Perceived barriers to the adoption of low-carbon energy in the South African Energy-Intensive Industry.

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

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ABSTRACT

Carbon dioxide is the predominant greenhouse gas associated with the combustion of fossil fuels. Energy-intensive industry is linked to high carbon emissions due to high energy consumption compared to other types of industry, hence the need for low-carbon energy options. With local and international pressure to reduce carbon emissions, this study seeks to explore the available options to facilitate low-carbon energy and to identify the barriers associated with their adoption within the South African energy-intensive industry. Most previous studies on this topic were conducted for industrialized countries, and this study focus on understanding the barriers that affect South Africa and possibly other developing countries. Quantitative approach was employed using online survey and descriptive statistics to gather and analyse information on low-carbon energy options available and employed within the South African energy-intensive industry and to understand the barriers to their adoption. The study found that regulatory, economic, facility structural design, and culture and behavioural barriers exist in the South African energy-intensive industry. The barriers identified provides the basis for planning and resource allocation for the energy-intensive industry.

KEY WORDS

a. Anthropogenic Carbon dioxide emissions

b. Barriers to adoption

c. Carbon emissions

d. Climate Change

e. Energy consumption

f. Energy Intensive Industry (EII)

g. Industrial Sector

h. Low-carbon energy

i. Low-carbon production

DECLARATION

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

Name: Signature:

Signed at ……………………………………………………

On the …………………………….. day of …………………… 20….

DEDICATION

A special dedication to my sister Portia, daughter Taki, son Khumo and nephew Mufunwa.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor, Dr Kolawole Ijasan, for his assistance and guidance throughout my research work.

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A special thanks to my family for their patience and understanding when I couldn't be available for them while working on this research and the entire qualification. The love and encouragement I receive from them inspires me to reach greater heights.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

CCS	- Carbon Capture and Storage
CCT	- Clean Coal Technology
CO_2	- Carbon dioxide
EII	- Energy-Intensive Industry
EIUG	- Energy Intensive Users' Group
GHGs	- Greenhouse Gases
INDCs	- Intended Nationally Determined Contributions
UNFCCC	- United Nations Framework Convention on Climate Change

CHAPTER 1. INTRODUCTION

1.1 Purpose of the study

The purpose of this study is to explore available options to facilitate the adoption of low-carbon energy in the South African energy-intensive industry and to identify barriers to their adoption. The findings of the study provide the basis for planning, highlight the areas of concern and guides intervention and resources required.

1.2 Context of the study

Climate change is recognized as one of the major global challenges faced by humankind (Polzin, 2017) and the United Nations Framework Convention on Climate Change (UNFCCC)'s objective is to lessen the concentrations of the greenhouse gasses in the atmosphere in order to minimise their impacts on the climate (Solomon, Plattner, Knutti, & Friedlingstein, 2009). Carbon dioxide is the predominant greenhouse gas associated with the combustion of fossil fuel (Tol, 2009) and according to Allwood, Cullen, and Milford (2010), more than half of man-made carbon emissions are as a result of energy use.

Of all greenhouse gasses, carbon dioxide from fossil and industrial process contributes 65% as depicted in **Figure 1-1** below. It is for this reason that this study only focusses on industrial sector's carbon emissions.

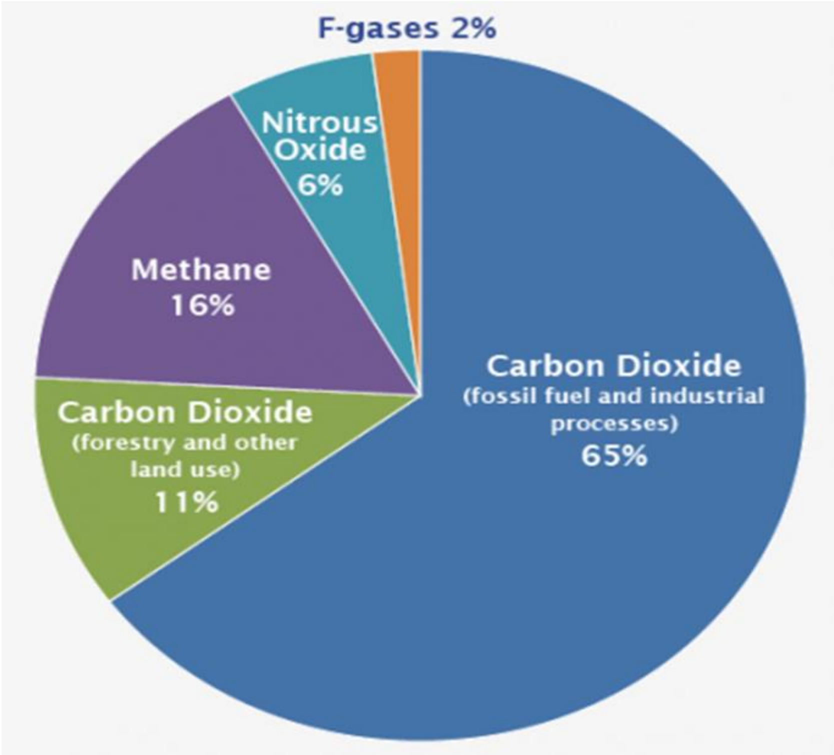


Figure 1-1: Global greenhouse gas emissions by gas (IPPC, 2014).

Carbon emissions from the industrial sector are mainly associated with the production of steel, aluminium, paper, plastic and cement, and the demand for these products is projected to increase until 2050 and beyond (Allwood et al., 2010). This is a cause for concern since carbon emissions must at least be halved by 2050 in order to curb the impacts of climate change (Allwood et al., 2010).

As shown in Figure 1-2 below, industrial sector contributes 23% of direct greenhouse gas emissions and 11% of indirect carbon dioxide emissions. This is a clear indication that industrial sector is one of the major contributor to greenhouse gas emissions compared to most sectors.

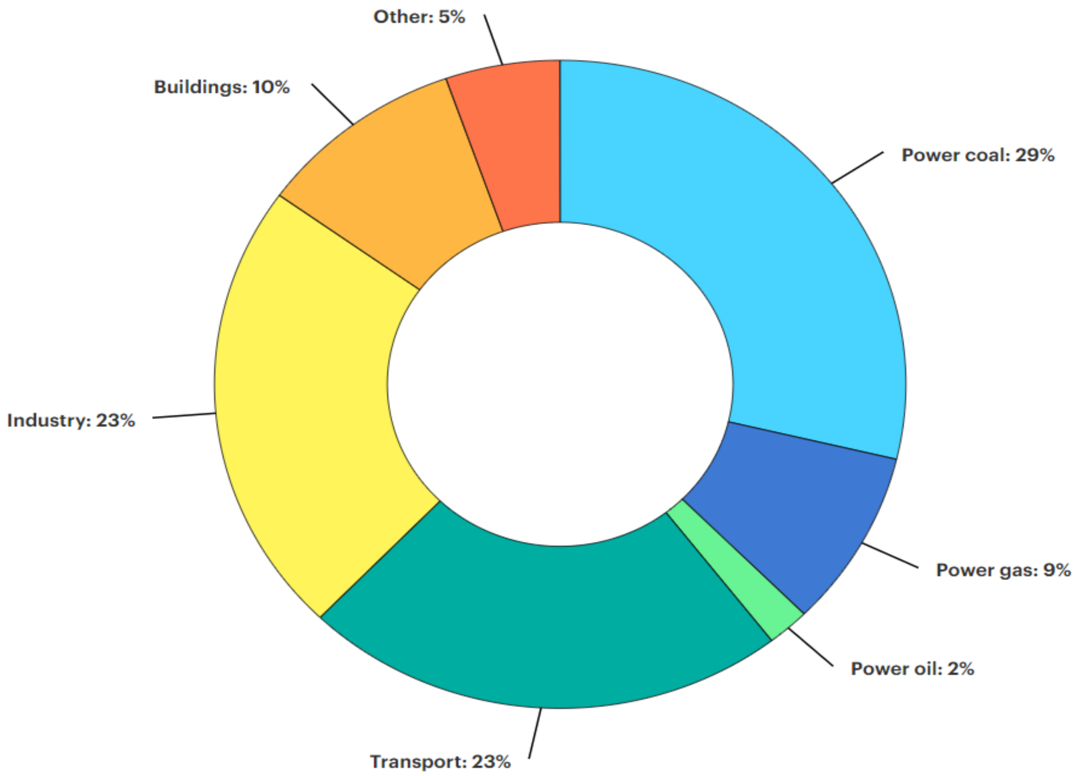


Figure 1-2: Global energy-related CO2 emissions by sector (IEA, 2021).

Literature points to the fact that carbon intensity and energy intensity have a close relationship, implying that energy-intensive industries (EII) can be associated with high carbon emissions since they utilise more energy than any other types of industry (Price, Worrell, & Phylipsen, 1999). In Price et al. (1999)'s view, the five energy intensive industries accountable for the majority of energy consumed and subsequent carbon emissions are: "iron and steel, chemicals, petroleum refining, pulp and paper, and cement." Energy-intensive industries will therefore benefit from the employment of low-carbon energy technologies to reduce their carbon intensity (Song & Oh, 2015).

The scientific community, policy makers, businesses and society in general agrees that in order to shift to a low-carbon economy, there must be decoupling of economic activities from the combustion of fossil fuels (Polzin, 2017). The deployment and the use of clean technologies is central to this transition, and will subsequently face out the carbon-intensive technologies (Polzin, 2017).

Since the 1990s, South Africa experienced rapid industrialization, fuelled by fossil fuels which led to high emissions of carbon dioxide (Zhao, Zhang, Wang, Zhang, & Liu, 2015). As a result, South Africa is one of the top carbon emitters in Africa and 13th in the world (S.-J. Lin, Beidari, & Lewis, 2015) and according to Arndt, Davies, Makrelov, and Thurlow (2013), the country also faces international pressure to reduce carbon emissions and to contribute to global climate change mitigation.

Apart from international pressure, South Africa's water supply, agriculture, coast lines, and infrastructure is under threat of climate change (Huxham, Anwar, & Nelson, 2019). The Paris Agreement, which South Africa is a signatory to, calls for a development strategy that places carbon emissions reduction at its core (Amusan & Olutola, 2016).

Identifying the barriers hindering the adoption of low-carbon energy in the energy-intensive industry will inform policy direction and implementation. Given the pressure to reduce carbon emissions, the study will provide an indication of where the country is, in terms of industrial carbon emission reduction based on the nature of barriers identified.

1.3 Research problem

Increased industrialisation and its subsequent greenhouse gas emissions pose a major threat to humans, the environment and contribute to climate change impacts (Maryam, Mittal, & Sharma, 2017; Zi & Zhenyao, 2011). Industrial sector uses substantial amount of energy and contribute to significant amount of carbon dioxide emissions (Thambiran & Diab, 2011).

The Intended Nationally Determined Contributions (INDCs), as prescribed in the Paris Agreement, demands for countries to significantly cut greenhouse gas (GHG) emissions from 2020 onwards (Amusan & Olutola, 2016). Zhao et al. (2015) suggests that in order to reduce the emissions and subsequently achieving international commitment to its carbon emission reduction targets, South Africa need to establish clean energy mechanisms and improve energy efficiency.

In order to reduce the impacts of climate change, the International Energy Agency (IEA) recommends that direct emissions from industrial sector be significantly reduced by 2050 (P. Taylor, 2010). On the other hand, the demand for goods from industries is also expected to grow in the future, which may lead to increased industrial carbon emissions (Allwood et al., 2010).

South African economy is extremely energy intensive, especially the industrial sector which contribute to significant amount of carbon emissions due to reliance on coal (Winkler & Marquand, 2009) and this calls for energy-intensive industries to shift to low-carbon energy and technologies (Nabernegg et al., 2017). In general, coal-abundant countries like South Africa are faced with difficulties of utilising other energy resources as opposed to coal and therefore need options to minimise carbon emissions from coal (Menyah & Wolde-Rufael, 2010).

The country is committed to the development of policies and strategies to address climate change, but for industrial facilities to transition to low-carbon energy, fundamental changes in the overall design and the replacement of fossil fuels with alternative energy resources is required. This research explores the viable low-carbon energy options and the barriers that energy-intensive industries encounter in employing them.

1.4 Research questions

Below is the main research question:

Which barriers affect the South African energy-intensive industry's ability to adopt low-carbon energy?

The main question is broken down into three (3) sub-questions:

1. What is the level of familiarity with the available options to facilitate low-carbon energy within the South African energy-intensive industry?
2. To what extent are the options to facilitate low-carbon energy employed in the South African energy intensive industries?
3. What are the barriers contributing to the South African energy-intensive industries' inability to adopt low-carbon energy?

1.5 Significance of the study

Y. Liu (2014) highlighted that most previous studies on the barriers associated with the adoption of low-carbon energy were conducted for industrialized countries, which are well developed, with minimal attempt to understand the barriers affecting developing countries like South Africa. This study therefore focuses on understanding the barriers affecting South Africa and possibly other developing countries, with the aim of informing decision making in the low-carbon energy pathways.

Understanding these barriers is essential in highlighting areas of concern and providing direction in terms of where intervention is required. The findings of the study will be particularly beneficial to the South African government in informing policy direction and development of implementation strategies. The energy-intensive industries will benefit from various mitigation options explored which ranges from simple and cheap options to the high-cost ones which can be adopted in the long-term. In this regard, the study will explore the various options available and feasible in the South African context and also identify barriers associated with their employment.

1.6 Delimitations of the study

- Although carbon emissions come from different points and processes in the industrial facility, this study only considered energy related carbon emissions.
- Data collection for the study was limited to the individuals working in the Gauteng province's energy-intensive industrial facilities (excluding power generation).
- The study is restricted to the experience, views and opinions of the selected respondents only.

1.7 Definition of terms

Anthropogenic Carbon dioxide emissions – These are man-made carbon dioxide emissions mainly associated with energy consumption through the combustion of fossil fuel (Schmalensee, Stoker, & Judson, 1998; Soon, Baliunas, Idso, Kondratyev, & Posmentier, 2001).

Barriers to adoption – Anything that significantly reduce the probability of "something to be adopted or employed" (Gillingham & Sweeney, 2012).

Carbon emissions – These are type of greenhouse gas emissions emitted to the atmosphere, mainly through human activities (Osmanski, 2020).

Climate change - The United Nations Framework Convention on Climate Change (UNFCCC), define it as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods”.

Energy consumption – Using energy as a source of heat or power in the industrial or production process (EIA, n.d.).

Energy-Intensive Industry (EII) – An Industry that requires higher energy input for its production than other types of industries (Song & Oh, 2015).

Industrial sector – “An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods” (EIA, n.d.).

Low-carbon energy - Energy resources which emit less or no carbon dioxide without compromising production (Yuan, Zhou, & Zhou, 2011).

Low-carbon production – Process of producing goods using energy and resources efficiently, leading to low carbon emissions (Tridech & Cheng, 2011). In other words, low-carbon production entails emitting less carbon while promoting economic growth.

1.8 Assumptions

- This research assumes that the transition to low-carbon energy in the industrial sector comes with challenges, hence the need to identify them.
- All the selected respondents had full knowledge of energy use in the South African energy-intensive industry.
- The study also assumes that the data provided is credible, accurate and ethical.

1.9 Structure of the report

Chapter 1: Introduction

This chapter introduces the whole study concept by outlining the purpose and significance of the study. It also provides background to the research problem, significance of the study, delimitations, definitions of the terms and assumptions of the study.

Chapter 2: Literature Review

This chapter reviews literature on the key concepts relating to the research questions. The literature review starts with the definition and background on low-carbon energy in the energy-intensive industry and proceeds to explore several options that facilitate low-carbon energy in the industrial sector. Literature review also covers barriers that impede the adoption of low-carbon energy, the extent of these barriers in developing countries, and the experience of other countries in the adoption of low-carbon energy. Two propositions are stated at the end of the chapter as informed by literature reviewed.

Chapter 3: Research Methodology

This chapter outlines the overall research approach, covering the design, data collection methods, population and sampling method, research instrument, procedure for data collection, analysis and interpretation. The validity, reliability, objectivity of research instrument and ethical considerations for the study methods are also covered in the chapter.

Chapter 4: Presentation of Results

In this chapter, online survey data and descriptive statistics are presented, covering low-carbon energy options available and employed in the South African energy-intensive industry and the barriers associated with their adoption.

Chapter 5: Discussion of the Results

The chapter focuses on the analysis and discussion of the results presented in chapter 4, in relation to the reviewed literature in Chapter 2. The discussions in this chapter are centred around options to facilitate the adoption of low-carbon energy and barriers to their adoption in the South African energy-intensive industry.

Chapter 6: Conclusions and Recommendations

This chapter provides a summary of the study findings and conclusions in relation to the research questions. Conclusions for each research question are made, followed by recommendations for the stakeholders affected and suggestions for further research.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter outlines the background to the research questions by reviewing different literature on what low-carbon energy in the energy intensive industries entails. Attention is on those studies that explored the options to facilitate low-carbon energy in the energy-intensive industries and those that identified various barriers in the adoption of low-carbon energy.

The discussions in this chapter are structured as follows:

- ✓ Section 2.2 provides definition and background discussion on low-carbon energy in the energy-intensive industry.
- ✓ Section 2.3 explores several options available to facilitate low-carbon energy in the industrial sector.
- ✓ Section 2.4 focus on identifying barriers that impede the adoption of low-carbon energy.
- ✓ Section 2.5 covers the additional barriers experienced by developing countries like South Africa in the adoption of low-carbon energy.
- ✓ Section 2.6 conclude the discussions by looking at the experiences of other countries in the adoption of low-carbon energy.

2.2 Definition and background discussion on low-carbon energy in energy intensive industries.

With more than half of man-made carbon emissions arising from the combustion of fossil fuels for industrial processes (Allwood et al., 2010), it is crucial to promote low-carbon energy in energy-intensive industries (Fujii et al., 2016).

Figure 2-1 below demonstrates the proportions of fuel combustion related carbon emissions from various sectors. The indication is that about 31.18% of Carbon dioxide emitted as a result of fuel consumption is from the industrial sector.

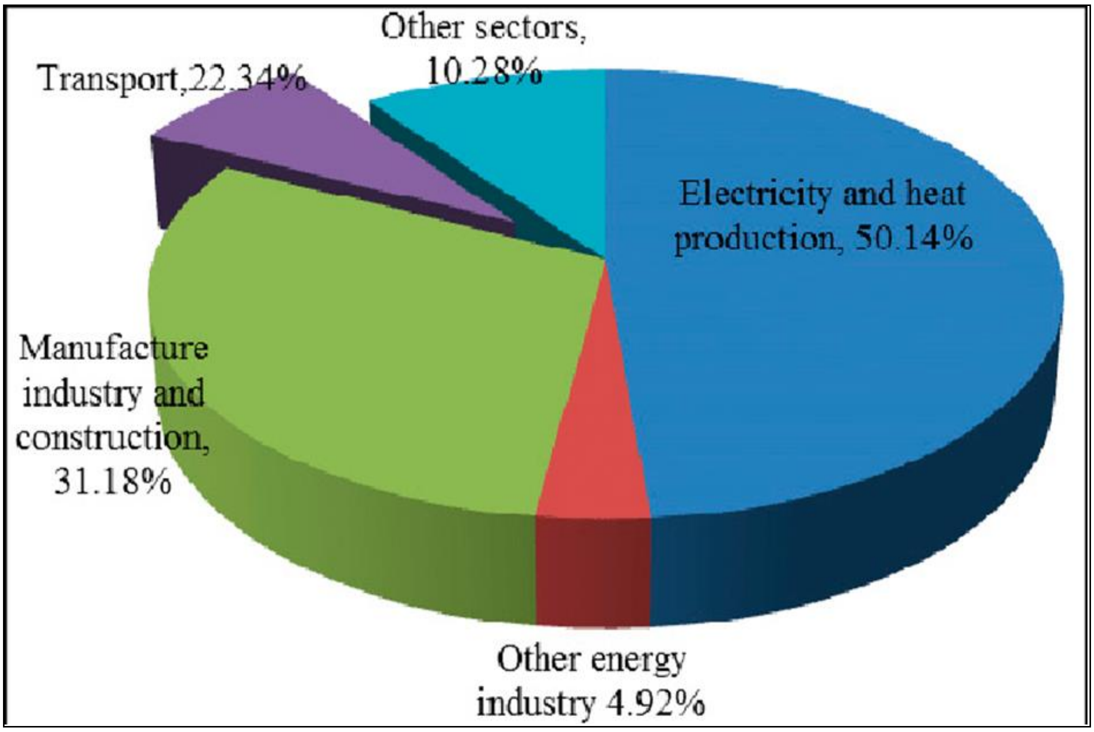


Figure 2-1: CO2 emissions from fuel combustion by different sectors (IEA, 2014).

Energy intensive industries are usually large in scale, with high initial capital investment, dominated by few large players in the market and consume higher amount of energy compared to other industries (Song & Oh, 2015). Its scope and classification doesn’t have enough scientific basis, making its definition debatable (Song & Oh, 2015). However, the classification of energy intensive industries by different authors are somewhat related, like Liddle (2012) who classifies them into pulp and paper, iron and steel, chemicals, non-metallic minerals and non-ferrous metal; while Price et al. (1999) classify them as chemicals, iron and steel, cement, petroleum refining and pulp and paper. Nabernegg et al. (2017) also identify “Petroleum, Iron and Steel, Non-metallic Minerals, Paper and Pulp, and

Chemicals" as energy intensive industries, supporting the notion that there is common understanding in the energy intensive industry concept amongst various authors.

In Sola and Mota (2020)'s interpretation, energy-intensive industries are those sectors with highest energy intensity, and these may include iron and steel, pulp and paper, chemicals, cement, amongst others. In the South African context, the major energy consumer in the industrial sector is Iron and steel, followed by chemical and petrochemical (Republic of South Africa, 2019).

Energy demand by various energy-intensive industries varies as depicted in figure 2-2 below. Iron and steel consumes the highest quantity (18%) of energy in the industrial sector followed by Chemical and petrochemical at 14%. Mining and quarrying, non-ferrous metals and non-metallic minerals accounts for 10%, 8% and 5% respectively and the other sub-sectors have insignificant energy consumption of 2% and less.

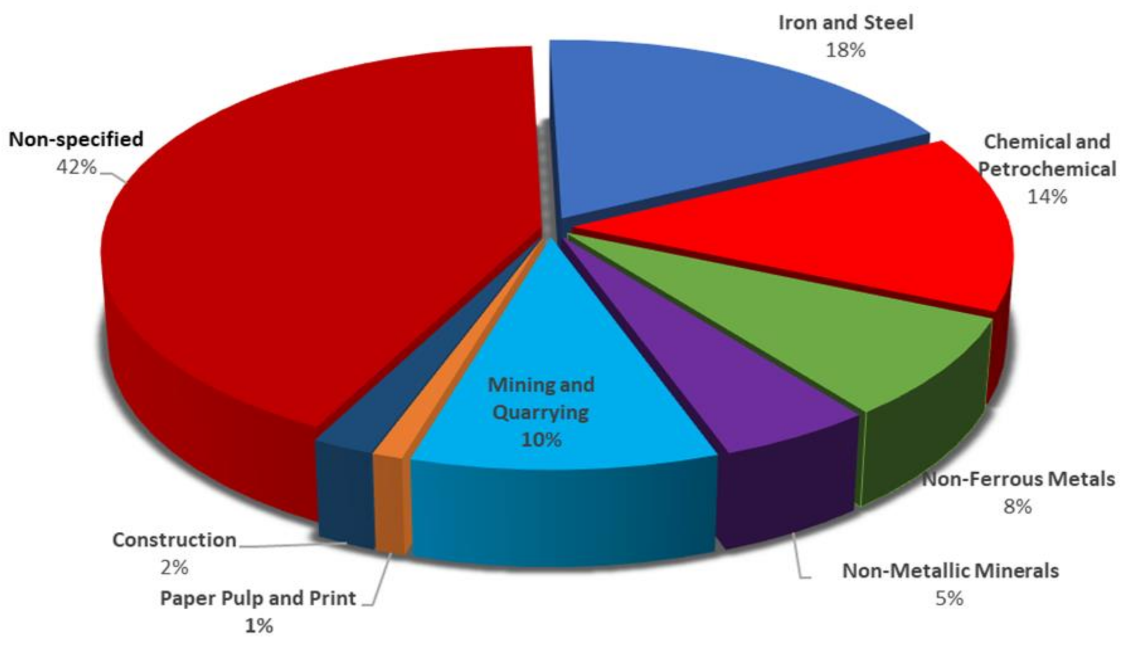


Figure 2-2: Energy demand by industrial sub-sectors (*Source: DoE Energy Balances, 2016)* as cited in Department of Energy (2019).

Figure 2-3 below shows that the highest consumed source of energy in the industrial sector is coal, followed by electricity and renewables. The least consumed sources of energy in the industrial sector were gas and petroleum products at 10% and 5% respectively.

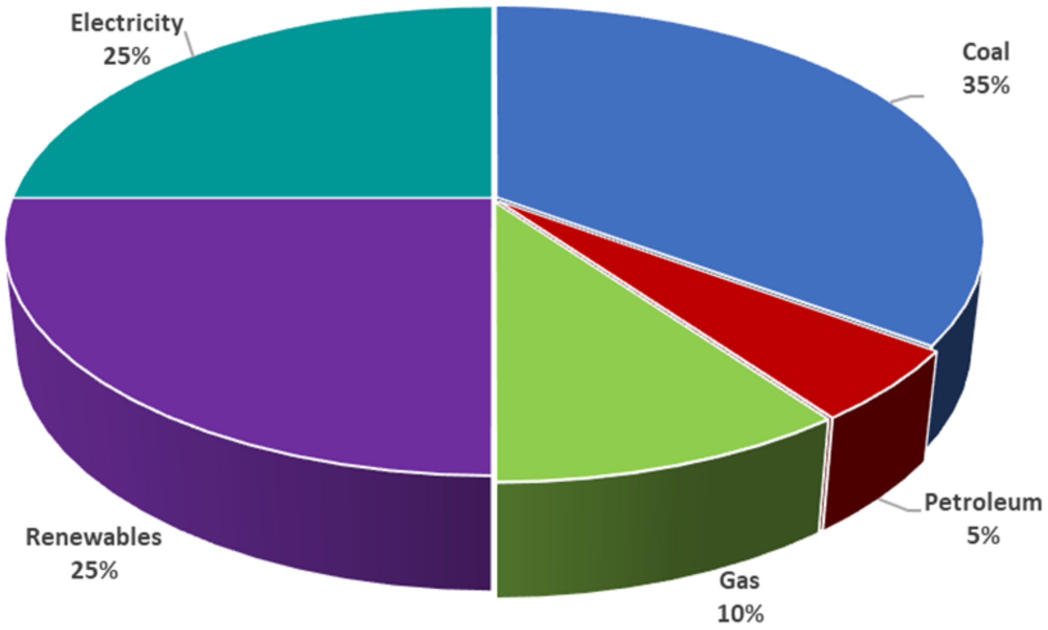


Figure 2-3: Energy demand in the industrial sector, 2016 (*Source: DoE Energy Balances, 2016)* as cited in Department of Energy (2019).

Low-carbon energy has been given different interpretations by different countries and organizations. Literature covers a diversity of linked concepts relating to low-carbon energy, including low-carbon development and low-carbon production (Yuan et al., 2011). In their review of literature, Yuan et al. (2011) describes low-carbon energy as replacing fossil fuels by low-carbon energy resources, with the important aspect being emitting less carbon while promoting economic growth. Baker, Newell, and Phillips (2014) considers transition to low-carbon energy as "a process of transformation from one energy system to another as well as a set of tools and concepts, to explain and enable such transitions".

Closely related to low-carbon energy is low-carbon production which entails industrial production using clean technologies and clean fuels. In this research, the two concepts are used interchangeably, and refers to industrial production using low-carbon fuels and technologies.

2.3 Options to facilitate the adoption of low-carbon energy.

Various options are available to transition to low-carbon energy in the energy-intensive industries and they range from improved energy efficiency, technological innovations, carbon sequestration and reuse (Allwood et al., 2010; Nabernegg et al., 2017). Fujii et al. (2016) suggests that introducing energy-saving technologies only will not reduce carbon emissions significantly, low-carbon fuels and raw materials must also be considered in energy-intensive industries. Allwood et al. (2010) further suggested that these options are possible and may have a huge impact, however, they are not easy to implement.

South African industrial development is centred around energy-intensive sectors and transitioning to low-carbon energy will therefore not be an easy task (Winkler & Marquand, 2009). In this section, five (5) broad categories of mitigating industrial carbon emissions were reviewed.

2.3.1 *Energy efficiency*

Bhandari, Singh, and Garg (2019) suggests that, for industrial sector to be competitive and sustainable, high efficiency technology with minimum air pollution need to be developed. Industrial sector is a significant energy consumer and one of the sectors with high potential for improving energy efficiency (Trianni, Cagno, Thollander, & Backlund, 2013).

Energy efficient technologies are believed to reduce energy demand, which in turn reduce the costs and demand for carbon emitting fossil fuels (Gillingham &

Sweeney, 2012; Pappas & Chalvatzis, 2017; Trianni et al., 2013). In general, combustion processes have some energy inefficiencies, due to the design of the equipment and operational limitations (Henriques Jr, Dantas, & Schaeffer, 2010) and this can be improved by employing energy efficient equipment's and practices. Energy efficiency measures can range from cheap alterations in daily operations to more expensive measures involving employment of new and advanced technologies (Henriques Jr et al., 2010). There are several options to achieve energy efficiency, like in iron and steel industry, where technologies to recover waste heat energy result in improved energy efficiency (Nabernegg et al., 2017).

Energy efficiency is prioritised in the policy agendas of most developed countries and this has encouraged more research and development and innovation in this regard (Song & Oh, 2015). Winkler and Marquand (2009) highlighted the potential of energy efficiency but warned that the benefits cannot be realised without a more concerted effort. In most cases, the high prices associated with energy efficient technologies becomes the main barrier to investment and subsequent implementation (Gillingham & Sweeney, 2012).

Investing in energy efficiency have yielded significant reductions in energy use and subsequent carbon emissions in many countries in past years (Hrovatin, Dolšak, & Zorić, 2016).

2.3.2 *Fuel substitution.*

Reducing the reliance on coal resources for economic development will contribute in significant reduction of carbon emissions (Zhao et al., 2015). Winkler and Marquand (2009) and Henriques Jr et al. (2010) affirmed that using low-carbon fuels instead of coal results in significant reduction in carbon emissions in the industrial sector.

According to Bloch, Rafiq, and Salim (2015), fuel substitution can facilitate sustainable development, hence, many countries are substituting coal with natural gas, oil and renewable energy to reduce the effects of climate change. Coal usage is more detrimental to the environment, but there is opportunity for inter-fuel substitution among coal, oil and renewable energy, which would lower emissions and promote environmental sustainability (Bloch et al., 2015).

Wesseh Jr and Lin (2018) purports that with capital investment toward fuel substitution, a significant amount of carbon emissions can be achieved. Innovations in different technologies and investment in resources like natural gas, with the aim of replacing coal and other petroleum products, could lead to reductions in carbon emissions (Wesseh Jr & Lin, 2018).

Several studies on fuel substitution focused mainly on the developed countries, with less interest in understanding the feasibility of fuel substitution in the developing countries like South Africa (B. Lin & Atsagli, 2017). For South Africa, the dominance of coal and petroleum in the energy mix, becomes a hindrance in the transition to low-carbon energy and based on the demand trend, there is no indication of demand for these resources going down in the near future (B. Lin & Atsagli, 2017).

Several substitutions are possible in the industrial sector and according to Henriques Jr et al. (2010), things like biomass resources have been used in the industrial sector. In iron and steel production, the use of coal in the blast furnace can be replaced by hydrogen as a reducing agent in "plasma blast furnaces" (Nabernegg et al., 2017).

2.3.3 *Materials recycling*

This is another viable option to achieve low-carbon production, which entails saving energy by cutting the need to manufacture new products (Henriques Jr et al., 2010). A good example is where Portland cement is produced with additives (ranging from fly-ash, slag from blast-furnace to calcined clays) which needs less energy, leading to less use of clinker, which consumes more thermal energy (Henriques Jr et al., 2010; Nabernegg et al., 2017). In the Iron and steel industry, using scrap could save the energy that would have been needed in the transformation of iron ore into metal (Henriques Jr et al., 2010).

In some instances, materials recycling, is achieved through industrial symbiosis (IS), which entails two or more distinct industrial facilities exchanging materials, energy or by-products to mutually benefit both parties (Dong, Gu, Fujita, Hayashi, & Gao, 2014). Through the reduced energy use, the associated carbon emissions would also be reduced, and this is also augmented by Li, Bao, Xiu, Zhang, and Xu (2010) who advocates that industrial symbiosis could meaningfully reduce carbon emissions.

As with other material recycling options, iron and steel industry has the highest potential in the industrial symbiosis system, due to it substantial excess materials and energy which can be used by other industrial facilities (Dong et al., 2014). Z. Liu et al. (2013) suggests that scrap metals have the potential to replace 80% of iron ore needed for primary steel production by 2050, thereby reducing carbon emissions associated with iron ore processing.

Iron and steel, aluminium, cement, glass, pulp and paper and ceramics are the energy-intensive industry segments with highest potential of reducing energy consumption and carbon emissions through materials recycling (Henriques Jr et al., 2010).

2.3.4 *Clean Coal Technologies (e.g. Carbon Capture and Storage).*

Coal is still abundant around the world and will continue providing much needed energy for variety of activities (Chen & Xu, 2010). Coal utilization is associated with air pollution and clean coal technologies are needed to minimize environmental impact for coal combustion (Chen & Xu, 2010). Clean coal technologies are most common and widely used in developed countries but there is an opportunity for developing countries to evaluate and include them in their environmental policy priorities (Tavoulareas & Charpentier, 1995).

According to Tavoulareas and Charpentier (1995), clean coal technologies can be classified into three basic categories in accordance to the combustion stage of the coal. The categories are: (1) pre-combustion technologies, which involves the cleaning of coal prior to combustion by crushing and removing impurities which cause pollution; (2) in situ technologies, which involve alteration of the design and conditions of operation for fuel burning appliances to reduce the emissions; and (3) post-combustion technologies, which aims to capture the emissions before they are released into the atmosphere (Tavoulareas & Charpentier, 1995).

The most common clean coal technologies in the industrial sector are coal transformation (gasification, Liquefaction) and carbon capture and storage technology (CCS) (Chen & Xu, 2010). Carbon capture and storage (CCS) is considered one of the effective means of reducing carbon emissions, and in turn minimising the impacts of climate change (Gaede & Meadowcroft, 2016; Tian, Jiang, Zhang, & Manovic, 2018). Carbon capture and storage (CCS) technologies therefore forms an integral part of low-carbon energy transitions (Lau, Ramakrishna, Zhang, Radhamani, & Fuels, 2021)

Since most energy-intensive industries' technology is built around coal as energy resource, it is important to explore and invest in some feasible clean coal technologies. Evidence suggests that large-scale CCS projects have been implemented slowly in most parts of the world due to social, technical and economic challenges, and only a few countries have been successful (Arranz, 2016; Gaede & Meadowcroft, 2016).

2.3.5 *Culture and behavioural change*

A differing view to technologies, was presented by Vickers, Vaze, Corr, Kasparova, and Lyon (2009), who cautioned that the over emphasis on low-carbon technologies may not be the only solution to the transition to low-carbon energy, and instead, suggested that culture and behavioural change by businesses might be a solution. Engau and Hoffmann (2009) made a case for culture and behavioural change through the improvement in early participation by firms in the policy making process, and they argue that industrial facilities will be in better position to set target for low-carbon energy transition.

In many instances, managers that are dedicated to long-term low-carbon energy strategies, have been found to be successful in promoting mitigating options like energy efficiency, supporting the notion that organisational and behavioural factors play an important role (Hrovatin et al., 2016). Hoffman (2010) also adds that company's climate change mitigation options are influenced by its adjustment or improvement of operating systems, like principles, priorities and values. To conform with the changing environmental requirements, companies ought to discard the old mode of operation and be flexible to learn new habits (Hoffman, 2010).

Dumitru et al. (2016) purports that leadership characteristics and behaviour are central to driving an organisation to its sustainability. Leaders are also responsible for influencing the behaviour of employees by setting operational standards that either support environmental sustainability or deter it (Dumitru et al., 2016). Other researches also concluded that, apart from structural and technological changes, behavioural changes in organizations can lead to substantial emission reductions (Dumitru et al., 2016).

Proposition 1

Having discussed the various options to facilitate the adoption of low-carbon energy, the following is proposed as a proposition: *options to facilitate the adoption of low-carbon production in the energy-intensive industry are available.*

2.4 Barriers to the adoption of low-carbon energy in energy-intensive industry.

Literature address the concept of climate change, carbon emissions and the way in which emissions can be reduced in different sectors. It is crucial to understand that barriers in the employment of low-carbon production exist and if not addressed, may deter the transition progress. This section reviews existing literature on barriers identified in other countries attempting to transition or in the process of low-carbon energy transition.

A number of barriers were identified in numerous literature ranging from lack of demand by consumers in green products, lack of support in environmental initiatives by organisations (Y. Liu, 2014), uncertainty in government actions, and limited capacity in innovation (Vickers et al., 2009). Roberts et al. (2018) brings in the politics and policy objectives as barriers if they are motivated by other priorities other than climate change. This is in line with Y. Liu (2014) who pointed out that socio-economic and political decisions of the country can influence or determine the pathway to low-carbon energy.

Y. Liu (2014)'s study of industrial firms in China identified four (4) main types of barriers as, regulatory, structural, cultural and contextual, while Vickers et al. (2009)'s identification of barriers include lack of awareness by management of the facility's impacts on the environment, poor strategic direction and limited innovation capacity. These and other major barriers will be discussed in detail below.

2.4.1 *Structural barriers*

According to Bhandari et al. (2019), and Y. Liu (2014), structural barriers entails structures of a company, its operational procedures and strategic direction. Walsh and Thornley (2012) purports that institutional issues relating to company strategy and priorities are the reason why some actions are not taken. In Y. Liu (2014)'s study findings on the barriers, the term-employment of managers was found to be affecting the development of long-term low-carbon strategies. This is in line with Zilahy (2004), as cited in Bhandari et al. (2019), who stressed that long-term planning is essential in the employment of cleaner technologies for sustainable production.

Management of the company is responsible for proper structuring and communicating a clear policy direction, which addresses energy sustainability and its targets (Sola & Mota, 2020). Companies which are cognisant of economic, social and environmental aspects in their strategic planning are more sustainable and likely to respond to the changing requirements as opposed to the profit driven companies (Bhandari et al., 2019).

Structural barriers can affect the decisions on low-carbon energy projects which require all internal stakeholders and players like energy specialists, operational managers, engineers and top management to be on board and with common goal (Sola & Mota, 2020).

2.4.2 *Regulatory barriers*

These include the industrial facility's policies and its regulatory obligations to different spheres of government (Y. Liu, 2014). Without clear and compelling policies, industrial facilities struggles to adopt low-carbon production (Bhandari et al., 2019). According to Bellevrat (2012), some countries or companies may have policies and regulations in place, but they may not be adequate to make any impact and to meet international requirements. In some cases, policies may be too ambitious to be implemented (Bellevrat, 2012; Winkler & Marquand, 2009).

Regulatory uncertainties, as stated by Engau and Hoffmann (2009) calls for policy makers to clarify roles, responsibilities and obligations for low-carbon initiatives. Y. Liu (2014)'s study found that unclear policy frameworks, unclear understanding of low-carbon production and uncertainties on government's commitment and activities hinders the adoption of low-carbon energy. This is in line with Åhman, Nilsson, and Johansson (2017)'s argument, which points that lack of focussed and comprehensive long-term policies for decarbonized materials market, deters the implementation of low-carbon production. This affects the investment decisions since the transition to low-carbon energy increases initial production costs (Åhman et al., 2017).

Government's regulatory framework and enforcement also plays a major role in influencing the adoption of cleaner production and the overall behaviour towards low-carbon technologies (Luthra, Govindan, & Mangla, 2017).

2.4.3 *Culture and behavioural barriers*

These include "organizational behaviour and culture such as ethos, habituation modes of practice, personalities and values of manager" (Y. Liu, 2014). For low-carbon energy and energy efficient technologies, it was established that cost is not necessarily the only barrier, but behavioural issues may be the main problem (Gillingham & Sweeney, 2012). This is in line with Burch (2010) and Hoffman (2010), who purported that lack of technological options and excessive costs are not the only reasons for slow progress in implementing climate change policy internationally, Instead, Institutional and cultural barriers were found to be playing a bigger role.

Culture and behavioural barriers are characterised by issues like management's resistance to change, production maximisation and increment of market share (Bhandari et al., 2019). In the case of Chinese firms, it was discovered that most managers' actions are influenced by the ambitions for growth and profits maximisation and low-carbon production is seen as a hindrance (Y. Liu, 2014).

Culture within an industrial facility influences the way employees perform their day-to-day work and when the drive to accept and implement cleaner production is not there, the transition to low-carbon energy doesn't occur (Bhandari et al., 2019). Socially inclined strategies, principles, and behaviour in facilities result in more sustainable operations and top management is responsible for influencing and upholding these (Sarkis, 2018).

In support of low-carbon production, top management ought to secure adequate resources, and influence behaviour of employees towards low-carbon production (Bhandari et al., 2019). Successful implementation of low-carbon production is facilitated by companies nurturing a culture of engagements and idea sharing amongst employees, which essentially create a platform for holistic policy formulation and inclusion in the overall transition (Bhandari et al., 2019; Dumitru et al., 2016).

2.4.4 *Contextual barriers*

Walsh and Thornley (2012) introduced the uncertainty with regards to the benefits and outcomes of low-carbon production as a significant barrier. The uncertainties can also be on the future prices of alternative energy prices, making it difficult to conduct cost-benefit analysis and to make long-term projections (Walsh & Thornley, 2012).

At an industrial facility's level, lack of understanding of cleaner technologies concepts and the impacts of climate change may compel the facility to adapt instead of mitigating impacts (Bhandari et al., 2019; Y. Liu, 2014). Competing priorities within an industrial facility and absence of technologies to support low-carbon initiatives, may also slow down the plans and commitment to low-carbon production (Y. Liu, 2014).

Lack of knowledge and skills within an organisation affect how employees initiate and participate in the implementation of cleaner technologies (Silva, Delai, de Castro, & Ometto, 2013). This view was supported by (Unnikrishnan & Hegde, 2007; Van Berkel, 2007), as cited in Bhandari et al. (2019), who indicated that some hindrances in the employment of cleaner technologies are as a result of lack of awareness and technical knowledge, and management is responsible for continuous skills development. In essence, the low-carbon energy transition process is highly reliant on the effectiveness of skills development programmes and the level of awareness of cleaner production concept (Bhandari et al., 2019).

2.4.5 *Political barriers*

The International Energy Agency (IEA)'s World Energy Outlook, 2014, suggest that there is an active support of fossil fuel industries by governments around the world, through subsidies and other benefits (IEA, 2014). Geels (2014) concluded that policymakers and incumbent facilities often form a strong alliance within a current administration, to ensure that the fossil fuels industry is protected, and status quo is maintained. This implies that those politically aligned facilities continue to enjoy political power and therefore influence policy (Roberts et al., 2018). By maintaining the status quo, innovation attempts and technological advancement are not supported by policy makers or political leaders (Granoff, Hogarth, & Miller, 2016)

Winkler and Marquand (2009) concurs with the above statements by pointing out that even though South African government's policies embrace the Sustainable Development Goals (SDGs), it still incentivises the energy-intensive industries, since they contribute significantly to the economy through investment, employment, and boosting the country's economy.

Baker et al. (2014), augmented this discussion by giving an example of Energy Intensive Users' Group (EIUG) in South Africa. This group has a huge membership which include some large resource and mining companies in the world and drives the country's coal monopoly and are among the largest greenhouse gas emitters (Baker et al., 2014). This literature demonstrates the level of political barrier that need to be overcome.

Gillingham and Sweeney (2012) gathered from different authors that if there was a way to bypass politics, the planet could be powered by 100% renewables.

2.4.6 *Economic barriers*

Countries like South Africa have their economy structured around mineral resources due to abundance and low-cost. Baker et al. (2014) however, suggest that the reliance on cheap coal by industries is no longer justifiable, taking into account the global carbon emissions crisis.

Literature highlight the high cost of technology as the most fundamental barrier to implementation, like in the case of Carbon Capture and Storage (CCS) technologies (Gillingham & Sweeney, 2012). Investments in low-carbon energy projects has been very low in Africa due to poor policy framework promoting trade and investment and this create a financial vacuum (Gujba, Thorne, Mulugetta, Rai, & Sokona, 2012). Lending patterns in most developing countries limit access to credit for most economic sectors, and this restrict investment in low-carbon technologies and options (Gulati, Naude, & Upadhyaya, 2018).

Without cleaner technologies investment, due to inadequate funding, the industrial sector struggles to save energy and to reduce carbon emissions

(Bhandari et al., 2019). Bhandari et al. (2019) further indicated that financial challenges relating to cleaner production are more noticeable in developing countries.

Henriques Jr et al. (2010) provided a dissimilar view, suggesting that some low-carbon technologies are affordable and may not require massive investment and therefore making it easy to be implemented in poor countries.

2.4.7 *Facility design and technological barriers*

Traditionally, energy-intensive industrial facilities comprise of complex technologies and processes that consumes high energy, and resulting in high carbon emissions (Du, Yi, Li, & Liao, 2015; Sola & Mota, 2020). They are usually large in scale, with high initial capital investment, making it difficult to switch to low-carbon energy technologies (Song & Oh, 2015). With old technologies being used in the energy-intensive industries, transitioning to low-carbon energy will be expensive and difficult to achieve in short-term (Reddy, 2013).

Most energy-intensive industries, in their nature, were built with environmental polluting technologies, which cannot be replaced easily and has been the biggest barrier in the low-carbon energy transition (Granoff et al., 2016). Infrastructure and equipment depreciates over time, and this increases inefficiencies and contribute to the industry's inability to transition to low-carbon production (Granoff et al., 2016). Outdated equipment's and technologies are amongst the major reasons for slow adoption of low-carbon energy in the industrial sector (Bhandari et al., 2019).

As pointed out above, once energy-intensive industries are built, it becomes expensive or technologically difficult to retrofit with cleaner technologies, and this creates a lock-in effect for polluting production until the technology reach its lifespan (Granoff et al., 2016). The ageing infrastructure, coupled with financial constraints, impedes the low-carbon energy transitions (Dumitru et al., 2016). According to Gulati et al. (2018), there is evidence which suggests that South Africa is not a technology innovator, meaning that the country adopt technologies from other countries, and this worsen the technological challenges that the industry is facing. (Gulati et al., 2018).

2.5 Barriers experienced by developing countries like South Africa in the adoption of low-carbon energy.

Economic growth depends on energy and this is most important for developing countries due to the need for economic catch up. Since energy is central to economic activities, the implication is that more economic growth would require more energy consumption (Gbadebo & Okonkwo, 2009). This section reviews existing literature on the challenges faced by developing countries in the low-carbon energy transition.

According to Gujba et al. (2012), developing countries, especially in Africa must facilitate economic growth by increasing energy consumption. Even though African countries face severe risk from global climate change, their priorities and objectives are not to reduce carbon emissions (Gujba et al., 2012). Bellevrat (2012) also advocate for developing countries to eliminate poverty, prioritise energy security and social upliftment as opposed to tackling carbon emission challenges.

For most developing countries, climate change is not at the top of their priority list, due to other pressing challenges like economic growth and poverty alleviation (Mertz, Halsnæs, Olesen, & Rasmussen, 2009).

In addition to the barriers outlined in previous sections, developing countries lacks technical, political, institutional, organisational and social stability and expertise (Adenle et al., 2017). Economic barriers are prevalent in most African countries since funding to perform various activities is sought and obtained from external sources and it's not always available (Gujba et al., 2012). Adenle et al. (2017) adds that the progress for low-carbon energy transition is also hindered by slow-paced development.

Many African countries lacks historical records to make necessary projections and prioritisation at national and company level (Katz et al., 2013). Transition to low-carbon energy needs institutional direction and leadership to steer policy direction and to develop programs that address environmental risks; However, many African countries face governance and institutional failures (Katz et al., 2013).

Even with all these developing countries challenges, Gujba et al. (2012) suggest that there is an opportunity for African countries to improve energy access through low-carbon development which will lead to low-emission and climate-resilient economies.

2.6 Experience by other countries in the adoption of low-carbon energy.

In trying to widen the understanding on low-carbon energy elsewhere, BRICS countries were assessed to draw some experiences. BRICS countries are different from one another in their culture, background, language, and the structure of their economies but they have one thing in common, their economic growth development has surpassed the economic growth of most industrialized countries (Zakarya, Mostefa, Abbes, Seghir, & Finance, 2015) and their emissions are expected to increase due to the high utilization of fossil fuels (Maryam et al., 2017). It is for this reasons that the experience of BRICS countries in low-carbon energy transition were reviewed, since there is similarity in some of the characteristics with South Africa.

Brazil, Russia, India and China are among the top carbon emitters in the world, which result mainly form fossil fuels combustion, except for Brazil, whose emissions are mainly from land-use and agriculture (Bellevrat, 2012). South Africa can draw some lessons from these countries since its' economy is also energy-intensive (Winkler & Marquand, 2009).

2.6.1 *Brazil*

Brazil's carbon emission profile is a bit different from other countries, with the bulk of the emissions coming mainly from agricultural and associated activities (Bellevrat, 2012). The reduction of carbon emissions in Brazil's industrial sector have been achieved through the reduction of energy intensity by companies, with the main aim being to reduce costs for energy, thereby maximising profits and becoming more competitive (Henriques Jr et al., 2010).

Brazil have implemented several cleaner technologies and cleaner sources of energy in the industrial sector, but according to R. P. Taylor, Govindarajalu, Levin, Meyer, and Ward (2008), there are barriers in the implementation of these. In addition, Brazil have some sectoral plans like energy conservation programmes in industries and other policies encouraging the transition to natural gas in industrial facilities and the utilisation of charcoal in the iron & steel industry (Åhman et al., 2017).

Despite all the effort to reduce carbon emissions, opportunities to mitigate these emissions still exist and need to be exploited (Åhman et al., 2017). The priorities in the carbon emission space are however different in Brazil which is now focussing on "green growth concepts" innovations, in a bid to be one of the best performing countries in the world (Bellevrat, 2012).

2.6.2 *Russia*

Russia is amongst the top five global carbon dioxide emitters and it is a major player in the exportation of fossil fuels (Martus, 2019). Like South Africa, Russia's economy is energy-intensive, with the industrial sector being dominated by iron and steel production (Korppoo & Kokorin, 2017). At a global scale, Russia is amongst the leaders in the production of a various metals (Martus, 2019).

Russia's plans to reduce energy intensive economy include awareness, regulation, and economic measures (Korppoo & Kokorin, 2017). Several big industrial facilities have also proactively focussed on reducing the consumption of energy through energy efficiency which aligns to government's plans (Martus, 2019). The Russian government provides incentives to encourage energy efficiency, and it also makes financial sense for industrial facilities to save energy (Martus, 2019). However, Korppoo and Kokorin (2017) argues that the government's energy efficiency programme does not have sufficient funding, legal infrastructure to enforce and human resources to implement it. These challenges therefore pose as barriers to the implementation of government's initiatives and deter the progress in the transition to low-carbon energy.

Russia being a major producer of coal globally, is one of the major barrier in its transition to low-carbon energy since the coal sector is very important and receiving incentives from government (Martus, 2019). In Korppoo and Kokorin (2017)'s view, other barriers include ineffective legislation and policy implementation, defective law-making procedures and bureaucracy.

2.6.3 *India*

India is one of the major carbon dioxide emitter due to it its reliance on coal for primary energy needs (Bellevrat, 2012; Pappas & Chalvatzis, 2017). Iron and steel production is one of the dominant industrial activities in India's economy and it is one of the most energy intensive sector, contributing significantly to carbon emissions (Pappas & Chalvatzis, 2017).

In order to transition to low-carbon energy, Pappas and Chalvatzis (2017) suggest that technological innovation is the solution, but the main barrier in India is the lack of policy support. Another challenge in India's adoption to low-carbon energy is the conflicting priorities, with poverty eradication and improved access to energy being at the top of the agenda (Bellevrat, 2012).

2.6.4 *China*

China is also one of the biggest carbon dioxide emitter and it has attracted a lot of debates around its need to significantly reduce the emissions (Wang, Engels, & Wang, 2018). China's industrial sector is extremely energy intensive and responsible for most of the country's carbon emissions (Y. Liu, 2014; Wang et al., 2018). The burning of coal in the industrial sector is the largest contributor of carbon emissions in China, with iron and steel industry being one of the highest in energy intensity (Wang et al., 2018). Carbon emissions in China are directly linked to industrial output, hence it is important to decouple carbon emissions and economic growth (Wang et al., 2018).

According to Wang et al. (2018), energy efficiency can be considered as one of the means to lower industrial carbon emissions in China, but this will require a change in policy direction. Even with evidence pointing towards policy change in China, the requirements for low-carbon energy are still poorly understood (Wang et al., 2018).

China's heavy reliance on coal due to abundance, pose as a major barrier in the adoption of low-carbon energy (Wang et al., 2018). In the Chinese situation, investing in clean coal technologies is very crucial since coal is expected to form part of the energy resources for the years to come (Wang et al., 2018).

In Y. Liu (2014)'s study on "*barriers to the low-carbon production in Chinese industrial firms"*, the two most common barriers to the adoption were "lack of financial incentives to stimulate low-carbon innovation" and "lack of a common definition of low-carbon production". Wang et al. (2018) also pointed out lack of low-carbon technologies investment as a major barrier in China. Overall, the barriers in china ranges from financial challenges, inadequate regulatory framework, lack of understanding of low-carbon concept, poor planning at an industrial facility level and low-carbon production being less prioritised (Y. Liu, 2014). China's priority in the low-carbon energy space is to get rid of inefficient technologies since its industrial output is directly linked to carbon emissions (Wang et al., 2018).

Proposition 2

Literature reviewed on various barriers, challenges faced by developing countries and experiences of other countries in low-carbon energy transitions, led to the following proposition: *Many factors affect the energy-intensive industry's ability to transition to low-carbon energy and developing countries experience additional barriers.*

2.7 Conclusion of Literature Review

Literature confirms that various options to facilitate the adoption of low-carbon energy are available and somewhat feasible. These are however faced with some barriers in their adoption, which are more severe in developing countries due to low-income status. The literature on experiences by other countries in the adoption of low-carbon energy was also covered to provide an understanding of the progress and the barriers that those countries are experiencing.

2.7.1 *Proposition 1*

Options to facilitate the adoption of low-carbon energy in the energy-intensive industry are available.

2.7.2 *Proposition 2*

Many factors affect the energy-intensive industry's ability to transition to low-carbon energy and developing countries experience additional barriers.

CHAPTER 3. RESEARCH METHODOLOGY

Literature review revealed that options to facilitate the adoption of low-carbon energy are available and employed around the world. Barriers to the adoption of low-carbon energy exist and are diverse as revealed in the previous chapter. The most significant gap identified in the literature review is the lack of these kind of studies in the developing countries. This study was therefore aimed at testing if the barriers identified in other studies apply in the South African energy-intensive industry by obtaining perceptions and views of individuals within the energy-intensive industry.

This chapter begins with a discussion on the overall research approach, followed by the design and data collection methods. Population and sample addresses the sample, sampling method and the respondents' profile. The research instrument, procedure for data collection, analysis and interpretation also form part of this chapter, with the limitations of the study also outlined. The validity and reliability of the research covered the discussions on external and internal validity, reliability and objectivity, with ethical considerations concluding the chapter.

3.1 Research approach

Quantitative, qualitative and mixed method are the three approaches used in conducting research (Creswell & Creswell, 2017). The three approaches are designed to serve different purposes. Qualitative methods are usually used to understand and explore the individuals' experience through utilisation of various methods like interviews, case study or observation (Arghode, 2012). Quantitative research, on the other hand uses numbers and statistical information rather than individual perceptions to understand the situation or occurrence (Arghode, 2012). Mixed method integrates the two methods in collecting data to obtain an additional dimension that cannot be obtained through employing either method.

Arghode (2012) suggest that, in quantitative method, the aim is to quantify the participants' responses and then interpreting them to make conclusions. Quantitative approach can be used to measure perceptions or opinions of a particular population and the researcher can quantify respondents' opinions, sentiments, and behaviours (McCusker & Gunaydin, 2015).

To test the existence of the barriers identified in other studies in the South African energy-intensive industries, perceptions and views of individuals within the energy-intensive industry had to be sought. For this reason, the study followed a quantitative method, which involved an investigation of available low-carbon options and multiple potential barriers as perceived by different individuals in the energy-intensive industry. Numerical data was generated through online questionnaire sent to the identified respondents from the energy-intensive industry in Gauteng province. This research method was the most appropriate for the study since the Likert-type scale built within the questionnaire was able to rank the barriers according to their significance.

3.2 Research design

Creswell and Creswell (2017) suggests that a researcher shouldn't end at selecting the research method, there is also a need to select the type of design within those methods. Quantitative method can take the form of experimental, nonexperimental and longitudinal designs (Creswell & Creswell, 2017).

This study followed a quantitative method in a form of survey, which according to Creswell and Creswell (2017), generates numeric or quantifiable perceptions, attitudes and trends for a population by studying only a sample of that population. This approach was able to quantify the participants' responses and interpreted them to make conclusions (Arghode, 2012).

Literature from chapter two (2) was used to inform and design the questionnaire, which was used to collect data (See Appendix A for questionnaire). The advantages of using questionnaire with some open-ended questions in answering the research questions was to cover a wide spectrum of views and enlightenments of the respondents. Additional open-ended questions provided an additional dimension and eliminated generalisation and speculations on the outcomes.

Another advantage of employing quantitative method in the form of online survey for this study is that the low-carbon energy options could be ranked according to the level of availability and employment and barriers could be ranked according to significance.

The disadvantage of this approach could be biasness in the results if the questionnaire was not properly designed. Since questionnaire was sent through an online platform, not all the identified respondents could respond to the questionnaire due to various reasons. Findings from quantitative research reveal behaviours and tendencies, but they fail to provide insight into why the selected population is behaving that way (McCusker & Gunaydin, 2015).

3.3 Data collection methods

Data collection methods are crucial in shaping the whole research and the outcomes or conclusions. The methodology used to collect and analyse data determine what the results can be used for and what conclusions can be drawn out of it. Quantitative research is characterised by numbers and statistics and to accurately measure and evaluate the key concepts, surveys and questionnaires are used (McCusker & Gunaydin, 2015).

Based on the above, online questionnaire was used as a data collection method. questions were crafted guided by the literature reviewed and was distributed through an online system (Qualtrics) anonymous link and e-mails to the identified respondents within the energy-intensive industry. To widen the number of respondents, the identified respondents were encouraged to identify more individuals who may have insights and experience in energy use and emissions within the energy-intensive industry.

3.4 Population and sample

3.4.1 *Population*

Rafeedalie (2019) defines population as a group of individuals, objects, institutions, and so forth, whose characteristics are similar and of interest to the researcher. The commonality in the characteristics of a population is what sets it apart from the rest of the group.

The population for this study is the individuals responsible for emissions management and reporting within the energy-intensive industrial facilities in Gauteng province. Gauteng province was selected as a study area to narrow down the scope of the research and for ease of access during data collection which was initially planned to be face-to-face interviews. Gauteng province might be small in terms of size, but it is the nation's biggest provincial economy and almost all types of industries can be found (StatsSA, 2019). The results from the respondents could therefore be more generalizable since they cover a variety of industrial facilities. The targeted individuals hold various positions in various industrial facilities but the common characteristic is their experience in energy use in industrial processes, climate change, environmental impacts and emissions management and reporting. The research targeted energy-intensive industries due to size and the level of carbon emissions.

3.4.2 *Sample and sampling method*

Sampling is the process of gathering information regarding the whole population by only studying a portion of it, so, the sample would be any number of individuals or objects chosen to represent the entire population (Haque, 2010). It is usually not possible and practical to collect data from all individuals or components within a population, and for that reason, a representative group (sample) falling within the population is selected to gather information applicable to the whole population (Rafeedalie, 2019). The results obtained from that sample can be generalised as the characteristics of the whole group or population.

According to Fragaszy, Boinski, and Whipple (1992), decisions on sampling affect the reliability and accuracy of data collected and analysed in relation to the identified population. For this study, individuals responsible for emissions reporting within Gauteng province energy-intensive industrial facilities were selected to participate, by providing insights about the energy-intensive industry based on their experience. As indicated under 3.4.1, Gauteng province energy-intensive industrial facilities were selected for ease of access during data collection. Data collection method was later changed to online survey due to the covid-19 pandemic. These individuals have experience in energy use in industrial processes, climate change, environmental impacts and emissions management and reporting. In Fragaszy et al. (1992)'s view, data sets with individuals being the unit of analysis provide additional analytical options.

Energy-intensive industries are usually large in scale and dominated by few players in the market and as result, email addresses for individuals from major identifiable energy-intensive industrial facilities across Gauteng province were included in the sample mailing list. Fifty-eight (58) email addresses for individuals responsible for emissions reporting were obtained from the Gauteng provincial database of Atmospheric Emission Licenses and Atmospheric Emission Inventory. Email addresses were the only information obtained from the database.

During data collection process, it was established that although several industrial facilities were identified, emissions in most of the big energy-intensive industrial facilities are managed by the same individual in various locations across the province, leading to the limited number of respondents.

Probability sampling method was used, since the population's characteristics are similar and well understood by the researcher and therefore every individual had equal chance of inclusion (Haque, 2010). This sampling method was appropriate for this study since all the identified individuals had adequate knowledge in industrial processes, climate change, environmental impacts and emissions management and reporting within the energy-intensive industry. Through probability sampling, data for this research was collected from twenty-six (26) individuals from various energy-intensive industries within Gauteng province, who randomly and voluntarily participated in the survey. Although the sample individuals were identified through energy-intensive industrial facilities, their views could not be linked to a specific industrial facility.

Based on the information gathered through the survey, the respondents for this study are working within the energy-intensive industry with experience ranging from 5 to over 20 years, with the majority being the ones with over 20 years of experience within the industry. The respondents hold different positions in various industrial facilities, including: General Manager; Managing Director; Operations Director; Production manager; Technical manager; Foundry Manager; Metallurgist; Environmental Officer/superintendent/specialist; Safety, Health and Environmental Quality coordinator; and Risk and Compliance manager.

Majority of respondents (40%) are within the iron and steel sector, followed by basic chemicals, refining and non-metallic minerals (mainly cement production). A smaller percentage of respondents are in the non-ferrous minerals sector.

Table 3-1: Profile of respondents

Description of respondents	Number to be sampled
Individuals working in the energy-intensive industry, with full knowledge of climate change, energy use and emissions. The respondents included:	**58** individuals were identified, and the survey link was sent to them.
General Manager; Managing Director; Operations Director; Production manager; Technical manager; Foundry Manager; Metallurgist; Environmental Officer/superintendent/specialist; Safety, Health and Environmental Quality coordinator; Risk and Compliance manager.	**26** individuals responded to the questionnaire.
TOTAL number of respondents	**26**
Response rate	**45 %**

3.5 The research instrument

Research instruments are tools used in obtaining relevant information required for a research project (Wilkinson & Birmingham, 2003). There are a number of alternatives to choose from, ranging from questionnaires, interviews, focus groups, observation, video research, and so forth (Wilkinson & Birmingham, 2003). A good research should be able to collect information on all research question asked.

For this study, questionnaire was deemed appropriate to reach all the identified individuals and according to Wilkinson and Birmingham (2003), it can be an effective way of gathering data in a structured form. Online questionnaire was used to collect data, which led to the identification of available options to facilitate low-carbon energy and the barriers to their adoption. Likert-type scale was incorporated into the questionnaire to classify and rank the barriers in terms of significance. According to Boone and Boone (2012), ordinal Likert-type scale observations can rank different magnitudes of a subject matter and was employed in this study.

3.6 Procedure for data collection

A questionnaire was developed and distributed through an online system (Qualtrics) to the identified individuals working within the energy-intensive industry. The link to the online questionnaire was sent to all identified respondents via e-mail and anonymous link. Respondents were provided with the participant information sheet detailing the topic, aim and ethical considerations (See Appendix B for participant information sheet). Responses were received through Qualtrics and they were all anonymous, and views expressed could not be linked to any industrial facility.

3.7 Data analysis and interpretation

Data analysis entails data examination for the purpose of gaining knowledge, information and insights about a specific subject (Grolemund & Wickham, 2014). According to Grolemund and Wickham (2014), data analysis is a sensemaking process, from which reliable ideas are generated out of experiential data.

After collecting data from the survey participants through questionnaire, descriptive statistics were developed to classify and rank the various barriers. Descriptive statistics were chosen to analyse the data due to their ability to describe characteristics of the gathered data through frequency, percentages, mean, bar graph and pie charts. Ahn, Pearce, Wang, and Wang (2013) also confirmed that descriptive statistics are relevant in ranking barriers for different research areas and was therefore suitable for this study.

The analysis was performed using Statistical Package for Social Sciences (SPSS) version 27 and Microsoft Excel 2016 (See Appendix C for analysis tables). In the process, statistics were used to descriptively evaluate the various low-carbon energy options and to assess the existence of various barriers in the South African energy-intensive industry.

3.8 Limitations of the study

- Using literature review to design the questionnaire might have created some predisposition and leave out some new barriers unidentified.

- Quantitative research can reveal behaviours and tendencies, but it fails to provide the insight and reasons for such behaviour.

- Limiting the respondents to Gauteng province resulted in low number of responses received and missed an opportunity to obtain valuable insights from industries outside Gauteng.

- Using e-mail to request response did not yield maximum results, leading to less representative findings.

3.9 Validity and reliability

Validity is defined as the extent to which a concept is accurately measured in a quantitative study (Heale & Twycross, 2015). Ascertaining the validity and reliability of a research tool is important in ensuring that the concepts are being measured correctly and the tool is providing uniform and consistent answers (Bolarinwa, 2015).

3.9.1 *External validity (generalisability)*

Validity relates to the extent at which the research instrument measures what it is intended to measure and external validity focuses on "how accurately the measures obtained from the study sample described the reference population from which the study sample was drawn" (Bolarinwa, 2015).

For this study, the sample comprised of individuals working in the energy-intensive industry, with experience in industrial energy use, climate change, environmental impacts and emissions management and reporting. The respondents have experience ranging from 5 to over 20 years within the energy-intensive industrial facilities, making the research findings valid and applicable to the entire energy-intensive industry.

3.9.2 *Internal validity*

Internal validity refers to the accuracy of the quantification of the research tool and if the tool managed to measure what it was intended to measure (Bolarinwa, 2015). The use of Likert-type scales questionnaire provided the quantification and the inclination of respondents' views towards or away from different concepts of the study. The study aimed to identify the available low-carbon energy options and the existing barriers in the energy-intensive industry. Data collected through questionnaire was able to measure the availability and employment of the low-carbon energy options in the South African energy-intensive industry and also identified the barriers and their level of significance.

3.9.3 *Reliability*

Reliability relates to the uniformity or consistency of the results of an instrument, meaning that, an estimate of reliability should be attained through different measures (Heale & Twycross, 2015). A good research is reliable, which imply that the results obtained from a research instrument and process can be duplicated or recreated (Bolarinwa, 2015). Reliability, or reproducibility is a good indicator of whether the questionnaire achieves consistent results (Del Greco, Walop, & McCarthy, 1987).

For this study, literature reviewed for different studies came up with closely related findings and this study was designed to test if the barriers identified in other studies apply in the South African context. Another way that this study's findings are reliable and reproducible, is the use of various respondents from different energy intensive industries, as respondents.

3.9.4 *Objectivity*

Objectivity relates to the ability to maintain "neutrality" in the research, which would enable the study to obtain the genuine findings without bias (Seymour, Mahroof, Rooke, & Crook, 1997). The questions for the questionnaire were guided by literature review and the response received were not influenced by anything outside that scope. The options provided for selection in questionnaire were based on the key concepts of the study.

3.10 Ethical considerations

According to Tracy (2010), ethical considerations in research include procedural, situational, relational, and exiting ethics. This research mainly focused on procedural ethics to ensure that there is no harm caused to any industrial facility linked to the selected individuals. The on-line questionnaire was accompanied by information sheet providing the background to the research and assuring that the views provided will not be linked to any industrial facility. Respondents were also informed that their participation is not compulsory, and they could withdraw from the study at any point. Confidentiality was also guaranteed, and no sensitive information relating to industrial facilities was obtained. The study's data collection procedure was approved unconditionally and is considered to have minimal risk by the University's human research ethics committee (non-medical) (See Appendix E for ethics clearance certificate).

CHAPTER 4. PRESENTATION OF RESULTS

4.1 Introduction

This chapter presents research results collected through an online questionnaire from individuals working in various energy-intensive industrial facilities. The study aims to explore available options to facilitate the adoption of low-carbon energy in the South African energy-intensive industry and to identify barriers to their adoption. Data collection focused on the perception and views of the individuals within the energy-intensive industry to assess the level of employment of the available low-carbon energy options and the perceived barriers to their adoption.

4.2 Overview of the energy-intensive industry in South Africa

As highlighted in chapter two (2), energy-intensive industries are usually large in scale and dominated by few large players in the market (Song & Oh, 2015). This sector consume higher amount of energy compared to other industries and is characterised by high initial capital investment, making it hard for industrial facilities to shift to new technologies (Song & Oh, 2015). According to Price et al. (1999), iron and steel, chemicals, petroleum refining, pulp and paper, and cement are the five energy-intensive industrial subsectors responsible for the majority of industrial energy use and the resultant carbon dioxide emissions.

4.3 Process followed and respondents' profile

A questionnaire was developed and distributed through an online system to various individuals working within the energy-intensive industry. All responses received were anonymous and the views expressed could not be linked to any industrial facility.

A total of twenty-six (26) responses were received from the online questionnaire. The respondents are working within the energy-intensive industry with experience ranging from 5 to over 20 years, and the majority are the ones with over 20 years of experience within the industry.

The next sections present the data collected through an online survey from various respondents within the energy-intensive industry. Data presentation is done according to propositions, with questionnaire questions forming subheadings to simplify the presentation of the results. Descriptive statistics in the form of pie and bar charts are used to present data.

4.4 Options to facilitate the adoption of low-carbon energy in the energy-intensive industry.

This section presents data pertaining to low-carbon production options available and the level of employment within the energy-intensive industry. To provide a better background on carbon emissions, this section starts by presenting data on the most common sources of energy and most common sources of carbon emission within the energy-intensive industrial facilities as perceived by the respondents. Figure 4-1 and 4-2 demonstrates the perceptions of respondents on the sources of energy and carbon emissions within the energy-intensive industry. This is to provide the basis for the sources of energy and carbon emissions in relation to the available options explored.

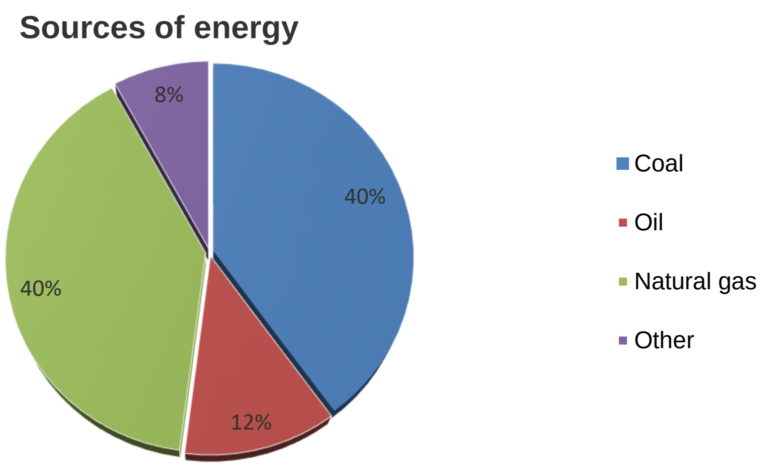


Figure 4-1: Most common sources of energy in the energy-intensive industry

Figure 4-1 demonstrates the proportions of various sources of energy in the energy-intensive industry. According to the respondents, apart from electricity, coal and natural gas are the most commonly used source of energy, followed by oil. The other sources of energy mentioned by respondents were outside the scope of this study and they include electricity, solar and pneumatics.

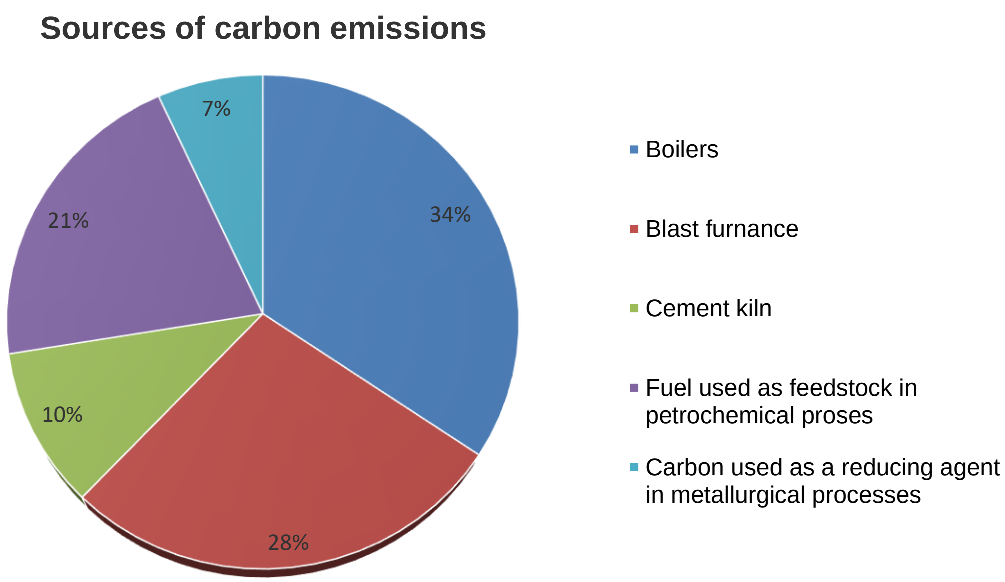


Figure 4-2: The most common sources of carbon emissions in the South African energy-intensive industry.

Figure 4-2 demonstrates the proportions of various sources of carbon emissions in the energy-intensive industry. Boilers are considered the main sources of carbon emissions, followed by blast furnace. The use of fuels as feedstocks in petrochemical processes was also considered a significant source of carbon emissions. Cement kilns and the use of carbon as a reducing agent in the commercial metallurgy is another source of carbon emissions identified by some respondents. The other sources of carbon emissions mentioned were Electric Arc Furnace, Heat treatment furnaces and galvanizing baths.

4.4.1 *Knowledge and level of employment for low-carbon production options.*

To assess the level of knowledge and employment of low-carbon production options, this section presents data on the level of familiarity to the options and the level of employment by various energy-intensive industrial facilities. Figure 4-3 below shows the respondents' level of familiarity with the available low-carbon production options in the South African energy-intensive industry.

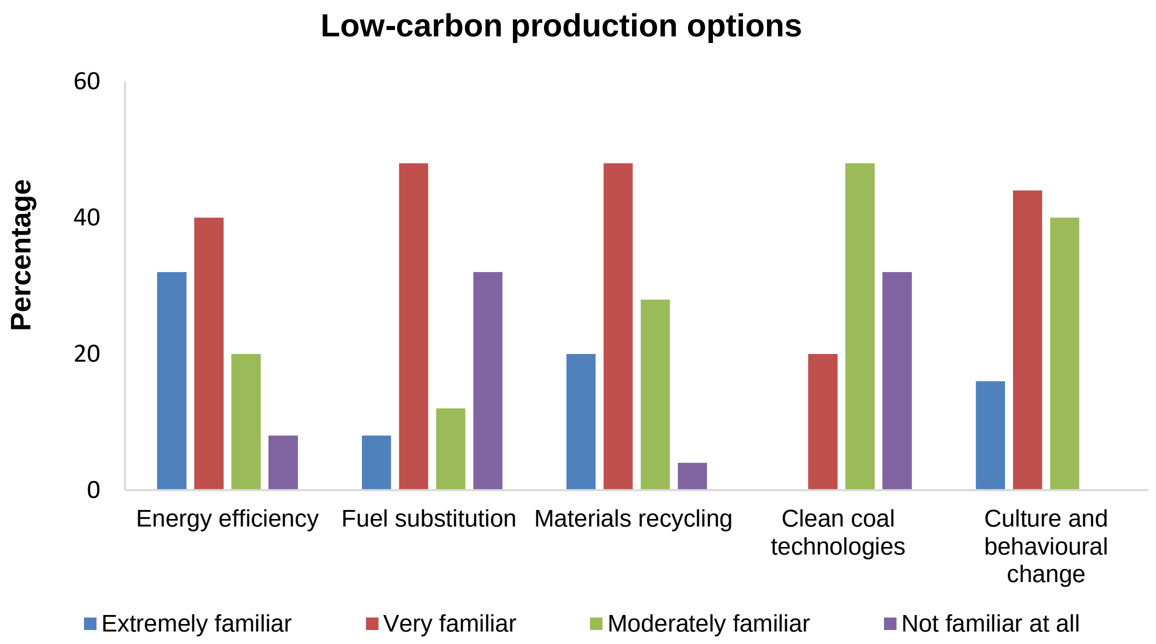


Figure 4-3: Familiarity with various low-carbon production options.

The statistics in figure 4-3 shows that some respondents were extremely familiar with some low-carbon production options, particularly energy efficiency, materials recycling and culture and behavioural change. None of the respondents were extremely familiar with clean coal technologies. A bigger portion of respondents ranged between moderately and very familiar with all options for low-carbon production. There was also a small percentage of respondents not familiar at all with some low-carbon options, especially fuel substitution and clean coal technologies.

In addition to understanding familiarity with available low-carbon energy options, the research also sought to establish the level of employment of those options. Below, figure 4-4 illustrates the extent in which the energy-intensive industry in South Africa employ various low-carbon production options.

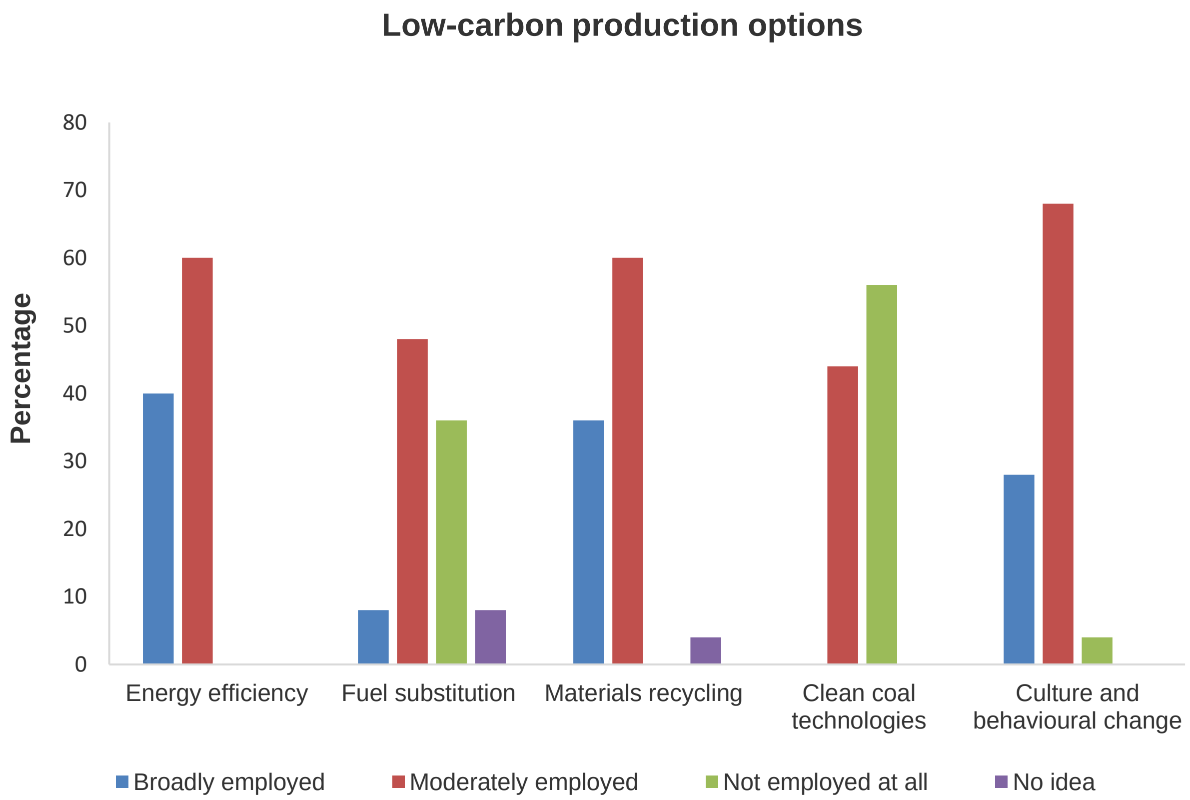


Figure 4-4: Level of employment for various low-carbon production options.

According to figure 4-4, most respondents were of the view that various low-carbon production options are moderately employed.

4.4.2 *Likelihood of the South African energy-intensive industry to employ low-carbon energy or to improve on the existing options.*

To evaluate the extent of the barriers inhibiting the adoption of low-carbon energy, it's important to understand the perceptions of respondents in relation to the industry's likelihood to employ low-carbon production and the timelines thereof. Figure 4-5 and 4-6 provide an indication of how likely it is for the South African energy-intensive industry to employ low-carbon production or to improve on the existing options and the possible timelines.

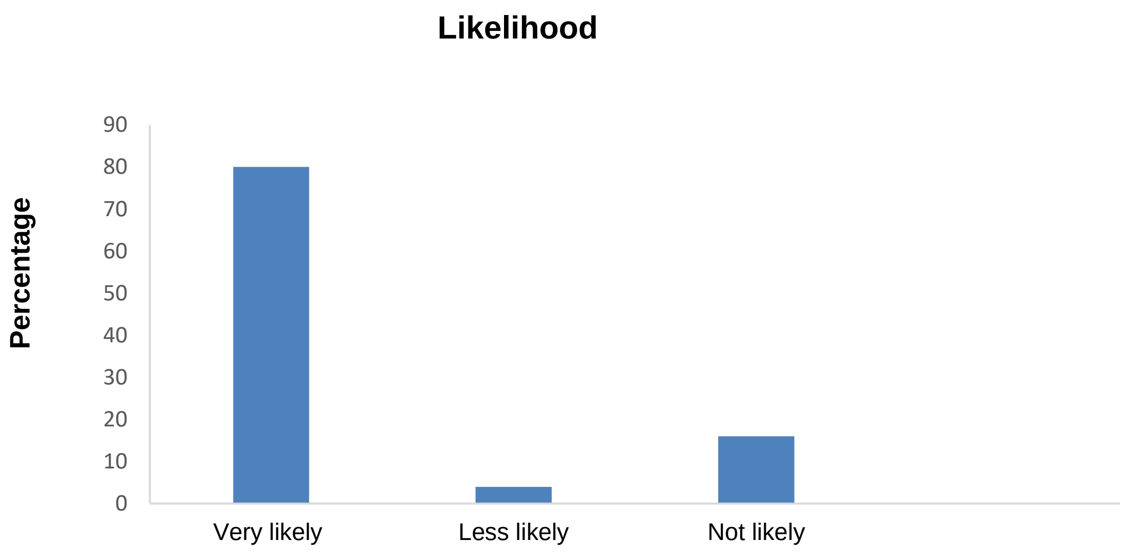


Figure 4-5: Likelihood of the South African energy-intensive industry to employ low-carbon energy.

From figure 4-5 above, it is evident that most of the respondents believed that the South African energy-intensive industry is likely to employ low-carbon energy options. The likelihood for the South African energy-intensive industry to employ low-carbon energy is linked to the estimated timelines below.

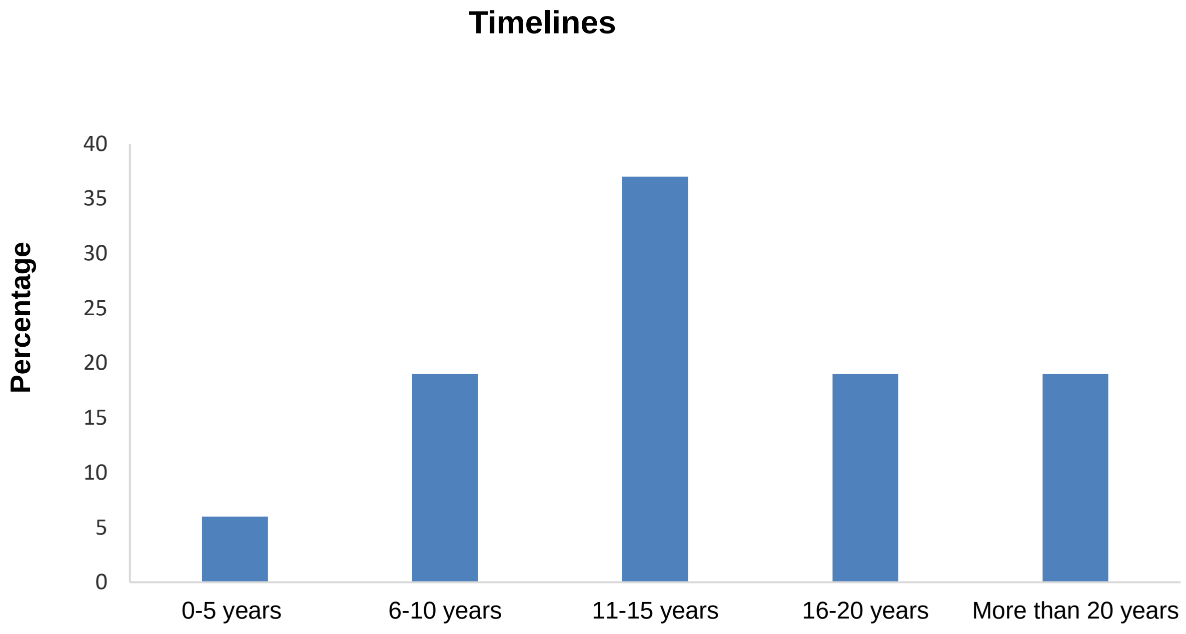


Figure 4-6: Timelines in relation to the likelihood of employment of low-carbon energy in the South African energy-intensive industry.

Figure 4-6 indicates the perceptions of respondents on the time it will take for the South African energy-intensive to employ low-carbon energy options. The results show that it is most likely that the south African energy-industry will employ low-carbon energy options in the next 11 to 15 years. Other respondents believed that it can take up to 20 or more years for the industry to employ low-carbon energy.

In conclusion, the results show that various options for low-carbon energy are employed in varying degrees in different industrial facilities. There was also an indication that the industry is likely to transition to low-carbon energy in the near future, hence the need to identify the barriers that could derail the process.

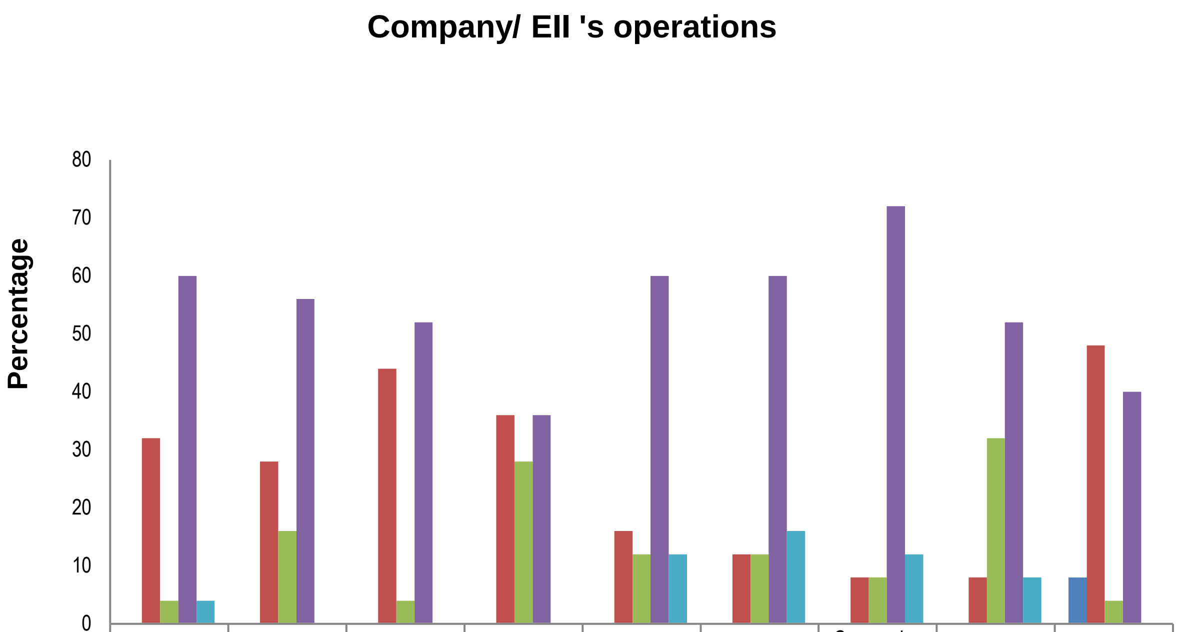
4.5 Factors that affect energy-intensive industry's ability to transition to low-carbon energy.

This section presents the data relating to possible barriers that hinders the energy-intensive industries' ability to transition to low-carbon energy. Various graphs are used to present data for different barriers.

4.5.1 *Barriers relating to company/industrial facility and the energy-intensive industry's characteristics and operating environment in relation to low-carbon energy.*

This section sought to get the views of the respondents on various aspects of the facilities/companies' day-to-day operations. The respondents were requested to provide their views on the following statements: (1) Companies' strategic direction include low-carbon energy; (2) Companies have policies that include plans to transition to low-carbon energy; (3) Companies have a general understanding of future prices for low-carbon energy and its impact on the company; (4) Companies have technologies to support the use of low-carbon energy; (5) Companies are aware of the benefits of low-carbon energy; (6) The energy-intensive industry in South Africa understands climate change and its impacts; (7) Companies are aware of their regulatory obligations in terms of carbon emissions and climate change; (8) Companies are aware of international requirements to reduce carbon emissions; and (9) The South African energy-intensive industry is agile to accommodate the changing environmental requirements.

Figure 4-7 below provides an indication of level of agreement or disagreement with various statements regarding companies' management and operation. These statements represent several possible barriers in the employment of various carbon emission mitigation options.



	Companies' strategic direction include low-carbon energy	Companies have policies that include plans to transition to low-carbon energy	Companies have a general understanding of future prices for low-carbon energy	Companies have technologies to support the use of low-carbon energy	Companies are aware of the benefits of low-carbon energy	The EII in South Africa understands climate change and its impacts	Companies are aware of their regulatory obligations for carbon emissions/ climate change	Companies are aware of international requirements to reduce carbon emissions	The South African EII is agile to accommodate changing environmental requirements.
Strongly disagree									8
Disagree	32	28	44	36	16	12	8	8	48
Neutral	4	16	4	28	12	12	8	32	4
Agree	60	56	52	36	60	60	72	52	40
Strongly agree	4				12	16	12	8	

Figure 4-7: Perceptions in relation to companies/industrial facilities' day-to-day operations.

4.5.2 *Reasons for slow uptake of low-carbon energy in the energy-intensive industry.*

The data presented in this section reflects the views of the respondents on different reasons for the slow uptake of low-carbon energy in industrial facilities. Multiple entry was enabled in the questionnaire to allow respondents to select more than one reason. Figure 4-8 below presents different reasons for industrial facilities not adopting or adopting the low-carbon energy at a slow pace.

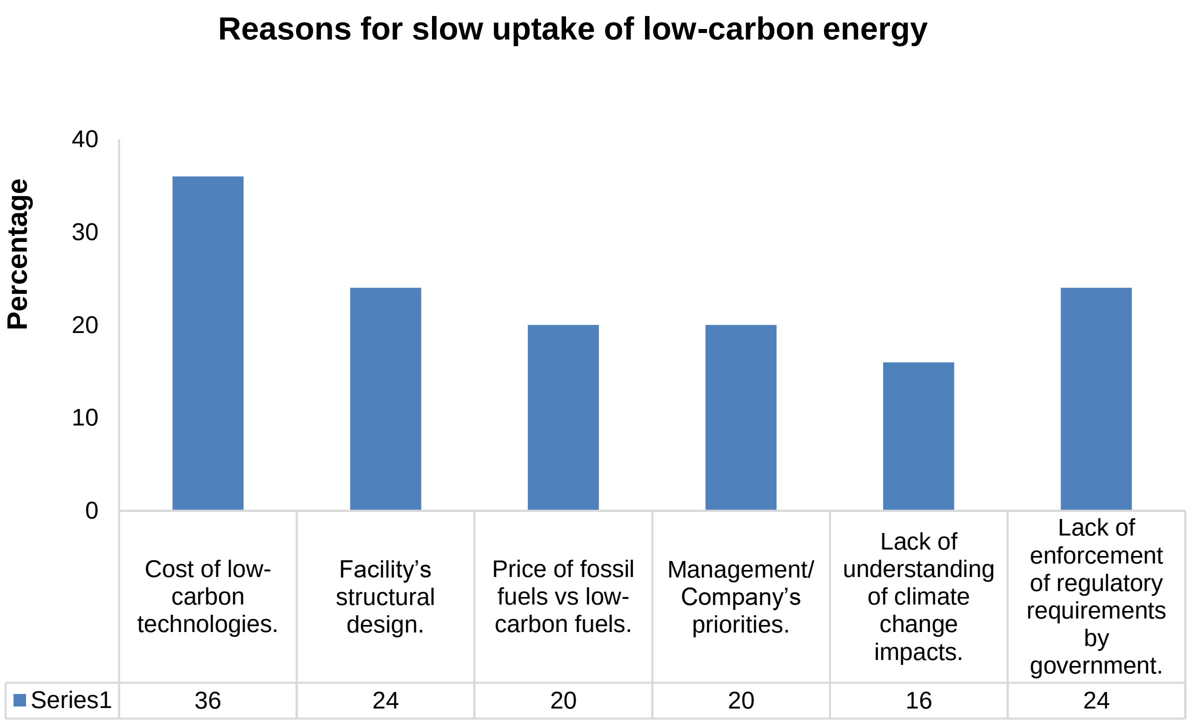


Figure 4-8: Reasons for slow uptake of low-carbon energy in the energy-intensive industry.

According to the respondents, cost of low-carbon energy technologies, structural design of the facility and lack of regulatory enforcement were among the highest rated reasons for the slow uptake of low-carbon energy options. These reasons represent the different barriers that exist within the energy-intensive industry.

4.5.3 *Adequacy and clarity of regulatory framework in driving low-carbon energy in the energy-intensive industry.*

This section present data on whether the regulatory framework is adequate and clear in facilitating the use of low-carbon energy. Figure 4-9 and 4-10 below present data on the views of respondents in terms of regulatory framework being adequate and clear. This provide an indication of weather regulatory barriers contribute to the South African energy-intensive industry's inability to transition to low-carbon energy.

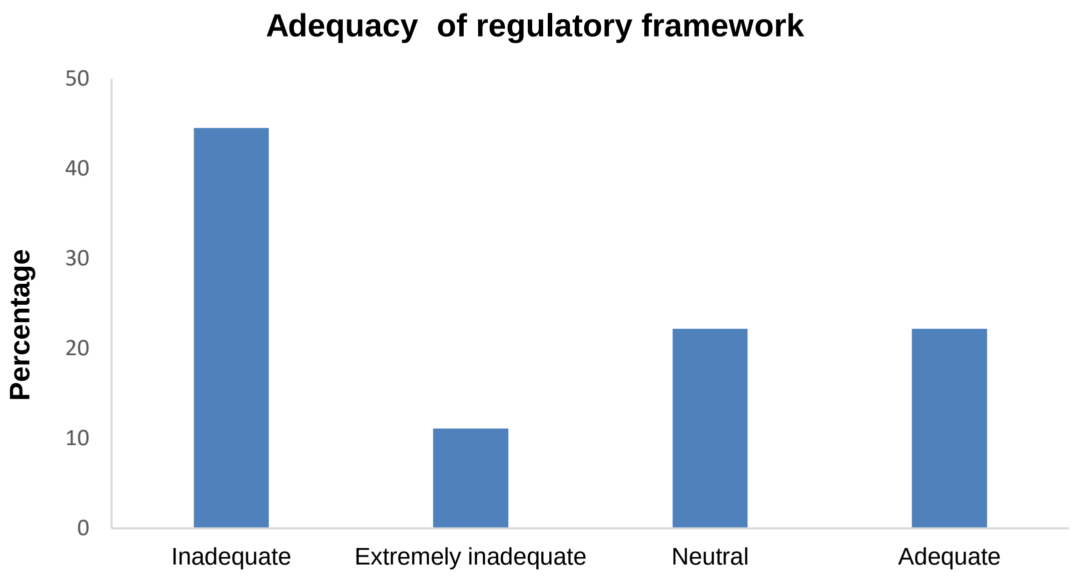


Figure 4-9: Adequacy of regulatory framework to drive low-carbon energy in the energy-intensive industry.

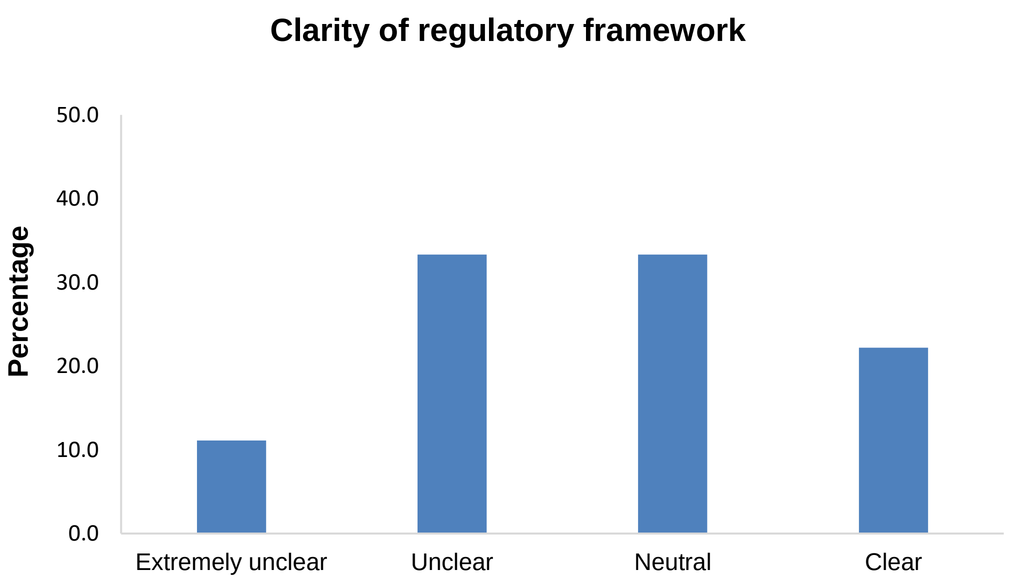


Figure 4-10: Clarity of reguatory regulatory framework to drive low-carbon energy in the energy-intensive industry.

Figure 4-9 and 4-10 provides an indication of whether regulatory framework to drive low-carbon energy in the energy-intensive industry is adequate and clear. According to the respondents, regulatory framework to drive low-carbon energy is inadequate and unclear.

4.5.4 *Existence of any form of fossil fuels subsidies from government in support of the energy-intensive industry?*

The data presented in this section sought to establish whether the participants are aware of any form of subsidy for fossil fuels. The existence of fossil fuel subsidy was linked to pollical barriers in the reviewed literature. Below, figure 4-11 demonstrates how well-known the fuel subsidy is within the South African energy-intensive industry.

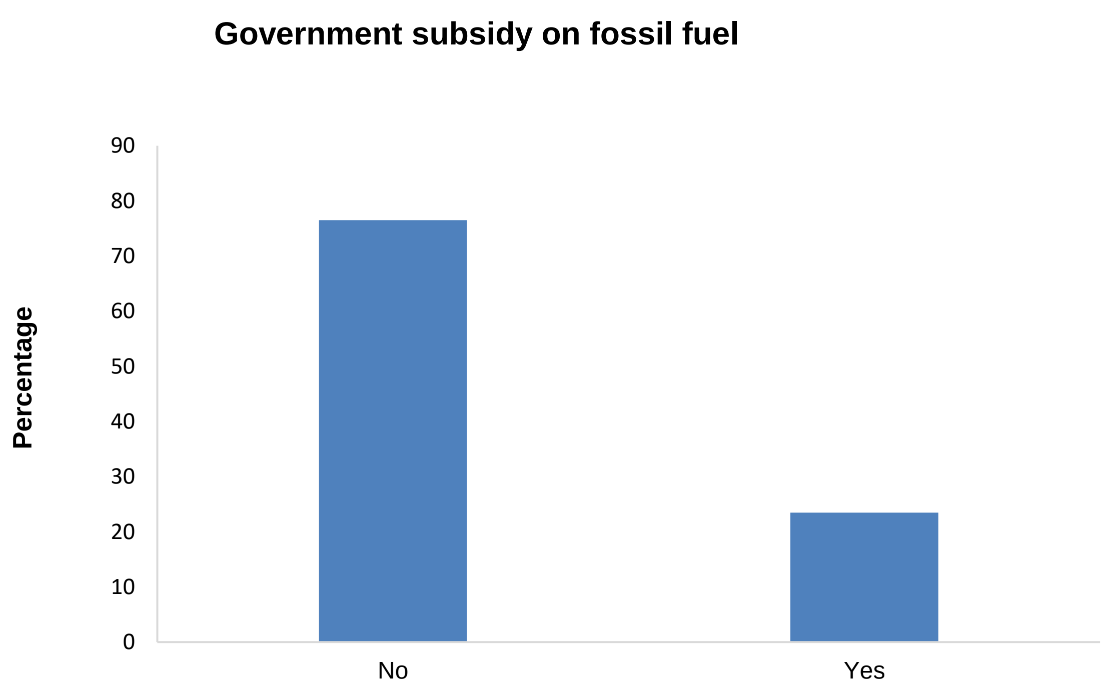


Figure 4-11: Knowledge of fossil fuels subsidy from government .

From the above graph, it is evident that majority of respondents were unaware of the government subsidy on fossil fuels. Respondents being unaware or aware of fossil fuel subsidy reflect its existence and widespread within the South African energy-intensive industry, which in turn confirm political support of fossil fuels.

4.5.5 *Additional inputs on low-carbon energy and its adoption in the Energy-Intensive Industry*

The survey provided the respondents with an opportunity to provide additional inputs on low-carbon energy in the energy-intensive industry. In this regard, four (4) respondents had additional inputs that are critical to this study.

One respondent provided this input into the study:

> *"South Africa has Natural Gas but since companies need large quantities, infrastructure is not available in other industrial sites, and this prohibits most companies to transition to Natural gas. The use of mobile containers is prohibitive, the trailers carry less than a 12hour supply for most companies, making it unsustainable."*

Another respondent was of the view that:

> *"Government's current regulatory environment being punitive is not helpful; carbon tax is less of an incentive than another way to collect money for the general fiscus."*

Another respondent indicated that:

> *"South Africa has a huge source of low-carbon energy but lacks the policies to drive these options."*

> *"Corruption and lack of long-term visions are impacting on changes which are required now in order for the survival of our industries in the future."*

Lastly, one respondent commented that:

> *"The study need to investigate what can be used to replace oil, petrol, diesel, natural gas, coal if used in a boiler/furnace/generator"*

> *"Using carbon capture and storage cannot make coal clean and it does not appear to be feasible for SA, since the cost is too high, and the country do not have the geological structures to store the emissions where they are emitted."*

In concluding the results relating to factors that affect energy-intensive industry's ability to transition to low-carbon energy, there is a clear indication that different barriers to the adoption of low-carbon energy exists.

4.6 Summary of the results presentation

This section presented data relating to the two (2) propositions below:

4.6.1 *Options to facilitate the adoption of low-carbon energy in the energy intensive industry are available.*

Data collection in this section sought to confirm the availability of low-carbon production options in the South African energy-intensive industry by first establishing if the respondents are familiar with the various options. The results in this respect indicates that options for low-carbon production in the industrial are to some extent known to the respondents.

The employment of various low-carbon production options by the South African energy-intensive industry was also assessed and the results shows that the respondents believed that the options are employed in varying degrees.

The questions on the likelihood and timelines for the energy-intensive industry to transition to low-carbon energy options were also included in the questionnaire to get the perceptions of the respondents based on their experience in the industry. The results indicate that it is likely for the industry to employ low-carbon energy or production options and majority of respondents felt that it may take between 11-15 years for the transition.

Overall, the results illustrate that options for low-carbon production are available in the South African energy-intensive industry, but the level of employment varies.

4.6.2 ***Many factors affect the energy-intensive industry's ability to transition to low-carbon energy and developing countries experience additional barriers.***

Data collection in this section focused on obtaining perceptions of respondents on possible barriers to the adoption of low-carbon energy. Factors that hinders the energy-intensive industry's adoption of low-carbon energy were explored through several questions in this section.

First, data on the companies and the entire South African energy-intensive industry was presented to assess various operational and management issues. Several positive statements were provided, and respondents indicated their level of agreement or disagreement. From the results, the perceptions on companies and the South African energy-intensive industry were drawn.

Several possible reasons for slow uptake of low-carbon energy were provided and respondents made their choices based on experience. This provided the ranking for the different reasons, which represented possible barriers. From the results presented, cost of low-carbon energy technologies, structural design of the facility and lack of enforcement were amongst the highest rated reasons for the slow uptake of low-carbon energy options.

The data on adequacy and clarity of regulatory framework was also presented and revealed that regulatory framework is perceived inadequate and unclear. Political barriers were reviewed in chapter two, and to ascertain if government was supporting the fossil fuel use, respondents were requested to indicate if they are aware of any form of government subsidy. The results provided a clear picture that this subsidy is not known, which may be an indication that political support of fossil fuel is not widespread in the energy-intensive industry.

Overall, the data presented indicate that barriers to the adoption of low-carbon energy exist in varying magnitude. There were additional inputs made by respondents and they will form part of discussions in the next chapter.

CHAPTER 5. DISCUSSION OF THE RESULTS

5.1 Introduction

The focus of this chapter is on the analysis and discussion of the results presented in chapter 4, in relation to the literature reviewed in chapter 2. The discussions are centred around the two (2) main topics that were covered in chapter 2, namely: Options to facilitate the adoption of low-carbon energy; and barriers to the adoption of low-carbon energy in the energy-intensive industry. The chapter is concluded by highlighting major findings of the study.

5.2 Options to facilitate the adoption of low-carbon energy in the energy-intensive industry.

In order to provide the basis for low-carbon production and the understanding of what industrial facilities can replace the current sources of energy and practices with, the study had to start by exploring the options for low-carbon production in the industrial sector.

According to Stenqvist and Nilsson (2012), industrial sector consumes about 30% of the energy demanded globally and it is also responsible for close to 50% of carbon dioxide (CO2) emissions. In recent years, industrial countries across the world are committing to combat climate change and global warming resulting from increased carbon dioxide (CO2) emissions (Chang, 2015). Nabernegg et al. (2017) suggests that energy-intensive industries can decarbonize their energy through various options and these were explored at length in chapter 2. Through literature review, five (5) broad categories for mitigating industrial carbon emissions were explored.

5.2.1 *Energy efficiency*

In Chang (2015)'s view, energy efficiency is one of the most feasible way to reduce emissions without necessarily impacting on economic growth. Industrial processes are responsible for bulk of global carbon emissions, warranting a significant improvement in industrial energy efficiency (Nabernegg et al., 2017). In the near future, energy efficiency is potentially the most important and cost-effective means for mitigating greenhouse gas emissions from industry.

In terms of energy efficiency, the study sought to establish two things: whether the respondents are familiar with the concept of energy efficiency and whether energy efficiency is employed in industrial facilities. From the results, it can be concluded that most respondents are familiar with the concept of energy efficiency in varying degrees, but of concern, is a small percentage of respondents (about 8%) who are not familiar with energy efficiency at all. The importance of energy efficiency awareness was emphasised by Trianni et al. (2013), who highlighted the need to develop policies to improve awareness at industrial level.

In terms of energy efficiency being employed in industrial facilities, the study revealed that it is employed. This was concluded since 60% of the respondents considered it to be moderately employed and 40% of them thought it was broadly employed in the South African energy-intensive industry.

From the results of the study, it can be deduced that energy efficiency is an available and employed option for low-carbon production in the South African energy-intensive industry. There is however an opportunity to improve overall knowledge and energy performance through training of employees and raising general awareness (Worrell, Bernstein, Roy, Price, & Harnisch, 2009).

5.2.2 *Fuel substitution*

Fuel substitution is considered one of the feasible option in reducing carbon emissions and in many instances, coal is substituted with oil, natural gas or renewable energy, since coal is more detrimental to the environment (Bloch et al., 2015).

The study established whether the respondents are familiar with the concept of fuel substitution and whether industrial facilities employ it. In terms of respondents' knowledge of fuel substitution, the results indicated that only 8% of the respondents are extremely familiar with it. There was also a considerable percentage of respondents (60%) ranging between moderately and very familiar with fuel substitution. 32% of respondents are however not familiar with the concept at all. Even with some respondents not conversant with the concept of fuel substitution, it can be concluded that this option is fairly known in the South African energy-intensive industry.

In terms of employment of fuel substitution in the energy-intensive industry as an option for low-carbon energy, the results revealed that a small percentage of respondents believed that fuel substitution is broadly employed, while 48% of respondents believed it to be moderately employed. A quite significant number (36%) of respondents believed that fuel substitution is not employed at all in the South African energy-intensive industry.

Overall, the study confirms that fuel substitution is known and somewhat employed in the South African energy-intensive industry. The level of employment of this option is quite low and the industry could make an impact on carbon reductions through research. This is in line with B. Lin and Atsagli (2017), who highlighted that fuel substitution yield substantial results in carbon emissions and the South African energy-intensive industry can benefit from research and investment into this option.

5.2.3 *Materials recycling*

According to Henriques Jr et al. (2010), materials recycling is a viable option to achieve low-carbon production. This option saves energy and minimise carbon emissions by limiting the need to manufacture new products.

The study results indicated that only 5% of respondents were not familiar with materials recycling, while 53% of respondents were very familiar with this concept. Additional 21% of respondents were extremely familiar with materials recycling, leading to the conclusion that this option is well known amongst the South African Energy-intensive industry employees. The fact that materials recycling is known, gives it a better chance for employment and therefore mitigating carbon emissions.

When it comes to the South African Energy-intensive industry employing materials recycling as an option to reduce carbon emissions, the study revealed that 60% of the respondents felt that it is moderately employed. Considering that an additional 32% of the respondents believe this option is broadly employed, it can be concluded that this option is available and employed in the South African energy-intensive industry.

Overall, the study concluded that fuel substitution is known and employed in the South African energy-intensive industry. Gale and Freund (2001), believe that increasing recycling of materials can reduce emissions in the overall production of goods, but this requires more research and investment in the South African energy-intensive industry.

5.2.4 *Clean Coal Technologies (CCTs)*

As Chen and Xu (2010) suggests, coal is still abundant around the world and will continue providing much needed energy for variety of activities, but its utilization is associated with air pollution. Clean coal technologies can reduce the impact of coal combustion on the environment (Chen & Xu, 2010). According to Tavoulareas and

Charpentier (1995), clean coal technologies are most common and widely used in developed countries but there is an opportunity for developing countries to evaluate and include them in their environmental policy priorities. According to Chen and Xu (2010), carbon capture and storage technology (CCS) is the most common clean coal technologies in the industrial sector.

The study sought to establish whether the respondents are familiar with clean coal technologies (particularly carbon capture and storage) and whether it is being employed in the industrial facilities. The results indicated that 32% of the respondents were not familiar at all with this option. 48% of the respondents were moderately familiar with the concept of clean coal technologies, while only 20% was very familiar. None of the respondents were extremely familiar with this option, and this indicates a knowledge gap for this low-carbon energy option in the South African energy-intensive industry.

In terms of clean coal technologies being employed in the South African energy-intensive industry, 56% of the respondents believed that it's not employed at all while 44% felt that it is moderately employed. None of the respondents believed that this option is broadly employed. From these results, it can be concluded that clean coal technologies option is not used in most industrial facilities.

Carbon capture and storage (CCS) is considered one of the effective means of reducing carbon emissions, and in turn minimising the impacts of climate change (Gaede & Meadowcroft, 2016; Tian et al., 2018). From the results of the study, it can be concluded that clean coal technologies as an option for low-carbon energy is not well understood and therefore not employed in most industrial facilities.

Clean coal technologies can be more relevant to the South African's economy, since it is extremely energy-intensive and relies heavily on coal (Winkler & Marquand, 2009; Zhao et al., 2015). Since there is abundant and cheap coal and most energy-intensive industries' technology is built around coal as an energy resources, it is important to explore and invest in some feasible clean coal technologies (Zhao et al., 2015).

5.2.5 *Culture and behavioural change*

As seen in chapter 2, Vickers et al. (2009) presented a different view to the use of low-carbon technologies, indicating that low-carbon technologies may not be the only solution for the transition to low-carbon energy. They suggested that culture and behavioural change by businesses and consumers might be a means to reduce carbon emissions.

When it comes to the respondents being familiar with culture and behavioural change, the results indicated that 44% of respondents were very familiar with the concept of culture and behavioural change, while 16% are extremely familiar with the concept. The remaining 40% of the respondents are moderately familiar with it and it can therefore be concluded that this option is known and available in the South African energy-intensive industry.

In terms of culture and behavioural change being employed in the energy-intensive industry, majority (68%) of respondents were of the view that it is moderately employed, and 28% believed that it is broadly employed. There was only 4% of respondents who believed that this option is not employed in the South African energy-intensive industry at all.

From the results, it can be concluded that culture and behavioural change is an available low-carbon production option and the South African energy-intensive industry is employing it.

5.2.6 *Likelihood of the South African energy-intensive industry to employ low-carbon energy or to improve on the existing options.*

Further to establishing the availability of low-carbon production options in the South African energy-intensive industry, the study sought to understand if the industry is likely to employ or improve on the existing low-carbon energy options. In this respect, the results indicate that 80% of the respondents believed that it is likely that the South African energy-intensive industry would employ or improve on the existing low-carbon energy options, and according to most respondents, it will take about 11-15 years for the options to be employed or improved upon.

5.2.7 *Conclusion on options to facilitate the adoption of low-carbon production in the South African energy-intensive industry.*

The study revealed that various options to facilitate low-carbon production are available and moderately employed in the South African energy-intensive industry, however, there is a big room for improvement in terms of maximising those options. There is a need for the South African energy-intensive industry to identify and overcome the barriers that impede the employment of any low-carbon production option. The table below summarises the low-carbon production options discussed and their availability in the South African energy-intensive industry.

Table 5-1: Low-carbon energy options and summary of findings

LOW-CARBON PRODUCTION OPTIONS	***SUMMARY OF FINDINGS***
Energy efficiency	• Well known in the South African energy-intensive industry. • Moderately employed in the South African energy-intensive industry. ➢ **Energy efficiency is an available option in the South African energy-intensive industry.**
Fuel substitution	• Well known in the South African energy-intensive industry. • Moderately employed in the South African energy-intensive industry. ➢ **Fuel substitution is an available option in the South African energy-intensive industry.**
Material recycling	• Well known in the South African energy-intensive industry. • Moderately employed in the South African energy-intensive industry.

LOW-CARBON PRODUCTION OPTIONS	SUMMARY OF FINDINGS
	➢ **Material recycling is an available option in the South African energy-intensive industry.**
Clean Coal Technologies (CCT)	• Not well understood in the South African energy-intensive industry. • Least employed option in the South African energy-intensive industry. ➢ **Clean Coal Technologies is not an available option in the South African energy-intensive industry.** • There is a need to improve awareness and research and development.
Culture and behavioural change	• Well known in the South African energy-intensive industry. • Moderately employed in the South African energy-intensive industry. ➢ **Culture and behavioural change is an available option in the South African energy-intensive industry.**

5.3 Barriers that affect the energy-intensive industry's ability to transition to low-carbon energy.

This study has identified a number of options for mitigating industrial carbon emissions and the previous section provided the discussions on the level of employment in the South African energy-intensive industry. It is therefore crucial to identify the barriers that impedes the employment of those low-carbon production options. Various barriers were reviewed in chapter 2 and in this section, seven (7) broad categories of barriers are discussed in line with the results of the survey.

5.3.1 *Structural barriers*

Structural barriers relates to the structures of a company, its operational procedures and strategic direction (Y. Liu, 2014). Organisation's structure is crucial in driving the process of low-carbon energy adoption through proper assessment and making right decisions (Trianni et al., 2013). This is in line with Walsh and Thornley (2012) 's view that institutional issues relating to the strategy and priorities of the company are the reason why some actions are not taken at an industrial facility level.

To get the perceptions of the respondents in relation to structural barriers, the respondents were requested to indicate their level of agreement or disagreement with the following statements: *Companies' strategic direction include low-carbon energy*; *and Companies have a general understanding of future prices for low-carbon energy and its impact on the company*.

The study revealed that 60% of the respondents agreed that companies' strategic direction includes low-carbon energy issues, and there was also 4% of respondents who strongly believed that strategic direction includes low-carbon energy issues. Considering that another 4% is neutral, there is only 32% of the respondents who don’t believe that companies’ strategic direction includes low-carbon energy.

In terms of companies having a general understanding of future prices for low-carbon energy and its impact on the company, 52% of the respondents agreed that companies understand the prices of low-carbon energy. There is also 44% of respondents who disagreed with this statement and the remaining 4% of respondents are neutral.

Figure 4-8, in chapter 4 outlines the various reasons for slow uptake of low-carbon energy in the energy-intensive industry and *management/company’s priorities* is one of the lowest rated reason. This adds to the perceptions of the respondents in the other two statements relating to structure of the company, who believed that companies’ strategic planning includes low-carbon energy and there is a general understanding of the concept.

From the results presented above, it can be concluded that structural barriers are not significant in the South African energy-intensive industry. This is a good indication for low-carbon energy transition since most of investments in technology are based on the company or managers’ long term planning and prediction of future operational conditions of the business (Hrovatin et al., 2016).

5.3.2 ***Regulatory barriers***

According to Y. Liu (2014), every industrial facility have policies and regulatory framework that should be complied with. Countries may have policies and regulations developed, but those policies and regulations may not be clear, adequate or may be too ambitious to influence any change in low-carbon energy (Bellevrat, 2012; Winkler & Marquand, 2009). Regulatory framework can shape the transition to low-carbon energy and it is therefore important to understand the extent of regulatory barriers in the South African energy-intensive industry.

To understand if regulatory barriers exist in the South African energy-intensive industry, the respondents were asked to indicate their level of agreement or disagreement with the statements: *Companies have policies that include plans to transition to low-carbon energy*; and *Companies are aware of their regulatory obligations in terms of carbon emissions and climate cha*nge.

The results revealed that 56% of respondents agreed that companies have policies that include plans to transition to low-carbon energy and none of the respondents strongly believed this. There was 16% of respondents who were neutral and 28% who strongly disagreed with the statement.

With regards to companies being aware of their regulatory obligations in terms of carbon emissions and climate change, the results indicated that 72% of the respondents agreed with the statement, and additional 12% strongly agreed. Only 8% respondents didn't think companies are aware of their regulatory obligations and the remaining 8% of respondents are neutral.

It must be noted the two statements on companies' policies and awareness of regulatory obligations relate to the regulation from the company's side and not necessarily the country's regulatory framework. From the results outlined above, it can be concluded that companies are aware of their regulatory obligations and they have, to some extent, policies and plans to transition to low-carbon energy.

In order for the South African energy-intensive industry to shift towards low-carbon energy, regulatory framework ought to be adequate and clear. Engau and Hoffmann (2009) purports that regulatory uncertainties can hinder the process, and policy makers need to clarify roles, responsibilities and obligations for low-carbon initiatives. The study sought to get the insights on various barriers through outlining possible reasons for slow uptake of low-carbon energy. In figure 4-8, chapter 4, *Lack of enforcement of regulatory requirements by government* was amongst the top three (3) out of six (6) possible reasons. This presents a concerning gap in the regulatory space.

Another important aspect to consider in regulatory framework is its adequacy and clarity in influencing the transition to low-carbon energy. Majority of the respondents (45%) believed that regulatory framework is inadequate, while the additional 11% of respondents thought it is extremely inadequate. There was only 22% of respondents who believed that regulatory framework is adequate and the remaining percentage (22%) was neutral. From the results presented, it can be concluded that regulatory framework is perceived to be inadequate.

In terms of regulatory framework being clear, the results revealed that 33% of respondents believed it to be unclear, with the additional 12% believing that it's extremely unclear. There is also a high percentage (33%) of respondents who were neutral in this matter. The remaining 22% of respondents were of the view that it is clear. From these results, regulatory framework to drive low-carbon energy is perceived to be unclear.

In addition to the results discussed above, one respondent added that "*South Africa has a huge source of low-carbon energy but lacks the policies to drive these options."* Another respondent felt that "*government's current regulatory environment being punitive is not helpful; carbon tax is less of an incentive than another way to collect money for the general fiscus."*

From the results discussed in the three paragraphs above, and the comments from the respondents, it can be concluded that regulatory barriers exist in the South African energy-intensive industry in the form of inadequate, unclear, punitive and lack of enforcement. This barrier seems to be significant and concerning since the country ought to reduce carbon emissions and industrial sector is considered to have high potential for significant carbon emissions through measures like energy efficiency (Hrovatin et al., 2016). Unclear policy frameworks, unclear understanding of low-carbon production and uncertainties on government's commitment and activities will hinder the adoption of low-carbon energy (Y. Liu, 2014).

5.3.3 *Culture and behavioural barriers*

Apart from technological, structural changes, or improved management of organisation, culture and behavioural changes can play an important role in combating climate change (Sola & Mota, 2020). Issues such as ethos, habituation modes of practice, personalities and values of manager contribute to the level of transition to low-carbon energy in an industrial facility (Y. Liu, 2014).

In this study, culture and behavioural barriers were evaluated by assessing if the respondents agree or disagree with the statement that "*the South African energy-intensive industry is agile to accommodate the changing environmental requirements*". The results revealed that majority (48%-disagreeing and 8% - strongly disagreeing) of the respondents were of the opinion that the industry is not agile. 40% of the respondents were of the view that it is agile, and the remaining 4% was neutral in the matter.

From these results, it was established that the South African energy-intensive industry is comfortable with the business as usual practices which may not address the emerging requirements of emission reduction. The inflexibility of the of the industry may be the cause for many problems as purported by Hoffman (2010), who suggested that most environmental challenges and their solutions are centred around organisational culture and behaviour.

It can therefore be concluded that culture and behavioural barrier exist in the South African energy-intensive industry in its entirety, and it is significant and require some attention. According to Y. Liu (2014), in some Chinese firms, it was discovered that managers' actions were influenced by the ambitions for growth and profits maximisation and low-carbon production is seen as a hindrance. This is a typical example of a company or manager's culture of maximising profits with less regard for the environment. To conform to the changing environmental requirements, companies ought to discard the old mode of operation and learn new systems (Hoffman, 2010).

5.3.4 *Contextual barriers*

Contextual barriers at an industrial facility's level may relate to lack of understanding of the impacts of climate change or low-carbon energy (Y. Liu, 2014). Without proper understanding of low-carbon energy, climate change and all requirements pertaining to emission reductions, it becomes almost impossible for companies to shift towards low-carbon production.

For contextual barriers to be assessed, the respondents were requested to indicate their level of agreement or disagreement with the following statements: *Companies are aware of the benefits of low-carbon energy*; *The energy-intensive industry in South Africa understands climate change and its impacts;* and *Companies are aware of international requirements to reduce carbon emissions.*

The study revealed that majority (60% - agreeing and 12% - strongly agreeing) of respondents believed that companies are aware of low-carbon energy. For energy-intensive industry in South Africa understanding climate change and its impacts , Majority of respondents (60% - agreeing and 16% - strongly agreeing) believed that the industry understands climate change and its impacts.

In terms of companies being aware of international requirements to reduce carbon emissions, 52% of respondents agreed with the statement and an additional 8% strongly agreed that companies are aware. Only 8% of respondents were of the view that companies are unaware of international requirements for carbon emissions and climate change, and the remaining (32%) were neutral.

From these results, it can be concluded that contextual barriers are insignificant and can be resolved through improved awareness programmes. This conclusion is also supported by the results on reasons for slow uptake of low-carbon energy in the energy-intensive industry, which revealed that *lack of understanding of climate change impacts* was the lowest rated reason. This implies that the South African energy-intensive industry has a good understanding of climate change and low-carbon energy.

5.3.5 *Political barriers*

According to Geels (2014), politics can interfere with the process of low-carbon carbon energy transitions if policymakers and incumbent facilities form an alliance within a current administration, to ensure that the fossil fuels industry is protected, leading to continued emissions. Winkler and Marquand (2009) augments the above statement by pointing out that even though South African government policies embrace the Sustainable Development Goals (SDGs), it still incentivises the energy-intensive industries, since they contribute significantly to the economy through investment, employment, and boosting the country's economy.

The study sought to ascertain if the statements made by various authors regarding political influence are applicable in the South African energy-intensive industry. Respondents were requested to indicate if they were aware of any form of fossil fuels subsidies from government for the energy-intensive industry and 77% of the respondents were not aware of it. There was only 23% of respondents who were aware of the government fossil fuel subsidy.

In addition to fossil fuel subsidy, one respondent raised the point that *"Corruption and lack of long term visions are impacting on changes which are required now in order for the survival of the industries in the future"*. This point is supported by Nochta and Skelcher (2020), who pointed out that public policy making dominated by short-term plans limits the available options from being realised into long-term visions. Corruption can be detrimental to the long-term environmental protection due to its ability to derail any measure, plans or innovations aimed at impact reduction, and in this case, low-carbon emission (Balsalobre-Lorente, Shahbaz, Jabbour, & Driha, 2019).

From the results of the survey, not many respondents were aware of the subsidy, which may lead to the conclusion that political barriers are not significant. However, with corruption and lack of long-term vision, political barriers become significant in the South African energy-intensive industry. The information on political interference is complex and may require a different method of data collection and this study had limitation in collecting relevant information. Political barriers in the South African energy-intensive industry could therefore not be fully ascertained.

5.3.6 *Economic barriers*

Industrial sector is highly energy-intensive, and responsible for majority of carbon emissions, and in order to lower those emissions, energy-intensive industry need to adopt low-carbon energy technologies (Nabernegg et al., 2017). Islas-Samperio, Birlain-Escalante, and Grande-Acosta (2020) suggests that obtaining a measurable level of carbon emission reduction will not be an easy task and it will require various mitigation measures to be put in place and this will be costly, especially for developing countries.

When respondents were requested to select the reasons for slow uptake of low-carbon energy in the energy-intensive industry, *cost of low-carbon technologies* was rated the highest out of the six (6) possible reasons provided. This is not only applicable in the South African energy-intensive industry as most literature highlight the high cost of technology as the most fundamental barrier to implementation, like in the case of Carbon Capture and Storage (CCS) technologies, which is considered unaffordable (Gillingham & Sweeney, 2012).

Low-carbon energy options require some form of initial investment, posing some greater challenges for industrial facilities with limited capital for such projects. From the results of the survey, it can be concluded that economic barriers exist in the South African energy-intensive industry, and it presents a major risk in the low-carbon energy transition progress.

5.3.7 *Facility design and technological barriers*

Usually, energy-intensive industrial facilities are designed with technologies that consumes high energy and resulting in high carbon emissions (Du et al., 2015). There is high initial cost involved in the establishment of energy-intensive industries and the existing infrastructure and the technologies used is of large scale (Song & Oh, 2015). For energy-intensive industries still using old technologies, transitioning to low-carbon energy will be expensive and difficult to achieve in the short to medium term (Reddy, 2013).

To get the perceptions of the respondents on industrial facilities' structural design, respondents were asked to select reasons for slow uptake of low-carbon energy in the energy-intensive industry. The results revealed that *facility's structural design* is rated second, after cost of low-carbon technologies. It can be concluded that facility 's structural design is one of the significant barrier in the South African energy-intensive industry and this have a correlating relationship with economic barriers.

As literature revealed, demand for manufactured goods is increasing but there is also a pressing need for the industrial sector to reduce its carbon footprint (Du et al., 2015). Given the ageing infrastructure and old technology in the South African energy-intensive industry, adoption of low-carbon energy will not be an easy task.

5.3.8 ***Barriers to the adoption of low-carbon energy in developing countries.***

Energy security and availability can serve as an indicator for economic development. Countries in pursuit of economic catch-up will continuously increase their energy use, which may not be in line with environmental requirements (Reddy, 2013). Granoff et al. (2016) suggests that developing countries are affected by all other barriers, and still face additional barriers unique to them.

Most developing countries are faced with infrastructure financing difficulties due to issues like low credit ratings, poor governance and weak regulatory framework (Granoff et al., 2016). All these challenges, together with the barriers identified in the previous sections, places the South African energy-intensive industry in a bad position to transition to low-carbon energy.

South Africa, like many developing countries, is faced with many challenges that require to be prioritised, leaving low-carbon energy development at the bottom of the priority list (Gulati et al., 2018).

5.3.9 *Conclusion on barriers that affect energy-intensive industry's ability to transition to low-carbon energy.*

It is important to note that the responses from various individuals reflect their experiences in their respective industrial facilities and this would therefore provide the picture of how the South African energy-intensive industry is performing in the low-carbon energy space. From the results and discussions, various barriers were confirmed to be existing in the south African energy-intensive industry. The table below summarises the barriers discussed and their significance in the South African energy-intensive industry.

Table 5-2: Identified barriers and summary of findings

BARRIERS	SUMMARY OF FINDINGS
Structural	• Low-carbon energy is believed to be part of company's strategic direction. • Companies have general understanding of low-carbon energy prices. • Management/company priorities rated low in terms of reasons for slow uptake of low-carbon energy. ➢ **Structural barriers are perceived to be insignificant**.
Regulatory	• Companies have relevant policies that include low-carbon energy transition. • Companies understand their regulatory obligation for climate change and low-carbon energy. ➢ **Companies' low-carbon energy policy is perceived to be in place.** • Lack of enforcement of legislations by government is amongst the top-rated reasons for slow uptake of low-carbon energy. • Regulatory framework is perceived to be inadequate and unclear. • South Africa is perceived to lack policies to drive low-carbon energy.

	• Carbon tax is perceived to be punitive and doesn't promote carbon emissions reductions. ➢ **Regulatory barriers are perceived to be significant**
Culture and behavioural	• The South African energy-intensive industry is not agile to accommodate the changing environmental requirements. • Culture and behaviour of the industry is at the centre of most environmental challenges and their solutions. ➢ **Culture and behavioural barriers are perceived to be significant.**
Contextual	• Companies are aware of low-carbon energy benefits • The South African energy-intensive industry understands climate change and its impacts. • Companies are aware of international requirements to reduce carbon emissions. ➢ **Contextual barriers are perceived to be insignificant.**
Political	• Corruption and lack of long-term vision highlighted as a concern. • Government subsidy on fossil fuel not well known. ➢ **The study had limitation in collecting political barriers data.**
Economic	• Rated number one reason for slow uptake of low-carbon energy. • Low-carbon energy technology is costly. ➢ **Economic barriers are perceived to be significant.**
Facility design and technology	• Rated one of the top reasons for slow uptake of low-carbon energy. • Most industries were built a long time ago and technology is ageing. • High capital is required to upgrade technology or retrofit. ➢ **Facility design and technology barriers are perceived to be significant.**

The study was able to find similarities to what literature has pointed out, and in addition, new barriers were identified, and the major ones are summarised in the table below.

Table 5-3: Additional barriers and summary of findings

BARRIERS	SUMMARY OF FINDINGS
Lack awareness on various low-carbon production options amongst employees of the energy-intensive industry.	• Even though most low-carbon production options are moderately or well known by employees of different industrial facilities, there is still a worrying number of employees who are not familiar with some low-carbon production options.
Lack of infrastructure for alternative energy.	• South Africa has natural gas and companies need large quantities. - Infrastructure is not available in other industrial sites. - This prohibits most companies to shift to natural gas. - The use of mobile containers is prohibitive, since the trailers carry less than 12hour of supply, making it unsustainable.

5.4 Conclusion

The discussions in this chapter were focussed on the availability of options to facilitate low-carbon energy in the South African energy-intensive industry and the barriers to their adoption.

In terms of options to facilitate low-carbon energy, the main finding is that these options are moderately known and moderately employed in the South African energy-intensive industry. There is an awareness or knowledge gap, and if closed, most of the barriers could be overcome.

South African energy-intensive industry must improve research and development for energy efficiency to identify the most cost-effective options suitable for the South African economic landscape. According to Gale and Freund (2001), the energy-intensive industries across the world has classified energy efficiency as an important measure since it also improves the cost of production. It is for this reason that a number of feasible energy efficiency options have been employed in many industrial facilities, which in turn lowered carbon emissions, but Gale and Freund (2001) believes that there is still room for more energy efficiency options.

There are other low-hanging fruits when it comes to these available options, like fuel substitution, which requires replacement of high carbon energy with low-carbon energy resources without necessarily replacing the entire technology. More research on this option can change the perceptions and improve the uptake in industrial facilities.

Material recycling is one feasible option that should be investigated and improved on. It is believed that increasing recycling of materials can reduce emissions in the overall production of goods, but more research and understanding is necessary (Gale & Freund, 2001).

One of the common clean coal technology option is carbon capture and storage, which is considered the best option in reducing emissions (Gale & Freund, 2001). This study revealed that this option is the least known and least employed in industrial facilities and this warrants further exploring and awareness raising in the South African energy-intensive industry.

Culture and behavioural issues are responsible for most decisions made in the company. South African energy-intensive industry could make a positive impact without costing the company, by adopting culture of environmental sustainability. The study revealed that culture and behavioural change is known and employed as an option for low-carbon energy.

The findings in terms of barriers to the adoption of low-carbon energy revealed that, some of the identified barriers are not significant in the South African energy-intensive industry and can be easily overcome through few measures. The barriers perceived as insignificant include structural and contextual barriers, since most companies are believed to have low-carbon energy included in strategic plans and have general understanding of low-carbon energy and its benefits. Companies are also believed to understand impacts of climate change and are aware of requirements to reduce carbon emissions.

There is inadequate and unclear regulatory framework to drive low-carbon energy and in addition, there is lack of enforcement. The country also lacks policies to facilitate the adoption of the available low-carbon energy options. The study concluded that regulatory barriers are significant and require attention.

The South African energy-intensive industry is believed to be rigid in its operations and this makes culture and behavioural barriers significant. It is easy for this barrier to be ignored or missed but it is central to the adoption of low-carbon energy since the culture of the company influences its priorities.

Political barrier was found to be existing, especially with the concern on corruption and lack of long-term vision. The study couldn't confirm the political interference in the promotion of fossil fuels due to data collection limitations.

The study found economic barriers to be the most significant since most options need some form of financing. Closely related to economic barriers is facility design and technological barriers, which were found to be significant. Most energy-intensive industrial facilities were built some years back with their technology centred around fossil fuels. Technologies in energy-intensive industries require high capital investment, which may not be available for most industrial facilities.

South African energy-intensive industry is facing all these identified barriers with the additional challenges faced by other developing countries. All these other challenges take priority in most instances, placing the country in a bad position in terms of low-carbon energy transitions.

CHAPTER 6. CONCLUSIONS & RECOMMENDATIONS

6.1 Introduction

This chapter provides a summary of the study findings and conclusions in relation to the research questions. The study was aimed at exploring available low-carbon production options in the South African energy-intensive industry and to identify barriers to the adoption of low-carbon energy. Conclusions for each research question ere made, followed by recommendations for the stakeholders affected and suggestions for further research. The main research question and sub-questions for the study are outlined below:

Which barriers affect the South African energy-intensive industry’s ability to adopt low-carbon energy?

The main question was broken down into three sub-questions:

1. What is the level of familiarity with the available options to facilitate low-carbon energy within the South African energy-intensive industry?

2. To what extent are the options to facilitate low-carbon energy employed in the South African energy intensive industries?

3. What are the barriers contributing to the South African energy-intensive industries’ inability to adopt low-carbon energy?

6.2 Conclusions on the available and employed options to facilitate low-carbon energy in the South African energy-intensive industry.

The study established that energy efficiency, fuel substitution, material recycling and culture and behavioural change are the available options currently known and employed in the South African energy-intensive industry. Clean coal technologies are also known but their level of employment is very low. The study found that even though the options are available, they are moderately known and moderately employed in the South African energy-intensive industry. Below is the summary of findings for each assessed low-carbon energy option:

Energy efficiency - The option is well known and moderately employed in the South African energy-intensive industry.

Fuel substitution – The option is moderately known and moderately employed in the South African energy-intensive industry.

Material recycling - The option is well known and broadly employed in the South African energy-intensive industry.

Clean coal Technologies – The option is not well known, and it is the least employed in the South African energy-intensive industry.

Culture and behavioural change - The option is well known and moderately employed in the South African energy-intensive industry.

When assessing the level of knowledge and level of employment for various low-carbon energy options, the study found that there is a general knowledge and awareness gap. This is believed to be one of the reason why some options are not employed in the energy-intensive industry.

The study also found that clean coal technologies are the least known and least employed in the South African energy-intensive industry. One of the commonly employed clean coal technology option is carbon capture and storage, and it is considered the best option in reducing emissions (Gale & Freund, 2001). The South African energy-intensive industry can benefit from more research on this option.

The major finding in terms of low-carbon production options is that most options are not well known in the South African energy-intensive industry, which is the reason why they are not broadly employed. South African energy-intensive industry must improve research and development for all low-carbon energy options suitable for the South African economic landscape.

6.3 Conclusions on barriers contributing to the South African energy-intensive industry's inability to adopt low-carbon energy.

The findings of the study revealed that barriers to the adoption of low-carbon energy exist in the South African energy-intensive industry and that the existing barriers varies in significance. South Africa is one of the top carbon emitters in Africa and the existence of these barriers threatens the progress for carbon emissions reduction.

The findings of the study indicate that most companies have low-carbon energy included in strategic plans and have general understanding of low-carbon energy and its benefits. There is also an indication that companies understand impacts of climate change and are aware of requirements to reduce carbon emissions.

The study therefore concluded that structural and contextual barriers are not significant in the South African energy-intensive industry.

The findings with respect to regulatory framework indicate that regulations to facilitate low-carbon energy is inadequate and unclear. The study also found that there is lack of enforcement of legislations by government and policies to facilitate the adoption of the available low-carbon energy options are lacking. The study therefore concluded that regulatory barriers are significant and require urgent attention.

For political barriers, there is a concern on corruption and lack of long-term vision, but the study couldn't confirm the political interference in the promotion of fossil fuels due to data collection limitations.

The findings of the study revealed that cost of low-carbon energy technology and facility structural design are considered the main reasons for slow uptake of low-carbon energy in the energy-intensive industry. Polzin (2017) suggest that the deployment and the use of clean technologies is central to the transition to low-carbon energy. Most industrial facilities are old, and their technologies are centred around fossil fuels, and the study therefore concluded that economic, industrial structural design and old technologies exist and are significant barriers to the adoption of low-carbon energy.

The study found that the South African energy-intensive industry is rigid in its operations and therefore not fast in implementing required measures to meet the new environmental requirements. Environmental conditions and compliance requirements are everchanging and requires industrial facilities to keep technologies and priorities up to date. The study concluded that culture and behavioural barriers are significant in the adoption of low-carbon energy.

In conclusion, regulatory, economic, culture and behavioural change, industrial structural design and technological barriers exist and affect the South African energy-intensive industry's ability to adopt low-carbon energy. In addition, lack of knowledge or awareness of low-carbon production options, and lack of infrastructure for alternative energy are also existing barriers in the South African energy-intensive industry.

6.4 Recommendations

This study concluded that barriers to the adoption of low-carbon energy exist in the South African energy-intensive industry and those barriers were explored and discussed in previous chapters. Understanding these barriers has highlighted areas of concern and provided direction in terms of where intervention is required. Below are the recommendations to the South African government and the South African energy-intensive industry.

South African government need to strengthen its regulatory framework aimed at addressing industrial sector's low-carbon energy. The regulatory framework and policies must have targets that will encourage the industrial sector to invest in new technologies and change general culture and behaviour in matters of low-carbon energy. Enforcement of legislation is critical in the success of carbon emissions reduction, so, government must improve in this regard.

On economic matters relating to infrastructure for alternative energy, South Africa must explore the public-private partnership option for the provision of the required infrastructure. Government must also provide enabling conditions for research and development on low-carbon energy options. There is also a need for government to engage with industrial sector on continuous basis to identify and resolve challenges faced by both parties in meeting the carbon emission reduction targets.

South African economy is energy intensive and relies heavily on coal due to abundance, and this present some challenges in the adoption of low-carbon energy. It is therefore crucial for the South African government and the energy-intensive industry to invest in clean coal technologies since coal is expected to form part of the energy resources for some years to come.

The South African energy-intensive industry must improve awareness amongst its employees and improve research on the most cost-effective options suitable for the South African economic landscape. Henriques Jr et al. (2010) suggest that some low-carbon technologies are affordable and may not require massive investment, and the South African energy-intensive industry must explore and invest in them.

6.5 Suggestions for further research

- The study couldn’t conclude on political interference in the adoption of low-carbon energy, further research must focus on how the South African political landscape facilitate or deter industrial low-carbon energy pathways.

- Further studies should also explore feasible replacements for fossil fuels in various industrial processes.

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APPENDICES

APPENDIX A: Questionnaire.

QUESTIONNAIRE

1. Basic demographic and background questions

1.1 Positions held in the energy intensive industry (previous and current) ____________________

1.2 Number of years within the energy intensive industry	
0 -5 years	
6 - 10 years	
11 - 15 years	
16 -20 years	
More than 20 years	

1.3. The sector you are currently in	
Food processing	
Pulp and paper	
Basic chemicals	
Refining	
Iron and steel	
Nonferrous metals (Primarily aluminium and other nonferrous metals)	
Non-metallic minerals (Primarily cement and other non-metallic minerals)	
Other (specify):	

1.4 In your experience, what are the most common sources of carbon emission in the energy intensive industry.	
Boilers	
Blast furnace	
Cement kiln	
The use of fuels as feedstocks in petrochemical processes	
The use of carbon as a reducing agent in the commercial	
Other (specify):	

1.5 In your experience, apart from electricity, what are the most common sources of energy in the energy-intensive industry?	
Coal	
Oil	
Natural Gas	
Other (specify)	

2. How familiar are you with the following options to facilitate low-carbon energy?				
	Extremely familiar	Very familiar	Moderately familiar	Not familiar at all
Energy efficiency				
Fuel substitution (with low-carbon fuels)				
Materials recycling				
Clean coal technologies (e.g. Carbon capture and storage technology)				
Culture and behavioural change				
Other low-carbon options	specify:			

3. In your opinion, to what extent does the energy-intensive industry in South Africa employ any of the options to facilitate low-carbon energy?				
	Broadly employed	Moderately employed	Not employed at all	No idea
Energy efficiency				
Fuel substitution (with low-carbon fuels)				
Materials recycling				
Clean coal technologies (e.g. Carbon capture and storage technology)				
Culture and behavioural change				
Other low-carbon options (Specify):				

4. Based on your understanding of the industry, how likely is the South African energy intensive industry to employ low-carbon energy or to improve on the existing options?	Extremely likely	Likely	Neither likely nor unlikely	Unlikely	Extremely unlikely

4.1 If likely, what might be the timelines?	0-5years	5-10 years	10-15 years	15-20 years

5. Please indicate your level of agreement with the statements below relating to low-carbon energy based on your experience in the energy-intensive industry.	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Companies' strategic direction include low-carbon energy.					
Companies have policies that include plans to transition to low-carbon energy.					
Companies have a general understanding of future prices for low-carbon energy and its impacts on the industry.					
Companies have technologies to support the use of low- carbon energy.					
Companies are aware of the benefits of low-carbon energy.					
The energy intensive industry in South Africa understands climate change and its impacts.					
Companies are aware of their regulatory obligations in terms of carbon emissions and climate change.					
Companies are aware of international responsibility to reduce carbon dioxide emissions.					
The South African energy-intensive industry is agile to accommodate the changing environmental requirements.					

6. In your opinion, what are the reasons for slow uptake of low-carbon energy in the Energy Intensive Industry (*You can select more than one)*	
Cost of low-carbon technologies.	
Facility's structural design.	
Price of fossil fuels vs low-carbon fuels.	
Management/Company's priorities.	
Lack of understanding of climate change impacts.	
Lack of enforcement of regulatory requirements by government.	

7. Are you aware of any form of subsidies from government for the energy intensive industry on fossil fuels?				
Yes		No		Additional comments:

8. In your opinion, is there adequate regulatory framework to drive low-carbon energy in the energy-intensive industry?				
Extremely inadequate	Inadequate	Neither adequate nor inadequate	Adequate	Extremely adequate

9. In your opinion, is the regulatory framework to drive low-carbon energy in the energy-intensive industry clear?				
Extremely unclear	unclear	Neither unclear nor clear	Clear	Extremely clear

Any additional comments on low-carbon energy and its adoption in the Energy Intensive Industry:

APPENDIX B: Participant Information Sheet

Participant Information Sheet

Dear participant

My name is Lydia Muditambi and I am a Masters student in Energy Leadership at the University of the Witwatersrand, Johannesburg. As part of my studies, I have to undertake a research project, and I am investigating the perceived barriers to the adoption of low-carbon energy in the South African Energy-Intensive Industries under the supervision of Dr Kolawole Ijasan. The aim of this research project is to explore the low-carbon energy options for the energy intensive industries and identify the barriers to the adoption of those options. This will provide an indication of the country's readiness in reducing the industrial carbon footprint.

As part of this project, I would like to invite you to take part in answering a questionnaire which will take around twenty (20) minutes. The response you provide will be treated as your own views based on your experience in the industry and will not be linked to a specific industrial facility.

There will be no personal costs to you if you participate in this project. You will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. You may withdraw at any time or not answer any question if you do not want to. The responses to the questionnaire will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be made available on request. If you wish to receive a summary of this report, I will be happy to send it to you. The data collected from this research project will be stored in a password locked laptop and will be kept for 3 years. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrec-medical.researchoffice@wits.ac.za.

Yours sincerely,

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APPENDIX C: Analysis tables

Analysis tables

Demographics

Variable	Description	Frequency	Percentage
Years within energy-intensive industry.	0-5 years	2	10
	6-10 years	4	20
	11-15 years	5	25
	16-20 years	1	5
	More than 20 years	8	40
Sector	Basic chemicals	2	10
	Food processing	1	5
	Iron and steel	8	40
	Nonferrous metals	1	5
	Nonmetallic minerals	2	10
	Refining	2	10
	Other	4	20

Sources of carbon emissions	Frequency	Percentage
Boilers	10	40
Blast furnace	8	32
Cement kiln	3	12
The use of fuels as feedstocks in petrochemical processes	6	24
The use of carbon as a reducing agent in the commercial	2	8
Other		

Q1_3 (Other)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		21	84.0	84.0	84.0
	Electric Arc Furnace	1	4.0	4.0	88.0
	electricity	1	4.0	4.0	92.0
	Heat treatment furnaces and galvanising baths.	1	4.0	4.0	96.0
	Methane from coal	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Sources of energy	Frequency	Percentage
Coal	10	40
Oil	3	12
Natural gas	10	40

Pneumatics	1	4
Solar	1	1

Research question 1: What is the level of familiarity with the options to facilitate low-carbon energy within the South African energy-intensive industry.

	Extremely familiar	Very familiar	Moderately familiar	Not familiar at all	Mean	SD
Energy efficiency	32	40	20	8	2.96	0.935
Fuel substitution	8	48	12	32	2.32	1.03
Materials recycling	20	48	28	4	2.84	0.80
Clean coal technologies (carbon capture and storage technology)		20	48	32	1.88	0.726
Culture and behavioural change	16	44	40		2.76	0.723

Research question 2: To what extent are the options to facilitate low-carbon energy employed in the South African energy-intensive industries?

	Broadly employed	Moderately employed	Not employed at all	No idea	Mean	SD
Energy efficiency	40	60			3.40	0.50
Fuel substitution	8	48	36	8	2.20	1.12
Materials recycling	36	60		4	3.28	0.678
Clean coal technologies (carbon capture and storage technology)		44	56		1.88	1.01
Culture and behavioural change	28	68	4		3.20	0.645

	Very likely	Moderately likely	Less likely	Not likely	Mean	SD
Likelihood of the South African energy-intensive industry to employ low-carbon energy.	80		4	16	3.44	1.16

	0-5 years	6-10 years	11-15 years	16-20 years	More than 20 years
Timelines	6	20	34	20	20

Research question 3: What are the barriers contributing to the South African energy-intensive industries' inability to adopt low-carbon energy?

Barriers	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	SD
Companies' strategic direction include low-carbon energy.		32	4	60	4	3.36	0.995
Companies have policies that include plans to transition to low-carbon energy.		28	16	56		3.28	0.891
Companies have a general understanding of future prices for low-carbon energy and its impacts to the industry.		44	4	52		3.08	0.997
Companies have technologies to support the use of low- carbon energy.		36	28	36		3.00	0.866
Companies are aware of the benefits of low-carbon energy.		16	12	60	12	3.68	0.90
The energy-intensive industry in South Africa understands climate change and its impacts.		12	12	60	16	3.80	0.866
Companies are aware of their regulatory obligations in terms of carbon emissions and climate change.		8	8	72	12	3.88	0.726
Companies are aware of international requirements to reduce carbon emissions.		8	32	52	8	3.60	0.764
The South African energy-intensive industry is agile to accommodate the changing environmental requirements.	8	48	4	40		3.24	1.09

Reasons for slow uptake of low-carbon energy	Frequency	Percentage
Cost of low-carbon technologies.	9	36
Facility's structural design.	6	24
Price of fossil fuels vs low-carbon fuels.	5	20
Management/Company's priorities.	5	20
Lack of understanding of climate change impacts.	4	16
Lack of enforcement of regulatory requirements by government.	6	24

Variable	Description	Frequency	Percentage

Knowledge of government subsidy on fossil fuel	No	13	76.5
	Yes	4	23.5
Adequacy of regulatory framework	Adequate	4	22.2
	Extremely inadequate	2	11.1
	Inadequate	8	44.5
	Neutral	4	22.2
Clarity of regulatory framework	Clear	4	22.2
	Extremely unclear	2	11.1
	Neutral	6	33.3
	Unclear	6	33.3

APPENDIX D: Ethical certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF GRADUATE SCHOOL OF BUSINESS ADMINISTRATION ETHICS COMMITTEE
CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE **PROTOCOL NUMBER: WBS/BA2289099/191**

PROJECT TITLE	Perceived barriers to the adoption of low-carbon energy in the South African Energy Intensive Industries.
INVESTIGATOR	Ms Luvhengo Lydia Muditambi
SCHOOL/DEPARTMENT OF INVESTIGATOR	MM (Energy Leadership)
DATE CONSIDERED	18 August 2020
DECISION OF THE COMMITTEE	Approved unconditionally
RISK LEVEL	MINIMAL RISK
EXPIRY DATE	30 JUNE 2021

ISSUE DATE OF CERTIFICATE 31 August 2020 **CHAIRPERSON** ____________________
(Dr MDJ Matshabaphala)

cc: Supervisor: Dr. Ijasan

DECLARATION OF INVESTIGATOR

To be completed in duplicate and ONE COPY returned to the Chairperson of the School/Department ethics committee.

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

____
Signature

Date 01 / 09 / 2020