners), fossil fuel utility industries, the transport industry (planes, rails, ships and pipelines), the property industry, commercial activities, farming and manufacturing industry.

According to Pollin (2016), the value of stranded carbon assets has not been adequately estimated with precision, as much depends on the clarity of carbon dependent utility companies, various fossil fuel investors, and the strategic implementation of various government climate policies. However, Carbon Tracker (2017) report estimates suggest that 60 to 80 percent of publicly listed carbon assets should be considered stranded if the world is serious and committed to a global energy transition. These stranded assets are estimated to potentially cost the fossil fuel industry about $28 trillion in revenues over the next two decades (Carbon Tracker, 2017; Kepler Cheuvreux, 2017).

The levels of awareness and interest in the issue of assets stranding differ across countries and regions. Much of the early work on stranded carbon assets originated in the United Kingdom, rapidly spreading to the United States of America and from there to other countries. Currently, there are significant awareness of stranded assets among financial institutions than in the energy sector. Few countries like the United States of America, Europe (particularly the United Kingdom, France, Netherlands, Sweden, Denmark, and Norway), China, and Australia are aware of asset stranding in the energy sector than elsewhere. While the awareness of stranded carbon assets in fossil fuel energy industry is rapidly increasing globally, strategies to mitigate its economic effect have not kept up and are not profound. Various countries have tackled the issue of stranded carbon assets differently through analyzing, studying and understanding their national carbon footprint while addressing it inclusively with various concepts such as gradual divestments of the energy sector, strategic and just energy transition, user energy preference and transition patterns amongst others.

2.3 The Global Energy Transition

The great fuel switch is already underway. The shift in global energy generating sources from fossil fuel to renewable sources of energy is ongoing. A renewable energy source emerges, leading to a structural and permanent change in supply, demand, energy mix and prices. The world now adds more renewable power capacity every year than it adds in net new capacity from all fossil fuels combined (REN21, 2017). Several concerns are driving this global transition from fossil fuels to renewables. One of the most crucial concerns is the issue of climate change and its effect on the earth's ecological system, which affects our health and the environment (Pindyck, 2013; Pollin *et al*, 2014; Robert, 2014; Sandbag, 2014 and Roy, 2016).

According to Rockström (2014), scientists have been campaigning against fossil fuel combustion for decades. Carbon dioxide (CO_2) and other greenhouse gases emitted from burning coal, oil, and natural gas are altering the atmospheric condition of the earth, changing the earth's temperature and climatic conditions which affect the lives of plants and animals(*ibid*). Roy (2016) highlight that over 3 million people die each year due to polluted air from combusted fossil fuel engines.

In addition to the death of plants and animals, the changes in atmospheric earth conditions have also resulted in various consequences, some of which include; melting ice sheets and glaciers, rising sea levels, worsened droughts in some areas, more intense rainfall in others, and more-destructive storms (Sandbag, 2014). If the world continues to rely heavily on fossil fuels, Pollin *et al,* (2014) argue that the global average temperature could rise by nearly six degrees (6°) Celsius by the year 2100.

According to Moyo (2016), the other crucial concern driving the global energy transition is the desire for a new world energy economy. This is propelled by the desire for local control over energy production, the shrinking in fossil fuel resources and overall energy security without the excessive use of planetary resources. The 'old economy', fuelled largely by coal and oil, is being replaced by a new one powered by solar and wind energy largely due to the possibility that replacing fossil fuels with renewable energy might help reduce greenhouse gases (GHGs) and mitigate climate change(*ibid*).

2.4 Stranded Assets and the Global Energy Transition

The world has entered a period of energy transition. The energy markets across the world are waking up to the threat of possible energy disruption, one premised on the possibility that trillions of dollars' worth of fossil fuel assets will be lost or become stranded as the world takes action on climate change (Atif *et al*., 2013). The global imperative to achieve sustainable growth and limit climate change, combined with a rapid decline in costs and rising investment into renewable energy, has put in motion a transition of how energy is produced, distributed and consumed (*ibid*). In the transition to greener and more sustainable economy, emerging technological innovations necessary to harness these renewable sources of energy are seen as the 'new' product which gets significant attention (Beiser, 2016). While this is good, understanding what will happen to the 'old' innovations with fiscal implications is also crucially important, as major economic values and employment opportunities are at stake.

The topic of 'stranded assets has created various concerns internationally since 2010. The concept has been endorsed by a range of significant international figures including UN Secretary-General Ban Ki-moon (McGrath, 2014); former US President Barack Obama (Friedman, 2014); Jim Kim, the president of the World Bank (World Bank, 2013a; World Bank, 2013b), Governor of the Bank of England and chair of the G20 financial stability Board (Carney, 2015); Angel Gurria, secretary-General of the OECD (Gurria, 2013); Christiana Figueres, former Executive Secretary of the UNFCCC (Figueres, 2013); Lord Stern of Brentford (London School of Economics, 2013) and Ben van Beurden, CEO of Shell Plc (Mufson, 2014).

The emergence of this topic has also drawn the significant interest of scholars and practitioners alike, as it has influenced many pressing topics facing the energy sector, investors, utility companies, policy-makers, energy regulators and civil society in relation to global environmental change.

According to Potsdam Institute (2017), for the world to have a chance of constraining the global average rise in temperature to two degrees (2°) Celsius, as the international community has agreed to do, it will need to dramatically reduce fossil fuel use. The focus on reducing the rise in temperature of our planet, together with up-coming disruptive technologies and business models will result in the loss and write-off of various assets, particularly along the energy sector.

According to Seba (2014), whether we mitigate climate change or just try to adapt to the effects, we will see severe socio-economic effects on the financial system. Economic history has shown that up-coming technologies and current energy business models possess a disruptive potential and that transitions often happen in waves of creative destruction (*ibid*). In many cases, it will not be incumbents adjusting to new market circumstances, but new entrants outcompeting incumbents. For some incumbent industries such as the coal and oil industries, the negative effects of emerging technological innovations and the need for alternative sources of renewable energy are obvious. For example, moving to 'transport as a service' (shared cars) and the idea of electric vehicles which do not have gearboxes and do not need fuel pumps may mean that much car manufacturing capacity, and associated insurance capacity becomes stranded. Another example can be seen from electric power generation deregulation; the related term stranded assets represent the existing investments in infrastructure for the incumbent utility that may become redundant in a competitive environment. Therefore, the timeline of the sustainability transition makes it highly relevant for the entire economy to look carefully at stranded assets as a major economic issue that deserves more attention.

2.5 Alternative Renewable Energy

The global energy shift is underpinned by the need to ensure future energy security without the worry of increasing energy consumption. According to REN21 (2017), the global energy transition is getting support due to the realization that economic growth can be decoupled from the growth in CO_2 emissions. Pollin (2016) argue that the worldwide use of solar cells to convert sunlight into electricity is expanding by over fifty percent (50%) a year, which shows an increasing capacity of renewable energy technology with minimal health and environmental consequences and increasing economic benefits. The economic benefits accrued to increasing renewable energy technology capacity particularly wind and photovoltaics (PV) are the decreasing cost of acquisition and low operation cost, which makes electricity generated from renewables cost competitive when compared with fossil fuels (Stern, 2016).

According to Stern (2016), early photovoltaic(PV) installations were typically small-scale and were mostly installed on residential rooftops. Now Barros *et al,* (2016) explain that in addition to millions of rooftop installations, thousands of large-scale solar utility projects are under construction globally. These large-scale solar utility project systems installed worldwide at peak power can easily be matched with the output of at least one hundred (100) nuclear reactors (*ibid*). Stern (2016) argue, therefore, that as technology progresses and as PV system costs (including batteries and another component) fall, the accelerating spread of rooftop installations both for residential and commercial purposes will reduce the market for fossil fuel-generated electricity in many countries.

In addition to the cost competitiveness of renewable energy, fossil fuel-generated energy has constantly increased in price. According to Barros *et al,* (2016), the constant increasing price of fossil fuel energy is due to the huge capital investment and increasing operational costs required to generate this energy. With the fossil fuel market shrinking, Stern, (2016) highlight that fossil fuel utility companies are forced to adapt or raise prices. Unfortunately, higher prices from fossil-fuel generated electricity have encouraged the installation of even more solar panels (*ibid*). Once underway, this cycle can reinforce itself, leading to what Yang and Cui (2012) described as a "death spiral" for electric utilities.

2.6 Death Spiral of Oil and Utility Companies

The death spiral scenario briefly highlighted above recently played out in Germany, where leading utilities such as the giants RWE (Rheinisch-WestfälischesElektrizitätswerk) and E.ON(from Greek word aeon which means age) found themselves at risk of bankruptcy (Yang and Cui, 2012). This was because rooftop solar installations were satisfying a growing share of residential needs and driving down wholesale power prices in Germany. Now, these utilities are retooling their business models to better accommodate renewables in order to survive in the new energy landscape (*ibid*). According to the UNEP (2015) report, a similar situation is unfolding in many sun-rich zones such as Southwest areas in the United States of America (U.S.A) and in most parts of Southern Africa where the number of rooftop installations is growing exponentially.

According to Staniskis *et al,* (2014), oil companies are also facing growth constraints on both the supply and the demand sides of the energy equation. Demand is weakening as vehicles become more efficient and as motorists look to alternatives to driving such as electric cars and the use of car services – Uber and Taxify (*ibid*). Meanwhile, on the supply side, Jackson (2017) highlights that the remaining oil reserves are less accessible than the large gushers found in decades past, making it costlier to bring new oil to market.

Seba (2014 unpaginated) explains that among those losing out in the energy transition are the big independent oil and gas companies, such as Chevron, ExxonMobil, and Shell—"three of the giants in the field". These three firms combined, spent half a trillion dollars between the years 2010 and 2016 to expand oil and gas production globally, but even with this hefty investment, their production declined in 2016. Each company suffered a drop-in profit that year. Furthermore, Davenport (2016) highlight that the stock market has not been kind to Big Oil investors and explains that while technology-based companies like Google, Microsoft, Facebook and Apple stock share Index rose fifty-four percent (54%) from the beginning of the year 2012 through to the second quarter of 2016, shares of Chevron and ExxonMobil rose only ten and nine percent (10%) and (9%) respectively, and those of Shell rose just three percent (3%). In late 2014 and early 2016, Chevron, Shell, and ExxonMobil each announced a cut in capital spending (*ibid*). This drop-in profit shows that firms such as Chevron, Shell and ExxonMobil may soon have to do something that large corporations are not accustomed to doing—namely, start shrinking their operations and cutting their losses which eventually results in the stranding of major assets.

According to David (2014), most fossil fuel companies are more dependent on government handouts than is generally realized. In 2013, governments worldwide subsidized the fossil fuel industry with over six hundred billion dollars, giving this aging industry over five times the one twenty billion dollars that went to renewables (*ibid*). About half of these fossil fuel subsidies were used in the operation and maintenance of old fossil fuel infrastructures. Coady et al, (2015) explain that in principle, taxpayers' money is being used to subsidize climate change.

According to Jackson (2017), companies like ExxonMobil and Shell in their struggle to remain in business have constantly strived and lobbied for the world to remain heavily dependent on fossil fuel. Their solution to whatever problems that a restructuring of the energy economy, particularly by renewable energy poses for them has been to vociferously deny alternative renewable energy existence. Chevron, ExxonMobil, BP and Shell simultaneously use their international existence, financial capacity and political muscle to fight and oppose renewable energy deployment in order to maintain their relevance (*ibid*). The South African utility company – Eskom has also found itself fighting to stay in business and has continuously denied the capacity of renewable energy. In addition to corruption, mismanagement and coal(lusion) labour practices accredited to Eskom, the utility company has developed various opposing strategies in order to dominate and remain relevant in South Africa's energy industry (Southern Africa Energy Report, 2018). It now seems apparent that if the world takes climate change seriously and the above-highlighted concerns sincerely, much of the fossil fuel resources still underground will never be used. However, the trending pulls and push factors of politics, coupled with the influential powers from multi-national organizations such as Chevron, ExxonMobil, BP and Shell are likely to make fossil fuel resources stranded unlikely.

2.7 Renewable Energy Transition: Highlights from Few Countries

The energy transition is unavoidable and has become a rapid disruption that is changing the entire economy of most nations. Due to the disruption created by the energy transition, we should experience the prospect of a half-century's worth of change within the next decade (Jackson, 2017). This means restructuring the world energy economy: saying farewell to fossil fuels, embracing efficiency, and quickly expanding the use of renewable forms of energy.

The cost of energy from fossil fuels is largely commodity-dependent and will increase over time as the fuels become more scarce(*ibid*). The need for a global energy transition is propelled by technology discovery, which involves the ability to produce power from wind, sun and water using newly invented technology devices. The cost of these devices is becoming cheaper as technology improves. Solar and wind are renewable energy that is widely distributed and are inexhaustible with every country having its own supply. In contrast to coal and oil, the amount of solar and wind energy consumed today does not reduce the amount available tomorrow.

The energy transition is progressing quicker in most countries than most people realize. For some countries, this energy transition is beginning to take shape and become reality while for others the direction is not yet clear. According to SolarEze (2018), between 2013 and 2014, Denmark generated about thirty-four percent (34%) to sixty-two percent (62%) of its electricity solely through wind technologies. Also, Spain, Portugal and Ireland generated over thirty-seven percent (37%), twenty-six percent

(26%) and, seventeen percent (17%) respectively from wind during this period (*ibid*).

According to the WWF (2018) annual report, currently, in Spain, the wind is challenging nuclear power to become the country's leading source of electricity. And in the United Kingdom, electricity generated from wind eclipsed that from coal (*ibid*). We also see the new economy surfacing in the state of South Australia, where wind farms now supply more electricity than coal plants do (Jackson, 2017). In the United States of America, the power generated from the wind and the sun as of September 2014, exceeded the country's electricity demand (*ibid*). According to Barros *et al,* (2016), the electricity generated from wind farms in China has surpassed that from nuclear power plants. Also, water for 170 million Chinese households is heated by rooftop solar water heaters, reducing their dependence on electricity generated from fossil fuel (*ibid*).

According to Steeves and Ouriques (2018: 649), "the energy transition in the United States of America is on display in their hundreds of utility-scale". With solar power plants under construction in the Southwest, Iowa and South Dakota, these areas in the United State of America are also generating at least twenty-six percent (26%) of their electricity from wind farms (*ibid*). Texas, which now gets nearly twenty-seven percent (27%) of its electricity from wind power, is building huge wind farms including long-distance transmission lines that will facilitate the sale of low-cost wind-generated power in Louisiana and Mississippi.

According to SolarEze (2018), the United States of America is rated as the number two coal consumer after China. However, the use of coal in the

United States of America has dropped to about twenty-eight percent (28%) between 2010 and 2016. The drop-in coal consumption in the United States of America has resulted in various coal-fired stations becoming stranded, liquidated or permanently closed (*ibid*). According to Steeves and Ouriques (2018), out of five-hundred coal plants that were fully generating electricity in the United States of America (U.S.A) at the beginning of 2010, about two-hundred and thirty (230) have closed or are scheduled to do so, leaving less than 270 plants in a dilemma of adaptation and minimal form of operation. Among the reasons for this drop are the local opposition to coal (often for health and environmental reasons); -the adoption of stricter air quality regulations that raise the price of coal-fired power; - the growing use of solar and wind energy (due to long-term cheaper cost); and the rapidly expanding availability of low-cost natural gas (*ibid*). A strong force in the U.S.A anti-coal movement is the Sierra Club's Beyond Coal campaign (SolarEze, 2018). Its goal is to close all the coal plants in the country by the year 2030, replacing them with a combination of efficiency gains and clean energy(*ibid*).

Thus far, Pratt (2018) claims that increased reliance on natural gas has helped the United States begin to wean itself off coal. The burgeoning use of horizontal drilling and hydraulic fracturing or "fracking" techniques to coax trapped oil and natural gas out of shale-rock formations reversed a decline in U.S. natural gas production, boosting it fifty-two percent (52%) between the year 2010 and 2016 (*ibid*). Yet, Steeves and Ouriques (2018) explain that while it has been touted as a "bridge fuel" to a clean energy economy, natural gas is losing its luster due to the effect the process of extraction has on earth's ecological system. In producing energy, Pratt

(2018) highlights that burning natural gas emits only half as much CO_2 as coal. However, recent studies, mostly from Carbon Tracker initiatives, have found that in many cases natural gas can actually be worse for the climate because of the extensive leakage of methane—a much more potent greenhouse gas—from wells, pipelines, and tanks.

According to SolarEze (2018), the technology needed to generate energy from solar and wind is falling fast, undercutting fossil fuels in a growing number of electricity markets. A July 2017 study, published by the Danish government, projected that the new wind farms coming online at the end of 2018 will supply electricity at half the cost when compared to that of coal and natural gas plants (*ibid*). Pratt (2018) explains that various parts of Australia are experiencing an increasing boom of solar-generated electricity, the cost of producing electricity from the sun has fallen well below that of coal. In fact, according to a 2017 analysis, Pratt (2018), citing Australia's government data report of 2017, argued that high electricity delivery costs mean that coal-fired power still will not compete with solar, even if the coal itself were free.

After looking at the global decline in coal burning in the United States, Denmark, Australia, United Kingdom, Germany and many other industrial countries, this research report also highlights the drop of coal usage in China. According to Steeves and Ouriques (2018), China uses more coal than Denmark, Australia, the United Kingdom and Germany combined. However, coal usage in China as at the beginning of 2018 has started to drop (*ibid*). Steeves and Ouriques (2018) state that two deeply held concerns in Beijing will bolster China's nascent energy transition. The first is the effect of coal burning on the health of the Chinese people and the resulting political unrest that it brings. The second is the scarcity of water, which is needed in large quantities to mine coal, to wash it, and to cool coal-fired power plants (*ibid*).

As for oil, the other major source of global CO_2 emissions, its use is fading out in many industrial countries—including in the leading consumer, the United States (Steeves and Ouriques (2018). American oil consumption dropped by fifteen percent (15%) between the year 2010 and 2016 (*ibid*). Part of this is due to people driving less and part is due to the development of fuel-efficient cars. Oil use can be reduced even further by increasing mass transit options and by electrifying the transport system and then powering it with solar and wind-generated electricity. Plug-in hybrid and all-electric cars can run largely on carbon-free electricity (Jackson, 2017). And since powering cars with wind-generated electricity costs roughly the equivalent of $1-per-gallon gasoline, the market will help drive the transition to electric cars (*ibid*).

Finally, the energy transition is advancing rapidly in some unexpected places such as the African continent. The developing nations of Africa have become a popular location for the application of renewable energy technology. Jackson (2017) argues that investing in the long-term energy solutions that alternative energy sources provide, most African nations would benefit significantly in the longer term. Falling costs for solar and wind energy are also opening the door for massive investments in Africa (*ibid*). A Bloomberg new energy finance report (2017) claims that wind and solar projects in Africa, Latin-America and central Asia are advancing fast, however, there will be even faster renewable energy installations in Africa between 2018 and 2020 than most parts of the world (*ibid*).

Numerous other global trends are signaling the fast-moving shift from fossil fuels to renewable sources of energy. The burning of coal, for example, is declining in many European countries and developed nations (Wagner and Arnold, 2016). Ultimately, since fossil fuel resources are finite, natural gas reserves are limited, and new wells are depleting so rapidly, it makes little or no sense, in my opinion, for any society particularly a developing country such as South Africa to invest in expanding any fossil fuel-based infrastructure and then have to abandon it (a stranded asset situation) in the nearest future.

2.7.1 Contextualizing South Africa's Energy Situation

South Africa has a large coal-based capital stock and a growing energy-intensive economy, with most of its energy coming from the combustion of fossil fuel. As the world takes action on climate change by avoiding the use of energy from fossil fuel combustion, South Africa seems to be digging itself deeper and deeper into fossil fuel-based energy sources, particularly coal-generated electricity. Carbon dependent companies such as Sasol, Shell, Bp, Eskom and other independent coal power producers, including coal mining companies and energy investors in South Africa seems to be pouring more money into energy generated from fossil fuel combustion (UNEP, 2015).

For instance, Eskom (formerly known as the Electricity Supply Commission) is the major publicly backed utility company for entire South Africa's electricity grid and is in charge of the entire installed coal-fired plant within the country. According to Eskom's (2018) annual report, a coal-fired plant in South Africa generates a capacity of approximately 42,000 megawatts (MW), with a peak capacity and approximately 34,200MW off-peak capacity. This generating capacity routinely operates at peak levels—largely due to heavy industrial consumption (Energy Association, 2018). As a result, preventative maintenance is generally neglected, and potential long-term grid functionality is less stable (*ibid*). Given that majority of these coal-fired plants had cost billions of dollars for construction, South Africa had some of the lowest electricity prices in the world, making any future changes politically and economically difficult (Eberhard, 2005).

Historically, South Africa has always considered itself blessed with an abundance of easily accessible and cheap coal. This meant that energy generation was cheap, that sufficient energy could be provided to a growing energy-intensive economy which has resulted in South Africa developing an energy-intensive industry sector. According to a University of Cape-Town (UCT, 2014) fossil-fuel report, South Africa's economy is underpinned by dependence on coal as its primary energy source. Coal accounts for about seventy percent (70%) of electricity generation in South Africa (*ibid)*. Winkler (2009) alludes that South Africa has an energy-intensive economy with most of its electricity generated from coal which serves as a backbone that drives the development and growth of the entire economy. Much of South Africa's manufacturing and service activities are linked to the energy sector (Eberhard, 2011). These manufacturing and service activities have been key in attracting energy-intense minerals beneficiation to South Africa and the also makes huge contributions to the country's GDP (*ibid*).

In retrospect though, the coal 'wealth' would rather be seen as 'resource curse'. Leading analysts such as Winkler et al. (2006) argue that the low-cost of energy did not offer the country an important economic edge, but rather led to inefficient energy use, accelerated national reserve depletion and significant pollution. It also made South Africa one of the highest greenhouse gas emitters in the world as indicated below.

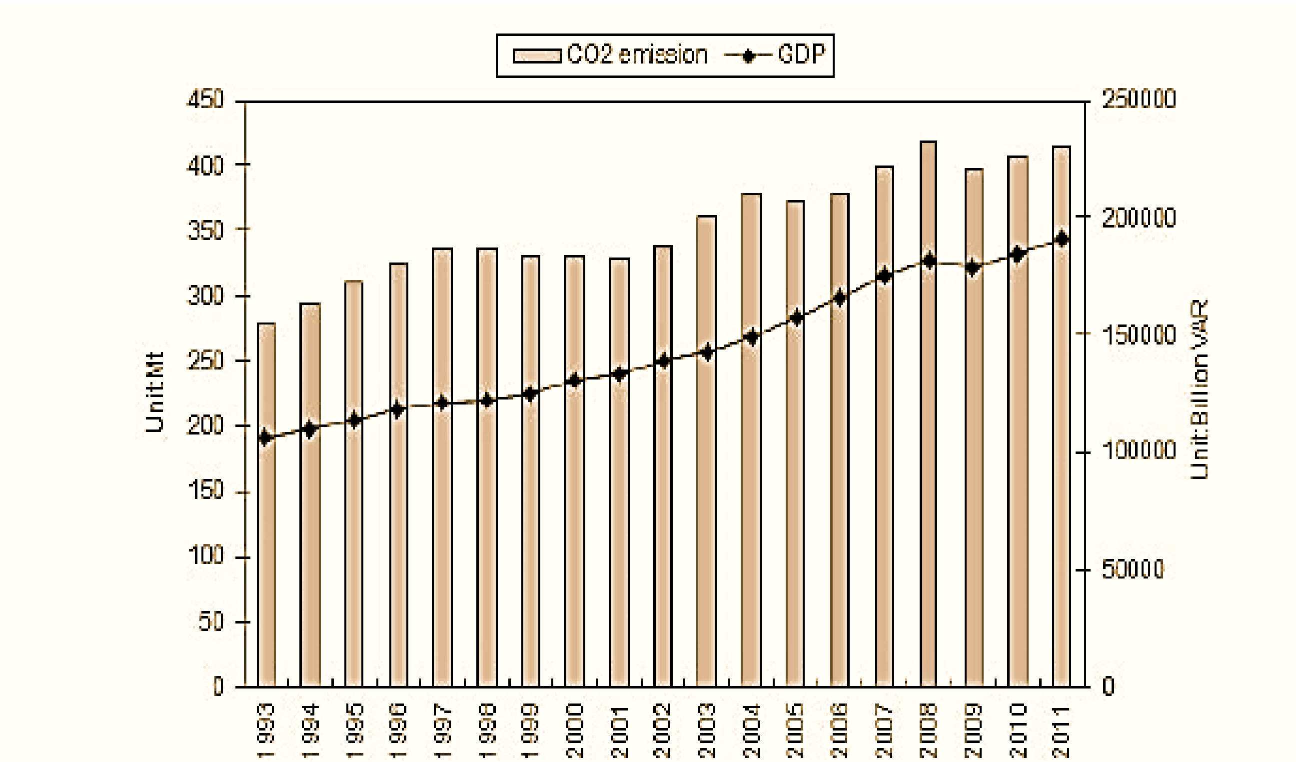
Table 1: A comparison of energy sector carbon dioxide emissions for selected countries and regions

	CO2/capital	CO2/GDP	CO2/GDP PPP	Cumulative energy CO2 emissions from 1950 to 2000	
	Tonnes/capita	Kg/1995 US$	Kg/1995 PPP US$	Mt CO2	% of world total
South Africa	**6.65**	**1.65**	**0.75**	**10,165**	**1.29**
Africa	0.89	1.16	0.45	13,867	1.75
Non-OECD	1.65	1.33	0.45	318,117	40.23
OECD	10.96	0.44	0.56	472,635	59.77
World	3.89	0.68	0.56	790,753	100.00

Notes: Percentages in the last column do not add up to 100 as rows are not mutually exclusive (for example, South Africa is part of Africa). PPP – Purchasing Power Parity. Mt CO_2 – million tonnes of carbon dioxide
Source: Winkler (2009)

Data regarding the South African carbon footprint and CO_2 emissions differ due to different sources of data and conversion factors used to aggregate the information. However, the South African economy, according to the UNEP (2015) report, is fossil fuel dependent due to its heavy reliance on coal which therefore places considerable pressures on the environment. It has been ranked among the world's top 10 largest carbon dioxide emitters with per capita emissions that are higher than many European countries and several times the average for developing countries (Winkler 2009).

Figure 1: Carbon emissions in South Africa



GDP and Energy-related CO_2 emissions in South Africa, 1993 – 2011
Source: UNEP (2015)

According to Benchmarks Foundation (2014), in the absence of alternative energy sources, South Africa's local economy relies on energy derived from fossil fuels combustion in order to satisfy its energy demand. Unfortunately, this reinforces the structural dependencies on coal and other fossil fuel supply networks and reduces the incentives for the introduction of possible alternatives into the energy system.

According to Winkler and Marquand (2009), relatively 'cheap' energy and lack of awareness on the environmental impacts of coal-based electricity subsequently limited the need for investment in energy efficiency or renewable energy sources. Also, the environmental costs, especially the costs in terms of environmental remediation, sterilized farmland and compromised tourism opportunities, as well as costs of healthcare-associated with respiratory diseases due to exposure to air pollution, were never incorporated into the costs of the electricity. By implication, even though the use of electricity was 'cheap', the global consequences were paid for by other sectors, the general public or government in the form of environmental rehabilitation and health care.

South Africa's energy system received an unexpected ally in the prominence and visibility of global climate change and mitigation efforts, as well as the country's national commitments to emission reductions. The first United Nations Conference was held in 1972, but it was only in 1992, at the same time that South Africa was negotiating its transition to democracy, that representatives from 178 nations met in Rio de Janeiro to discuss global environmental issues that would become central to policy implementation. At the conference, more than 130 nations, including South Africa, signed a Convention on Climate Change and a Convention on Biodiversity. This international commitment, although possibly not recognized at the time, signaled an important step in South Africa's journey to a cleaner energy future.

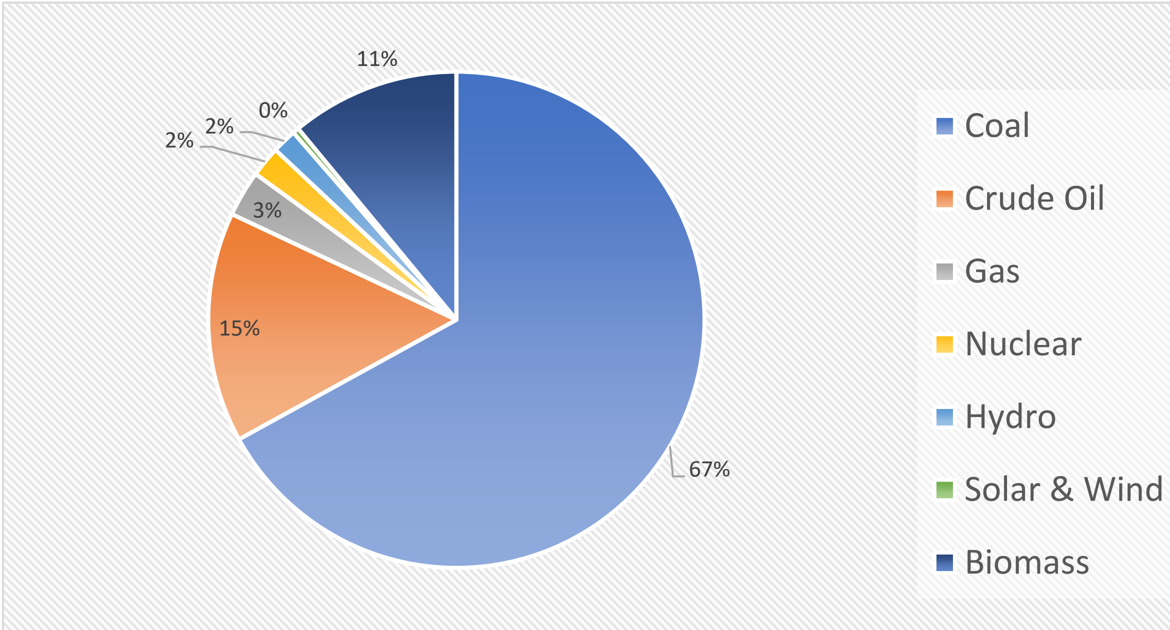
South Africa's Climate Change White Paper was largely informed by a process known as the Long-Term Mitigation Scenario (LTMS) formulation. The LTMS, led by the Department of Environmental Affairs (DEA), was a Cabinet-mandated process that took place in South Africa between 2005 and 2008. The LTMS arose out of the realization that South Africa would need to contribute its share to fossil fuel combustion mitigation, but identifying that the economy had been built around energy-intensive industry, which is heavily reliant on coal. The country also needed to address poverty and inequality, so any move to a low carbon development path would require a major shift in thinking and action. However, a potential 'advantage' was that such Third World issues could be strategically addressed in the process of creating renewable energy solutions, as an alternative.

In Copenhagen in December 2009, the South African government, led by President Jacob Zuma, internationalized this pledge that the country will take mitigating action that would reduce South Africa's emissions by 34% below the Business As Usual trajectory before 2020. In order to fulfill this commitment, the government realized that it needed to develop alternative plans to deliver a secure, affordable and sustainable energy system. This energy system will be created through the improvement of energy governance and by developing policies and legislation to guide the government's decisions and development pathways. However globally, large scale renewable energy was still in its infancy, with many skeptics unconvinced of the technical and financial viability, reliability and the price at which the technology would be able to deliver energy. Global electricity generated by wind and solar between 2000 - 2009 was less than 2.5% of total primary energy consumption, hence, feasibility to meet global demand was not certain at this time.

This uncertainty also affected South Africa where, at the time, the country had an entrenched mindset of employing the vast coal reserves to generate electricity at a large-scale in order to achieve the lowest possible cost. In fact, Eskom (the national utility) at the time was required to operate at neither a profit nor a loss, since the country had an oversupply of electricity and was mothballing and decommissioning operational power plants as the reserve margin was about 25% in 1998. A positive spin-off of this situation, and very importantly, was that Eskom and the newly elected democratic government were able to fast track their electrification programme to households to provide them with electricity for the first time, with about 61% of new households having access to electricity in 2001 and 83% by 2008 (Eskom, 2010). During this time Eskom was also able to allow the price of electricity to reduce in real terms. From an environmental perspective, however, these developments effectively tightened the grip of coal generation and ensured that coal would remain the country's primary energy resource for the foreseeable future.

According to mass electrification report Eskom (2010), the utility company (Eskom) had an excess capacity between 1998 and 2001 which resulted in the marginalization of renewable energy (RE) technology. Renewable energy as alternative energy options was, often being left to a few demonstration or pilot projects such as the Solar Home Systems (SHS) largely driven by international renewable energy lobby groups and the donor community. SHS was introduced to close the electricity distribution gap and provide basic electrification access such as lighting and power for monochrome television sets, radio and mobile phone charging, primarily in areas such as Limpopo, Eastern Cape and KwaZulu-Natal provinces that were not connected to the grid (DoE, 2013).

Figure 2: Total primary energy supply in South Africa



Source: South Africa Department of Energy – Energy Balances (2016)

Figure 2 above shows the split of primary energy supply in South Africa. However, a number of large-scale solar and wind projects have recently come online in 2017 and 2018 as part of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) or (REI4P) and as shown in the figure above, at the end of 2016, wind and solar only contributed less and 0% to primary energy supply. While fossil fuels (coal and crude oil) still dominate, contributing above 80% to primary energy supply due to energy sector lock-ins, squarely by the national power utility Eskom. However, due to chronic maintenance backlogs and underinvestment and delay in new capacity, South Africa has been subject to regular rolling power cuts dating back to 2008.

Partial recognition of RE technologies in South Africa came in 2008 when the Government acknowledged its intent to diversify power generation through the National Integrated Resource Plan (NIRP). While not binding, this lays out the country's intention to diversify South Africa's generation to include more nuclear, wind, and solar power. This led to the 2009 Renewable Energy Feed-In Tariffs (REFIT) programme which was expected to facilitate the introduction of RE into the power system. This approach was informed by international experience, where feed-in-tariffs were successfully used in countries such as Germany, Denmark and Costa-Rica to encourage RE uptake.

The REFIT programme was accelerated in the wake of severe electricity shortages experienced during 2008. In mid-2009, the National Energy Regulator of South Africa (NERSA) published REFITs with proposed tariffs policy, which demonstrated South Africa's commitment to accepting RE into the energy mix and as such, it stimulated market interest. The rapid changes following from this announcement catapulted South Africa into the world spotlight, drawing investor interest from across the globe. RE implementation became a topical issue nationwide with international and multilateral donors providing technical and financial assistance for the development of various RE technologies to enable a diversified energy sector and mitigate CO_2 and other greenhouse gases emissions. The Global Environment Facility (GEF) also provided a grant for advisory services under the Renewable Energy Market Transformation Project. South Africa was fortunate in that, over and above its rich coal resources which were the main source of carbon emissions, it is also well endowed with nondepletable RE sources, notably solar and wind.

According to Climate Wire (2013), South Africa has an average of more than 2,500 hours of sunshine per year and average direct solar radiation levels range between 4.5 and 6.5kWh/m^2 per day, placing it in the top-3 in the world. Many reviews of South Africa's progress in implementing various RE technology have been positive, earning the country accolades from abroad. The UNEP (2014) Report has placed South Africa among the top-10 countries in respect of RE investment. However, RE is only starting to be harnessed at a utility-scale with significant pressure on the energy sector to transform (*ibid*).

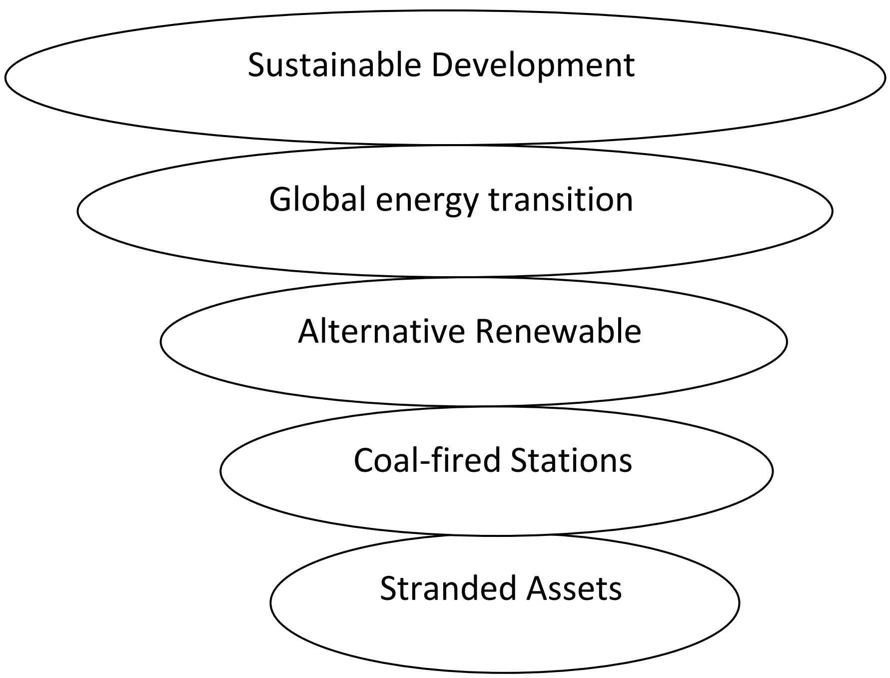
According to the draft Integrated Renewable Resource Plan (IRP,2018), South Africa's energy transition process is aimed at achieving a 'sustainable energy future'. This sustainable energy future will involve a steady move away from fossil fuels, including coal-generated electricity and crude oil derivatives (petrol, diesel, LPG, paraffin, heavy fuel oil etc.). The draft IRP (2018) also aims to improve energy use efficiency in all sectors (residential, commercial, transport and industry) and maximizing the use of transitional cleaner fuels in the medium term (e.g. natural gas) as well as steadily developing large-scale renewable energy options to replace fossil fuels. Depending on how the energy transition physically and economically plays out in South Africa's energy sector, the possibility of assets stranding is unavoidable.

South Africa is faced with pressure from the international community on mitigating greenhouse gases and at the same time pressure from within the country on better socio-economic development for its citizens. This dilemmatic state has resulted in various short-term investment decisions on new coal-based energy infrastructure to alleviate South Africa's socio-economic status-quo but with medium to long-term economic consequences.

2.8 Conceptual Framework

The conceptual framework below highlights various concepts as used in this research report.

Fig 3: Conceptual framework



Source: Author, 2018

2.9 Conclusion

Given that the recently negotiated outcome of the UNFCCC's Paris Agreement will require commitment even from developing countries to reduce their greenhouse gas emissions, continued investment in high-emitting infrastructure may create costly risks for South Africa in the future. The energy sector, which in South Africa accounted for 80% of emissions in 2010 (DEA 2014), will need to meet decarbonization targets in the medium to long term. Indeed, various literature in their global analysis of coal-fired power and mitigation has shown that limiting warming to 2°C over the course of the century will require the complete phase-out of coal-based electricity generation by 2050. Investing in new coal-fired assets in the short-term may well prove costly in the longer-term, as the risk associated with not recouping those investments due to policy shifts or technology changes grows higher, especially for coal-fired plants like Kusile and Medupi.

CHAPTER 3: RESEARCH METHODS

3.0 Introduction

Having reviewed the pertinent literature relating to the study, this chapter describes the research design employed by the researcher. It outlines various approaches that adopted in gathering the relevant information needed in order to derive a conclusive result and to answer the research questions posed. It also explains various systematic secondary data collection methods adopted during the entire research. It reviewed and analyzed published and unpublished academic information, extraction from policy documents, reports, and articles that are related to the topic.

3.1 Nature of the Research

This research is designed using a qualitative approach with the adoption of a systematic evaluative review. A Systematic Evaluative Review (SER) (also known as the systematic overviews) is a scientific tool which can be used to summarise, appraise and communicate the results of implications of otherwise unmanageable qualities of research (CRD report 4: 2001) – to synthesize the result of a number of small studies. SER combines results from different studies into a single summary for quick reference (*ibid*). This method of research deals with a specific research topic and its related wider subject area. It tries to provide a discussion on the literature in terms of its contribution to knowledge in a particular area (Welman et al., 2005). SER is often used to directly compare academic research findings with each other in terms of theory and empirical evidence and to sharpen, focus and identify research questions that remain unanswered in the specific topic (*ibid*).

According to Smit (2009), a systematic overview attempts to satisfy the curiosity of the researcher and desire for a better understanding, determine priorities for future research and develop a new hypothesis about an existing phenomenon. Based on the aforesaid, this research report tries to identify important variables or concepts in a particular area i.e. the concept of stranded assets in energy transition era; while formulating penetrating questions about them–the possibility in South Africa; and generates hypothesis for further investigation (Wellman *et al*., 2005).

According to Smit (2009: 67), such studies are usually "…{conducted} by the in-depth or comprehensive narrative of various literature". The researcher ensures that the quality and rigor of the research are demonstrated, and the link is made apparent from the beginning to the end. Such systematic overview approach is valuable as it allows for interpretivism. SER also combines results from different studies into a singular summary estimate for quick reference (Babbie and Mouton, 2008).

3.2 The Research Process

A major element in the research framework is the specific research methods that involved the forms of data collection, data sorting or collation, data analysis and interpretation that the researcher proposes for their studies (Creswell, 2009). The research process for this report was broken down into various equally important stages, each with its own set of unique, specifically-designed data-collection methods.

3.2.1 Data Collection Technique

This report is built on various literature sources extracted through exploring *primary and grey literature sources* which are the first occurrence of a piece of work which includes reports from market research, government reports, conference proceedings, etc. Examples of primary literature sources used in this study include the 'White Paper on Renewable Energy', 'Integrated Resource Plan (2018)', 'Renewable Energy Feed-In Tariff' and the South African 'Long-term Mitigation Strategy'. Examples of grey sources used in this report include 'State of Energy Report 2015 – 2018 and the 'Energy Efficient Strategy for South Africa'.

Also, a global scale narrative was explored, i.e. exploring reports from the International Energy Agency and particularly reports and analysis on sustainable forms of renewable energy and alternative energy sources. These reports assist in compiling a comprehensive argument on the present situation in South Africa. Furthermore, reports and reviews from Eskom and Infrastructural Development Bank (IDB) in South Africa on the issue of stranded assets were sourced after. This report strategically analyzed these primary literature sources before moving on to secondary literature sources for an important reason: by reading primary sources first made me open-minded and was not influenced by bias from any lobby groups or political influence.

According to Welman *et al*. (2005), as information flows from primary to secondary sources, it becomes less detailed and authoritative but more easily accessible. Examples of secondary literature sources used in this report are journals, books, newspapers, periodicals and conference proceedings. The primary function of researching secondary literature sources in this study was for information on the various perspectives and positions not duly found throughout the primary literature sources. Books specifically focused on stranded assets concepts provided this study with a greater understanding of them that could then be applied to the primary literature sources. For example, I extensively studied books relating to the concept of 'fossil fuel stranded assets' in order to gain insight into the concept. This allowed me to not only apply the knowledge and theory to the primary literature sources but also in the process of developing my proposed report framework. Numerous questions arise for the researcher when comparing arguments for numerous policies document during a literature review (Barrientos, 2007). An example of such question when comparing literature sources is "h*ow do any two (or more) piece of literature relate to the central question you are asking" (ibid: 23)?*

Tertiary literature sources were also explored during this research. These tertiary sources are also referred to as search tools and are designed to locate primary and secondary literature. Tertiary sources may also include indexes and abstracts as well as encyclopedias and bibliographies including relative references cited in various relevant materials i.e. each source being a means of locating additional references. The purpose here is to provide a deeper understanding of the issue and the existing literature about it, as well as highlight opportunities for future work, especially in South Africa.

Table 2: Details of stages and data collection methods

Data Collection Process	
Design	Aim

• Review, previous research on the topic by exploring:
• Primary, Secondary & Tertiary literature sources i.e.
  ◦ Government publications/reports, Books, Journals, research dissertations and thesis.
  ◦ Newspapers, periodicals, conference proceedings.
  ◦ Internet sources
	• Understanding the global energy transition debate;
	• Understanding the South African energy transition process and the electricity market.
	• Exploring the concepts of stranded assets globally;
	• Exploring the concepts and support mechanisms used to promote RE;

Source: Author (2018)

3.2.2 Data Processing and Content Analysis

Descriptive and data extractive tool can be constructed by using a combination of research critique frameworks, findings that are related to the research question (Welman et al., 2005). This was achieved by first; thorough literature review; and secondly, by organizing and grouping various sets of data accordingly to their related themes and relevance. The contents collected from various sources were grouped, arranged and analyzed according to various common themes. According to Neuman (2006:322) "content analysis is a technique for gathering and analyzing the content of the text. The content here refers to the meaning of words, pictures, symbols, ideas, themes, or any message that can be communicated".

Neuman (2006:323) further states that "content analysis lets a researcher reveal the content (i.e., a book, article, movie, etc.). It lets him or her probe into and discover content in a different way from the ordinary way of reading a book or watching a television program". The content analysis allowed the researcher to extract similar categories of data to generate or create common themes. According to Cooper and Emory (1995) as cited in Sieff (2007: 29) "content analysis is particularly useful for handling research questions as answers to the questions often contain messages, which could be interpreted to have a multitude of meanings".

Based on the aforesaid, the first stage of data processing and analysis was obviously the most difficult in terms of formulating the design and certainly the more time-consuming of the two stages. Before the analysis of various literature was possible, the researcher was required to develop an initially proposed framework by embarking on a systematic online literature search using various search engines such as Google scholar, Microsoft books, Worldwide Science, Refseek amongst others. Some of the search terms used in identifying relevant literature include renewable energy, stranded coal assets, fossil fuel use in the 4^{th} industrial era, coal-fired station in South Africa just to mention a few. Only once this 'basic' framework idea was completed then the researcher needed to analyze, sort and group various literature according to their relevant themes. The proposed framework was fundamentally developed using concepts and information provided by doing a thorough literature review.

Barrientos (2007: 12) states the following about the importance of literature review processes:

"…any kind of research or investigation is going to at some level involve a study of the relevant literature. You should be able to analyze and use literature in order to support your own research write-up. It is likely going to involve you in a search for information using literature from a diverse range of sources, be they academic, non-governmental organizations [NGOs], governmental or community groups. You may well need to combine various forms of literature which may form part of any final report you present".

The literature presented in this report was crucial for the remainder of the study for five equally important reasons (Welman et al., 2005). Barrientos (2007) argues that literature-based research is a constantly iterated process of:

i. *Gathering and assimilating;*
ii. *Evaluating and analyzing;*
iii. *Formulating your own arguments based on what you have gathered;*
iv. *Structuring and writing up your arguments*.

The second stage was only performed after the first stage had been completed. This stage involved keeping track of global energy transition, identifying renewable energy motivators in South Africa and the present situation of coal infrastructure (i.e. coal power assets) in South Africa between April 2018 to November 2018. The second important step, therefore, was the collating, sorting and assimilation of data.

Furthermore, the literature review is not simply comparing the literature in a general way. According to Barrientos (2007), a literature review involves, weighing up various perspectives and arguments while comparing and analyzing them in preparation to support one's own use. This means that, in order to formulate one's own argument, it needs to be rooted and integrated with other forms of related research. Therefore, Thomas and Mohan (2007) alluded that analyzing and probing literature must be in terms of one's own central question, or research aims, in this way, comparing literature is done, not in and of itself, but rather in terms of its relative importance to the investigation being carried out. In other words, a literature review on global energy transition and stranded assets mitigation strategies transforms a broad summary of literature into an analytical study through which the research can develop its own arguments and status quo analysis. This was an important concept for this study.

3.2.3 Data Sorting / Collation

This was achieved by identifying important concepts and keywords relevant to the aims of the study. Specific words in this particular study included words and phrases such as 'renewable energy', 'fossil fuel', 'stranded assets', 'energy transition', 'renewable energy implications' and 'fossil fuel deprecation'. This literature was mostly identified, obtained and collated through numerous publicly available sources. The author found over 1000 literature citations with various references and relevant to stranding coal-fired power assets globally. Out of 1000 search results, about 50 literature had a direct link with South Africa.

This 50 literature were then sorted and analyzed in order of their relevance, occurrences and dates. A few of them were also used as reference materials for this report however, a total of 10 literature form the main reference due to their argument on the South African context. The 10 selected literature most had a direct impact on coal-fired plants with the others impacting on the wider coal power value chain – from transmission and distribution of electricity to coal mining and the transport and storage of coal or being cross-cutting in nature. Also, the 10 selected literature was personally determined to be of 'high' importance as they were cited on google scholar as the highest sourced literature in relation to South African energy status-quo.

This literature included the cost competitiveness of renewable energy in South Africa, alternative solutions to coal fire stations, the financial distress of distribution companies such as ESKOM, and CITY POWER, air pollution regulation, water scarcity, and the evolution of coal shortage. These literature were each analyzed and grouped according to their connected argument while trying to draw a connection between their underlying policy or market failure to buttress my argument.

3.3 Ethical Concerns and Mode of addressing them

This research is aware of the issues of plagiarism and has made sure that all ideas, concepts, and knowledge are accurately attributed to their authors.

3.4 Limitations to the Study

According to Creswell (2003), it is difficult to identify potential weaknesses of the study as a researcher. However, the following are some of the issues identified that influenced the outcomes of the research.

Please note these are not absolute, but experienced circumstances that hindered and limited the extensive exploration of my investigation.

- The academic calendar (in form of time) of about 6 months from the build-up from proposal stage.
- Also, since this study is concerned with the concept of stranded assets which is fairly a new idea in relation to developing and designing energy infrastructures in Africa, sifting through various global debates and contextualizing stranded assets to Africa seems like an information overload. According to Creswell (2003: 148) "information overload often leads to lack or missing of important information and exact direction of the study" because of the complexity in navigating and scoping various reports from government agencies, the private sector and international agencies on the subject matter.

3.5 Validity and Reliability

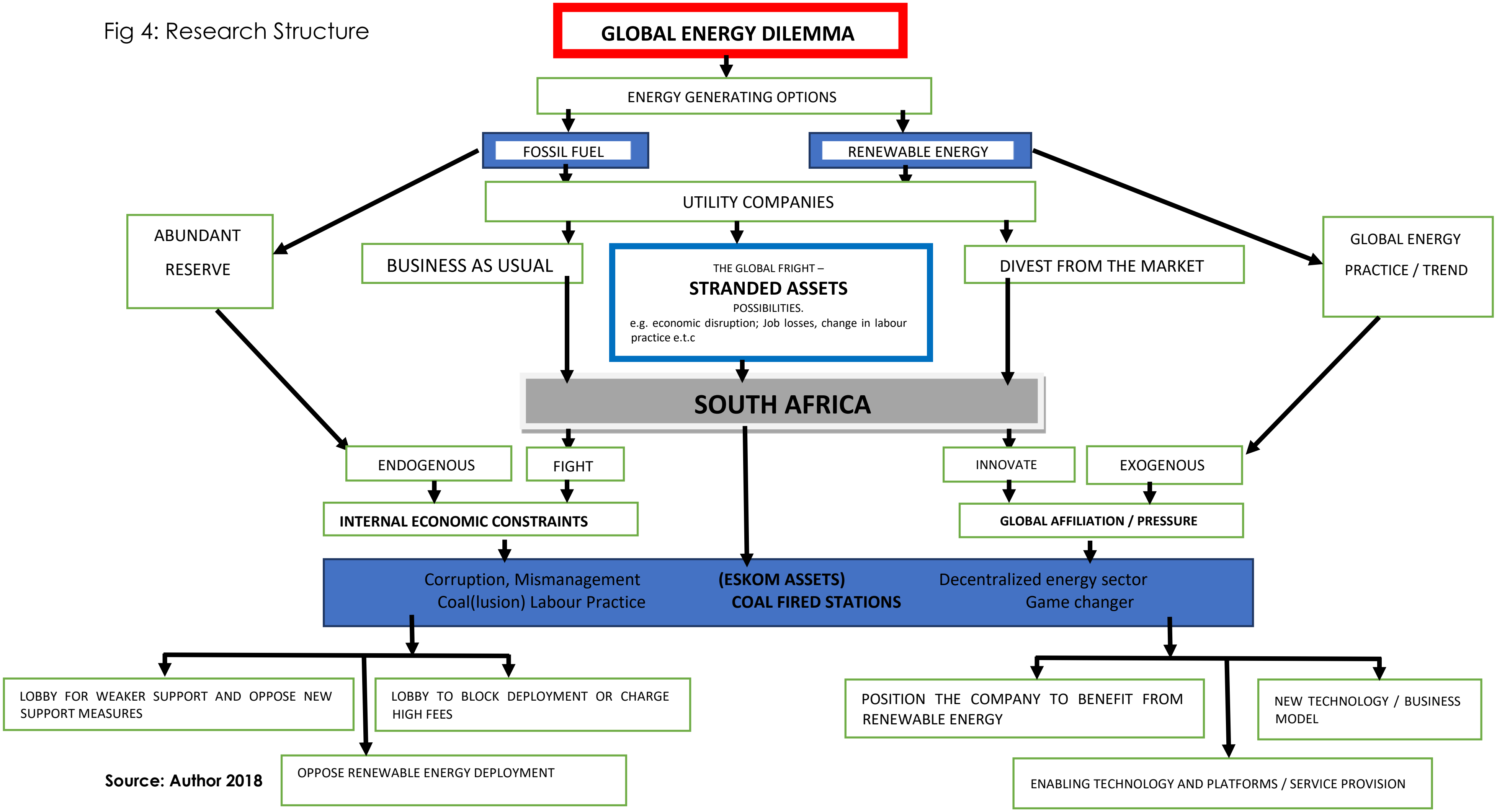
The validity and reliability of this research are based on the rigorous literature review and analysis that have been used to justify the research. The research considers two important components in confirming its validity and reliability. These components according to Trochim (2006) documented happening due to time and the socio-economic change of people and places. Neuman (2006: 188) explains that reliability also means that "qualitative researchers use a variety of techniques (e.g. document analysis) to note, analyze and present their discourse consistently". This study used the systematic evaluative review (as explained above) to analyze various literature and gather relevant information from different referenced, confirmed and reliable literature sources.

Neuman (2006: 188) further states that "validity suggests truthfulness". It refers to how well an idea "fits" with actual reality. The absence of validity occurs if there is a poor fit between the constructs a researcher uses to describe, theorize, or analyze the social world and what actually occurs in the social world. In simple terms, the validity of this research is concerned with the energy transition process in South Africa and the possibility of coal-fired stations becoming stranded assets in relation to the socio-economic condition of South Africa. It explains the social reality and how well it conflicts with the global constructs which are used to understand the concept of stranded assets. Furthermore, Merriam (2009: 213) states that "internal validity deals with the question of how the research findings match reality". The external validity of this research is concerned with the extent to which assets stranding may result in the death spiral of various utility companies in Africa, particularly during this global energy transition. This utility death spiral trends of utility companies can also be applied to South African energy utility company (Eskom).

3.6 Conclusion

This chapter concludes with highlighting the entire research structure

Fig 4: Research Structure



Source: Author 2018

CHAPTER 4: DISCUSSIONS, SUMMARIES, AND CONCLUSION

4.0 Introduction

There are some clear high-level indications of massive assets stranding which might result in various economic implications based on the above-stated energy status-quo of South Africa. This chapter pulls together various discussions on the extent to which fossil fuel assets particularly coal-fired stations can become stranded assets in South Africa due to the unprepared renewable energy transition. Borrowing stranded assets mitigation strategies and experiences from a few countries in chapter 2, this chapter concludes with possible frameworks that can be adopted into South Africa's energy market in order to mitigate massive stranded assets situation.

4.1 Discussions and Possible Scenarios

The energy sector in South Africa has responded with a renewed focus on energy efficiency and the inclusion of significant renewable energy in the latest national electricity plan (the draft Integrated Resource Plan 2018), which is being implemented through the new Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) for mainly solar photovoltaic and wind renewable electricity roll-out. While RE implementation took more than a decade to realize the policy aspirations articulated in the founding policy documents, the rapid achievements within a short period since the procurement process started in 2011 shine brighter even though it still faces some challenges of commitments from the government and its utility entity – Eskom.

Eskom has essentially monopolized the generation and transmission of electricity in South Africa. The sole utility company (Eskom) has enjoyed several enormous government advantages, including virtually unmatched incentives like long-term coal purchasing contracts at fixed prices, free forward exchange cover from government entities, and long-term tax-exempt status (Winkler, 2005a, 2005b). Eskom plans to continue to inject massive capital investments into an expansion of the country's energy infrastructure, with a primary focus on increasing coal supply to the newly developed coal-fired infrastructure - Kusile and Medupi, these two new coal-fired plants, are scheduled to receive progressive reinvestment throughout their life-cycle. However, these coal-fired stations – Kusile and Medupi are identified as high risk, short-term energy infrastructure scheduled to become stranded assets before reaching the end of their economic lifetime of 30 years for a new plant. According to Eskom assets depreciation practice, after 30 years is the period over which assets are depreciated on their financial records and this depreciation period also aligns with the plant lifetimes for new plants in the Integrated Resource Plan update.

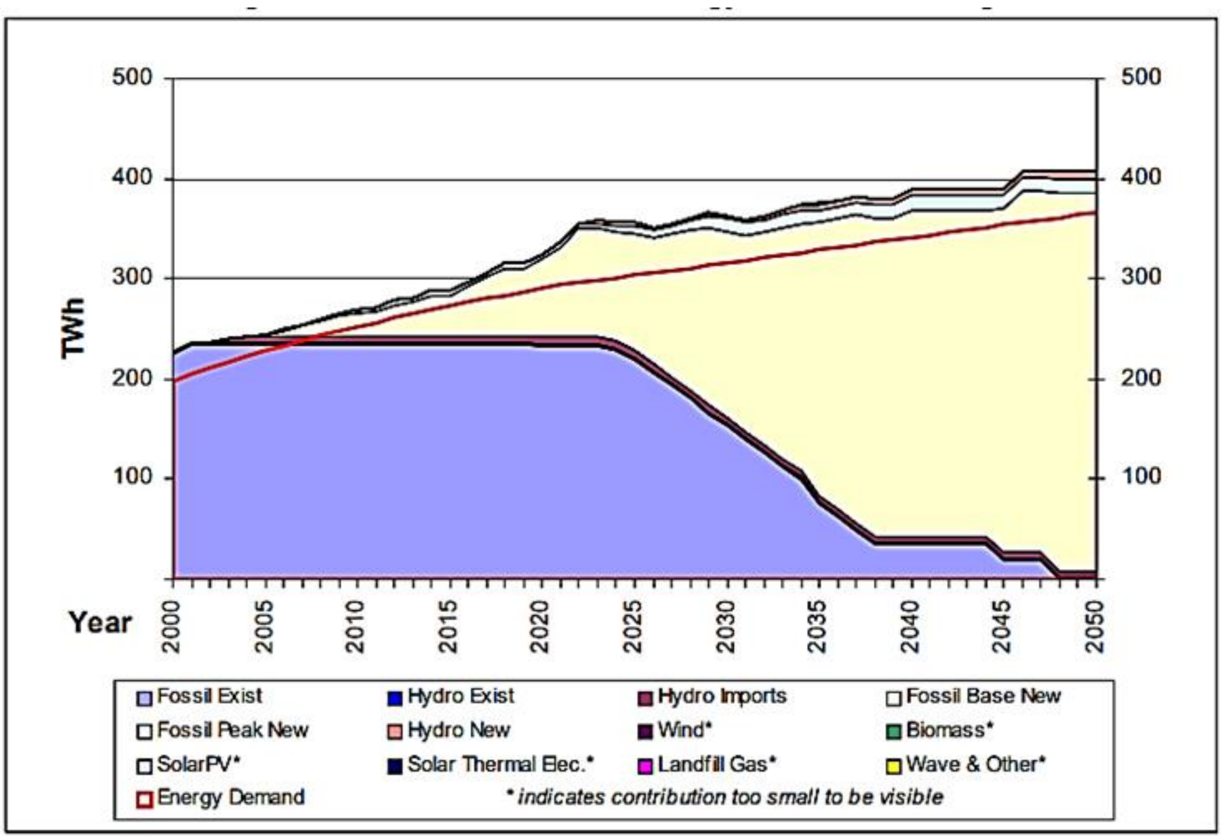
Even though plant closure may not be a financial risk in terms of paying off the investment, retiring plant before the end of its planned life is still "stranding" that asset, since Eskom is foregoing earnings on a plant that could otherwise run for a further 20-30 years. Unfortunately, if Eskom continues to monopolize the South African electricity market, three likely scenarios have been proposed for South African future energy.

4.1.1 Scenario 1: Business as usual

This scenario is based on the progressive investment and continuous reinvestment on coal-fired station in order to maintain economic balance. This scenario assumes very little active support from decision-makers and the financial market for the acceptance of renewable generation technology. This scenario is based on ongoing electricity generation practice and the present electricity status-quo of South African with little or no decrease in capacity for coal-fired plants until 2025 to 2050. This raises major environmental and economic red flags. It also highlights the opportunity to harness RE a country like South Africa will have missed during the next 6 years including the capacity crunch the country has to prepare for to have alternative solutions in place for implementation on a large scale.

The renewable energy contribution in this scenario reaches a maximum of four percent (4%).

Figure 5: Business as usual – energy demand matching



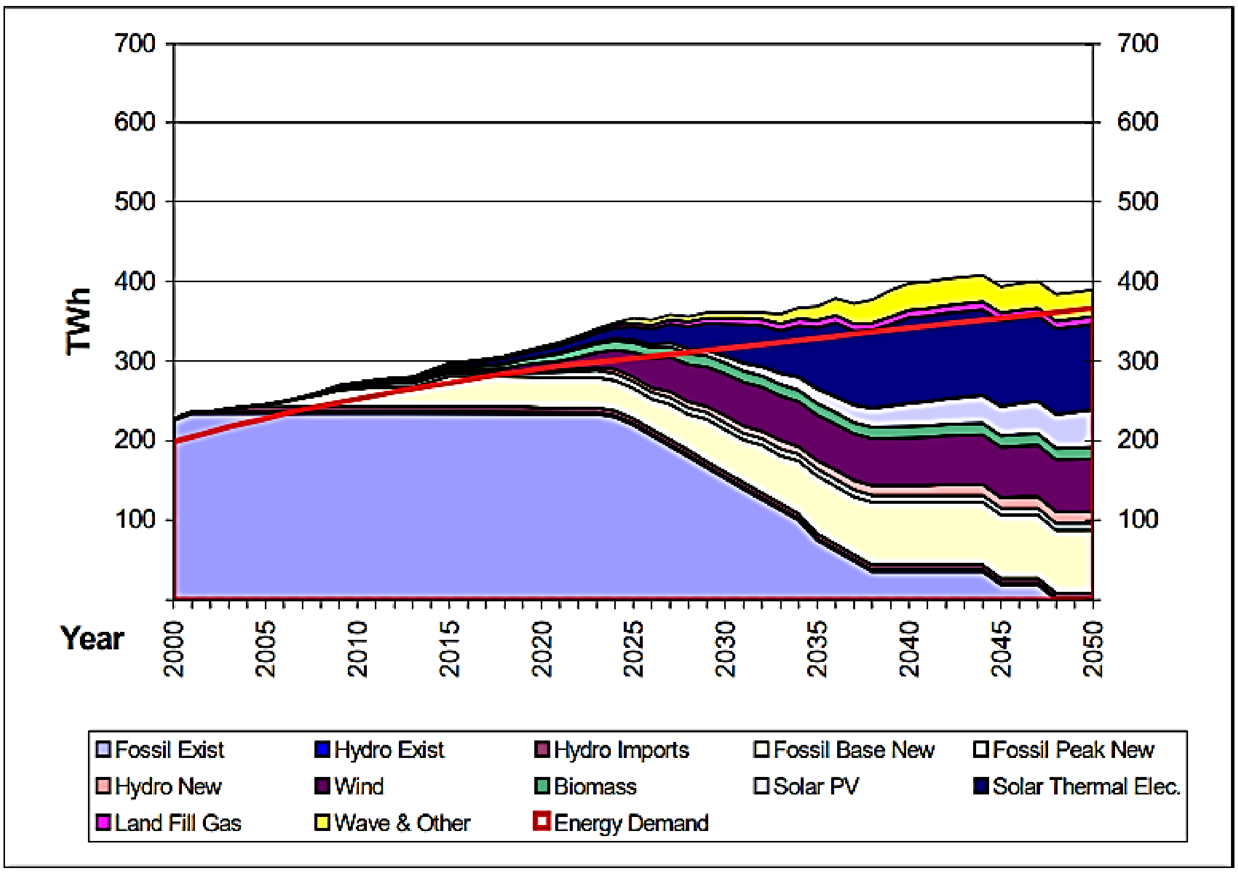
Source: Draft IRP (2018)

Figure 5 above illustrates the possibility of business as usual. A progressive renewable future in which renewable energy plays a moderate role in electricity generation as we can see today and will possibly increase by 2020 to about 13.3 percent. Figure 5 above also shows the possibility of RE contributing to about 70 percent by 2050. The pre-2020 large scale installations of renewable energy would place South Africa in a strong position to expand RE capacity rapidly from 2022 onwards. During this period (2022), various coal-fired plants are scheduled to be decommissioned and stranded.

4.1.2 Scenario 2: Progressive Renewable

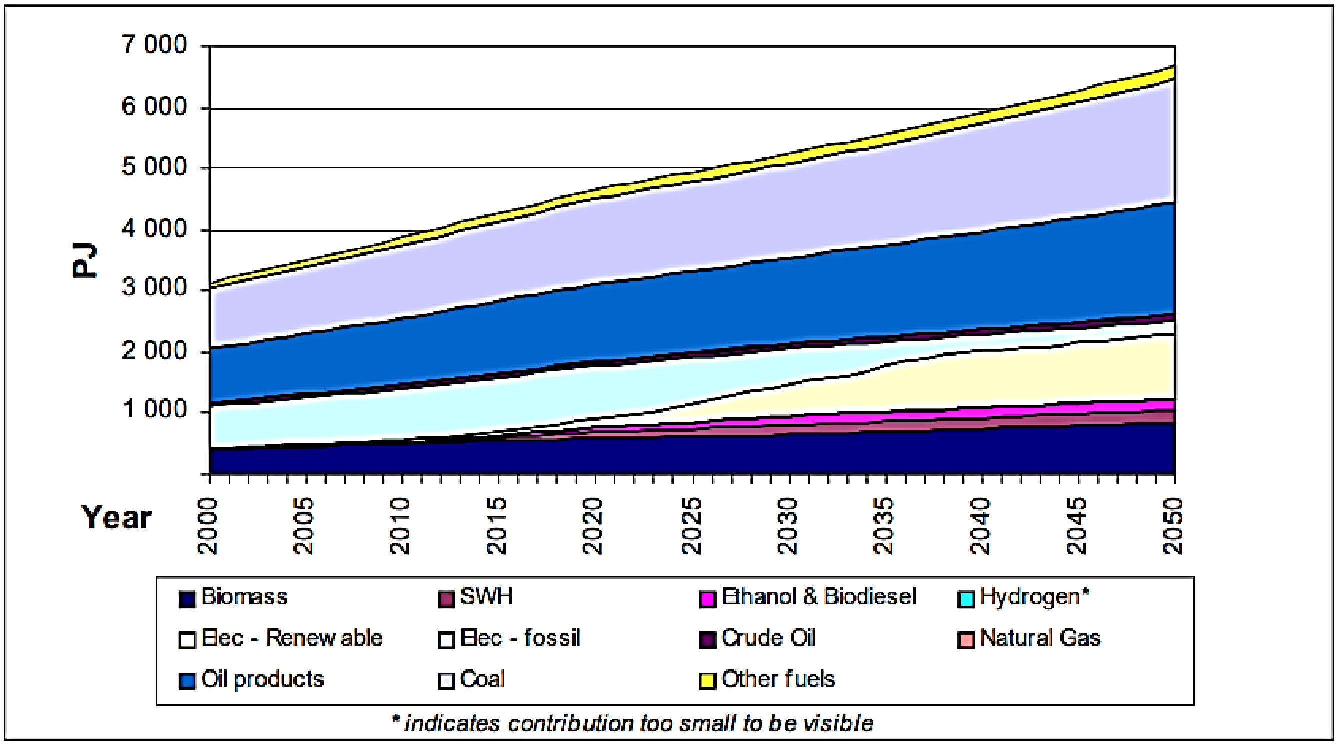
This scenario is formulated on the premise of increasing electricity demand and how it can be met. It highlights a progressive investment and encouragement of renewable energy as an alternative source of electricity. This scenario assumes incremental support from decision-makers and possible acceptance of R.E to the financial market.

Figure 6: Progressive Renewable 1 – Equating electricity demand



Source: Draft IRP (2018)

Figure 7: Progressive Renewable 2 – Final energy supply (in PJ)



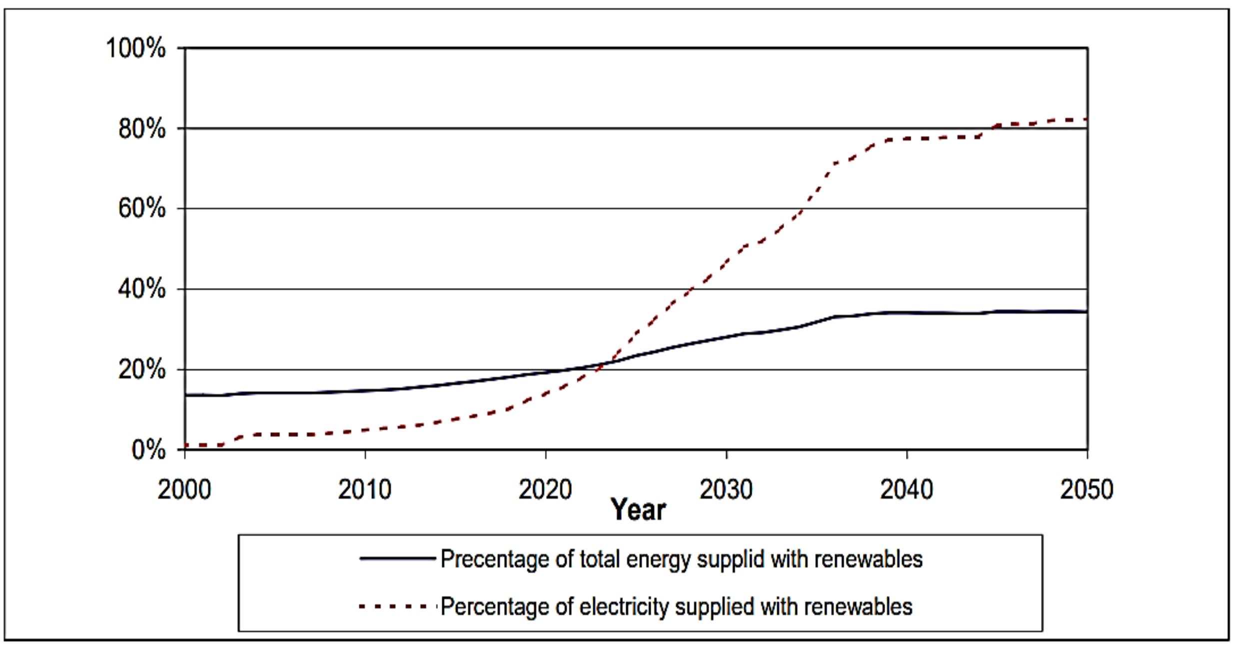
Source: Draft IRP (2018)

Scenario 2 illustrates how renewable energy (RE) is emerging into reality in the yearly interval, particularly in relation to the required growth rates for emerging industries such as solar PV, wind and solar thermal electricity. This scenario assumes RE as a large-scale industry which is expected to gradually develop at a 20 percent annual growth rate.

The assumption here is that RE will take several years before they can start to add energy capacity to the grid on the scale required. Lower cost options as we see today such as biomass, landfill gas and selected wind sites, are initially more attractive than solar and large-scale wind. However, these low-cost options have a limited resource base and it becomes important to balance development effort - harvesting the lowest-cost resources but, at the same time, developing the necessary technical capacity to harness the large-scale solar and possible wave technologies.

Although speculative, Figure 7 highlights, somewhat surprisingly, that renewable energy options are likely to be the most cost-effective options for energy supply in the future. Coal pricing is particularly difficult to predict, but if prices do continue to rise, it will not be long before solar thermal technologies present a large-scale, economically viable power supply option. Therefore, there is a likely possibility of renewables drastically increasing capacity in the electricity sector and the entire energy industry after 2020 and beyond.

Figure 8: Progressive Renewable 3 – Percentage renewable contribution to total final energy demand and to electricity supply



Source: Draft IRP (2018)

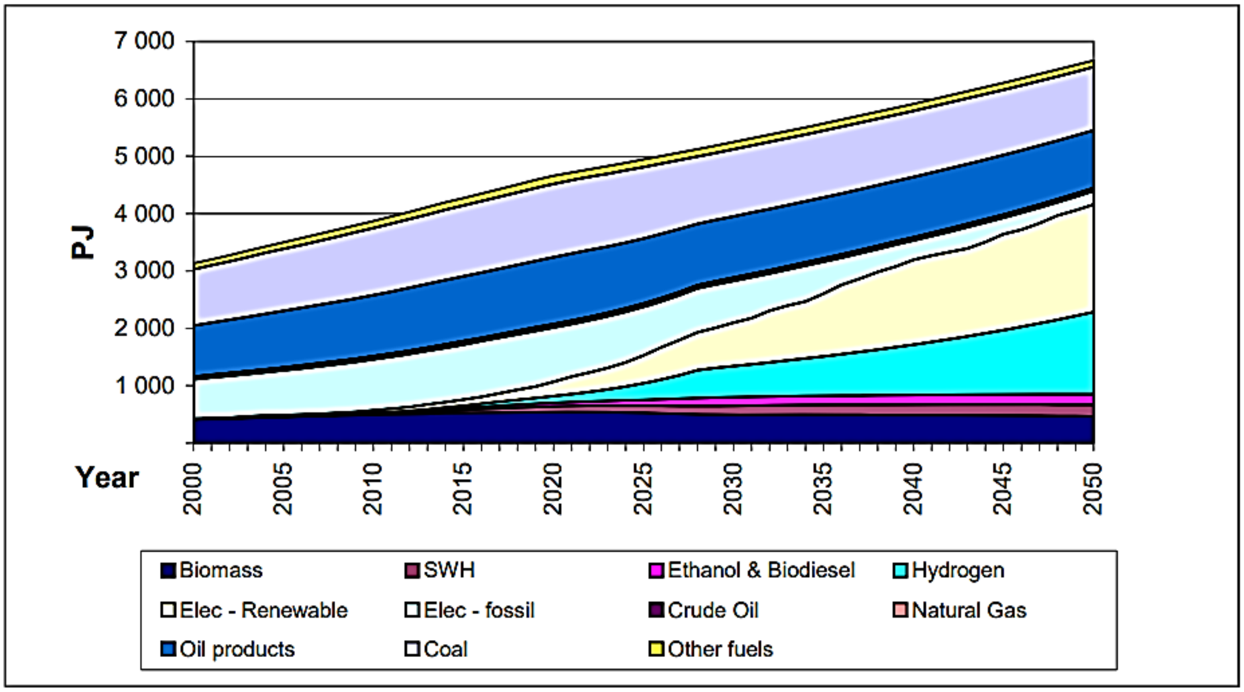
There are sufficient renewable energy resources in South Africa to provide about 18 percent of the electrical demand by 2020, and easily 80 percent or more by 2050. From a total energy perspective, the medium-term contribution of 25 percent is quite feasible considering South Africa's exposure to solar radiation. However, in the longer term, it will be difficult to achieve more than a 35 percent contribution by 2050 if fossil fuel market price remains constant or drops. Indeed, it should be noted that in figure 7 above - Progressive Renewable 2, shows the total consumption of fossil fuels increases from 2005 to 2050, with obvious concerning implications for climate change, fossil resources and the environment. Although, this scenario does not single out electricity generation but identifies the energy sector with electricity being part. This scenario also assumes a possibility of the energy mix with a lower possibility of coal-fired stations becoming stranded assets after 2020.

4.1.3 Scenario 3: High Renewable

This scenario looks at the options to achieve a net reduction in fossil fuel consumption before 2050 and could be considered as a global pressure - climate change driven scenario. It differs in two primary ways from the 'Progressive Renewable' scenario in that firstly, it is assumed that a large proportion of the current non-electrical energy demand in South Africa (e.g. transport, coal or oil-based process energy supply in industry) can be met by electricity (produced using renewable resources) and secondly, it is assumed that Hydrogen can be generated from renewable resources on a large scale. This can be stored, transported and used as required, much like coal, oil and natural gas – thereby replacing a significant part of the remaining non-electrical demand.

The total energy demand has not been reduced, thus leaving a similar allowance for economic growth to that given in the business as usual and progressive renewable scenarios. Figure 9 below shows this high renewable scenario. It should be noted that total electricity demand has risen significantly (to 600 TWh, or 2108 PJ) as projected by 2018 electricity demand.

Figure 9: High Renewable: Total energy supply mix



Source: Draft IRP (2018)

The direct use of Hydrogen or other renewably produced energy carriers contributes 1400 PJ to the total energy demand by 2050. With these (or similar measures) it will be noted that the percentage contribution of renewable energy to the total final energy demand rises to 60% by 2050.

Furthermore, there is a net reduction in fossil fuel contributions, thereby allowing South Africa to reduce its CO_2 emissions in line with the requirements for developed countries set out in the Kyoto Protocol.

Based on all the above scenarios (1, 2 and 3), achieving scenario 3, the high renewable scenario can be extremely challenging for South Africa due to its high dependence on coal and its corrupt utility company (Eskom). For South Africa to make the necessary shifts in the energy economy in order to achieve a similar high renewable trajectory, it will have to demonopolize the electricity sector, strategically develop the economy using approaches that do not require an increase in energy consumption and energy efficiency will have to be effectively promoted at all levels.

Having examined the scenarios above, the research highlights the risks currently facing South Africa. Firstly, that electricity planning will assume a higher share of the national carbon budget for the sector to 2050 and will invest in fossil power accordingly. In later years, this capacity will either have to be stranded wholesale and retired prematurely, or become stranded capacity with plants run at low average load factors. As in Jackson (2017), we find that less stringent near-term climate policy results in longer-term stranded capacity. This risk was highlighted in the IRP update (2018); therefore, gradual decommissioning of coal-fired stations was extended to 2022 partly to overcome the risk.

According to the DoE (2013), Medupi and Kusile coal-fired stations were built on the assumption that the carbon emission caps would continue at the same level, therefore the risk of building coal-fired generation station during this period and might only lead up to 2022. These coal-fired stations have led to a constraint in reducing the emissions or underutilization of generation capacity if the cap needed to be reduced over time as indicated by the government's peak-plateau-decline (PPD) objective.

Given that the electricity sector is a lower-cost option for decarbonization, the research argues that the IRP 2010 emission constraints (which allow for new coal-fired capacity to be built), should be revisited under the scenarios outlined above, the rate of retirement required to meet the emission constraints exceeded the rate at which the fleet is scheduled to retire, especially when new coal plants are put into consideration.

As with any scenario work, the discussions stated above are not intended to be predictive, they have been produced using a fairly simple modeling approach to allow readers to grapple with the magnitude of assets stranding facing the electricity sector including the challenge that lies ahead of South Africa's energy transition. However, the magnitude and effect of assets stranding on South Africa's economy highlighted from these scenarios can be mitigated if strategically planned. According to Mathiesen (2016), South Africa can reduce the value of future stranded assets by gradually accelerating policies alongside inclusive action plans.

Delaying action and continuing with the business as usual outlook means that future course corrections will result in significantly more asset stranding. Some developed countries highlighted in the literature review have shown the possibility of mitigating further stranded assets in the future which are accompanied by negative economic impacts.

4.2 Summaries

South Africa has four key challenges that informed the development of the above scenarios for which these summaries are based. Firstly, the country has very high levels of poverty and inequality (StatsSA 2014;). A central challenge in achieving a reduction in poverty is the high unemployment rate (24% using the strict definition or 37% using the broad definition) and low skills base, and it is imperative that job losses are minimized across sectors. Much of South Africa's industrial base is premised on energy and carbon-intensive mining, minerals beneficiation or chemicals processes. Higher electricity prices are therefore viewed as a risk to those sectors. While they account for a relatively small portion of total GDP, they are still large employers and are viewed as key to industrial development in the country. Understanding the effects of mitigation and the potential to alter the development trajectory of the economy to make it more pro-poor and structurally able to meet mitigation goals is a key area of work (see Altieri et al, 2015, 2016; Baker et al, 2015; Winkler and Marquard, 2009).

Secondly, South Africa is carbon and energy-intensive economy with a high dependency on coal and has committed to global agreements to reduce emissions to avoid dangerous anthropogenic interference in the climate system. The mounting pressure as a result of South Africa's commitment to global agreements to reduce emissions and limit the use of carbon-intensive assets, particularly coal assets is increasing. Although, the government of South Africa and it's coal energy sector are collectively striving against asset stranding through increasing capital expenditures and operating cost while various government policies and interventions are either postponed or not enforced.

Thirdly, new fossil fuel infrastructure and coal-fired plant interventions in South Africa were established before asset stranding risk became widely recognized hence a precautious approach towards implementing any renewable energy policy. This means that the government has not fully agreed on how the future of South Africa's energy will be structured and align with the global energy trend.

Finally, various financial institutions in South Africa are still supporting stressed coal power plants. Renewable energy in South Africa has not fully gained the financial acceptance large due to large-scale RE performance stability, therefore, the unlikely possibility of scenario three (high-scale renewable) and low possibility of stranded assets according to Eskom assets records.

4.3 Conclusion

The three scenarios highlighted in the discussion above identify the possibility of assets stranding in the electricity sector. However, the four challenges highlighted in the summary also identify the unlikely possibilities of stranding energy sector assets within the next decade in South Africa. In concluding this report, the author identifies that the likely possibility of assets stranding in South Africa can only be influenced when large cumulative investment is allocated to renewable energy to provide the infrastructure required to meet electricity demand of South Africa.

Having identified some issues that might lead to massive coal-fired plant assets in South Africa, this final section seeks to address the global energy transition influence that might affect South Africa. More specifically this section tries to answer the sub-questions specified on page 13, namely: "to what extent can global energy transition affect the South African energy industry"; and "what are the risk factors facing fossil fuel assets in South Africa?"

In reply: there are political influences attributed to pursuing a global energy transition, particularly the acceptance of renewable energy. This is sold to developing nations as trying to ensure an equitable position on stranding fossil fuel assets. Although, the magnitude of these risks varies and are not clearly stated to developing countries due to the dynamics attributed to specific policy mitigation strategy. However, there are risk factors attributed to accepting and pursuing the global energy transition trend including subscribing to any equitable position on climate change (some of these risks include; loss and damage, climate finance, mitigation targets and adaptation). To elaborate on this risk further, three points are worth bearing in mind.

First, if it is agreed that humanity as a whole may not emit more than half a trillion tons of carbon, if it is to have a 50% chance of not triggering a 2°C world, and if we also bear in mind that the Paris Agreement aims for an even more stringent target (Allen et al. 2009:11; Collins and Knutti 2013:1033) then proposals to allocate the remaining extraction rights to resource-rich developing countries are likely to encounter some serious political obstacles. First, some resource-rich developed countries—aware of this and seeking to avoid dangerous climate change but wishing to utilize their own reserves—will simply resist plans to allocate extraction rights to the least advantaged.

Alternatively, they might not contest any allocation of extraction rights to the least advantaged but also will not curb their own extraction of fossil fuels. This would maintain the flow of fossil fuels and not result in any price increase and thus not dampen the consumption of fossil fuels. As a result, humanity will exceed the trillion ton cumulative carbon budget and cause dangerous climate change. It is notable, in this context, that the Paris Agreement made no further step towards allocating specific responsibilities and limiting rights to emit greenhouse gases. In addition to this, the USA has consistently resisted attempts to appeal to principles of historical responsibility.

On the other hand, it can be argued that while some resource-rich affluent countries will resist allocating extraction rights to developing countries they might be less opposed to policies compensating developing countries for not using fossil fuels in their own countries. In other words, they might support a proposal that is similar in spirit to REDD. Building on this, it can be argued that there could be a system whereby those in developing countries do not develop their fossil fuels and are compensated financially for doing so where those who pay for the compensation can include that as part of their contribution to mitigation.

This would help address the problem that faced the Yasuní-ITT Initiative—namely the lack of sufficient funds. It would also bring it closer in nature to existing flexibility mechanisms, such as the Clean Development Mechanism (CDM), which is an established feature of the international climate regime. It is also similar to other forms of paying for environmental services. The CDM is not unproblematic and there have been some very serious shortcomings and flaws (Caney 2010c: 217-218). However, it is worth considering a policy which seeks both to mitigate climate change and which does so in ways that further development. Furthermore, since doing so gives some flexibility to high emitting countries it might be welcomed by them.

In short, then, while there is a political risk the precedents of the REDD and CDM suggest that it is not insuperable. A scheme for stranding assets in which those who abstain from using them receive compensation for that (distributed equitably among those affected) and in which those who pay for the fund have that included as part of their mitigation commitments is worth serious consideration as an equitable and feasible way of addressing climate change in a way that respects the principle of Common but Differentiated Responsibilities and Respective Capabilities.

Second, if the policies towards stranding fossil fuel assets adopt the different criteria analyzed earlier in this paper then, as noted, this will lead to the differentiation between non-Annex I countries. As such, some countries are likely to resist the fragmentation of Annex I and the unity of the G77. As evidence for this, it is worth noting that some opposed using Equity Reference Framework indicators "as a means to differentiate between developing countries" (Ad Hoc Working Group on the Durban Platform 2013: 4). To give one important

example, India has objected to the differentiation among non-Annex I countries that an ERF would entail.

In reply: although breaking down the binary division between developed and developing countries might encounter some resistance it is not clear how much longer this binary framework can last in the UNFCCC process. The emergence and joint statement by other groups like Brazil, South Africa, India and China (BASIC) might signal evolution from the old divisions found in the Kyoto Protocol.

A **third** point, as was noted above, although stranding fossil fuel assets necessarily raises questions of distributive justice those are not the only considerations. More generally, one can distinguish between two perspectives. One might be called "duty-bearer justice": this seeks to ensure that the path to a zero-carbon world shares burdens equitably, with due respect to the right to develop and honoring the principles of common but differentiated responsibility.

The focus of this paper has been looking at the possibility of asset stranding in South Africa and what it might mean in the context of accepting the global energy transition trend. However, there is a second perspective—what might be termed "harm-avoidance justice": this seeks to prevent harm. In this case, it prioritizes preventing dangerous climate change. Ideally, policies honor both sets of considerations. However, in practice, policymakers may be forced to strike a balance. It is thus important to investigate how this balance can be properly struck – particularly in South Africa in such a way that does not preclude reaching an effective climate regime that succeeds in avoiding dangerous climatic changes. At the same time, it is important to ensure that the transition to a safe climate and zero-carbon world honors duties to those with plenty of reserve and poor economy.

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Appendix 1: Ethics Clearance

SCHOOL OF ARCHITECTURE AND PLANNING
HUMAN RESERCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE
PROTOCOL NUMBER: SOAP039/07/2018

PROJECT TITLE:	Renewable energy and it implications on fossils fuel: A Stranded Assets scenario in South Africa?
INVESTIGATOR/S:	Olalekan Olufemi Ajibola (Student No: 1171872)
SCHOOL:	Architecture and Planning
DEGREE PROGRAMME:	Masters of Architecture SEEC (MSEEC)
DATE CONSIDERED:	21 September 2018
EXPIRY DATE:	21 September 2019
DECISION OF THE COMMITTEE:	Approved

CHAIRPERSON ______________________
(Professor Daniel Irurah)

DATE: 21-09-2018

cc: Supervisor/s: Brian Boshoff

DECLARATION OF INVESTIGATORS
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to endure 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.

Signature ______________ **Date** 21-09-2018

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