

https://dspace.org/

Utilisation of liquefied natural gas as energy by heavy-duty vehicles in South Africa

Tlalang, Kgosietsile

2024

University of the Witwatersrand, Johannesburg

https://hdl.handle.net/10539/44481

Tlalang, Kgosietsile. (2024). Utilisation of liquefied natural gas as energy by heavy-duty vehicles in South Africa [Master's dissertation, University of the Witwatersrand, Johannesburg].WireDSpace.https://hdl.handle.net/10539/44481

Downloaded from a DSpace repository. https://dspace.org/

FINAL RESEARCH REPORT

Utilisation of liquefied natural gas as energy by heavy-duty vehicles in South Africa

BY

Kgosietsile Tlalang

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 Business Administration

Johannesburg, 2024

Utilisation of liquefied natural gas as energy by heavy-duty vehicles in South Africa

Abstract

The transport sector in South Africa significantly contributes to greenhouse gas emissions, with over fourteen percent of the total emissions attributed to it. The reliance on fossil fuels, particularly diesel, for vehicular road transportation exacerbates this issue. High operating costs per kilometre of diesel negatively affect the sustainability of heavy-duty vehicle operations.

To address these challenges, a conceptual framework was employed to investigate various factors influencing the decision-making process to adopt LNG as an alternative fuel. Qualitative research methods were utilised to gain insights into the owners' environmental awareness, economic considerations, and long-term sustainability goals regarding LNG adoption. The findings reveal a growing interest among heavy-duty vehicle operators in transitioning to LNG because of its environmental benefits, cost efficiency, and long-term sustainability prospects.

Key stakeholders such as vehicle manufacturers, fuel providers, and logistics services are actively exploring LNG solutions to enhance fuel diversity, reduce emissions, and achieve cost efficiencies. Volvo Southern Africa, a major heavy-duty vehicle manufacturer, is leading efforts to provide environmentally friendly solutions to the industry. Similarly, some logistics services providers are undertaking pilot programmes to explore alternative energy technologies as part of their commitment to environmental sustainability.

The research underscores the potential of LNG to transform the heavy-duty vehicle sector by offering a cleaner, more sustainable fuel alternative. Analysis of the estimated payback period and net present value demonstrates the economic viability of LNG heavy-duty vehicles compared to diesel counterparts. However, to realise the full potential of LNG adoption in South Africa, investment in infrastructure for importation and distribution is crucial. Additionally, concerns about potential government levies and taxes on LNG need to be addressed to encourage its utilisation.

KEYWORDS

Qualitative research, Liquefied Natural Gas, Fuel, Heavy-duty logistics industry, Environmental awareness, Economic awareness, Knowledge and awareness, Decision-making process, Long-term sustainability, Adoption of LNG

TABLE OF CONTENTS

APPENDICES v
LIST OF FIGURES v
LIST OF TABLES v
LIST OF ACRONYMS vi

CHAPTER 1. INTRODUCTION 7

1.1 STATEMENT OF PURPOSE 7
1.2 BACKGROUND OF THE STUDY 7
1.3 RESEARCH PROBLEM 9
1.4 RESEARCH OBJECTIVES 9
1.5 RESEARCH QUESTIONS 10
1.6 RATIONALE 10
1.7 DELIMITATIONS OF THE STUDY 11
1.8 DEFINITION OF TERMS 11
1.9 ASSUMPTIONS 12

CHAPTER 2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK 13

2.1 INTRODUCTION 13
2.2 BACKGROUND DISCUSSION 13
2.3 FIRST RESEARCH QUESTION 14
2.3.1 ECONOMIC IMPACT OF ADOPTING LNG AS FUEL 15
2.4 SECOND RESEARCH QUESTION 15
2.4.1 ENVIRONMENTAL AWARENESS OF LNG AS AN ALTERNATIVE FUEL 15
2.5 THIRD RESEARCH QUESTION 16
2.5.1 KNOWLEDGE AND AWARENESS OF LNG AS ALTERNATIVE FUEL 16
2.6 FOURTH RESEARCH QUESTION 16
2.6.1 LONG-TERM SUSTAINABILITY OF UTILISING LNG 16
2.7 FRAMEWORK 17
2.7.1 THEORETICAL FRAMEWORK 17
2.7.2 CONCEPTUAL FRAMEWORK 17

CHAPTER 3. RESEARCH METHODOLOGY 18

3.1 RESEARCH APPROACH 18
3.2 RESEARCH DESIGN 18
3.3 DATA COLLECTION METHODS 20
3.4 POPULATION AND SAMPLE 20
3.4.1 POPULATION 20
3.4.2 SAMPLE AND SAMPLING METHOD 21

3.4.3 Research instrument 21
3.4.4 Procedure for data collection 22
3.4.5 Data analysis strategies and interpretation 22
3.5 Possible limitations and challenges of the study 23
3.6 Quality Assurance 23
3.6.1 Transferability 23
3.6.2 Credibility 24
3.6.3 Dependability 24
3.7 Ethical considerations 25

CHAPTER 4. FINDINGS 26

4.1 Interest in adopting LNG by heavy-duty vehicle operators 28
4.1.1 Awareness of LNG as an alternative fuel by heavy-duty vehicle operators 28
4.1.2 Environmental awareness 29
4.1.3 Competitive advantage of adopting LNG as fuel 29
4.1.4 Long-term sustainability of LNG usage in heavy-duty vehicle industry 32
4.1.5 Infrastructure required to adopt LNG as fuel 32
4.1.6 Concerns on the adoption of LNG as fuel 33

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS 35

5.1. Conclusion 35
5.1.1 Conclusion regarding research question 1 35
5.1.2 Conclusion regarding research question 2 35
5.1.3 Conclusion regarding research question 3 36
5.1.4 Conclusion regarding research question 4 37
5.2 Recommendations 39
5.3 Suggestions for further research 39

REFERENCES 40

APPENDIX A- Content Analysis table 46

APPENDIX B- Thematic analysis 49

APPENDIX C- Turnitin Originality Report 50

APPENDIX D- Sources of secondary data 51

APPENDICES

APPENDIX A: Content Analysis table

APPENDIX B: Thematic analysis

APPENDIX C: Turnitin Originality Report

APPENDIX D- Sources of secondary data

LIST OF FIGURES

Figure 1: Conceptual framework

Figure2: Thematic map indicating the 6 themes.

Figure 3: Historical trend of LNG prices versus diesel

Figure 4: Historical LNG trends in Africa

LIST OF TABLES

Table1: Summary of themes discussed.

Table 2: Consistency table: research questions, hypothesis, data collection detail and data analysis method

LIST OF ACRONYMS

AA- Automobile Association

CNG-Compressed Natural Gas

DDF-Diesel Dual Fuel

FFS- Fuel Firing Systems

LNG- Liquefied Natural Gas

MMBtu- Million British Thermal Units

NBI-National Business Initiative

RAF-Road Accident Fund

RFA-Road Freight Association

SANEDI- South African National Energy Development Institute

CHAPTER 1. INTRODUCTION

1.1 Statement of purpose

The purpose of this qualitative study was to investigate the interest of owners and operators of heavy-duty vehicles in South Africa by adopting liquefied natural gas (LNG) as fuel. The study set out to explore factors which influence their motivations and decision-making processes, environmental concerns, and long-term sustainability.

A conceptual framework indicated in Figure 1 as used to investigate the owner's environmental awareness, economic considerations, long-term sustainability goals, knowledge, and awareness of LNG in the decision-making process to adopt LNG as fuel.

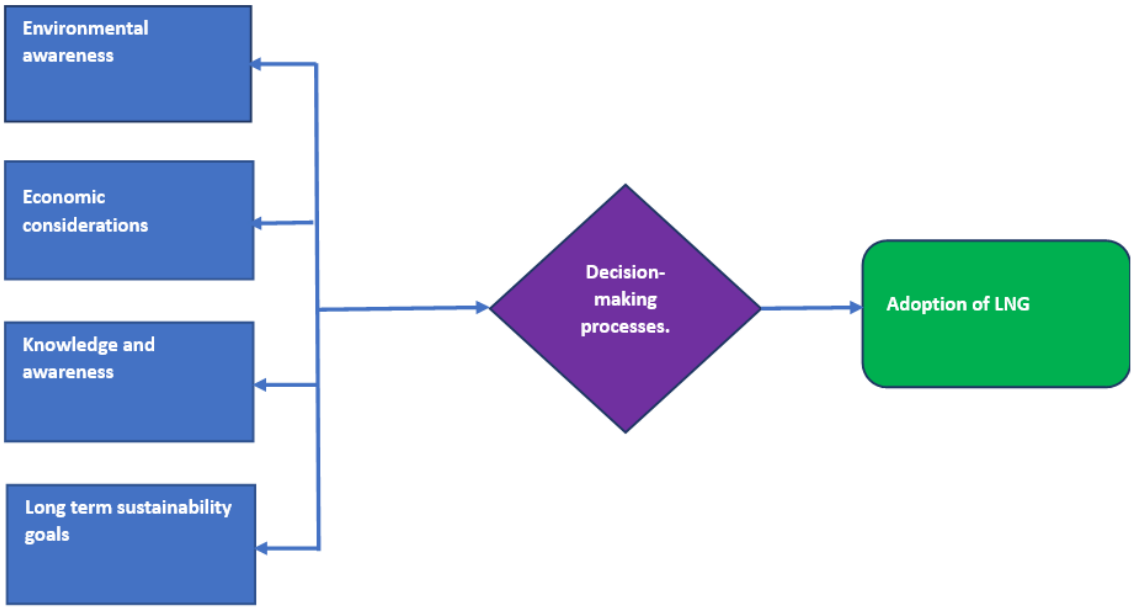


Figure 1: Conceptual framework

1.2 Background of the study

The South African transport sector contributes over fourteen percent of the total greenhouse gas emissions (Ajum et al., 2020). A study by Mohammad et al. (2021) found that high emissions significantly expose the environment to increasing amounts of greenhouse gases. Furthermore, earlier research found that South Africa relies on fossil fuels as its primary source of energy for vehicular road transportation (Wright et al., 2019). Fossil fuels and oil contribute 70.7% and 21.6%, respectively, while natural gas makes up 2.6% of the country's energy mix (SAGMP, 2021).

The country's oil and gas demand is met through imports from other countries. Over 90% of oil is imported from various countries (Oladunni, Mpofu, & Olanrewaju, 2022). This has created a volatile fossil fuel market, with fuel increases imposed on vehicle owners and operators on a monthly basis. Thus, the need for alternative sources of fuel for the transport industry, that would be both economic and environmentally friendly (de Oliveira et al., 2019). Renergen has been awarded the first onshore rights to explore and produce petroleum in South Africa. The gas field covers an area of 187 000 hectares spreading across Welkom, Virginia and Theunissen. Tetra4, the company which owns Renergen, provides natural gas storage and refuelling facilities and maintenance to depots owned by their clients. In Virginia, Free State, Tetra4 provides natural gas to Megabus for 10 natural gas dedicated buses. The company also provides a similar service to a major logistics company for 15 trucks, which are powered by diesel and dual fuel (SAGMP, 2021).

Natural gas, which is in liquid form and has been cooled down to minus 162 degrees Celsius, is referred to as Liquefied Natural Gas (LNG) (Mohammad et al., 2021). LNG is lighter than air, non-toxic, non-corrosive and odourless. It is safe because in its liquid form, it cannot cause any ignition. It has a density of 0,43 kg/L and can be stored and transported at low temperatures using cryogenic containers (Met Group, 2020). The main component of LNG is methane, which makes up ninety-four (94) percent of the gas (Met Group, 2020).

LNG has been proposed as a positive way forward towards minimising the environmental effects of fossil fuel as well as mitigating the over dependency on fuel imports. It is the most rapidly growing source of energy, with adequate sustainability qualities (Mokrani, 2022). Adopting LNG as fuel can thus lead to reduced emissions (Boretti, 2020). Using LNG as fuel can further improve the exhaust emissions of CO_2 by up to 15% (Marcogaz, 2021). Engines of LNG Heavy-Duty Vehicles emit an average of between minus 3 and 5 decibels dB of noise. This is 50% less than the average noise of diesel fuelled engines (Marcogaz, 2021). The performance of both engines is the same since the energy density of LNG and that of diesel are equivalent (Marcogaz, 2021). It also makes it efficient for long hauling distances and ideal where pipeline infrastructure is not available (Marcogaz, 2021).

This study set out to investigate the motivations and decision-making processes of heavy-duty vehicle owners and operators to determine their interest in adopting LNG as fuel.

1.3 Research problem

Heavy-duty vehicles in South Africa rely on diesel for fuel. The combustion of diesel fuel in heavy-duty engines emits greenhouse gases, nitrogen oxides, and other particulate matter. These emissions adversely affect air quality and contribute negatively to the carbon footprint of heavy-duty vehicle operations (Mohammad et al., 2021).

The high operating cost per kilometre of diesel has a negative impact on the sustainability of operating heavy-duty vehicles (Mohammad et al., 2021). According to the Department of Mineral Resources and Energy (n.d.), fuel cost in South Africa is subjected to factors such as changes in the price of crude oil, supply and demand factors and the rand dollar exchange rate. About 90% of the crude petroleum used in the production of fuel in South Africa is imported (Stats SA, 2020).

The transition to more sustainable fuel sources is critical for reducing the environmental impact of heavy-duty vehicles. However, there is limited understanding of the factors that influence the interest and decision-making processes of owners and operators of these vehicles in adopting LNG as a fuel alternative.

1.4 Research objectives

The following research objectives were explored:

1. To analyze the economic factors influencing the decision-making process of owners and operators in adopting LNG as fuel for heavy-duty vehicles.
2. To investigate the correlation between environmental consciousness and the adoption rate of LNG as fuel.
3. To evaluate the current knowledge and awareness levels of LNG as fuel among heavy-duty vehicle owners and operators.
4. To examine the potential long-term sustainability benefits of adopting LNG as fuel in heavy-duty vehicles.

1.5 Research questions

The following research questions were answered:

1. What is the role of economic factors in the owners and operators' decision-making process of adopting LNG as fuel in heavy-duty vehicles?
2. How does the environmental awareness of owners and operators of heavy-duty vehicles affect their decision-making process of adopting LNG as fuel?
3. How does knowledge and awareness of LNG as fuel determine its adoption as fuel by the owners and operators ?
4. How can the adoption of LNG as fuel by the owners and operators improve the long-term sustainability of operating heavy-duty vehicles?

1.6 Rationale

LNG as a transportation fuel produces fewer emissions than other fuels. When compared to diesel in heavy-duty vehicles, it emits between 7% and 15% fewer greenhouse gas emissions. Engines of LNG Heavy-Duty Vehicles emit on average between minus 3 and 5 decibels dB of noise. This is 50% less than the average noise of diesel fuelled engines (Marcogaz, 2021).

Natural gas is used to replace diesel in two ways:

• Diesel Dual Fuel (DDF) - Natural gas is mixed with air at a certain design dynamic ratio before the piston cylinder in a vehicle engine. Energy from diesel is replaced with energy from gas, resulting in low diesel consumption for the same engine performance (Arefin, Nabi, Akram, Islam & Chowdhury, 2020).

• Dedicated Natural Gas Truck - These trucks require spark plugs to ignite LNG fuel and generate combustion. They do not use diesel as fuel. Volvo FH LNG is a dedicated natural gas truck which uses about 5% of diesel as a liquid spark plug. LNG has a higher energy density and is thus preferred over Compressed Natural gas by major manufacturers of heavy-duty vehicles. This results in longer hauling distances (Boretti, 2020).

LNG is better suited to heavy-duty vehicles which are constantly in motion compared to small vehicles which are mostly parked because of its cryogenic temperatures (Boretti, 2020). LNG can be compressed to 1/600th of its original volume. In addition,

the energy density of LNG is like that of diesel, which makes it efficient for long hauling distances (Marcogaz, 2021).

According to Kabeyi and Olanrewaju (2021), to convert a diesel engine to LNG requires alterations to the engine to enable injection of LNG into the air intake by installing two fuel injection systems. One injects a combination of gas and diesel while the other injects only gas. A certain amount of diesel is then injected into the engine, which creates combustion in the engine.

Answering the research questions above provided insights on the interests of transitioning heavy-duty vehicles to LNG, the awareness of LNG as an alternative fuel, and determined the interest to adopt it as a replacement for diesel. The economic and environmental effects of LNG as fuel versus diesel were unpacked. Challenges facing this transition were outlined as valuable insights for the government, heavy-duty vehicle owners, operators, and all other stakeholders.

1.7 Delimitations of the study

The study focused on utilising qualitative approaches to gather, assess, and understand data, emphasising the extraction of open-ended information, analysis of textual or visual content, and presentation of findings using graphical representations and tables, accompanied by results interpretation.

Secondary data for qualitative research are private and public documents (Creswell & Creswell, 2018). For this research, secondary data as qualitative documents were gathered, drawing from public and private sources such as journals, manufacturers' websites, government sector reports, and industry reports. Primary data collection methods were excluded to constrain the analysis of previously collected data by other researchers.

Secondary data collection primarily targeted heavy-duty vehicle owners, operators, and stakeholders within South Africa, with some supplementary data sourced externally to assess the transferability of findings across diverse settings.

1.8 Definition of terms

- Environmental awareness- Environmental consciousness refers to the overall understanding and concern regarding issues related to the environment (Geng & He, 2021).

- Fossil fuel- fossil fuels are formed from decomposed plants and organisms which have been buried beneath the earth and have carbon content. They include oil, coal, and natural gas. They are used for producing heat and energy, which stimulate processes such as steel and plastic making. Burning fossil fuels emits greenhouse gases and carbon dioxide, which are the primary causes of global warming and climate change (Nunez, 2019).
- Heavy-duty vehicles- Large commercial vehicles dominate the overall mileage of trucks because of their primary use in long-haul transportation. Additionally, their elevated energy consumption per vehicle results in heavy-duty vehicles contributing more significantly to the carbon dioxide emissions of the truck fleet (Kluschke, Gnann, Plötz, & Wietschel, 2019).
- Liquefied Natural Gas- LNG is a non-toxic liquid, formed when natural gas is cooled down to -162 degrees celcious. This process makes it easier to store and transport the gas as it is reduced 600 times its original volume. LNG is non-toxic, colourless and when in liquid form does not ignite (Hayes, 2022).
- Long-term sustainability- fulfilling current requirements while safeguarding resources and reducing socioeconomic and environmental effects for the benefit of future generations (Anwar, Dong, & Khan, 2023).

1.9 Assumptions

In the realm of research, it is imperative to conduct a rigorous examination of the available data, recognising its limitations, and simultaneously upholding transparency concerning the underlying assumptions. Understanding and acknowledging these assumptions is crucial in qualitative research, as they play a pivotal role in assuring the credibility and soundness of the research findings (Cropley, 2022). The assumptions which guided this study are as follows:

i. The primary researchers who collected data utilised methods which were rigorous and ethical.
ii. Primary data received from previous participants, and utilised in the initial research studies, were compiled in a thoughtful and honest manner.
iii. Secondary data collected were sufficient and relevant to answer the research questions of this research project, even though they were used in other research contexts.
iv. Documents used are authentic and accurate.

CHAPTER 2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Introduction

The objective of this chapter was to understand the research problem, identify the research gap, and develop a framework for the interpretation of the research findings. The literature reviewed is discussed in Section 2.2 and the research problem detailed in Section 2.3. The literature review was conducted to understand the theoretical or conceptual framework. The framework used for the interpretation of research findings is detailed in Section 2.6.

The second part of the literature review was conducted to answer the research questions mentioned in Section 1.4, to determine the interest of heavy-duty vehicle owners in adopting LNG as a fuel source.

2.2 Background discussion

Natural gas is available to be used as LNG in South Africa. It is imported from gas fields in Mozambique, known as Pande and Temane (Mokrani, 2022). In addition, Renergen has been awarded the first onshore rights to explore and produce petroleum in South Africa. The gas field covers an area of 187 000 hectares spreading across Welkom and Virginia, Free State, South Africa (Offshore Energy, 2022). Natural gas is considered a clean fuel and cheaper than diesel (Smajla et al., 2021). Its availability for heavy-duty vehicles will result in environmental and economic benefits for the country (SAGMP, 2021).

LNG in heavy-duty vehicles presents an opportunity to reduce CO_2 emissions. Despite high capital cost initially, the environmental impact is lower compared to diesel (Smajla et al., 2021). Increased use of LNG in road transport has the potential to increase competitive advantage through improved environmental and financial results (Marcogaz, 2021). Substitution of diesel by LNG in heavy-duty vehicles may be as Diesel Dual Fuel (DDF) or Dedicated Natural Gas engines (Renergen. n.d.). Diesel fuel network and infrastructure is available in large scale across all major routes in the country.

The environmental impact of natural gas can be noticed throughout the value chain, from exploration to processing and utilisation. Amongst others, these effects are on

land, groundwater, emissions, management of waste, water conservation and ecosystems. These effects, if not managed, may have a negative effect on the surrounding communities. Pollution of the atmosphere may be significantly reduced through the development of LNG because of its low greenhouse gas emissions (SAGMP, 2021).

According to Osorio-Tejada, Llera and Scarpellini (2015, p. 240), cost savings of operating heavy-duty vehicles on LNG are realised because of lower prices of LNG compared to diesel. A study conducted in the USA, where about 3 600 trucks are operated on LNG, revealed that the payback period for a new LNG dedicated vehicle which covers a distance of 192 000 km per year is less than three years. A study conducted in China on an engine converted to LNG indicated a payback period of less than 2 years. In Europe, data collected from 182 LNG vehicles purchased in 2013 in Spain indicated a payback period between one and two years. The main considerations and determining factors for adopting LNG should primarily be based on economic perspectives, such as the financial benefits associated with this type of fuel (Smajla et al., 2021).

Various pilot projects are currently being conducted to determine the feasibility of LNG use in heavy-duty vehicles in South Africa (Renergen, n.d.). Renergen has partnered with Total to install LNG dispensing pumps along the N3 between Johannesburg and Durban (Naidoo, 2020). Volvo Trucks has unveiled its LNG based truck and made it available to the South African market for analysis (Volvo Trucks, n.d).

According to Arefin et al. (2020), although vehicles with LNG fuelled engines cover a driving range between 700 and 1000 km, all factors should be taken into consideration to determine their viability. Infrastructure costs, capital costs, conversion costs and LNG storage requirements costs are some barriers to transitioning to LNG. These may be addressed by offering financial assistance to specific fleets (SAGMP**,** 2021).

2.3 First research question

What is the role of economic factors in the owners and operators' decision-making process of adopting LNG as fuel in heavy-duty vehicles?

2.3.1 Economic impact of adopting LNG as fuel

LNG fuelled heavy-duty vehicles are more economical than their diesel counterparts. The analysis in a study by Smajla et al. (2021) indicated that an LNG vehicle consumed 0.306 US dollar per kilometre while the diesel consumed 0.444 US dollars per kilometre. This represents a saving of 0.138 US dollars per kilometre by an LNG vehicle. According to Arefin et al. (2020), vehicles with LNG fuelled engines cover a driving range between 700 and 1000 km.

LNG presents a stronger economic appeal in scenarios involving long-distance transportation, however, infrastructure limitations, initial investments, and challenges related to storage pose potential barriers to its uptake (Mokrani, 2022).

It is proposed that the economic factors involved in the decision-making process of owners and operators regarding the adoption of LNG as fuel in heavy-duty vehicles are pivotal.

2.4 Second research question

How does the environmental awareness of owners and operators of heavy-duty vehicles affect their decision-making process of adopting LNG as fuel?

2.4.1 Environmental awareness of LNG as an alternative fuel

Liquefied Natural Gas in heavy-duty vehicles is considered a cleaner fuel than diesel (Smajla et al., 2021). Its usage by heavy-duty vehicles will result in decreased negative effects on the environment (SAGMP, 2021).

In aligning with the South African governmental climate change pledge through decarbonisation efforts, substituting coal and oil with LNG has the potential to reduce greenhouse gas emissions not only by 2030, but also in the foreseeable future (Mokrani, 2022). The emissions resulting from fossil fuel usage in transportation can be mitigated through the adoption and the utilisation of engine technologies that are less carbon-intensive, such as LNG (SANEDI, 2021).

It is proposed that heavy-duty vehicle owners who are aware of LNG as an alternative fuel are likely to adopt it.

2.5 Third research question

How does knowledge and awareness of LNG as fuel determine its adoption as fuel by the owners and operators ?

2.5.1 *knowledge and awareness of LNG as alternative fuel*

The first stage of SANEDI's project focused on assessing sustainable energy and technology solutions to reduce greenhouse gas (GHG) emissions through extensive consultations with industry stakeholders across different sectors of the coal, oil, and gas industries, with the objective of determining their perspectives pertaining to cleaner fossil fuel technologies. A summary of the stakeholder engagements was collated, with the intention to be further expanded in subsequent phases, to develop roadmaps on LNG uptake (SANEDI, 2021).

Various pilot projects are currently being conducted to determine the feasibility of LNG in heavy-duty vehicles (Renergen, n.d.). Volvo Trucks has unveiled its LNG based truck and made it available to the South African market for analysis (Volvo Trucks, n.d.). Renergen has partnered with Total to install LNG dispensing pumps along the N3 between Johannesburg and Durban (Naidoo, 2020).

It is proposed in this research that the level of knowledge and awareness regarding LNG as a fuel significantly influences its adoption.

2.6 Fourth research question

How can the adoption of LNG as fuel by the owners and operators improve the long-term sustainability of operating heavy-duty vehicles?

2.6.1 *Long-term sustainability of utilising LNG*

According to the US Department of Energy (2016), historically, the prices of LNG have exhibited more stability than diesel prices, with less fluctuations. The study also revealed that the cost of LNG was R3.03 cheaper than diesel. LNG fuelled heavy-duty vehicles have shown an extended driving range, reaching up to 700–1000 km per tank because of their superior energy density (Arefin et al., 2020). These factors are likely to have a positive impact on the long-term sustainability of long-haul heavy-duty vehicle operators' businesses.

It is proposed in this research that the economic factors involved in the decision-making process of owners and operators regarding the adoption of LNG as fuel in heavy-duty vehicles are pivotal.

2.7 FRAMEWORK

2.7.1 Theoretical Framework

To interpret the research findings, Everett Rogers Diffusion of Innovation Theory was applied. The theory explains the adoption of new technologies within a social system while providing a framework for understanding factors which influence the adoption (Dearing & Cox, 2018). This theory is in line with the research purpose in that it can be used to explain the interest of adopting LNG as fuel by identifying characteristics of adoption such as:

- Benefits and advantages of adopting LNG as fuel.
- Alignment of LNG utilisation with the owner's value system.
- Perceptions of owners about the adoption and utilisation of LNG.
- Visible results of LNG by the owners who are utilising it as fuel.
- The possibility of having a test phase before rolling out on a large scale.

An application of this theory can provide insights into the owner's decision-making process, knowledge and awareness, and the interest of owners in adopting LNG as fuel (Dearing & Cox, 2018).

2.7.2 Conceptual Framework

The conceptual framework indicated in Figure 1 indicates that the interest in adoption of LNG is influenced by managers' environmental awareness, economic awareness, knowledge and awareness of LNG and long-term sustainability goals of operating heavy-duty vehicles. The economic benefits of LNG are realised on long-haul heavy-duty vehicles; however, LNG requires a significant capital start-up compared to CNG (Osorio-Tejada et al., 2015).According to the South African Gas Master report Infrastructure costs , capital costs, conversion costs and LNG storage requirements costs are some barriers to transitioning to LNG. These may be addressed by offering financial assistance to specific fleets (SAGMP, 2021).

CHAPTER 3. RESEARCH METHODOLOGY

The procedure followed and methods used in this research are explained in this section. Data collection methods are discussed in Section 3.2. The description of the population, the sample and the sampling methods are described in Section 3.3.1, research instrument in Section 3.4, procedure for data collection in Section 3.5, data analysis in Section 3.6, limitations and challenges in Section 3.7, quality assurance in Section 3.8 and ethical considerations in Section 3.9.

3.1 Research approach

A qualitative method was chosen for this research. It was selected for its ability to enrich knowledge and provide an understanding of the research problem. This method studies how people interpret their experiences in their minds and how they express them using their own words. Data collected using this method are the descriptive type and are known as narratives (Cropley, 2022).

The advantages of qualitative research are its distinct characteristics. Qualitative research enables the exploration of new insights, establishment of broadly defined objectives, the emergence of content, formulation of hypotheses, and establishment of credibility. Its essence can be grasped through its comprehension of reality, the types of questions investigated, and the methods used. Qualitative research is primarily inductive and adaptable in nature. Qualitative methodology poses some challenges regarding rigour, and heavily relies on distinct criteria for validity, such as the plausibility of conclusions (Cropley, 2022).

Other disadvantages of qualitative research are its propensity to give rise to unique ethical concerns which can arise when researchers delve into the personal and sensitive experiences of participants, requiring them to share the intricate details of their deeply meaningful or even distressing life events (Cropley, 2022).

3.2 Research design

Research design is a method chosen to collect data. An exploratory research design was used. This research method explores topics with limited understanding to gain deeper knowledge. Through the study, insights were gathered to develop a hypothesis or a theory. The hypothesis and theories can be used to aid in understanding the decision-making process of heavy-duty vehicle owners (Cropley, 2022).

Document analysis is a process for inspecting and appraising various types of documents, including both traditional printed materials and digital content transmitted via computers and the internet. It involves a comprehensive review and interpretation of data to uncover significance, enhance comprehension, and construct empirical knowledge (Glen, 2009).

For this research, documentary analysis was done using secondary data. As indicated in Section 1.8(i), an assumption was made that data from previous researchers was collected using rigorous methods which met ethical standards. Document analysis offers several advantages and disadvantages in qualitative research (Glen, 2009). The advantages of document analysis are:

i. It is a time-efficient method as it involves data selection rather than data collection, streamlining the research process.

ii. Many documents are in the public domain, easily accessible, and do not require authors' permission. The internet has further expanded the availability of documents for analysis.

iii. Document analysis is cost-effective because it often uses existing data, eliminating the need to gather new information. The focus is on evaluating the content and quality of documents.

iv. Documents are unobtrusive and non-reactive, meaning they remain unaffected by the research process, reducing concerns related to researcher influence and reflexivity. Unlike observations, documents do not alter the events they describe.

v. Documents are stable and suitable for repeated reviews, ensuring consistency in the analysis process.

vi. Documents often include precise names, references, and event details, enhancing the accuracy and reliability of the research.

vii. Documents provide extensive coverage, spanning a wide range of time, events, and settings, making them valuable for comprehensive research.

The disadvantages of document research are:

i. Documents are not created with research in mind, often lacking the level of detail needed to fully address a research question.

ii. Document retrieval can be challenging, and in some cases, access to specific documents may be intentionally restricted.

iii. Document collections may exhibit biased selectivity, especially in organisational contexts, as they may be aligned with corporate policies or the agenda of certain organisational units, potentially skewing the available information.

3.3 Data collection methods

Data were collected from secondary sources which have been used by other researchers in various studies. This data were sourced from private and public documents such as journals, government reports, industry reports and manufacturers' websites to answer the research questions. The exploratory nature of this study justifies the use of secondary sources because of the time available to conduct the research, access to diverse sources and the opportunity to understand historical context through observing trends over time. Data relevant to the research questions were collected from such studies, even though some studies consulted were conducted to answer different questions in varying contexts.

These secondary data were used to explore the motivations, behaviours, and perspectives of owners and operators in the heavy-duty industry towards the adoption of LNG.

3.4 Population and sample

3.4.1 *Population*

A population is referred to as the whole group which the research is intended to make an inference about (Bhandari, 2020). Throughout the research journey, researchers might gather qualitative materials, which can take the form of either publicly available documents such as newspapers, records of meetings, and official reports, or privately held documents such as personal journals, diaries, letters, and emails (Creswell & Creswell, 2018).

For this research, documents were reviewed to collect secondary data from public and private sources. A wide range of secondary data sources, such as government records, academic research, newspapers, and online databases, was searched to access diverse perspectives and data types.

3.4.2 *Sample and sampling method*

When conducting research about a group of people, data are not collected from all members of the group. A group referred to as the sample is selected to take part in the research (Bhandari, 2020). The study was conducted by collecting secondary data on stakeholders in the heavy-duty vehicle environment such as logistics operators, manufacturers, and the government in South Africa. Some secondary data were collected from sources outside South Africa.

A purposeful sampling of secondary data sources where owners, stakeholders and operators of heavy-duty vehicles were studied was used. For this sampling method, sources relevant to addressing the research questions, and which were deemed likely to provide insights to the research objective were selected.

The fundamental concept in qualitative research involves the deliberate selection of documents and materials with the intent of gaining a deeper understanding of the problem and addressing the research question effectively (Creswell & Creswell, 2018).

3.4.3 *Research instrument*

The secondary data collected for this study encompassed a diverse array of secondary sources, such as journals, government reports, industry reports, and manufacturers' websites from both South African and international contexts. Extracts of raw data relevant to the research questions were compiled and organised into tables alongside corresponding codes, facilitating the identification of patterns, themes, and pertinent insights aligned with each research question. Appendix A provides a tabulation delineating the type of secondary source, name of the source, the raw data transcript, key statements from the raw data, and the emergent code.

The emergent codes identified were then combined together to identify themes as indicated in Appendix B. These themes were then analysed to determine patterns as indicated in Figure 4.1.

3.4.4 *Procedure for data collection*

Qualitative research can be carried out without the necessity of collecting new data. In this approach, researchers engage with pre-existing narratives that are available (Cropley, 2022). Data were collected from available papers, government reports, industry reports, journals, manufacturers' websites, which were applicable to the research questions. In addition, data were sourced from academic data bases such Google scholar using research questions and keywords. Government sector reports were explored to search for published reports, statistics, and other forms of data. Citations of sources identified were reviewed to access additional scholarly articles for secondary data.

3.4.5 *Data analysis strategies and interpretation*

The analytic strategy which was used during this study is thematic analysis. Creswell and Creswell (2018) explain this strategy as a generic form of analysis in which the researcher collects data, conducts an analysis to identify themes or perspectives and reports on identified themes. The method is used to identify, analyse and report themes through coding and categorising secondary data to unpack meaning. For this study, the following steps were followed:

i. Secondary data were collected from private and public documents. The researcher familiarised themselves with data regarding content and context.
ii. Raw data extracts relevant to research questions were identified and descriptive codes which capture key ideas and patterns were assigned to them. Coding of data was done by segmenting sentences into paragraphs and assigning a label to those segments.
iii. The process followed in (ii) above was repeated throughout secondary data collected to identify different codes.
iv. Related codes were grouped together to establish meaningful themes. Each theme was named to capture its essence.
v. Themes were checked to ensure consistency with the secondary data collected.
vi. A thematic map indicated in Figure 4.1 was compiled to indicate the patterns arising from the themes identified.

3.5 Possible limitations and challenges of the study

Possible limitations of the study are:

i. The study only focused on the interest of owners and operators of heavy-duty vehicles who may opt for LNG as fuel. LNG may be used in various other forms of engines.
ii. The answers to the research questions are only applicable to heavy-duty vehicle operators.
iii. Secondary data from operators who have experience at various levels of management and operation of LNG fuelled vehicles were limited because of the uptake of LNG currently in South Africa.

3.6 Quality Assurance

3.6.1 *Transferability*

Transferability in research refers to the ability of findings to be applied to different contexts (Smith, 2022). These contexts may be similar groups, circumstances, or situations. The following factors pertaining to the research maximise the transferability of findings:

- The context of the research is the South African heavy-duty logistics industry. This industry accounts for the transportation of goods to all parts of the country and continent. To achieve this, it is reliant on diesel as a source of fuel. LNG has the potential to reduce this reliance on diesel, which may be a cost efficient, environmentally friendly, and secure form of energy (SAGMP, 2021).

- Secondary data collected and the analysis thereof were presented transparently to improve the transferability of findings.

- Attention was paid to the selection of the sample. The sample selected was a representative of owners and operators in the heavy-duty logistics industry.

- The researcher has no experience of the industry studied and thus no perspective regarding the answers to research questions. There was no bias.

- Data collection and analysis was detailed to allow other researchers to apply the findings to different contexts.

3.6.2 *Credibility*

Credible research is trusted by readers, and they believe the findings can be applied in their contexts. These findings are reliable, consistent and can be replicated by other researchers (Stenfors, Kajamaa & Bennett, 2020).

For this study, credibility is determined by considering the following factors:

- Triangulation: This included the involvement of a supervisor allocated by Wits University Business School who assisted with guarding against individual bias and ensuring that the interpretation of data was correct, having discussions about the findings and analysis, and using different sources for collection of data during the literature review.

- Sufficient research time: Time allocated for this research study was well over a year, which allowed time to develop thorough understanding and knowledge of the subject. Sufficient time was allocated to further conduct a literature review to study documents related to secondary data.

- Transparent reporting: Honesty, vulnerability and transparency are indicators of sincerity in research (Tracy, 2010). The findings, methods used, and the analysis were explained transparently throughout the report.

- Thick description: Context of the study, methods used to analyse data, and all participants were described to allow similar studies in the future to replicate the research.

- Audit trail: All documents and data collected were maintained to ensure that interested parties may have access when required.

3.6.3 *Dependability*

The assumptions that were made by the researcher in this study are listed in Section 1.8 and the limitations in Section 3.8. Secondary data used are available to other researchers for peer review to verify and validate findings. All sources of secondary data were documented to allow for the assessment of research quality. Dependability is an indication of how consistent and reliable the research findings throughout a period and various settings are. Where possible, the staff conducting coding should

not have knowledge of the project to eliminate bias (Creswell & Creswell, 2018). For this research, the researcher had knowledge of coding.

3.7 Ethical considerations

In qualitative research, there are various types of ethics. The types of ethics which this report addresses are procedural, situational, relational, and exiting (Tracy, 2010).

Procedural ethics: Data collected and information used in this report were not obtained fraudulently, fabricated, or intentionally omit other relevant information.

Situational ethics: Situational ethics pertain to ethical principles that arise from a thoughtful evaluation of unique conditions within a given context (Tracy, 2010). Each situation is unique and requires the researcher to constantly analyse information and data critically. This flexibility was employed during the research to identify information and instances which might not be revealed and to maintain moral obligation.

Besides the above, the following factors were addressed in this report to ensure ethical conduct:

i. Ethical treatment of data: Sources of secondary data are disclosed in report. Only publicly available data was utilised with no infringements on any intellectual property.
ii. Transparency and integrity: The research was conducted in a transparent and honest manner to maintain integrity. The findings of the report were not misrepresented.
iii. Ethical review and approval: The University requires ethics approval for research work. An application was submitted to the ethics committee for ethics clearance. After submitting a proposal, an ethics clearance certificate was issued for the research study to continue.
iv. Continuous reflection on ethics: Throughout the study, there was continuous reflection on ethics with the guidance from the supervisor. This ensured that any decision or conclusion made was done ethically.

CHAPTER 4. FINDINGS

The study identified six main themes relating to the interest in adopting LNG as fuel. Firstly, it discussed the inclination among heavy-duty vehicle operators in South Africa and internationally towards embracing LNG as a fuel option. Fuel Firing Systems, FFS has recognized the potential of LNG as a cleaner fuel alternative, not only on its own fleet but among its product offerings (FFS, 2020). These findings align with a report from renergen about Timelink, a South African logistics operator, who has entered into an agreement with Renergen, and converted some of its heavy-duty vehicles to LNG (Renergen, n.d).

Secondly, it examined the acknowledgment among these operators of LNG's potential as a feasible alternative to conventional fuels. A project carried out by SANEDI (2021) involving various stakeholders identified the need by heavy-duty vehicle industry personnel to transition to a cleaner fuel such as LNG.

Thirdly, the study investigated the environmental awareness surrounding the detrimental effects of current fossil fuel usage and the potential advantages of transitioning to LNG. Because of its lower emissions compared to coal and oil, LNG has garnered significant recognition in the global market (Arefin et al., 2020).

The fourth theme delved into the economic factors associated with adopting LNG, emphasising its potential to provide competitive advantages. Timelink has entered into an agreement with Renergen, and has converted some of its heavy-duty vehicles to LNG. Timelink currently holds an advantage over its competitors when engaging with customers who prioritise logistics suppliers with lower carbon footprints. Additionally, the company benefits from reduced operating costs and enhanced operational flexibility (Renergen, n.d).

The fifth theme explored the sustainability considerations influencing the preference for LNG among heavy-duty vehicle operators. As indicated on Figure 4.1, LNG prices have exhibited greater stability, experiencing minimal fluctuations compared to diesel over time. This contributes positively to the sustainability of operators utilising it. Heavy-duty vehicles fuelled by LNG boast an extended range, reaching up to 700–1000 km, because of the fuel’s higher energy density (Arefin et al., 2020). There is, however, a perception by heavy-duty vehicle operators that the government may implement taxes and levies on the usage of LNG, when the revenue loss from taxation because of diesel levies is negatively affected by LNG uptake (SANEDI, 2021).

Lastly, the study scrutinised the challenges related to infrastructure, particularly the availability of LNG for refuelling heavy-duty vehicles in South Africa. Successful adoption of LNG lies in the establishment and development of infrastructure in South Africa (SANEDI, 2021). Constructing an LNG import terminal stands as the optimal decision for South Africa to expedite the integration of natural gas into its energy blend (Mokrani, 2022). Table 4.1 gives a summary of themes covered during the research.

Table 4.1: Summary of themes discussed

Interest in adopting LNG.	**Awareness of LNG**	**Environmental awareness**	**Infrastructure**	**Sustainability**	**Competitive advantage**
• Transition to cleaner energy. • Alternative fuel • Demand for cleaner fuels is increasing	• LNG is highly recognised as an alternative fuel. • Engagement with local stakeholders resulted in some infrastructure development. • LNG is used by some popular heavy duty vehicle models. • Local operators' engagement	• LNG has potential to improve carbon footprint. • South African government has set targets to reduce carbon emissions. • Customers concerned with their contribution to the environment.	• Access to refuelling network • South Africa must consider LNG import terminal. • Filling stations are planned along major routes	• LNG allows long term sustainability. • Operators in Europe have seen a range up to 1000km when using LNG	• Usage of gas has potential economic benefits. • LNG Prices are stable. • Usage of gas has potential economic benefits

The study synthesised data from South African and international sources, focusing primarily on the South African context while drawing insights from global perspectives.

Figure 4.1 provides a summary overview of the specifics underlying each of the themes covered during the research investigation.

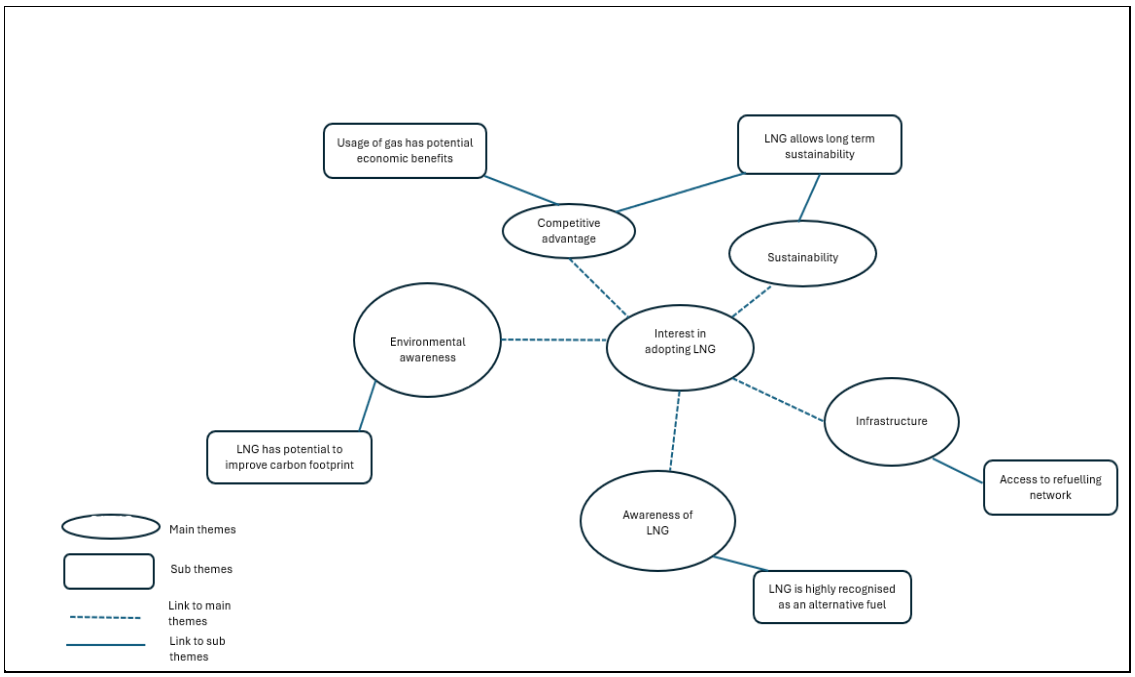


Figure 4.1: Thematic map indicating themes.

4.1 Interest in adopting LNG by heavy-duty vehicle operators

4.1.1 *Awareness of LNG as an alternative fuel by heavy-duty vehicle operators*

LNG trucks are becoming increasingly prevalent across the globe (SANEDI, 2021). Volvo Trucks Southern Africa, a manufacturer of heavy-duty vehicles, is determined to pave the way forward by making available environmentally friendly and innovative solutions to the heavy-duty vehicle sector both locally and internationally. As such**,** Volvo Trucks has initiated the testing process of LNG operated heavy-duty vehicles in South Africa. The test is conducted using two vehicles with a specific aim at heavy-duty transport in long and short hauling operations (Volvo Trucks, 2020)

Fuel Firing Systems (FFS), a prominent South African provider of maritime fuels servicing local and international fleets across seven ports in the Western and Eastern Cape, has responded to the increasing demand for eco-friendly fuel alternatives by expanding its energy offerings to include LNG. This strategic move aims to enhance fuel diversity, promote sustainability, and empower clients to mitigate their environmental impact.

Initially, FFS initiated the importation of LNG using Isotainers and established a compact facility to demonstrate the versatility of LNG. This initiative provided FFS with invaluable experience in managing LNG logistics and effectively implementing the technology.

In the transportation sector of the initiative, FFS modified a truck to operate on a blend of LNG and diesel, integrating a refuelling station within the pilot facility to cater to the truck's LNG requirements. Throughout a designated operational period, meticulous observations were conducted on the truck's fuel consumption and other pertinent metrics (FFS, 2020).

4.1.2 *Environmental awareness*

According to the National Business Initiative (NBI, 2023), Imperial, a logistics services provider in South Africa and across the African continent, is undertaking pilot programmes to explore future alternative energy technologies as part of its commitment to long-term environmental sustainability and emission reduction efforts. These initiatives include a range of solutions, such as pure- and dual-fuel LNG trucks. Central to the evaluation of these technologies' feasibility are several key factors: ensuring safety measures are met, assessing the consistent availability of both fleet and fuel, evaluating the adequacy of refuelling infrastructure, and considering the total cost of ownership. Additionally, Imperial seeks collaboration with clients willing to engage in partnership ventures aimed at advancing these innovative energy solutions.

With the increasing global demand for cleaner fuels, FFS has decided to add LNG to the suite of fuels it provides and give FFS' customers options to reduce their environmental footprint (FFS, 2020).

4.1.3 *Competitive advantage of adopting LNG as fuel*

According to the US Department of Energy (2016), a quarterly publication aimed at informing clean cities coalitions and other stakeholders about the current prices of alternative and conventional fuels across the United States, LNG prices have historically exhibited stability; they have experienced minimal fluctuations when compared to diesel. This trend is illustrated in Figure 4.2, which presents data collected between 2012 and 2022.

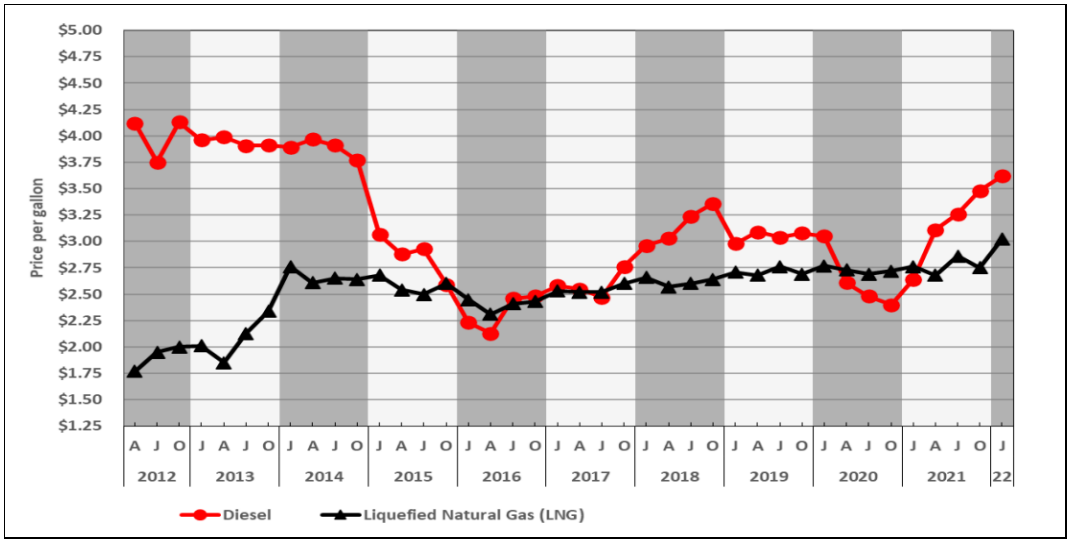


Figure 4.2: Historical trend of LNG prices versus diesel

Arefin et al. (2020) conducted a review on liquefied natural gas as fuels for dual fuel engines, exploring the opportunities, challenges, and responses associated with this technology. Their research indicated that LNG heavy-duty vehicles offer lower fuel costs compared to their diesel counterparts. Through analysis of the estimated payback period and net present value of LNG heavy-duty vehicles under different conditions, they concluded that these vehicles represent a promising and sustainable alternative for transportation.

Renergen has collaborated with Timelink, a specialist services provider in long distance transport services to provide LNG and substitute diesel in its heavy-duty vehicle fleet. This gives them a competitive edge in meeting the developing demands of environmentally conscious customers. By offering a lower carbon footprint through LNG and DDF technology, they can attract clients seeking greener logistics solutions. Moreover, the reduced operating costs and enhanced operational flexibility further strengthen their value proposition in the market, setting them apart from competitors and solidifying their position as industry innovators (Renergen, 2023). Moreover, according to Renergen, its subsidiary Tetra4,has received four DAF CF 430 trucks from Babcock, a transport solutions company. Over the past three and a half years, Babcock has been supporting an increasing number of DAF trucks running on natural gas in South Africa. It reported are 24 dual fuel vehicles in operation (Engineering News, 2022).

LNG fuelled heavy-duty vehicles can be operated over a range of distances between 700 and 1000 km because of its higher energy density (Arefin et al., 2020).

The information provided by the South African National Energy Development Institute (SANEDI) indicates that the cost of LNG is currently approximately 18% lower than the cost of diesel when compared on a per heating value basis (R/GJ). This cost advantage underscores the economic benefits of transitioning to LNG as a fuel source, especially for industries seeking to reduce operating expenses and improve cost efficiencies while also lowering their carbon footprint (SANEDI, 2021).

Figure 4.3 below depicts the wholesale gas prices in various African nations from 2015 to 2020, expressed in US dollars per MMBtu. The chart highlights trends in gas prices across different countries. In South Africa, the prices have remained below $1 USD with minimal changes throughout this period (Ouki, 2022).

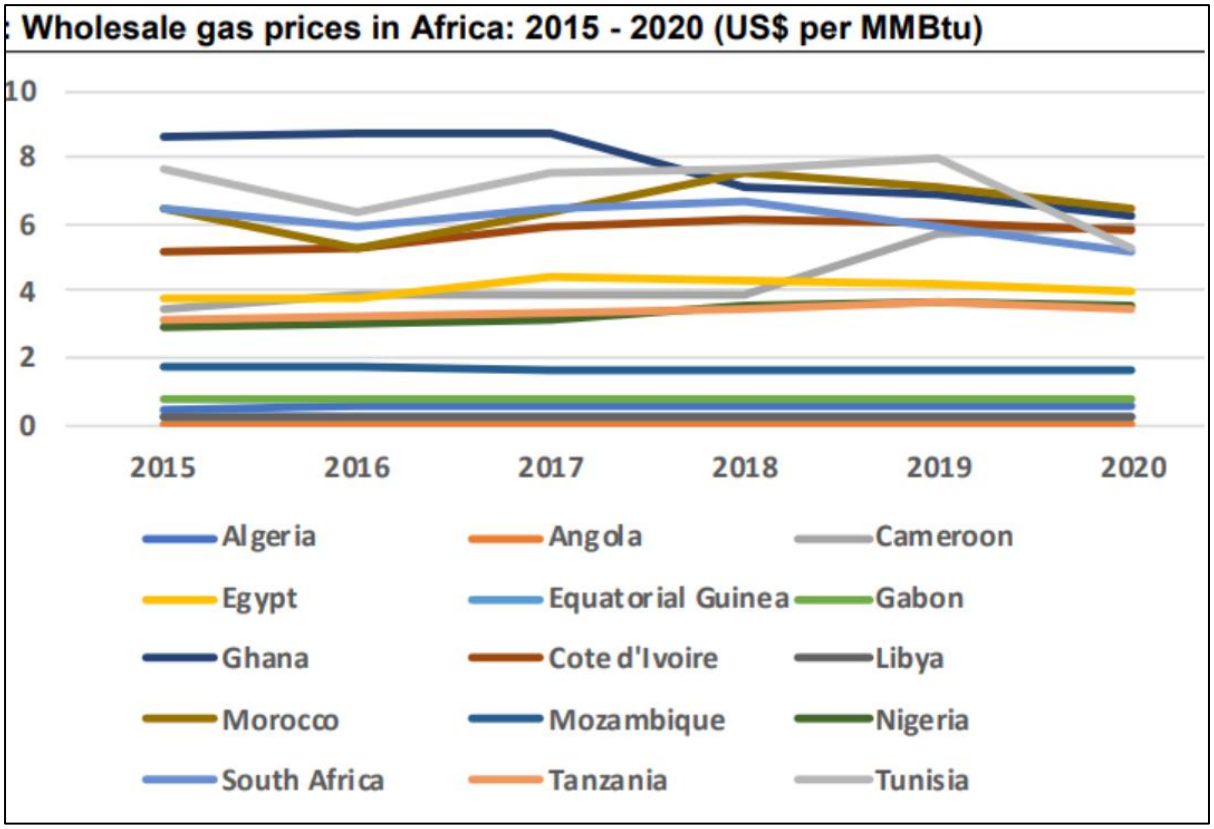


Figure 4.3: Historical LNG trends in Africa

4.1.4 *Long-term sustainability of LNG usage in heavy-duty vehicle industry*

The new LNG fuelled heavy-duty vehicles manufactured by Volvo and delivered to South Africa, offer fuel efficiency equivalent to diesel vehicles at the same driving speed. Because of the relatively low cost of LNG, these vehicles offer customers an opportunity to minimise the cost of fuel (Volvo Trucks, 2020). According to Volvo Southern Africa, heavy-duty vehicle operators in Europe have reported a haulage range of about 1000 km per 205 kg LNG tank.

Comparative analysis conducted by FFS revealed an 11% reduction in energy consumption when the truck operated on the LNG-diesel blend, primarily because of the enhanced combustion efficiency of LNG. These results indicate potential for cost savings on fuel expenditure (FFS, 2020).

In an effort to foster greener transport solutions, the US Department of Energy conducted research on switching from old diesel to 2011 heavy-duty vehicles powered by natural gas and utilising LNG for consistent city-to-landfill routes. Operating six days weekly with dual daily refuelling, the findings revealed that, despite upfront costs and the need for new infrastructure, there are considerable long-term gains. These include marked reductions in both fuel expenses and carbon emissions, coupled with enhanced public perception through commitment to environmental care (Argonne National Laboratory, 2013).

In 2001, SF Recycling & Disposal, a subsidiary of Norcal Waste Systems, Inc. based in San Francisco, USA, began deploying 14 heavy-duty, waste transfer trucks powered by LNG to investigate cleaner emission technologies. An important finding from this initiative was that drivers reported the performance of the LNG trucks to be on par with or even better than that of diesel trucks (Chandler & Proc, 2004).

4.1.5 *Infrastructure required to adopt LNG as fuel*

In order to increase the utilisation of LNG in South Africa, the infrastructure to import and distribute it will be required (SANEDI, 2021). Constructing an LNG import terminal stands out as the optimal choice for South Africa to expedite the integration of natural gas into its energy blend (Mokrani, 2022).

Recently, collaborations among stakeholders in the heavy-duty vehicle industry have culminated in the establishment of refuelling infrastructure along the N3 highway, connecting Johannesburg and Durban (Volvo Trucks, 2020).

Renergen, the operator of a small LNG plant in South Africa, has inaugurated what it claims to be the country's inaugural commercial LNG production facility, marking the initial phase of its Virginia gas and helium development. Additionally, Renergen is strategising for the second phase of the Virginia gas project, slated for operationalisation in 2026. As part of its expansion plans, Renergen aims to establish a number of LNG filling stations across South Africa, facilitating the delivery of fuel to specific customers along major highways once the Virginia project advances to its second phase. The second phase will boost this output to about 680 tons daily. This increased production is comparable to 940,000 liters of diesel per day. (Renergen, 2023).

Renergen and Total, in collaboration with logistics firms such as Imperial and Black Knight, are set to initiate LNG truck fuelling initiatives along key national road networks within South Africa (SANEDI, 2021).

4.1.6 *Concerns on the adoption of LNG as fuel*

Although there were positive perspectives amongst the owners and operators of heavy-duty vehicles in adopting LNG as fuel, there were also concerns identified. According to the South African National Energy Development Institute (SANEDI), the initial phase of their study aimed to chart a pathway towards transitioning to cleaner fuels. Throughout the consultation process, a focused strategy was employed to engage with key industry stakeholders, with the goal of gaining insights into their existing strategies and viewpoints regarding cleaner fossil fuel technologies. Additionally, efforts were made to seek clarification on any objectives and timelines outlined in their publicly available plans (SANEDI, 2021).

In this context, the Road Freight Association (RFA) voiced concerns about the potential imposition of government levies and taxes on LNG. There is apprehension within the RFA that once LNG consumption surpasses a certain threshold, government authorities may introduce taxes. Consequently, the RFA stressed the necessity for the government to provide clarity on this matter and to commit to a definitive stance.

The adoption of LNG as fuel by heavy duty vehicle industry may lead to loss of revenue from fuel levies by the government. A SWOT Analysis (Strengths, Weaknesses, Opportunities, and Threats) conducted for the national development of natural gas revealed that one of the weaknesses is the absence of Road Accident Fund levies (RAF) on LNG (SAGMP,2021). Furthermore, an article by Statistics South Africa, states that during the 2019/20 fiscal year, RAF collected R41.2 billion from the levy, which accounted for 99.8% of its total revenue, making it the primary source of income for the Fund. At the same time, the general fuel levy generated R80 billion for the government, comprising approximately 6% of the total tax revenue. Of the revenue from the RAF levy, 93% was used for claim payments. Furthermore, R13.2 billion from the general fuel levy was specifically allocated to South Africa's eight metropolitan municipalities in the 2019/20 fiscal year (Stats SA, 2021).

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Conclusion regarding each of the research questions is outlined below. Contribution to knowledge from this research is highlighted on Table 5.1.

5.1.1 *Conclusion regarding research question 1*

The role of economic factors in the decision-making process of owners and operators regarding the adoption of LNG as fuel in heavy-duty vehicles is pivotal. The summary highlights several key economic considerations. Firstly, the high operating cost per kilometre of diesel negatively affects sustainability, prompting interest in more cost-effective alternatives like LNG. Diesel prices are subject to fluctuations driven by factors such as crude oil prices, supply and demand dynamics, and currency exchange rates, influencing overall fuel costs. LNG-fuelled vehicles demonstrate cost advantages over diesel counterparts, with significant savings per kilometre. Operators like Timelink have recognised these economic benefits, converting vehicles to LNG to gain competitive advantages in cost-effectiveness and operational flexibility. Additionally, LNG-fuelled vehicles offer economic appeal in long-distance transportation scenarios because of their substantial driving range. However, barriers such as infrastructure limitations, initial investments, and storage challenges may affect the widespread adoption of LNG. Overall, economic factors play a crucial role in shaping owners and operators' decisions regarding the adoption of LNG as fuel in heavy-duty vehicles, driving interest in cost-effective and sustainable alternatives to diesel.

5.1.2 *Conclusion regarding research question 2*

The environmental awareness of owners and operators of heavy-duty vehicles significantly influences their decision-making process regarding the adoption of LNG as fuel. The summary highlights the environmental challenges associated with the South African transport sector, including its substantial contribution to greenhouse gas emissions. With the sector heavily reliant on fossil fuels, there is growing recognition of the need to minimise environmental effects and reduce dependency on imported fuels. LNG has emerged as a favourable alternative because of its potential to mitigate these environmental concerns. Companies like Imperial are actively exploring LNG as

part of their commitment to long-term environmental sustainability and emission reduction efforts.

Furthermore, initiatives by companies like FFS to add LNG to their fuel offerings demonstrate a response to the increasing global demand for cleaner fuels. This indicates a growing awareness among owners and operators of heavy-duty vehicles about the environmental benefits of LNG. As a result, this awareness likely plays a significant role in their decision-making process, prompting them to consider and adopt LNG as a fuel option. Overall, environmental consciousness drives the inclination towards LNG adoption among heavy-duty vehicle owners and operators, shaping their decisions in favour of more sustainable fuel choices.

5.1.3 *Conclusion regarding research question 3*

The knowledge and awareness of LNG as a fuel play a crucial role in determining its adoption by owners and operators of heavy-duty vehicles. Pilot projects currently underway in South Africa, such as those led by Renergen and Volvo Trucks, aim to assess the feasibility of LNG in this sector. These initiatives provide valuable insights into the practicality and benefits of using LNG as a fuel for long-haul transportation. Partnerships between companies like Renergen and Total demonstrate a concerted effort to expand the availability of LNG infrastructure, increasing accessibility for vehicle operators.

Furthermore, projects conducted by organisations like SANEDI highlight the importance of industry personnel being informed about cleaner fuel alternatives like LNG. As stakeholders become more knowledgeable about the environmental and economic advantages of LNG, they are more likely to consider its adoption. This awareness influences decision-making processes, prompting owners and operators to explore LNG as a viable option for their fleets.

Overall, the knowledge and awareness of LNG as a fuel directly affect its adoption by owners and operators of heavy-duty vehicles, driving interest and facilitating the implementation of pilot projects and collaborations aimed at promoting its use in the transportation sector.

5.1.4 *Conclusion regarding research question 4*

The adoption of LNG as fuel by owners and operators can significantly improve the long-term sustainability of operating heavy-duty vehicles in several ways.

Reduced Energy Consumption: Comparative analysis has shown that using an LNG-diesel blend can lead to an 11% reduction in energy consumption because of LNG's enhanced combustion efficiency. This reduction translates to lower fuel consumption, ultimately reducing operational costs and environmental impact.

Stable Pricing and Cost Savings: LNG prices have exhibited greater stability compared to diesel, making it a more reliable and potentially cost-effective fuel option in the long term. The potential for cost savings on fuel expenditure further motivates owners and operators to adopt LNG.

Extended Range: Heavy-duty vehicles fuelled by LNG boast an extended range of 700–1000 km because of the higher energy density of LNG. This extended range enhances operational flexibility and reduces the need for frequent refuelling, thereby improving efficiency and reducing downtime.

Environmental Benefits: LNG combustion produces fewer emissions compared to diesel, resulting in lower greenhouse gas emissions and improved air quality. This aligns with sustainability goals and regulatory requirements aimed at reducing carbon footprints and mitigating environmental impact.

Infrastructure Development: Successful adoption of LNG as a fuel requires the development of infrastructure, including LNG refuelling stations and import terminals. Investing in infrastructure not only supports the adoption of LNG but also creates opportunities for job creation and economic growth.

Overall, the adoption of LNG as fuel by owners and operators of heavy-duty vehicles can contribute to long-term sustainability by reducing energy consumption, stabilising pricing, extending vehicle range, reducing emissions, and fostering infrastructure development.

Table 5.1 : Consistency table

Research question	Research Question	Proposition	Conclusion	Key differences
1.	What is the role of economic factors in the decision-making process of adopting LNG as fuel in heavy-duty vehicles?	The economic factors involved in the decision-making process of owners and operators regarding the adoption of LNG as fuel in heavy-duty vehicles are pivotal	LNG-fuelled vehicles offer economic appeal in long-distance transportation.	LNG operators consider economic factors when adopting LNG. There are however risks to adopting such as possible tax levies.
2	How does the environmental awareness of owners and operators of heavy-duty vehicles affect their decision-making process of adopting LNG as fuel?	Heavy-duty vehicle owners who are aware of LNG as an alternative fuel are likely to adopt it.	LNG is as a favourable alternative to mitigate environmental concerns.	Heavy duty vehicle operators who are aware of LNG are likely to adopt in when there is government support, infrastructure, and less concerns regarding possible levies.
3	How does knowledge and awareness of LNG as fuel determine its adoption as fuel ?	The level of knowledge and awareness regarding LNG as a fuel significantly influences its adoption	The current level of knowledge and awareness remains modest. A select number of operators are engaged in trial runs.	None
4	How can the adoption of LNG as fuel improve the long-term sustainability of operating heavy-duty vehicles?	The utilisation of LNG as fuel in heavy-duty vehicles can improve long-term sustainability	Heavy-duty vehicles fuelled by LNG have a longer driving range than diesel.	None

5.2 Recommendations

The relevance of these findings for heavy-duty vehicle operators in South Africa is multifaceted. It highlights the potential for LNG to serve as a cleaner, more cost-effective alternative to traditional diesel fuel. The adoption of LNG can lead to reductions in fuel costs and improve the country's carbon footprint, enhancing the competitiveness and environmental sustainability of operators' fleets. The development of necessary LNG infrastructure, such as refuelling stations, further supports the viability of LNG, enabling operators to make a seamless transition to more eco-friendly operations while maintaining operational efficiency.

The utilisation of natural gas has the potential to benefit the South African economy in terms of market developments and employment creation (SAGMP, 2021). This is also evident from the decision by FFS to increase their fuel offering service to LNG because of the increased demand for cleaner fuels by environmentally conscious customers. These customers benefit in terms of long-term sustainability of their operations (FFS, 2020).

5.3 Suggestions for further research

This study relied on secondary data gathered from numerous previous research endeavours. The process of collecting primary data remained separate from this research, ensuring independence from potential biases or inaccuracies inherent in primary data collection. Potential biases present in the secondary data, originating from diverse sources addressing various research inquiries, were acknowledged.

Part of the secondary data utilised originated from analyses of LNG price trends over time. However, it is important to note that such data may have temporal limitations because of the changing nature of trends over time.

In the future, there is an opportunity to explore how the integration of secondary data with primary data obtained directly from heavy-duty vehicle operators and owners through qualitative methods could synergistically address and overcome existing limitations.

REFERENCES

Ajum, F., Godinho, C., Burton, J., McCall, B., & Marquard, A. (2020). A Low-Carbon Transport Future for South Africa: Technical, Economic and Policy Considerations. *Energy Systems Research Group, University of Cape Town, South Africa*.

Anwar, G. A., Dong, Y., & Khan, M. A. (2023). Long-term sustainability and resilience enhancement of building portfolios. Resources, Conservation & Recycling. Advance online publication. https://doi.org/10.1016/j.rcns.2023.06.002

Arefin, M. A., Nabi, M. N., Akram, M. W., Islam, M. T., & Chowdhury, M. W. (2020). A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses. *Energies, 13*(23), 6127. https://doi.org/10.3390/en13226127

Argonne National Laboratory. (2013). *Enviro Express Kenworth LNG tractor: Connecticut Clean Cities Future Fuels Project*. US Department of Energy. Retrieved from: https://www.anl.gov

Bhandari, P. (2020). Population vs. Sample | Definitions, Differences & Examples. Retrieved: from https://www.scribbr.com/methodology/population-vs-sample/

Boretti, A. (2020). Advances in Diesel-LNG internal combustion engines. *Energies, 13*(4), 874. https://doi.org/10.3390/en13040874

Chandler, K., Proc, K. (2004). Norcal prototype LNG truck fleet: Final results1. US Department of Energy. https://www.nrel.gov/docs/fy04osti/36239.pdf

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approach*. Sage publication

Cropley, A. (2022). *Qualitative Research Methods: A practice-oriented introduction*. University of Hamburg.

Dearing, J., & Cox, J. (2018). Diffusion Of Innovations Theory, Principles, And Practice. *Health Affairs, 37.* 183-190. 10.1377/hlthaff.2017.1104.

Department of Mineral Resources and Energy. (n.d.). Petroleum Industry Framework. Retrieved from : https://www.energy.gov.za/files/petroleum_frame.html

Department of Mineral Resources and Energy. (2021). South African Energy Sector Report 2021 [PDF document]. Retrieved from: https://www.energy.gov.za/files/media/explained/2021-South-African-Energy-Sector-Report.pdf

Engineering News. (2022, April). Renergen chooses DAF to drive LNG revolution. https://www.engineeringnews.co.za/article/renergen-chooses-daf-to-drive-lng-revolution-2022-04-05

FFS (2020). FFS LNG Demonstration Plant. Retrieved from https://www.ffs.co.za/ffs-lng-demonstration-plant/

Geng, M.-M., & He, L.-Y. (2021). Environmental Regulation, Environmental Awareness, Environmental Governance Satisfaction. *Sustainability, 13*(3960). https://doi.org/10.3390/su13073960

Glenn, A., & Bowen, (2009). Document Analysis as a Qualitative Research Method. *Qualitative Research Journal, 9*(2), 27-40. http://dx.doi.org/10.3316/QRJ0902027

Hayes, A. (2022). Liquefied Natural Gas: What it is, How it Works. Retrieved from https://www.investopedia.com/terms/l/liquefied-natural-gas.asp

Hennink, M., & Kaiser, B. N. (2020). Sample sizes for saturation in qualitative research: A systematic review of empirical tests. *Journal of Mixed Methods Research, 14*(2), 175-203.

Kabeyi, M. J. B., & Olanrewaju, O. A. (2021). Conversion of diesel and petrol engines to biogas engines as an energy transition strategy. *Journal of Sustainable Energy and Environment, 12*(3), 34-47. DOI: 10.1234/jsene.v12i3.2345

Kluschke, P., Gnann, T., Plötz, P., & Wietschel, M. (2019). Market diffusion of alternative fuels and powertrains in heavy-duty vehicles: A literature review. *Energy Reports, 5*, 1010-1024. https://doi.org/10.1016/j.egyr.2019.07.017

Marcogaz. (2021, June). Liquefied natural gas as transportation fuel. Retrieved from https://www.marcogaz.org/images/publications-documents/2021/2021-LNG-Transportation.pdf

Met Group. (2020, September 30). Natural Gas: Environmental Impact. Mind the FyouTure.Retrieved from: https://group.met.com/en/mind-the-fyouture/mindthefyouture/natural-gas-environmental-impact

Mohammad, N., Mohamad Ishak, W. W., Mustapa, S. I., & Ayodele, B. V. (2021). Natural Gas as a Key Alternative Energy Source in Sustainable Renewable Energy Transition: A Mini Review. *Frontiers in Energy Research, 9,* 625023. 10.3389/fenrg.2021.625023.

Mokrani, T. (2022). The role of natural gas in the South African energy mix. ("The Role of Natural Gas in the South African Energy Mix") Institute for Catalysis and Energy Solutions (ICES), College of Science, Engineering and Technology, University of South Africa. *Energy Reports, 8*, 442-448. https://doi.org/10.1016/j.egyr.2021.11.033

Naidoo, K. (2020, June). From next year trucks on the N3 could save 25% on fuel thanks to LNG – but motorists can't have any. The South African. Retrieved: https://www.thesouthafrican.com/news/from-next-year-trucks-on-the-n3-could-save-25-on-fuel-thanks-to-lng-but-motorists-cant-have-any/

National Business Initiative (NBI). (2023). Decarbonising the South African Transport Sector. Retrieved from: https://www.nbi.org.za/wp-content/uploads/2023/08/Decarbonising-the-South-African-Transport-Sector_Final_17March2023.pdf

Nunez, C. (2019). What are Fossil Fuels? Learn how human use of fossil fuels—non-renewable energy sources, such as coal, oil, and natural gas—affect climate change. National Geographic. Retrieved from: https://www.nationalgeographic.com/environment/article/fossil-fuels

Offshore Energy. (2022, February). Renergen launches South Africa's first LNG auction. Offshore Energy. Retrieved from: https://www.offshore-energy.biz/renergen-launches-south-africas-first-lng-auction/

Oladunni, O. J., Mpofu, K., & Olanrewaju, O. A. (2022). Greenhouse gas emissions and its driving forces in the transport sector of South Africa. *Journal of Environmental Management*, 280(1), 111394. Retrieved from :https://doi.org/10.1016/j.jenvman.2020.111394

Osorio-Tejada, J., Llera, E., & Scarpellini, S. (2015). LNG: An alternative fuel for road freight transport in Europe. CIRCE – Centre of Research for Energy Resources and Consumption, University of Zaragoza, Spain.

Ouki, M. (2022). Africa's LNG import prospects in an era of high volatility and uncertainties. Oxford Institute for Energy Studies. Energy Insight: 118.

Patton, M. (2020). *Qualitative research and evaluation methods* (4th ed.). Sage Publications.

Renergen. (2023). Renergen to supply LNG to South Africa's Timelink1. Retrieved from: https://www.renergen.co.za/news/renergen-to-supply-lng-to-south-africas-timelink/

Renergen. (n.d.). What we do. Renergen.Retrieved from: https://www.renergen.co.za/about-renergen/what-we-do/

SAGMP (2021). South African Gas Master Plan: Base case Report (v 01) Stakeholder Consultation, Department of Mineral Resources and Energy, September 2021.

SANEDI. (2021). Roadmap towards cleaner fossil fuels technologies - Phase 1. Retrieved from : https://sanedi.org.za/wp-content/uploads/2021/10/SANEDI-Cleaner-Fossil-Fuels-Roadmap-Phase-1-Report.pd

Shell (n.d.). Liquefied Natural Gas (LNG). Shell. Retrieved from :https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng.html

Stats SA. (2021). *Annual consumer price inflation slightly up in April.* Statistics South Africa. https://www.statssa.gov.za/?p=14933

Stats SA. (2022). Growing with the flow: Tracking products through our economy. Retrieved from: https://www.statssa.gov.za/?p=15398

Stenfors, T., Kajamaa, A., & Bennett, D. (2020). How to... assess the quality of qualitative research. *Clinical Teacher, 17*(6), 596-599. doi:10.1111/tct.13242

Smajla, I., Karasalihović Sedlar, D., Drljača, B., & Jukić, L. (2021). Fuel switch to LNG in heavy truck traffic. *Energy, Ecology and Environment, 6*(2), 144-153. doi:10.1007/s40974-021-00222-1

Smith, J. R. (2022). What is Trustworthiness in Qualitative Research? *Journal of Qualitative Research, 15*(3), 127-141. Retrieved from: https://www.statisticssolutions.com/what-is-trustworthiness-in-qualitative-research/

Tracy, S. J. (2010). Qualitative Quality: Eight "Big-Tent" Criteria for Excellent Qualitative Research. *Qualitative Inquiry, 16*(10), 837-851. https://doi.org/10.1177/1077800410383121

Volvo Trucks Southern Africa. (2024). Volvo Trucks tests LNG trucks for local market. Volvo Trucks. Retrieved from: https://www.volvotrucks.com/en-en/news/press-releases/2024/03/volvo-trucks-tests-lng-trucks-for-local-market.html

Volvo Trucks. (n.d.). Gas-Powered Trucks. Volvo Trucks. Retrieved from: https://www.volvotrucks.com/en-en/trucks/renewable-fuels/gas-powered-trucks.html

Wright, J., Winkler, H., & Merven, B. (2019). Energy for Sustainable Road Transport in South Africa: The Role of Alternative Fuel Vehicles. Sustainability, 1 de Oliveira, D., Diaz-Chavez, R., & Santos, T. T. (2019). Sustainable alternative jet fuels: A review. Renewable and Sustainable Energy Reviews, 115, 109384. 1(19), 5349. https://doi.org/10.3390/su11195349

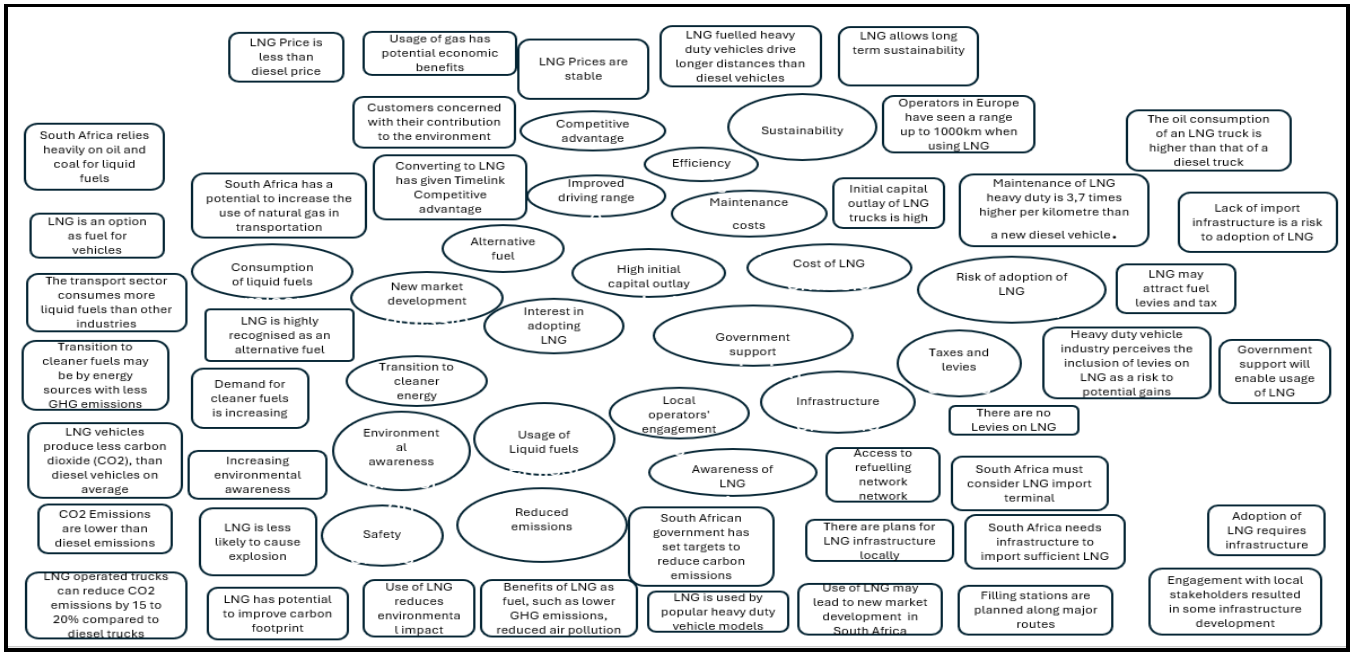
APPENDIX A- Content Analysis table

RAW DATA ANALYSIS				
Source Type	**Name of Source**	**Raw data transcript**	**Significant statemer**	**Emergent Code**
Journal	https://spiral.ic.ac.uk/bitstream/10044/1/75665/2/LNG%20for%20HGVs%20-%20spiral%20version.pdf	The financial case for operators is positive only if a publicly accessible refuelling network is available	Access to refuelling network	Infrastructure
Journal	Jozef Gnap and Marek Dočkalik* Impact of the operation of LNG trucks on the environment https://doi.org/10.1515/eng-2021-0096 received May 14, 2021; accepted August 25, 2021	trucks can reduce CO2 emissions by 15–20% compared to diesel vehicles of emission	LNG operated trucks can reduce CO2 emissions by 15 to 20% compared to diesel trucks	Reduced emissions
Journal	Jozef Gnap and Marek Dočkalik* Impact of the operation of LNG trucks on the environment https://doi.org/10.1515/eng-2021-0096 received May 14, 2021; accepted August 25, 2021	The data obtained and calculated show that LNG vehicles produce, on average, a lower amount of greenhouse gas CO2 than diesel vehicles.	LNG vehicles produce less carbon dioxide (CO2), than diesel vehicles on average	Reduced emissions
Journal	The Role of Natural Gas in the South African Energy Mix Touhami Mokrani Institute for Catalysis and Energy Solutions (ICES), College of Science, Engineering and Technology, University of South Africa tmokrani@unisa.ac.za	An LNG import terminal is the best option for South Africa to accelerate the penetration of natural gas in the energy mix.	South Africa must consider LNG import terminal	LNG Infrastructure
Journal	The Role of Natural Gas in the South African Energy Mix Touhami Mokrani Institute for Catalysis and Energy Solutions (ICES), College of Science, Engineering and Technology, University of South Africa tmokrani@unisa.ac.za	South Africa produces liquid fuels from oil, covering 54.4 % of the total fuel demand, while coal covered 42.3 % of the total demand via Sasol coal to liquids (CTL) plant.	South Africa relies heavily on oil and coal for liquid fuels	Usage of liquid fuels
Journal	The Role of Natural Gas in the South African Energy Mix Touhami Mokrani Institute for Catalysis and Energy Solutions (ICES), College of Science, Engineering and Technology, University of South Africa tmokrani@unisa.ac.za	Natural gas might help the energy transition by reducing emissions compared to coal	South Africa has a potential to increase the use of natural gas in transportation	Usage of LNG
Government sector report	THE SOUTH AFRICAN ENERGY SECTOR REPORT 2021	As the largest user of liquid fuels, the transport sector consumed 726 306TJ in 2018	The transport sector consumes more liquid fuels than other industries	Consumption of liquid fuels
Government sector report	NORCAL PROTOTYPE LNG TRUCK FLEET: FINAL RESULTS By Kevin Chandler, Battelle Ken Proc, National Renewable Energy Laboratory	Maintenance costs for the prototype LNG trucks were 2.3 times higher per mile than for the newest commercial diesel trucks.	Maintanance of LNG heavy duty vehicles is higher per kilometer than a new diesel vehicle.	Maintanance cost
Government sector report	NORCAL PROTOTYPE LNG TRUCK FLEET: FINAL RESULTS By Kevin Chandler, Battelle Ken Proc, National Renewable Energy Laboratory	The oil consumption was small, and the difference between the LNG and new diesel trucks is not considered significant:	The oil consumption of an LNG truck is not significantly higher than that of a diesel truck	Maintanance cost
Government sector report	CLEAN CITIES ALTERNATIVE FUEL PRICE REPORT JANUARY 2022	Historically, the prices of CNG, LNG and propane have been much more stable, with minimal up and down swings in price, when compared to gasoline or diesel.	LNG Prices are stable	Cost of LNG
Government sector report	CLEAN CITIES ALTERNATIVE FUEL PRICE REPORT JANUARY 2022	On average, during this reporting period, LNG cost about $0.60 less than diesel on a per diesel gallon equivalent (DGE) basis.	LNG Price is less than diesel price	Cost of LNG
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Similarly GHG emissions emanating from the use of fossil fuels in transport can be reduced by replacing fossil fuel with renewable biofuels, using less carbon intensive engine technology such as LNG/CNG vehicles,	Benefits of LNG as fuel, such as lower GHG emissions, reduced air pollution	Reduced emissions
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	n SA requires additional gas imports into SA. This requires LNG import infrastructure in ports and associated gas transmission pipelines	South Africa needs infrastructure to import sufficient LNG	Infrastructure
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	The South African Government has committed to reducing carbon emissions in line with specified targets for South Africa.	South African government has set targets to reduce carbon emissions	Reduced emissions
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Cleaner fossil fuels is a concept that implies using fossil fuels as an energy source, but with reduced GHG emissions. Due to its high dependency on fossil fuel for its energy supply, SA wishes to leverage this concept in its journey to meeting its NDC targets.	Transition to cleaner fuels may be through the use of energy sources with less GHG emissions	Transition to cleaner energy
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	The risk for a successful natural gas power project in SA is the lack of supporting gas infrastructure to support	Lack of import infrastructure is a risk to adoption of LNG	Risk of adoption of LNG

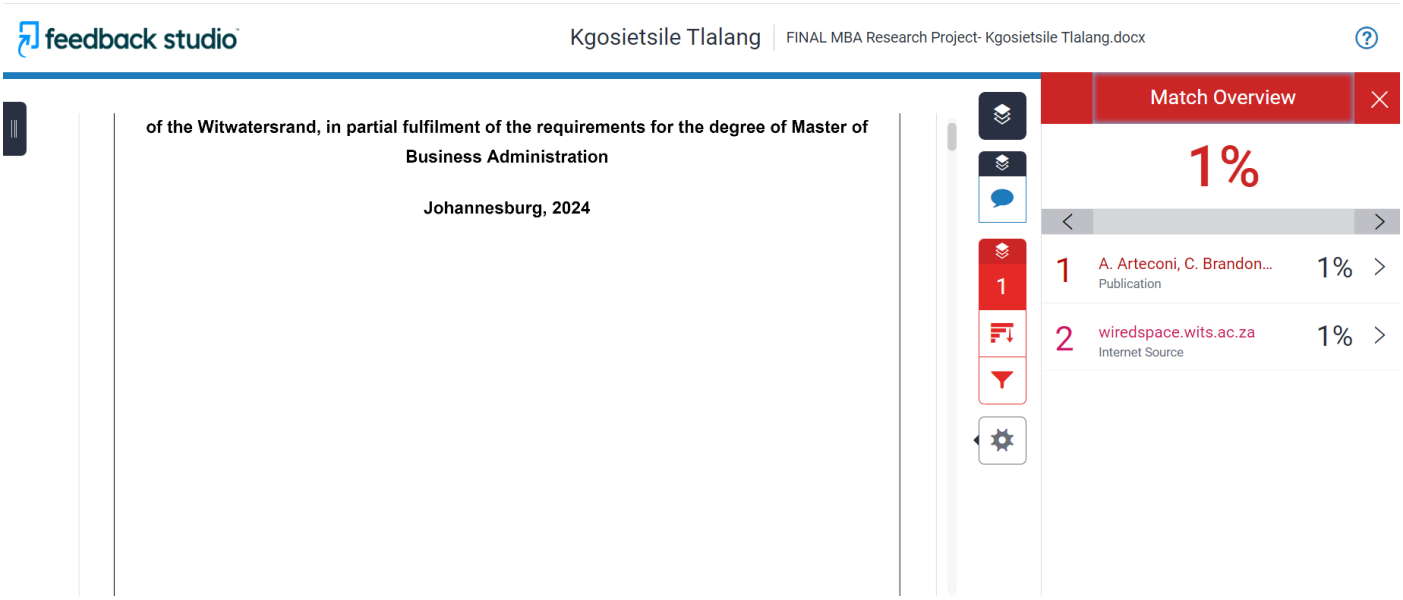
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Potential users are also concerned there is a risk of LNG attracting fuel levies and taxes in future	LNG may attract fuel levies and tax	Risk of adoption of LNG
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	LNG CO2 emissions are 0.18 kg CO2/kWh versus diesel at 0.25 kg CO2/kWh, or 28% less than diesel	CO2 Emissions are lower than diesel emissions	Reduced emissions
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Cost of LNG is currently about 18% less than cost of diesel on an R per heating value (R/GJ) basis19	Cost of LNG is lower than that of diesel	LNG has higher Rand per heating value(R/GJ) than diesel
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	LNG currently does not attract fuel levies	There are no Levies on LNG	Taxes and levies
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Locally Renergen and Total have plans with logistics companies (Imperial and Black Knight) to roll out LNG truck fueling programmes along major national road routes	There are plans for LNG infrastracture locally	Infrastructure
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Key requirement for successful take up of technology is development of LNG infrastructure in SA,	Adoption of LNG requires infrastructure	Infrastructure
Industry report	ROADMAP TOWARDS CLEANER FOSSIL FUELS TECHNOLOGIES - PHASE 1	Government imposing taxes and levies on LNG to offset the revenue loss from the reduction in diesel sales is viewed as a high risk for LNG by SA freight transport industry	Heavy duty vehicle industry perceives the inclusin of levies on LNG as a risk to potential gains	Risk to adoption of LNG
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	LNG fuelled trucks have a higher range (up to 700–1000 km) due to higher energy density	LNG fueled heavy duty vehicles drive longer distances than diesel vehicles	Efficiency
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	LNG is not explosive; therefore, to be ignited, first, it must be vaporized and then mixed with air at a proper portion .	LNG is less likely to cause explosion	Safety
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	LNG is cleaner than coal and oil, therefore, it has got a plethora of recognition in the global market	LNG is highly recognised as an alternative fuel	Awareness of LNG
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	The LNG truck was about 30–40% more expensive than the diesel truck in 2013 according to energy analysts Enerdata.	Initial capital outlay of LNG trucks is high	High Capital cost
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	The LNG truck was about 30–40% more expensive than the diesel truck in 2013 according to energy analysts Enerdata.	LNG consumption lower than diesel	Cost of LNG
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	more government support like subsidies and stricter environmental regulations would influence on increase of natural gas in transport sector.	Government support will enable usage of LNG	Government support
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	Overall, it was concluded that increasing environmental awareness, more government support like subsidies and stricter environmental regulations would influence on increase of natural gas in transport sector.	Increasing environmental awarenes	Environmental awarenes
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	Most popular LNG heavy trucks on the European market that are currently available are Iveco Stralis Natural Power, Volvo FM Metan Diesel, Hardstaff Merceds Benz Actros and Scania G 340 LNG.	LNG used by popular heavy duty vehicle models	LNG awareness
Government report	South African Gas Master Plan: Basecase Report version 01	The utilisation options for natural gas in South Africa are thus power generation, industrial co generation, CNG or LNG vehicles, petrochemical synthesis, residential/commercial heating, and future exportation	LNG is an option as fuel for vehicles	Alternative fuel
Government report	South African Gas Master Plan: Basecase Report version 01	The economy of South Africa can capture real benefit from developing natural gas resources, generating employment (directly and indirectly), increasing GDP (directly and indirectly), increasing foreign direct investments and with potential future exports, increase the inflow of foreign currency, stemming both from the extraction and utilization of natural gas.	Usage of gas has potential economic benefits	New market development

Manufacturer's website	https://www.volvotrucks.co.za/en-za/news/press-releases/2020/nov/pressrelease-201103.html#:~:text=Volvo%20Trucks%20Southern%20Africa%20has,be%20used%20in%20local%20testing.	Many of our customers already work hard to reduce their environmental footprint.	Customers concerned with their contribution to the environment	Environment awarenes
Manufacturer's website	https://www.volvotrucks.co.za/en-za/news/press-releases/2020/nov/pressrelease-201103.html#:~:text=Volvo%20Trucks%20Southern%20Africa%20has,be%20used%20in%20local%20testing.	Many of our customers already work hard to reduce their environmental footprint. We therefore see a clear potential for LNG units as a vital part of the solution," said Marcus Hörberg, vice president of Volvo Group Southern Africa	LNG has potentialt to improve carbon footprint	Alternative fuel
Manufacturer's website	https://www.volvotrucks.co.za/en-za/news/press-releases/2020/nov/pressrelease-201103.html#:~:text=Volvo%20Trucks%20Southern%20Africa%20has,be%20used%20in%20local%20testing.	With the 205kg LNG tank, European operators are seeing usable range of up to 1000km, this is dependent on the terrain and payload carried.	Operators in Europe have seen a range up to 1000km when using LNG	Improved driving range
Manufacturer's website	https://www.volvotrucks.co.za/en-za/news/press-releases/2020/nov/pressrelease-201103.html#:~:text=Volvo%20Trucks%20Southern%20Africa%20has,be%20used%20in%20local%20testing.	When it comes to the provision of LNG to fleets, new local developments and partnerships in the segment have resulted in the establishment of a limited infrastructure, specifically on the N3 highway between Durban and Johannesburg.	Engagement with local stakeholders resulted in some infrastructure developmen	Local operators engagement
Manufacturer's website	https://ffs-refiners.com/another-ffs-first-successful-importation-and-utilisation-of-lng-in-south-africa/	With the increasing global demand for cleaner fuels, FFS has decided to add LNG (Liquified Natural Gas) to the suite of fuels it provides. This will allow for diversification, long term sustainability and give FFS' customers options to reduce their environmental footprint	Demand for cleaner fuels is increasing	Environment awarenes
Manufacturer's website	https://ffs-refiners.com/another-ffs-first-successful-importation-and-utilisation-of-lng-in-south-africa/	With the increasing global demand for cleaner fuels, FFS has decided to add LNG (Liquified Natural Gas) to the suite of fuels it provides. This will allow for diversification, long term sustainability and give FFS' customers options to reduce their environmental footprint	LNG allows long term sustainability	Sustainability
Manufacturer's website	https://ffs-refiners.com/another-ffs-first-successful-importation-and-utilisation-of-lng-in-south-africa/	With the increasing global demand for cleaner fuels, FFS has decided to add LNG (Liquified Natural Gas) to the suite of fuels it provides.	Use of LNG reduces environmental impact	Environmental awarenes
Manufacturer's website	https://ffs-refiners.com/another-ffs-first-successful-importation-and-utilisation-of-lng-in-south-africa/	FFS has been building a relationship with a strategic partner to assist with the rollout of LNG into the South African market.	Use of LNG may lead to new market development development in South Africa	Interest in adopting LNG
Manufacturer's website	https://lngprime.com/africa/renergen-pens-lng-supply-deal-with-south-african-transport-company/80580/	Renergen said it plans to have "multiple" LNG filling points across South Africa that will deliver the fuel to selected customers across all the major highways once the Virginia project is in its second phase.	Filling stations are planned along major routes	Infrastructure
Manufacturer's website	https://lngprime.com/africa/renergen-pens-lng-supply-deal-with-south-african-transport-company/80580/	Timelink now has a distinct advantage over competitors when speaking to customers demanding a lower carbon footprint from their logistics suppliers, as well as enjoying a reduced operating cost and increasing operational flexibility,"	Converting to LNG has given Timelink a Competitive advantage	Competitive advantage

APPENDIX B- Thematic analysis



APPENDIX C- Turnitin Originality Report



APPENDIX D- Sources of secondary data

SOURCES OF SECONDARY DATA		
List of secondary data	**Sources**	**Year published**
Journal	The Oxford institute for Energy studies	2022
Journal	Jozef Gnap and Marek Dočkalik* Impact of the operation of LNG trucks on the environment https://doi.org/10.1515/eng-2021-0096 received May 14, 2021; accepted August 25, 2021	2021
Journal	The Role of Natural Gas in the South African Energy Mix Touhami Mokrani Institute for Catalysis and Energy Solutions (ICES), College of Science, Engineering and Technology, University of South Africa tmokrani@unisa.ac.za	2022
Government sector report	THE SOUTH AFRICAN ENERGY SECTOR REPORT 2021	2021
Government sector report	Norcal prototype LNG truck fleet: Final results1. US Department of Energy. https://www.nrel.gov/docs/fy04osti/36239.pdf	2004

Government sector report	CLEAN CITIES ALTERNATIVE FUEL PRICE REPORT JANUARY 2022	2022
Industry report	Roadmap towards cleaner fossil fuels technologies - Phase 1. Retrieved from : https://sanedi.org.za/wp-content/uploads/2021/10/SANEDI-Cleaner-Fossil-Fuels-Roadmap-Phase-1-Report.pd	2021
Journal	A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses Md Arman Arefin 1 , Md Nurun Nabi 2,*, Md Washim Akram 3 , Mohammad Towhidul Islam 1 and Md Wahid Chowdhury 1	2020
Government report	South African Gas Master Plan: Basecase Report version 01	2021
Manufacturer's website	https://www.volvotrucks.co.za/en-za/news/press-releases/2020/nov/pressrelease-201103.html#:~:text=Volvo%20Trucks%20Southern%20Africa%20has,be%20used%20in%20local%20testing.	2024
Manufacturer's website	https://ffs-refiners.com/another-ffs-first-successful-importation-and-utilisation-of-lng-in-south-africa/	2021
Manufacturer's website	https://lngprime.com/africa/renergen-pens-lng-supply-deal-with-south-african-transport-company/80580/	2023

Journal	Fuel switch to LNG in heavy truck traffic. *Energy, Ecology and Environment, 6*(2), 144-153. doi:10.1007/s40974-021-00222-1	2019
Journal	Decarbonising the South African Transport Sector. Retrieved from: https://www.nbi.org.za/wp-content/uploads/2023/08/Decarbonising-the-South-African-Transport-Sector_Final_17March2023.pdf	2023
Journal	Fuel switch to LNG in heavy truck traffic. Energy, Ecology and Environment, 6(2), 144-153. doi:10.1007/s40974-021-00222-1	2021
Journal	Enviro Express Kenworth LNG tractor: Connecticut Clean Cities Future Fuels Project. US Department of Energy. Retrieved from: https://www.anl.gov	2013
Journal	Norcal prototype LNG truck fleet: Final results1. US Department of Energy. https://www.nrel.gov/docs/fy04osti/36239.pdf	2004
Journal	Qualitative Quality: Eight "Big-Tent" Criteria for Excellent Qualitative Research. Qualitative Inquiry, 16(10), 837-851. https://doi.org/10.1177/1077800410383121	2020
Journal	What is Trustworthiness in Qualitative Research? Journal of Qualitative Research, 15(3), 127-141. Retrieved from: https://www.statisticssolutions.com/what-is-trustworthiness-in-qualitative-research/	2010

Government website	Growing with the flow: Tracking products through our economy. Retrieved from: https://www.statssa.gov.za/?p=15398	2022
Government website	Annual consumer price inflation slightly up in April. Statistics South Africa. https://www.statssa.gov.za/?p=14933	2021
Manufacturer's website	Liquefied Natural Gas (LNG). Shell. Retrieved from :https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng.html	No date
Manufacturer's website	Renergen to supply LNG to South Africa's Timelink1. Retrieved from: https://www.renergen.co.za/news/renergen-to-supply-lng-to-south-africas-timelink/	2023
Book	Qualitative research and evaluation methods (4th ed.). Sage Publications	2020
	LNG: An alternative fuel for road freight transport in Europe. CIRCE – Centre of Research for Energy Resources and Consumption, University of Zaragoza, Spain.	2015
Journal	Renergen launches South Africa's first LNG auction. Offshore Energy. Retrieved from: https://www.offshore-energy.biz/renergen-launches-south-africas-first-lng-auction/	2022

Online news article	From next year trucks on the N3 could save 25% on fuel thanks to LNG – but motorists can't have any. The South African. Retrieved: https://www.thesouthafrican.com/news/from-next-year-trucks-on-the-n3-could-save-25-on-fuel-thanks-to-lng-but-motorists-cant-have-any/	2020
Online article	Natural Gas: Environmental Impact. Mind the FyouTure.Retrieved from: https://group.met.com/en/mind-the-fyouture/mindthefyouture/natural-gas-environmental-impact	2020
Government sector report	South African Energy Sector Report 2021 [PDF document]. Retrieved from: https://www.energy.gov.za/files/media/explained/2021-South-African-Energy-Sector-Report.pdf	2021
Government sector website	Petroleum Industry Framework. Retrieved from : https://www.energy.gov.za/files/petroleum_frame.html	No date
Journal	Advances in Diesel-LNG internal combustion engines. Energies, 13(4), 874. https://doi.org/10.3390/en13040874	2020
Online publication	Long-term sustainability and resilience enhancement of building portfolios. Resources, Conservation & Recycling. Advance online publication. https://doi.org/10.1016/j.rcns.2023.06.002	2023

Journal	A Low-Carbon Transport Future for South Africa: Technical, Economic and Policy Considerations. Energy Systems Research Group, University of Cape Town, South Africa.	2020
Online news article	Renergen chooses DAF to drive LNG revolution. https://www.engineeringnews.co.za/article/renergen-chooses-daf-to-drive-lng-revolution-2022-04-05	2022
	Liquefied natural gas as transportation fuel. Retrieved from https://www.marcogaz.org/images/publications-documents/2021/2021-LNG-Transportation.pdf	2021
Journal	Conversion of diesel and petrol engines to biogas engines as an energy transition strategy. Journal of Sustainable Energy and Environment, 12(3), 34-47. DOI: 10.1234/jsene.v12i3.2345	2021
Journal	Environmental Regulation, Environmental Awareness, Environmental Governance Satisfaction. Sustainability, 13(3960). https://doi.org/10.3390/su13073960	2021
Journal	What are Fossil Fuels? Learn how human use of fossil fuels—non-renewable energy sources, such as coal, oil, and natural gas—affect climate change. National Geographic. Retrieved from: https://www.nationalgeographic.com/environment/article/fossil-fuels	2019

Journal	Population vs. Sample | Definitions, Differences & Examples. Retrieved: from https://www.scribbr.com/methodology/population-vs-sample/	2020