Analysing South Africa's Automotive Energy Consumption: Application of Index Decomposition Analysis

by

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I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Engineering to the Durban University of Technology, Durban. It has not been submitted previously for any degree or examination to any other University. Due acknowledgement has been made of the use of any material contained in or derived from this research report.

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Acknowledgement

"The true meaning of life is to plant trees, under whose shade you do not expect to sit." — Nelson Henderson wrote in a blog in 2009

With this being my first effort towards energy studies in manufacturing, it has opened up understanding towards energy consumption at an economical level revealing even more ideas for future studies. I must confess this was a long and emotional journey, as one had to break the bias of having a teacher to explain every single detail of content before one could grasp understanding of an idea or topic; self-study and research has taught me the true art of discipline and patience.

In submitting this work, I would like to thank GOD for giving me the strength, patience and guidance to persevere with this research. Furthermore, I am greatly indebted to my advisor/supervisor Dr. Oludolapo A. Olanrewaju for guiding me closely and allowing me the freedom to follow my own course even though I got lost at certain points; this helped amplify my knowledge, thinking and understanding. He was always there for me when I needed him and still is, responding timeously when needed. I highly appreciate the time you have spared for me.

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Abstract

This research focuses on applying the Index Decomposition Analysis (IDA) to South Africa's automotive industry to decompose energy consumption and further make use of regression analysis to understand how it relates to the economy. South Africa has been going through an energy crisis, which has resulted in ongoing load shedding as a way to manage this crisis. Looking at South Africa's energy generation, it can be noted that the entire country depends on Eskom as the main supplier and of electricity, but it is unable to keep pace with the demand.

The results of the research show that there exists a nexus across all segments between energy consumption and GDP; furthermore, the decomposition results show that energy consumption in some years experienced a reduction. However, it can be seen that an increase in energy consumption year on year is predominant; this then suggests that the reductions experienced were the result of a special event; hence, it can be deduced that overall energy consumption has increased slightly. The increase is as a result of the activity effect which contributed the most towards this whilst the structural effect yielded a negligible contribution. Lastly, the intensity effect contributed to the reduction in energy consumption as a result of sectoral shifts; this reduction contributed towards keeping the overall increase in energy consumption low.

This study aimed to outline the differences in energy consumed during the production of different vehicle classes, citing various factors responsible for the changes in energy consumption during vehicle production, raising awareness with manufacturers on the impact industrial energy consumption has on the national energy grid and on advising medium to large manufacturers to become suppliers.

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List of abbreviations

Abbreviation	Expansion
GDP	Gross Domestic Product
MW	Mega watt
IPP	Independent Power Producer
GW	Giga watt
BMW	Bavaria Motor Works
VW	Volkswagen
US	United States
SUV	Sport utility vehicle
kWh	Kilo watt hour
HVAC	Heating, ventilation and air conditioning
MWh	Megawatt hour
MMBtu	one million British Thermal Units
WIOD	World Input-Output Database
LMDI	Log Mean Decomposition Index
IDA	Index Decomposition Analysis
SDA	Structural Decomposition Analysis
IPCC	Intergovernmental Panel on Climate Change
SE4All	Supporting Sustainable Energy for All
GWh	Giga watt hour
MCV	Medium commercial vehicle
HCV	Heavy commercial vehicle
LCV	Light commercial vehicle
PAS	Passenger vehicles
IEA	International Energy Agency
ANN	Artificial Neural Network
DEA	Data Envelopment Analysis
IR	Intensity Re-factorization
AR	Activity Revaluation
CNC	Computer Numerical Control
Mtoe	Millions of tonnes of oil equivalent
NAAMSA	National Association of Automobile Manufacturers of South Africa
GVM	Gross Vehicle Mass
KPA	Key Performance
GJ	Giga Joule

Chapter 1

1.1 Introduction

1.1.1 Chapter overview

In this chapter the background to the research is outlined to give the reader an insight as to what the study is about, the rationale behind the study, the research question, the aims and objectives of the study, the methodology to be used and a break-down of each chapter to be included in this study.

1.1.2 Introduction

Since the early 1990s South Africa's energy consumption has seen a tremendous increase (Inglesi-Lotz and Blignaut, 2011). The main factor contributing to this is the structural changes brought about by the democratisation of the country. Pre-1990, due to the apartheid policies almost two thirds of the South African population did not have access to electricity. So as part of the growth and development plan proposed by the newly elected ANC government, electricity provision was seen as an important factor, hence the energy demand has followed the GDP trend closely.

In 2009, South Africa's Electricity consumption grew by $1.4 bn, which added to the ongoing energy crisis. Since late 2007 South Africa has experienced widespread load shedding on a rotational basis because the energy supply was falling behind demand; this was a great concern as it destabilized the national grid. This concern is on-going and to date the national distributor of electricity, Eskom, has been implementing load shedding as a way of managing this crisis.

Ninety-six point seven percent of South Africa's electricity is produced by Eskom and of this 92.6% is produced by coal-fired power stations (Mahotas, 2010). South Africa's renewable energy industry is relatively small. In addition to this, South Africa has limited natural gas resources which accounts for only 3% of energy consumption (Mahotas, 2010). Furthermore, statistics show thaGreetings, Thank you for the reportt the Koeberg power station in Cape Town is the only nuclear power station in South Africa (Mahotas, 2010).

Looking at Table 1.1 it can be seen that the renewable resource energy generation industry is relatively young and even when the components are combined this industry does not even contribute up to 10% to the South African energy market.

Research has shown that Industry is the biggest consumer of energy world-wide. South Africa being a developing country has an industry with a total percentage turnover of 2.3 trillion, with Trade and Manufacturing industries being the largest contributors, with each contributing 36% and 27% respectively to GDP (Mukwakungu et al., 2018).

Table 1.1: Electricity Production South Africa

Electricity Production	**Share (%)**
Coal-fired	92.6%
Nuclear Power	5.7%
Pumped	1.2%
Hydroelectric	0.5%
Gas turbine	0.1%

1.1.3 Background

Worldwide, countries have begun exploring the challenge of harnessing sustainable energy as it is deemed a more cost effective approach when it comes to reducing the continuously increasing energy consumption and focusing on sustainable economic development. South Africa being a developing country is no exception.

Forty percent of southern Africa's electricity comes from South Africa which country has been considered as one of the four cheapest electricity producers in the world. Eskom, being South Africa's leading electricity supplier, supplies over 90% of the electricity used in the country, supplying electricity to 6000 industrial, 18 000 commercials, 70 000 agricultural and three million residential consumers. In addition to this, Eskom operates 29 power stations with a total nominal capacity of 44 134MW, comprised of a mixture of coal-fired, nuclear, gas-fired, hydro-, pump storage and wind farm power stations. The coal-fired stations are the dominant stations, responsible for generating 36 441MW of electricity daily followed by 1860 MW from the single nuclear power station, and the remainder being generated from the smaller generation plants (Keneilwe Ratshomo, 2018).

Most of South Africa's electricity generation comes from a group of four suppliers that form the national public electricity utility, namely:

1. Eskom
2. Municipal suppliers
3. Independent Power Producers (IPPs) in partnership with Eskom
4. Independent generators (Keneilwe Ratshomo, 2018).

Figure 1.1 summarises South Africa's electricity generation, transmission and distribution process flow/ structure.

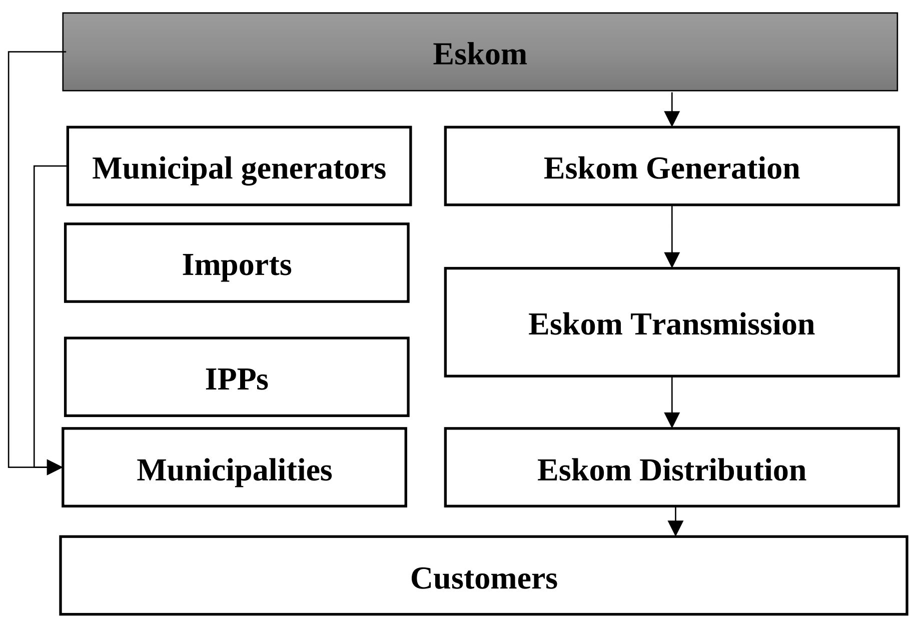

Figure 1.1: Electricity generation, transmission and distribution

Currently Eskom has a nominal installed capacity of about 44,175MW; however, this is not enough as SA has been experiencing ongoing periods of rotational load shedding. The Utility and Independent Power Producers (IPPs) together with the government are currently addressing the electricity supply issues. Forecasts show that South Africa will need over 40,000 MW new generation capacity by 2025 and Eskom is part of the Southern African Power Pool, a group of utilities in the region aiming to create a common market for electricity in the region (Mahotas (2010). In addition to the plans for the growing of SAs' renewable energy industry, the government has proposed that renewable energy should contribute 18.2 GW to South Africa's energy grid by 2030.

Various studies have shown that industry is the biggest consumer of energy world-wide, particularly in developing countries owing to rising populations and catching up on economic growth (Reddy and Ray, 2010) (Mahotas, 2010). Olanrewaju et al. (2012) stated that 37% of global energy usage is due to the industrial sector; similarly, Haiyan Zhang (2014) listed China as being among the developing countries that accounted for 17.5% of the world's total primary energy consumption due to its industrial sector (Hongguang Nie, 2014). Hasanbeigi et al. (2014) in a study done in a developing country delved deeper into industry to understand which specific sector was responsible and noticed that about 27% of primary energy consumption came from the manufacturing sector under the umbrella of industry.

Table 1.2 outlines South Africa's energy consumption. It shows the various segments responsible for electricity consumption. The industrial segment which accounts for 40.9 % of the consumption is the largest consumer followed by the residential segment which consumes 36.8%; the remainder is consumed by commercial, other and transportation with each accounting for 11.4%, 8.1% and 2.7% respectively.

Table 1.2: Electricity Consumption in South Africa

Electricity Consumption	Share (%)
Industrial Segment	40.9%
Residential Segment	36.8%
Commercial	11.4%
Transportation	2.7%
Other	8.1%

Dehning et al. (2017) also emphasised the energy consumption levels accounted for by industry. In addition to this, the study by Dehning et al. (2017) emphasises how the manufacturing sector was at the time paying attention to the energy costs and environmental effects caused by poor energy efficiency.

The research work will look at the South African automotive manufacturing industry as the subject of the study. Dehning et al. (2017) undertook a similar study aimed at analysing and quantifying the internal and external factors influencing the energy intensity of automotive plants. The study focused on 14 major companies, which account for 90% of the automotive industry market share and outlined that 9-12% of the total cost of manufacturing a car goes to energy consumption. This indicates an opportunity for reduced energy consumption and cost saving, therefore assisting manufacturers to stay competitive in this sector.

South Africa’s automotive industry contributes 6% to the Gross Domestic Product (GDP) and accounts for more than 12% of the country’s manufacturing exports. The automotive industry has created employment for +/- 300 000 people, including those in component manufacturing, retail and aftersales market as well as in the tyre manufacturing industry. Toyota, Ford, BMW, VW, Nissan, Mercedes Benz and others are some of the manufacturers with manufacturing plants in South Africa together with component manufacturers such as Bloxwitch, Arvin Exhaust, Flexonics and Corning. The manufacturing plants are found both in the coastal and inland regions of South Africa.

Looking at Africa's entire work-force at large including all industries, studies have showed that there are over 200 million workers aged between 15 and 24 years, and this group is expected to grow by 57% by 2034, which means that by 2034 Africa will have the largest work-force globally (Davies, 2018). By 2030 about 200 million of this population would have moved into the cities. South Africa dominates Africa's automotive market with 47%, or 564 000, of vehicle sales in 2017 alone, followed by Egypt with 15%, or 180 000, vehicles sales for the same year. Furthermore, it manufactures more car brands than any other African country with a total number of nine different original equipment manufacturers with manufacturing plants, which cater for both local and export markets.

Figure 1.2 shows the complete life cycle which is directly and indirectly affected by the automotive industry (Johannes Jordaan, 2018). This image shows that energy is consumed both up- and downstream within the automotive industry, upstream being the manufacturers of sub components

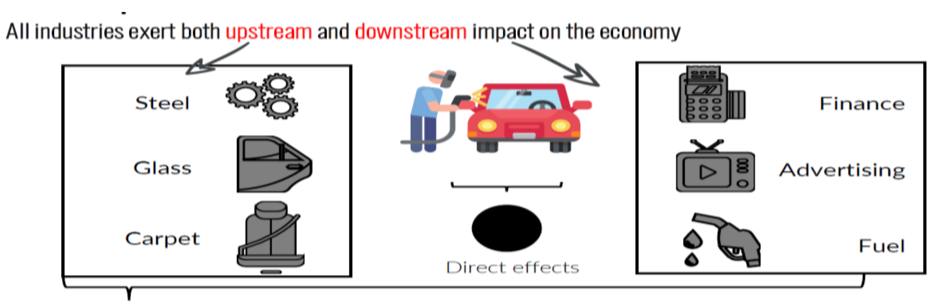

Figure 1.2: Electricity consumption by South African automotive industry (Johannes Jordaan, 2018)

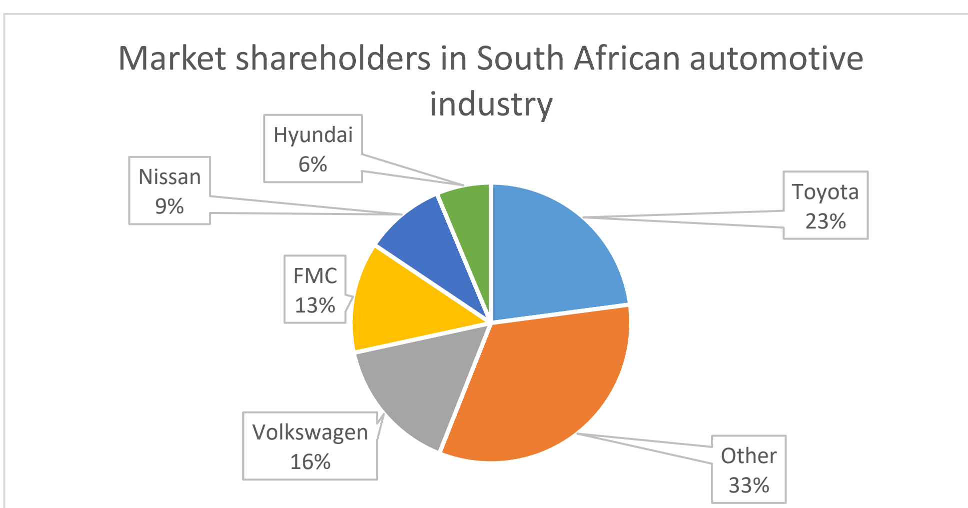

Figure 1.3: Market shareholders in South African

that make up a car, the intermediary being the main assembly of the car, and downstream being the aftermarket.

Figure 1.3 above outlines the top five market shareholders in the South African automotive industry and it can be seen that Toyota and Volkswagen lead the pack by holding 22.9% and 15.6% of market share respectively. A study done by Worrell (2018) in the United States (US), which is a developed country, shows that the automobile sector was shifting from mostly cars to more light vehicles (trucks, minivans and SUVs), the reasons being the relatively lower costs of production,

little competition from foreign markets and increasing demand, which drives up their prices. The process of manufacturing a vehicle consists of five basic steps namely:

1. parts manufacture
2. vehicle body production
3. chassis production
4. painting
5. assembly (Worrell, 2018).

Table 1.3: Distribution of electricity use in vehicle assembly plants

End-Use	Share of electricity use (%)	Estimated typical electricity consumption(1995) (kWh/car)	Average electricity applied in analyses of study (kWh/car)
HVAC	11-20%	95-170	160
Paint system (e.g. Fans)	27-50%	230-320	260
Lighting	15-16%	130-140	130
Compressed air	9-14%	80-120	120
Materials Handling/tools	7-8%	60-70	60
Metal Forming	2-9%	20-80	30
Welding	9-11%	80-95	80
Miscellaneous	4-5%	35-45	20
Total	100%	730-1040	860

Table 1.3 from the study by Worrell (2018) outlines the distribution of electricity use in vehicle assembly plants. From Table 1.3 we can see that paint systems, lighting, heating, ventilation and air conditioning (HVAC) are the top three consumers of energy, accounting for 27-50%, 15-16%

and 11-20% of electricity use respectively. Similarly a study done by *STAR* (2015) which involved 44 assembly plants and 13 companies in the automotive industry showed that natural gas and electricity were the predominant energy sources used in assembly plants. This was based on the criteria listed above and formulated by *STAR* (2015):

Table 1.4: Plant size criteria based on energy consumption (*STAR*, 2015).

Plant Energy Use	Electric (MWh)	Fuels (MMBtu)
Small	~78,700	~473,930
Medium	~121,000	~851,560
Large	~188,000	~1,636,000

According to table 1.4 a small plant consumes 78,700 MWh, whereas a medium plant consumes 121,000 MWh and a large plant consumes 188, 000 MWh on an annual basis. The study went on further to outline that electricity was the largest energy cost, representing 64% of energy costs as shown in figure 1.4. In addition to this, in 2011 assembly plants spent over $441 million on electricity and over $273 million on fuels (*STAR*, 2015).

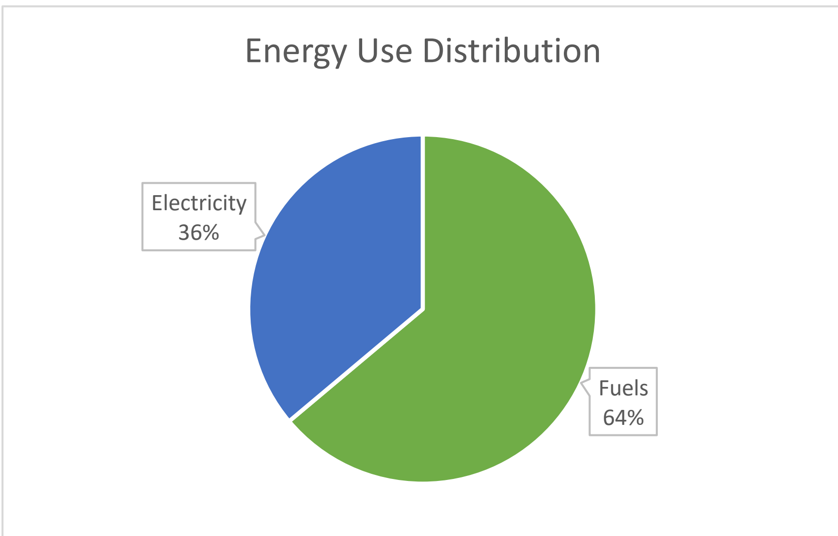

Figure 1.4: Energy use distribution (*STAR*, 2015).

Table 1.5: Major energy uses (STAR, 2015).

Use/Process	Share of energy use
Paint Booths	30-50%
HVAC	11-20%
Lighting	15.0%
Compressed air	9-14%
Welding	9-10%
Material Handling/tools	7-8%
Metal Forming	2-9%
Miscellaneous	4-5%

Furthermore, the study outlined the major uses of energy as can be seen listed in table 1.5. Comparing these findings to the findings of Worrell (2018), it can noticed that HVAC has over-taken lighting by taking up second position when coming to the major consumers of energy; however, the top three have not changed. Moreover, the study by Timma and Blumberga (2014) argued that technological developments were the major driving forces behind the reduction of energy intensity. In addition to this, Voigt et al. (2014) analysed energy intensity trends and drivers in 40 major economies using the WIOD database. The study employed logarithmic mean divisia index decomposition to study trends in global energy intensity between 1995 and 2007 to attribute efficiency changes to either changes in technology or changes in the structure of the economy, and to highlight sectoral and regional differences. By so doing this study also proved that technological developments were the major driving forces behind the reduction of energy intensity. Similarly, this thesis will employ LMDI as a tool under IDA to decompose energy consumption in the automotive industry of South Africa by selecting and conducting a study on an automotive producer.

1.1.3 Methodology

Index decomposition analysis (IDA) is an analytical tool which was initially used by researchers to study trends in electricity consumption in the industry in the early 1980s. The aim was to decompose changes in industrial structure and industrial sector energy intensities to determine their impact on energy consumption. After 1990, studies in other energy consuming sectors such as residential, transportation and services were undertaken following the actions taken by a number of national and international organizations in the 1990s.

Various nations such as Australia, Canada, New Zealand and the United States and international organizations such as the European Union, International Energy Agency and the World Bank, etc. have adopted IDA to study economy-wide energy efficiency trends. This can be seen by the International Energy Agency and World Bank using IDA as a tool to monitor changes made in energy efficiency globally as part of the Global Tracking Framework of Sustainable Energy for all objectives, which was a global initiative led by the Secretary-General of the United Nations (al, 2013b) (Wang, 2013) (Bank, 2015).

History has shown that in recent years the application of IDA has grown beyond the traditional scope of energy and emissions. Some new application areas, just to mention a few, include material and resource requirements, water use and food production (Zhao et al., 2017), pollutant emissions (Kaneko, 2019), and toxic chemical management (Managi, 2012a). This has led to an emerging growth in the number of prospective analysis studies, such as analyzing projected energy savings or reduced emissions, making future forecasts, and harmonizing and comparing results across different models (Ang, 2015).

IDA is linked to index number problems in economics and statistics and it is further linked to systems design and management. The basic concept was mostly formalized in the 1980s; however, over time the methodology has continuously been refined by researchers (Ang, 2015). This can be seen in the search for methods that give out decomposition results without leaving a residual term, particularly studies where decomposition deals with a complex dataset (Ang, 2015).

Logarithmic Mean Divisia Index (LMDI) decomposition has been the most popular IDA approach since the mid-2000s; this was noticed by a gradual shift towards the Divisia index in the 1990s. In addition to this the LMDI decomposition methods have become the *de facto* methods in IDA among researchers (Ang, 2015).

Several years since it was first proposed, IDA and its application has continued to attract interest among researchers and policy makers. Researchers in the Department of Industrial and Systems Engineering have done innovative work in this area, including coining the term "Index

Decomposition Analysis" and the development of the popular LMDI methods. Research is being undertaken to push the boundaries further, both on the application and methodological fronts. Index Decomposition Analysis is a tool used to study changes in energy consumption over a period of time in major energy consuming sectors (Ang and Wang, 2015) (Xu and Ang, 2014a). The application of IDA in understudying and analyzing energy consumption has been noticed by and earned the respect energy researchers; hence this study will use Index Decomposition Analysis to understand the changes in the energy consumption of the automotive industry over time. This study will consider activity, structure and intensity as the decomposed effects to understand the use of energy in the automotive industry. The Global Tracking Framework of the SE4All program initiated by the United Nations (Bank, 2015) and IPCC assessment reports IPCC (2007) are examples of studies that used IDA in policy development and assessment.

IDA commonly uses a single dimensional dataset; however, with time this has changed with various studies now using more sophisticated datasets such as energy consumption by geographical region and by economic sector in a single dataset. In addition to this it was recommended that when dealing with energy data that has multiple attributes, the IDA method would be suitable (Ang and Wang, 2015); this research will therefore follow this approach.

1.1.4 Problem Statement

In addition to this the study mentioned that Eskom was the main supplier of electricity out of a pool of four. Although South Africa has four electricity suppliers, Eskom still generated more than 90% of the electricity (Mahotas, 2010). Industries in South Africa consumed more than 35% of electricity, which was almost 50% of the grid's electricity. Considering the fact that the South African energy sector by agreement has to supply electricity to some neighbouring countries, industry and residential areas etc. it stands to reason that its grid would be under extreme pressure, hence the sector has resorted to rolling out "blackouts", also known as "scheduled load shedding" as a last resort to manage its electricity crisis.

South Africa has a growth rate of 1.43% and the department of energy has forecasted that as of 2017 to 2035 the manufacturing sector will demand an average increase of 3346 GWh (low energy intensive), 5298 GWh (moderate energy intensive) and 7012 GWh (high energy intensive) (CSIR, 2017), already Eskom resorts to "load shedding" as a means of managing the current demand, this negatively affects the GDP, and sooner or later investors will lose confidence in the country which will negatively affect the GDP even more.

Furthermore, South Africa has a small pool of Suppliers. These are industries and companies that generate their own electricity. Some Suppliers in South Africa included Sasol and some metallurgical industries, pulp mills etc. (Keneilwe Ratshomo, 2018). BMW South Africa's Rosslyn plant also partially joined the group of Suppliers as 25-30% of its electricity came from a newly built "Bio2Watt biogas plant" built in 2015 (Communications, 2015). The plant was said to receive approximately 500 tons of Bio2Watt's waste per day which was used to generate renewable energy (Communications (2015). Keneilwe Ratshomo (2018) stated that in the year 2016/17, Eskom supplied a total of 214 121GWh of electricity in bulk to:

- 5.8million residential customers
- 81 806 agricultural customers
- 50 956 commercial customers
- 2706 industrial customers
- 1012 mining customers.

Medium to large industries, which are those that consume more than 121 000 MWh annually (*STAR*, 2015) should consider joining the growing pool of Suppliers. South Africa was home to six major vehicle manufacturing plants (Toyota, Ford, BMW, Mercedes-Benz, Volkswagen and Nissan), nine MCV, HCV and bus assemblers and 500 automotive components s with a total output of 587 000 vehicles produced in 2017 (Johannes Jordaan, 2018), of which 42% were sold locally and 58 were exported. Similarly, the focus of this research is on the South African automotive industry.

South Africa currently has an energy supply crisis and the demand is continuously growing, this study serves to outline a solution that will ease the pressure on the grid. This solution will be applicable to industries only, based on the fact that their processes demand high levels of energy and most industries have enough resources to setup small scale energy generating facilities to sustain their own demands.

1.1.5 Research Aim

Being a developed country and one of the world's leading automotive manufacturers, the US took a bold step by shifting their mass production focus from PAS towards LCVs as they consumed less energy and the market preference had shown a shift to them (Worrell, 2018). A similar trend has been observed in the South African automotive industry. This study aims to outline green energy solutions based on what advanced industries are doing.

This study decomposed the energy consumption used when manufacturing four different vehicle classes namely:

1. Passenger vehicle
2. Light commercial vehicle
3. Medium commercial vehicle
4. Heavy commercial vehicle.

1.1.6 Research Objectives

For this study, the objectives are as follows:

- To determine and outline the differences in energy consumed during production of different vehicle classes.
- To understand the various factors responsible for the changes in energy consumption during vehicle production.
- To raise awareness among manufacturers on the impact industrial energy consumption has on the national energy grid.

1.1.7 Research Question(s)

1. How likely is it that medium to large manufacturers will move to auto-generation of electricity as part of their green energy KPI?

2. What are the differences in energy consumption when manufacturing different vehicle classes?
3. Which decomposition effect will be liable for positive and negative changes in energy consumption?
4. How does GDP affect vehicle production output and how does this affect the change in energy consumption?

1.1.8 Research Rationale

This study is motivated by the current ongoing energy crisis in South Africa. The national grid is currently constrained and research has shown that industry is the largest consumer of energy on the overall grid. In addition to this, the entire grid is mostly dependent on one national producer which is struggling to meet the demand. This study found that the automotive industry in South Africa contributes a substantial amount to the GDP. Furthermore, the study observed the changes being made by the automotive industries of both developed and developing countries to align with global energy demands and the market itself. In addition, the author observed that certain automotive manufacturers in South Africa have stated that they intend moving towards green energy; however, only a few, if not just one, are actually doing so.

Therefore, this research intends to advise industry on the extreme pressure being placed on the power grid and also provides, or outlines, solutions to ease this pressure.

1.1.9 Significance of the research

In South Africa as a developing country energy, trends have showed that the energy consumption rate would increase in line with the population growth and development of the country (Inglesi-Lotz and Blignaut, 2011). Although the increase was ongoing, the country was already experiencing a crisis, which meant that quick solutions were required.

On the other hand, the South African automotive industry contributes a significant share towards the country's GDP; furthermore, the industry is experiencing a shift from petro/diesel powered vehicles to electric and hybrid vehicles powered by green energy. Another shift is that the market is showing a preference for light commercial vehicles like SUVs as opposed to passenger vehicles, as they are more conventional. They also consume less energy when being produced.

Some industries have already made a shift to become suppliers of electricity to support their industry; this brings about cost benefits and grows the renewable resource energy generation sector and by so doing aligns industries with global green energy standards.

1.1.10 Limitations

- Conflicts arising from the governments energy polices.
- Limited access to data from various manufacturers.
- Data used was from a single automotive industry mass producer and can therefore be used to estimate a rough average based on volume and the amount of energy used to mass produce vehicles.
- The energy consumption of vehicles once they have been sold.
- The detailed energy consumption of serviceable components in a vehicle.
- Data used in this research is limited to the automotive industry only.

1.1.11 Outputs

Rofhiwa Machivha, O.A Olanrewaju (2020). Understanding industrial energy sources: A comparison between Electricity and Natural Gas using LMDI. *Proceedings of 2nd African International Conference on Industrial Engineering and Operations Management.*

1.1.12 Research design

Below is Figure 1.8 illustrating the research design, which is the path followed in order to fulfil the requirement of answering the research question. This research consists of interconnected phases which support each other; however, each phase or stage can be developed independently.

Figure 1.8 begins with "defining the problem", which paves the foundation of the thesis; it is then followed by "gathering literature for review", which paves the way for the literature review and selecting a suitable methodology to use in the thesis, and this makes up chapter 1 and 2. Chapter 3 begins by gathering information from various sources including "Manufacturer A" that will be used as a case study. This information is the process used through the IDA techniques to validate its usefulness.

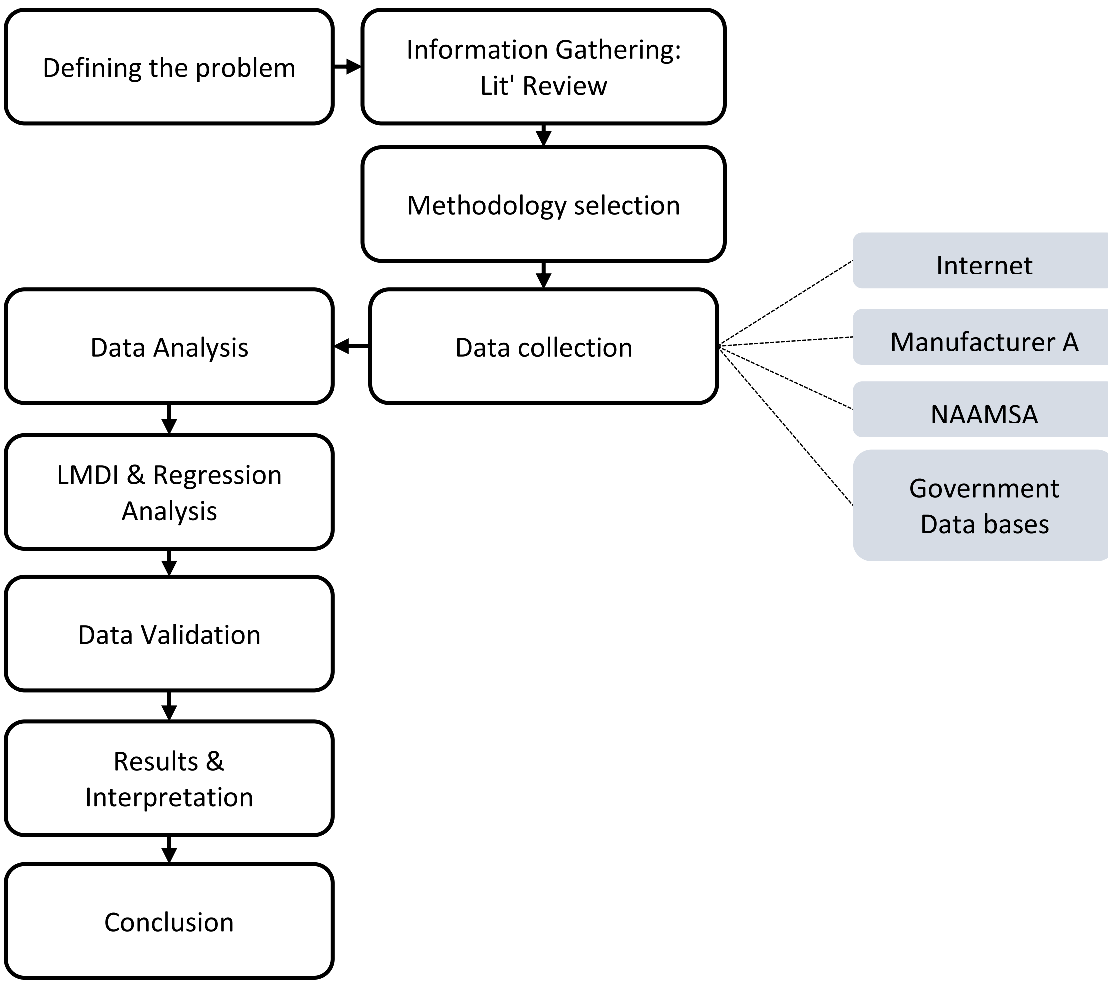

Figure 1.5: Research design

1.1.13 Thesis Layout

This thesis includes six chapters, listed below as follows:

<u>Chapter 1: Introduction and Background</u>

This chapter gives a detailed background to South Africa's energy situation. It touches on the major consumers of energy. This chapter further looks at the world-wide trends in developed and developing countries and outlines what South Africa should consider doing. The chapter outlines the methodology, problem statement, research aim, research objectives, research question(s), and research rationale, significance of the research, limitations and outputs of the study.

Chapter 2: Literature Review

Chapter 2 looks at literature which has been published with the aim of understanding the significance of the subject and to benchmark how other countries and industries have tackled this concern. The knowledge gained from this chapter was then used as a framework to form the roadmap for this thesis.

Chapter 3: Research Methodology

Chapter 3 discusses the research strategy and the methodology used to approach the problem and explains how the data was gathered, it further outlines ad interprets the raw data gathered. This chapter details the process followed to identify and analyze problems and outlines the planning applied to conduct the study.

Chapter 4: Results, Analysis & Interpretation Analysis

Chapter 4 discuses and outlines the results retrieved from the application of Index Decomposition Analysis methodology. This chapter graphically and statistically presents the data and discusses the results provided by the LMDI application.

Chapter 5: Discussion, Conclusion and Recommendations

Chapter 5 concludes the thesis and gives the recommendations of the study by answering the research questions and objectives. This chapter also outlines possible future research opportunities.

CHAPTER 2

2.1 Literature Review

2.1.1 Introduction

In developing countries, the industrial output continued to grow due to the increasing population, which resulted in an increase in energy usage. Furthermore, it was commonplace that this energy was primarily provided by the burning of fossil fuels, with the most common one being coal (Reddy and Ray, 2010). Over the past decade the global energy consumption has been on a constant increase as forecasted by the International Energy Agency (IEA). Global awareness has been raised with the objective of promoting lower energy consumption in all economic sectors especially the industrial and transport sectors as they were seen as the major contributors to this increase; therefore, by increasing pressure on these sectors there was a chance that the energy demand could be reduced. In 2011 research reported that over 50% of the world's total energy consumption was due to industry. In addition to this it was noted that 80% of the supply for this consumption was fueled through the burning of fossil fuels.

The International Energy Agency created awareness that as the demand for energy increased the closer we got to depleting our natural resources; hence calls have been made to look for green energy generation solutions to help avoid an increase in extreme climatic changes, melting of polar caps and the rising of water levels (Dehning et al., 2017).

The study by Kraft (1978) discussed a nexus between energy consumption and economic growth. According to (Chi Zhang (2019) industry was known to be a major key performance measure to economic growth. Studies by Liao et al. (2018), Tekkaya (2018), Wu et al. (2018) and Stoycheva et al. (2018) pointed out that industry was the biggest contributor to energy consumption world-wide.

With South Africa being a developing country, studies have showed that 92% of electricity produced by its national electricity provider, Eskom was produced through the burning of coal (Inglesi-Lotz and Blignaut, 2011). The South African renewable energy industry was still relatively small; however, it was growing. Below are the approximate average generation projections of this industry:

- Wind – 8.4 GW
- Solar PV – 8.4 GW
- CSP – 1 GW
- Other – 0.4 GW (Mahotas, 2010)

Research has showed that in developing countries, as energy consumption increased so did the output. South Africa on its own saw its energy consumption increase by 25% while its output increased by 52.6% and this was shown in the study by Inglesi-Lotz (2012) which outlined similar increases in countries such as:

- Brazil where energy consumption increased by 60% while its output increased by 52%
- China where energy consumption increased by 76% and output increased by 375%
- Mexico where energy consumption increased by 27% and its output for the same period increased by 62%
- India where energy consumption increased by 49% while output increased by 161%.

The world was at a stage where both developed and developing countries were facing challenges with regard to energy conservation (Inglesi-Lotz, 2012). Post 1994, South Africa's GDP grew correspondingly with energy consumption as shown in figure 1 above.

In South Africa, the early 90s saw political instability followed by the country's first democratic elections in 1994. Previously energy was not seen as a priority in so-called 'non-white' areas but when the current ANC government came into power they made the provision of electricity in these areas a priority seeing that this had not been prioritized by the previous apartheid administration. As a result of the ever-increasing demand for electricity over the years Eskom was forced to begin

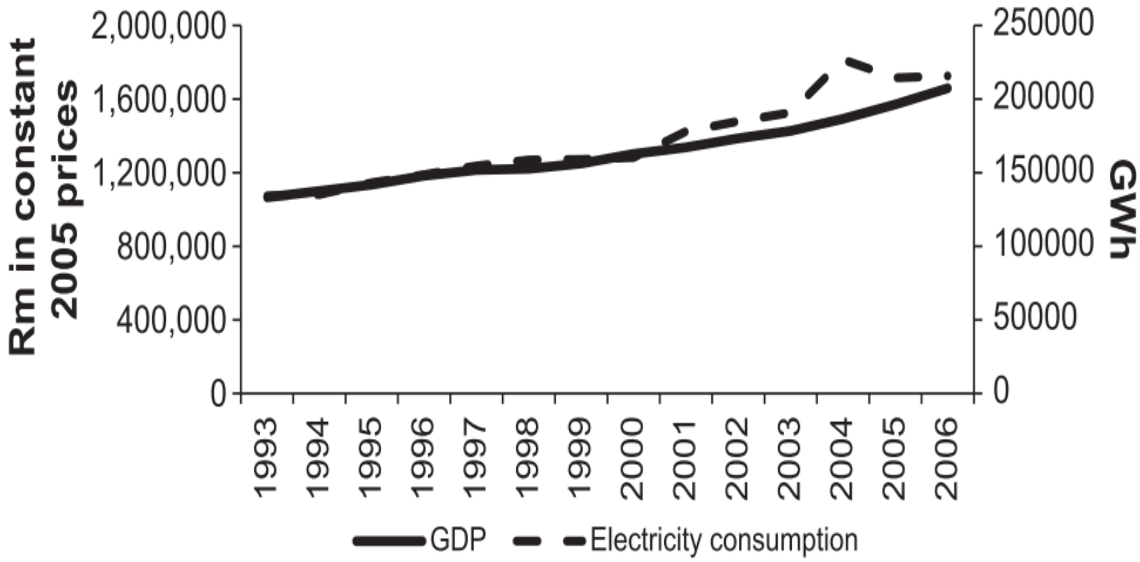

Figure 2.1: Electricity consumption and gross domestic product (GDP) in South Africa 1993 – 2006 (Inglesi-Lotz, 2012)

rolling out load shedding to avoid blackouts. Fast forward to 2020 and the country has been forced to once again implement "load shedding" as a standard way of mitigating the demand for energy. Gross mismanagement and corruption are two additional factors that have brought Eskom to its knees.

The study by Inglesi-Lotz and Blignaut (2011) showed a sharp increase in electricity consumption for the period 1993-2006. Inglesi-Lotz and Blignaut (2011) broke down this consumption by applying various decomposition techniques. This resulted in improvements in the efficient provision of electricity. This study found 'changes in production' and 'structural changes' in the economy as the main contributors to the energy inefficiency. Similarly, the study by Olanrewaju et al. (2013) put forward a method which followed LMDI, an IDA technique, ANN and DEA to study the total energy efficiency and optimization of the industrial sector. Olanrewaju et al. (2013) used LMDI to break down energy consumption into activity, structure and intensity and used the data from the breakdown as input for the ANN technique. In addition, a linear regression model validated and verified ANN by comparing specifically measured energy consumption and corresponding predicted energy consumption. Furthermore, it was used to determine the measured energy consumption and its optimization reductions, whereas its super-efficient DEA model was used for sensitivity analyses.

Two main decomposition methodologies were applied to decompose the energy consumption in South Africa. Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA), which explained direct (first-round) effects to the economy in different sectors and commodities and examined the effects on them individually required data-intensive energy input-output analysis (Wachsmann et al., 2009). The advantages and disadvantages of these methodologies were discussed in detail by (Hoekstra R, 2003).

Index Decomposition Analysis (IDA) has been used as a tool to study energy consumption, economy-wide energy efficiency trends and sectoral changes world-wide (Xu and Ang, 2014b). IDA could easily be applied to any available data at any level of aggregation (Ma, 2006).

2.1.2 Background to IDA

Decomposition took place between time points and IDA was a method used to aggregate the total amount of change into contributions made by various components (Jiang et al., 2015). Ang (2015) was a respected researcher when it came to the application of IDA. Ang (2015) argued that LMDI was an ideal method to use when dealing with sophisticated datasets such as energy consumption by geographical region and economic sector in a single data set.

Xu and Ang (2014b) discussed ways, or methods, to use in addressing the limitations of single level IDA methodology. Traditionally IDA was known to analyze energy consumption using single dimensional energy datasets such as industrial energy consumption. LMDI was known to be the perfect IDA method to use when dealing with energy data that had multiple data attributes because it satisfied the two required properties (perfect decomposition at the sub-category level and consistency in aggregation) when dealing with multiple attributed data in both additive and multiplicative decomposition analysis.

IDA could be divided into two groups known as the Laspeyer Index and the Divisa Index. The Divisa Index was a weighted sum of logarithmic growth rate where the weights were the component shares in total value given in the form of a line integral, whereas the Laspeyer Index measured the percentage change in some aspect of a group of items over time, using weights based on values in same base year (Wang et al., 2014). SDA and IDA were first compared in the early 2000s; however, there were gaps when it came to defining SDA (Su and Ang, 2012). Aal (2013b) identified the drivers of energy use for energy consuming sectors using the IDA framework. In this study two approaches (Intensity Re-factorization (IR) and Activity Revaluation (AR)) were applied in the decomposing energy data. The study indicated that the AR approach was more useful when applied to decompose the aggregate energy intensity change even though it was more complex then IR because of an additional step in its application process.

Ang (2015) explained that IDA was first used in the 1980s to analyze industrial energy consumption. However, over time this method has been applied to various studies such as analyzing accounting frameworks for tracking economy-wide energy efficiency trends; furthermore, al (2013a) discovered limitations such as large variations in data for factors in IDA identity during a study on partial decomposition analysis which focused on a multi-country comparison of energy consumption using IDA. In addition to these limitations,Xu and Ang (2014a) proposed a hybrid model over two IDA techniques which were named ’model A’ and ‘model B’. This study discusses the advantages of the hybrid model over the limitations of IDA.

IDA, ANN and DEA were some of the energy models employed in energy studies. Olanrewaju et al. (2013) did various studies, which successfully combined IDA, ANN and DEA. Some of the literature mentioned in this study focuses on using IDA. IDA is a method that decomposes energy into three effects: Activity, Structure and Intensity.

IDA has been widely adopted in energy studies since the 1980s and has further branched into researching analytical components of accounting frameworks for tracking economy-wide energy efficiency trends.

2.1.3 Common causes of energy consumption

World-wide, energy consumption has become a major concern as the consumption is continuously increasing. With an increase in energy consumption the environment is negatively impacted as the generation of energy in most countries is achieved through the burning of fossil fuels. Studies have shown that the industrial sector is a major consumer of energy world-wide. Since the industrial sector is a major consumer of energy, governments and industries themselves are adopting new improvement methods to tackle energy efficiency which will enhance productivity and reduce environmental impacts. The study by Ang (2015) outlined:

1. driving motors (47%)
2. electrical heating/melting (28%)
3. air compression (10%)
4. lighting (4%)

as the four the main energy consumption operations in industry (Ang, 2015).

The growing trend of ICT in developed and developing countries has been perceived to benefit energy efficiency; however, the study by Zhou et al. (2018) used a three-tier structural decomposition analysis to understand this phenomenon and found that a productive structure exerted a negative effect on China's energy intensity change, whereas ICT contributed a 4.54% increment in energy intensity which was broken down and pointed at technology-intensive service sectors to be the common denominators. Liao et al. (2018) looked at energy optimization and found that machining parameters contributed significantly to the increment in energy consumption, and put forward a proposal to establish the relationship between the machining parameters in order to optimize energy.

As energy demanding sectors increased and developed, energy consumption increased as indicated by the above study. The study by Timma and Blumberga (2014) indicated that technological and structural effects had a direct effect on energy. However, the technological effect had a positive effect on energy efficiency as opposed to the structural effect, which had little or no positive effect on energy efficiency.

Similarly, the study by Ghazanfari (2015) indicated that taking a closer look at industrial parameters was one way of identifying areas for energy optimization, and this was validated by a case study done on CNC machines in the automotive industry whereby the parameters of CNC machines were modified in order to release energy savings.

Another study similar to the ones mentioned above was by ChinHao Chong (2017) who used LMDI to study energy consumption in the Guangdong province of China based on an energy allocation diagram. This study's findings indicated that GDP and population growth were the main driving factors for growth in energy consumption. Furthermore, the study indicated that the improvement in energy supply efficiency reduced energy consumption growth.

China was the largest energy consumer world-wide according to (Guangfei Yang 2016). He identified the focus points for improving the energy efficiency of China and, it being a vast country, Yang (2016) focused on the provincial level first and discovered that energy prices were less influenced by the growth in energy consumption than the total population growth. In addition, the study by Yan (2015) indicated that as economies developed so did energy consumption. This was proved by sampling 30 provinces in China for the period 2000-2012 where the energy consumption growth was monitored together with the rate at which they were developing and a relationship was discovered between the two measurements.

For the period 1980-2010, many economies experienced a sharp increase in energy consumption. A study by Wang (2013) decomposed the change in energy intensity across all the economies and discovered that changes in the labour-energy ratio had a negative impact on energy intensity, whereas technological progress, output structure change and capital accumulation had a positive impact on energy intensity reduction. Furthermore, for the period 2002-2007, the production structure effect had a negative impact on the energy intensity of China (Haiyan Zhang 2014). The changes in production structure could be attributed to the production of energy intensive goods for capital investment and export thus benefiting industrial profits, whereas negatively impacting the overall energy intensity of the country.

The period 1991-2011 saw energy consumption increase by an average of 6.23% with coal playing a big role in the fuel mix by contributing 68% of the total primary energy demand for this period in countries with a wide database of industries. However, in conclusion a new trend had been noticed whereby the economies' energy consumption was decreasing due to the intensity effect (Wang et al., 2014). To decompose this, Wang et al. (2014) generalized LMDI in a study entitled 'Using a new generalized LMDI (logarithmic mean Divisia index) method to analyze China's energy consumption'. This was successfully done by combining the econometrics model to LMDI and was further used to study the driving factors of Chinas' energy consumption. The results indicated that the energy intensity effect played a dominant role in decreasing energy consumption during the study period. However, the investment effect and labour effect were the critical factors in the growth of energy consumption.

Hasanbeigi et al. (2014) studied the energy consumption of the steel industry of a developed country which accounted for 27% of that nation's total energy consumption. The study used LMDI to analyze data for the period 2000-2010. The results indicated that energy intensity reduction contributed to reducing the impact the steel industry had on the economy's overall energy intensity. Furthermore, this study forecasted that energy intensity would also play a role in the decrease of the country's overall energy consumption. However, the structural effect and the pig iron ratio effect increased the energy demand instead.

Voigt et al. (2014) looked at energy intensity in forty major economies with the aim of understanding the effect that structural change and technological improvements had on these economies. The study indicated that technology was a key component of structural energy efficiency improvement whereas structural change did not contribute much to the improvement in energy efficiency of the consumption.

Hongguang Nie (2013) used a combination of IDA and SDA to decompose energy intensity for the year 2000-2009 in the non-residential area of China. Hongguang Nie (2013) decomposed energy intensity into three factors: Sectoral changes, Technological changes and Sub-sectoral changes as a residual variable. The study findings indicated that technological changes were the main contributor towards an improvement in energy consumption. Furthermore, Hongguang Nie (2013) applied SDA for the period 2002-2005 to decompose the increase in energy consumption. The study findings indicated a shift towards energy intensive products for domestic consumption and export, and in addition to the findings, over-capacity also contributed to the consumption.

Hongguang Nie (2014) indicated in a study that even if demand for energy was saturated, usage would continue to rise through the application of LMDI methodology which focused on only four measures (floor-space, energy demand from appliances, change in energy mix and population). The study furthermore indicated that floor-space represented improved living conditions hence the increase in energy consumption. Even if the population growth remained stable, an improvement in living conditions would affect energy efficiency negatively.

2.1.4 Energy Optimization

Tekkaya (2018) did a study on energy saving using manufacturing technology. This study outlined that the use of lightweight components would have a significant effect on energy saving for both the manufacturing operations and in the after sales market. Another study relating to this topic was done by Worrell (2018) who published a journal on energy efficiency improvement and cost saving opportunities for the vehicle assembly industry which listed various case studies relating to this topic. Furthermore, Stoycheva et al. (2018) developed a multi-criteria decision analysis framework with the aim of contributing to sustainable manufacturing in the automotive industry, which would help manufacturers to select materials using green technology criteria.

The United States of America's and Chinas' transport systems were listed as the top energy consumers based on a study by Wu et al. (2018) which used the LMDI model to analyze the causes of these consumptions and it outlined that traffic intensity and economic growth were the main causes. The study further indicated that the US transport system had invested in technology with the aim of optimizing its energy efficiency. This study proposed that China could benchmark against the US as the first step to improving energy efficiency. In addition, a study by Wang et al. (2018) outlined that renewable energy would be an efficient vehicle to support China's energy saving endeavour.

Dehning et al. (2017) proposed a different strategy from IDA to break down energy consumption. A multiple linear approach was put forward to identify and quantify factors influencing energy consumption in the automotive industry to help promote efficient decision-making, which would help plants to be competitive. The study by Fysikopoulos et al. (2012) looked at energy consumption on the automotive industry assembly line. That study found that by modelling an assembly line in advance and by including energy considerations, energy saving could be realized.

Energy efficiency improvement was one of the most cost-effective approaches towards sustainable economic development and the reduction of continuously increasing energy consumption internationally. Inglesi-Lotz (2012) examined the factors which affected the increasing trend in energy efficiency in South Africa from 1993-2006. The study particularly focused on the impact of structural changes and the utilization efficiency of the country's energy intensity. The study concluded that structural changes played a negative role in increasing economy-wide energy efficiency, whereas the energy usage's intensity contributed to the decreasing trend of energy efficiency.

2.1.5 Application and Trend of IDA in Various Countries

A study by Liu et al. (2019) conducted in China during the period 1995-2015 indicated that economic growth was a major driver of energy consumption, whereas energy intensity effectively reduced growth of total energy consumption. Furthermore, these studies revealed that the structural effect played a negative role; however, it had less effect on the growth of energy consumption. Furthermore, Yanqiu Wang (2019) applied IDA in 30 different provinces in China during the period 2006-2015. The outcome of this study was similar to that of Liu et al. (2019) in the sense that the structural effect was found to be the most significant contributor to the energy consumption of these provinces. The study further outlined that the energy intensity effect could effectively curb the growth of China's energy consumption.

Chi Zhang (2019) did another study in China on the application of IDA which supplemented his two previous studies. This study was based on the analysis of electricity consumption in China (1990-2016) using the index decomposition and decoupling approach, and the decoupling status between economic growth and electricity consumption. The analysis was conducted at both national and sectoral levels and the outcomes revealed that the economic activity effect was the main driving force of energy consumption in China and energy intensity was the key to limiting consumption.

2.1.6 IDA Applied in a Different Field

Kaneko (2019) used IDA to analyze air pollution abatement in 10 industrial sectors of China during the period 1998-2009. This was done by applying LMDI, which is a method of IDA to divide the data collected into pollution intensity, end-of-pipe treatment, energy mix, productive efficiency change and production scale change. The outcome of this study improved end-of-pipe treatment equipment technology and its energy efficiency. Zhao et al. (2017) applied IDA in a different field relating to pollution with the intention of understanding the driving forces that changed the water footprint during the period 2001-2010. In a study Managi (2012b) analyzed toxic chemical substance management in three U.S manufacturing sectors from 1991-2008 by applying LMDI to five factors: cleaner production, end-of-pipe treatment, transfer for further management, mixing of intermediate material, and production scale.

In addition to the studies referred to in the previous paragraphs, the study of Geng et al. (2017) augmented the list of studies that proved that IDA could be used in different applications. Geng et al. (2017) applied IDA to a complex chemical process with the aim of improving the energy efficiency of this process. The outcome of this study indicated that there were potential energy savings amounting to 5.33%.

2.1.7 Conclusion

The literature review has revealed that energy consumption has become a global concern, and industry has been identified as one of the biggest contributors to its consumption world-wide. The literature has informed us that fossil fuels are the common source used to generate energy world-wide. It should also be noted that the continued use of fossil fuels to generate energy has a negative impact on the environment.

The literature then discussed the energy structure of developing countries, particularly focusing on South Africa. The results showed that developing countries like South Africa have a relatively small renewable energy generating industry. In addition to this a global appeal has been made to countries to reduce the gap between energy generation through fossil fuels and energy generation through green renewable resources as forecasts have shown that energy demand will continue to increase with time.

The literature has further outlined that IDA was one of the main methodologies being used to decompose energy consumption in various sectors, industries and economies. The literature further discussed in detail the common causes of energy consumption; furthermore, it briefly discussed key points on energy optimization and it concluded by showing that IDA could be applied to different fields such as decomposing economic performance, air pollution and analyzing chemical substance management just to mention a few.

This study focuses on decomposing the energy consumption of industry, particularly focusing on the automotive sector. The Study by Ang (2015) identified driving motors (47%), electrical heating/melting (28%), air compression (10%) and lighting (4%) as the four main energy consuming operations in industry and all these are present in the automotive industry. IDA will be used to decompose the nexus between the auto industry and economic performance.

Chapter 3

3.1 Research Methodology

3.1.1 Introduction

The manufacturing industry in South Africa has shown great concern about the consumption of energy. This has been mainly due to the constant increase in energy costs and to the ecological burden related to energy production and use (Fysikopoulos et al., 2012). Thus energy efficiency has now become a top priority nationally and internationally. The Industrial sector's energy consumption for the year 2009 was 324 Mtoe, which was about 40% of the total energy use of the economy (Mahotas, 2010). Studies have shown that about 20-40% of energy used in industry may be unnecessary (Fysikopoulos et al., 2012). Furthermore, it is necessary to keep in mind that most of the energy is supplied in the form of electricity, and in addition to this about 66% of all electricity is generated through fossil fuels.

It has also been noted that based on research done in similar developing countries, the majority of manufacturing companies do not have a strategy for working with energy efficiency, which may cause incorrect interpretations of data. This study focuses on the automotive industry and it is therefore important to take note of the following: on average, the total energy consumed during the complete life cycle of a car can be broken down into four main stages:

- Raw material processing
- car manufacturing
- car use
- car recovery.

This study takes into consideration the manufacturing of a car (press, body, paint and assembly shops) which is estimated to consume up to 700kwh/vehicle, which is about 9-12% of the total manufacturing costs.

The South African automotive industry makes a significant contribution to the country's GDP; furthermore, its entire supply chain leaves a large footprint in the manufacturing industry. With industry being the largest energy consumer in the South African economy ─ and this was the case with other similar economies worldwide (Deloitte, 2017),– it would be interesting to know what the contributing factors to the energy consumed in the automotive industry are.

The literature reviewed and discussed in the previous chapter gave a clear overview and background to the study. In addition to this, a similar approach is considered to meet the study requirements. This approach is IDA with a mix of LMDI to decompose the energy consumption of ’Manufacturer A’ as a sample case study which will indicate the average consumption of the automotive industry in South Africa. The study will adopt a quantitative method to analyze the change in energy consumption between periods, depending on the time and the various investments added to improve production at ’Manufacturer A’.

3.1.2 Index Decomposition Analysis (IDA) - Logarithmic Mean Divisa Index (LMDI) Method

To meet the objectives of this research, the study followed a quantitative research method, which was supported by the IDA-LMDI additive decomposition methodology used to decompose the energy consumption for the periods covered by the study. Researchers around the early 1980s first used IDA in the analysis of industrial electricity. Over the last two decades, decomposition techniques such as IDA have been used as analytical tools and have attracted considerable interest in energy literature. Some of them focused on the decomposition of energy consumption as well as energy intensity just to mention two (Ang, 2015). IDA is used to break down changes in energy consumption over a period of time into three responsible factors (i) changes in the structure of the economy, (ii) changes in efficiency and (iii) production changes (Inglesi-Lotz and Blignaut, 2011). In most literature, these factors are commonly known as structure and intensity effects, using subsector data (al, 2013b).

In economy-wide studies, the total energy consumption is the sum of energy consumption of different energy consuming sectors, which are made up of subsectors. This builds a clear hierarchical structure of energy consumption information, where IDA can be employed at different levels of sector disaggregation. Largely, changes in the aggregate energy consumption at a particular level are regularly decomposed to give the contributions of variables connected to the overall activity change, structural movements and energy efficiency improvement. The choice of level will differ from study to study depending on data availability and the quality or study scope and objective (Xu and Ang, 2014b).

Literature by (Ang, 2015 , Zhang et al., 2011, al, 2013b, Wang et al., 2014) proved that the multiplicative and additive Log Mean Divisia Index method (LMDI) should be the preferred method for the following reasons:

- Good adaptability
- Ease of use
- Consistent aggregation
- Ease of result interpretation
- Perfect decomposition with no residual term
- Firm theoretical foundation.

(Ang, 2015) presented eight LMDI models together with their origin, decomposition formulae, and strengths and weaknesses as summarized in the research paper titled: LMDI decomposition approach: A guide for implementation. Guidelines on the choice of these models were provided to assist users in implementation and more details can be found in the research paper.

LMDI decomposition approach comprises two different methods, LMDI-I and LMDI-II. These methods differ in the weights of formulae used and there are various studies where each of these models has been employed. A decomposition analysis problem can be formulated either additively or multiplicatively. In additive decomposition analysis, the arithmetic (or difference) change of an aggregate indicator such as total energy consumption is decomposed. However the aggregate change and decomposition results are given in a physical unit (Ang, 2015).

Therefore, from the study of (Ang, 2015) this study employs the LMDI-I Additive model to decompose the changes in energy consumption of manufacturer A, from period 0 to t, so ΔE_{tot}, can be expressed as follows:

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \quad (1)$$

Additive Decomposition Formulae:

$$\Delta E_{act} = \sum_{ij} \frac{E_{ij}^T - E_{ij}^0}{\ln E_{ij}^T - \ln E_{ij}^0} \ln \frac{W^T}{W^0} \tag{2}$$

$$\Delta E_{str} = \sum_{ij} \frac{E_{ij}^T - E_{ij}^0}{\ln E_{ij}^T - \ln E_{ij}^0} \ln \frac{S_i^T}{S_i^0} \tag{3}$$

$$\Delta E_{int} = \sum_{ij} \frac{E_{ij}^T - E_{ij}^0}{\ln E_{ij}^T - \ln E_{ij}^0} \ln \frac{I_i^T}{I_i^0} \tag{4}$$

With each symbol defined below:

1. ΔE_{act} – Change in Activity
2. ΔE_{str} – Change in Structural
3. ΔE_{int} – Change in Intensity
4. ΔE - Change in energy consumption
5. w_i - Intensity effect
6. S_i - Structural effect
7. I_i - Intensity effect
8. ΔE_{ij} - Change in energy consumption at sub-sector $(_{ij})$
9. E_{ij}^0 - Energy consumption at sub-sector $(_{ij})$ for period 0
10. E_{ij}^T - Energy consumption at sub-sector $(_{ij})$ for period T

3.1.3 Linear Regression

This thesis serves to examine the relationship between energy and GDP output by decomposing the changes in energy consumption of Manufacturer A; therefore, using regression analysis for statistical modelling would be ideal. According to (Foley, 2018)it was a set of statistical processes for predicting a relationship between different variables. This was normally a relationship between a dependent variable and one or more independent variable(s) (Anon). Regression analysis also allowed for the identification and characterization of similarities or a relationship between multiple variables.

Regression analysis was an evaluation tool which allowed one to:

- Describe the relationships among the dependent variables and the independent variables statistically.
- Estimate the values of the dependent variables; this could be estimated from the observed values of the independent variables.
- Identify prognoses risk factors that influenced the outcomes, and determine individual prognoses (Schneider et al., 2010).

Regression analysis furthermore used a model to describe the relationship between these variables in a simple mathematical form. In addition to this, below is the list of the top three well-known models and the rest are listed in Table 3.1:

1. Linear regression
2. Logistic regression and
3. Cox regression (Schneider et al., 2010).

Linear regression was commonly used when the relationship between variables was linear; therefore, other methods such as variable transformations and other more complex techniques could be employed for non-linear data. With linear regression the following conditions must be met:

The dependent variable Y must be continuous while the independent variables may be either continuous, binary or categorical. This will be represented by the straight line formulae as listed below:

$$y = mx + c \qquad (5)$$

A linear relationship could be described by the "correlation coefficient". The correlation coefficient was known to give information regarding the direction and strength of relationships between multiple variables. This information was deduced from the criteria listed below:

- $r = \pm 1$: perfect linear and monotone relationship. The closer r was to 1, the stronger the relationship, and the further away r was from 1, the weaker the relationship.
- $r = 0$: no linear or monotone relationship

- $r < 0$: negative, inverse relationship (high values of one variable tended to occur together with low values of the other variable)
- $r > 0$: positive relationship (high values of one variable tended to occur together with high values of the other variable) (Schneider et al., 2010).

Table 3.1 : Regression Models (Schneider et al., 2010)

Regression models

<table>
<tr><th></th><th>Application</th><th>Dependent variables</th><th>Independent variables</th></tr>
<tr><td>Linear regression</td><td>description of linear relationship</td><td>Continuous (weight, blood pressure)</td><td rowspan="4">Continuous and/or categorical</td></tr>
<tr><td>Logistic regression</td><td>Prediction of probability of belonging to groups(outcome: yes/no)</td><td>Dichotomous (success of treatment: yes/no)</td></tr>
<tr><td>Proportional hazard regression(ox regression)</td><td>Modelling of survival data</td><td>Survival time (time from diagnosis to event)</td></tr>
<tr><td>poisson regression</td><td>Modelling of counting processess</td><td>Counting data: whole numbers representing events in temporal sequence (e.g., the number of times a woman ave birth over a certain period of time)</td></tr>
</table>

3.1.4 Raw Data Collection

The researcher used knowledge from research papers published in both developing and developed countries because they have employed the same methodology to similar industries aiming to understand the different effects on energy consumption. To achieve the objectives of this research, data was collected from institutions such as the National Association of Automobile Manufacturers of South Africa and Statistics South Africa. This approach also outlines the analysis of data. The goal was to understand how automobile industries affect South Africa's energy consumption.

According to Bhat (2019), Document Review was one of five methods (observations, survey and questionnaire, interviews, probability sampling and document review) that could be used to gather data for a quantitative research paper. Document review collected data after reviewing existing historical documents. This method was considered to be very efficient and manageable as it used stored data. This method mainly looked at primary types of documents for collecting qualitative research data. In this study, Public Records of Vehicle Annual Sales representing the average manufacturing output, GDP growth, Population growth and recent investments made by some automotive manufacturers' as shown in Public Records data were collected. With this document review, ongoing official records of an organization were analyzed for further research.

Figure 3.1 outlines detailed data gathering communication methods by outlining the resources used and how or what each resource was used for.

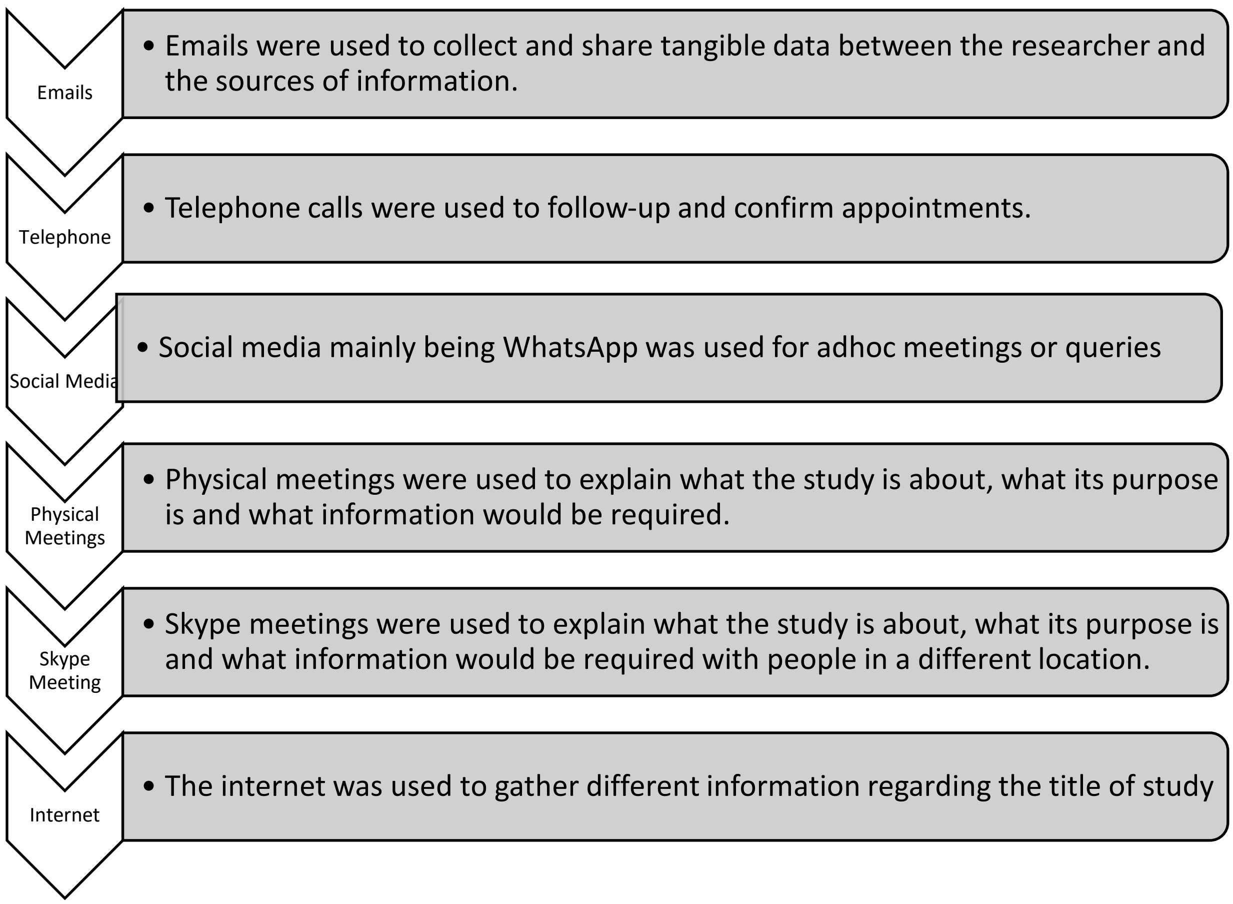

Figure 3.1: Detail data gathering communication methods

We collected the energy and GDP data from 2009 to 2018 and grouped them as follows: 2009 (year 0) to 2010 (year T), 2010 (year 0) to 2011 (year T), 2011 (year 0) to 2012 (year T), and so on until period 2018. The database included a total of four vehicle market segments (PAS, LCV, MCV and HCV) produced by Manufacturer A.

Table 3.2: Raw combined energy consumption data for Manufacturer A

Year	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
GJ Elec	423986	433103	426196	412659	340586	393221	404062	446571	418869	406163

Table 3.3: Conversion factors from physical units to electricity equivalent.

Conversion Factor for two energy units:		
From unit Symbol	Equals Result	To unit Symbol
1 gigajoule GJ	0.28	megawatt hours MWh

Table 3.4: Energy conversion results using data from table 3.2 and 3.3 divided into market sectors

Market Sector →	Passenger	LCV	MCV	HCV
Year ↓	Energy (0000+04 MWh)	Energy (0000E+05 MWh)	Energy (0000E+03 MWh)	Energy (0000E+03 MWh)
2009	7553	1287	5352	2488
2010	8062	1251	5096	2869
2011	7757	1341	5401	3048
2012	7441	1318	5892	3273
2013	5374	1183	5589	2750
2014	6811	1207	5298	2688
2015	7563	1127	5865	2759
2016	8108	1478	6539	2668
2017	8242	1337	4489	2307
2018	7474	1430	4244	2690

Table 3.5: Raw combined GDP (output units) data for Manufacturer A

YEAR	TOTAL MARKET		
	TOTAL	SA PRODUCTION	SHARE
2009	395,222	90,711	23.0%
2010	492,906	100,963	20.5%
2011	571,413	109,414	19.1%
2012	623,926	121,276	19.4%
2013	649,215	126,749	19.5%
2014	644,259	127,534	19.8%
2015	617,648	123,028	19.9%
2016	547,546	117,071	21.4%
2017	557,702	127,444	22.9%
2018	348,014	84,227	24.2%

Table 3.6: GDP (output units) breakdown by market sector

Market Sector →	Passenger	LCV	MCV	HCV
Year ↓	GDP	GDP	GDP	GDP
2009	23073	39335	1635	760
2010	28601	44382	1808	1018
2011	28224	48792	1965	1109
2012	26734	47361	2117	1176
2013	23307	51330	2424	1193
2014	29284	51931	2278	1156
2015	31927	47578	2476	1165
2016	27654	50434	2230	910
2017	32499	52740	1770	910
2018	30165	57720	1713	1086

Table 3.2 presents the combined/total energy consumption data of Manufacturer A for the period 2009 to 2018 in gigajoules. By saying combined/total, it means that this is the summed total energy used to produce the different vehicles regardless of the market they are meant for. This data was then converted into electricity units (megawatt hours) by using the conversion factor presented in Table 3.3. Table 3.4 presents a breakdown of the converted energy consumption data by market sector for the period under investigation.

Tables 3.5 and 3.6 present the GDP on output units. Looking at Table 3.5 the first column presents the years and column 2 presents the total GDP output by Manufacturer A; this includes locally and internationally produced products. Column 3 presents the total GDP output by Manufacturer A showing only locally produced products. The last column presents the total market GDP share contribution by Manufacturer A to the automotive industry. Table 3.6 on the other hand starts with the period of investigation shown in the first column followed by the market sectors in columns 2-5 starting with the passenger vehicle sector, followed by the light commercial vehicle sector, then the medium commercial vehicle sector and lastly the heavy commercial vehicle sector.

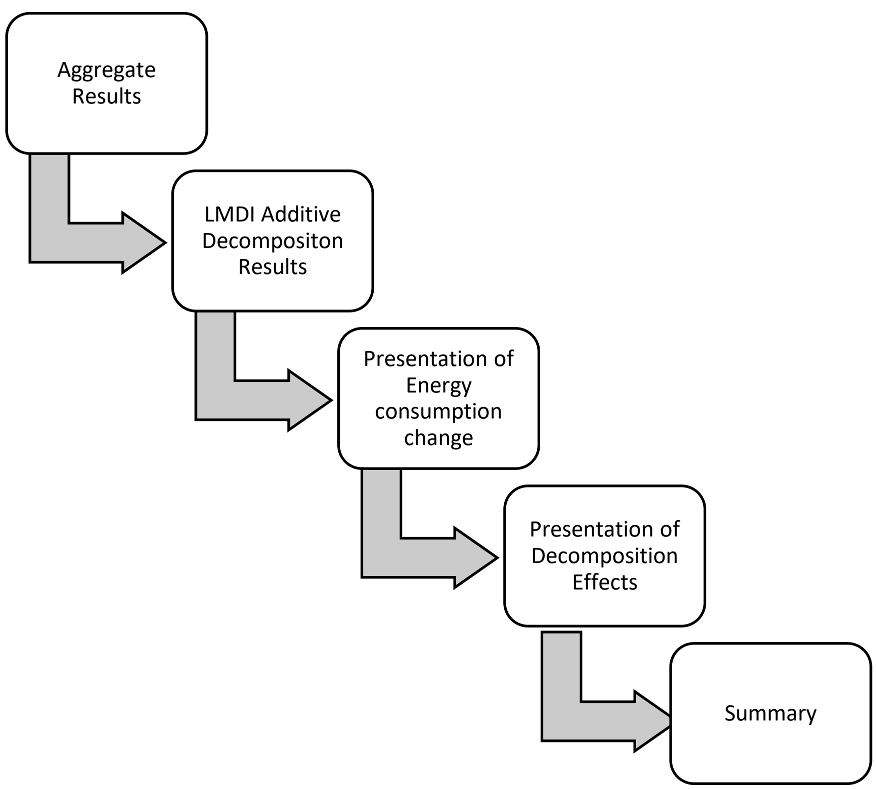

Figure 3.2: Structure of case study

This study follows an additive decomposition analysis approach, which studies the difference in the change of an aggregate indicator such as total energy consumption. The aggregate change and decomposition results are given in a physical unit. Furthermore, a quantity indicator is used; therefore we get the simplest standard IDA identity which has three factors that, when taken through decomposition exercise, lead to the well-known activity, structure, and intensity effects (Ang, 2015).

The case study collected the total energy consumption data of Manufacturer A. This data combines the energy used for all products by segment produced by Manufacturer A. Figure 4.2 outlines the breakdown of each segment:

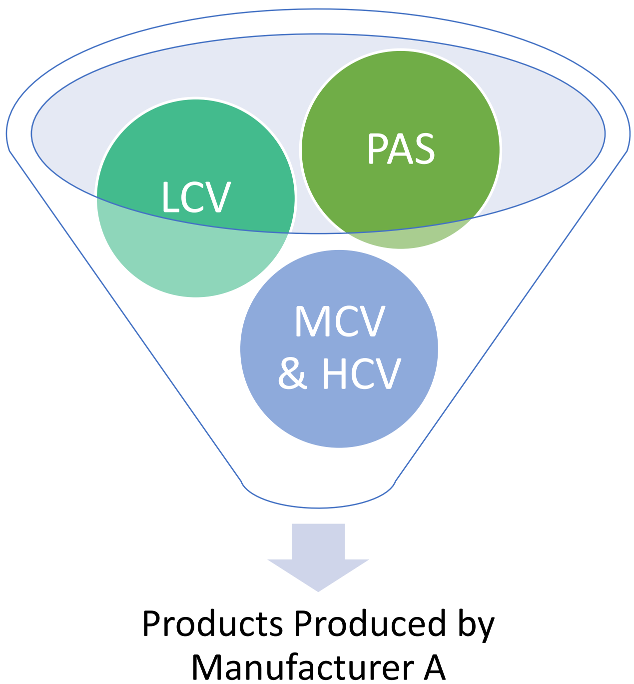

Figure 3.3: Vehicle market segments

From figure 3.4 we can understand the following:

1. PAS vehicles are small vehicles meant to carry a few passengers, have a small loading capacity and are known to have a gross vehicle mass (GVM) ranging between 750-3500 kg. These vehicles are small in body size therefore they will have more body panels and parts.

Figure: 3.4: Passenger Vehicles Class

LCVs are small-medium conventional vehicles meant to carry passengers/ families and luggage or double up as a business vehicle which can carry goods or be used as a maintenance vehicle, e.g. panel van, have a small-medium loading capacity and are known to have a gross vehicle mass (GVM) averaging 3500 kg.

Figure: 3.5: LCV Class

2. MCVs are medium-sized vehicles meant to carry medium-large quantities of passengers or medium-large quantities of goods; they have a medium-large loading capacity and are known to have a gross vehicle mass (GVM) greater than 3500 kg, but less than 16000 kg.

Figure: 3.6: MCV Class

3. HCVs are large commercial trucks which have a large loading capacity and are known to have a gross vehicle mass (GVM) of >16000 kg. These vehicles are large in body size and have a large loading/carrying capacity for both goods and passengers as a mode of transport.

Figure: 3.7: HCV Class

Manufacturer A's energy consumption will be made up of the combined energy consumed when producing each of these vehicle segments/classes; also note that each of these products are produced on separate production lines. This chapter describes the energy consumption of an automotive manufacturer (Manufacturer A) by market segments stated as follows: passenger, lower, medium, and heavy commercial vehicle.

3.1.5 Case Study

An Index Decomposition analysis is applied to Manufacturer A's production mix to understand the energy relationship of each product market to GDP. This case study analyses the energy consumption vs GDP of Manufacturer A's vehicle production mix for the period 2009 to 2018 for the South African automotive industrial sector. The projections are all given by the gross domestic product (GDP) output expressed in production output units and megawatt hours for the energy consumption projections.

3.1.5.1 Presentation

The data presented below in figures 3.8 and 3.9 is the energy consumption and GDP data of four market segments: Passenger (PAS), Light commercial (LCV), Medium commercial (MCV) and Heavy commercial (HCV) vehicles in the automotive industry. According to figures 3.9 and 3.10 presenting Manufacture A's energy consumption, it can be seen that economic activities induced the overall growth in energy consumption.

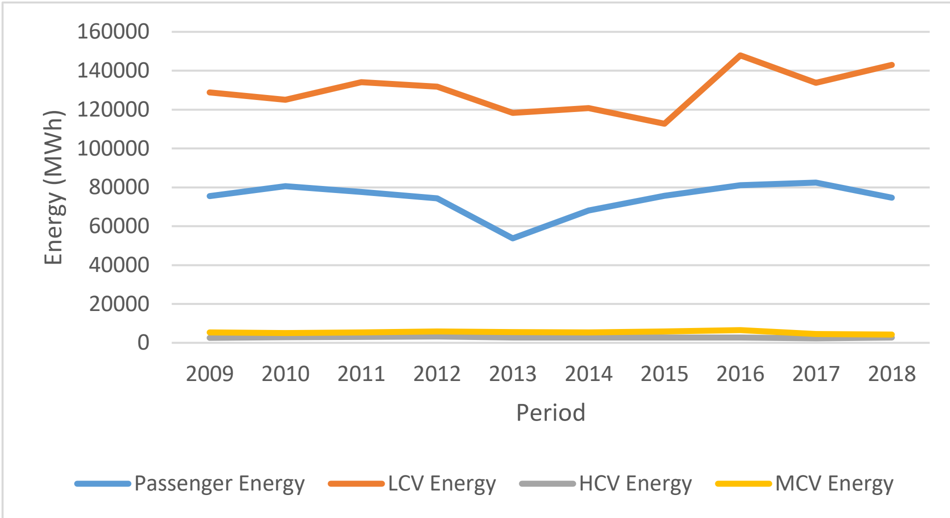

Figure 3.8: Energy consumption data of Manufacturer A

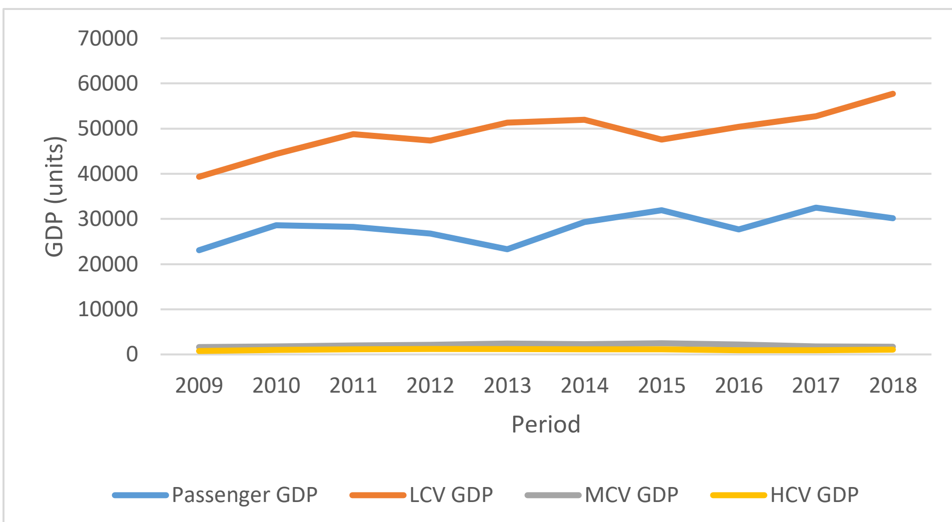

Figure 3.9: GDP data of Manufacturer A

From figure 3.10 for the period 2009-2010 the PAS vehicle segment experienced an increase of 7% in energy consumption and an increase of 24% in GDP, for the period 2010-2011 a reduction of 4% in energy consumption and a further 1% reduction in GDP was registered, for the period 2011-2012 a similar reduction of 4% and a further 5% reduction was registered, for the period 2012-2013 a further reduction of 28% and 13% for energy consumption and GDP respectively was registered, for the period 2013-2014 the tables turned and an increase of 27% and 26% for energy consumption and GDP respectively was registered, for the period 2014-2015 a further increase of 11% and 9% in energy consumption and GDP respectively was registered, for the period 2015-2016 an increase of 7% in energy consumption and a reduction of 13% in GDP was registered, for the period 2016-2017 a slight increase of 2% and 18% in energy consumption and GDP respectively was registered, followed by a reduction of 9% and 7% in energy consumption and GDP respectively for the period 2017-2018.

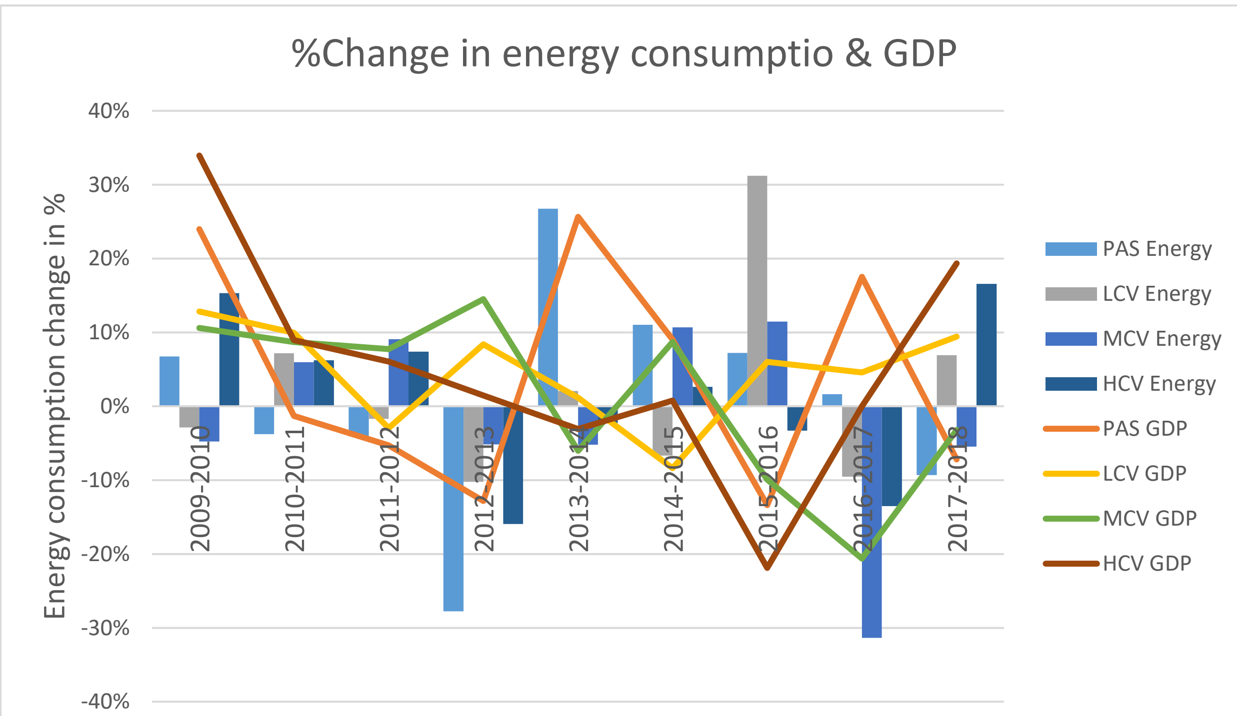

Figure 3.10: Percentage change in energy consumption and GDP for Manufacturer A

To conclude, for the period 2009-2018 the passenger vehicle segment registered an overall 8% and 36% increase in energy consumption and GDP respectively. Furthermore, there was a positive correlation between energy consumed (figure 3.8) and the GDP (figure 3.9) by the PAS vehicle market segment produced by Manufacturer A for the period 2009-2018. This correlation is identified by the equation (1) with a coefficient = 0.534 and this proves that there was a strong correlation and a linear relationship between energy consumption and GDP for the PAS vehicle segment as can be seen in figure 3.11.

Energy = 1.4088(GDP)+32737 *(1)*

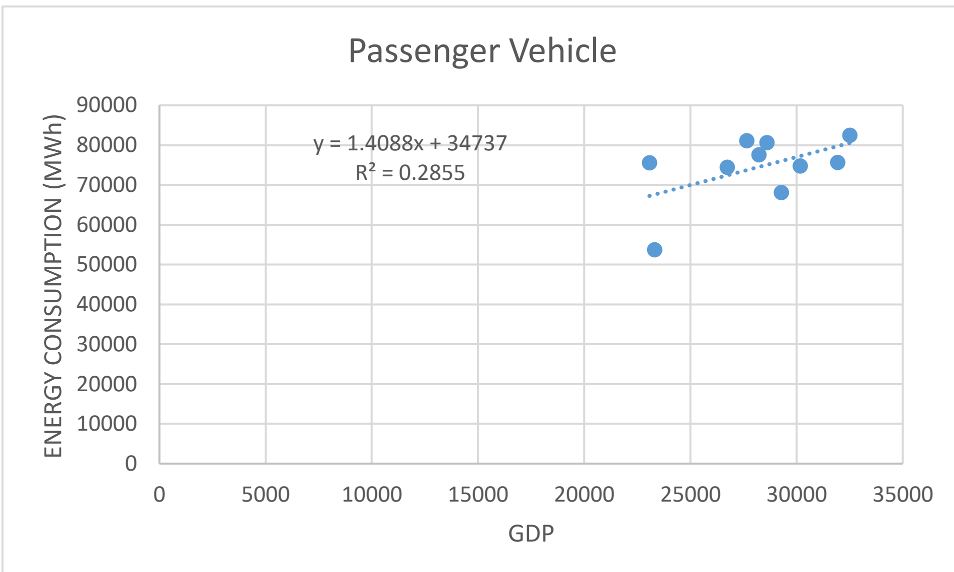

Figure 3.11: PAS vehicle energy consumption and GDP correlation

From figure 3.10 for the period 2009-2010 the LCV segment registered a decrease of 3% in energy consumption and a GDP increase of 13%, for the period 2010-2011 an increase of 7% and 10% in energy consumption and GDP respectively was registered, for the period 2011-2012 a reduction of 2% and 3% for energy consumption and GDP respectively was registered, for the period 2012-2013 a reduction of 10% in energy consumption and an 8% increase for GDP was registered, for the period 2013-2014 a slight increase of 2% and 1% in energy consumption and GDP respectively was registered, for the period 2014-2015 a reduction of 7% and 8% for energy consumption and GDP respectively was registered, for the period 2015-2016 an increase of 31% and 6% for energy consumption and GDP respectively was registered, followed by a decrease of 10% in energy consumption and a GDP increase of 5% for the period 2016-2017, and lastly for the period 2017-2018 a slight increase of 7% and 9% for energy consumption and GDP respectively was registered.

To conclude, for the period 2009-2018 the LCV segment registered an overall 16% and 41% increase in energy consumption and GDP respectively. Furthermore, there was a minor positive correlation between energy consumed (figure 3.8) and the GDP (figure 3.9) by the LCV market segment produced by Manufacturer A for the period 2009-2018. This correlation is identified by the equation (2), with a coefficient = 0.315 and this proves that there was a fair correlation and a linear relationship between energy consumption and GDP for the LCV segment as can be seen in figure 3.12.

$$Energy = 0.6871(GDP)+95856 \qquad (2)$$

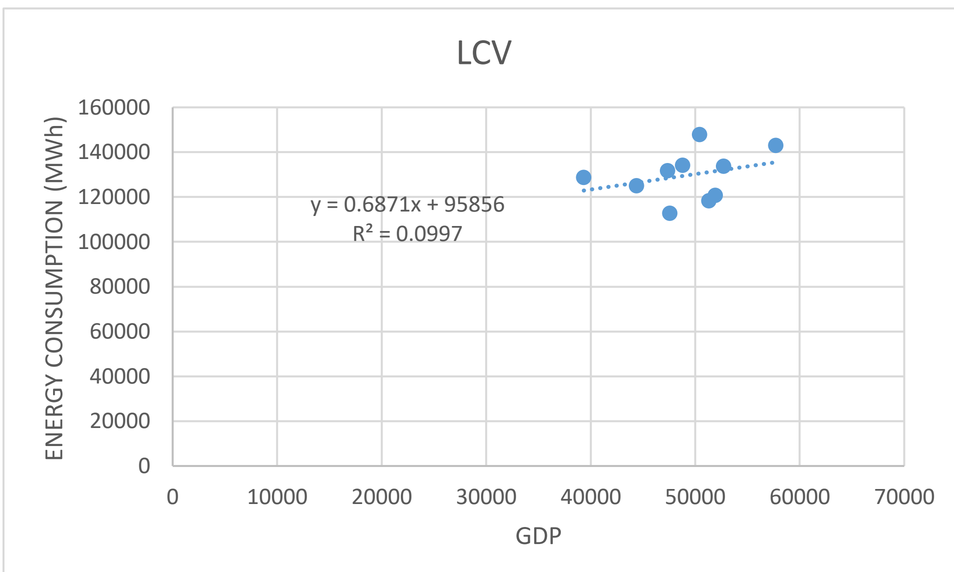

Figure 3.12: LCV energy consumption and GDP correlation

From figure 3.10 for the period 2009-2010 the MCV segment registered a decrease of 5% in energy consumption and a GDP increase of 11%, for the period 2010-2011 an increase of 6% and 9% in energy consumption and GDP respectively was registered, for the period 2011-2012 a further increase of 9% and 8% in energy consumption and GDP respectively was registered, for the period

2012-2013 a decrease of 5% in energy consumption and a GDP increase of 15% respectively was registered, for the period 2013-2014 a decrease of 5% and 6% in energy consumption and GDP respectively was registered, for the period 2014-2015 an increase of 11% and 9% in energy consumption and GDP respectively was registered, for the period 2015-2016 a continued increase of 11% in energy consumption and a GDP decrease of 10% respectively was registered, followed by the period 2016-2017 with a big decrease of 31% and 21% in energy consumption and GDP respectively, and lastly a further decrease of 5% and 3% in energy consumption and GDP respectively was registered for the period 2017-2018.

To conclude, for the period 2009-2018 the MCV segment registered an overall 15% reduction in energy consumption and a GDP increase of 10%. Furthermore, there was a strong positive correlation between energy consumed (figure 3.8) and the GDP (figure 3.9) by the MCV market segment produced by Manufacturer A for the period 2009-2018. This correlation is identified by the equation (3) with a coefficient = 0.661 and this proves that there was a strong correlation and a linear relationship between energy consumption and GDP for the MCV segment as can be seen in figure 3.13.

$$Energy = 01.4525(GDP)+2411.4 \quad (3)$$

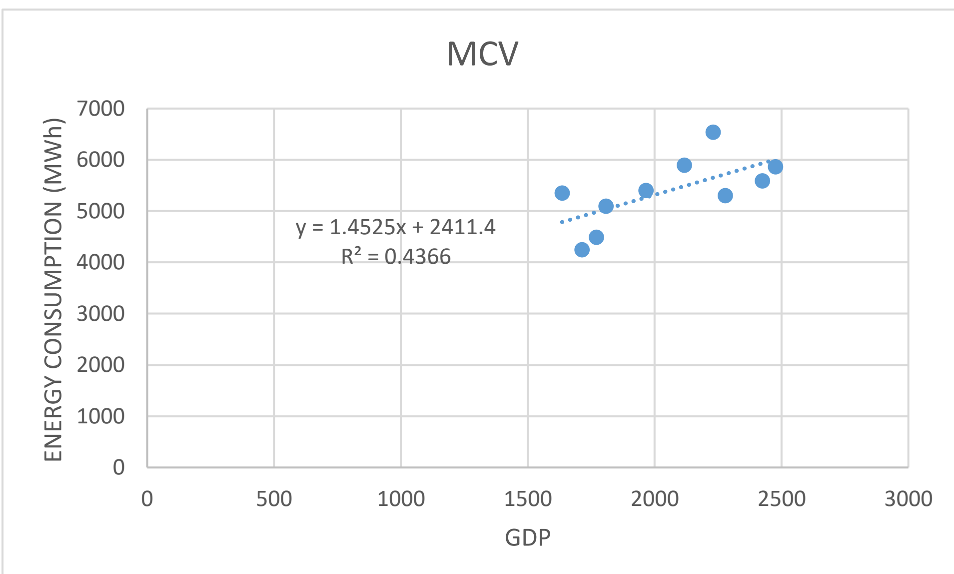

Figure 3.13: MCV energy consumption and GDP correlation

From figure 3.10 for the period 2009-2010 the HCV segment registered an increase of 6% and 9% in energy consumption and GDP respectively, a further increase of 6% an 9% in energy consumption and GDP respectively was registered for period 2010-2011, similarly for the period 2011-2012 a further increase of 7% and 6% in energy consumption and GDP respectively was registered, for the period 2012-2013 a slight decrease of 16% in energy consumption and a minor GDP increase of 1% respectively was registered, similarly for the period 2013-2014 a minor decrease of 2% and 3% in energy consumption and GDP respectively was registered, for the period 2014-2015 a slight increase of 3% and 1% in energy consumption and GDP respectively was registered, for the period 2015-2016 a decrease of 3% and 22% in energy consumption and GDP respectively was registered, followed by the period 2016-2017 with another decrease of 14% in energy consumption and no change in GDP registered, and lastly for the period 2017-2018 a big increase in energy consumption and GDB of 17% and 29% respectively was registered.

To conclude, for the period 2009-2018 the HCV segment registered an overall increase of 13% and 46% in energy consumption and a GDP respectively. Furthermore, there was a strong positive correlation between energy consumed (figure 3.8) and the GDP (figure 3.9) by the HCV market segment produced by Manufacturer A for periods 2009-2018. This correlation is identified by the equation (4), with a coefficient = 0.629 and this proves that there was a strong correlation and a linear relationship between energy consumption and GDP for the HCV segment as can be seen in figure 4.14.

$$Energy = 1.1676(GDP)+1530.6 \quad (4)$$

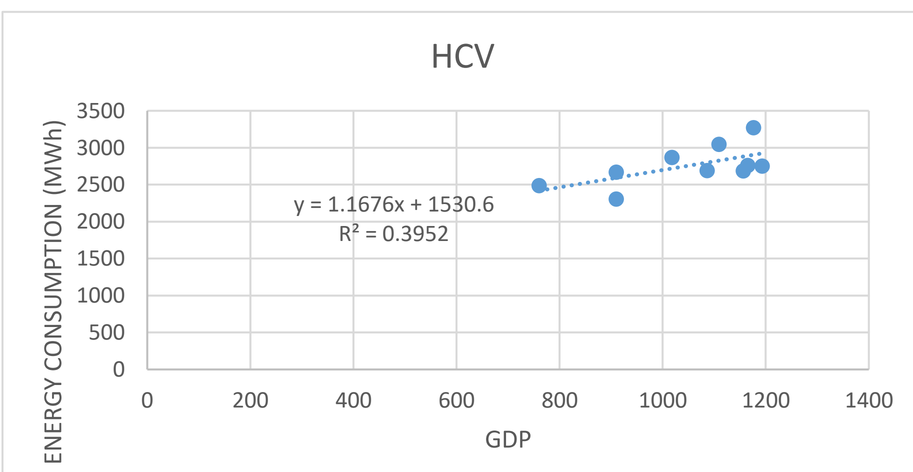

Figure 3.14: HCV energy consumption and GDP correlation

Chapter 4

4.1 Results, Analysis & Interpretation Analysis

4.1.1 Introduction

The purpose of decomposing Manufacturer A's total energy consumption is to quantify the contribution of all the effects. This will help convince the automotive industry to improve their energy efficiency and consider designing their own renewable energy plants to join the suppliers group. This chapter will be presented in a case study format which has employed the direct application of the LMDI formulae.

Multi-national companies like automotive manufacturers (Manufacturer A) were interested in knowing how each plant performed in comparison to others and in addition to this they were also interested in knowing which factors influenced its energy performance (Dehning *et al*., 2017). Hence this study provides an insight into how the LMDI approach could be used to identify and quantify factors influencing the energy intensity of automotive plants at market segment level. This approach will further assist in supporting strategic decision-making and forecasting of the future energy demand of an automotive plant.

In addition to this the previous chapters have outlined South Africa's energy structure; furthermore, they have also detailed the energy crisis the country is experiencing. The study has further outlined that industry consumes the most energy in the country, which is similar to other developing and developed countries globally. In addition to this NAAMSA has taken the initiative to map out an action plan on improving energy efficiency within the automotive industry sector which aligns to South Africa's objective of reducing energy consumption within the industrial sector. In addition, this will align South Africa's infrastructure with those of other developing countries.

This initiative will see automotive manufacturing realizing more cost savings from the production line. Furthermore, this will allow them to diversify their energy sources, which will ease the demand burden on the South African energy supply system. The Automotive industry supply chain consumes large amounts of energy from the raw material phase to the after sales market. This has forced manufacturers to innovate by altering the design of their products by looking at alternative materials and changing the operation of the diesel/petrol engines. For example, in recent years a new market of battery powered vehicles has emerged.

This chapter outlines the energy consumption decomposition results of Manufacturer A. The aggregate energy consumption in megawatt hours (MWh) and gross domestic product in output units are shown in Table 4.1 which has 11 columns divided into two sections defined and named in the following order: Section 1: Year, Market, $Energy_{0,}$ $output_0$, Structural $effect_0$ and Intensity $effect_0$, and Section 2: Year, $Energy_{T,}$ $output_T$, Structural $effect_T$ and Intensity $effect_T$.

Table 4.1: Decomposed total energy consumption of Manufacturer A

	Market	E0	W0	S0	I0		ET	WT	ST	IT
Period (2009)	PAS	75537.74	23073.00	0.36	3.27	Period (2010)	80623.76	28601.00	0.38	2.82
	LCV	128777.23	39335.00	0.61	3.27		125109.04	44382.00	0.59	2.82
	MCV	5352.76	1635.00	0.03	3.27		5096.60	1808.00	0.02	2.82
	HCV	2488.13	760.00	0.01	3.27		2869.65	1018.00	0.01	2.82
	Total	212155.86	64803.00	1.00	3.27		213699.05	75809.00	1.00	2.82
Period (2010)	PAS	80623.76	28601.00	0.38	2.82	Period (2011)	77579.72	28224.00	0.35	2.75
	LCV	125109.04	44382.00	0.59	2.82		134115.28	48792.00	0.61	2.75
	MCV	5096.60	1808.00	0.02	2.82		5401.22	1965.00	0.02	2.75
	HCV	2869.65	1018.00	0.01	2.82		3048.32	1109.00	0.01	2.75
	Total	213699.05	75809.00	1.00	2.82		220144.54	80090.00	1.00	2.75
Period (2011)	PAS	77579.72	28224.00	0.35	2.75	Period (2012)	74412.21	26734.00	0.35	2.78
	LCV	134115.28	48792.00	0.61	2.75		131826.01	47361.00	0.61	2.78
	MCV	5401.22	1965.00	0.02	2.75		5892.52	2117.00	0.03	2.78
	HCV	3048.32	1109.00	0.01	2.75		3273.31	1176.00	0.02	2.78
	Total	220144.54	80090.00	1.00	2.75		215404.06	77388.00	1.00	2.78
Period (2012)	PAS	74412.21	26734.00	0.35	2.78	Period (2013)	53741.19	23307.00	0.30	2.31
	LCV	131826.01	47361.00	0.61	2.78		118356.52	51330.00	0.66	2.31
	MCV	5892.52	2117.00	0.03	2.78		5589.25	2424.00	0.03	2.31
	HCV	3273.31	1176.00	0.02	2.78		2750.81	1193.00	0.02	2.31
	Total	215404.06	77388.00	1.00	2.78		180437.77	78254.00	1.00	2.31
Period (2013)	PAS	53741.19	23307.00	0.30	2.31	Period (2014)	68113.09	29284.00	0.35	2.33
	LCV	118356.52	51330.00	0.66	2.31		120788.86	51931.00	0.61	2.33
	MCV	5589.25	2424.00	0.03	2.31		5298.51	2278.00	0.03	2.33
	HCV	2750.81	1193.00	0.02	2.31		2688.80	1156.00	0.01	2.33
	Total	180437.77	78254.00	1.00	2.31		196889.25	84649.00	1.00	2.33
Period (2014)	PAS	68113.09	29284.00	0.35	2.33	Period (2015)	75632.84	31927.00	0.38	2.37
	LCV	120788.86	51931.00	0.61	2.33		112708.97	47578.00	0.57	2.37
	MCV	5298.51	2278.00	0.03	2.33		5865.47	2476.00	0.03	2.37
	HCV	2688.80	1156.00	0.01	2.33		2759.80	1165.00	0.01	2.37
	Total	196889.25	84649.00	1.00	2.33		196967.09	83146.00	1.00	2.37
Period (2015)	PAS	75632.84	31927.00	0.38	2.37	Period (2016)	81089.62	27654.00	0.34	2.93
	LCV	112708.97	47578.00	0.57	2.37		147887.25	50434.00	0.62	2.93
	MCV	5865.47	2476.00	0.03	2.37		6539.01	2230.00	0.03	2.93
	HCV	2759.80	1165.00	0.01	2.37		2668.39	910.00	0.01	2.93
	Total	196967.09	83146.00	1.00	2.37		238184.28	81228.00	1.00	2.93
Period (2016)	PAS	81089.62	27654.00	0.34	2.93	Period (2017)	82423.99	32499.00	0.37	2.54
	LCV	147887.25	50434.00	0.62	2.93		133759.24	52740.00	0.60	2.54
	MCV	6539.01	2230.00	0.03	2.93		4489.08	1770.00	0.02	2.54
	HCV	2668.39	910.00	0.01	2.93		2307.94	910.00	0.01	2.54
	Total	238184.28	81228.00	1.00	2.93		222980.25	87919.00	1.00	2.54
Period (2017)	PAS	82423.99	32499.00	0.37	2.54	Period (2018)	74742.61	30165.00	0.33	2.48
	LCV	133759.24	52740.00	0.60	2.54		143018.18	57720.00	0.64	2.48
	MCV	4489.08	1770.00	0.02	2.54		4244.46	1713.00	0.02	2.48
	HCV	2307.94	910.00	0.01	2.54		2690.88	1086.00	0.01	2.48
	Total	222980.25	87919.00	1.00	2.54		224696.13	90684.00	1.00	2.48

Table 4.2 presents the energy decomposition results for Manufacturer A for the period 2009-2018. Column 1 shows the periods covered by this study, followed by the sum of the decomposition effects, followed by the three effects, namely, activity, structure and intensity. The last row sums up all the projections, which will outline which effect is responsible for the overall change in energy consumption.

4.1.1.1 Additive LMDI Decomposition analysis results

Table 4.2: Results of energy consumption decomposition for Manufacturer A, 2009-2018: additive decomposition (MWh)

Period	ΔE_{tot}	ΔE_{act}	ΔE_{str}	ΔE_{int}
2009-2010	1543.19	33394.298	0.298	-31851.411
2010-2011	6445.49	11912.846	1.437	-5468.791
2011-2012	-4740.48	-7473.197	-0.230	2732.943
2012-2013	-34966.3	2194.834	-30.752	-37130.367
2013-2014	16451.5	14797.441	14.789	1639.254
2014-2015	77.8346	-3525.908	0.046	3603.696
2015-2016	41217.2	-5058.350	34.417	46241.120
2016-2017	-15204	18237.033	-6.920	-33434.139
2017-2018	1715.88	6927.425	0.914	-5212.463
Summary	12540.3	71406.422	13.999	-58880.160

The results presented in this section are interpreted as follows: the results have been divided into three effects (activity, structure and intensity) as stated above. The activity effect is positive when more output can be produced with the same energy use. This indicates an improvement in energy efficiency when positive. The structural effect measures the changes in composition. Therefore, if the structural effect is positive, it indicates that there is a movement towards more energy intensity.

The third effect, which is the intensity effect, measures improvements in energy efficiency, fuel mix changes, efficient energy management practice, changes in technology, and any other factor which is not related to volume of output or composition. Therefore, if this effect is positive, it then indicates signs of a poor energy efficiency scenario whereas a negative intensity effect points to improvement in energy efficiency.

From figure 4.1 and figure 4.2 the LMDI additive decomposition results show that between 2009 and 2010 there was a marked change in energy consumption for Manufacturer A. The total change in energy consumption saw an increment of 1543.19 MWh. The activity effect proved to be the most apparent. This effect showed an overall growth in energy consumption and this could be an indication of an increase in output while neglecting to reflect energy efficiency. The structure effect contributed a fair share towards the overall growth in energy consumption, which indicated changes in production composition, such that the composition was strictly concentrated on energy intensive products. The intensity effect on the other hand proved to contribute towards positive energy efficiency; however, this contribution seemed to be negligible which could be attributed to improvements in energy efficiency.

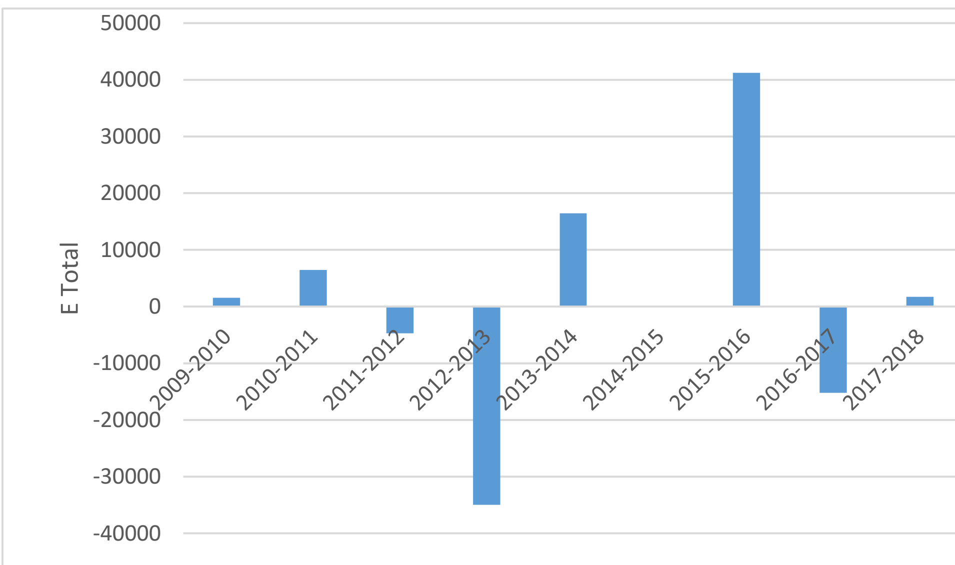

Figure 4.1: Decomposed total energy consumption of Manufacturer A

For the period 2010-2011, figure 4.1 and figure 4.2 present the LMDI additive decomposition results which show that there was a fair change in energy consumption for Manufacturer A. The total change in energy consumption saw an increment of 6445.49 MWh. The activity effect proved to be the most apparent. This effect showed an overall growth in energy consumption, and this could be attributed to the increase in production outputs reacting to demand increment in the markets. The structure effect contributed a minor share towards negative energy efficiency. The intensity effect on the other hand proved to contribute towards positive energy efficiency which could be attributed to improvements in energy efficiency, and although the structure and intensity effects proved to contribute towards positive energy efficiency, the activity effect was still deemed to be apparent.

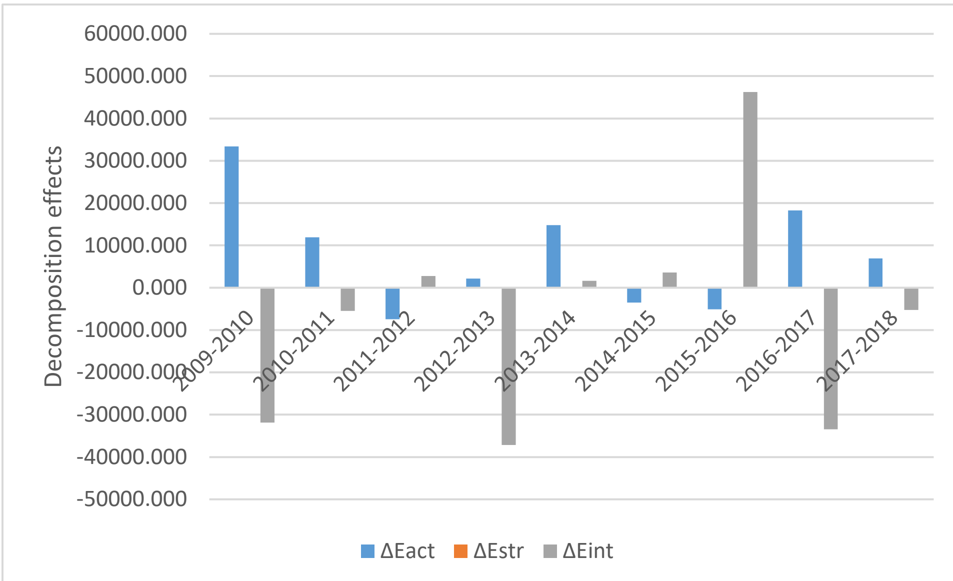

Figure 4.2: Decomposed activity, structure and intensity effects

From figure 4.1 and figure 4.2 the LMDI additive decomposition results show that between 2011 and 2012 there was a strong change in energy consumption for Manufacture A. The total change in energy consumption saw a reduction by 4740.48 MWh. The activity effect contributed strongly towards positive energy efficiency which could be attributed to producing more units with a low energy consumption rate. The structure effect contributed towards the positive energy efficiency. The intensity effect contributed a fair share towards the overall growth in energy consumption. This was attributed to poor management of energy efficiencies.

For the period 2012-2013, figure 4.14 and figure 4.15 present the LMDI additive decomposition results which show that there was a massive change in energy consumption for Manufacturer A. The total change in energy consumption saw a decrease of 34966.3 MWh. The activity effect had a negligible impact on the overall change in energy consumption; this effect contributed to a slow growth in energy consumption. This could be attributed to the increase in production outputs reacting to demand increment in the markets, more specifically the PAS vehicle market as outputs increased. The structure effect contributed to a certain extent towards an improvement in positive energy efficiency which could be as a result of moving towards a lesser energy intensive composition. Lastly, the intensity effect was deemed to have contributed towards positive energy efficiency which could be attributed to improvements in energy efficiency, and although the structure and intensity effects proved to have contributed towards positive energy efficiency, the intensity effect was deemed to be the most apparent, which was a sign of a sectoral improvement in positive energy efficiency.

As for the period 2013-2014, figure 4.1 and figure 4.2 presenting the LMDI additive decomposition results show a major shift change in energy consumption for Manufacturer A compared to the previous period. The total change in energy consumption saw an increment of 16451.5 MWh as opposed to the decrease seen in the previous period. The activity effect proved to be the most apparent. This effect showed an overall growth in energy consumption and this was attributed to the increase in production outputs reacting to demand increment in the markets; however, as the demand increased the energy efficiency decreased as a result of poor control. The structure effect outlook also contributed towards negative energy efficiency which was a result of a shift towards a more energy intensive production composition. In addition to the increment contribution by the activity effect, the intensity effect contributed a negligible increment which could be attributed to poor energy efficiencies by Manufacturer A.

The LMDI additive decomposition results show that for the period 2014-2015 as presented in figure 4.1 and figure 4.2 there was a fair change in energy consumption for Manufacturer A similar to the previous period. The total change in energy consumption saw a minor increment of 77.8346 MWh. The activity effect contributed slightly towards positive energy efficiency which could be attributed to producing more units with a low energy consumption rate. This could be attributed to the increase in production outputs reacting to demand increment in the markets; however, looking at the increment rate of energy consumption in comparison to the output growth rate, it showed improvements in energy efficiency. The structure effect made a negligible contribution towards a growth in energy consumption. In addition to this, the intensity effect contributed slightly towards a continued growth in energy consumption as a result of poor energy efficiency management.

Similar to the previous period, the LMDI additive decomposition results show that for the period 2015-2016 as presented in figure 4.1 and figure 4.2 there was a strong change in energy consumption for Manufacturer A. The total change in energy consumption saw an increment of 41217.2 MWh. The activity effect contributed slightly towards positive energy efficiency, which could be attributed to a low energy intensive production mix; however, this could be more attributed to the production composition, hence the structure effect made a significant contribution towards an improvement in energy efficiency due to an energy-efficient focused composition. However, the intensity effect was most apparent and thus contributed towards a growth in energy consumption and this was as a result of poor sectoral energy efficiency management.

Lastly for the periods 2016-2017 and 2017-2018, figure 4.1 and figure 4.2 present the LMDI additive decomposition results which show that there was a positive change in energy consumption for Manufacturer A. The total change in energy consumption saw a decrease of 15204 MWh and an increase of 1715.88 MWh between 2017 and 2018. For the period 2016-2017, the activity effect contributed significantly towards a growth in energy consumption; similarly, for the period 2017-2018 a contribution towards energy consumption could be noticed.

The structure effect for these periods justifies why the overall outlook indicated a decrease in energy consumption. A shift towards a much lesser energy intensive composition is one of the reasons why we have a drop in energy consumption, and in addition to this, the intensity effect further emphasizes the drop, showing an improvement in energy efficiency management and most likely a shift towards more energy efficient technology.

Figure 4.3 summarizes the factors responsible for energy consumption for the period 2009-2018. The LMDI decomposition results show that the total change in energy consumption for the period 2009 to 2018 increased by 12540.2613 MWh. For activity effect, changes in the level of activity between 2009-2010, 2013-2014 and 2016-2017 were considered to have had a substantial impact. If the intensity and share of Manufacturer A were kept unchanged in value in addition to using the initial year values, and implying that if the activity effect alone would have changed, the energy demand for Manufacturer A's activities would be considered to have increased by 71406.422 MWh.

For the structure effect, the structural change within the period is considered while the intensity and share are left unchanged. This suggests that the share of Manufacturer A's activities in the industrial output had declined and if only this had changed, the energy demand would have increased by a minimal 13.999 MWh, for the intensity effect, we looked at the changes in energy intensity within the period under investigation and kept the other two factors at their initial values. This suggested that the intensity of Manufacturer A had decreased and their intensity would have also reduced the energy demand by 58880.160 MWh between 2009 and 2018 if other things did not change. Therefore, it could be concluded that from the period under investigation, the total energy demand had increased, which implied that energy efficiency had not been effectively practiced.

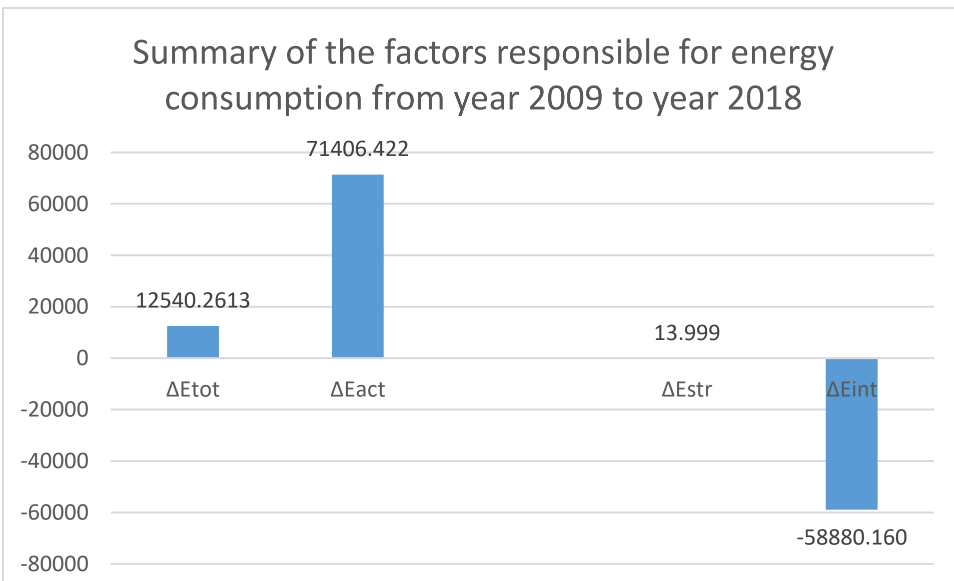

Figure 4.3: Summary of factors responsible for energy consumption

Figure 4.4 outlines the energy consumption per unit of all four vehicle sizes, and the one thing that stands out is that the energy consumption per vehicle stays constant across all classes regardless of the size of the vehicle which then justifies that it is cheaper to produce more LCVs as opposed to PAS vehicles.

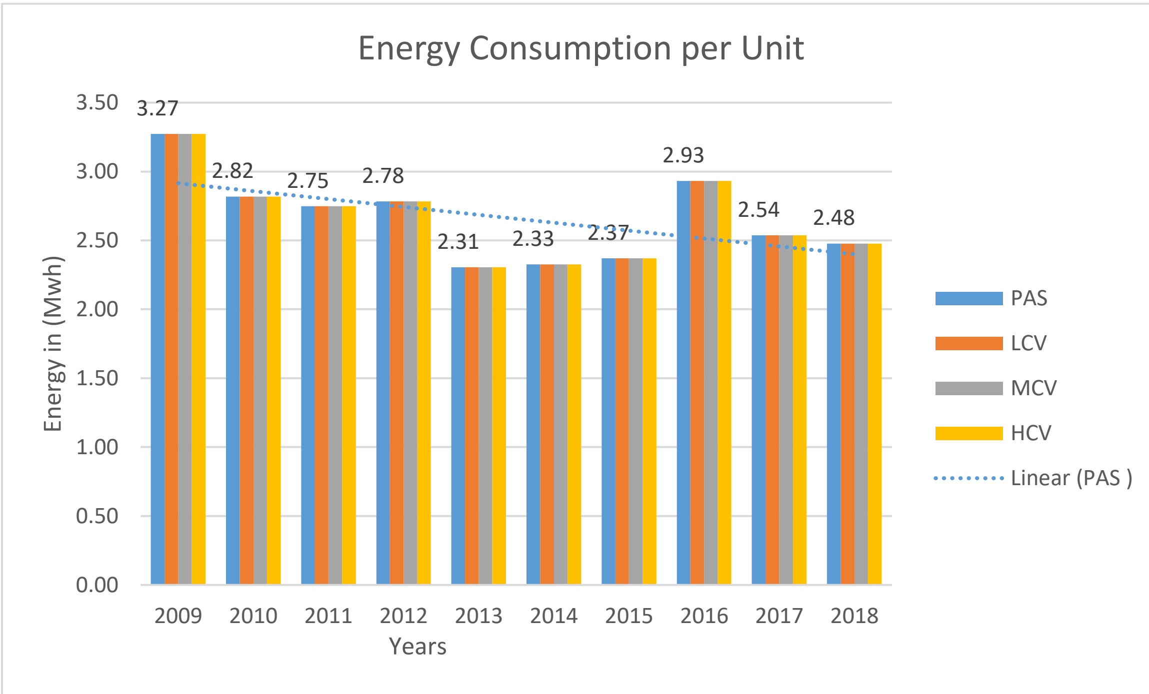

Figure 4.4: Energy consumption per unit

Figure 4.4 further shows us that although the total energy consumption increases with the GDP, the energy consumption per unit follows a decreasing trend therefore Manufacturer A is making an attempt to improve their energy efficiencies; however, there is still more room for improvement in order to realise more energy savings.

Figure 4.1 presents the overall decomposed total energy consumption for the period of study. Two distinct spikes were noticed, namely, that for the year 2012-2013, a sharp drop in energy consumption was observed and for the year 2015-2016, a sharp increase in energy consumption was observed. Capozzi (2009) explained that when a new vehicle was introduced, it went through four stages: introduction, growth, maturity and decline which were known as a vehicle’s product life cycle. The two spikes discussed above are as a result of one of these four stages.

The stage being discussed specifically in this case is the decline stage, where the market experiences a drop in interest in the product due to the introduction of newer or more advanced products by competitors; hence the drop in energy consumption, which is a ripple effect of the drop in production output as presented in table 4.2 in chapter 4.

To counteract the drop in demand that competitor companies capitalize on, there was an increase in marketing, a facelift of models to make them look modern, prices were slashed and discounts were offered. As a result, the demand again increased, which saw a sharp increase in energy consumption. Thus, the production output also increased.

4.1.2 Conclusion

This research outlined the energy consumption differences between different vehicle classes and it was noted that LCV vehicles consumed the most energy due to high production volumes. However, it has an energy consumption equivalent to all the other vehicle classes. In addition, it was observed that the activity effect led to an overall increase in energy consumption for Manufacturer A.

Manufacturer A depended on two types of energy sources namely, electricity and gas. Figure 4.5 outlines the annual energy consumption by source and it can be observed that an average of 410 542 GJ of electricity was consumed and an average of 352 148 of gas was consumed. Referring to *STAR* (2015), it could therefore classify Manufacturer A as a medium to large plant based on the average annual electricity consumed.

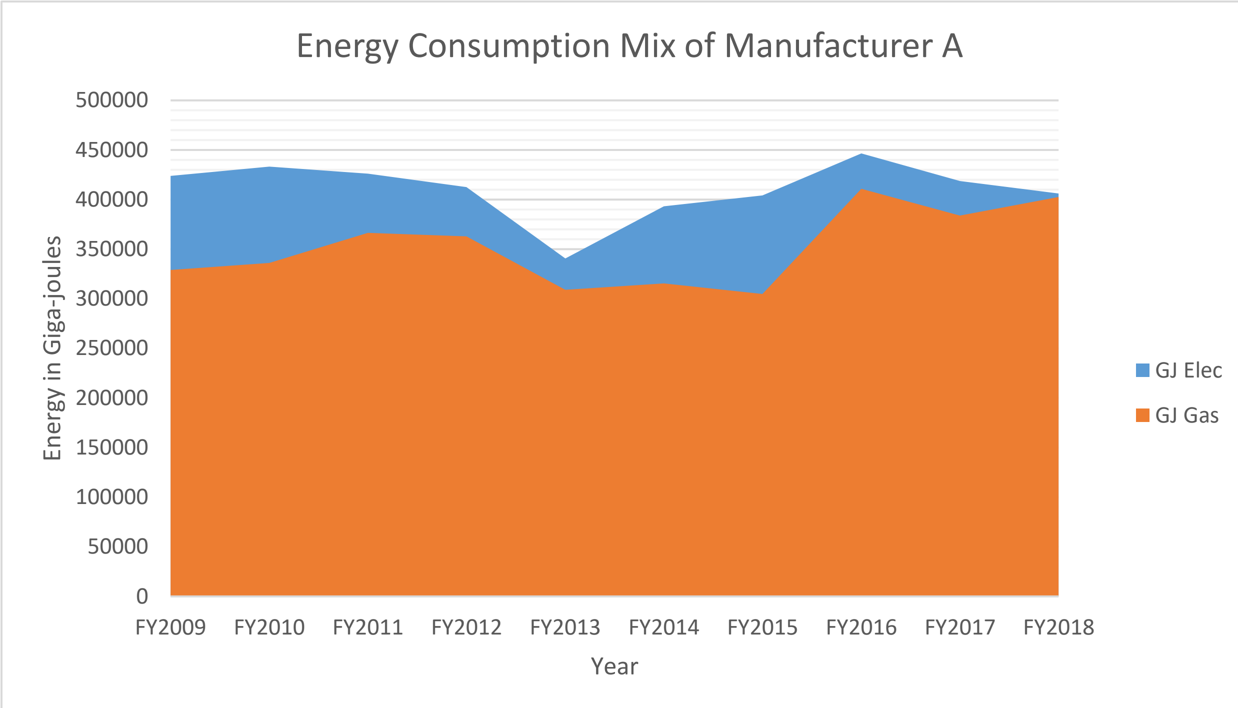

Figure 4.5: Total energy consumption for Manufacturer A in GJ

Figure 4.6 presents Manufacturer A's energy distribution and it can be seen that electricity was the highest energy cost, therefore it would be ideal for Manufacturer A to consider becoming an supplier which would add renewable energy as part of its energy mix.

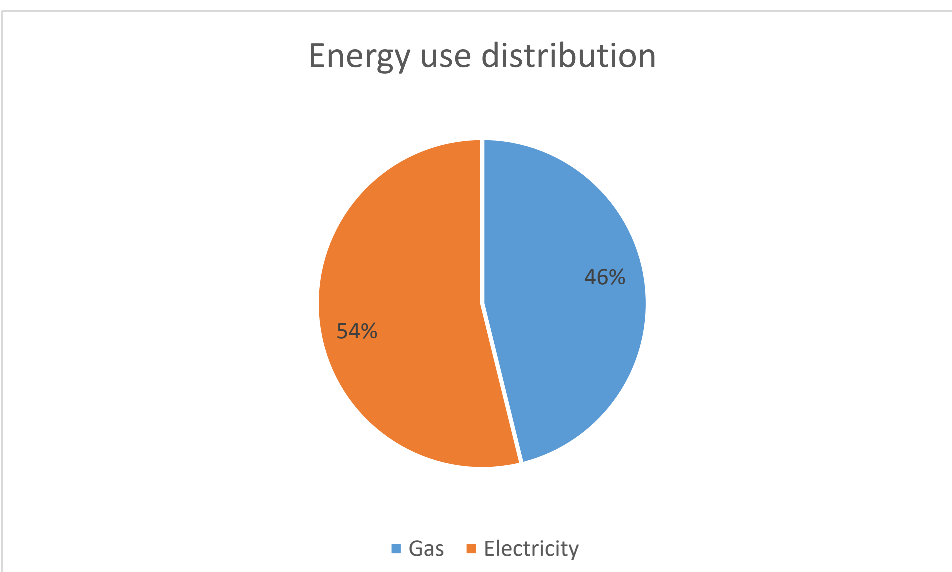

Figure 4.6: Energy use distribution of Manufacturer A

Chapter 5

5.1 Discussion, Conclusion and Recommendations

5.1.1 Discussion & Conclusion

Chapter 4 applied LMDI to the gathered data leading to the result generated. This chapter concludes the study and makes recommendations based on the findings of this study. This chapter reports on how the findings met the objectives and aims of the study, how the research questions were answered and makes recommendations for future studies and gives the conclusion of the study.

A case study was used with the aim of meeting the research objectives. The case study was based on Manufacturer A located in South Africa. Manufacturer A was selected on the basis that they are one of the top five producers of motor vehicles in South Africa. The study divided Manufacturer A's products (vehicles) into four vehicle class categories namely:

- Passenger vehicle (PAS)
- Light commercial vehicle (LCV)
- Medium commercial vehicle (MCV)
- Heavy commercial vehicle (HCV).

Based on the size and usage of the vehicles, the study looked at the production/sales output of each vehicle class to determine the contribution each class made towards the GDP. LCV class has the highest output followed by PAS, MCV and HCV. Similarly, the study looked at the energy consumption of each vehicle class to find out which of the four categories consumed the most energy, it is clear that the LCV category consumed the most energy for the period covered in the study, and this may seem to contradict the case raised by Worrell (2018) who said that LCVs consumed less energy than PAS vehicles during production. However, this is not the case because of the volumes produced for each of these respective models.

5.1.2 Recommendations

Based on the research findings it is therefore recommended that Manufacturer A invests in a renewable energy plant as benchmarked from Communications (2015), which discussed that BMW South Africa's Rosslyn plant built a Bio2Watt biogas plant which was responsible for supplying 25-30% of its electricity. In addition to this, it is recommended that Manufacturer A increases its energy efficiency KPAs by employing more operational and behavioral strategies focused on shifts, weekend and public holiday shut down practices, and focuses on compressed air use and leaks.

Tekkaya (2018) presented various methods of saving energy through manufacturing technology. This research has outlined methods such as load-adjusting and the use of light-weight materials where possible. Similarly, Worrell (2018) went into more detail by assessing the energy consumption of each process involved in vehicle assembly and the possible energy saving opportunities available in vehicle assembly plants.

Further research on the automotive industry moving towards auto-generating renewable energy to compensate for its own energy use is needed to understand its viability in this sector as a whole.

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