Electric cars: their carbon implications and adoption in South Africa

By

Mokhele Edmond Moeletsi

Submitted in partial fulfilment of the requirements for the Masters in Business Administration to be awarded at the Nelson Mandela University

January 2019

Supervisor: Professor Christiaan Adendorff

NELSON MANDELA UNIVERSITY

DECLARATION

I, Mokhele Edmond Moeletsi (student number 217803296), hereby declare that the *treatise* for Masters in Business Administration *to be awarded* is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

……………………………………... (Signature)

Official use:
In accordance with Rule G5.6.3,

5.6.3 A treatise/dissertation/thesis must be accompanied by a written declaration on the part of the candidate to the effect that it is his/her own work and that it has not previously been submitted for assessment to another University or for another qualification. However, material from publications by the candidate may be embodied in a treatise/dissertation/thesis.

ACKNOWLEDGEMENTS

If it was not for an amazing God and Jesus Christ, I would not have been where I am today. I am grateful that He has given me life.

I'm very grateful for the support that I obtained from my supervisor, Professor Christiaan Adendorff. The initial interaction with Dr Heidi van Rensburg is also acknowledged. It was not going to be possible to finish this study without their guidance.

To my wife (Mamoeketsi Moeletsi), for all the support she has given me, thank you for your love and support.

To my children, Moeketsi and Mamokhele Moeletsi, for inspiring me on a daily basis to become a better father. I will not forget Sedupe, Mpatleleng and Sechaba Moeletsi, "ntate moholo o wa le rata haholo"

I am thankful to my parents for all they have done throughout my life. "Akhele you are still the driving force of my life"

To my brothers (Seeiso, Ramoitoi & Makhate), who had been by my side all the way, I love you so much.

To 'Me Manthuseng Lefethe, I am grateful for your presence in our family.

To the amazing team at the Agricultural Research Council (Phumzile, Sewela, Molatelo, Teboho, Sabelo, Lindumisa and Mulalo) for helping me during the data collection of this study.

To all my friends who had been very helpful in disseminating the questionnaire and to all the people who dedicated their time in filling it, thank you all.

ABSTRACT

Climate change is a reality that is starting to have an impact on society through decreased agricultural production and increased extreme weather events, resulting to worldwide disasters. It is caused by human activities that release greenhouse gas emissions into the atmosphere. One of the key areas of concern is the mobility sector which accounts for around 20% of the total energy use, with a GHG footprint of close to 14% of the global emissions. International organisations are concerned about the elevating GHG emissions resulting from the increasing internal combustion engine vehicles, leading to the recent wave in electrifying the vehicles which presents many of advantages as well as major constraints. This study used the quantitative research approach to investigate the possible benefits of electric vehicles to our environment in the future. The projections of vehicle population size were estimated using three cases, and the electric vehicle penetration into the market by 2030 was investigated with four different scenarios. Further research was done to investigate the possible barriers present in the South African market that impede the adoption of electric vehicles.

The results showed that the projection of the business-as-usual case, coupled with mitigation scenarios, present a better option for mitigation. The worst case of exponential increases in vehicle population does not present any GHG emissions moderation hope for any of the mitigation scenarios used in the study. The other case shows high mitigation potential, but it leads to a case of economic decline where the numbers of vehicles are decreasing with time. The findings of the study on barriers to adoption of electric vehicles in the market highlighted the high purchase price, high battery price and high likelihood for owning a secondary vehicle based on the current circumstances, as the main barriers that the respondents in the Gauteng Province found to be unattractive. But generally the willingness to buy electric vehicles was high for the majority of the factors that were presented. With these perceived positive opinions by the respondents, it is down to government and private companies to provide an environment conducive to changed opinions conducive for the consumers. This relates to advancing the technology and providing policy support for the accelerated adoption of electric vehicles.

Table of Contents

LIST OF ABBRIVIATIONS

BEV (Battery electric vehicle)
CDM (Clean development mechanism)
CH_4 (Methane)
CO_2 (Carbon dioxide)
EPA (Environmental Protection Agency)
E-REV (Extended range electric vehicle)
EV (Electric vehicle)
GHG (Greenhouse gas)
HEV (Hybrid electric vehicle)
ICE (Internal combustion engine)
IPCC (Intergovernmental Panel on Climate Change)
NAMA (Nationally appropriate mitigation actions)
N_2O (Nitrous oxide)
PHEV (Plug-in hybrid electric vehicle)
UNEP (United Nations environmental programme)
UNFCCC (United Nations framework convention on climate change)
WMO (World meteorological organisation)

LIST OF FIGURES

LIST OF TABLES

1. CHAPTER 1: SCOPE OF THE STUDY

1.1 INTRODUCTION

Climate change is a major threat to our society (EPA, 2016). Our planet is warming up and the climate is changing drastically, requiring a lot of adjustment in the way human beings have been living. Throughout the world, scientists are observing clear signs that the earth's atmosphere is rapidly changing. It is not only scientists; even ordinary people are seeing changes in the environment they are living in (IPCC, 2014). Anthropogenic activities have excessively augmented the amount of carbon dioxide (CO_2) in the atmosphere by over 40 percent since the late 1700s, with other greenhouse gases like methane (CH_4) and nitrous oxide (N_2O) also increasing at an alarming rate (IPCC, 2014). These gases have increased temperatures of the surface and caused a lower atmosphere of the earth during the last half a century.

The international community realised the importance of understanding the science of global warming and its implications on existing global systems by forming an independent body, the IPCC, in 1988, which led to the United Nations Framework Convention on Climate Change (UNFCCC) and the formulation of the Kyoto Protocol (UNFCCC, 2014). The Kyoto Protocol represents the first international agreement to reduce GHG emissions. The latest accord is the Paris climate agreement adopted by consensus on 12 December 2015, where parties set to keep a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels. This calls for massive implementation of mitigating projects globally with all the countries expected to submit and implement their mitigation plans, regardless of whether it is a developed or developing country (UNFCCC, 2018).

South Africa is one of the world's most carbon-intensive countries owing to the economy that is dependent on coal-fired electricity, energy-intensive mining and heavy industry (Alton, Arndt, Davies, Hartley, Makrelov, Thurlow & Ubogu, 2014). As a signatory to the Kyoto Protocol and the Paris Agreement, South Africa has to demonstrate commitment towards combating climate change by embarking on mitigation and adaptation measures (UNFCCC, The Paris Agreement, 2018). The country has been in the forefront in terms of rectifying the historical circumstances by embarking on emission reduction initiatives that are not synonymous with other developing countries (Niehaus, Feiboth, & Goedhals-Gerber, 2018).

Climate change discussions have intensified in the last 20 years at different levels including international, political, national, regional, societal and business level, mainly due to the adverse impacts of global warming which have been registered all over the world (IPCC, 2014; Qian & Schaltegger, 2017). By acknowledging that there is a need to protect the environment through appropriate and effective intervention, governments in some developing and most developed countries have responded by introducing regulations intended to confine environmentally harmful activities (Tsai, Shen, Lee, Chen, Kuo, & Huang, 2012). This has led to the introduction of regulations to tackle the issues of increasing anthropogenic GHG emissions such as the Emission Trading Scheme in Europe as well as carbon taxes in countries like Australia, Japan, Norway, South Korea and Switzerland (Scott, Weber, & Hendrickson, 2008). The main aim of these anti-emission measures is to force the organisations to include environmental sustainability in their strategies (Tsai et al., 2012). There is a high expectation that carbon disclosure will continue to increase in all the countries including developing countries especially after the signing of the Paris Agreement (UNFCCC, 2018).

Global warming is affecting the sustainability of current production and consumption systems and its impact is global with long-term problems and irreversible damage (Abreu, Freitas, & Rebouças, 2017).The issue of sustainability has become crucial in recent times of increasing greenhouse gas emissions and depletion of our natural resources. Sustainability can be defined as maintaining economic growth, meeting social needs, preserving our natural resources and reducing harmful impacts on the atmosphere (Niehaus, Feiboth, & Goedhals-Gerber, 2018). The main objective of sustainable solutions is to ensure that future generations are guaranteed the ability to meet their own needs (Niehaus, Feiboth, & Goedhals-Gerber, 2018). The driving forces for sustainability are either internal or external. The main external forces are the UNFCCC and international bodies which are advocating for carbon disclosure while internal forces can be bourne from society at large (Niehaus, Feiboth, & Goedhals-Gerber, 2018). Ever-increasing prices of electricity and fuel are also forcing the organisations to find solutions like utilisation of renewable energy and retrofitting of their equipment to ensure eco-efficiency in their production. Increasing eco-efficiency most of the time is in line with increased productivity because GHG emission losses is an indication of inefficiencies in the system.

Passenger vehicles in South Africa are a significant contributor to greenhouse gas emissions in the transport sector, with their contribution projected to rise in the future due to an increasing population and gross domestic product (Gajjar & Mondol, 2016). There are a number of ways of reducing GHG emissions from this sector. The main strategy that has been used by a number of countries is the promotion of high efficiency technologies that outbid the current internal combustion engine (ICE) vehicles that are highly inefficient. The varying technologies that are present, including hybrid systems, plug-in hybrid systems, fuel cell systems, biogas systems and full electric systems broaden the choices of emissions reductions in the road transport sector thus complicating the mitigation approaches (Department of Transport, 2017; Gajjar & Mondol, 2016).

1.2 PROBLEM STATEMENT

Ownership of vehicles is growing at a faster rate than the human population with the world having 50 million cars in 1950 and the figure rising to 600 million after 50 years and expecting to increase to 3 billion vehicles by 2050 (Gärling & Thøgersen, 2001; Samara, 2016). Without downplaying the importance of vehicles in our lives, their ever increasing population has a negative impact on the environment through emission of greenhouse gas emissions resulting from the combustion of fossil fuel (Gärling & Thøgersen, 2001). This has resulted in emissions from the transport sector alone being at around 15% of the total global emissions. In South Africa, transport contributes close to 11% of total emissions with a road transport share of around 91% (Department of Transport, 2017). It is evident that carbon emissions from the transport sector have to be prioritised if the global community is serious about reducing greenhouse gas emissions since it is a major contributor (Ajanovic & Haas, 2016).

Substituting conventional vehicles with electric vehicles has the potential of reducing local pollution and greenhouse emissions from the transportation sector (Gärling & Thøgersen, 2001). Electric vehicles can be a solution for offering urban dwellers with a better quality of life without much pollution. The use of electric vehicles will tend to reduce our greenhouse gas emissions in the transport sector. Thus it is important for the governments around the world to initiate policy measures that support the market penetration of electric vehicles both at local and national level (Ajanovic & Haas, 2016). Electric vehicles have many advantages compared to conventional vehicles, including low emissions when utilised, high energy efficiency, reduced noise and low operating costs (Sandra Ly, Helena Sundin, 2012). Nevertheless, these socio-economic benefits are accompanied by multiple challenges such as high purchase prices, low driving range in between recharging, low variety of models, small loading capacity, need for regular charging, low maximum speed and acceleration (Gärling & Thøgersen, 2001; Jabeen, Olaru, & Smith, 2012).

In South Africa the adoption of electric vehicles has been extremely slow with only around 375 full electric vehicles being sold since their introduction in the market in 2013 (Wheels24.co.za, 2018). The charging stations in South Africa as also limited with Gauteng having the highest number of around 90. These might be one of the many reasons why South Africa has been struggling to make some forward strides in the sector. The data from the sales figures does not show an increase in the vehicles like in other emerging countries such as China and India; implying that there is a non-conducive environment for the adoption of electric vehicles in South Africa (Wheels24.co.za, 2018). Is it a matter of technology introduced; supporting infrastructure; prices of the vehicles or the type of vehicles? According to Dane (2013), South Africa does not have any major policy that can assist the country in shaping the way forward regarding the electric vehicle market and its proportion of the local industry. It remains to be seen whether the newly adopted green transport strategy will provide the stimulus needed to attract investment into electric mobility exceeding US$513 billion by 2050 on electric vehicles and US$488 billion by 2030 on hybrid vehicles, as stated in the South Africa Intended Contributions to climate change response (Department of Environmental Affairs, 2015; Department of Transport, 2017).

1.3 RESEARCH QUESTIONS

The study intends to address the following research questions:

Research Question 1:

What will be the impact on transport carbon emissions of introducing electric vehicles in the Gauteng Province?

Research Question 2:

What are the main reasons for the low adoption of electric vehicles in Gauteng and South Africa as a whole?

Research Question 3:

What are the possible impetuses that can be explored to improve the perception of electric vehicles among people living in South Africa?

In addressing these three research questions listed above, the main objective of the study will be achieved.

1.4 RESEARCH OBJECTIVES

1.4.1 **Primary objective**

The primary objective of this study is to ascertain whether there will be any benefits that can be obtained by adopting electric vehicles to assist the government in their greenhouse gas emissions reduction targets. It is also important to understand the barriers that hinder motorists to purchase full electric vehicles in the current South African automotive market as well as policy recommendations that can enhance electric vehicle adoption in the future.

1.4.2 **Secondary objectives**

To achieve the abovementioned primary objective, the following secondary objectives are formulated:

1. To investigate direct carbon dioxide reductions as a result of the adoption of electric vehicles in the Gauteng Province of South Africa;

2. To study the perception of the Gauteng residents on issues regarding electric vehicles in South Africa, especially their adoption;
3. To investigate possible policy recommendations that has the potential to improve future adoption of electric vehicles in South Africa.

1.5 CONCEPTUAL RESEARCH FRAMEWORK

The framework for undertaking the task of investigating the role that electric vehicles would have in helping South Africa mitigate climate change, is outlined in Figure 1.1 below, with all the contributing factors that have led to the investigation.

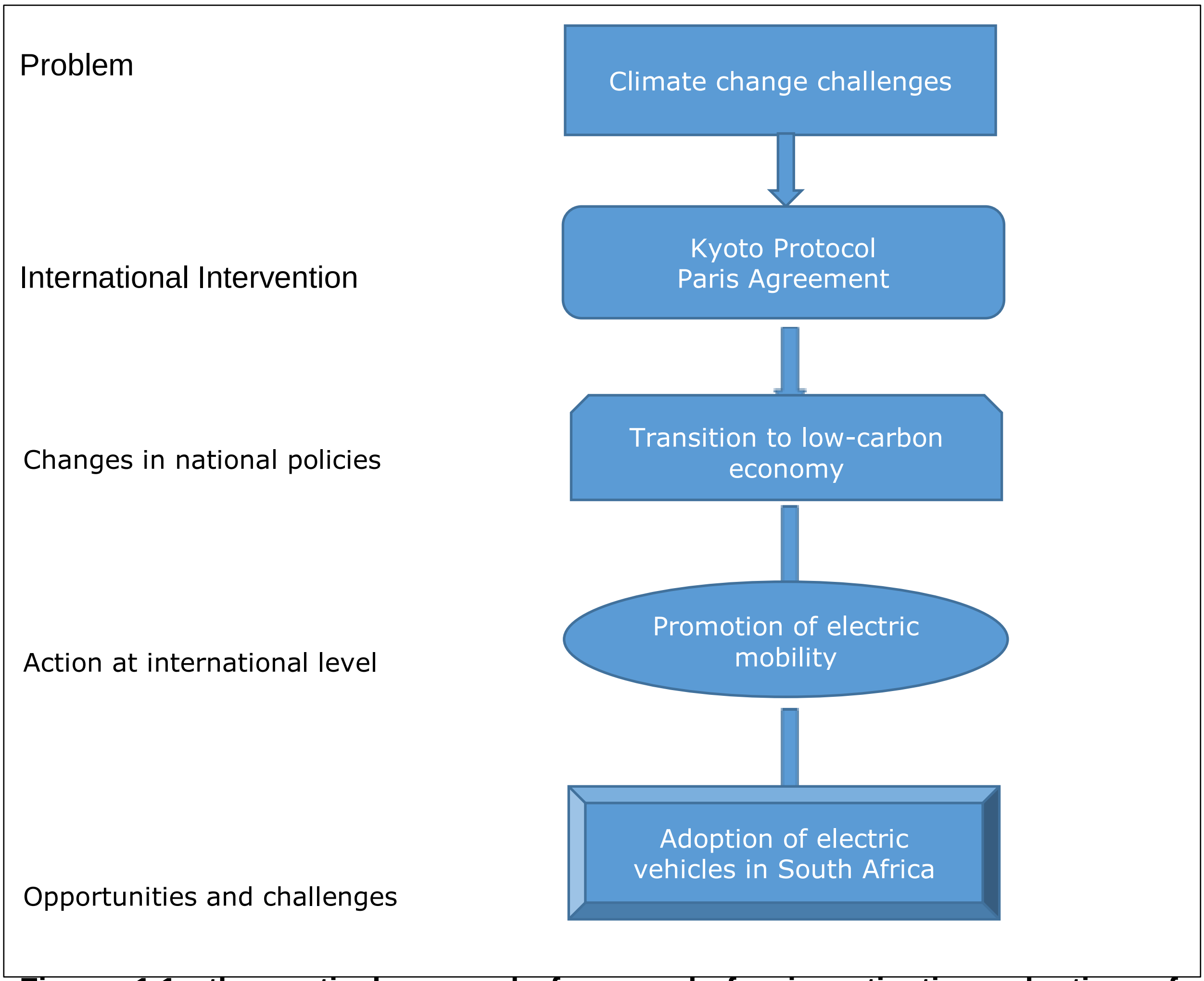

Figure 1.1: theorectical research framework for investigating adoption of electric vehicles in South Africa

Source : *Researcher's own construction (2018)*

1.6 RESEARCH METHODOLOGY

There are three main approaches to research; namely: a quantitative approach, a qualitative approach and a blended approach (Petrovic, Koprivica, & Bokan, 2017). The study utilises the quantitative research approach in addressing the main issues relating to greenhouse gas emission implications and adoption of electric vehicles in Gauteng, South Africa. In determining the contribution that electric vehicles will have in carbon reduction, a direct emissions approach promoted by the 2006 IPCC guidelines was employed (Paustian et al., 2006). The IPCC method gives guidance on how to estimate emissions of CO_2, CH_4 and N_2O from human-induced sources utilising national datasets and activity-based emission intensity values relevant to a particular country (IPCC, 2006).

In determining the barriers to adoption of electric vehicles in South Africa, a questionnaire consisting of structured questions was administered using Survey Monkey facilities from September to November 2018. The questionnaire had five main sections: 1) background information; 2) car ownership information; 3) awareness of environmental impacts of driving cars; 4) barriers to adoption of electric vehicles and 5) recommendations for policy change and technology improvement.

1.7 ETHICAL ISSUES

The student and study promoter examined ethical criteria and concluded that there is no need to acquire full ethical clearance. The study is therefore subjected to FORM E ethics clearance process of the Nelson Mandela University.

1.8 OUTLINE OF THE STUDY

This study consists of five chapters covering the following content:
Chapter 1 is the introductory chapter, which covers the entire scope of the study. The main topics include: background information, the problem statement and research objectives. The aim of this chapter is to highlight the main reasoning for the investigation as well as introducing the methods that were used to conduct the study. The conceptual research framework is also presented.

Chapter 2 covers the literature review related to electric vehicles and their role as a future mobility option. Some of the topics include: introduction to climate change, importance of low-carbon technologies, electric vehicles' history and barriers to electric vehicles' adoption. Some of the literature included in this chapter is on electric vehicle history, technology, perceptions on electric vehicles, market share and policy considerations for adoption of electric vehicles.

Chapter 3 covers the research design and methodology which includes: research paradigms, research design and ethical issues. The chapter covers the research design with greater emphasis on quantitative research and a case study approach. The chapter also covers a description of the case being studied, the means of data collection, types of data collected and data analysis.

Chapter 4 covers results obtained from all the analyses as well as the discussions associated with them. The results on the carbon emissions from the current passenger vehicles are presented, as well as carbon implications projections because of introduction of future electric vehicles in the market. Results from the questionnaire that was administered on the barriers to adoption of electric vehicles as well as the policy incentives that can be considered in the South African environment will also be presented.

Chapter 5 includes the conclusions that are drawn from the results and suggests recommendations that can be adopted. The chapter states some of the main findings that were obtained based at the main research questions of the study. The perceived contribution the study will be outlined as well as some of the limitations that are known.

1.9 CHAPTER SUMMARY

The chapter set the scene by outlining the background of the study. It is important to note that electric vehicles have been found as one of the key solutions that can assist in reducing the greenhouse gas emissions that are related to anthropogenic activities. However, their adoption is hampered by a number of issues that need to be addressed in order to ensure sustainability in the future.

2. CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Chapter 1 provided a background to the study of electric vehicles and their perceived role as the future means of transport. It also highlights a need for our government policies to be practical in shifting our economy from a fossil-fuel based (high intensity carbon emitting) to a low-carbon economy.

The aim of the study is to assess the positive impact that the roll-out of electric vehicles will have on the greenhouse gas emissions from the transport sector in an effort to curb climate change. The study will also dwell on the factors that form barriers to the adoption of the electric vehicles that are in the market. The last part of the study will make recommendations to government on ways to promote electric vehicles to the public as well as propositions for the manufacturers on some of the technical drawbacks that impedes consumers from embracing the new technology.

This chapter commences with the introduction of climate change and scientific facts behind its evolution. Possible implications of climate change on our livelihoods will be lightly covered. It will then touch on efforts by the United Nations Framework Convention on Climate Change to mobilise all the countries to work hand in hand in fighting climate change for future generations. It is imperative to have a look at transitioning to a low-carbon economy specifically in the transport sector. The issues of high energy efficient vehicles and electric vehicles will also be deliberated in detail. As the focus of the study is on full electric vehicles, the history of electric vehicles will feature moderately. Another important aspect of the study is to highlight some of the benefits that can be derived from the widespread use of electric vehicles. As with all the new technologies invested in all over the world, there will be some shortcomings that have to be highlighted.

2.2 CLIMATE CHANGE

Climate change as a result of global warming is one of the main challenges that has faced the world in recent times (Tsai et al., 2012). Throughout the world, scientists are seeing clear signs that the earth is rapidly changing (Becker & Bugmann, 1999). It has been concluded through a number of studies that climate change is primarily caused by the acts of human beings (Giannarakis, Konteos, Sariannidis, & Chaitidis, 2017; IPCC (Intergovernmental Panel on Climate Change), 2014). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), increasing greenhouse gas concentrations are the cause of global mean temperature increases Figure 2.1. The more we increase the anthropogenic greenhouse gas emissions, the more we intensify the 'greenhouse effect' thus amplifying the heat accumulation within the atmosphere. Greenhouse gas (GHG) emission concentrations have been increasing on the earth's surface and atmosphere, elevating the greenhouse effect and hence causing global warming. Temperature trends are showing that global mean surface temperatures have increased since the late 19th century and the last three decades have been continually warmer at the earth's surface than the previous decades (Stocker et al., 2013) as illustrated in Figure 2.1.

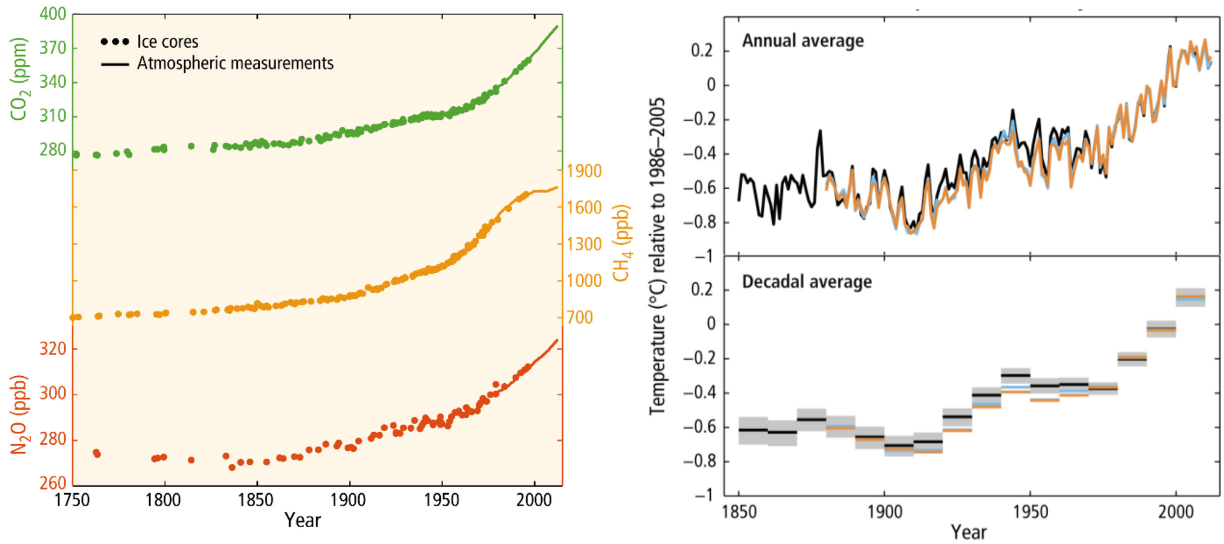

Figure 2.1: Observed changes in atmospheric greenhouse gas concentrations and surface temperature

Source: *IPCC (2014)*

Figure 2.1 shows the observed changes in greenhouse gas concentrations as well as rising earth surface temperatures. Global warming is the cause of changing precipitation patterns, increasing frequency of meteorological hazards, changes in quality and quantity of water resources, shifting terrestrial and freshwater habitats, increasing heat waves, shifting and decreases in crop production and ocean acidification (IPCC (Intergovernmental Panel on Climate Change), 2014). The climate change impacts have affected human beings in a number of ways and the most vulnerable societies are the poor and rural communities who do not have the means of adapting (Mendelsohn, Basist, Kurukulasuriya, & Dinar, 2007). The global nature of greenhouse gas emissions coupled with increasing climate change impacts around the world, calls for new and more holistic approaches to preventing and/or reducing climate change (Schaltegger & Csutora, 2012).

2.3 INTERNATIONAL AGREEMENTS AND CONVENTIONS ON CLIMATE CHANGE

Awareness of climate change has led to an evolving international consensus on the importance of both increasing our scientific understanding of global change and its linkages with societal issues (Githeko & Woodward, 1991). The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) in 1988 (Parry, 2004). Its main objective was to assess scientific, technical and socio-economic information relevant to the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation.

The first IPCC assessment report completed in 1990 led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Most countries joined this international treaty to reduce global warming and to cope with whatever temperature increases are inevitable. South Africa signed the UNFCCC in June 1993 (Department Environmental Affairs (South Africa), 2014). The second assessment report completed in 1995 provided key inputs to the negotiations which led to the adoption of the Kyoto Protocol to the UNFCCC in 1997. The Kyoto Protocol represents the first international agreement to reduce greenhouse gas emissions. Under the Kyoto Protocol, emissions reduction targets for developed countries (Annex I) were at a minimum of five per cent emissions reduction compared to 1990 levels over the five-year period 2008 to 2012.

Developing Country Parties (Non-Annex I) have been contributing to global mitigation efforts in several ways under different UN programmes and initiatives. The clean development mechanism (CDM) has been an important avenue of action for the Non-Annex I countries to implement projects that reduce emissions and enhance sinks capabilities. The Nationally Appropriate Mitigation Actions (NAMAs) has been one of the initiatives which has been agreed upon and it is implemented with the support of developed countries. Moreover, under the Paris climate agreement adopted by consensus on 12 December 2015, parties have committed to keep a global temperature rise of below 2°C above pre-industrial levels. South Africa became a party to the Paris Agreement on 22 April 2016 and ratified the agreement on 1 November 2016. Since all countries have to contribute towards the reduction in GHG emissions through nationally determined contributions, South Africa has to be determined to achieve its goals by involving all the major stakeholders (government, non-governmental organisations, private companies, research institutions, academic institutions etcetera).

In order to meet the Paris Agreement on greenhouse gas emissions targets, South Africa has to be determined to cooperate with other countries in an effort to ensure temperature increases are kept well below 2°C above pre-industrial levels and the country is implementing a mitigation strategy in order to realise the target of a low-carbon economy (Department of Environmental Affairs, 2015). It is important to recommend strategies that can promote the adoption of electric vehicles in the South African automotive market as they present an opportunity for sustainable mobility. It is important to have a thorough view of all the strategies and work with the ones that are cost-effective (Čadež & Czerny, 2010).

2.4 TRANSITION TO LOW-CARBON ECONOMY

Many countries are taking action against climate change by developing climate change policies that ensure that there is a change in the way things have been conducted (Fankhauser, 2012). One of the solutions is to shift to economies that are highly sensitive to carbon emissions. According to Goldman-Sachs (2010), transitioning to a low-carbon economy would not be easy but presents world economies with opportunities and serious challenges. It has to be recognised that fossil fuels have been responsible for providing energy for more than 100 years with high reliability and affordability (Goldman-Sachs, 2010). The alternative energy sources still have to provide the level of confidence that the fossil fuel option has been delivering and that is a major challenge.

There are four main steps that can ensure that decarbonisation efforts around the world are made possible (Fankhauser, 2012). The first step is to put in place a strong legal and institutional basis for a low-carbon policy. The second step relates to translation of low-carbon objectives into an achievable roadmap per economic sector (Fankhauser, 2012; Winkler & Marquand, 2009). The third step is to put in place all the required policies and strategies to implement the roadmap and the final step is to carry out public campaigns that deal with socio-economic consequences of the transition to a low-carbon economy (Fankhauser, 2012; Zhu, 2016).

2.5 CARBON EMISSIONS AND TRANSPORT

Carbon dioxide (CO_2) emissions from fossil fuel combustion and industrial processes contributed to over 78% of the increase in total GHG emissions from 1970 to 2010 owing to the vast expansion of business and human livelihoods (IPCC (Intergovernmental Panel on Climate Change), 2014). Thus climate change has a strong linkage with economic and social activities (Schaltegger & Csutora, 2012). In Europe, road transport accounts for close to a fifth of the total carbon dioxide emissions and furthermore, between 1990 to 2010, CO_2 emissions from the transport sector have increased by 23% (Rezvani, Jansson, & Bodin, 2015). While emissions from other sources are decreasing with time, emissions from transport are increasing with time (Bessenbach & Wallrap, 2013). The trend is the same all over the world with developing countries having even greater increases in transport emissions as affordability of cars is increasing with the introduction of Japanese and European low priced second-hand imports. The issue of dumping the low energy efficient vehicles in third world countries is of concern to issues of transitioning to a low-carbon economy and is seen as unethical conduct that undermines climate change initiatives.

Substituting current automobiles with an environmentally friendly fleet is inevitable and this could either be done by increasing the efficiency and reducing the emissions of traditional vehicles, switching to less harmful fuels, or by finding less polluting propulsion systems (Gärling & Thøgersen, 2001). The first two solutions have not yielded much fruit and now the focus is to find ways of developing efficient propulsion systems using alternative energy sources. This has led to the re-evaluation of electric vehicles as a primary means of transport. Electric vehicles (EVs) are considered a solution to the increasing GHG emissions in the current transport sector, as well as high pollution caused by the fumes coming out of the exhausts (Rezvani, Jansson & Bodin, 2015; Wang, Yu, Yang, Miao, & Ye, 2017). EVs uses electricity as fuel, and although this has many advantages as a vehicle fuel, it has two distinct disadvantages: storage problems and slow refuelling (Pearre, Kempton, Guensler, & Elango, 2011).

2.6 ELECTRIC VEHICLES

There are four classes of electric vehicles categorised according to their fuel technology, namely: battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs) and extended-range battery electric vehicles (E-REVs) (Rezvani et al., 2015; Wang et al., 2017). The most common electric vehicle in the current world market is the HEV. The HEV consist of an internal combustion engine that is complemented by electric motor driven by a battery (Rezvani et al., 2015). But one can argue that the HEV is not an electric vehicle, it is just a fuel-efficient vehicle. A PHEV is the advancement of the HEV, with increased battery power and a plug-in charger for electricity charging (Rezvani et al., 2015). An E-REV is also operated by battery but has a fuel tank to extend the driving range when the battery is flat (Rezvani et al., 2015). Lastly, a BEV is solely battery powered, and is charged from the electricity grid (Rezvani et al., 2015). This study will focus mainly on the BEVs and any referral to electric vehicles in the subsequent text should be associated with BEV.

2.6.1 History

The invention of electric vehicles has beena cumulative effect of efforts from a number of people, companies and countries. It evolved from a series of breakthroughs starting with battery technology through to the electric motor, and was influenced by a number of scientists (Matulka, 2014). According to Høyer, (2008), electric vehicles' history is more aligned to battery history, with Italians Alessandro Volta and Luigi Galvani being some of the pioneers that demonstrated that electric energy could be stored. The work carried out by Michael Farraday between 1820 and 1830 on electric current and magnetism laid the foundation for electric motors and generators which form the main components of electric vehicles (Høyer, 2008). The first full electric vehicle was manufactured in 1842 in Scotland powered by a rechargeable lead battery (Samara, 2016). In the United States the first battery operated electric vehicle was made in 1890 by William Morrison who developed a six-passenger station wagon capable of a top speed of 22.5 kilometres per hour (Matulka, 2014). Other inventors like Thomas Edison also contributed by developing a more efficient battery using nickel-iron (Høyer, 2008). In the early 1900s, electric vehicles were at their prime accounting for more than a third of all vehicles on the road (Matulka, 2014; Samara, 2016). An engineer named Ferdinand Porsche invented the first hybrid vehicle powered by electricity and fuel shown in Figure 2.2 (Matulka, 2014). According to Samara (2016), around 1920s electric vehicle technology was enhanced and charging stations networks improved in Europe. Some of the technological breakthroughs which were achieved in this period (1880 to 1920) form a basis for the current electric vehicle technologies. Even though electric vehicles date as far back as the 19th century, most of the advancement happened at the start of the 21st century (Rezvani et al., 2015).

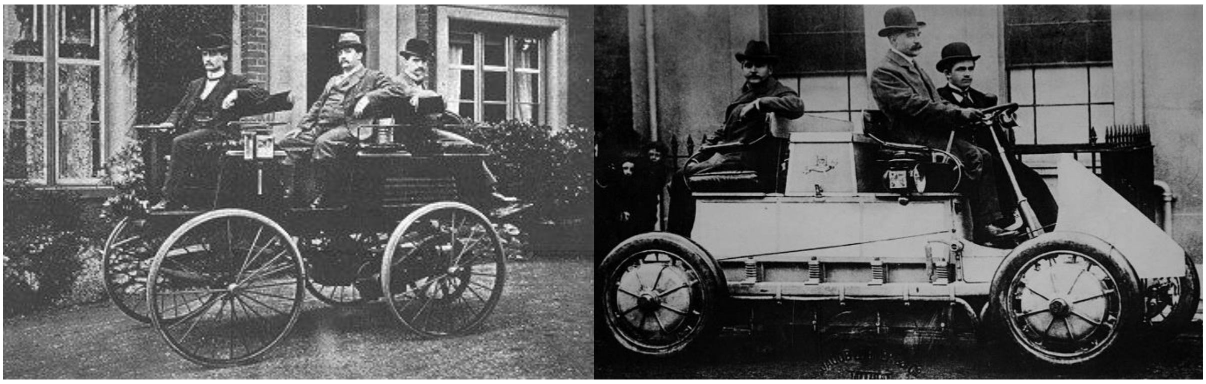

Figure 2.2: Electric vehicles produced in the 1880s

Source: *Matulka (2014)*

Figure 2.2 shows some of the early electric vehicles that were developed in the 19th century and early 20th century. The vehicle on the left side is the "first crude electric vehicle" that was developed by Robert Anderson in 1832, while the other vehicle is the "Lohner-Porsche Mixte," the pioneer of hybrid vehicles developed by Ferdinand Porsche in 1901.

Despite the positive impacts of electric vehicles and the efforts by national governments and international organisations to promote the adoption of electric vehicles, their market share as of 2011 was around 0.06% (Rezvani et al., 2015). There are a number of BEVs in the market, especially in Europe and the United States(Singer, 2017). In the South African market there are only two BEVs; namely the Nissan Leaf and BMW i3, shown in Figure 2.3 and Figure 2.4 below, with a number of vehicle manufacturers promising to introduce their version of electric vehicles post 2018.

Figure 2.3: The Nissan leaf

Source: *Nissan* (*2017*)

The Nissan Leaf is the first full electric car to be introduced to the South African market in 2013 and has sold less than 100 units to date. It has a top speed of 144km/h with a torque of 254nm. It is powered by a battery pack of 24kwh. It can drive up to 195 km per one charge.

The BMW i3 was launched in South Africa in 2015 and has sold over 200 units to date. It has a top speed of 150km/h with a torque of 250nm. It is powered by a battery pack of 22kwh. It can drive up to 200 km per one charge.

Figure 2.4: The BMW i3
Source : *BMW (2013)*

2.6.2 **Advantages of Using Electric Vehicles**

It has been documented by a number of researchers that fuel for electric vehicles is cheap relative to diesel or petrol (Gärling & Thøgersen, 2001). The fuel cost of driving an electric vehicle is dependent on the cost of electricity per kilowatt-hour and the energy efficiency of the vehicle (Idaho National Laboratory, 2010). A study conducted in Canada using data from 1999 to 2004 states that the fuel price for electric vehicles is 3.23 times cheaper than that of the conventional vehicle(Granovskii, Dincer, & Rosen, 2006). The studies conducted by Idaho National laboratory showed that fuel for electric vehicles costs on average 3.3 cents per mile while the fuel costs for a gasoline vehicle are around 15.9 cents per mile (Idaho National Laboratory, 2010). In addition, electric vehicles have low operating costs. Electric motor maintenance is minimal (Gärling & Thøgersen, 2001). Electric motors last significantly longer than internal combustion engines (Gärling & Thøgersen, 2001). Electric vehicles also have relatively high energy efficiency.

2.6.3 **Current Technologies Employed in Electric Vehicles**

EVs went through a series of technological developments before gaining their recent popularity (Yong, Ramachandaramurthy, Miao, & Mithulananthan, 2015). Efforts have been dedicated to improving the technologies of the battery, power train and charging infrastructure.

A battery operated electric vehicle relies heavily on battery technology. The main challenge with BEVs is storing enough energy in batteries to deliver a satisfactory driving range and recharging the battery without extreme inconvenience to the driver

(Fulton, Seleem, Francisco, Alessandra, & Deger, 2017). Battery technology has been improving and becoming less expensive with time (Figure 2.5). Most of the BEVs depend on a lithium-ion based battery; this is a technology which has been used in the last 25 years in portable electronics. It has the advantage of delivering relatively high energy density, high specific energy and a good lifecycle. A battery is the core component of an electric vehicle but the current EV battery has some constraints (relatively low energy density) which affect the potential all-electric drive range of the EV.

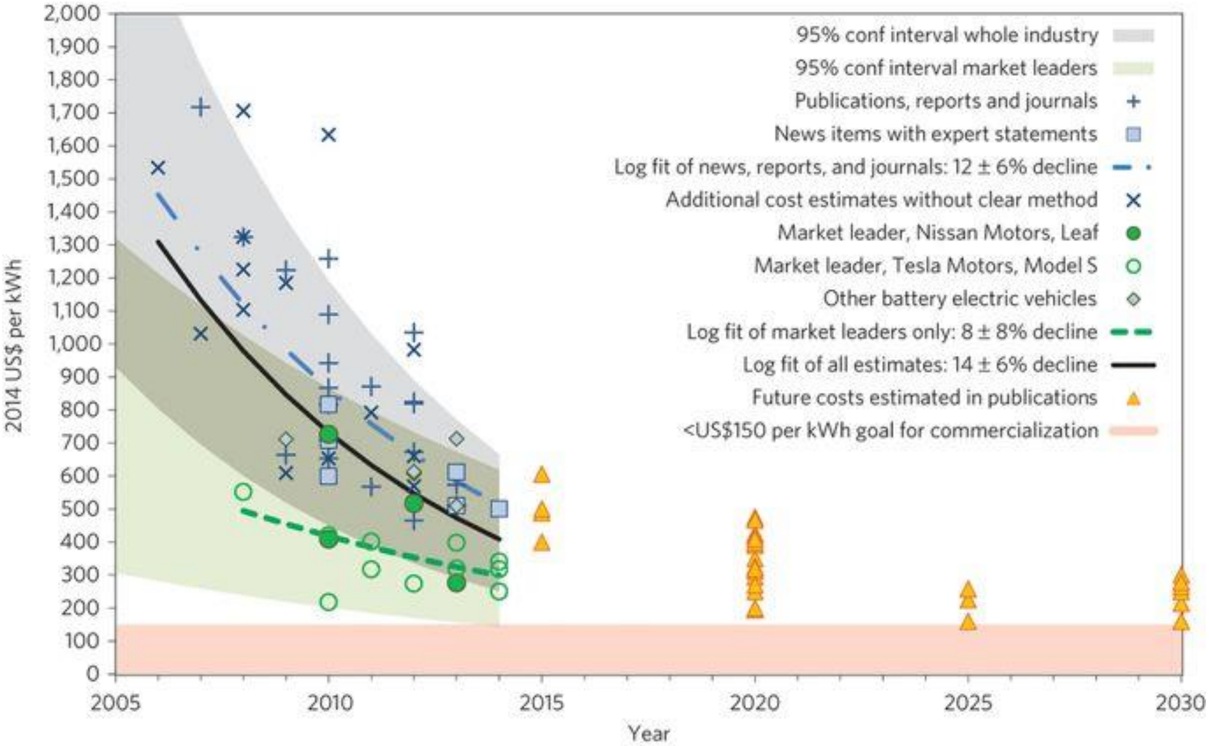

Figure 2.5: Estimates of costs of lithium-ion batteries for use in electric vehicles

Source: *Fulton et al. (2017)*

EV battery technology went through a lot of development phases in order to design a battery with high energy density, high power density, which is also inexpensive, safe and durable (Yong et al., 2015). The original battery technology used in transportation was a lead-acid battery, but due to its low energy intensity, heaviness and environmentally depleting technology, it was replaced by nickel-based battery technology (Andwari, Pesiridis, Rajoo, & Martinez-, 2017). Even though these had a relatively higher energy intensity as compared with the lead-acid battery, the drawbacks include: poor charge and discharge efficiency, high self-discharge rate, and poor performance in cold regions. Sodium-nickel chloride batteries were also introduced after nickel-based batteries. These batteries have high energy density and power density making them ideal for EV application (see Table 2.1 below). However, the extreme operating temperature exceeding 245ºC has raised safety concerns. The recent introduction of lithium-based batteries with high energy density, high power density, which are light, cheap, non-toxic and have a fast charge capability, has given hope to the EV community. There are some battery technologies in the experimental phase including: lithium–sulfur (Li–S), zinc-air (Zn-air) and lithium-air (Li-air). These new inventions have the potential to offer better capabilities than all the previous versions of electric vehicle battery technologies.

Electric vehicles need to be recharged on a regular basis, and this can occur either at home or at work, when shopping, or during other types of stops when travelling. Conductive charging is another important technology that has been developed to improve on the deployment of electric vehicles. The vehicle is charged through a cable plugged to the electrical grid and the method is highly efficient, light, compact, and allows bi-directional power flows (Andwari et al., 2017).

As discussed earlier, EVs can be categorised into four main different types based on the vehicle hybridisation ratio (Yong et al., 2015), which are hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). One of the technologies that are present in the current electric vehicles is a regenerative braking system, which is an energy recovery system that converts kinetic energy to chemical energy stored in a battery during braking.

A range extender is another technology that is being used in electric vehicles to solve the issue of having low driving range per charge in the current battery technology (Andwari et al., 2017). A range extender is a power generating system in the form of either a small internal combustion engine associated with a generator or a fuel cell producing electricity to charge the battery during low battery power (

Figure 2.6: Powertrain showing a range extender

Source: Andwari et al. (2017)

Table 2.2). When the battery range is inadequate, the engine is turned on, and consumes fuel to generate mechanical energy that is converted into electrical energy by a generator (Figure 2.6). The resulting electricity is either stored or consumed by the electric motor to power the vehicle (Andwari et al., 2017).

Table 2.1: Comparison of different battery types used to drive an electric motor

Battery type	Nominal voltage (V)	Energy density (Wh/Kg)	Volumetric energy density (Wh/L)	Specific power (W/kg)	Life cycle	Self-discharging (% per month)	Memory effect	Operating temperature (ºC)	Production cost ($/KWh)
Lead-acid	2.0	35	100	180	1000	< 5	No	-15 to 50	60
Nickel-cadmium	1.2	50 - 80	300	200	2000	10	Yes	-20 to 50	250 – 300
Nickel-Metal hydride	1.2	70 – 95	180 - 220	200 - 300	< 3000	20	Rarely	-20 to 60	200 - 250
Sodium-nickel chloride	2.6	90 – 120	160	155	> 1200	< 5	No	245 to 350	230 – 345
Lithium-ion	3.6	118 – 250	200 – 400	200 – 430	2000	< 5	No	-20 to 60	150
Lithium-ion polymer	3.7	130 - 225	200 – 250	260 – 450	> 1200	< 5	No	-20 to 60	150
Lithium-ion phosphate	3.2	120	220	2000 – 4500	> 2000	< 5	No	-45 to 70	350
Zinc-air	1.65	460	1400	80-140	200	< 5	No	-10 to 55	90 -120
Lithium-sulfur	2.5	350 – 650	350	-	300	8 - 15	No	-60 to 60	100 – 150
Lithium-air	2.9	1300 – 2000	1520 - 2000	-	100	< 5	No	-10 to 70	-

Source: Andwari et al. (2017)

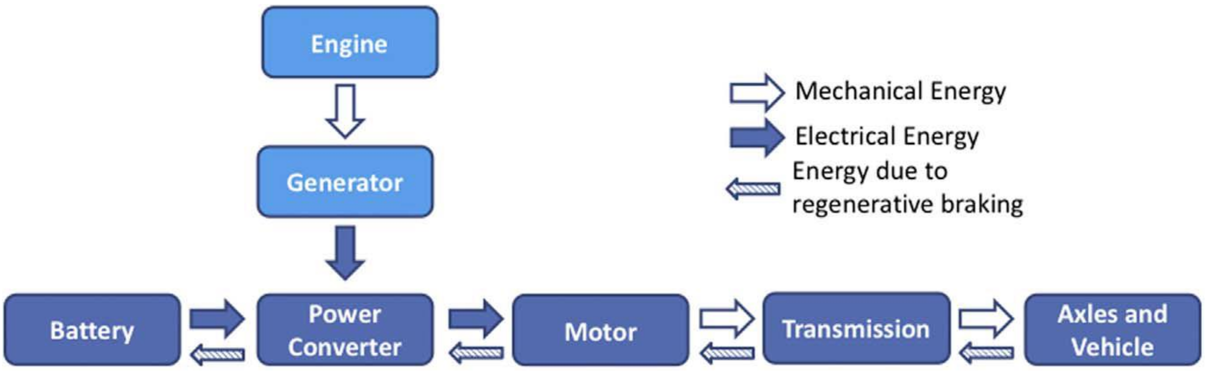

Figure 2.6: Powertrain showing a range extender

Source: Andwari et al. (2017)

Table 2.2: Summary of some of the technologies used in electric mobility

Technology	Lifecycle stage	Competitiveness impact
Regenerative braking system	Mature stage	Technology that helps in transferring energy back to the battery during braking that would have been lost otherwise.
Nickel-based battery	Decline stage	Poor competitiveness edge due to its toxic components and other drawbacks
Lithium-ion battery	Maturity stage	The latest commercial batteries that have the highest energy density than any other battery in the market.
Range extender	Maturity stage	Enables the electric vehicle to increase its driving range by coupling a generator.
Conductive charging	Growth stage	The technology allows power to flow in both direction allowing storing of power generated from the electric vehicle.

Source: *Researcher's own construction (2018)*

The continuous development of electric vehicle technologies is crucial to ensure that EV technology competes with internal combustion vehicles and to widen the EV adoption (Yong et al., 2015).

2.7 BARRIERS TO ADOPTION OF ELECTRIC VEHICLES

Electric vehicles command high prices in comparison with conventional vehicles thus making them unpopular with many people (Gärling & Thøgersen, 2001). The consumers find the risk too high to buy an electric vehicle with a low guarantee of easy recharge (Bonges & Lusk, 2016). Most consumers are nervous of expensive new technology and thus buying an ‘unreliable’ electric vehicle which would be far more costly than a traditional vehicle, becomes too risky (Plug in America, 2016).

Compared to traditional vehicles, current electric vehicles have the challenge of having limited driving range due to the battery used (Gärling & Thøgersen, 2001). The current battery technology has no capacity to propel the vehicle to the desired range on one charge. This limited range is another factor that prevents consumers from buying electric vehicles and has been found as the number one constraint in studies undertaken (Bonges & Lusk, 2016; Wang et al., 2017). The stored battery energy can take electric vehicles between 50km and 200km for the standard electric vehicles, while more advanced electric vehicles are proclaimed to go up to 500km (Bessenbach & Wallrap, 2013). To improve the range there must be improvements in the battery energy density and technology (Bonges & Lusk, 2016). The shortcoming of a limited range can be solved through the availability of a second vehicle, which can be used for long distance trips or in cases of emergencies (Jabeen, Olaru & Smith, 2012). Thus this makes an electric vehicle in the current technology advancement to be best suited for short trips around the city (Jabeen et al., 2012). But this would not be viable for households that do not have resources to afford two vehicles.

Charging of a vehicle can be an inconvenience to motorist, which causes them to carefully plan their trips without accommodating any major changes to their travelling routes (Jabeen et al., 2012). The other drawback is that charging the battery to full charge takes a very long time, up to eight hours, or even more (Gärling & Thøgersen, 2001). Electric vehicles have shorter availability on a daily basis due to the amount of time spent on recharging the battery (Gärling & Thøgersen, 2001). It has to be noted that the amount of time it takes to have an electric vehicle to be charged even at a fast charging station, is too long compared to the convenience of the traditional vehicle. This has to be changed by investing more resources in research that will enable scientists to come up with a battery that can be charged at a fraction of the estimated 30 minutes for the DC level 3 fast charger (Bonges & Lusk, 2016).

The usability of an electric vehicle is highly disadvantaged by poor networks of recharging stations (Gärling & Thøgersen, 2001). According to Bonges & Lusk (2016), availability of recharging stations is one of the major considerations when one buys an electric vehicle. Thus the poor network of charging stations can be one of the main determinants of low acceptance of the technology in major developing nations. In the United States there are around 7000 public charging stations, showing low density per area (Bonges & Lusk, 2016). The proportion of fast chargers has to be increased around the main roads in regions which want to move extensively into electric vehicles. The costs of a level 2 charging station is estimated to be in the region of up to $21 000, while the level 3 charging station costs up to $85 000(Bonges & Lusk, 2016). This tremendous price disparity will derail the rate of putting up fast charging stations and thus have an impact on the market penetration of the electric vehicle technology. Compatibility of charging stations is another issue that has to be addressed. The type of charging station at these networks needs to be compatible with the vehicles without utilisation of an adapter. In the US, there exists over six different charging systems, deflating an already poor network. This calls for standard recharging sockets for all the vehicles so that any recharge station installed can be utilised by any of the electric vehicles.

According to Kloess (2011), battery costs and fuel prices are the main factors that affect the economic competitiveness of hybrid and electric vehicles. In recent times hybrid vehicles have become close to being cost effective with pure electric propulsion systems (PHEVs & BEVs) still being highly ineffective due to high battery costs and relatively low fuel prices (Kloess, 2011). Thus it is recommended that in the near future (up to 2020) people are encouraged to convert to hybrid systems, while more efficient and less costly batteries are being invented with the conversion to full electric fuel technology post 2020 (Kloess, 2011).

There are few models that are available for electric vehicles, mostly comprising hatchback vehicles thus limiting the number of people that would be interested in buying them (Plug in America, 2016). Internal combustion engine vehicles have a variety of models ranging from tiny compacts to vans. All these disadvantages create a challenge for marketers and policy-makers who are interested in increasing market penetration of electric vehicles. In order to win the battle, the role of advocates of electric vehicles has to be to create a global market that is adequately informed mostly about the advantages of this new technology rather than its shortcomings (Gärling & Thøgersen, 2001).

2.8 PERCEPTIONS ON ELECTRIC VEHICLES

The study conducted in Seattle and Austin in the US showed that around 9% of all vehicles in those cities never exceed 160km per day, thus indicating the possibility of a market for the BEVs (Bonges & Lusk, 2016). But the other study conducted in major United States cities on the willingness to adopt electric vehicles showed a weak desire on the part of the consumers to either buy or lease electric vehicles (Wang et al., 2017). It has to be noted that people's choices are influenced by attitudes, preferences and habits, thus the need for new technologies to be aligned as much with the norms of people to ease the transition (Jabeen et al., 2012). The electric vehicle technology's poor adoption figures are mainly attributed to the consumers' perception of them [factors that influence consumers' intentions to buy EV] (Rezvani et al., 2015).

On the other hand, the study by Jabeen et al. (2001) on the perceptions of drivers of electric vehicles yielded an average satisfaction score of 3.96 out of 5 among the people who were used to conduct a trial on both converted electric vehicles and manufactured electric vehicles. The trial monitored the performance, benefits, infrastructure and practical implications of electric vehicles in Western Australia (Jabeen et al., 2012). This is an indication that the experience of electric vehicles is good and drivers can easily shift to new transport technology. Surveys related to attitudes, knowledge and perceptions of electric vehicles differ according to age, gender and education level (Wang et al., 2017). It can be noted that environmental and sustainability aspects of electric vehicles' technology has a part to play in their adoption by the consumers (Wang et al., 2017).

2.9 MARKET SHARE OF ELECTRIC VEHICLES

The global count of electric vehicles (EVs) in 2015 was over 1 million vehicles (Figure 2.7) and this increased by over 60% in 2016 to 2 million vehicles worldwide (Fulton et al., 2017). This rapid increase of electric vehicles on the road has been championed by China, the United States, Japan and several European countries. The uptake of EVs is attributed to a number of factors including:

- strong technological progress
- battery cost reductions
- policy and government support including purchase incentives
- driving and parking access advantages, and
- increased public charging infrastructure.

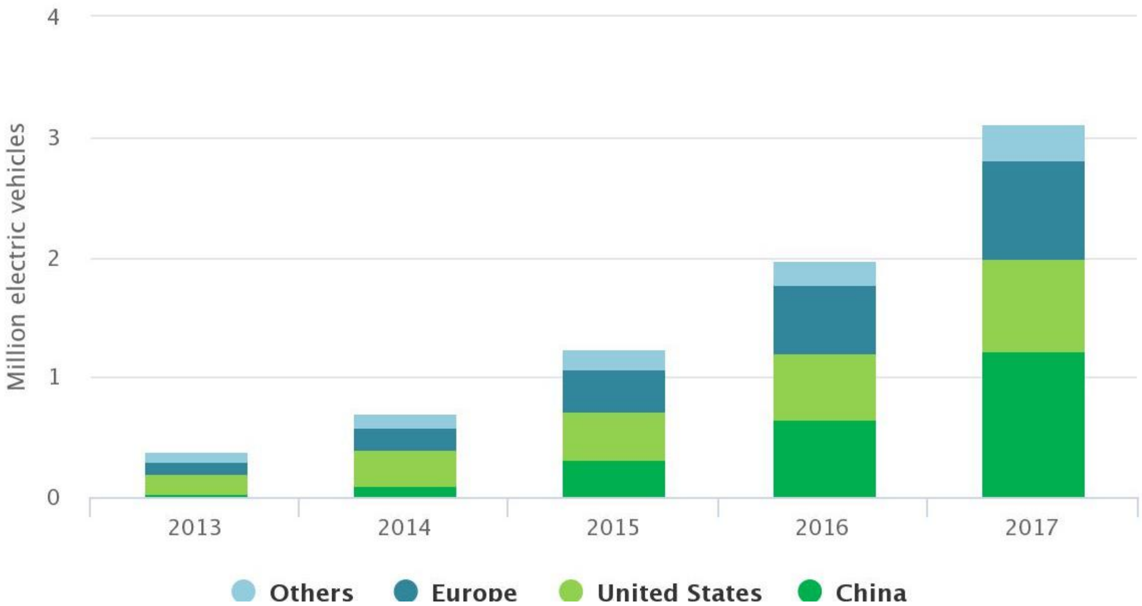

Figure 2.7: Stock of electric vehicles from 2013 to 2017
Source: International & Agency (2018)

2.10 POLICY CONSIDERATIONS FOR ELECTRIC VEHICLES

The increased environmental hazards as a result of elevated use of fossil fuel has caused the world to investigate alternative sources of energy (Jabeen et al., 2012). In the transport sector electric mobility has been at the forefront of this evolution. This requires a drastic shift in the mind-set of people in order to accept new energy sources and resources that can be utilised to achieve their desired goal. Countries use different strategies to improve the adoption of EVs with Germany concentrating on research and development to ensure that consumers of the new technology are satisfied (Bessenbach & Wallrap, 2013). Many developed and emerging economies have initiated some public policies and financial incentives that are geared towards the adoption of electric vehicles (Rezvani et al., 2015; Wang et al., 2017). The European Union has collectively set the mandatory targets for its members, of a 40% reduction in transport emissions compared to the 2007 base year (Bessenbach & Wallrap, 2013). As a result of these targets, alternative propulsion systems using renewable energy and low carbon fuel has been on the rise in Europe.

Electric vehicles are considered a solution with more effort being focused on improving their functionality in order to bridge the gap that exists between them and the traditional cars, but less work has been done on customer acceptance (Bessenbach & Wallrap, 2013). The realisation of adopting electric vehicle technology lies in the hands of the people. It is documented by Wang et. al. (2017) that in 2008, the majority (69%) of the consumers were not aware of electric vehicle technology. It is also government's sole responsibility to educate its citizens about the causes of climate change and the impact on human livelihoods to make it easy for people to buy into any changes that government introduces, which address the issue.

Electric vehicle purchasing incentives have been introduced in some of the countries to lure consumers to the new technology that minimises greenhouse gas emissions (Bonges & Lusk, 2016). The adoption rate of EVs is twice as high in these countries compared to those with no incentives and the states with highest incentives in the US surpassed the 1% adoption rate recommended (Plug in America, 2016).

The owners of electric vehicles in some countries are afforded the luxury of convenient parking spaces in major congested areas like shopping malls (Bonges & Lusk, 2016). The introduction of free charging stations in some of the developed countries are among the policies that are helping society to transform to low-carbon transportation (Bonges & Lusk, 2016).

In the US, the department of energy has been heavily involved in ensuring that the network of electric vehicle charging stations is increased (Bonges & Lusk, 2016). The New Zealand government has also vowed to support and increase a roll-out of public charging infrastructure (Zhu, 2016). Other policy consideration in New Zealand include (Zhu, 2016):

- Extension of exemption for electric vehicles from road user charges;
- Nationwide electric vehicle promotion and awareness;

- Permission of electric vehicles to access bus lane and high occupancy lanes; and
- Method to have tax benefit for owners of electric vehicles.

2.11 PROJECTIONS FOR THE USE OF ELECTRIC VEHICLES

The sales forecasts for electric vehicles show a stagnant growth with minimal market share in the near future with around 2.4% of sales of new vehicles by 2022 (Bonges & Lusk, 2016). In the future, battery technology will definitely change and there is a possibility of having a battery with 200kwh instead of the 20kwh one being currently used and thus driving range issues will be eliminated (Bonges & Lusk, 2016). Provisions have to be made to ensure that current charging stations can still be used in the future so that infrastructure investment is optimised. At the moment there is poor awareness of electric vehicles in most markets, thus any future rise in the adoption requires massive marketing and campaigning (Plug in America, 2016).

2.12 SUMMARY

Climate change is one of the major issues that the current generation has to solve in a practical manner in order to minimise the hazardous impacts on livelihoods for the future generations. The United Nations with its sister organisations, has taken a lead role by engaging all the nations in the fight to stagnate climate change. The consensus is that all countries need to shift to a low-carbon economy with the use of renewable energy and highly efficient energy sources. The transport sector's greenhouse gas emissions have been increasing at an alarming rate all over the world. This is due to growing demand for vehicles produced and purchased. Several mitigation options can be considered in this sector including radical changes in public transportation policy and shifting from internal combustion engine vehicles to electric vehicles. The latter have been on the rise in the majority of the developed countries, mostly due to obligations to meet GHG reduction targets set. Electric vehicles present consumers with the benefits of having high energy efficiency, low operating costs and low carbon emissions. But there are a number of glitches that need to be addressed including low driving range, expensive cost of vehicles, high battery costs and consumer mind-set shifts.

3. CHAPTER 3: MATERIALS AND METHODS

3.1 INTRODUCTION

The previous chapter presented an appropriate literature review related to electric cars and their role in the low- carbon economy transition. This chapter will focus attention on the research design and methodologies that will be followed to achieve the objectives of the study.

3.1.1 Research Paradigm

Research can be defined as a scientific and systematic search for, or investigation of, appropriate information on a specific topic (Kothari, 2004). Research encompasses defining and redefining problems, formulating hypotheses or suggested solutions; collecting, organising and evaluating data; making deductions and reaching conclusions (Kothari, 2004). Researchers mostly ask two fundamental types of research questions: “What is going on (descriptive research)? and Why is it going on (explanatory research)?” (De Vaus, 2001). According to Antwi & Hamza (2015), research methodology depends on the paradigm that guides the research venture. The way in which researchers develop research designs is affected by whether the research question is descriptive or explanatory (De Vaus, 2001). It affects what information is collected. A paradigm is “a perspective based on a set of assumptions, concepts, and values that are held by a community or researchers” (Johnson & Chirstensen, 2000). According to Mittwede (2012), every paradigm is based upon pre-assumptions regarding reality and how it may be understood, making these paradigms combinations of assumptions.

There are two distinct research approaches: quantitative research and qualitative research. These approaches differ according to the following characteristics: pertaining to being (ontology), theories of knowledge (epistemology), values (axiology), language (rhetoric), and the process of research (Mittwede, 2012). Quantitative research utilises a deductive (top down) approach that tests the theory or hypothesis using data with much reliance on the collection of measurable data (Johnson & Chirstensen, 2000). The deductive reasoning starts with the general statement followed by a more specific statement inferred from the observed phenomenon and moves to specific conclusions based on logical reasoning (Khaldi, 2017). The typical steps that are used are the following (Figure 3.1): statement of the hypothesis, based on an already existing theory or research literature; gathering of relevant data to test the hypothesis and finally a decision on whether to accept or reject the initial hypothesis (Khaldi, 2017). Quantitative purists call for assumptions that are consistent with a positivist philosophy and believe that research should be objective (Johnson & Onwuegbuzie, 2004). According to Antwi & Hamza (2015) quantitative, or positivistic research, is based on observations and experiments using properties which are independent of the researcher and instruments. Positivism is more concerned with discovering the truth and presenting it by quantitative means (Antwi & Hamza, 2015).

Qualitative research deals with an inductive (bottom-up) approach that aims at generating new theories or hypotheses using data that cannot be represented as numbers or commitment to gain understanding of reasons behind a phenomenon (Johnson & Chirstensen, 2000; Taguchi, 2018; van Griensven, Moore, & Hall, 2014). Qualitative research is more geared towards meaning, social context and personal experience. Qualitative data, conversely, deals with information that is difficult to quantify such as interview transcripts, observations of non-verbal communication, drawings and film (van Griensven et al., 2014). The inductive reasoning starts from specific observations and moves towards a general conclusion utilising the following steps (Table 3.1): observation; identification of patterns derived from these observations and drawing conclusions on the basis of these patterns (Khaldi, 2017). Qualitative data can assist researchers in determining chronological flows of information, the causality of incidences and detailed explanations of variances (Miles & Huberman, 1984). Qualitative radicals are mostly against positivism and believe in the superiority of constructivism, idealism, relativism, humanism, hermeneutics and postmodernism (Johnson & Onwuegbuzie, 2004).

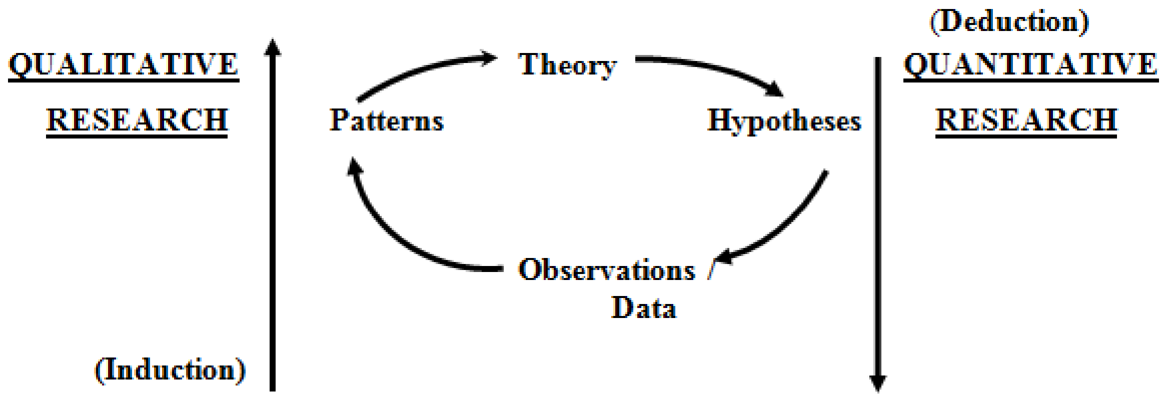

Figure 3.1: The Schematic diagram of both qualitative and quantitative reasoning
Source: *Khaldi (2017)*

In recent times there has been the introduction of mixed research which combines both quantitative and qualitative research (Johnson & Onwuegbuzie, 2004). Mixed methods research has gained popularity and is another step forward because research methodology continues to evolve and develop (Creswell, 2007). It utilises the strengths of both approaches (qualitative and quantitative research), and acknowledges that complexities in other fields cannot always be investigated fully using a single approach (Creswell, 2007; van Griensven, Moore & Hall, 2014). According to Creswell (2014), multiple methods or mixed methods was based on the notion that both traditional methods have biases and weaknesses, and the collection of quantitative and qualitative data simultaneously will tend to neutralise the weaknesses of each form of data. Mixed methods research may be viewed by most researchers as providing a more comprehensive picture, having great scope and deep understanding of the subject under investigation (van Griensven et al., 2014).

The study will employ the positivistic paradigm. According to Healy & Perry (2000), the positivism paradigm measures quantitatively independent facts about a single apprehensible reality and this study investigates the current reality of anthropogenically induced climate change which is affecting the way people live in the 21st century. Furthermore, this paradigm which is highly dominant in the field of science, works with data whose analysis is value-free and data does not change because they are being observed (Healy & Perry, 2000). The greenhouse gas emissions emitted from the transport sector has a major impact on the globe and necessitates the use of different technologies which need to be assessed. In the positivism paradigm, a statistical evaluation of the results is conducted and this can be applied for an array of problems (Schrag, 1992). In this study, statistical analysis will form a basis for the recommendations in line with the positivistic research paradigm. The data for this study is also specific and precise, its reliability is moderate to high while its validity is low, which is synonymous with the positivism paradigm.

3.2 RESEARCH DESIGN

Research design is key for any kind of research because it facilitates the smooth running of the various research operations; hence making research as efficient as possible in an effort to maximise output while utilising minimal inputs of effort, time and money (Kothari, 2004).

3.2.1 Study area

The study was conducted in the Gauteng province of South Africa (Figure 3.2). There are about 14.717 million people residing in Gauteng, representing around 25.4% of people living in South Africa (Statistics South Africa, 2018). Even though Gauteng is a highly populated province, it is the smallest province in terms of size with 18 178km^2 equivalent to 1.49% of the total area of the country. Based on the proportions of the 2011 census, the distribution of people within the province is shown in Table 3.1 below (Statistics South Africa, 2011).

Table 3.1: Distribution of 2018 Gauteng population per district

District	Percentage	Population
City of Johannesburg	36.1	5 312 837
City of Tshwane	23.8	3 502 646
Ekurhuleni	25.9	3 811 703
Sedibeng	7.5	1 103 775
West Rand	6.7	986 039
Gauteng	**100**	**14 717 000**

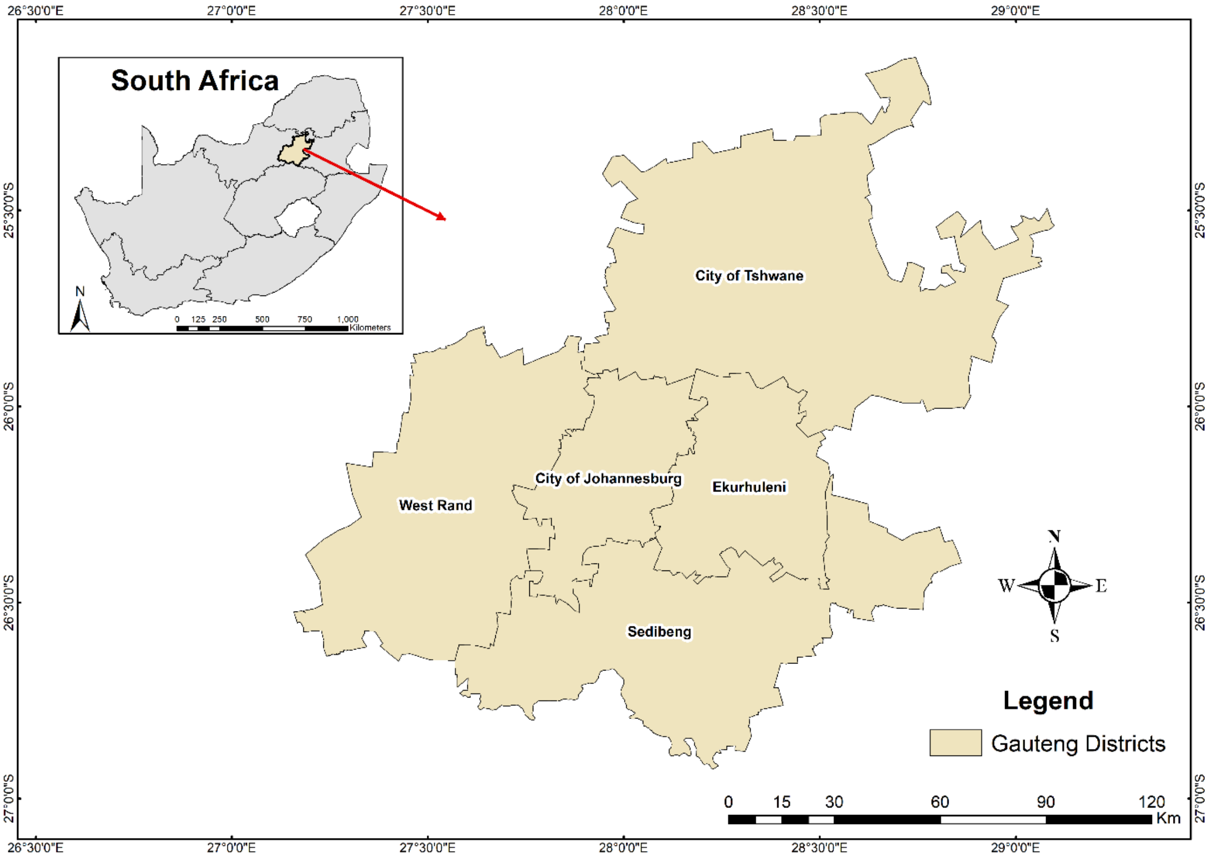

Figure 3.2: The Map of Gauteng showing all the districts

Source: Researchers own contribution (2018)

Gauteng is home to the country's largest city, Johannesburg, and it is the main economic hub of the country. Gauteng is a landlocked province surrounded by the Free State, North West, Limpopo and Mpumalanga provinces. The name Gauteng originates from the Sesotho word "gauta" which means "gold" because of the historical flourishing gold industry in the region. Gold was first discovered in Gauteng in 1886 and the region became the single largest gold producer in the world (Gauteng Info, 2018). The province also houses the country's administrative capital, Pretoria.

The number of vehicles in the province has been increasing linearly from the year 2000 to 2018. This is shown by data in Table 3.2 obtained from eNatis, a South African company responsible for keeping records of registered vehicles (eNaTIS, 2010, 2011, 2013, 2014, 2018). By the end of September 2018, the province's vehicles were in total 38.78% of the total vehicles in the country (eNaTIS, 2018). The transport sector is one of the main emitters of greenhouse gas emissions in South Africa contributing around 13% of the total emissions (544 314 Gg CO_2 eq.) (Department of Transport, 2016).

Table 3.2: Number of registered light vehicles in the Gauteng province

Year	**Number of passenger vehicles**
2000	1619321
2001	1656851
2002	1683599
2003	1733474
2004	1793560
2005	1907656
2006	2042811
2007	2155748
2008	2201397
2009	2256780
2010	2361782
2011	2454894
2012	2562594
2013	2676080
2014	2773847
2015	2859623
2016	2931299
2017	2979764

Source: (eNatis.com)

3.2.2 Research Approach

The approach used in this investigation is the case study. The case study method is highly valuable to use when there is a need to obtain detailed information of an issue, event or phenomenon of interest (Hyett et al. 2014). This is an established research design that is used extensively in a wide variety of disciplines including social sciences and hard sciences (Crowe, Cresswell, Robertson, Huby, Avery, Sheikh & Zainal, 2011). Case studies can be approached in a number of ways depending on the standpoint of the researcher, whether they take a critical, interpretivist or positivist approach (Crowe et al., 2011; Zainal, 2007). The main stages of research activity when planning and undertaking a case study are: defining the case; selecting the case(s); collecting and analysing the data; interpreting data; and reporting the findings. This study, is investigating the carbon emissions implications of adopting electric vehicles in the Gauteng province of South Africa. The factors affecting the adoption of electric vehicles are also researched.

3.2.3 Sampling Design

The target group is all the people residing in the Gauteng Province with the potential to buy a vehicle. It has been concluded that the activities of human kind have been contributing to climate change, which has a negative impact on the globe and it is a threat to human survival in the future. It is imperative that the selection of the means of obtaining data and from whom the data will be acquired, be done with sound judgment (Tongco, 2007). Since the study concentrates on investigating the adoption of electric vehicles in the Gauteng Province, the study uses the purposive/judgemental non-probability sampling, in which the sampling members conform to the predetermined criteria. The use of social media as a means of disseminating the survey is a form of the snowball sampling approach. According to Tongco (2007), purposive sampling is a non-random technique that does not require underlying theories or a set number of informants; rather the researcher decides what needs to be known and sets out to find ways of obtaining that information.

3.2.4 Research Methodology and Data collection

The methodology of conducting this research will be dependent on the objectives of the study.

3.2.4.1 Research question 1 (Investigate the potential impact of switching to electric vehicles on national carbon accounting from the transport sector)

This section will investigate the greenhouse gas emissions impact of adopting electric vehicles in Gauteng. The estimation of GHG emissions will first be estimated using vehicle statistics from 2000 to 2017 as the basis of the investigation, as well as the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines together with the findings of Tongwane (2009), Tongwane, Piketh, Stevens, & Ramotubei (2015) and Goyns' (2008) research will be used to estimate GHG emissions from the internal combustion engine vehicles.

In road transport, it is key to estimate CO_2 carefully because this is the main GHG and efforts to improve emissions of other gases should be minimal as they make a small contribution to the total emitted (IPCC, 2007). The following steps were used to estimate GHG emissions from light passenger vehicles in the Gauteng Province:

- Collect fuel statistics as well as average distance travelled by passengers;
- Estimate carbon dioxide emissions using the appropriate methodology;
- Estimate methane and nitrous oxide emissions using the appropriate methodology; and
- Combine the emissions using latest global warming potential for each of the GHGs.

To estimate carbon dioxide emissions from motor vehicles the following equation is used:

$$\boldsymbol{CO_2\ emmisons} = \sum \boldsymbol{N_{a,b}} \times \boldsymbol{Dist_{a,b}} \times \boldsymbol{EF_{a,b}})$$ **Equation 2.1**

Where N_{ab} is the number of vehicles per fuel type (a) and engine size (b); $Dist_{ab}$ is the average distance travelled per fuel type and engine size; EF_{ab} is the emissions factor for a vehicle per fuel type and engine size.

The vehicle types were categorised according to the proportions obtained in Posada, (2018) as shown in shown in Table 3.3. It is estimated that 83% of the cars run on petrol while 17% of the vehicles use diesel, while the proportion of hybrids and electric vehicles was negligible in 2015 (Posada, 2018; Tongwane et al., 2015).

Table 3.3: Number of vehicles in Gauteng per vehicle class and fuel type

Vehicle class	Fuel type			
	Diesel		Petrol	
	%	Number of vehicles	%	Number of vehicles
Mini	0	0	8	238381
Small	5.61	167165	27.39	816157
Lower medium	3.57	106378	17.43	519373
Medium	1.19	35459	5.81	173124
Upper medium	0.17	5066	0.83	24732
Sport	0.34	10131	1.66	49464
Off-road	0.51	15197	2.49	74196
MPV	0.68	20262	3.32	98928
SUV	3.57	106378	17.43	519373

Source: Posada (2018)

Estimated emissions factors for all the car categories listed in Table 3.3 are shown in Table 3.4 obtained from a study commissioned by Posada (2018).

Table 3.4: Emission factors for different vehicle class in South Africa

Vehicle class	**Emission factor (g CO_2/km)**	
	Diesel	**Petrol**
Hybrid	N/A	110
Plug-in Hybrid	N/A	50
Mini	N/A	125
Small	120	140
Lower medium	118	148
Medium	118	138
Upper medium	135	165
Sport	130	180
Off-road	128	149
MPV	165	198
SUV	182	180

Source: Merven, Stone, Hughes, & Cohen (2012); Posada (2018); Fontaras Pistikopoulos, & Samaras, (2008); Alternative Fuels Data Centre (2018)

The distances travelled for motor vehicles were estimated based on the average distance travelled obtained from Tongwane et al. (2015) of 15 867 km and this was kept constant throughout the period of the study.

Over and above carbon dioxide, vehicles also emit methane (CH_4) and nitrous oxide (N_2O) from the exhaust (Waldron, Harnisch, Lucon, & Mckibbon, 2006). The emissions of CH_4 and N_2O are highly correlated to vehicle distance travelled rather than fuel consumption (Tongwane, 2009). It has been found that emissions of these other greenhouse gas emissions are insignificant in comparison with the CO_2 emissions and normally constitute 5 - 6 % of the total transport emissions from light vehicles, while CO_2 emissions amount to 94-95%, based on the global warming potential of each green-house gas (U.S. Environmental Protection Agency, 2005). Thus emissions from other GHG emissions were estimated using the following equation:

$$Other\ emissions = \frac{CO_2\ emmisons \times 5}{95} \qquad \text{Equation 2.2}$$

In order to assess the impact of the introduction of electric vehicles in the South African passenger vehicle greenhouse gas emissions, the following steps were undertaken:

- Use of statistical packages to forecast vehicle population until 2030;
- Assumptions on the desired proportions of electric vehicles in the future based on government policy;
- Estimation of the number of electric vehicles based on desired proportions until 2030; and
- Calculating direct emissions reduction based on the desired electric vehicle proportions.

Forecasting of vehicle population

The XLSTAT ARIMA model was used to forecast the vehicle population from 2018 to 2030 based on the trend recognised from the base values from 2000 to 2017(XLSTAT, 2018) (Figure 3.3). The forecast yielded three cases, namely:

1. Economic decline case
2. Business as usual
3. High economic growth case.

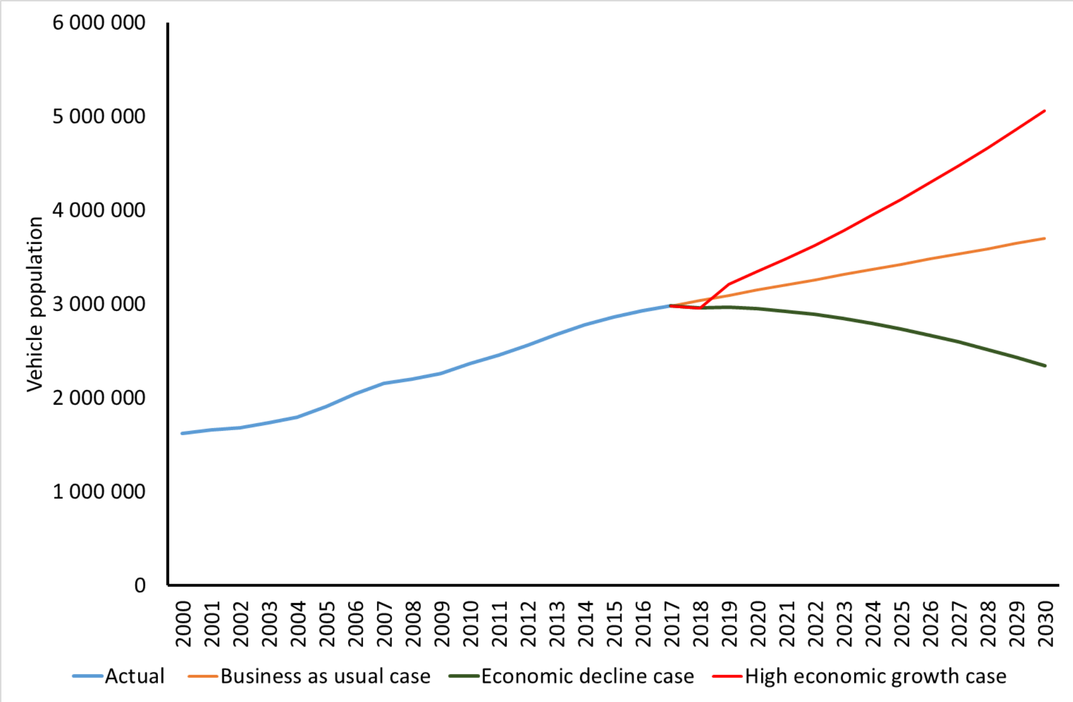

Figure 3.3: Gauteng passenger vehicle forecast from 2018 to 2030

Source: Researchers own contribution (2018)

Assumptions on future electric vehicles

Based on the South African Nationally Intended Contributions, which project to invest in electric vehicles and hybrid vehicles, the latter is projected to have a 20% population by 2030 (Government of South Africa, 2015). The exponential model to the adoption of electric vehicles was used in this study. The model was chosen based on the fact that currently in South Africa there is no enabling environment for the uptake of the technology, thus the hope is that when the current policies are implemented, the growth will increase tremendously. Currently, SA's current market penetration percentage is around 0.008, 0.012 and 0.037% for plugin electric vehicle, full/battery electric vehicles and hybrid vehicles respectively (Posada, 2018; Smith, 2018). The following four scenarios were chosen to estimate the impact of adoption of electric vehicles in the future (Table 3.5). Scenario B constitutes a scenario where there is a continuation in internal combustion engine (ICE) vehicles with no effort to promote zero exhaust vehicles or high energy efficient vehicles.

Table 3.5: Scenarios for estimating electric vehicles from 2018 to 2030 in the Gauteng Province

Scenario	HEV (%)	PHEV (%)	EV (%)
1	5	5	10
2	5	10	5
3	10	5	5
B	0	0	0

Source: Researchers own contribution (2018)

The following coefficients for the exponential equation will be used to estimate annual market penetration between 2018 and 2030 (Table 3.6).

Table 3.6: Coefficients used in determining exponential equation for different scenarios of projected market penetration

	Scenario 1			Scenario 2			Scenario 3		
coefficients	HEV	PHEV	EV	HEV	PHEV	EV	HEV	PHEV	EV
y(1)	0.037	0.008	0.012	0.037	0.008	0.012	0.037	0.008	0.012
y(13)	5	5	10	5	10	5	10	5	5
a	0.0246	0.0047	0.0067	0.0246	0.0044	0.0073	0.0232	0.0047	0.0073
b	1.505	1.710	1.751	1.505	1.812	1.653	1.595	1.710	1.653

$y(x) = ab^{x_i}$ where y is the market penetration and x in the year increment with 2017 as the base(i.e if estimating for 2025, x = 2025 – 2017).

Source: Researchers own contribution (2018)

The greenhouse gas emissions savings were then calculated on the assumption that upstream carbon emissions difference between internal combustion engine vehicles and electric vehicles is negligible.

3.2.4.2 Research questions 2 and 3 (To investigate the barriers of adoption of electric vehicles in South Africa and policy recommendations)

The first step in investigating the obstacles that might present in the South African market was to conduct a survey. There are a number of ways of conducting a survey and all these approaches have their advantages and disadvantages. Thus, there is a need to carefully choose the right instrument based on the nature of the investigation. The communication instrument in surveys can take any of the following forms:

personal interviews, telephonic interviews, web-based survey, self-administered survey and one-on-one interviews.

In this study, the web-based survey was selected due to low cost, efficiency and limited time available to conduct the research. The survey was conducted using Survey Monkey facilities and was obtained from the website "https://www.surveymonkey.com/r/electriccars," and the survey was run from the 24 September to 08 November 2018. The questionnaire was circulated to the respondents through the use of Facebook, email and WhatsApp, creating a snowball sampling approach. The survey focused mainly on people residing in the Gauteng province due to the fact that the province has the highest charging network in the country. However, the views of the motorists and ordinary people on some of the challenges of the adopting full-electric vehicles are assumed to be more or less the same across the country.

The survey was made up of 38 questions subdivided into four sections. All the questions were of the multiple choice format giving respondents a little latitude to be descriptive. In most of the questions, a Likert scale approach was used with questions mostly asking the degree in which the respondent agrees or disagrees with a certain statement. Nevertheless, additional information obtained was captured to aid with the explanations regarding certain choices. The five sections present in the questionnaire were as follows (a full questionnaire appears in Appendix A) (Jabeen, 2016; Krupa et al., 2014):

1. *General information*: age, gender, race, education, region of residence, type of dwelling and property ownership.
2. *Car ownership*: number of cars owned, type of vehicle owned, type of fuel used for the vehicle, engine size of the vehicle and kilometres travelled on daily basis.
3. *Awareness of environmental impacts of driving vehicles*: awareness that vehicles emit greenhouse gas emissions that cause climate change, awareness of any full electric vehicle in the South African market and awareness of anybody owning an electric vehicle.
4. *Adoption of electric vehicles - consideration of current purchases of electric vehicles depending on following traits* : electric vehicles reduce emissions and pollution, no purchases of fuel resulting in money savings, driving range of up

to 200km, the vehicle needs regular charging, charging takes around 8 hours, limited quick charging stations around the country, only compact vehicles in the South African market, warranty of 6 years or more and over 100 000km, battery costs over R130 000 out of the warranty and it costs over R479 000 to buy it.

5. *Recommendations on policy and adjustments*: chances of buying a full electric vehicle if driving range is increased drastically; chances of buying a full electric vehicle if there will be a charging station at workplace; chances of buying a full electric vehicle if there will be charging station at each of the major fuel filling stations; chances of buying a full electric vehicle if vehicle variety in South Africa industry is increased; chances of buying a full electric vehicle if there will be government financial incentives in the form of tax rebates; chances of buying if there is a financial incentives in the form of annual vehicle license renewal and toll gate exemptions; chances of buying an electric vehicle if government provides a dedicated lane for electric vehicles on major congested roads and any other suggestions that would make them buy electric vehicles. Seven of the eight questions for drivers were multiple choice in nature with one questions being an open-ended one.

3.2.5 Data Analysis

The study employs the quantitative research paradigm and it also follows descriptive research, as it seeks to understand factors affecting adoption of electric vehicles in South Africa and their implications on future carbon emissions.

3.2.5.1 Research Question 1 (Investigate the potential impact of switching to electric vehicles on national carbon accounting from the transport sector)

The time series of carbon dioxide emissions from burning of fossil fuel by passenger vehicles in Gauteng underwent a trend analysis using the Man-Kendall trend test. This was done through the use of XLSTAT software (XLSTAT, 2018). The trend test was based on the following assumptions:

H0: There is no trend in the time series data (Null Hypothesis)

Ha: There is a trend in the time series data (Alternative Hypothesis).

Descriptive statistics from the STATISTICA software were used to compare emissions estimates obtained from different scenarios. Projected emissions from 2019 to 2030 will be compared with the base emissions starting from 2000 to 2018. The percentage increase/decrease in emissions will be discussed in relation to the country's obligations in the Paris Agreement. The visibility of all the cases and scenarios for the projected future will be assessed.

3.2.5.2 Research questions 2 and 3 (To investigate the barriers of adoption of electric vehicles in South Africa and policy recommendations)

To check for the reliability or internal consistency of the questionnaire used to investigate the barriers to adoption of electric vehicles and recommendations for future policy consideration, Cronbach's alpha statistic was used. Cronbach's alpha test whether the likert-scale type of multiple-choice questions are reliable (StatisticsHowTo, 2014). The equation used is as follows:

$$\propto = \frac{N * \bar{c}}{\bar{v} + (N-1) * \bar{c}}$$

Where N is the number of items, $\bar{c}$ is the average covariance between item-pairs and $\bar{v}$ is the average variance.

Descriptive statistics from the STATISTICA statistical package were used to analyse the data that was collected in this study. Statistical methods used include the following: frequency tables and pie charts. The responses to the closed-ended survey questions were converted to percentages based on the total number of responses for any particular question relating to a certain perceived barrier for the adoption of electric vehicles in South Africa. The bias of the respondents was then revealed based on the respondents' answers to certain barrier factors. The "strongly agree" and "agree" responses were mostly grouped together, while the "strongly disagree" and "disagree" responses were also clumped together during the analysis and interpretation. The same approach was used while analysing the policy consideration factors.

3.3 ETHICAL CONSIDERATIONS

Our research approach utilised both primary data and secondary data. The conducting of a survey to determine barriers to the adoption of electric vehicles in South Africa represents the former approach, while the determination of carbon emissions reductions as a result of adopting electric vehicles utilised the latter approach. According to Bessenbach & Wallrap (2013), ethics related to research deals with the manner in which investigations were conducted (Is the approach responsible and moral correct?). In the first objective, most of the data was collected from the Department of Transport without any modification. In conducting this survey, all the respondents' data was treated with confidentiality, without linking any of the information to anyone.

3.4 CHAPTER SUMMARY

The chapter was devoted to describing the methods that were used to ensure that the research questions and objectives outlined in chapter 1, are fully addressed. The research design employed was tabled as well as the paradigm associated with it. The quantitative approach was employed to achieve the desired goals.

4. CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. INTRODUCTION

In the previous chapter, the study area, research design and paradigm, data collection approach and data analysis were presented. In this chapter, the results that were obtained from the methods are presented. Firstly, the main results from the estimation of GHG emissions are dealt with, followed by the results from the questionnaire on barriers to adoption of electric vehicles and lastly, some of the policy considerations for improved market penetration will be discussed.

4.2. CARBON EMISSIONS FOR ADOPTING ELECTRIC VEHICLES

4.2.1. Carbon emissions from 2000 to 2017

Carbon emissions emanating from passenger vehicles have been increasing steadily from the year 2000 to 2017 (Table 4.1 and Table 4.2). As shown in Table 4.1, the results obtained from a trend analysis, the p-value is lower than the significance level ($\alpha = 0.05$) and thus one should reject the null hypothesis H_0 (there is no trend in the time series) in favour of the alternative hypothesis H_a (there is a trend in the time series). Most of the emissions are from small petrol vehicles (hatchback), sport utility vehicle (SUV) and lower medium (sedans) vehicles with scores of around 28%, 23% and 19% respectively (4.1. Even though the estimated population of SUVs is similar to lower medium vehicles, it is their high emission intensity that results in a 4% GHG emissions contribution. The other vehicles' contribution is lower than 8%.

Table 4.1 : Mann-Kendall trend test / Two-tailed test (Total emissions)

Kendall's tau	1
S	153.000
Var(S)	697.000
p-value (Two-tailed)	< 0.0001
alpha	0.05

Source: Researcher's own contribution

Combined with other greenhouse gases (methane, nitrous oxide and other trace gases) the total emissions from Gauteng passenger vehicles range from 4075Gg CO_2 Equivalent in 2000 to 7457Gg CO_2 Equivalent in 2017. In the period 2000 to 2010

GHG emissions from passenger vehicles in Gauteng accounted for around 13% of all the road transport emissions stated in the GHG inventory for South Africa (2000-2010) (Department of Environmental Affairs, 2014). The study conducted by Tongwane (2009) states that motor vehicles in Gauteng account for around 14% of the total road transport which is comparable to the results obtained. Tongwane et al. (2015) calculated 6300 Gg CO_2 equivalent of motorcars emissions in Gauteng in 2009, which is comparable to 5773 Gg CO_2 equivalent obtained from this study. It can also be stated that motor vehicles' GHG emissions rate of increase was estimated to be 3.8% from 2000 to 2017. In their study, Tongwane et al. (2015) obtained a rate of increase of 2.6% in South Africa. Table 4.2 below stipulates the annual carbon dioxide emissions per vehicle class from year 2000 to 2017.

Table 4.2: Annual carbon dioxide emissions per vehicle class from year 2000 to 2017

Year	Emissions by vehicle class (Gg CO_2/year)																
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	
2000	256.9	101.7	1068.3	63.7	718.7	21.2	223.4	3.5	38.2	6.7	83.2	9.9	103.4	17.0	183.1	98.2	874.1	**3871.2**
2001	262.9	104.1	1093.1	65.1	735.4	21.7	228.6	3.5	39.0	6.8	85.2	10.1	105.8	17.3	187.4	100.5	894.4	**3960.9**
2002	267.1	105.8	1110.8	66.2	747.2	22.1	232.2	3.6	39.7	6.9	86.6	10.3	107.5	17.6	190.4	102.1	908.8	**4024.9**
2003	275.1	108.9	1143.7	68.2	769.4	22.7	239.1	3.7	40.8	7.2	89.1	10.6	110.7	18.2	196.1	105.1	935.7	**4144.1**
2004	284.6	112.7	1183.3	70.5	796.0	23.5	247.4	3.8	42.3	7.4	92.2	10.9	114.5	18.8	202.9	108.8	968.2	**4287.7**
2005	302.7	119.9	1258.6	75.0	846.7	25.0	263.2	4.1	44.9	7.9	98.1	11.6	121.8	20.0	215.8	115.7	1029.7	**4560.5**
2006	324.1	128.4	1347.7	80.3	906.7	26.8	281.8	4.4	48.1	8.4	105.0	12.4	130.4	21.4	231.0	123.9	1102.7	**4883.6**
2007	342.1	135.5	1422.3	84.8	956.8	28.3	297.4	4.6	50.8	8.9	110.8	13.1	137.6	22.6	243.8	130.7	1163.7	**5153.6**
2008	349.3	138.3	1452.4	86.6	977.0	28.9	303.7	4.7	51.9	9.1	113.2	13.4	140.5	23.1	249.0	133.5	1188.3	**5262.7**
2009	358.1	141.8	1488.9	88.7	1001.6	29.6	311.3	4.8	53.2	9.3	116.0	13.7	144.1	23.6	255.2	136.9	1218.2	**5395.1**
2010	374.7	148.4	1558.2	92.9	1048.2	31.0	325.8	5.1	55.6	9.7	121.4	14.4	150.8	24.7	267.1	143.2	1274.9	**5646.2**
2011	389.5	154.3	1619.6	96.5	1089.6	32.2	338.6	5.3	57.8	10.1	126.2	15.0	156.7	25.7	277.6	148.9	1325.1	**5868.8**
2012	406.6	161.0	1690.7	100.8	1137.4	33.6	353.5	5.5	60.4	10.6	131.7	15.6	163.6	26.8	289.8	155.4	1383.3	**6126.2**
2013	424.6	168.1	1765.5	105.2	1187.7	35.1	369.2	5.7	63.1	11.0	137.6	16.3	170.8	28.0	302.7	162.3	1444.5	**6397.5**
2014	440.1	174.3	1830.0	109.1	1231.1	36.4	382.6	5.9	65.4	11.4	142.6	16.9	177.1	29.0	313.7	168.2	1497.3	**6631.3**
2015	453.7	179.7	1886.6	112.4	1269.2	37.5	394.5	6.1	67.4	11.8	147.0	17.4	182.5	29.9	323.4	173.4	1543.6	**6836.3**
2016	465.1	184.2	1933.9	115.3	1301.0	38.4	404.4	6.3	69.1	12.1	150.7	17.9	187.1	30.7	331.5	177.8	1582.3	**7007.7**
2017	472.8	187.2	1965.9	117.2	1322.5	39.1	411.1	6.4	70.2	12.3	153.2	18.2	190.2	31.2	337.0	180.7	1608.5	**7123.5**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher's own contribution

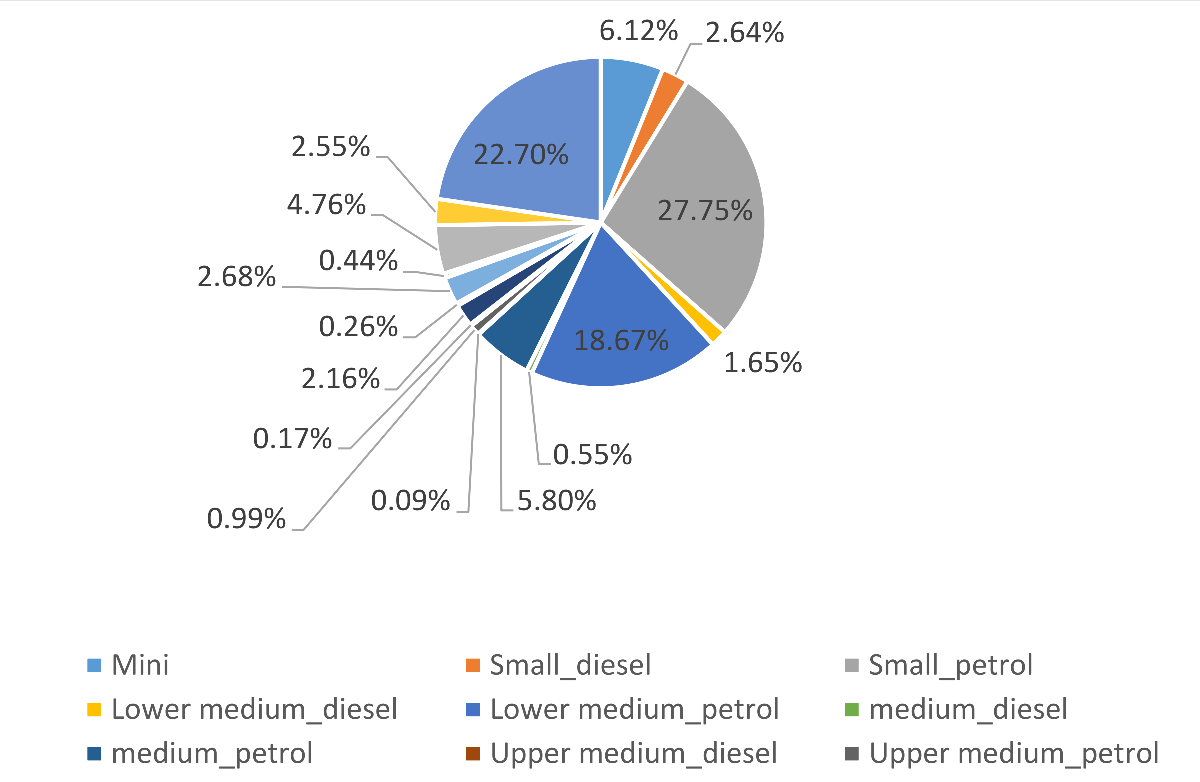

Figure 4.1: Percentage carbon dioxide emissions in the year 2017 from passenger vehicles in Gauteng

Source: Researcher's own contribution (2018)

4.2.2. Projected carbon emissions for economic decline case

Under this case, it is clear that there is a general decrease in the emissions owing to the downward movement of the number of vehicles with time (Table 4.3, Table 4.4, Table 4.5 & Table 4.6). If the country's policies are geared towards not promoting low-carbon technologies (Scenario B), then in 2030 there will still be a 20% reduction in emissions. This is an implication that, there can be significant reductions in emissions if government can embark on efforts that reduce the number of vehicles on the road without any efforts towards technological changes. This can be realised in a number of ways. Government can promote the use of public transport by improving the network as well as drastically reducing the prices. This will entice motorists to leave their vehicles at home and potential new motorists will not find a reason to buy their own motor vehicles. Government can also provide rebates to people willing to recycle their vehicles older than a certain age. But scenario 1 yields the best mitigation with the potential reduction in emissions in 2030 of 35% followed by scenario 2 with 34% and scenario 3 with 32%, compared to 2018 carbon estimates.

Table 4.3: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High Mitigation) for Scenario B

Year	Emissions by vehicle class (Gg CO_2/year)																	
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	
2018	413.4	186.9	1962.2	116.9	1320.1	39.0	410.3	6.4	70.1	12.3	152.9	18.1	189.9	31.1	336.4	180.4	1605.5	**7051.8**
2019	393.1	186.5	1958.0	116.7	1317.2	38.9	409.4	6.4	69.9	12.2	152.6	18.1	189.4	31.1	335.7	180.0	1602.0	**7017.2**
2020	371.4	185.4	1946.6	116.0	1309.5	38.7	407.0	6.3	69.5	12.2	151.7	18.0	188.3	30.9	333.7	178.9	1592.6	**6956.7**
2021	348.8	183.7	1928.6	114.9	1297.4	38.3	403.2	6.3	68.9	12.1	150.3	17.8	186.6	30.6	330.6	177.3	1577.9	**6873.2**
2022	325.5	181.4	1904.7	113.5	1281.4	37.8	398.3	6.2	68.0	11.9	148.4	17.6	184.3	30.2	326.5	175.1	1558.4	**6769.3**
2023	301.9	178.6	1875.5	111.8	1261.7	37.3	392.1	6.1	67.0	11.7	146.1	17.3	181.5	29.8	321.5	172.4	1534.5	**6646.8**
2024	278.1	175.4	1841.3	109.7	1238.7	36.6	385.0	6.0	65.8	11.5	143.5	17.0	178.2	29.2	315.7	169.3	1506.5	**6507.3**
2025	254.3	171.7	1802.5	107.4	1212.6	35.8	376.9	5.9	64.4	11.3	140.5	16.6	174.4	28.6	309.0	165.7	1474.7	**6352.1**
2026	230.7	167.5	1759.2	104.8	1183.5	34.9	367.8	5.7	62.8	11.0	137.1	16.2	170.2	27.9	301.6	161.7	1439.4	**6182.3**
2027	207.5	163.0	1711.9	102.0	1151.6	34.0	357.9	5.6	61.1	10.7	133.4	15.8	165.6	27.2	293.5	157.4	1400.6	**5998.8**
2028	184.8	158.1	1660.5	99.0	1117.1	33.0	347.2	5.4	59.3	10.4	129.4	15.3	160.7	26.4	284.7	152.6	1358.6	**5802.4**
2029	162.7	152.9	1605.4	95.7	1080.0	31.9	335.7	5.2	57.3	10.0	125.1	14.8	155.3	25.5	275.2	147.6	1313.5	**5593.8**
2030	141.3	147.3	1546.6	92.2	1040.5	30.7	323.4	5.0	55.2	9.7	120.5	14.3	149.6	24.5	265.1	142.2	1265.4	**5373.7**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher's own contribution

Table 4.4: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High Mitigation) for Scenario 1

Year	Emissions by vehicle class (Gg CO_2/year)																			
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	413.2	186.8	1961.1	116.9	1319.3	39.0	410.1	6.4	70.0	12.3	152.8	18.1	189.7	31.1	336.2	180.3	1604.6	0.2	1.9	**7049.9**
2019	392.7	186.3	1956.3	116.6	1316.0	38.9	409.0	6.4	69.9	12.2	152.4	18.1	189.3	31.1	335.4	179.8	1600.6	0.3	2.9	**7014.0**
2020	370.9	185.1	1943.7	115.8	1307.6	38.6	406.4	6.3	69.4	12.2	151.5	18.0	188.1	30.9	333.2	178.7	1590.3	0.5	4.3	**6951.5**
2021	348.0	183.2	1924.1	114.7	1294.4	38.2	402.3	6.2	68.7	12.0	149.9	17.8	186.2	30.5	329.8	176.9	1574.3	0.9	6.5	**6864.7**
2022	324.3	180.7	1897.6	113.1	1276.6	37.7	396.8	6.2	67.8	11.9	147.9	17.5	183.6	30.1	325.3	174.4	1552.6	1.6	9.7	**6755.3**
2023	300.1	177.5	1864.1	111.1	1254.1	37.0	389.8	6.1	66.6	11.7	145.3	17.2	180.4	29.6	319.6	171.4	1525.2	2.6	14.4	**6623.6**
2024	275.4	173.6	1823.2	108.7	1226.5	36.2	381.2	5.9	65.1	11.4	142.1	16.8	176.4	28.9	312.5	167.6	1491.7	4.4	21.3	**6469.0**
2025	250.2	168.9	1773.4	105.7	1193.0	35.2	370.8	5.8	63.3	11.1	138.2	16.4	171.6	28.1	304.0	163.0	1451.0	7.4	31.5	**6288.8**
2026	224.6	163.1	1712.7	102.1	1152.2	34.0	358.1	5.6	61.2	10.7	133.5	15.8	165.7	27.2	293.6	157.4	1401.3	12.4	46.5	**6077.6**
2027	198.4	155.9	1637.1	97.6	1101.3	32.5	342.3	5.3	58.5	10.2	127.6	15.1	158.4	26.0	280.6	150.5	1339.4	20.6	68.3	**5825.6**
2028	171.4	146.7	1540.2	91.8	1036.1	30.6	322.0	5.0	55.0	9.6	120.0	14.2	149.0	24.4	264.0	141.6	1260.2	34.1	100.0	**5516.1**
2029	143.0	134.4	1411.6	84.1	949.6	28.0	295.2	4.6	50.4	8.8	110.0	13.0	136.6	22.4	242.0	129.8	1155.0	56.4	145.9	**5121.0**
2030	112.8	117.6	1234.4	73.6	830.4	24.5	258.1	4.0	44.1	7.7	96.2	11.4	119.4	19.6	211.6	113.5	1009.9	93.0	212.4	**4594.1**

1*= Mini car(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher's own contribution

Table 4.5: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High Mitigation) for Scenario 2

Year	Emissions by vehicle class (Gg CO_2/year)																			
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	1.9	413.2	186.8	1961.1	116.9	1319.3	39.0	410.1	6.4	70.0	12.3	152.8	18.1	189.7	31.1	336.2	180.3	1604.6	**7049.9**
2019	0.3	2.9	392.7	186.3	1956.3	116.6	1316.0	38.9	409.0	6.4	69.9	12.2	152.4	18.1	189.3	31.1	335.4	179.8	1600.6	**7014.1**
2020	0.6	4.3	370.9	185.1	1943.8	115.8	1307.6	38.6	406.4	6.3	69.4	12.2	151.5	18.0	188.1	30.9	333.2	178.7	1590.4	**6951.7**
2021	1.1	6.5	348.0	183.3	1924.2	114.7	1294.4	38.2	402.3	6.2	68.7	12.0	149.9	17.8	186.2	30.5	329.9	176.9	1574.3	**6865.1**
2022	2.0	9.7	324.3	180.7	1897.7	113.1	1276.6	37.7	396.8	6.2	67.8	11.9	147.9	17.5	183.6	30.1	325.3	174.4	1552.7	**6756.0**
2023	3.5	14.4	300.1	177.6	1864.3	111.1	1254.2	37.0	389.8	6.1	66.6	11.7	145.3	17.2	180.4	29.6	319.6	171.4	1525.4	**6625.2**
2024	6.3	21.3	275.4	173.7	1823.5	108.7	1226.7	36.2	381.3	5.9	65.1	11.4	142.1	16.8	176.4	28.9	312.6	167.6	1492.0	**6472.1**
2025	11.1	31.5	250.3	169.0	1774.0	105.7	1193.4	35.2	370.9	5.8	63.4	11.1	138.2	16.4	171.6	28.2	304.1	163.1	1451.5	**6294.5**
2026	19.6	46.5	224.7	163.2	1713.6	102.1	1152.8	34.0	358.3	5.6	61.2	10.7	133.5	15.8	165.8	27.2	293.8	157.5	1402.0	**6087.9**
2027	34.6	68.3	198.6	156.0	1638.3	97.6	1102.1	32.5	342.6	5.3	58.5	10.2	127.7	15.1	158.5	26.0	280.9	150.6	1340.4	**5844.0**
2028	60.8	100.0	171.6	146.8	1541.8	91.9	1037.2	30.6	322.4	5.0	55.1	9.6	120.1	14.2	149.2	24.5	264.3	141.7	1261.4	**5548.2**
2029	106.6	145.9	143.2	134.6	1413.1	84.2	950.6	28.1	295.5	4.6	50.5	8.8	110.1	13.0	136.7	22.4	242.2	129.9	1156.1	**5176.1**
2030	186.0	212.4	112.8	117.6	1234.4	73.6	830.4	24.5	258.1	4.0	44.1	7.7	96.2	11.4	119.4	19.6	211.6	113.5	1009.9	**4687.1**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher’s own contribution

Table 4.6: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High Mitigation) for Scenario 3

Year	Emissions by vehicle class (Gg CO_2/year)																			
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	1.9	413.2	186.8	1961.1	116.9	1319.3	39.0	410.1	6.4	70.0	12.3	152.8	18.1	189.7	31.1	336.2	180.3	1604.6	**7049.9**
2019	0.3	3.1	392.7	186.3	1956.2	116.6	1316.0	38.9	409.0	6.4	69.9	12.2	152.4	18.1	189.3	31.1	335.4	179.8	1600.5	**7014.1**
2020	0.5	4.9	370.8	185.1	1943.6	115.8	1307.5	38.6	406.4	6.3	69.4	12.2	151.5	17.9	188.1	30.9	333.2	178.7	1590.2	**6951.6**
2021	0.9	7.7	347.9	183.2	1923.8	114.7	1294.2	38.2	402.3	6.2	68.7	12.0	149.9	17.8	186.1	30.5	329.8	176.8	1574.0	**6865.0**
2022	1.6	12.2	324.2	180.7	1897.1	113.1	1276.2	37.7	396.7	6.2	67.8	11.9	147.8	17.5	183.6	30.1	325.2	174.4	1552.2	**6756.0**
2023	2.6	19.2	299.9	177.5	1863.3	111.0	1253.5	37.0	389.6	6.0	66.5	11.7	145.2	17.2	180.3	29.6	319.4	171.3	1524.5	**6625.3**
2024	4.4	30.2	275.1	173.5	1821.7	108.6	1225.5	36.2	380.9	5.9	65.1	11.4	142.0	16.8	176.3	28.9	312.3	167.4	1490.5	**6472.6**
2025	7.4	47.2	249.9	168.7	1771.1	105.6	1191.5	35.2	370.3	5.8	63.3	11.1	138.0	16.4	171.4	28.1	303.6	162.8	1449.1	**6296.4**
2026	12.4	73.8	224.2	162.8	1709.3	101.9	1149.9	34.0	357.4	5.6	61.0	10.7	133.2	15.8	165.4	27.1	293.0	157.1	1398.5	**6092.9**
2027	20.6	114.8	197.9	155.5	1632.4	97.3	1098.2	32.4	341.3	5.3	58.3	10.2	127.2	15.1	157.9	25.9	279.8	150.0	1335.6	**5855.7**
2028	34.1	178.1	170.7	146.1	1534.4	91.4	1032.2	30.5	320.8	5.0	54.8	9.6	119.6	14.2	148.5	24.4	263.0	141.0	1255.4	**5574.0**
2029	56.4	275.5	142.4	133.9	1405.8	83.8	945.7	27.9	293.9	4.6	50.2	8.8	109.5	13.0	136.0	22.3	241.0	129.2	1150.2	**5230.2**
2030	93.0	424.7	112.5	117.3	1231.4	73.4	828.4	24.5	257.5	4.0	44.0	7.7	96.0	11.4	119.1	19.5	211.1	113.2	1007.5	**4796.2**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher’s own contribution

4.2.3. Projected carbon emissions for business as usual case

The business as usual case shows increasing carbon dioxide emissions attributed to increase in passenger vehicles in all the scenarios (Table 4.7, Table 4.8, Table 4.9 and Table 4.10). Scenario B results in close to a 20% increase in emissions by 2030 without any mitigation measures. If government adopts mitigation option 1, there will be 0.8% increase in emissions by 2030 while mitigation options 2 and 3 result in 3% and 5% increases respectively. These mitigation options are in line with the South African intended mitigation contributions that were presented to the UNFCCC which follow the peak, plateau and decline trajectory (Government of South Africa, 2015). The country chose this approach in order to respond to both development goals like the need to eradicate poverty and eliminate inequality (necessitating an increase in economic activity which is proportional to GHG emissions in the current environment and technological advances) as well as climate change issues. Scenarios 1, 2 and 3 reach peak emissions in 2028, 2027 and 2027 respectively.

In the business as usual scenario, other strategies employed in other countries include encouraging motorists to use their vehicles occasionally, encouraging them to embark on cycling and walking (Woodcock et al., 2009). Reducing motor vehicle usage in South Africa from an average exceeding 15 000 km on an annual basis to less than 10 000 km, has the potential to reduce the emissions by more than a quarter. As stated in earlier discussions, policies that promote ride sharing and use of public transport can be an effective way of reducing vehicle usage. The other co-benefits of reducing the number of vehicles on the road at a point include reduced air pollution that has a positive impact on people's health, and reduction in motor vehicle accidents, thus having a positive impact on the economy (Woodcock et al., 2009).

Vehicle emissions in this case can also be mitigated by reducing the vehicle congestion on our roads (Bharadwaj, Ballare, Rohit, & Chandel, 2017). High congestion on roads increases vehicle fuel consumption and thus increases GHG emissions. This is the case in South Africa, especially in the Gauteng province during peak hours like 06:00 to 09:00 and 15:00 to 18:00 on major roads including the N1 between Pretoria City and Johannesburg City. By solving the issue of traffic congestion, the country will benefit through reduced unproductive time spent on the road, as well as reductions in tailpipe emissions leading to air pollution (Bharadwaj et al., 2017). A comprehensive approach towards solving the problem is needed because increasing the number of lanes connecting major cities in Gauteng Province did not solve the issue. One of the suggested ways on improving operational efficiency of urban streets in Gauteng is the banning of trucks in peak hours (Wheels24.co.za, 2015). However, this could have an impact on the economy as the potential effects of such an action are not well understood, and if government considers this policy its implementation has to ensure that the delivery of services are not hampered (Castro, Kuse, & Hyodo, 2003). The study by Wang et al. (2014) suggests that the use of congestion carbon tax can help mitigate emissions during peak hours as it reduces GHG emissions and diverts motorists to public transportation. Tables 4.7 to 4.10 below depict the annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 for "Business as usual" case.

Table 4.7: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (Business as usual) for scenario B

Year	Emissions by vehicle class (Gg CO_2/year)																	
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	
2018	421.9	190.7	2002.5	119.3	1347.1	39.8	418.7	6.5	71.5	12.5	156.0	18.5	193.7	31.8	343.3	184.1	1638.4	**7196.3**
2019	409.3	194.2	2039.0	121.5	1371.7	40.5	426.3	6.6	72.8	12.7	158.9	18.8	197.3	32.4	349.5	187.4	1668.3	**7307.4**
2020	396.0	197.7	2075.6	123.7	1396.3	41.2	434.0	6.7	74.1	13.0	161.7	19.2	200.8	32.9	355.8	190.8	1698.2	**7417.7**
2021	382.0	201.2	2112.1	125.9	1420.9	42.0	441.6	6.9	75.4	13.2	164.6	19.5	204.4	33.5	362.1	194.1	1728.1	**7527.3**
2022	367.2	204.6	2148.6	128.1	1445.5	42.7	449.3	7.0	76.7	13.4	167.4	19.8	207.9	34.1	368.3	197.5	1758.0	**7636.2**
2023	351.8	208.1	2185.2	130.2	1470.0	43.4	456.9	7.1	78.0	13.7	170.3	20.2	211.4	34.7	374.6	200.9	1787.9	**7744.4**
2024	335.6	211.6	2221.7	132.4	1494.6	44.1	464.5	7.2	79.3	13.9	173.1	20.5	215.0	35.3	380.9	204.2	1817.8	**7851.8**
2025	318.6	215.1	2258.3	134.6	1519.2	44.9	472.2	7.3	80.7	14.1	176.0	20.9	218.5	35.8	387.1	207.6	1847.7	**7958.5**
2026	301.0	218.6	2294.8	136.8	1543.8	45.6	479.8	7.5	82.0	14.4	178.8	21.2	222.0	36.4	393.4	210.9	1877.6	**8064.4**
2027	282.6	222.0	2331.4	138.9	1568.4	46.3	487.5	7.6	83.3	14.6	181.7	21.5	225.6	37.0	399.7	214.3	1907.5	**8169.7**
2028	263.5	225.5	2367.9	141.1	1593.0	47.0	495.1	7.7	84.6	14.8	184.5	21.9	229.1	37.6	405.9	217.7	1937.4	**8274.2**
2029	243.6	229.0	2404.4	143.3	1617.5	47.8	502.7	7.8	85.9	15.0	187.4	22.2	232.6	38.2	412.2	221.0	1967.3	**8378.0**
2030	223.1	232.5	2441.0	145.5	1642.1	48.5	510.4	7.9	87.2	15.3	190.2	22.5	236.2	38.7	418.5	224.4	1997.2	**8481.0**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher's own contribution

Table 4.8: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (Business as usual) for scenario 1

Year	Emissions by vehicle class (Gg CO_2/year)																			
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	421.6	190.6	2001.3	119.3	1346.4	39.8	418.5	6.5	71.5	12.5	155.9	18.5	193.6	31.8	343.1	184.0	1637.5	0.2	2.0	**7194.4**
2019	408.9	194.0	2037.2	121.4	1370.5	40.5	426.0	6.6	72.8	12.7	158.7	18.8	197.1	32.3	349.2	187.3	1666.8	0.3	3.0	**7304.1**
2020	395.4	197.4	2072.6	123.5	1394.3	41.2	433.4	6.7	74.0	13.0	161.5	19.1	200.5	32.9	355.3	190.5	1695.7	0.6	4.6	**7412.2**
2021	381.1	200.7	2107.2	125.6	1417.6	41.9	440.6	6.8	75.3	13.2	164.2	19.5	203.9	33.4	361.2	193.7	1724.1	1.0	7.0	**7518.0**
2022	365.9	203.9	2140.7	127.6	1440.1	42.5	447.6	7.0	76.5	13.4	166.8	19.8	207.1	34.0	367.0	196.8	1751.5	1.8	10.8	**7620.4**
2023	349.6	206.9	2172.1	129.4	1461.2	43.1	454.2	7.1	77.6	13.6	169.3	20.1	210.2	34.5	372.4	199.7	1777.1	3.1	16.5	**7717.4**
2024	332.3	209.5	2200.0	131.1	1480.0	43.7	460.0	7.1	78.6	13.8	171.4	20.3	212.9	34.9	377.2	202.2	1800.0	5.3	25.3	**7805.7**
2025	313.5	211.6	2222.2	132.4	1495.0	44.1	464.6	7.2	79.4	13.9	173.2	20.5	215.0	35.3	381.0	204.3	1818.2	9.3	38.7	**7879.4**
2026	293.1	212.8	2234.7	133.2	1503.3	44.4	467.2	7.3	79.8	14.0	174.1	20.6	216.2	35.5	383.1	205.4	1828.3	16.1	59.2	**7928.3**
2027	270.4	212.4	2230.5	132.9	1500.5	44.3	466.4	7.2	79.7	13.9	173.8	20.6	215.8	35.4	382.4	205.0	1824.9	28.0	90.4	**7934.6**
2028	244.6	209.3	2198.0	131.0	1478.6	43.7	459.6	7.1	78.5	13.7	171.3	20.3	212.7	34.9	376.8	202.0	1798.3	48.7	138.3	**7867.3**
2029	214.5	201.6	2117.0	126.2	1424.2	42.1	442.6	6.9	75.6	13.2	165.0	19.6	204.8	33.6	362.9	194.6	1732.1	84.5	211.3	**7672.2**
2030	178.5	186.0	1952.8	116.4	1313.7	38.8	408.3	6.3	69.7	12.2	152.2	18.0	188.9	31.0	334.8	179.5	1597.7	146.8	322.9	**7254.5**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol); 18*= Hybrid vehicle; 19*=Plug-in hybrid vehicle

Source: Researcher's own contribution

Table 4.9:Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (Business as usual) for scenario 2

Year			Emissions by vehicle class (Gg CO_2/year)																
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	2.0	421.6	190.6	2001.3	119.3	1346.4	39.8	418.5	6.5	71.5	12.5	155.9	18.5	193.6	31.8	343.1	184.0	1637.5	**7194.4**
2019	0.4	3.0	408.9	194.0	2037.2	121.4	1370.5	40.5	426.0	6.6	72.8	12.7	158.7	18.8	197.1	32.3	349.2	187.3	1666.8	**7304.2**
2020	0.7	4.6	395.4	197.4	2072.6	123.5	1394.3	41.2	433.4	6.7	74.0	13.0	161.5	19.1	200.5	32.9	355.3	190.5	1695.8	**7412.4**
2021	1.2	7.0	381.1	200.7	2107.3	125.6	1417.6	41.9	440.6	6.8	75.3	13.2	164.2	19.5	203.9	33.4	361.3	193.7	1724.1	**7518.4**
2022	2.2	10.8	365.9	203.9	2140.8	127.6	1440.2	42.5	447.6	7.0	76.5	13.4	166.8	19.8	207.1	34.0	367.0	196.8	1751.6	**7621.3**
2023	4.1	16.5	349.7	206.9	2172.3	129.5	1461.4	43.2	454.2	7.1	77.6	13.6	169.3	20.1	210.2	34.5	372.4	199.7	1777.3	**7719.3**
2024	7.6	25.3	332.3	209.6	2200.5	131.1	1480.3	43.7	460.1	7.1	78.6	13.8	171.5	20.3	212.9	34.9	377.2	202.3	1800.4	**7809.4**
2025	13.9	38.7	313.6	211.7	2222.9	132.5	1495.4	44.2	464.8	7.2	79.4	13.9	173.2	20.5	215.1	35.3	381.1	204.3	1818.8	**7886.5**
2026	25.6	59.2	293.2	212.9	2235.8	133.2	1504.1	44.4	467.5	7.3	79.9	14.0	174.2	20.6	216.3	35.5	383.3	205.5	1829.3	**7941.8**
2027	47.1	90.4	270.6	212.6	2232.2	133.0	1501.6	44.3	466.7	7.2	79.7	14.0	173.9	20.6	216.0	35.4	382.7	205.2	1826.3	**7959.7**
2028	86.8	138.3	244.8	209.5	2200.2	131.1	1480.1	43.7	460.0	7.1	78.6	13.8	171.4	20.3	212.9	34.9	377.2	202.2	1800.1	**7913.1**
2029	159.6	211.3	214.7	201.8	2119.1	126.3	1425.6	42.1	443.1	6.9	75.7	13.3	165.1	19.6	205.0	33.6	363.3	194.8	1733.8	**7754.7**
2030	293.5	322.9	178.5	186.0	1952.8	116.4	1313.7	38.8	408.3	6.3	69.7	12.2	152.2	18.0	188.9	31.0	334.8	179.5	1597.7	**7401.2**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol); 18*= Hybrid vehicle; 19*=Plug-in hybrid vehicle

Source: Researcher's own contribution

Table 4.10: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (Business as usual) for scenario 3

Year			Emissions by vehicle class (Gg CO_2/year)																
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	2.0	421.6	190.6	2001.3	119.3	1346.4	39.8	418.5	6.5	71.5	12.5	155.9	18.5	193.6	31.8	343.1	184.0	1637.5	**7194.4**
2019	0.3	3.2	408.9	194.0	2037.1	121.4	1370.4	40.5	425.9	6.6	72.8	12.7	158.7	18.8	197.1	32.3	349.2	187.3	1666.7	**7304.2**
2020	0.6	5.2	395.4	197.4	2072.4	123.5	1394.2	41.2	433.3	6.7	74.0	13.0	161.5	19.1	200.5	32.9	355.3	190.5	1695.6	**7412.3**
2021	1.0	8.4	381.1	200.7	2106.9	125.6	1417.4	41.9	440.5	6.8	75.2	13.2	164.2	19.5	203.9	33.4	361.2	193.7	1723.9	**7518.3**
2022	1.8	13.6	365.8	203.8	2140.1	127.5	1439.7	42.5	447.5	6.9	76.4	13.4	166.8	19.8	207.1	34.0	366.9	196.7	1751.0	**7621.2**
2023	3.1	22.1	349.5	206.8	2171.1	129.4	1460.5	43.1	453.9	7.0	77.5	13.6	169.2	20.0	210.1	34.5	372.2	199.6	1776.3	**7719.4**
2024	5.3	35.8	332.0	209.4	2198.3	131.0	1478.9	43.7	459.7	7.1	78.5	13.7	171.3	20.3	212.7	34.9	376.9	202.1	1798.6	**7810.2**
2025	9.3	57.9	313.2	211.4	2219.5	132.3	1493.1	44.1	464.1	7.2	79.3	13.9	172.9	20.5	214.7	35.2	380.5	204.0	1816.0	**7889.1**
2026	16.1	93.9	292.5	212.4	2230.5	132.9	1500.5	44.3	466.4	7.2	79.7	13.9	173.8	20.6	215.8	35.4	382.4	205.0	1825.0	**7948.6**
2027	28.0	152.1	269.7	211.9	2224.7	132.6	1496.6	44.2	465.2	7.2	79.5	13.9	173.4	20.5	215.3	35.3	381.4	204.5	1820.2	**7976.2**
2028	48.7	246.4	243.8	208.7	2191.0	130.6	1473.9	43.5	458.1	7.1	78.2	13.7	170.7	20.2	212.0	34.8	375.6	201.4	1792.6	**7951.0**
2029	84.5	398.9	213.9	201.0	2110.6	125.8	1419.9	41.9	441.3	6.9	75.4	13.2	164.5	19.5	204.2	33.5	361.8	194.0	1726.9	**7837.7**
2030	146.8	645.8	178.5	186.0	1952.8	116.4	1313.7	38.8	408.3	6.3	69.7	12.2	152.2	18.0	188.9	31.0	334.8	179.5	1597.7	**7577.4**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol); 18*= Hybrid vehicle; 19*=Plug-in hybrid vehicle

Source: Researcher's own contribution

4.2.4. Projected Carbon Emissions for High Economic Growth Case

The high economic growth case of an accelerated increase in vehicle population shows a rise in carbon dioxide of close to 60% when there are no mitigation options being implemented by the state (Scenario B-Table 4.11). This exponential growth in vehicle numbers can only be realised if there is significant economic growth in South Africa. Even under the mitigation 1 option, the GHG emissions still increase by over 35% in comparison with the 2018 estimates (Table 4.12). The other options (scenarios 2 and 3) show relatively high increases (38%) [41%] in GHG emissions (Table 4.13, Table 4.14). It can be deduced from these results that government should not allow this case to be realised in future regardless of the economic situation. This can be achieved by putting in place necessary measures that can promote sharing of transport and also through improved efficiency of public transport and other means.

There can also be an introduction of hefty carbon taxes on vehicles with internal combustion engines by a certain year. Carbon tax can be introduced in a number of ways but the common one is by inserting an extra fuel levy and the other one is by introducing extra charges over and above the annual vehicle licence renewal price that is proportional to the vehicle's emission profile (Bureau, 2011). The former method is the desired one as it will penalise motorists depending on their driving pattern, routes and timing of their trips. The use of one standard charge will present an unfair charge for those people owning vehicles but relying more on public transport for day-to-day travel.

In cases of an ever increasing rise in the number of vehicles, mitigation can be a three-pronged approach looking at vehicle energy use efficiency, vehicle distance travelled and fuel content (Lewis, Zako, Biddle, & Isbell, 2018). Even though recent studies have shown that there is a drastic improvement in energy efficiency and fuel content with a reduction of Sulphur in most fuel, this is not having a significant reduction as vehicle distances travelled have been increasing with time. According to Lewis et al. (2018), vehicle distances travelled per year have been increasing at a faster rate than the population, thus nullifying the efforts made in other initiatives.

Table 4.11: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High economic growth) for scenario B

Year	Emissions by vehicle class (Gg CO_2/year)																	
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	
2018	430.4	194.5	2042.7	121.7	1374.2	40.6	427.1	6.6	73.0	12.8	159.2	18.9	197.6	32.4	350.2	187.8	1671.3	**7340.9**
2019	425.6	201.9	2120.0	126.3	1426.2	42.1	443.3	6.9	75.7	13.3	165.2	19.6	205.1	33.6	363.4	194.9	1734.5	**7597.6**
2020	420.6	210.0	2204.6	131.4	1483.1	43.8	461.0	7.2	78.7	13.8	171.8	20.4	213.3	35.0	377.9	202.6	1803.7	**7878.8**
2021	415.2	218.6	2295.6	136.8	1544.3	45.6	480.0	7.5	82.0	14.4	178.9	21.2	222.1	36.4	393.5	211.0	1878.2	**8181.4**
2022	408.9	227.9	2392.6	142.6	1609.6	47.5	500.3	7.8	85.4	15.0	186.4	22.1	231.5	38.0	410.2	219.9	1957.6	**8503.1**
2023	401.6	237.6	2494.9	148.7	1678.4	49.6	521.7	8.1	89.1	15.6	194.4	23.0	241.4	39.6	427.7	229.3	2041.3	**8841.9**
2024	393.0	247.8	2602.2	155.1	1750.5	51.7	544.1	8.4	92.9	16.3	202.8	24.0	251.8	41.3	446.1	239.2	2129.0	**9196.3**
2025	382.9	258.5	2714.1	161.7	1825.8	53.9	567.5	8.8	96.9	17.0	211.5	25.1	262.6	43.1	465.3	249.5	2220.6	**9564.8**
2026	371.2	269.6	2830.4	168.7	1904.1	56.2	591.8	9.2	101.1	17.7	220.6	26.1	273.9	44.9	485.2	260.2	2315.8	**9946.6**
2027	357.7	281.0	2950.9	175.9	1985.1	58.6	617.0	9.6	105.4	18.5	229.9	27.3	285.5	46.8	505.9	271.2	2414.3	**10340.6**
2028	342.2	292.9	3075.3	183.3	2068.8	61.1	643.0	10.0	109.8	19.2	239.6	28.4	297.5	48.8	527.2	282.7	2516.1	**10746.0**
2029	324.6	305.1	3203.5	190.9	2155.1	63.6	669.8	10.4	114.4	20.0	249.6	29.6	309.9	50.8	549.2	294.5	2621.0	**11162.2**
2030	304.8	317.7	3335.3	198.8	2243.8	66.3	697.4	10.8	119.1	20.9	259.9	30.8	322.7	52.9	571.8	306.6	2728.9	**11588.4**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol)

Source: Researcher's own contribution

Table 4.12: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High economic growth) for scenario 1

Year			Emissions by vehicle class (Gg CO_2/year)																	
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	2.0	430.1	194.4	2041.5	121.7	1373.4	40.6	426.9	6.6	72.9	12.8	159.1	18.9	197.5	32.4	350.0	187.7	1670.4	**7338.9**
2019	0.3	3.1	425.2	201.7	2118.1	126.2	1424.9	42.1	442.9	6.9	75.6	13.2	165.0	19.6	204.9	33.6	363.1	194.7	1733.0	**7594.2**
2020	0.6	4.9	420.0	209.7	2201.4	131.2	1480.9	43.7	460.3	7.1	78.6	13.8	171.5	20.3	213.0	34.9	377.4	202.4	1801.1	**7872.9**
2021	1.1	7.7	414.2	218.1	2290.3	136.5	1540.8	45.5	478.9	7.4	81.8	14.3	178.5	21.2	221.6	36.4	392.6	210.5	1873.9	**8171.3**
2022	2.0	12.0	407.4	227.0	2383.7	142.1	1603.6	47.4	498.4	7.7	85.1	14.9	185.7	22.0	230.6	37.8	408.6	219.1	1950.3	**8485.6**
2023	3.5	18.9	399.2	236.2	2479.9	147.8	1668.3	49.3	518.5	8.1	88.6	15.5	193.2	22.9	239.9	39.4	425.1	228.0	2029.0	**8811.2**
2024	6.3	29.6	389.2	245.4	2576.8	153.6	1733.5	51.2	538.8	8.4	92.0	16.1	200.8	23.8	249.3	40.9	441.7	236.9	2108.3	**9142.3**
2025	11.2	46.5	376.8	254.4	2670.8	159.2	1796.7	53.1	558.4	8.7	95.4	16.7	208.1	24.7	258.4	42.4	457.8	245.5	2185.2	**9469.8**
2026	19.9	73.0	361.5	262.5	2756.2	164.3	1854.2	54.8	576.3	8.9	98.4	17.2	214.8	25.5	266.7	43.8	472.5	253.3	2255.1	**9778.7**
2027	35.5	114.5	342.2	268.9	2823.2	168.2	1899.2	56.1	590.3	9.2	100.8	17.7	220.0	26.1	273.2	44.8	484.0	259.5	2309.9	**10043.0**
2028	63.2	179.6	317.6	271.9	2854.6	170.1	1920.3	56.7	596.9	9.3	101.9	17.8	222.4	26.4	276.2	45.3	489.4	262.4	2335.6	**10217.6**
2029	112.6	281.5	285.8	268.6	2820.5	168.1	1897.4	56.0	589.7	9.2	100.7	17.6	219.8	26.0	272.9	44.8	483.5	259.3	2307.7	**10221.8**
2030	200.5	441.2	243.9	254.1	2668.3	159.0	1795.0	53.0	557.9	8.7	95.3	16.7	207.9	24.6	258.2	42.4	457.4	245.3	2183.1	**9912.5**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol); 18*= Hybrid vehicle; 19*=Plug-in hybrid vehicle

Source: Researcher's own contribution

Table 4.13: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High economic growth) for scenario 2

Year	Emissions by vehicle class (Gg CO_2/year)																		
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	2.0	430.1	194.4	2041.5	121.7	1373.4	40.6	426.9	6.6	72.9	12.8	159.1	18.9	197.5	32.4	350.0	187.7	1670.4	**7338.9**
2019	0.4	3.1	425.2	201.7	2118.1	126.2	1424.9	42.1	442.9	6.9	75.6	13.2	165.0	19.6	204.9	33.6	363.1	194.7	1733.0	**7594.3**
2020	0.7	4.9	420.0	209.7	2201.4	131.2	1481.0	43.7	460.3	7.1	78.6	13.8	171.5	20.3	213.0	34.9	377.4	202.4	1801.2	**7873.1**
2021	1.3	7.7	414.2	218.1	2290.4	136.5	1540.8	45.5	478.9	7.4	81.8	14.3	178.5	21.2	221.6	36.4	392.6	210.5	1874.0	**8171.8**
2022	2.5	12.0	407.4	227.0	2383.8	142.1	1603.7	47.4	498.4	7.7	85.1	14.9	185.8	22.0	230.6	37.8	408.7	219.1	1950.4	**8486.5**
2023	4.7	18.9	399.2	236.2	2480.2	147.8	1668.5	49.3	518.6	8.1	88.6	15.5	193.3	22.9	240.0	39.4	425.2	228.0	2029.2	**8813.3**
2024	8.9	29.6	389.3	245.5	2577.2	153.6	1733.8	51.2	538.9	8.4	92.0	16.1	200.8	23.8	249.4	40.9	441.8	236.9	2108.6	**9146.6**
2025	16.7	46.5	376.9	254.4	2671.6	159.2	1797.3	53.1	558.6	8.7	95.4	16.7	208.2	24.7	258.5	42.4	458.0	245.6	2185.9	**9478.4**
2026	31.6	73.0	361.7	262.6	2757.6	164.3	1855.1	54.8	576.6	9.0	98.5	17.2	214.9	25.5	266.8	43.8	472.7	253.5	2256.2	**9795.3**
2027	59.7	114.5	342.5	269.1	2825.3	168.4	1900.7	56.1	590.7	9.2	100.9	17.7	220.2	26.1	273.4	44.8	484.3	259.7	2311.6	**10074.7**
2028	112.7	179.6	318.0	272.1	2857.4	170.3	1922.3	56.8	597.5	9.3	102.1	17.9	222.7	26.4	276.5	45.4	489.8	262.7	2337.9	**10277.1**
2029	212.6	281.5	286.1	268.9	2823.4	168.3	1899.3	56.1	590.3	9.2	100.8	17.7	220.0	26.1	273.2	44.8	484.0	259.5	2310.0	**10331.8**
2030	401.1	441.2	243.9	254.1	2668.3	159.0	1795.0	53.0	557.9	8.7	95.3	16.7	207.9	24.6	258.2	42.4	457.4	245.3	2183.1	**10113.0**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol); 18*= Hybrid vehicle; 19*=Plug-in hybrid vehicle

Source: Researcher's own contribution

Table 4.14: Annual forecasted carbon dioxide emissions per vehicle class from year 2018 to 2030 (High economic growth) for scenario 3

Year	Emissions by vehicle class (Gg CO_2/year)																		
	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	16*	17*	18*	19*	
2018	0.2	2.0	430.1	194.4	2041.5	121.7	1373.4	40.6	426.9	6.6	72.9	12.8	159.1	18.9	197.5	32.4	350.0	187.7	1670.4	**7338.9**
2019	0.3	3.3	425.2	201.7	2118.0	126.2	1424.9	42.1	442.9	6.9	75.6	13.2	165.0	19.6	204.9	33.6	363.1	194.7	1732.9	**7594.3**
2020	0.6	5.5	420.0	209.6	2201.2	131.2	1480.8	43.7	460.3	7.1	78.6	13.8	171.5	20.3	213.0	34.9	377.4	202.3	1801.0	**7873.0**
2021	1.1	9.1	414.2	218.1	2290.0	136.5	1540.6	45.5	478.8	7.4	81.8	14.3	178.4	21.1	221.6	36.3	392.6	210.5	1873.7	**8171.7**
2022	2.0	15.1	407.3	227.0	2383.1	142.0	1603.2	47.3	498.3	7.7	85.1	14.9	185.7	22.0	230.6	37.8	408.5	219.1	1949.8	**8486.5**
2023	3.5	25.2	399.0	236.1	2478.8	147.7	1667.5	49.2	518.3	8.0	88.5	15.5	193.1	22.9	239.8	39.3	424.9	227.8	2028.1	**8813.4**
2024	6.3	41.9	388.9	245.2	2574.8	153.4	1732.1	51.1	538.4	8.4	92.0	16.1	200.6	23.8	249.1	40.9	441.4	236.7	2106.6	**9147.5**
2025	11.2	69.6	376.4	254.0	2667.5	159.0	1794.5	53.0	557.7	8.7	95.3	16.7	207.9	24.6	258.1	42.3	457.3	245.2	2182.5	**9481.4**
2026	19.9	115.8	360.8	262.0	2751.1	164.0	1850.8	54.7	575.2	8.9	98.3	17.2	214.4	25.4	266.2	43.7	471.6	252.9	2250.9	**9803.7**
2027	35.5	192.5	341.3	268.2	2815.9	167.8	1894.3	55.9	588.8	9.1	100.6	17.6	219.4	26.0	272.4	44.7	482.7	258.8	2303.9	**10095.7**
2028	63.2	320.0	316.6	271.0	2845.5	169.6	1914.2	56.5	595.0	9.2	101.6	17.8	221.7	26.3	275.3	45.2	487.8	261.6	2328.1	**10326.2**
2029	112.6	531.5	284.9	267.8	2812.0	167.6	1891.7	55.9	588.0	9.1	100.4	17.6	219.1	26.0	272.1	44.6	482.1	258.5	2300.8	**10442.3**
2030	200.5	882.4	243.9	254.1	2668.3	159.0	1795.0	53.0	557.9	8.7	95.3	16.7	207.9	24.6	258.2	42.4	457.4	245.3	2183.1	**10353.6**

1*= Mini vehicle(petrol); 2*= small vehicle (diesel); 3*=small vehicle (petrol); 4*=lower medium vehicle(diesel); 5*= lower medium vehicle(petrol); 6*=medium vehicle(diesel); 7*=medium vehicle(petrol); 8*=upper medium vehicle(diesel); 9*=upper medium vehicle(petrol); 10*=sport vehicle(diesel); 11*=sport vehicle(petrol); 12*=offroad vehicle(diesel); 13*=offroad vehicle(petrol); 14*=MPV vehicle(diesel); 15*=MPV vehicle(petrol);16*=SUV vehicle(diesel); 17*=SUV vehicle(petrol); 18*= Hybrid vehicle; 19*=Plug-in hybrid vehicle

Source: Researcher's own contribution

4.3. BARRIERS TO ADOPTION OF ELECTRIC VEHICLES

The survey to understand the barriers that exist in the South African automotive market in relation to the adoption of electric vehicles was administered from the 24 September to 8 November 2018. A total number 446 responses was received in that period. Only 408 respondents were able to answer all the questions. All the data was used in the analysis.

4.3.1. Reliability

The results of the Cronbach's alpha are shown in Table 4.15. All the values are above 0.8 indicating that the survey question show high level of reliability (StatisticsHowTo, 2014).

Table 4.15: Reliability tests of the survey questions using Cronbach's alpha

Variable	Cronbach's Alpha
Barriers to adoption of electric vehicles	0.875
Policy recommendations for future adoption of electric vehicles	0.899

4.3.2. Basic Information

Most of the respondents (41%) were between the ages of 25 and 34, followed by the age group of between 35 and 44 with 29.6% (Table 4.16). The age groups of the respondents are more or less similar to the ones obtained in the study conducted by Zhu (2016). Among the respondents, 49.55% were female while 50.45% were male. In terms of race, close to 90% of the respondents were black, with second highest race being white with around 9%. The data representation resembles that of the Gauteng province census data with some minor deviations (Statistics South Africa, 2014). The education levels of the respondents is significantly different from the one obtained from the 2011 census, with most respondents having post-graduate qualifications and Bachelor's degrees. Over 85% of the respondents have post-matric qualifications compared to only around 18% recorded in the 2011 census (Statistics South Africa, 2014). It can also be noted that most people were from the City of Tshwane (56.7%), followed by the City of Johannesburg and City of Ekurhuleni with the dominant dwelling settings being a suburb (76%) and township (20%). In terms of home ownership, over 47% of the respondents own houses in the province, with 43% renting. Table 4.16 below depicts all the demographic data obtained from respondents.

Table 4.16: Basic information obtained from the respondents

Type of information	**Categories**	**Percentage**
Age group	<18	0.45%
	18-24	15.70%
	25-34	41.03%
	35-44	29.60%
	45-54	8.74%
	55-64	3.36%
	65+	1.12%
Gender	Female	49.55%
	Male	50.45%
Race	Black	89.01%
	Coloured	1.12%
	Indian	1.12%
	White	8.74%
Highest education	Did not attend school	0.00%
	Primary School	0.22%
	Secondary School	1.35%
	High School	11.66%
	College certificate	6.50%
	College Diploma	12.33%
	Bachelor's Degree	29.15%
	Post-graduate qualification	38.79%
City of residence	Ekurhuleni Municipality	10.31%
	City of Johannesburg	24.22%
	City of Tshwane	56.73%
	Sedibeng Municipality	4.71%
	West Rand Municipality	4.04%
Type of settlement	Informal	1.57%
	Rural	2.47%
	Suburb	76.01%
	Township	19.96%
Property ownership	Own	46.86%
	Rent	43.27%
	Live with friends/relatives	9.87%
	Homeless	0.00%

Source: Researcher's own contribution

4.3.3. Car Ownership

Most people that answered the questionnaire had 1 vehicle (45.2%), followed by people who do not own a vehicle (26.7%) and those with 2, 3, 4 and 5 or more scored 21.6%, 4.4%, 1.2% and 0.9% respectively. Most people drive a hatchback (45.1%) then a sedan (31.8%), van (11.8%) and SUV (10.8%). All the motorists interviewed owned either a petrol-fuelled vehicle (81.7%) or diesel vehicle (18.3%) with no hybrid and electric vehicle owners. In a study conducted in New Zealand, at least 3% of the respondents owned an electric vehicle (Zhu, 2016). The most common vehicles have engine sizes between 1.4l-1.5l (36%), 1.6l-1.9l (29%) and 2l-2.5l (22%). It is important to note that over 89% of the people who responded travel less than 100km per day (Table 4.17).

Table 4.17: Distance travelled on daily basis

Distance	Percentage
Less than 20km	32.2%
20km to 49km	36.5%
50km to 99km	20.6%
100km to 149km	7.8%
150km to 199km	1.9%
200km to 249km	1.4%
250km and more	1.4%

Source: Researcher's own contribution

4.3.4. Awareness of Environmental Impacts of Driving Vehicles

Among the respondents, about 92% of the people had an idea that tailpipe gases contribute to climate change. Surprisingly, 71% of the respondents knew that there are full electric vehicles in the South African automotive market. As the footprint and visibility of electric vehicles is very low, proportions of respondents with knowledge of electric vehicles was expected to be low. Around 88% of the respondents did not know anybody who owns an electric vehicle. This value was also expected to be close to 100% due to the low adoption of electric vehicles in South Africa. Over 40% of the respondents showed that they are willing to pay extra money to purchase an electric vehicle, while 39% are not sure with 21% of the people not currently in a position to devote extra funds to an electric vehicle. The response to the purchase of an electric vehicle, given that it contributes less to air pollution and climate change compared to traditional vehicles, showed that the majority (76%) of the respondents demonstrated their ambition of buying an electric vehicle based on their environmental integrity.

4.3.5. Barriers to Adoption of Electric Vehicles

Respondents were presented with key factors that affect the adoption of electric vehicles and were asked how likely they would be to buy an electric vehicle given those circumstances (Table 4.18). There were five categories (1: very likely; 2: likely; 3: neither likely nor unlikely; 4: unlikely; 5: very unlikely). It has to be noted that the first question has a positive viewpoint which is likely to affect the subsequent answers.

Table 4.18: Percentage of respondents showing the degree to which they are likely to purchase an electric vehicle based on the current status

Factor	1*	2*	3*	4*	5*
It requires no purchase of fuel and thus potentially saves you money in the long run	53.2	34.0	7.1	4.3	1.4
It can only run for a range of around 200km before recharging its battery	23.5	34.7	12.8	20.2	8.8
There is the inconvenience of recharging a battery when it runs out	15.7	29.9	14.7	27.3	12.4
It has to be charged up to 8 hours at home for a full charge	15.7	25.4	15.7	28.0	15.2
Currently there are limited quick (up to 30 minutes for 80% charge) public charging stations in South Africa	16.4	30.4	17.3	25.4	10.5
It currently comes only as a hatchback in the South African market	18.5	40.9	17.1	17.1	6.4
Current models in the South African market have a maximum speed of 150km/h	26.3	39.4	15.5	13.8	5.0
It carries a warranty of 8 years or 150 000km / 6 years or 100 000km depending on the make of the vehicle	31.6	46.6	10.7	7.8	3.3
it currently costs between R450 000 and R600 000	7.4	20.9	17.8	30.2	23.8
It currently costs between R100 000 and R400 000 to buy the battery pack if faulty after expiry of warranty	8.6	17.3	13.3	28.7	32.1
One might need an extra normal vehicle for emergencies that require driving for more than 200km or when your battery is flat	9.1	23.6	12.2	28.9	26.3
Average	**20.5**	**31.2**	**14.0**	**21.1**	**13.2**
1* (very likely); 2*(likely); 3* (neither likely nor unlikely); 4*(unlikely); 5*(very unlikely)					

Source: Researcher's own contribution (2018)

4.3.5.1. Cost savings attributed to electric vehicles

Respondents felt strongly that they would buy an electric vehicle if it would save them money in the long run (Table 4.18). Around 87% of the people chose category 1 and category 2. These results are in contradiction with the findings recorded by Tsang et al. (2012), which state that consumers tend not to be intrigued by future long-term savings but rather interested in the current financial savings, as the conditions in the future are uncertain. But a study done by Krupa et al., (2014) in the US showed an 86% satisfaction with the fact that PHEV will make them save on monthly spending in the future. It must be noted that consumers are likely to save money, as electricity needed to propel an electric vehicle for 100 kilometres is far less expensive than the required diesel or petrol to cover the same distance. Additionally, EVs have fewer moving parts, which makes their maintenance comparatively cheaper compared to ICE vehicles (Bessenbach & Wallrap, 2013).

4.3.5.2. Driving range of the current EVs is 200km

Most of the respondents were not bothered about the current driving range of the electric vehicles, with over 58% demonstrating their willingness to purchase a vehicle based on that condition (Table 4.18). This may be because most of the respondents (89%) travel daily distances of less than 100km and thus would not be inconvenienced by that driving range. It has to be noted that some studies show that the problem of range limitation in electric vehicles increases anxiety in drivers which make them to be highly conservative in their trip planning (Tsang et al., 2012). This makes owners of the electric vehicles travel shorter distances than they would have if owning a vehicle with no limitation and hence, this results in a negative driver experience.

4.3.5.3. Inconvenience of charging a vehicle on a regular basis

The idea of charging your vehicle on a regular basis depending on the level of the battery can be an inconvenience for some people (Table 4.18). This necessitate some change of habits and requires some form of discipline. One can easily forget to charge the battery even if one has been warned by the electronic system present in the vehicle. The idea of not being able to drive to work due to a flat battery is a constraint to the adoption of EVs because home chargers are mostly not fast enough to enable one to properly attend to this kind of circumstance. In the survey the numbers were split with the majority (45.6%) still in favour of purchasing the EV given this condition, while a considerable amount of people (39.7%) were not in favour of regular charging.

4.3.5.4. Long recharge times of up to 8 hours and limited fast charging spots

According to Tsang et al. (2012), the majority of the charging stations are equipped with standard chargers that can take between 6 to 8 hours for a full recharge. The respondents were not satisfied with this condition, with the majority (43.2%) saying that it is a major constraint to their potential purchase of EVs, while 41.1% demonstrated no concern about the issue (Table 4.18). This current feature makes it undesirable for the majority who compared this with re-fuelling of an ICE vehicle, which takes less than 10 minutes. Other methods like battery swaps have been suggested in an effort to find a solution for this problem, while fast charging technology has been in development in major companies with future charging times of up to 15 minutes (Tsang et al., 2012). The consideration of buying an electric vehicle in the wake of limited fast charging infrastructure in the country is not a major concern for most of the respondents.

4.3.5.5. Limited variety of vehicle classes

Respondents in the Gauteng Province are not sensitive to the fact that all the vehicles in the South African market are compact vehicles with limited space (Table 4.18). Around 59% of the people stated that there will buy electric vehicles even if there is limited choice in terms of vehicle classes. This is highly surprising, as the information on vehicle ownership showed that the majority of people have relatively spacious vehicles, with only 45% driving hatchbacks. Given also that in South Africa most families comprise more than four people, the choice of a compact vehicle might be highly influenced by affordability.

4.3.5.6. Low top speed of ordinary EVs

The fact that electric vehicles in the market are perceived to have a top speed of 150km/hr, is not a major concern to most respondents (66%) [Table 4.18]. There are a few (20%) who would prefer a vehicle with a higher top speed, or better performance. The fact that the performance of EVs was viewed negatively by most consumers in the study by Hardman et al. (2016), is in slight contradiction with the findings of this study. South African motorists might perceive a top speed of 150km/hr as high performance based on the fact that maximum speed allowed in the country is 120km/hr. Other studies also state that consumers find high performing vehicles more desirable and are willing to pay extra for that high acceleration capability (Hardman, Shiu, & Steinberger-Wilckens, 2016; Tsang et al., 2012).

4.3.5.7. Warranty of 6 to 8 years on EVs and high battery costs

Generally, EVs have a longer warranty than ICE vehicles, with some warranties being up to 10 years in other countries (Table 4.18). In the South African market, warranties of up to 8 years are present, which gives motorist satisfaction that any battery pack failure in that period will be fixed by the manufacturer. Over 75% of the respondents showed appreciation of the long warranties. In contrast, the majority (over 60%) felt that the exorbitant prices of the batteries beyond the warranty lifecycle are a major constraint to purchasing electric vehicle.

4.3.5.8. It currently costs between R450 000 and R600 000 to own an electric vehicle

Respondents are likely not to purchase an electric vehicle given their current prices in South Africa (Table 4.18). More than 54% of the respondents are unlikely to buy either the Nissan Leaf or BMW i3, which are the electric vehicles that are currently available in the market, due to their purchase price. Fewer than 30% of the respondents are likely to buy at the current price. It can be deduced that, since the ICE vehicles of the same size and specifications are relatively cheaper costing around R300 000, consumers find it too expensive to own an EV. The main reason for this price difference is attributed to the prices of rechargeable battery packs (Bessenbach & Wallrap, 2013). A study by Zhu (2016) in New Zealand also demonstrated that 64% of the respondents stated that current EV prices prevent them from adopting this technology.

4.3.5.9. The possibility of needing a secondary ICE vehicle in cases of emergencies

Since there are many uncertainties surrounding the use of electric vehicles, it is stated that households would be encouraged to buy a secondary vehicle (Table 4.18) Most respondents (55%) showed dissatisfaction with the condition, while some (32%) would not mind having multiple vehicles. In South Africa, there is electricity uncertainty caused by scheduled load shedding conducted by the power producer as well as unplanned regular electricity blackouts caused by malfunctioning old infrastructure. This can cause major challenges for households that need to charge their only vehicle overnight in preparation for their daily commuting.

4.4. FUTURE POLICY AND TECHNOLOGICAL ADVANCEMENTS IN RELATION TO ADOPTION OF ELECTRIC VEHICLES IN SOUTH AFRICA

Respondents were presented with an opportunity to state their willingness to purchase electric vehicles in the future given certain technological advances and policy changes and their results are shown in Table 4.19 below.

Table 4.19: Percentage of respondents showing the degree in which they are likely to purchase an electric vehicle based on the future technological and policy changes

Factor	1*	2*	3*	4*	5*
If the driving range can be increased tremendously	35.0	46.6	12.3	4.9	1.2
If there will be a charging station at your workplace	46.6	40.4	7.4	4.2	1.5
If there will be a charging stations at major filling stations around the country	44.9	38.7	10.5	4.9	1.0
If their prices would be comparable with normal vehicles with the same functions	57.0	34.8	4.0	2.7	1.5
If the vehicle variety in the South African market is increased	43.6	41.9	9.6	3.9	1.0
If there is a government financial incentive in the form of tax rebate of a fixed amount	48.5	38.0	7.6	4.4	1.5
If there is a government financial incentive in the form of annual vehicle license renewal and toll gates exemptions	48.0	37.5	8.6	3.2	2.7
If government can allow electric vehicles to drive in dedicated bus lanes in major congested roads	42.4	35.3	15.7	4.2	2.5
Average	**45.8**	**39.2**	**9.4**	**4.0**	**1.6**
1* (very likely); 2*(likely); 3* (neither likely nor unlikely); 4*(unlikely); 5*(very unlikely)					

Source: Researcher's own contribution (2018)

Since the driving range of electric vehicles is one of the major thorns in their adoption all over the world, respondents are willing (over 80%) to make future purchases of EVs if this problem is solved (Table 4.19). In order to fulfil this promise, there has to be major breakthroughs in the development of rechargeable batteries. There are signs of success in this area as some of the new vehicles coming to the market in Europe and North America are proclaimed to have driving ranges exceeding 600km. Based on this information, consumers will have less range anxiety in the future and the number of electric vehicles will definitely increase on South African roads.

One of the major obstacles that was presented is the lack of convenient charging spots in some of the countries, including South Africa. It is suggested that placing charging stations at workplaces will sort out the problem. The respondents attest to this notion, with 87% stating that they are likely to buy an EV if there is a policy that encourages employers to install charging stations in their parking lots (Table 4.19). This should be supported by government subsidies for the employers to be compensated for their electricity usage during charging. An increase in charging spots will also help curb the pre-conceived range anxiety.

The poor network of charging stations is currently a deterrent that prevents consumers from purchasing EVs (Table 4.19). The charging points that are present in South Africa are not on the major roads and this can cause a huge inconvenience for motorists. The respondents in Gauteng indicated that their adoption of electric vehicles would be enhanced if charging stations are present at major filling stations across the country. The presence of this infrastructure at these strategic points would not change driving patterns of motorists, thus enhancing their positive experience on this emerging technology.

It has been documented all over the world that the purchase price is the main constraint for the improved footprint of EVs. At the current price, EVs are more than twice as expensive as the vehicles in their class and the motive to become ecologically sensitive can be suppressed by these other disadvantages (Ginsberg & Bloom, 2004). Over 90% of the respondents in Gauteng Province showed their willingness to purchase an EV if and only if, their prices become comparable to the traditional vehicles (Table 4.19). In order to bridge this price gap, a number of countries in the developed world and emerging economies have introduced lucrative incentives for new EV purchases. This has been a successful intervention by governments in Europe and China, with other countries being encouraged to follow.

As stated earlier, governments have a major role to play in ensuring that electric vehicles are adopted by the majority in order to help in their mitigation initiatives. One of the main initiatives has been the introduction of tax rebates of a fixed amount. This makes the EVs more affordable and it is an indication that governments are also committed to the cause of combating climate change. Around 86% of the people showed strong support for the idea (Table 4.19). It must be noted, however, that rebates alone will not change the purchasing behaviour of consumers. Other initiatives like basic educational programmes on television can ensure that people are well informed and are in a position to make the right choices.

In most areas the electric vehicles are compact vehicles and the variety is very low compared with that of ICE vehicles. The fact that one struggles to obtain an SUV or a bakkie with an electric powertrain in South Africa can be challenging to some of the consumers whose travel routes are composed of gravel and untarred roads. The respondents showed that they would be willing to buy electric vehicles if there were a variety of classes (Table 4.19). In other areas where the technology has been piloted for a number of years, there has been many new classes that have been introduced to the market to stimulate adoption.

The introduction of exemptions on annual vehicle registration renewals has the potential to induce more people to consider purchasing of electric vehicles. This can be coupled with toll gate exemptions and free charging at malls. The results show that over 85% of the people believe that this incentive could entice them to purchasing EVs (Table 4.19). There are a number of countries, like Norway, which have adopted this policy and people have responded positively to this initiative.

The other intervention would be that of allowing EVs to use dedicated bus lanes on major congested roads. This initiative showed the lowest appreciation during the survey, with only 77% of the people stating that it might influence them in purchasing an EV. Nevertheless, this could be a major boast to motorists residing in Gauteng especially in peak hours.

4.5. SUMMARY OF THE CHAPTER

In this chapter analysis of data was done for the projected electric vehicle market penetration for different vehicle population dynamics based on three cases (economic decline, business as usual and high economic growth). The analysis of the questionnaire on the adoption of electric vehicles in South Africa was also presented.

The results showed that the cases of economic decline and business as usual present a potential for mitigation in most scenarios, while the high economic growth case showed no mitigation perspective. It was deduced from the results that most people are aware of the environmental impacts of vehicles. Generally, people residing in Gauteng showed a high likelihood of purchasing electric vehicles in the future provided there is an improvement in technological drawbacks and policy improvements.

5. CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This closing chapter aims at summarising the study and will dwell on the following topics: rationale of the research; how the research questions and objectives were addressed; the environment conducive to the adoption of electric vehicles in the future; some of the main findings of the environmental benefits of adopting electric vehicles in South Africa; policy recommendations for the adoption of electric vehicles in South Africa; the contribution that the study has made to the body of knowledge; limitations that are present in the current study that need to be declared and areas that can be explored for future research to enhance the understanding of the dynamics associated with future electric mobility.

5.2 REFLECTIONS

Climate change became a global issue towards the end of the 20th Century as governments, scientists and international organisations became aware of the adverse impact that increased greenhouse gases has had on our climate since the start of industrialisation. This condition is caused by increasing levels of the greenhouse gas emissions that are the result of human activities around the world. All the main economic activities contribute one way or another, but the main culprit is the energy through combustion of fossil fuel. The transport sector is one of the contributors to increased greenhouse gas emissions, with more than 14% of the total global GHG emissions (Jochem, Babrowski, & Fichtner, 2015). The main problem is that these emissions are projected to rise over time up to 70% by 2050 based on the business as usual scenario (Abdul-Manan, 2015).

The concerns raised by governments, the private sector and international organisations on energy security as well as climate change, has led to ground breaking research and developments in the transport sector. The introduction of internal combustion engine vehicles in 1807 and their development for over the last 200 years, has made it possible for people to be transported from one place to another with ease (Zhu, 2016). But these developments have been at the heart of climate change and the pollution problems that the world is facing.

In the context of what has been discussed in preceding paragraphs on the challenges to reduce carbon emissions, many studies indicate that the need to change the propulsion system and convert to electric vehicles, presents the world with a solution to attain a sustainable future (Anable, Skippon, Schuitema, & Kinnear, 2011). A lot of research has focused on electrifying passenger cars as they contribute to over 90% of the transport emissions, thus this class presents an opportunity for massive gains in the fight against increasing greenhouse gas effect. Electric vehicles available in the current market differ according to their degree of hybridisation, starting with hybrid vehicles with limited battery power to full electric vehicle with enhanced battery power.

The electric vehicle market is in its infancy stage with very few vehicle manufacturers embarking on producing them on a large scale. The reason is that there are still many technological unknowns that have to be solved in order for the vehicle to reach the same satisfaction levels of the internal combustion engine (ICE) vehicle. Some of the issues include the slow rate of development of the battery technology with current batteries having low energy density per weight, posing a dilemma to manufacturers on size of battery and range needed to reduce customer anxiety. Uptake of the electric mobility technology is a challenge with a number of manufacturers having to abandon their production of electric vehicles due to low market penetration. Everything is dependent on the preparedness of the consumers to embrace the new technology in the transport sector (Wang et al., 2017). The majority of the people are still not aware of the electric vehicle technology in the world and South Africa included.

5.3 RESEARCH FRAMEWORK

The study was based on the framework shown in Figure 5.1, and as discussed in the preceding paragraphs showing the route of the problem (climate change). Climate change has been affecting our societies in a number of ways leading to an intervention by the United Nations. The two main bodies to understand climate change at the initiation of the United Nations are the Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC). Two main agreements to mitigate climate change were put in place (Kyoto Protocol & Paris Agreement) in the last 30 years. These two main climate mitigation initiatives forced national governments to change their policies and adopt the low-carbon economies that promoted renewable energy and high-energy efficient technologies. This led to the promotion of electric vehicles across the world as the alternative to the ICE vehicles, which are highly inefficient. But since the technology is still evolving there is a lot ground that needs to covered in order to make this technology a first choice in the transport sector. One of the main hurdles is to convince the consumers that the technology is a viable alternative.

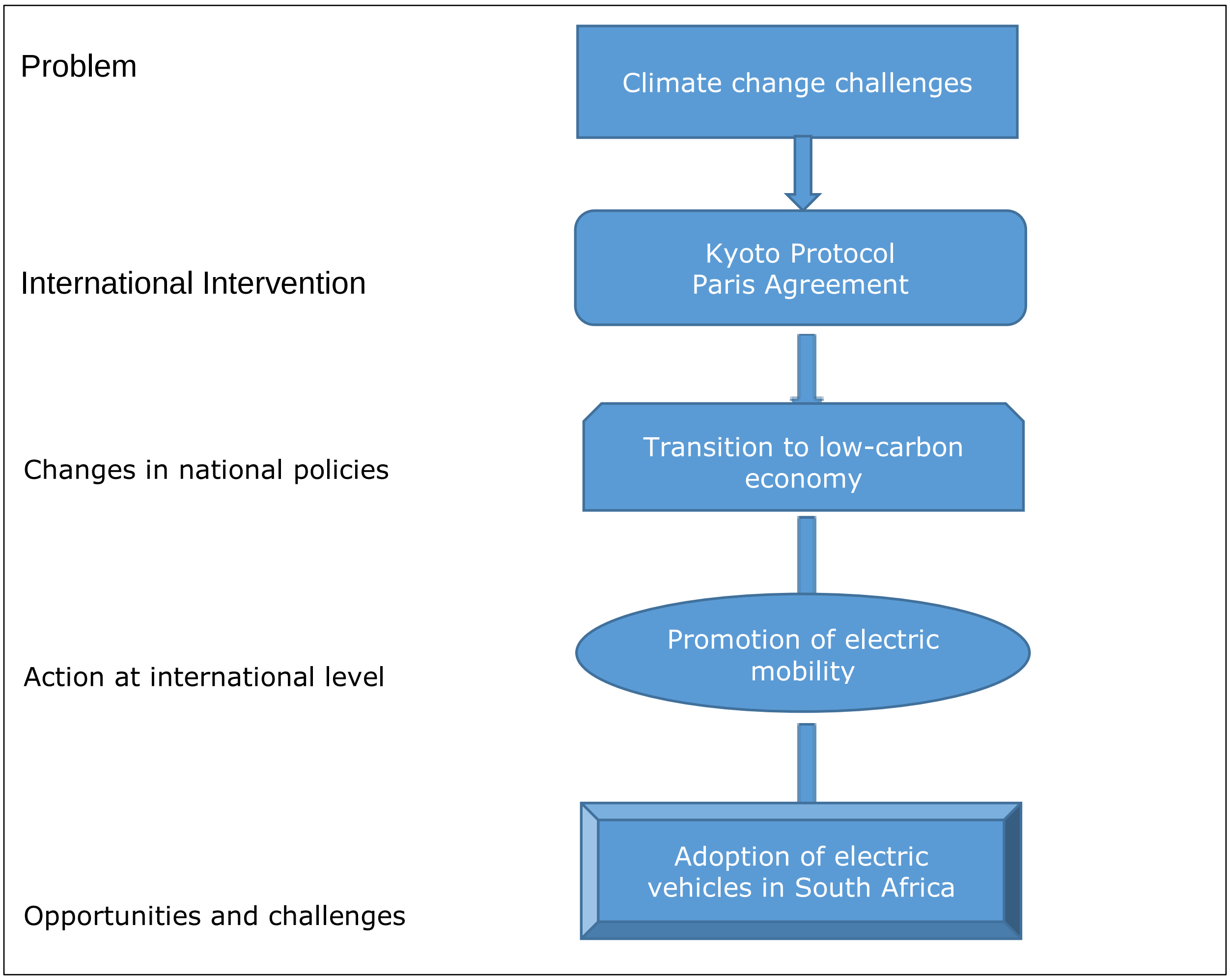

Figure 5.1: Framework for investigating adoption of electric vehicles in South Africa

Source : *Researcher's own construction (2018)*

5.4 ADDRESSING THE PROBLEM STATEMENT, RESEARCH QUESTIONS AND RESEARCH OBJECTIVES

This research aimed at understanding the impacts that the adoption of electric vehicles in the future will have on the fight against climate change. The other main concern before embarking on the study was the low adoption of electric vehicles that have been introduced in the South African market since 2013. To address these main research objectives, two methodologies were employed. The following two paragraphs shows how the three research questions were answered. The first paragraph deals with the research question on electric vehicles and carbon emissions (What will be the impact of introducing electric vehicles in Gauteng Province on transport carbon emissions?). The second paragraph tackles the research questions on barriers to adoption of electric vehicles and policy recommendations (What are the main reasons for the low adoption of electric vehicles in Gauteng and South Africa as a whole?)[What are the possible impetuses that can be explored to improve the perception of electric vehicles among people living in South Africa?]

Historical GHG emissions from passenger vehicles were estimated for the case study area of Gauteng Province from 2000 to 2017, using recommendations from the latest IPCC guidelines for computing national GHG inventories. Future vehicle population projections up to year 2030 were made using the ARIMA model of the XLSTAT resulting in three cases: a) economic decline case (decrease in passenger vehicles with time); b) business as usual (increase in vehicles based on the current trend); c) high economic growth case (radical increase in number of vehicles). Four different scenarios representing varying percentages of electric vehicle by 2030 were assumed using three types of electric vehicles, namely: hybrid vehicle; plug-in hybrid vehicle and full battery powered vehicle.

Since consumers are at the main drivers of the adoption of any new technology in the market, to determine the factors that affect the adoption of electric vehicles in the South African automotive industry, a survey was conducted on “Survey Monkey” for a period close to two months. The survey was constructed to gather basic demographic information, issues related to the environment, ownership of vehicles, barriers to adoption of electric vehicles and recommendations for policy and technological advancements.

The study employed a case study approach whereby Gauteng Province was selected to address the objectives of this investigation. This method enabled a selection of a small geographical extent in a single case design that focused on electric vehicles and their adoptability in South Africa. To fulfil the first objective, quantitative data on the vehicle population and IPCC methodologies were employed to estimate greenhouse gas emissions from passenger vehicles. Descriptive statistics were utilised to analyse the results enabling data to be summarised in a meaningful way. Closed-ended questions (quantitative research) were used to gather information for the adoption of electric vehicles in the South African market as well some of the considerations that need to be considered in order to facilitate an increase in the market penetration of electric vehicle in South Africa.

Based on the methods employed to address the primary objectives, one can thus conclude that the study tackled key issues that would enable proper discussions and deductions on key issues raised in this investigation. The main findings and conclusions for the research questions 1, 2 and 3 are contained in section 5.5, 5.6 and 5.7 respectively.

5.5 ENVIRONMENTAL BENEFITS OF THE ADOPTION OF ELECTRIC VEHICLES

Historical results obtained show that passenger vehicle GHG emissions have been increasing significantly since 2000 to date, at an average percentage increase of around 4% per year. The three cases presented produced different results under different scenarios. The economic decline case offered the highest possible mitigation potential with scenario B (0%HEV;0%PHEV;0%EV), scenario 1 (5%HEV;5%PHEV;10%EV), scenario 2 (5%HEV;10%PHEV;5%EV) and scenario 3 (10%HEV;5%PHEV;0%EV) showing 20%, 35%, 34% and 32% reduction in GHG emissions by 2030 in comparison with 2018 values. The business as usual case resulted in increases in GHG emissions by 20%, 0.8%, 3% and 5% for scenario B, scenario 1, scenario 2 and scenario 3 respectively. The case of a high economic growth rate presented the worse results in terms of mitigation with an increase of 60%, 35%, 38% and 41% for the same scenarios. Based on this data, the South Africa government should be highly satisfied with the business as usual GHG information, as it presents the country with an opportunity to grow its economy and at the same time address issues of climate change mitigation. But to achieve this, there has to be a strong policy that anchors the behaviour of both manufacturers and consumers towards the same objective.

5.6 BARRIERS TO ADOPTION OF ELECTRIC VEHICLES IN SOUTH AFRICA

The electric vehicle technology is considered as “disruptive” and requires a substantial modification in consumer behaviour as its “modus operandi” differs significantly to that of an internal combustion engine vehicle (Anable et al., 2011). This study investigated the consumers’ responses to some of the factors that are unique to the electric vehicle technology. It was discovered that the respondents had a high willingness to purchase electric vehicles with an average percentage of slightly over 50%. The respondents were satisfied with the fact that there is a possibility of reducing their monthly running costs of a vehicle in future if they buy an electric vehicle. The issue of the electric vehicle having a limited range did not seem to be a constraint to the respondents, maybe because close to 90% of the people travel less than 100km per day. The issue of having limited quick charge stations around the country and limited vehicle variety did not have a negative effect on their willingness to consider buying an electric vehicle. They also showed appreciation of the high warranty on a battery. The main factors that yielded unwillingness to purchase an electric vehicle were the issue of high purchase prices of the vehicle and high battery costs. The other main constraint was the one that indicated the possibility of owning an alternative vehicle in cases of emergencies and electricity blackouts. Based on their affordability and other social circumstances, the willingness to buy electric vehicle varies and technological advancement has a role to play to increase their rate of absorption in the market.

5.7 POLICY RECOMMENDATIONS FOR ADOPTION OF ELECTRIC VEHICLES

Even though the participants of the questionnaire on barriers to adoption of electric vehicles in Gauteng showed positive sentiments, they are still of the view that a number of factors need to be changed in order for them to buy electric vehicle in numbers in the future. Policy incentives are considered as one of the most effective measures that can ensure that electric vehicle sales increase. Government has a role to play in ensuring that there are enough incentives for companies that are willing to invest in manufacturing electric vehicles in South Africa. Government should also carefully consider the issue of consumer subsidies for the purchase of the vehicles, as this was found as the main constraint in this study and other studies across the world. Dedicating resources to research and development in the country will ensure local content that can improve acceptability of the technology by the consumers. Other considerations for government are the issuing of exemptions on toll gates and other transport related levies. In order to improve on range anxiety, government should consider the issue of expanding the quick charging stations at strategic areas in partnership with the private sector. Currently in South Africa, vehicle manufacturers are the ones heavily ensuring that charging station density is increased across the country. In countries which have government support for the technology, the market share of EVs has increased tremendously.

5.8 CONTRIBUTION OF THE RESEARCH

The study is very useful to the electric vehicle industry in South Africa which is very limited compared with the situation in other emerging countries like China and India. These countries have a vast number of manufacturers that are present in the electric mobility industry with high numbers of new entrants in the passenger vehicle space. The study will add value to the work done by the electric vehicle industry association (EVIA) of South Africa. Firstly, it raised awareness of the potential consumers on the electric vehicles in South Africa and some of the factors that govern their acceptability into the market. The results can also be of help to the manufacturers who can take advantage of the areas that the respondents felt need to be improved in order for them to consider buying this future mobility vehicle.

5.9 LIMITATIONS OF THE STUDY

In South Africa, people are not very eager to participate in questionnaires that are not manned, thus the response rate to this electronic survey was very low. This led to a low total number of respondents and the statistical significance of the study might be questioned, as there were only 446 responses obtained out of 14 million people living in the Gauteng province. But, the racial proportion of the responses resembles that of the province, indicating that the results can be utilised one way or another. The study was based in the Gauteng Province and thus the findings might not be generalisable to all the other provinces as the dynamics differ significantly. It has to be noted that due to low literacy on issues of climate change and electric mobility, there is a chance that some of the respondents were not aware of what was being asked by some of the questions but had to answer based on how they perceived the question. This problem could have been solved if the questionnaire was administered either through one-on-one or telephonic interviews. Due to limited time for the study, the survey had to be executed within a period of less than two months and if there was more time, the study would have obtained more respondents.

The analysis undertaken in the estimation of the greenhouse gas emissions reduction through the adoption of electric vehicles in the future utilised basic assumptions that might change with time. It is important that the people that will use the results and conclusions made become aware of the assumptions made on parameters like upstream greenhouse gas emissions. It has been noted in some literature that distances travelled by people in the future will increase but this study assumed a constant distance travelled annually.

5.10 FUTURE RESEARCH OPPORTUNITIES

The study concentrated on Gauteng Province and thus it will be desirable to look at the responses from other provinces and compare the issues of importance. The other study that will benefit society, will be the views and experiences of owning an electric vehicle in the South African environment. A detailed study entailing the projection of the potential market for electric vehicles in South Africa will add to the already existing literature. A study that can explore the sensitivity and uncertainty of the greenhouse gas emissions reduction of electric vehicle can be beneficial to the environmental departments of government.

5.11 SUMMARY OF THE CHAPTER

The study of future mobility solutions is highly important as it will assist in paving the way for policy changes, or strategies that can benefit our society. This research had contributed to an understating of adoption barriers of electric vehicles in South Africa, especially in Gauteng Province, as well as indicating their positive environmental impacts.

REFERENCES

Abdul-Manan, A. F. N. (2015). Uncertainty and differences in GHG emissions between electric and conventional gasoline vehicles with implications for transport policy making. *Energy Policy*, *87*, 1–7. https://doi.org/10.1016/j.enpol.2015.08.029

Abreu, M. C. S. de, Freitas, A. R. P. de, & Rebouças, S. M. D. P. (2017). Conceptual model for corporate climate change strategy development: Empirical evidence from the energy sector. *Journal of Cleaner Production*, *165*, 382–392. https://doi.org/10.1016/j.jclepro.2017.07.133

Ajanovic, A., & Haas, R. (2016). Dissemination of electric vehicles in urban areas: Major factors for success. *Energy*, *115*, 1451–1458. https://doi.org/10.1016/j.energy.2016.05.040

Alternative Fuels Data Center. (2018). Hybrid and Plug-In Electric Vehicle Emissions Data Sources and Assumptions. Retrieved from https://afdc.energy.gov/vehicles/electric_emissions_sources.html

Alton, T., Arndt, C., Davies, R., Hartley, F., Makrelov, K., Thurlow, J., & Ubogu, D. (2014). Introducing carbon taxes in South Africa. *Applied Energy*, *116*, 344–354. https://doi.org/10.1016/j.apenergy.2013.11.034

Anable, J., Skippon, S., Schuitema, G., & Kinnear, N. (2011). Who will adopt electric vehicles ? A segmentation approach of UK consumers. *Eceee 2011 Summer Study*, 1015–1026. https://doi.org/978-91-633-4455-8

Andwari, A. M., Pesiridis, A., Rajoo, S., & Martinez, R. (2017). A review of Battery Electric Vehicle technology and readiness levels. *Renewable and Sustainable Energy Reviews*, *78*(February), 414–430. https://doi.org/10.1016/j.rser.2017.03.138

Antwi, S. K., & Hamza, K. (2015). Qualitative and Quantitative Research Paradigms in Business Research : A Philosophical Reflection. *European Journal of Business and Management*, *7*(3), 217–226.

Becker, A., & Bugmann, H. (1999). Global Change and Mountain: Regions The Mountain Research Initiative. *GTOS-28*, (April).

Bessenbach, N., & Wallrap, S. (2013). Why do Consumers resist buying Electric Vehicles ?, 137. Retrieved from http://studenttheses.cbs.dk/bitstream/handle/10417/4329/nadine_bessenbach_og_sebastian_wallrapp.pdf

Bharadwaj, S., Ballare, S., Rohit, & Chandel, M. K. (2017). Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region. *Transportation Research Procedia*, *25*, 3542–3555. https://doi.org/10.1016/j.trpro.2017.05.282

BMW. (2013). The BMW i3, 1–12. http://www.bmwi3.co.za/

Bonges, H. A., & Lusk, A. C. (2016). Addressing electric vehicle (EV) sales and range anxiety through parking layout, policy and regulation. *Transportation Research Part A: Policy and Practice*, *83*, 63–73. https://doi.org/10.1016/j.tra.2015.09.011

Bureau, B. (2011). Distributional effects of a carbon tax on car fuels in France. *Energy Economics*, *33*(1), 121–130. https://doi.org/10.1016/j.eneco.2010.07.011

Čadež, S., & Czerny, A. (2010). Carbon management strategies in manufacturing companies: An exploratory note. *Journal for East European Management Studies*, *15*(4), 348–360. https://doi.org/10.2307/23281754

Castro, J. T., Kuse, Y., & Hyodo, T. (2003). a Study on the Impact and Effectiveness of the Truck Ban Scheme in Metro Manila. *Journal of the Eastern Asia Society for Transportation Studies*, *5*(October), 2177–2192.

Creswell, J. W. (2007). Research Design: Qualitative, Quantitative and Mixed Method Aproaches. *SAGE Publications*, 203–223. https://doi.org/10.4135/9781849208956

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., Sheikh, A., & Zainal, Z. (2011). Case study as a research method. *BMC Medical Research Methodology*, *11*(1), 100. https://doi.org/10.1186/1471-2288-11-100

Dane, A. (2013). *The potential of electric vehicles to contribute to South Africa's greenhouse gas emissions targets and other developmental objectives: How appropriate is the investment in electric vehicles as a NAMA?* Energy Research Center, University of Cape Town, pp. 1–40, 2014.

De Vaus, D. (2001). *Part I What is Research Design? In Research Design in Social Research* (illustrate). London: SAGE Publications. Retrieved from https://www.nyu.edu/classes/bkg/methods/005847ch1.pdf

Department Environmental Affairs (South Africa). (2014). South Africa's 1st Biennial Update report, (November), 158 pp.

Department of Environmental Affairs. (2014). GHG Inventory for South Africa. *South Africa Government*, (August), 222. Retrieved from https://www.environment.gov.za/sites/default/files/docs/greenhousegas_invetorysouthafrica.pdf

Department of Environmental Affairs. (2015). *South Africa's Intended Nationally*

Determined Contribution. https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx

Department of Transport. (2016). *Draft Green Transport Strategy 2016 - 2021*. *Green Insights*. Retrieved from https://www.caia.co.za/wp-content/uploads/2016/08/Draft GTS Revised v5.pdf

Department of Transport. (2017). Green Transport strategy : 2017 - 2050, (41064). Retrieved from https://www.gov.za/sites/default/files/41064_gon886.pdf

eNaTIS. (2010). *Live vehicle population as per the National Traffic Information System* (Vol. 5). http://www.enatis.com/index.php/downloads

eNaTIS. (2011). *31 December 2011 - Live vehicle population as per the National Traffic Information System*. http://www.enatis.com/index.php/downloads

eNaTIS. (2013). 31 December 2013 - Live vehicle population as per the National Traffic Information System, (November), 55–60. http://www.enatis.com/index.php/downloads

eNaTIS. (2014). *Live vehicle population as per the National Traffic Information System*. Retrieved from http://www.enatis.com/index.php/statistics/13-live-vehicle-population/439-vehicle-population-statistics-for-novemberdecember-2014

eNaTIS. (2018). 30 September 2018 - Live vehicle population as per the National Traffic Information System. http://www.enatis.com/index.php/downloads

EPA (U.S. Environmental Protection Agency). (2005). *Greenhouse Gas Emissions from a Typical Passenger Vehicle*. *EPA-420-F-14-040a*. https://doi.org/10.1002/ep.10071

EPA (U.S. Environmental Protection Agency). (2016). What Climate Change Means for Guam. *https://www.epa.gov/sites/production/files/2016-09/documents/climate-change-gu.pdf*

Fankhauser, S. (2012). A practitioner ' s guide to a low-carbon economy : lessons from the UK Samuel Fankhauser Policy paper Centre for Climate Change Economics and Policy Grantham Research Institute on Climate Change and. *Centre for Climate Change Economics and Policy*, (January), 1–30.

Fulton, L. M., Seleem, A., Francisco, B., Alessandra, S., & Deger, S. (2017). *Electric Vehicles: Technology Brief*.

Gajjar, H., & Mondol, J. D. (2016). Technoeconomic comparison of alternative vehicle technologies for South Africa’s road transport system. *International Journal of Sustainable Transportation*, *10*(7), 579–589. https://doi.org/10.1080/15568318.2015.1026007

Gärling, A., & Thøgersen, J. (2001). Marketing of electric vehicles. *Business Strategy and the Environment*, *10*(1), 53–65. https://doi.org/10.1002/1099-0836(200101/02)10:1<53::AID-BSE270>3.0.CO;2-E

Gauteng Info. (2018). Gauteng Information. Retrieved from https://www.gauteng-info.co.za/provinces/info

Giannarakis, G., Konteos, G., Sariannidis, N., & Chaitidis, G. (2017). The relation between voluntary carbon disclosure and. https://doi.org/10.1108/IJLMA-05-2016-0049

Ginsberg, J. M., & Bloom, P. N. (2004). Choosing the Right Green Marketing Strategy. *MIT Sloan Management Review*, (Fall), 79–84.

Githeko, A. K., & Woodward, A. (1991). International consensus on the science of climate and health : the IPCC Third Assessment Report, 43–60.

Goldman-Sachs. (2010). *Transition to a low carbon economy*. *Discovery.Ucl.Ac.Uk*. Retrieved from http://discovery.ucl.ac.uk/1315882/

Goyns, P. H. (2008). Modelling real-world driving , fuel consumption and emissions of passenger vehicles : a case study in Johannesburg, (January), 223.

Granovskii, M., Dincer, I., & Rosen, M. A. (2006). Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles. *Journal of Power Sources*, *159*(2), 1186–1193. https://doi.org/10.1016/j.jpowsour.2005.11.086

Hardman, S., Shiu, E., & Steinberger-Wilckens, R. (2016). Comparing high-end and low-end early adopters of battery electric vehicles. *Transportation Research Part A: Policy and Practice*, *88*, 40–57. https://doi.org/10.1016/j.tra.2016.03.010

Healy, M., & Perry, C. (2000). Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. *Qualitative Market Research: An International Journal*, *3*(3), 118–126. https://doi.org/10.1108/13522750010333861

Høyer, K. G. (2008). The history of alternative fuels in transportation: The case of electric and hybrid cars. *Utilities Policy*, *16*(2), 63–71. https://doi.org/10.1016/j.jup.2007.11.001

Hyett, N., Kenny, A., Dickson-swift, V., 2014. Methodology or method ? A critical review of qualitative case study reports study reports. International Journal of Qualitative Studies on Health and Well-being 9, 1–12. https://doi.org/10.3402/qhw.v9.23606

Idaho National Laboratory. (2010). *Comparing energy costs per mile for electric and gasoline-fueled vehicles*. https://doi.org/INL/MIS-11-22490

India Department of Heavy Industries. (2008). Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles. *Atmospheric Environment*, *42*(18), 4023–4035. https://doi.org/10.1016/j.atmosenv.2008.01.053

International, I. E. A., & Agency, E. (2018). Global EV Outlook 2018. https://doi.org/10.1787/9789264302365-en

IPCC. (2006). Chapter 1 Introduction to the 2006 Guidelines , p1- 12. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC. (2007). Emissions: Enery, Road Transport. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, 55–70. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_3_Road_Transport.pdf

IPCC (Intergovernmental Panel on Climate Change). (2014). *Climate Change 2014: Synthesis Report*. https://doi.org/10.1017/CBO9781107415324

Jabeen, F. (2016). The Adoption of Electric Vehicles: Behavioural and Technological Factors. PhD Thesis, The University of Western Australia. 309pp.

Jabeen, F., Olaru, D., & Smith, B. (2012). Acceptability of electric vehicles: findings from a driver survey. *2012 ATRF Proceedings*, (January 2015), 1–15. Retrieved from http://therevproject.com/publications/uwa/C2012-ATRF-Acceptability Of Electric Vehicles: Findings From A Driver Survey-Jabeen Braunl Et Al-ref.pdf

Jochem, P., Babrowski, S., & Fichtner, W. (2015). Assessing CO2emissions of electric vehicles in Germany in 2030. *Transportation Research Part A: Policy and Practice*, *78*, 68–83. https://doi.org/10.1016/j.tra.2015.05.007

Johnson, & Chirstensen, L. (2000). *Quantitative, Qualitative, and Mixed Research*. *Educational Research: Quantitative, Qualitative, and Mixed Approaches* (Fifth Edit). https://doi.org/No. 13-0028-EF.

Johnson, R., & Onwuegbuzie, A. (2004). Mixed Methods Research: A Research Paradigm whose Time has Come, *33*(7), 14–26.

Keith Paustian, Ravindranath, N. H., Amstel, and A. van, Gytarsky, M., Kurz, W. A., Ogle, S., … Somogyi, Z. (2006). Introduction. *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use*, (Suppl), 11–29. https://doi.org/10.1111/j.1440-1843.2006.00937_1.x

Khaldi, K. (2017). Quantitative, Qualitative or Mixed Research: Which Research

Paradigm to Use? *Journal of Educational and Social Research*, *7*(2), 15–24. https://doi.org/10.5901/jesr.2017.v7n2p15

Kloess, M. (2011). *Potentials of hybrid and electric cars to reduce energy consumption and greenhouse gas emissions in passenger car transport-Techno-Economic Assessment and Model-Based Scenarios*. Technical University of Vienna.

Kothari, C. R. (2004). *Research Methodology: Methods & Techniques*. *New Age International (P) Ltd*. https://doi.org/10.1017/CBO9781107415324.004

Krupa, J. S., & et al. (2014). Analysis of a Consumer Survey on Plug-In Hybrid Electric Vehicles. *Transportation Research: Part A: Policy and Practice*, *64*(0), 14–31.

Lewis, R., Zako, R., Biddle, A., & Isbell, R. (2018). Reducing Greenhouse Gas Emissions from Transportation and Land Use: Lessons from West Coast States. *Journal of Transport and Land Use*, *11*(1), 343–366. https://doi.org/http://dx.doi.org/10.5198/jtlu.2018.1173

Matulka, R. (2014). The History of the Electric Car. https://doi.org/10.1049/ip-a-1.1985.0014

Mendelsohn, R., Basist, A., Kurukulasuriya, P., & Dinar, A. (2007). Climate and rural income, *81*, 101–118. https://doi.org/10.1007/s10584-005-9010-5

Merven, B., Stone, A., Hughes, A., & Cohen, B. (2012). Quantifying the energy needs of the transport sector for South Africa: A bottom-up model. *University of Cape Town - Energy Research Centre, South Africa, Tech. Rep.*, (June), 1–78. Retrieved from http://www.erc.uct.ac.za/Research/publications/12-Merven-etal_Quantifying_energy_needs_transport sector.pdf

Miles, M. B., & Huberman, A. M. (1984). Drawing Valid Meaning from Qualitative Data: Toward a Shared Craft. *Educational Researcher*, *13*(5), 20–30. https://doi.org/10.3102/0013189X013005020

Mittwede, S. K. (2012). Research paradigms and their use and importance in theological inquiry and education. *Journal of Education and Christian Belief*, *16*(1), 23–40. https://doi.org/10.1177/205699711201600104

Nissan. (2017). *Nissan We Make Promises . We Keep Promises .* Retrieved from https://www.nissan.co.za/vehicles/new/leaf.html

Parry, M. L. (2004). Membership WHO is WHO in the IPCC, (December).

Pearre, N. S., Kempton, W., Guensler, R. L., & Elango, V. V. (2011). Electric vehicles: How much range is required for a day's driving? *Transportation Research Part C: Emerging Technologies*, *19*(6), 1171–1184.

https://doi.org/10.1016/j.trc.2010.12.010

Petrovic, A., Koprivica, V., & Bokan, B. (2017). Quantitative, Qualitative and Mixed Research in Sport Science: a Methodological Report. *South African Journal for Research in Sport, Physical Education and Recreation*, *39*(392), 181–197.

Plug in America. (2016). Evaluating Methods to Encourage Plug-in Electric Vehicle Adoption. *Plug in America*. Retrieved from https://pluginamerica.org/wp-content/uploads/2016/11/PEV-Incentive-Review-October-2016.pdf

Posada, F. (2018). South Africa's New Passenger vehicle CO2 emission standards: Baseline determination and benefits assessment. Retrieved from https://www.globalfueleconomy.org/media/461198/south-africa-pv-emission-stds_icct-white-paper_17012018_vf-1.pdf

Qian, W., & Schaltegger, S. (2017). Revisiting carbon disclosure and performance: Legitimacy and management views. *British Accounting Review*, *49*(4), 365–379. https://doi.org/10.1016/j.bar.2017.05.005

Rezvani, Z., Jansson, J., & Bodin, J. (2015). Advances in consumer electric vehicle adoption research: A review and research agenda. *Transportation Research Part D: Transport and Environment*, *34*, 122–136. https://doi.org/10.1016/j.trd.2014.10.010

Samara, S. (2016). *Electric cars*. https://doi.org/10.1063/1.2914561

Sandra Ly, Helena Sundin, L. T. (2012). Electric cars,The climate impact of electric cars, focusing on carbon dioxide equivalent emissions. Retrieved from https://www.diva-portal.org/smash/get/diva2:529571/FULLTEXT01.pdf

Schaltegger, S., & Csutora, M. (2012). Carbon accounting for sustainability and management . Status quo and challenges. *Journal of Cleaner Production*, *36*, 1–16. https://doi.org/10.1016/j.jclepro.2012.06.024

Schrag, F. (1992). In Defense of Positivist Research Paradigms. *Educational Researcher*, *21*(5), 5–8. https://doi.org/10.3102/0013189X021005005

Singer, M. (2017). *The Barriers to Acceptance of Plug-in Electric Vehicles : 2017 Update The Barriers to Acceptance of Plug-in Electric Vehicles : 2017 Update*.

Smith, S. (2018). By the numbers : we take a closer look at the BMW i brand..., pp. 1–8. Retrieved from https://www.carmag.co.za/news/numbers-take-closer-look-bmw-brand/

Statistics South Africa. (2011). *Provincial profile : Gauteng Province*. *Census 2011*. Retrieved from http://www.statssa.gov.za/publications/Report-03-01-76/Report-03-01-762011.pdf

Statistics South Africa. (2014). *Census 2011 Provincial profile : Gauteng*.

Statistics South Africa. (2018). Mid-year population estimates 2018, (July). https://doi.org/Statistical release P0302

StatisticsHowTo. (2014, December). Cronbach's Alpha : Simple Definition , Use and Interpretation. Retrieved from https://www.statisticshowto.datasciencecentral.com/cronbachs-alpha-spss/

Stocker, T. F., Dahe, Q., Plattner, G.-K., Alexander, L. V., Allen, S. K., Bindoff, N. L., Xie, S.P. (2013). Technical Summary. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 33–115. https://doi.org/10.1017/CBO9781107415324.005

Taguchi, N. (2018). Description and explanation of pragmatic development: Quantitative, qualitative, and mixed methods research. *System*, *75*, 23–32. https://doi.org/10.1016/j.system.2018.03.010

Tongco, M. D. C. (2007). Purposive Sampling as a Tool for Informant Selection. A Journal for Plant, People and Applied Research, *5*, 147–158. https://doi.org/10.17348/era.5.0.147-158

Tongwane, M. (2009). *Transport Sector Greenhouse Gas Inventory for South Africa for the base year 2009*. University of Witwatersrand.

Tongwane, M., Piketh, S., Stevens, L., & Ramotubei, T. (2015). Greenhouse gas emissions from road transport in South Africa and Lesotho between 2000 and 2009. *Transportation Research Part D: Transport and Environment*, *37*, 1–13. https://doi.org/10.1016/j.trd.2015.02.017

Tsai, W., Shen, Y., Lee, P., Chen, H., Kuo, L., & Huang, C. (2012). Integrating information about the cost of carbon through activity-based costing. *Journal of Cleaner Production*, *36*, 102–111. https://doi.org/10.1016/j.jclepro.2012.02.024

Tsang, F., Pedersen, J. S., Wooding, S., & Potoglou, D. (2012). Bringing the electric vehicle to the mass market a review of barriers , facilitators and policy interventions. *Working Paper*, 1–77. https://doi.org/WR-775

UNFCCC (United Nations Framework Covention on Climate Change). (2014). First steps to a safer future: Introducing The United Nations Framework Convention on Climate Change. http://unfccc.int/essential_background/convention/items/6036.php

UNFCCC (United Nations Framework Covention on Climate Change). (2014). The Paris Agreement. http://unfccc.int/paris_agreement/items/9485.php van Griensven, H., Moore, A. P., & Hall, V. (2014). Mixed methods research - The best of both worlds? *Manual Therapy*, *19*(5), 367–371. https://doi.org/10.1016/j.math.2014.05.005

Waldron, C. D., Harnisch, J., Lucon, O., & Mckibbon, R. S. (2006). Mobile Combustion BT - 2006 IPCC Guidelines for National Greenhouse Gas Inventories. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, *2*(3), 3.1-3.78. Retrieved from papers2://publication/uuid/9C9A9763-5D27-44C9-8AE7-195E79565B60

Wang, J., Chi, L., Hu, X., & Zhou, H. (2014). Urban traffic congestion pricing model with the consideration of carbon emissions cost. *Sustainability (Switzerland)*, *6*(2), 676–691. https://doi.org/10.3390/su6020676

Wang, Yu, J. L., Yang, P., Miao, L. X., & Ye, B. (2017). Analysis of the barriers towidespread adoption of electric vehicles in Shenzhen China. *Sustainability (Switzerland)*, *9*(4), 1–20. https://doi.org/10.3390/su9040522

Wheels24.co.za. (2015). Rush-hour truck ban : SA economy at risk ?, pp. 1–6. Retrieved from https://www.wheels24.co.za/News/Rush-hour-truck-ban-SA-economy-at-risk-20150716

Wheels24.co.za. (2018). Electric vehicles in SA : Uptake of EVs slow but steady, 1–4. Retrieved from https://www.wheels24.co.za/News/Gear_and_Tech/electric-vehicles-in-sa-uptake-of-evs-slow-but-steady-20180116

Winkler, H., & Marquand, A. (2009). Changing development paths: From an energy-intensive to low-carbon economy in South Africa. *Climate and Development*, *1*(1), 47–65. https://doi.org/10.3763/cdev.2009.0003

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D., … Roberts, I. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*, *374*(9705), 1930–1943. https://doi.org/10.1016/S0140-6736(09)61714-1

XLSTAT. (2018). ARIMA. https://www.xlstat.com/en/solutions/features/arima

Yong, Y. J., Ramachandaramurthy, V. K., Miao, K., & Mithulananthan, N. (2015). A review on the state-of-the-art technologies of electric vehicle , its impacts and prospects. *Renewable and Sustainable Energy Reviews*, *49*, 365–385. https://doi.org/10.1016/j.rser.2015.04.130

Zainal, Z. (2007). Case study as a research method.

Zhu, J. (2016). *Analysis of New Zealand Specific Electric Vehicle Adoption Barriers and Government Policy*. Victoria University of Wellington.

Appendix A: Questionnaire used to assess the barriers to adoption of electric vehicles in South Africa

Barriers to adoption of Electric vehicles in Gauteng

We're very interested to know about your awareness of the role electric vehicles have in improving environmental conditions and your understanding of some of the key issues regarding their adoption in the South African market.

This survey should only take about 10 minutes to complete. There are no personal questions and no individuals are identified. Your answers will be used in scientific research related to climate change mitigation.

Please feel free to contact us if you have specific questions about this survey, by sending an email to moeletsim@arc.agric.za or mmoeletsi@hotmail.com .

Thank you very much for helping us in this study!

Mokhele Moeletsi

1. Background Information

*1. Please select your age

- ○ Under 18
- ○ 18-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65+**

*2. What is your gender?

- ○ Female
- ○ Male

* 3. What is your race?

- Black
- Coloured
- Indian
- White
- Other (please specify)

* 4. What is the highest level of education you have completed?

- Did not attend school
- Primary School
- Secondary School
- High School
- College certificate
- College Diploma
- Bachelor's Degree
- Post-graduate qualification

* 5. You are a person that invests in new technologies and friends use you as a point of reference for new technologies?

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

* 6. In which municipality in Gauteng do you live?

- Ekurhuleni metropolitan municipality(Germiston, Boksburg, Kempton Park surrounding areas)
- City of Johannesburg metropolitan municipality
- City of Tshwane metropolitan municipality (Pretoria)
- Sedibeng district municipality (Vereeniging, Vanderbijlpark, Heidelberg and Meyerton surrounding areas)
- West Rand District Municipality (Randfontein, Krugersdorp and Carletonville surrounding areas)

* 7. In which type of settlement do you currently live?

- Informal
- Rural area
- Suburb
- Township
- Other (please specify)

* 8. Which of the following best describes your current property ownership in Gauteng?

- Own
- Rent
- Live with friends/relatives
- Homeless

2. Car ownership

* 9. How many vehicles do you own?

- 0
- 1
- 2
- 3
- 4
- 5 and more

* 10. What kind of vehicle do you use on daily basis?

- Hatchback
- Sedan
- SUV
- Van/Bakkie
- Other
- Public transport

* 11. What type of fuel does it use?

- Petrol
- Diesel
- Hybrid
- Electric
- N/A(I do not own a car)
- Other (please specify)

* 12. What is the engine size of that car?

- Less than 1.0l
- Between 1.0l and 1.5l
- Between 1.6l and 1.9l
- Between 2.0l and 2.5l
- Greater than 2.5l
- N/A(I do not own a car)

* 13. On average how many kilometers do you travel on a daily basis?

- Less than 20km
- Between 20km and 49km
- Between 50km and 99km
- Between 100km and 149km
- Between 150km and 199km
- Between 200km and 249km
- 250km and more

3. Awareness of environmental impacts of driving vehicles

*14. Are you aware that scientists found out that gases coming out of the exhaust of vehicles contribute towards climate change?

- Yes
- No

*15. Are you aware that there are full electric vehicles in the South African market with zero direct greenhouse gas emissions? e.g Nissan Leaf and BMW i3

- Yes
- No

*16. Do you know anybody who owns a full electric vehicle in South Africa?

- Yes
- No

17. Would you pay extra money for environmentally friendly vehicle?

- Yes
- No
- Not Sure

4. Barriers to adoption of electric vehicles

* 18. Would you consider buying an electric vehicle given that it has less contribution to pollution and climate change?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 19. Would you consider buying an electric vehicle given that it requires no purchase of fuel and thus potentially saves you money in the long run?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 20. Would you consider buying an electric vehicle given that it can only run for range of around 200km before recharging its battery?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 21. Would you consider buying an electric vehicle given that there is an inconvenience of recharging a battery when it runs out (more like your cellphone)?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 22. Would you consider buying an electric vehicle given that it has to be charged up to 8hours at home for a full charge?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 23. Would you consider buying an electric vehicle given that currently there are limited quick (up to 30minutes for 80% charge) public charging stations in South Africa?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 24. Would you consider buying an electric vehicle given that it currently comes only as a hatchback in the South African market?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

25. Would you consider buying an electric vehicle given that the current models in the South African market have the maximum speed of 150km/h?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 26. Would you consider buying an electric vehicle given that it comes with the warranty of 8 years or 150 000km / 6 years or 100 000km depending on the make of the vehicle in the South African market?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 27. Would you consider buying an electric vehicle given that it currently costs between R450 000 and R600 000?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 28. Would you consider buying an electric vehicle given that it costs between R100 000 and R400 000 to buy the battery pack if faulty after expiry of warranty?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

29. Would you consider buying an electric vehicle given that you might need an extra normal vehicle during emergencies that require driving for more than 200km or when your battery is flat?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

5. Recommendations for policy change and improvement

* 30. Would you consider buying an electric vehicle in the future if their driving range can be increased tremendously?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 31. Would you consider buying an electric vehicle in the future if there can be a charging station at your workplace?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 32. Would you consider buying an electric vehicle in the future if there can be charging stations at major filling stations around the country?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

33. Would you consider buying an electric vehicle in the future if their prices would be comparable with normal vehicles with the same functions?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

*34. Would you consider buying an electric vehicle in the future if the vehicle variety in the South African market is increased (more choices e.g sedan, van, SUVs)?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

*35. Would you consider buying an electric vehicle in the future if there can be a government financial incentive in the form of tax rebate of a fixed amount?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

*36. Would you consider buying an electric vehicle in the future if there can be a government financial incentive in the form of annual vehicle license renewal and toll gates exemptions?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

* 37. Would you consider buying an electric vehicle in the future if government can allow electric vehicles to drive on dedicated bus lanes in major congested roads?

- ◯ Very likely
- ◯ Likely
- ◯ Neither likely nor unlikely
- ◯ Unlikely
- ◯ Very unlikely

38. (OPTIONAL)What are other suggestions/conditions that would make you be attracted to buying full electric vehicle?