Econ 399-17 LNG Project – Techno-Economic Analysis of Energy in the Western Cape Transport Sector:

Report 1 of 3

Detailed Statistical Annex and Supporting Report for Focus Area A – Transport Demand Analysis

FINAL REPORT

Report prepared for
The Department of Economic Development, Western Cape Provincial Government

December 2019

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Acronyms & Abbreviations

ACSA: Airports Company of South Africa

BEV: Battery Electric Vehicle

CAGR: Compound Annual Growth Rate

CHP: Combined Heat & Power (electricity generation with heat recovery from the exhaust)

GDPR: Regional Gross Domestic Product

GVM: Gross Vehicle Mass

HCV: Heavy Commercial Vehicle (> 7 t GVM)

ICE: Internal Combustion Engine (conventional petrol and diesel technology)

LCV: Light Commercial Vehicle (< 3.5 t GVM)

LPG: Liquid Petroleum Gas

MCV: Medium Commercial Vehicle (3.5 – 7 t GVM)

PJ: PetaJoules - 10^{15} Joules of Energy

SAT: South African Tourism

Stats SA: Statistics South Africa

WCG: Western Cape Government

tkm: tonne.kilometres of freight demand

btkm: billion tonne.kilometres of freight demand

pkm: passenger.kilometres of passenger transport demand

bpkm: billion passenger.kilometres of passenger transport demand

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Department of Logistics, University of Stellenbosch, Bob Stewart of PetroLogistics, Julie Womack of the Tourist Guide Institute and Venasan Pillay of Chevron Corporation. **The authors are solely responsible for the accuracy of the content and the views expressed in the report.**

Executive Summary

The Western Cape Government (WCG) commissioned a desktop study to provide an overview of the Western Cape transport and fuel supply sectors, to assess the potential for technology disruption and, in that context, assess the potential for natural gas uptake in the transport sector. The Terms of Reference were broken down into the following work-streams undertaken by the indicated parties.

Project Terms of Reference and Responsible Organisations and Persons

Task / Focus Area	Lead Organisation	Lead Author/s
Focus Area A: Demand Analysis – Breakdown of transport fuels by volume, passenger and freight and economic sector	Sustainable Energy Africa (SEA)	Adrian Stone
Focus Area B: Supply Analysis – Quantify the current sources of liquid and gas petroleum fuels	CAPIC	Jurgens Kühl
Focus Area C: Disruptive Technology Intervention – Assess the potential impacts of disruptive transport technologies on a ten-year view including the availability of natural gas	eScience (project lead)	Theo Fischer and Malin Govender
Focus Area D: Socio-Economic implications – Analysis of the balance of benefits and externality costs of the current transport system, economically and environmentally	Prevision	Dr Daniel Marais
Focus Area E: Investment Risk Analysis – Document review and analysis of risks associated with significant investment into improving the sustainability of the transport system	CAPIC	Jurgens Kühl

The outputs from the study are described in three separate reports:

1. Report 1 - Detailed Statistical Annex and Supporting Report for Focus Area A – Transport Demand Analysis (this document)
2. Report 2 – Focus Areas B-E, Findings & Recommended Actions
3. Report 3 – The Summary Report

This has been done as the Scope of the Terms of Reference was extensive and generated a great deal of information. The statistical annex in particular includes a great deal of detail which was best incorporated in a separate report for Focus Area A of the Terms of Reference.

In practice, all parties collaborated across the focus areas to varying degrees and the partnering organisations and authors take collective responsibility for errors not dealt with before final release as well as errors in judgement that future developments might expose.

Study Objectives

The overall project objectives as determined in discussion with the client were as follows:

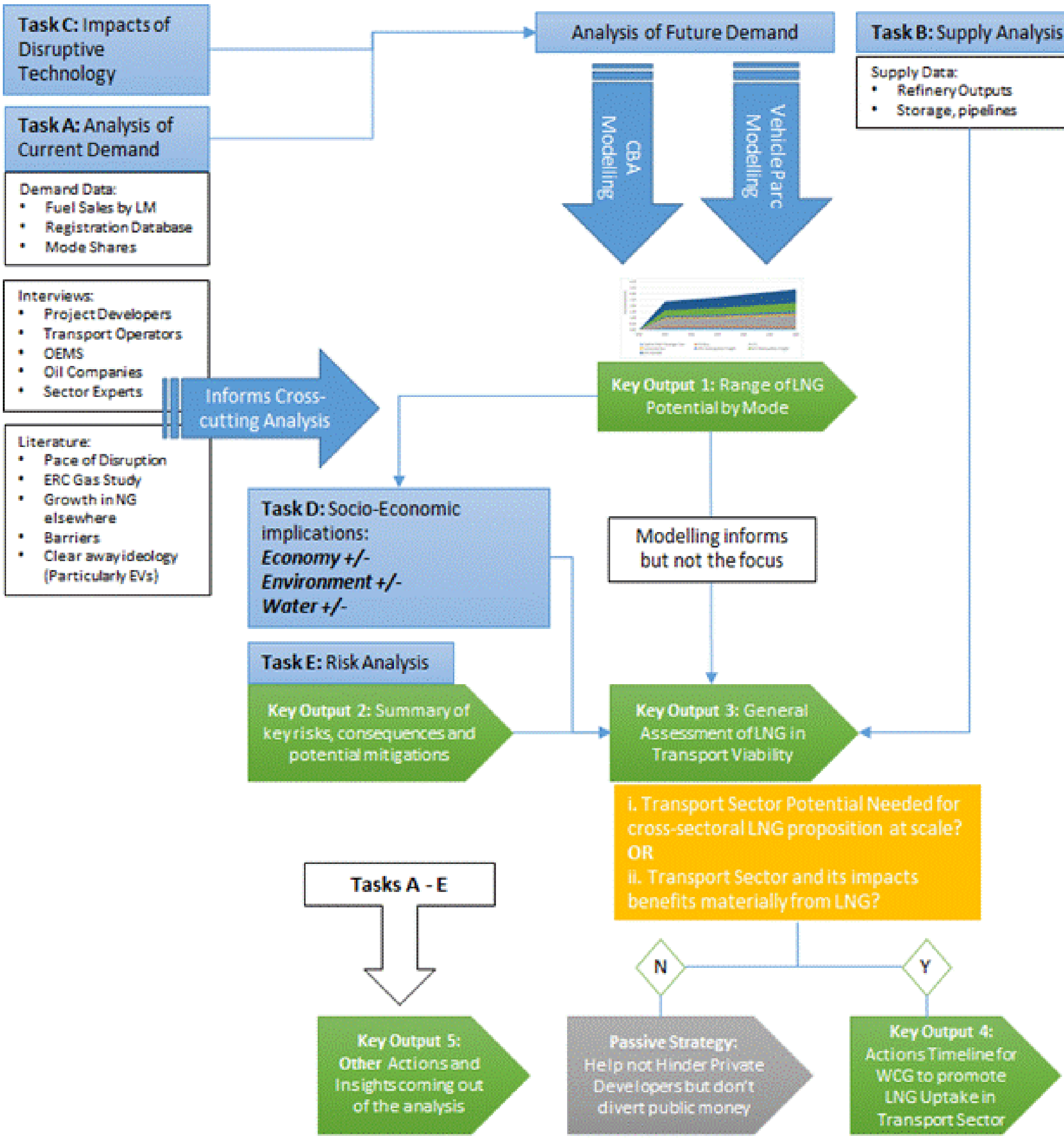
- Sketch the landscape of Transport Sector demand in the province and where possible in its district and local municipalities as well as the supply system that meets this demand for mostly liquid petroleum fuels.
- Assess the potential for disruption of demand and supply.

- In the context of the above assess the potential for natural gas uptake in transport, evaluating potential socio-economic impacts and risks arising from this.
- While modelling was strongly emphasised in the proposal, actions not modelling should be the focus of the investigation. The approach should in this way assist the Western Cape Government (WCG) to articulate their commitment to future investments in the transport fuels sector modulating the level of effort relative to their overall economic impact.
- Propose actions that explore to what extent fuel substitution by natural gas (in all its forms) could be meaningful.
- Also highlight any other issues of economic or environmental importance for the Western Cape Province arising from the investigation.

High Level Methodology & Outputs

At a high level the project team combined the tasks in the Terms of Reference together to achieve the project objectives as shown in the figure below, defining Key Outputs (green blocks) as concrete deliverables aligned to the objectives as follows:

- Key Output 1: An estimate of potential demand for natural gas as a transport fuel by mode.
- Key Output 2: A summary of key risks in the supply of transport fuels, consequences and potential mitigations.
- Key Output 3: A general assessment of the viability of natural gas uptake in the Western cape transport sector
- Key Output 4: An Actions Timeline for the Western Cape to stimulate natural gas uptake in the Transport Sector
- Key Output 5: Other Actions and Insights coming out of the analysis



High Level Project Methodology – Combining Tasks to Achieve Objectives

Actions were prioritised by the Western Cape Government and so Key Outputs 4 and 5 above can be considered the primary outcomes of the study. Key Output 4 the actions proposed to promote LNG uptake in transport in the Western Cape were however seen as contingent on either of the two criteria shown in the orange box above as follows:

i. The transport potential identified in Key Output 1 is needed for a viable LNG import contract so that natural gas is available across sectors

ii. The transport sector, transport fuels supply and their impacts are considered to benefit materially from LNG uptake.

The approach was to add to the picture sketched by the cross-cutting interviews and literature with a richer local view from the 5 focus areas and then tie up the opinion and evidence into an overall conclusion (Key Output 3). This conclusion would inform a decision on whether either of the two criteria above are satisfied and based on that outcome to follow either of the following two strategies:

1. In the case of neither criteria being met follow a passive strategy (grey box above) whereby project developers and the market are supported but significant public money is not diverted and neither is an active program drawing on WCG staff devised.
2. An active strategy that seeks to support market development through a program of actions over time

Report Layout

This report documents Task A of the Terms of Reference, the demand analysis, which defined a wide range of transport, energy and economic statistics as deliverables. These were required to define the parameters of the transport landscape in the Western Cape that faces potential disruption and offers potential for natural gas substitution. An extensive data collection exercise supported by modelling informed the detailed statistical annex presented in Appendix A which forms a substantive deliverable of this task that has uses and relevance beyond this project.

As shown above Task A is the main input to Key Output 1, the transport sector demand potential for natural gas in the Western Cape. This Key Output is therefore the primary finding presented in this report. The demand analysis also generated important insights informing Key Outputs 3 and 5 and so these findings are reported in their own sub-sections. Tasks B – E and key outputs 2 and 4 are documented in Report 2.

Timeframes

Work on this study commenced in April 2018 with the first research, interviews and model development taking place over the ensuing 6 months. A presentation set was prepared at the end of September 2018 detailing the initial findings and formally presented. The process of revisions and formal reporting was completed in February 2019.

Key Assumptions

Each task involved many assumptions which are explained in the relevant sections of the two reports. The following key assumptions however informed the overall findings and thinking of the study:

- That growth in natural gas production will continue to grow regionally and globally on a ten year view and that extreme climate events won't induce drastic co-ordinated global curtailment of all fossil fuels including natural gas other than for peaking electrical power supporting renewable.
- That local regulatory barriers can be cleared within 2 years such that generally favourable natural gas prices arising from new global sources can still be leveraged.
- That Nigeria will not be a supplier of an LNG contract with the Western Cape in which case very high fugitive methane emissions in the supply chain would mean a high social cost to fuel substitution due to 'wells-to-wheels' environmental damage costs.
- That the PetroSA refinery in Mossel Bay will likely close due to a lack of a local gas supply but that a continued glut in global refining capacity will readily supply refined product and competitive prices to meet demand and growth in demand.
- That port infrastructure will readily expand to meet refined product import needs and that the growth in independent dealers supported by government competition and BEE policy will support this.
- That battery electric vehicles will likely come to dominate the passenger car market in the medium to long term due to the fact that the technology is mature, is being globally heavily incentivised and that it can leverage the existing electricity distribution network.
- That electro-mobility technology like fuel cells and fuel cell battery hybrids will be slower to offer commercial solutions in the heavy-duty space, particularly long haul articulated trucks, opening

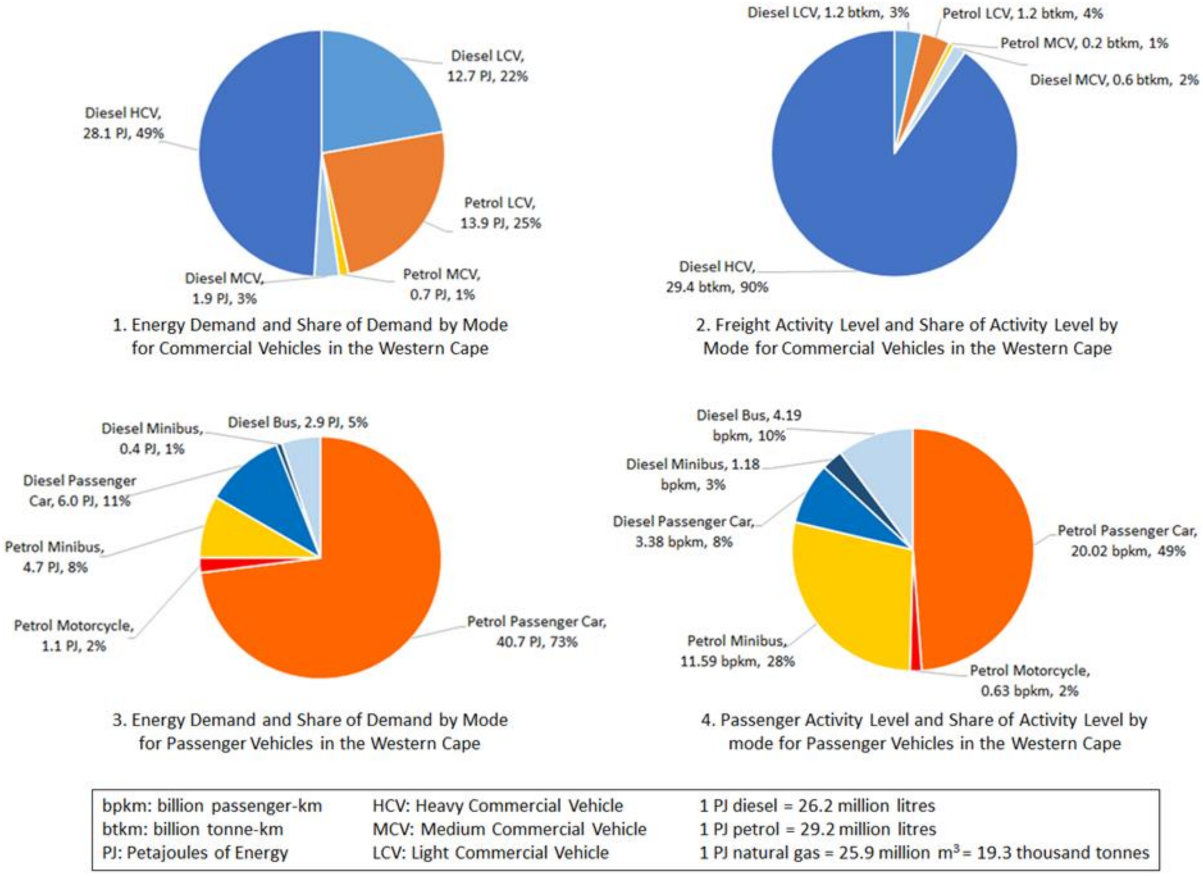
up a potential opportunity for natural gas as a transport fuel over the window required to amortise LNG terminal and regasification infrastructure.

Demand Picture

A detailed picture of energy demand and activity by transport mode and fuel was produced for the Western Cape and is presented in the Statistical Abstract in Appendix A. A summary view is shown in the four charts below. In general, passenger transport energy demand is strongly dominated by private passenger cars and freight by heavy commercial vehicles operating on corridors, in particular the N1 highway.

Three quarters of road transport passenger transport energy demand in the Western Cape is consumed by passenger cars (Chart 3 below) but they supply just under half of the supply of passenger.km (Chart 4). Petrol fuelled minibus taxis, by contrast, are the biggest providers of public transport but use a relatively modest amount of energy being about five times more efficient than passenger cars in moving people. The activity level plotted in Chart 4 below is calculated as the product of the assumed mileage of a mode and the assumed average occupancy (passengers per vehicle). The mileage is far more certain than occupancy and can also be checked by calibrating a model that balances the number of vehicles with the fuel consumed. The activity outcomes in Chart 4 are outputs of the model described in Appendix B2 and are highly sensitive to the assumed occupancies of the modes which are drawn from various sources (Stone, Maseela, & Merven, 2018) (Kane, 2017) (SEA, 2015).

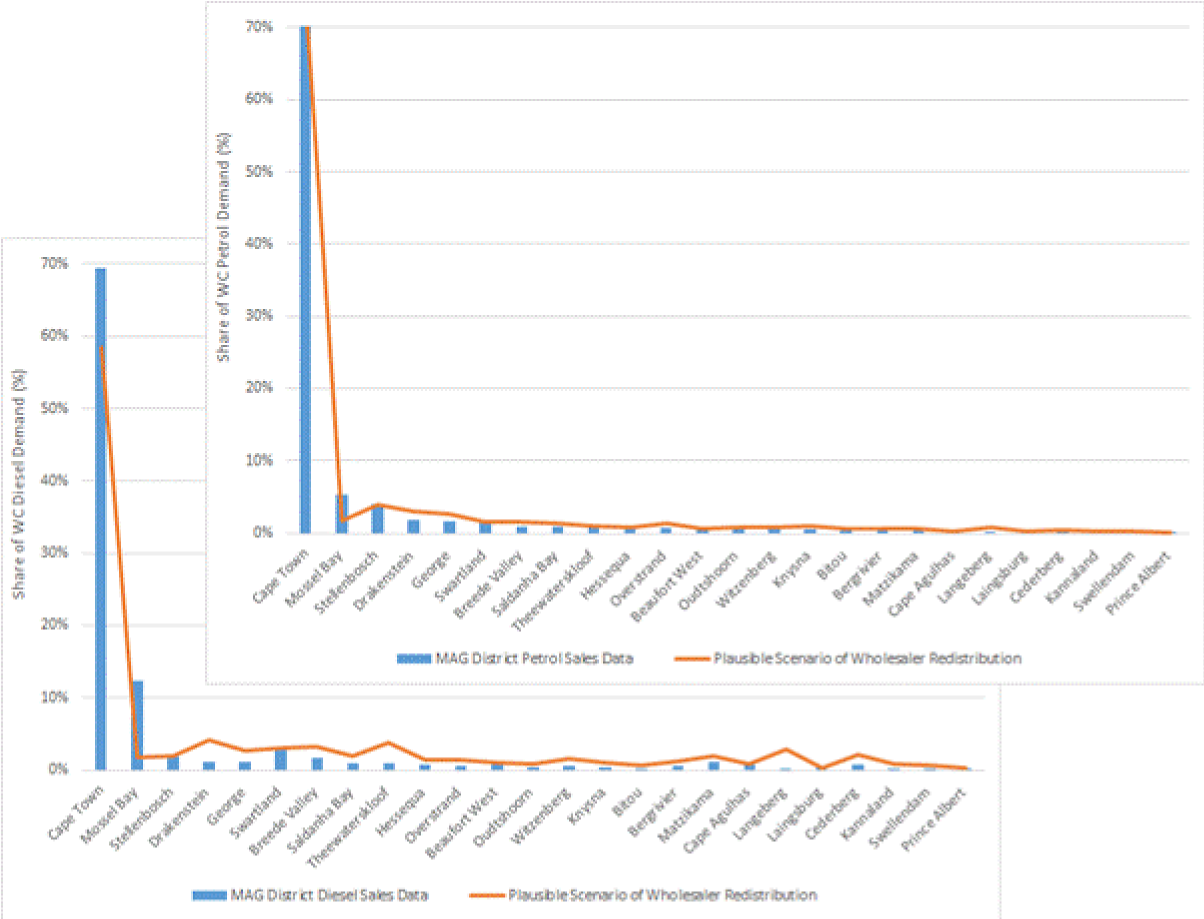
For commercial vehicles, around three quarters of energy demand is for diesel, and the remaining quarter is petrol (Chart 1 below). Diesel fuelled Heavy Commercial Vehicles (HCV) account for around half of freight energy demand while demand from petrol and diesel LCVs are around a quarter each even though they don't move a high share of ton.km (Chart 2) due to shorter trip distances. This is because their energy intensity (MJ/tkm) is around 5 to 10 times higher than an HCV depending on operating conditions. The activity level plotted in Chart 2 below is calculated as the product of the assumed mileage of a mode and the assumed average load factor (tonnes per vehicle). The load factor assumptions can be viewed as more certain than passenger mode occupancies because they are based on an exercise that calibrated a vehicle parc model with detailed HCV sub-categories with the tonne-km activity level published in the Logistics Barometer of the University of Stellenbosch, Department of Logistics (Stone, Maseela, & Merven, 2018) (Havenga J. , Simpson, de Bod, & Braun, 2016)



Overview of energy demand and activity by mode and fuel for the Western Cape 2016[1]

The City of Cape Town Metropolitan municipality dominates both petrol and diesel demand even allowing for volumes that are likely redistributed to other municipalities as shown below.

[1] Source: Author's calculations using model described in Appendix B2 based on data from (eNatis, Accessed 2018) and (DOE, 2018)



The Highly Pareto Distribution of Liquid Fuels Between Municipalities in the Western Cape

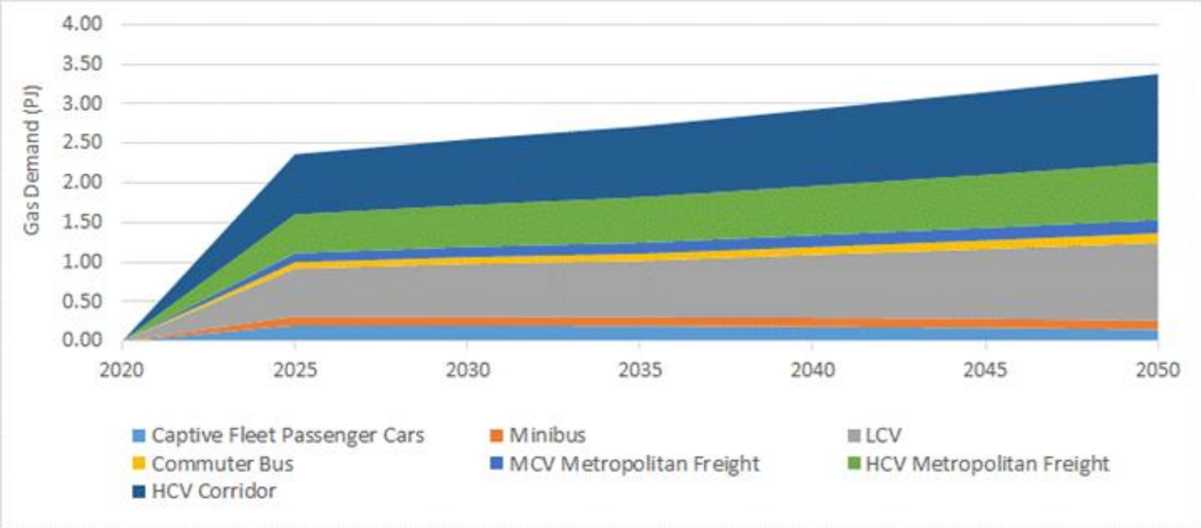
Key Output 1 - An Estimate of the Range of Natural Gas Potential by Mode

The ranges of potential natural gas market penetration by mode were combined with the base case projections of the vehicle parc described in Appendix C to build-up upper and lower outcomes for natural gas uptake in energy terms into the future from the contributions of each mode. The results are presented below in the two stacked area graphs. These are combined into a range, shown in tyen following line graph into which, in the opinion of the consultants, the demand from the transport sector will probably fall given a natural gas supply at scale. The uncertainties are viewed as large and the value of this exercise is seen as developing a plausible range of what the transport sector could contribute to a natural gas energy economy in the Western Cape.

The dotted line shown in the range diagram shows one of many possible pathways. By way of example, a possible storyline for that pathway would be a delayed ramp up in demand due to infrastructure development but then successful market development in one or more modes with quite rapid curtailment nearing 2050 due to aggressive global action against climate change and competing electro-mobility technologies in the heavy-duty modes. The intention of this exercise is not however to develop such scenarios because currently there is not enough information to give one precedence over another. Rather the point is to convey a sense of scale of both the potential uptake and its uncertainty as well as the drivers of a low or high pathway. The following are important features of the upper and lower limits.

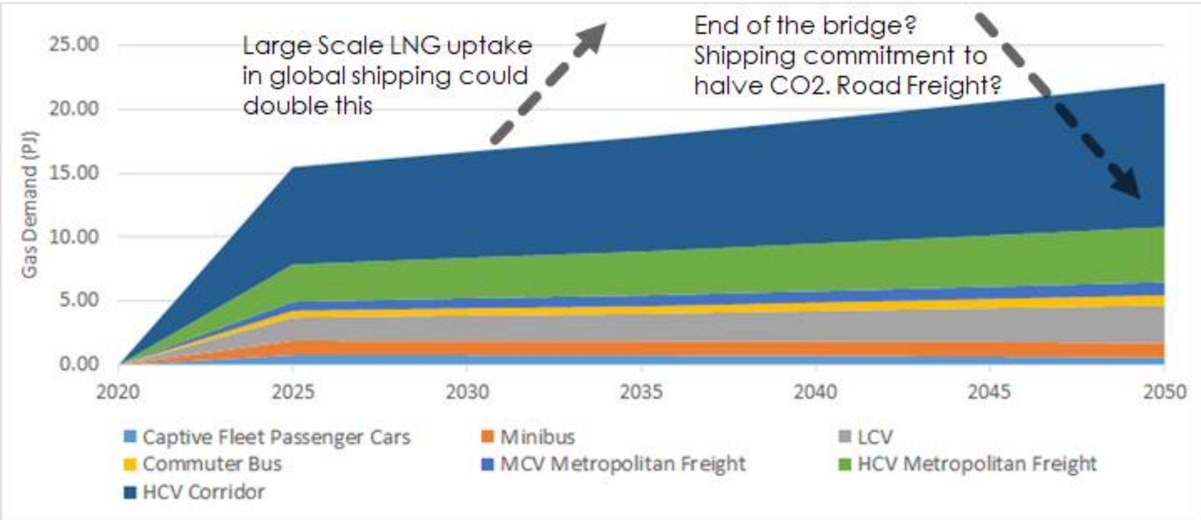
- They have been calculated by multiplying the percentage penetration ranges estimated in Section 9 above by the relevant mode demand (e.g. Petrol LCV but not Diesel LCV) as projected by the vehicle parc model (see Appendix C6) for each year of the projection. This converts the percentage penetration into a demand for energy.

- In Section 9 above the primary considerations in deriving an estimated potential were economic feasibility of that mode given a range of typical price differentials between natural gas and petroleum fuels, infrastructure demands for that mode and any institutional barriers. The final numbers were therefore the result of expert opinion after review of both quantitative and qualitative data. The upper and lower limits in energy units presented below should be understood in the same way.
- A range is proposed not only to reflect large uncertainties such as price and competition from other new technologies but also the level of active market development by both public and private sectors. The following storylines illustrate the drivers of an outcome tending either to the upper or lower limits:
    - In the short and medium term, given that a bulk LNG supply is present and if natural gas remains cheaper than petrol or diesel, the outcome will plausibly tend towards the upper end of the range with active market development, favourable policy and the debottlenecking of approvals and licenses. The availability of heavy-duty truck models in South Africa at premiums no higher than the parent markets is also extremely key to this outcome and the co-operation of the OEMs in this regard should not be assumed.
    - Low oil prices relative to gas, failure of stakeholders to work together and regulatory gatekeeping will skew outcomes to the lower end. Given the pivotal role of heavy commercial demand, the realisation of competitive pressure from alternatives such as battery electric vehicles, fuel cell vehicles, fuel cell-battery electric hybrids and catenaries would make the lower demand scenario more likely. The risk of this is far higher after 2030.
    - The upward sloping dotted arrow in the upper range stacked area diagram below illustrates the possible, but at this stage highly uncertain, additional potential uptake of natural gas by marine bunkering discussed in detail in Appendix H. The findings of this section draw the following conclusion, "*A potential of 20 - 50 PJ on a 20 - 30-year view may not be unreasonable depending on the rate of LNG penetration into the global shipping fleet.*" This has not been added as a wedge on the basis that it can be considered to balance the risk of fuel cells and/or battery technologies displacing gains in gas penetration after 2030.
    - The downward sloping dotted arrow serves as a warning of the often quoted idea of natural gas being a bridge fuel to a low or zero carbon future. The marine bunkering demand is especially susceptible to a hard end to this bridge because it is driven purely by international markets over which local policy exercises no control. Beyond the MARPOL sulphur regulations, the International Maritime Organisation (IMO) has committed the shipping industry to reduce its CO_2 emissions by half by 2050 (Gabbatiss, 2018) (Murphy, 2018)
- The ramp up of demand between 2020 and 2025 is similarly not deterministic and is premised simply on gas becoming available in 2020, possibly only at small scale with the supply maturing until 2025 to the point of an LNG terminal with associated transmission and distribution infrastructure being in place. The range of penetration rates presented in Section 9 are applied from 2025 onwards and interpolated between 2020 and 2025 assuming zero uptake in 2020.



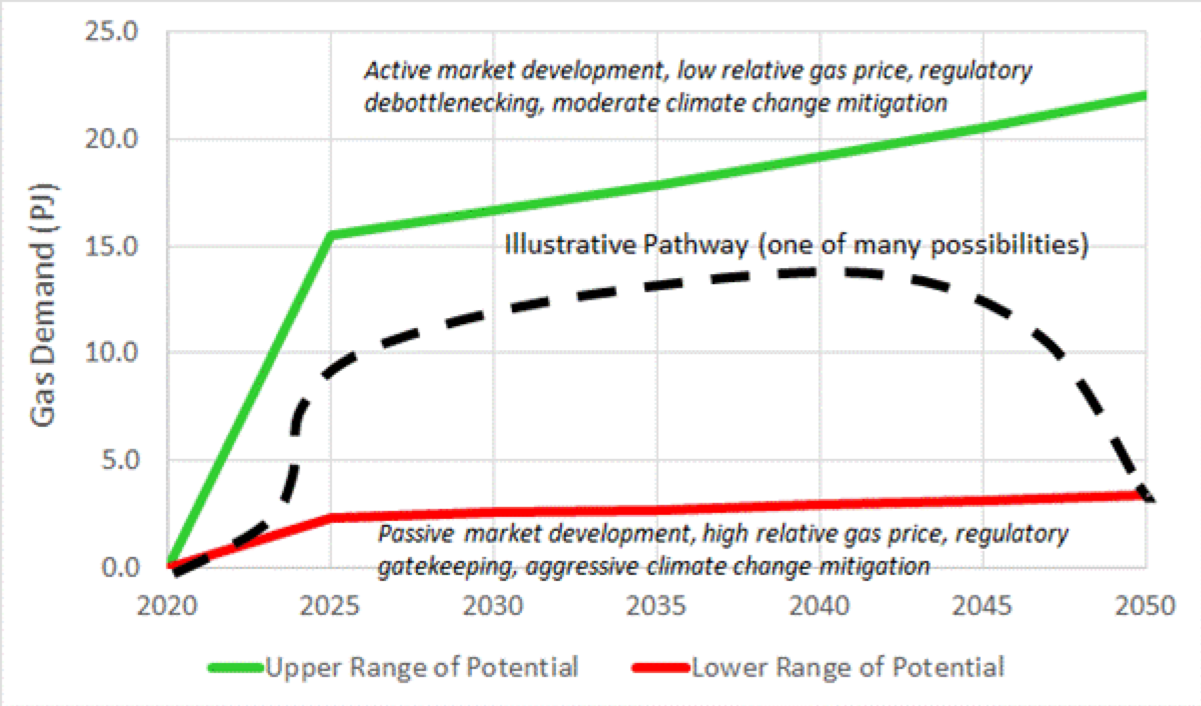
Note: See Figure C- 19 for data table

Build-up of Lower Natural Gas Uptake Estimate (Moderate oil price and Moderate Gas Price but enough differential for CNG retrofits and bulk LNG; inactive Market Development)



Note: See Figure C- 20 for data table

Build-up of Upper Gas Uptake Estimate (High oil price and Low gas Price; Highly Active Market Development)



Combination of Upper and Lower Potential Estimates into a Probable Range of Natural Gas Uptake by the Transport Sector

The purpose of considering these numbers, as perceived by the project team, is to act to realise them should a bulk LNG supply project need this demand to be more economically viable. While the project team may not necessarily start from the viewpoint that natural gas is beneficial to the transport sector on a stand-alone basis, there appears to be a strong case that an LNG supply is positive for the provincial economy in general.

In the longer term, the outcomes of the electro-mobility disruption, including the emergence of cost competitive hydrogen fuel cells for heavy duty applications, and the aggression with which climate change mitigation may be pursued globally are the largest uncertainties. There is however a reasonable possibility that marine bunkering supply could fill the gap of a shift to electro-mobility in the heavy duty truck space in the medium term.

Findings

Findings Relating to Key Output 3: General Assessment of the Viability of Natural Gas Uptake in the Transport Sector

The Western Cape economy, in common with the rest of South Africa has a freight intensive economy with goods concentrated on corridors, in particular the N1 which accounts for over 50% of total tonne-km of freight activity in the province (see Table A- 23) Metropolitan distribution with heavier vehicles accounts for about 5% of tonne-km due to shorter trip distance. This concentration on corridors and the scale of logistics companies that have developed to provide freight services in this environment, provide the largest opportunity for liquid fuel substitution by natural gas

The statistics suggest that most current corridor fuelling actually happens in Cape Town[2] and so a corridor gas fuelling station would likely only need one refuelling point in the case of LNG trucks.

[2] Caution needs to be exercised with this evidence. If independent wholesalers based in Cape Town were supplying most of the diesel to, for example, Beaufort West, the DoE statistics would not reveal this. Technically however typical long-haul articulated trucks have sufficient range to not have to refuel between Cape Town and Gauteng.

Current models have claimed ranges of 1000 km (Volvo FH LNG and FM LNG) to 1600 km (Iveco Strialis – see Appendix E), the latter comparable to diesel truck ranges. CNG trucks having much lower range, are more suited to local (intra-metropole) freight distribution (see Appendix D2 for detail). An LNG refuelling station would need to be within 1000 km of both Cape Town and Gauteng (vicinity of Colesburg) and near the railway line so that LNG supply could be railed.

The Food and Beverages manufacturing sector is highly freight intensive and an important exporter of goods to Gauteng and provider of employment growth. This sector could be a key target for market stimulation of natural gas fuel switching or shifting to rail where viable.

The substitution of petrol by CNG offers significantly better paybacks than diesel because its cost per unit energy is higher. Retro-fit technology is also cheap and typically pays back in a year or two for most price scenarios. Captive petrol fleets exist in the minibus taxi industry and in LCV applications like courier companies.

There are current pilots in the metropolitan freight space but CNG paybacks don't seem attractive unless prices are very favourable and the fuel is not taxed (see Appendix D2 for detail on Cost Benefit Analysis). A tax holiday would would effectively be a subsidy and not sustainable or equitable in the long term (see Report 2, Task D – Socio Economic Impacts). LNG may be an option in metropolitan freight for operators that can accommodate this technology and the extra capital cost.

Findings Related to Key Output 4: An Actions Timeline for the Western Cape to stimulate natural gas uptake in the Transport Sector

- The scale of freight operations on the N1 corridor therefore make it ideal for a long haul pilot but LNG rather than CNG fuelling is required to make practical use of long range gas truck technology. The existing gas supply in Gauteng is CNG so a pilot would need either to rail up LNG to both a midway station and to the end point in Gauteng or else deploy a small scale liquefaction plant in Gauteng. This decision would require a detailed feasibility study but indicative costs are presented in Appendix D2 and Appendix G and can be summarised as follows:
  - Dispensing Costs (Corridor & Gauteng Station): +/- R30/GJ
  - Rail Costs (Corridor Station): +/- R45/GJ @ R2/tkm[3]
  - Rail Costs (Gauteng Station): +/- R67/GJ @ R2/tkm
  - Small Scale Liquefaction Plant including dispensing, storage and transport: +/- R150/GJ
- These estimates are far from conclusive but suggest that if LNG was needed in Gauteng it might be competitive to rail it from the coast particularly Richard's Bay. If landed costs were low enough a pilot might even be able to pass the full amortised costs of the installation to the customer.
- Fortunately, the IDC has initiated a large minibus taxi pilot in Gauteng which provides many useful lessons but has also highlighted the barriers to success. It would make sense to leverage this project and those who worked on it as much as possible in planning for natural gas transport sector market development.
- In the case of petrol minibuses and LCVs which have the most attractive economics if they can be centrally fuelled, this is a case of trying to reach many niches and market stimulus in this space will require targeted information and a rapidly deployable turnkey solution for providing the fuel and the conversion kits.
- Large logistics companies supplying long-haul services turn over truck stock quickly (1st life) before selling vehicles on for other uses (2nd life). Building a market therefore requires targeting these

[3] SA fleet average in 2013 was 90c/tkm with rail generally cheaper for bulk commodities. Source: CSIR (2013), State of Logistics 2013 – Bold Steps Forward

companies early on to build market momentum. A contracted gas price that guarantees operational costs over the 1st life of a new LNG truck would be a powerful incentive to fuel switching.

Findings Relating to Key Output 5: Other Actions and Insights Coming out of the Analysis

- Agriculture and moving around agricultural products and derivatives is far more important to the Western Cape economy even than the 8% sector share of GDPR suggests. Agriculture and the Food and Beverages manufacturing sector are large employers have been extremely valuable generators of employment growth against a backdrop of a shrinking manufacturing sector.
- Real petrol and diesel prices have escalated in line with oil at around 2.9% p.a. (in $ terms) on a 30 year view and are highly correlated to oil price and rand/dollar (R^2 = 93-95%). While taxes and levies have returned to previous highs in 1988, in general fuel prices track the oil price and the rand dollar exchange rate quite closely.
- Tourism in the Western Cape is very car centred and petrol demand is highly seasonal. Targeting this market could create a small but significant boost for sustainable transport. The Uber ehailing service is seeing very rapid growth with tourists and could provide opportunities for promoting 'green' tourism.
- This demand for passenger transport by the tourism sector is significant at just over 6% of total demand estimated for the province and is of the order of the entire Metro Rail system demand in 2012 (Table A- 14).
- Furthermore, as shown in Table A- 22 in a comparison to the freight demand and GDPR contribution of economic sectors, tourism contributes over 4% to provincial GDPR, similar in scale to key sectors such as Food and Beverage manufacture and Agriculture. It is clear that planning and policy making for tourism transport is important.
- This is reflected in the wealth of statistics collected by South African Tourism, Cape Town Tourism and Stats SA. These surveys could be far better leveraged for more technically useful data with little effort which would be useful, when combined with appropriate tourist orientated marketing and ticketing solutions in shifting the current tourist transport demand away from passenger cars.
- Modelling using the tool described in Appendix B2, suggests that the official fuel sales data provides quite a poor picture of fuel demand on a regional basis. The results suggest that the true demand for Cape Town lies somewhere in the range from the DoE figure down to 25% less, Mossel Bay ranges down to 70% less and the other municipalities from 50% less to as much as 100% higher. Langeberg Municipality is an example of a municipality where attributed fuel volumes seem particularly low.
- In general the data landscape has improved relative to previous years in terms of the scope of sources and the professionalism of personnel charged with a data mandate. The following general data problems however persist:
    - In most cases there is a complete lack of scientifically relevant metadata
    - Data is often poorly validated
    - Data is published in non-machine readable formats in discreet files for short time periods making repurposing very difficult
    - Organisations without a data mandate have a poor culture of transparency and are reluctant to respond to requests for data. The prevailing principle is that all data is proprietary until there is a compelling reason or explicit external instruction to make it public rather than the reverse. A competitive economy and indeed a healthy society however require a strong public data culture.

- This project has demonstrated that it is now no longer possible to produce an accurate greenhouse gas inventory at local or regional level for South Africa due to supply side data quality. This is not unique to South Africa as Uganda has over 50 fuel suppliers which makes collation of supply-side data highly problematic there. Model based imputation is the standard industry alternative but this is not simply a question of leveraging existing traffic models. Energy modellers and transport modellers are interested in different things and their models typically don’t reconcile without quite a lot of engagement. This engagement needs to happen and in the context of far more positive engagement around data quality between stakeholders than has hitherto been the case.
- The possibility of rapid penetration of BEV vehicles into the passenger car market, such that they account for 100% of sales by 2035, has the potential to reduce petrol demand by half by 2040 while diesel will likely still grow. This storyline implies not only cost parity between EVs and ICE vehicles in the global market by around 2025 but that sufficient models representing this market are available in South Africa. This result accounts for a high average vehicle age diluting the penetration of EVs into the market even though sales are high. The implications are serious in terms of the balance of products (slate) produced by local refining capacity given that diesel could still grow strongly.
- A Ride-sharing disruption combined with a shift to lower carbon transport has the potential to reduce demand for petrol by over 20% by 2040 relative to today even though demand for transport will have grown significantly. This would however require the urban bus system to attain and maintain passenger-km supply growth rates of 4.5% annualized and the rail system to recover and attain and maintain passenger-km supply growth rates of 2.5% annualised. The use of SUV’s would have to decline by 1% annualized although this is against the trend now seen in the United States for example (Bloomberg, 2018). Realistically, there is neither the will not the money currently to approach these mode shifts but ride-sharing is a potentially low-cost rapidly deploying game changer that can reduce passenger-km and therefore, potentially energy demand, by 30% relative to baseline (not today’s demand) or around 14 PJ by 2040[4].

[4] Estimated using the ratio of occupancies with and without ride sharing - see Table C- 4 above: 1 – (1.4/1.995) = 30%

1 Introduction

The evolution of an alternative fuel or disruptive technology in the transport system faces the twin challenges of the spatial distribution of energy supply and the development of a market in one or more sectors or modes that can foster the technology. The latter generally requires investment in the former but it is important to understand the spatial aspects of demand with respect to sectors to guide this investment, particularly in its initial phases. This section gives a statistical overview of transport and transport energy demand in the Western Cape to try and define some of the challenges to the development of transport technology markets and actions that would be required to overcome them.

A clear picture is inhibited however by data and data transparency. A good national picture can, for example, be derived by calibrating a demand model to balance known fuel sales. As the study region becomes smaller however there is less certainty as to how fuel is distributed and the interpretation is dependent on the effort expended by the industry to track its sales spatially and its willingness to provide metadata on the methods for doing so and changes to these methods over time. At no time however has such metadata been published. Furthermore, the statistics in question have suffered from a recent history of controversy over competition issues within a contested industry and while the Department of Energy (DoE) have invested significantly, much work still needs to be done to address quality issues.

The demands for reliable data are however increasing due to the ever increasing complexity of infrastructure planning and the commitments of cities and regions to report on greenhouse gas emissions, a significant share of which derive from transport fuels. The available bottom up data of travel behaviour does not at this time address the gap. Therefore the need for stakeholders to work together to develop better frameworks for collecting and purposing data has become a pressing issue. As well as drawing conclusions from the data as to the potential and barriers for new transport technologies, this report therefore also makes recommendations on institutional measures to improve the data situation.

2 Study Methodology

The overall project objectives as determined in discussion with the client were as follows:

- Sketch the landscape of Transport Sector demand in the province and where possible in its district and local municipalities as well as the supply system that meets this demand for mostly liquid petroleum fuels.
- Assess the potential for disruption of demand and supply.
- In the context of the above assess the potential for natural gas uptake in transport, evaluating potential socio-economic impacts and risks arising from this.
- While modelling was strongly emphasised in the proposal, actions not modelling should be the focus of the investigation. The approach should in this way assist the Western Cape Government (WCG) to articulate their commitment to future investments in the transport fuels sector modulating the level of effort relative to their overall economic impact.
- Propose actions that explore to what extent fuel substitution by natural gas (in all its forms) could be meaningful.
- Also highlight any other issues of economic or environmental importance for the Western Cape Province arising from the investigation.

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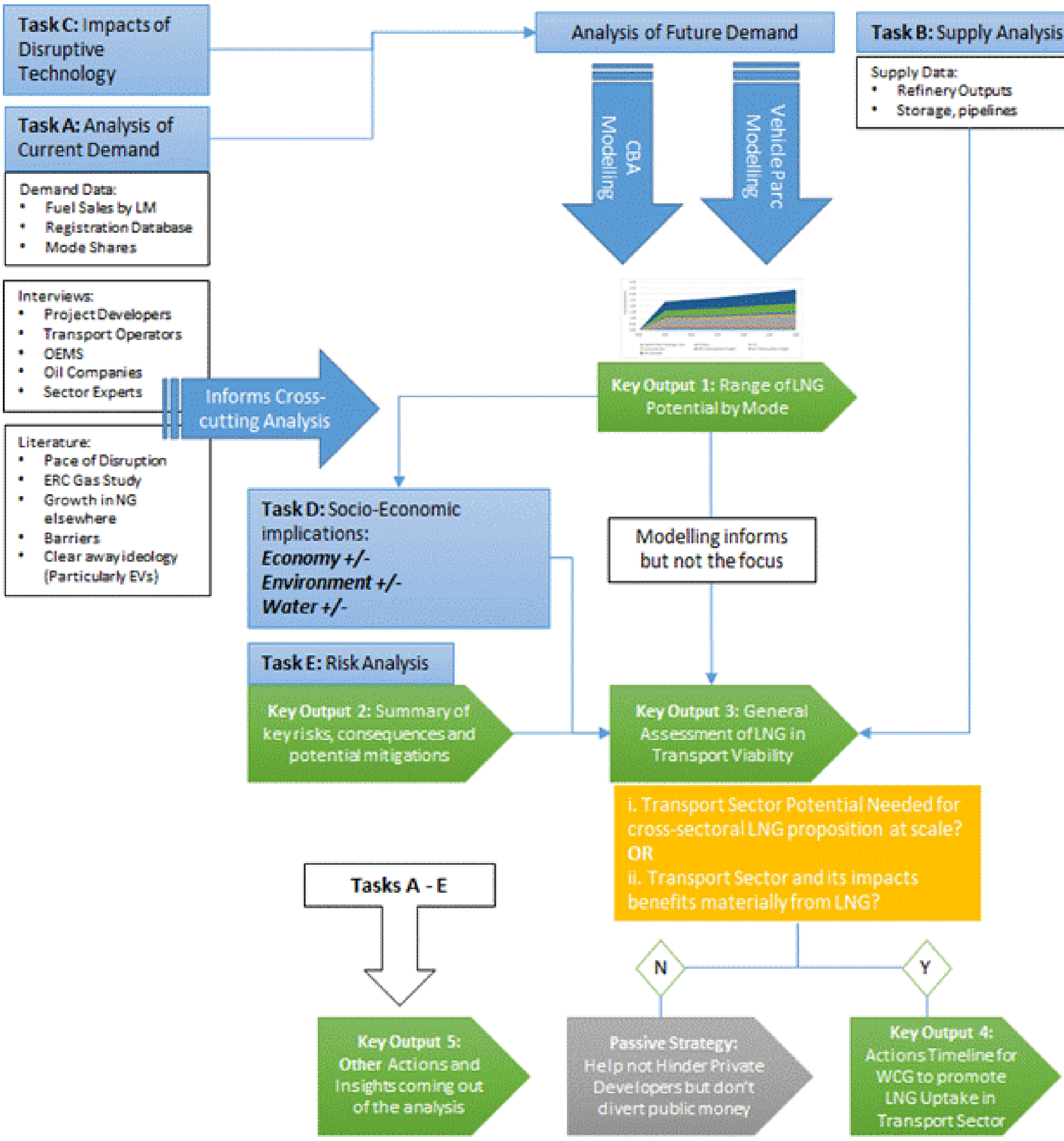


Figure 1: High Level Project Methodology – Combining Tasks to Achieve Objectives

This report is a supporting report to the main report and only covers the activities listed below in relation to the above. Each activity required its own tools and methodology which have been described in the indicated sections of the report.

1. **Deliverables defined for Task A in the Terms of Reference**: For the years 2000 to 2016 for transport fuel demands and the year 2016 for passenger and freight demand detail.
   - See Appendix A for the detailed output of this activity – The Statistical Abstract of Energy for Transport in the Western Cape.
   - See Appendix B for notes on the methodologies used

2. **Analysis of Future Demand:** For the calibration years of 2006, 2010 and 2015 projected using a vehicle parc model to 2050 under scenario.
   - See Appendix C for notes on the methodology
3. **Key Output 1: Range of LNG fuel switching potential by mode**
   - See Appendix D for notes on the methodology
4. **Key Output 5: Other Actions and Insights coming out of the analysis:** These are findings unrelated to LNG uptake potential arising from the Task A analysis only. Other additional finding are documented in the main report in a consolidated list.

In general, Task A and the activities required to produce Key Output 1 were extremely data intensive and hampered by poor data quality and gaps in the data. A great deal of model based imputation, validation and cross checking was therefore required. It is beyond the scope of this project to describe all of this detail and any omissions relate more to this limitation than a lack of transparency. Some of the data problems that were encountered are described in more detail below with a view to encouraging stakeholder collaboration to improve the situation.

3 The Reliability of Fuel Sales Data

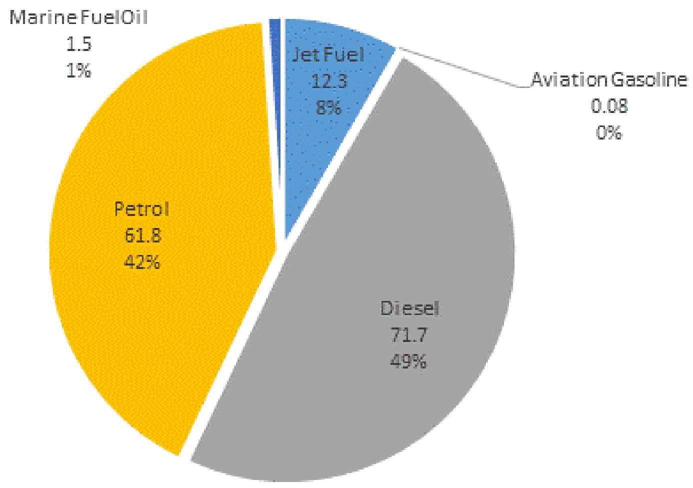
Metadata for the published fuel sales data is largely non-existent and the structure of the industry has changed markedly with the emergence of large independent wholesalers. Members of the industry have previously cautioned that spatially disaggregated fuel sales data should be interpreted with caution due to the continual shifts in patterns of how the depots of oil majors and other supply nodes are supplied from bulk storage (Moldan, 2008). This situation is now magnified by the purchases from the oil majors of large volumes by un-surveyed entities that redistribute the fuel.

The statistical annex of demand data for this report presents detailed figures from the published fuel sales statistics (DOE, 2018) (DoE, accessed 2018) on the basis that this is the best information available from an energy perspective. The case of Mossel Bay in which the PetroSA refinery is situated may offer some guidance as to the levels of uncertainty. The small number of registered vehicles locally would suggest that around 2 PJ of petrol and over 6.5 PJ of diesel attributed to the Mossel Bay Local Municipality area are in fact redistributed. Independent wholesalers deal more in diesel because a wholesaler margin can be added to the regulated price so this makes sense. We might expect the same order of activity and perhaps greater in Cape Town where the Chevron refinery is situated. It seems likely therefore that as much as 10 – 30 PJ of the 120 PJ (8 – 25%) demand for petrol and diesel in the province is uncertainly distributed. At a local level the distortions may therefore be very large if we consider that most municipalities have demands less than 1PJ. It is beyond the scope of this study to assess each municipality in detail on a case by case basis which is what would be required to rebalance the entire province. An initial assessment and sensitivity analysis using the tool described in Appendix B2 however suggest that the true demand for Cape Town lies somewhere in the range from the DoE figure down to 25% less, Mossel Bay ranges down to 70% less and the other municipalities from 50% less to as much as 100% higher. Langeberg Municipality is an example of a municipality where attributed fuel volumes seem particularly low.

South Africa has undertaken national and regional large scale travel surveys that offer insights into transport energy demand (Stats SA, 2013) (Nel, 2016). Typically, these are based on the travel diaries of a group of surveyed respondents. The difficulty arises from an energy perspective when translating these trips into distance. Furthermore, it is extremely difficult to draw a truly representative sample from a spatially distributed population where choices and behaviours differ markedly across a region and not just within a population that occupy a space within the region. Data from a travel survey which was used to estimate total daily distance travelled in the Cape Town Metropolitan Area (Nel, 2016) was used by (Kane, 2017) to estimate total annual passenger kilometres at around 21.1 billion. This was compared to the results of an energy balance model described in Appendix B2. Survey data focussing on corridors would be expected to underestimate total passenger kilometres and indeed this figure is far lower than the fuel balance derived estimate of 31.7 billion passenger.km (Table A-13) even after the assumption of redistribution of 15% diesel and 5% petrol to other municipalities. The model however allows us to test the plausibility of 21.1 billion passenger.km and for this recalibration the model requires the rest of the province to consume far too much even allowing for errors in the assumed energy intensities of modes. The true demand lies between therefore and effort needs to be expended to develop new methods to attribute transport energy demand spatially for the purposes of planning as well as commitments to report on greenhouse gas emissions.

4 Overview of the Demand for Transport Fuels in the Western Cape

Liquid fuels demand in the Western Cape dominated by petrol and diesel as shown by Figure 2 below. The majority of petrol is consumed by passenger transport and light commercial vehicles (LCV), although there has been a steady shift to diesel into the LCV, minibus and passenger car modes, mirroring trends in the EU before the vehicle manufacturer emissions scandal.



Source: (DoE, accessed 2018)

Figure 2: Western Cape Liquid Fuel Demand in 2016 (Note: Numbers are in units of PJ, percentages are share of energy demand)

A historical view on petroleum fuel sales in the Western Cape according to the Department of Energy's published statistics (DoE, accessed 2018) is presented in Figure 3 below. Petrol demand has levelled off in recent years, which can be attributed to the increasing efficiency of motor vehicles, steady dieselisation as well as the reduction in transport activity due to increasing recessionary pressures (Stone, Maseela, & Merven, 2018)

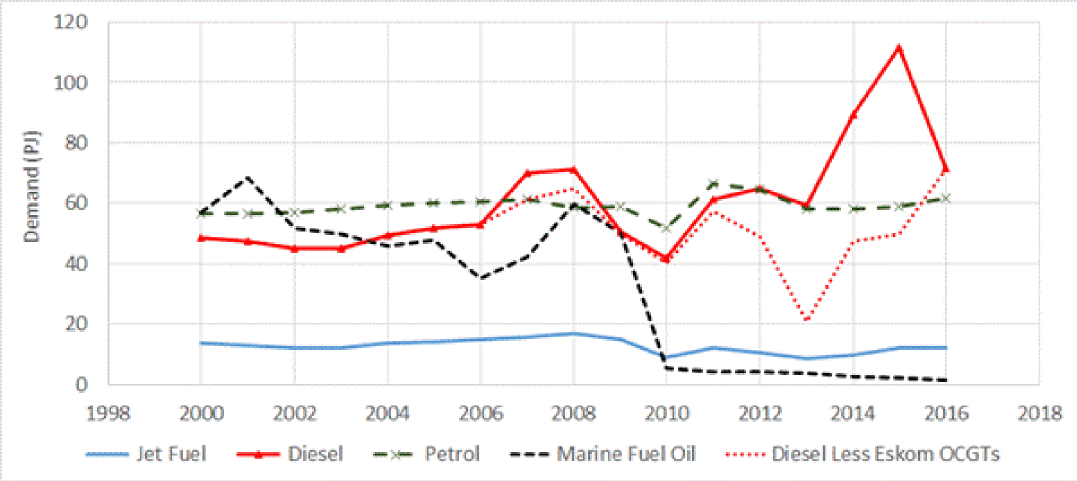


Figure 3: Historical Consumption of Petroleum Fuel in the Western Cape according to the Department of Energy's Magisterial Districts Statistics (DoE, Accessed 2018)

The impact of diesel demand from Eskom's Ankerlig and Gourikwa OCGT plants during the electricity crisis can be seen, although 2013 is inconsistent once corrected for Eskom's demand. This is likely because diesel was being imported from other provinces due to the price opportunities offered by high demand, a possibility confirmed as probable by an interview with staff of Astron Energy (ex Chevron) (Pillay, 2018). The effect of the economic downturn from 2008 on petrol, diesel and jet fuel demand is evident. Furnace Oil (including marine bunkers) has dropped to a fraction of former demand since 2008. The apparent collapse of the bunkering industry in South Africa's ports, particularly Cape Town was investigated for this project and confirmed as true (Lockhart-Barker, 2018) (Jones, 2017).

The City of Cape Town Metropolitan municipality dominates both petrol and diesel demand even allowing for volumes that are likely redistributed to other municipalities (orange lines in figure below – see Appendix B2 for explanation) as shown below.

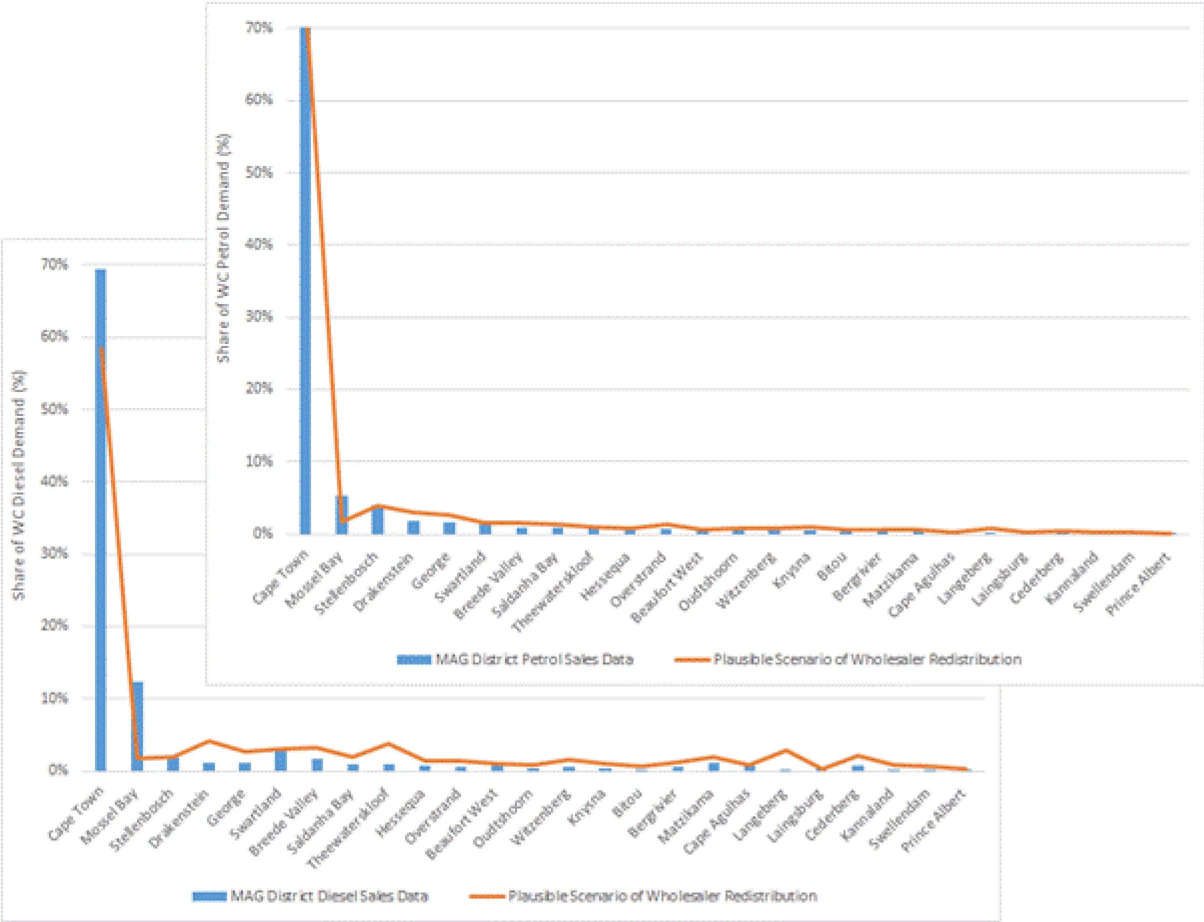


Figure 4: The Highly Pareto Distribution of Liquid Fuels Between Municipalities in the Western Cape[5]

Passenger and freight activity levels and energy demand for petrol and diesel road transport are presented in detail in Table A- 13 in Appendix A2. The main features of the data in Appendix A2 for passenger and freight modes are briefly discussed in Section 5 and Section 6 below.

5 Passenger Transport in the Western Cape

Three quarters of road transport passenger transport energy demand in the Western Cape is consumed by passenger cars (Figure 5) but they supply just under half of the passenger.km (Figure 6). Petrol fuelled minibus taxis, by contrast, are the biggest providers of public transport but use a relatively modest amount of energy. The activity level plotted in Figure 6 below is calculated as the product of the assumed mileage of a mode and the assumed average occupancy (passengers per vehicle). The mileage is far more certain than occupancy and can also be checked by calibrating a model that balances the number of vehicles with the fuel consumed. The activity outcomes in Figure 6 are outputs of the model described in Appendix B2 and are highly sensitive to the assumed occupancies drawn from various sources (Stone, Maseela, & Merven, 2018) (Kane, 2017) (SEA, 2015).

[5] Source: Blue bars are direct from (DoE, accessed 2018). Orange lines are author's calculations using model described in Appendix B2 based on data from (eNatis, Accessed 2018) and (DoE, accessed 2018)

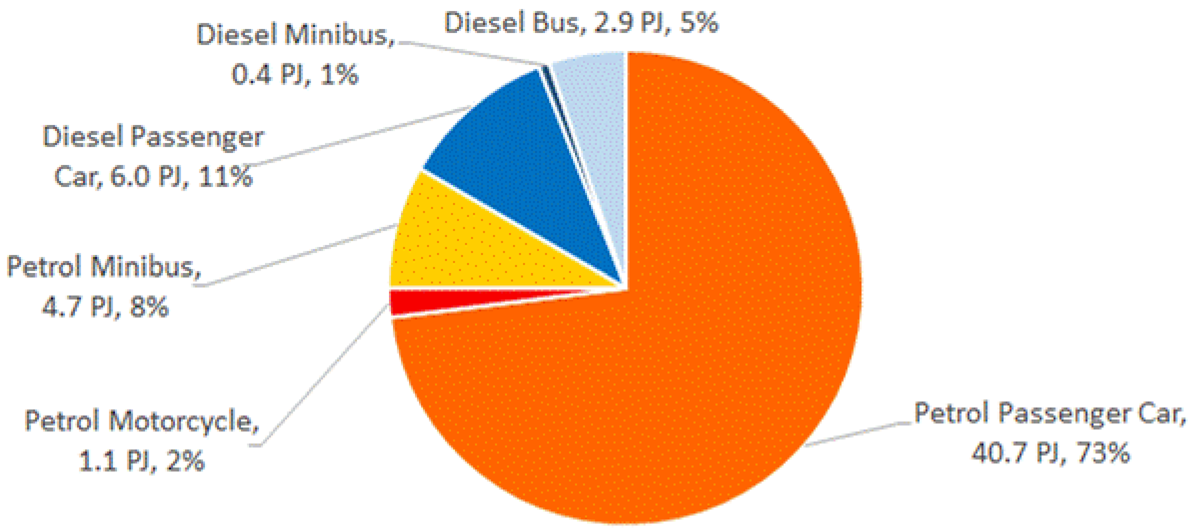


Figure 5: Road Transport Passenger Transport Energy Demand (PJ) for the Western Cape, 2016[6]

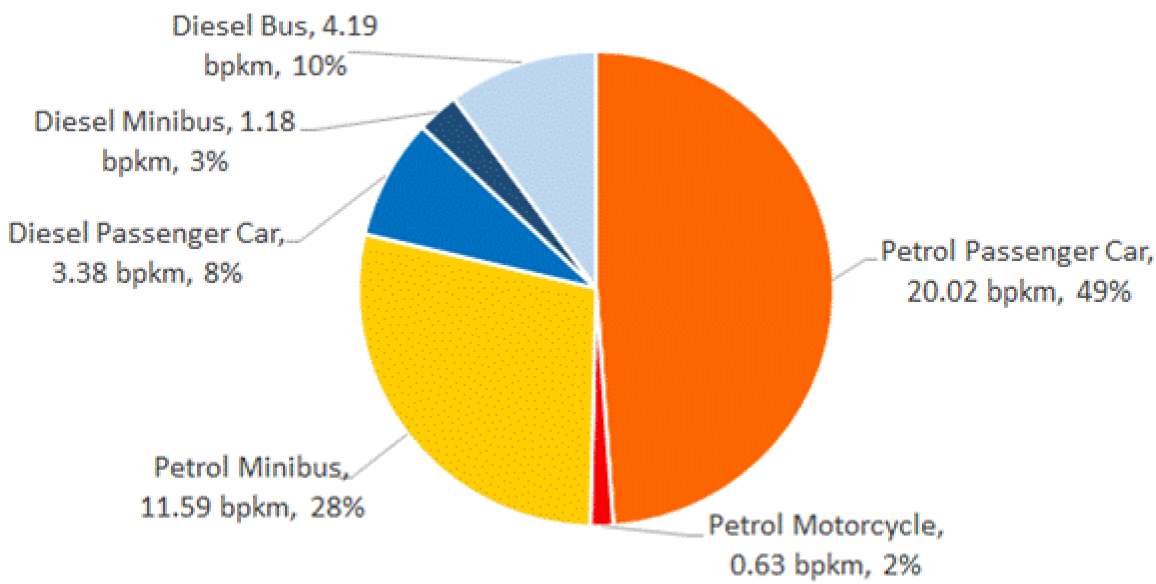


Figure 6: Road Transport Passenger Transport Activity (bpkm) for the Western Cape, 2016 [6]

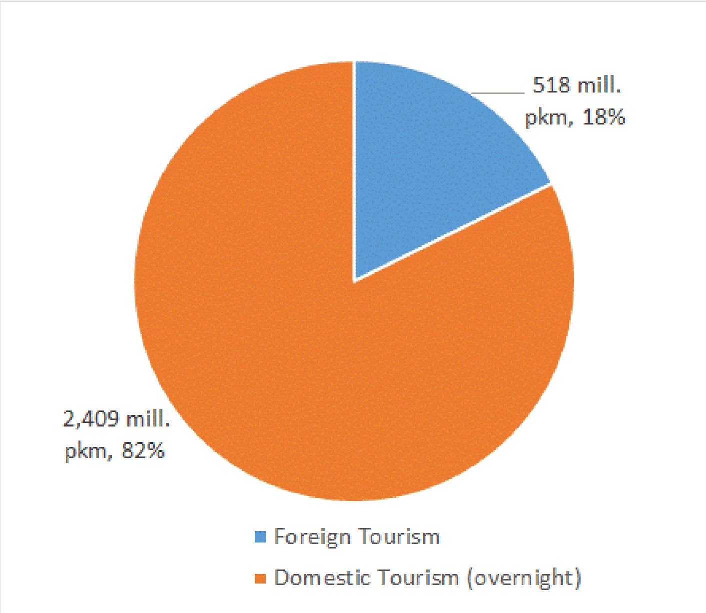
Motorcycles play a very minor role in passenger transport but they are growing more rapidly (4% CAGR) than the other modes in the registration database albeit off a low base (Table A- 11). The City of Cape Town's passenger transport energy data is presented in detail in Table A- 16 and is similar to the province for road transport because Cape Town dominates the province in terms of scale. The available data however enables a richer picture showing high levels of walking (given the short trip lengths), low levels of cycling and the significant but deteriorating contribution of the city's commuter rail endowment. The paucity of public information encountered in the preparation of this dataset on rail activity levels over time should be a source of very great concern given the extremity of the rail crisis.

[6] Source: Author's calculations using model described in Appendix B2 based on data from (eNatis, Accessed 2018) and (DOE, 2018)

5.1 Tourism and Transport

The Western Cape had 1,579,226 international and regional foreign tourist arrivals in 2016 (South African Tourism, 2018) of which, given 2013 figures, about 95% also visited Cape Town (Womack, J, 2015). The detailed arrivals data, length of stay and transport preferences for these groups are presented in Table A- 18 to Table A- 22. International Arrivals at Cape Town international Airport has been showing marked growth of nearly 13% annually on average over the last 5 years. The demand for road transport services will be growing proportionally. The Uber taxi service in particular has shown very rapid recent growth in this sector (Table A- 19).

The total demand for passenger.km for domestic and foreign tourism respectively is presented below.



Source: Author's calculations with data from (Stats SA, 2017) *and* (South African Tourism, 2018) *as input*

Figure 7: Estimated Demand for Passenger.km by Tourism in the Western Cape by Mode

This demand is completely dominated by passenger cars, mostly private in 2016, although 2018 figures show taxis taking a larger share of preference. The main uncertainty with this data is that preference is surveyed but not activity levels and so trip frequency and distance have been assumed.

Table 1: Estimated Foreign and Domestic Passenger Transport Demand in 2016 the Western Cape

Mode	Million pkm	Share
Passenger Car	2,747	94%
Tour Bus	97	3%
Minibus	56	2%
Train	10	0%
Other	17	1%
TOTAL	2,927	100%

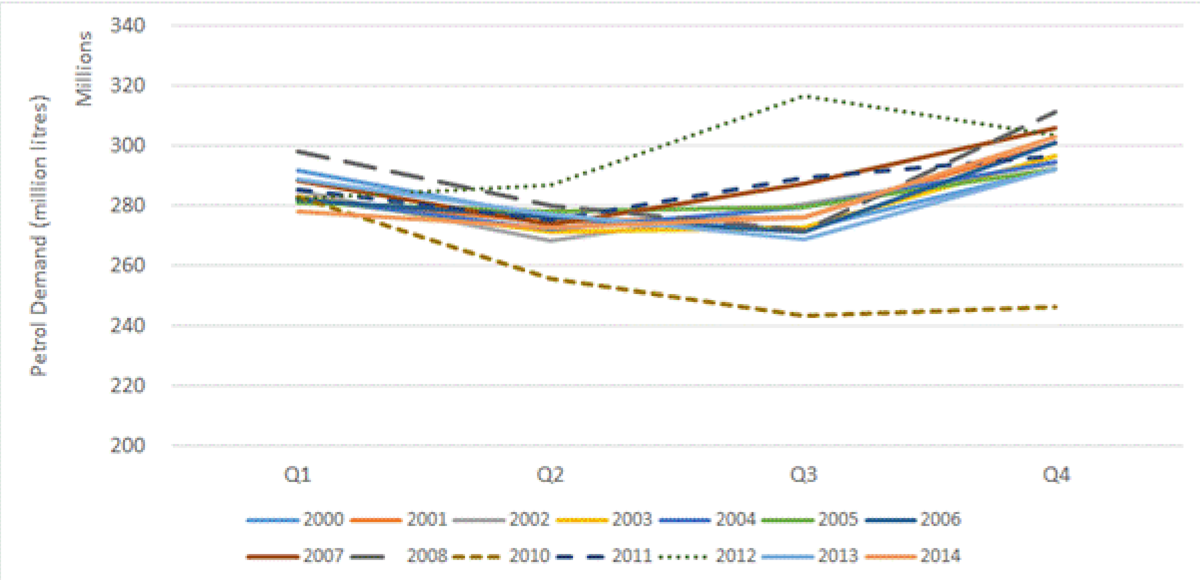
Author's calculations with data from (Stats SA, 2017) *and* (South African Tourism, 2018) *as input*

This demand for passenger transport by the tourism sector is significant at just over 6% of total demand estimated for the province and is of the order of the entire Metro Rail system demand in 2012 (Table A- 16). Furthermore, as shown in Table A- 24 in a comparison to the freight demand and GDPR contribution of economic sectors, tourism contributes over 4% to provincial GDPR, similar in scale to key sectors such as Food and Beverage manufacture and Agriculture. It is clear that planning and policy making for tourism transport is important. This is reflected in the wealth of statistics collected by South African Tourism[7], Cape Town Tourism and Stats SA. These surveys could be far better leveraged for more technically useful data with little effort which would be useful, when combined with appropriate tourist orientated marketing and ticketing solutions in shifting the current tourist transport demand away from passenger cars.

In terms of alternative fuel opportunity, the 97 million passenger.km estimated to be covered by tour buses translates to an opportunity of around 65 TJ but this should be considered highly uncertain without better data being collected on numbers of tour buses and their level of activity. The total share of tourism transport demand estimated in the course of this investigation compares well however with the order of magnitude of seasonal variations in petrol demand discussed below.

5.1.1 Seasonal Variations in Petrol Demand

The Western Cape and Cape Town in particular has a large and growing international Tourist economy and a high share of domestic tourism which, when added to elevated local activity in the summer months, causes distinct seasonality as shown below in Figure 8. This is useful as a guide to the level of transport activity that can be attributed to activities other than daily commuting for work and education. This is bearing mind that there is still significant tourism, particularly foreign tourism, in winter.



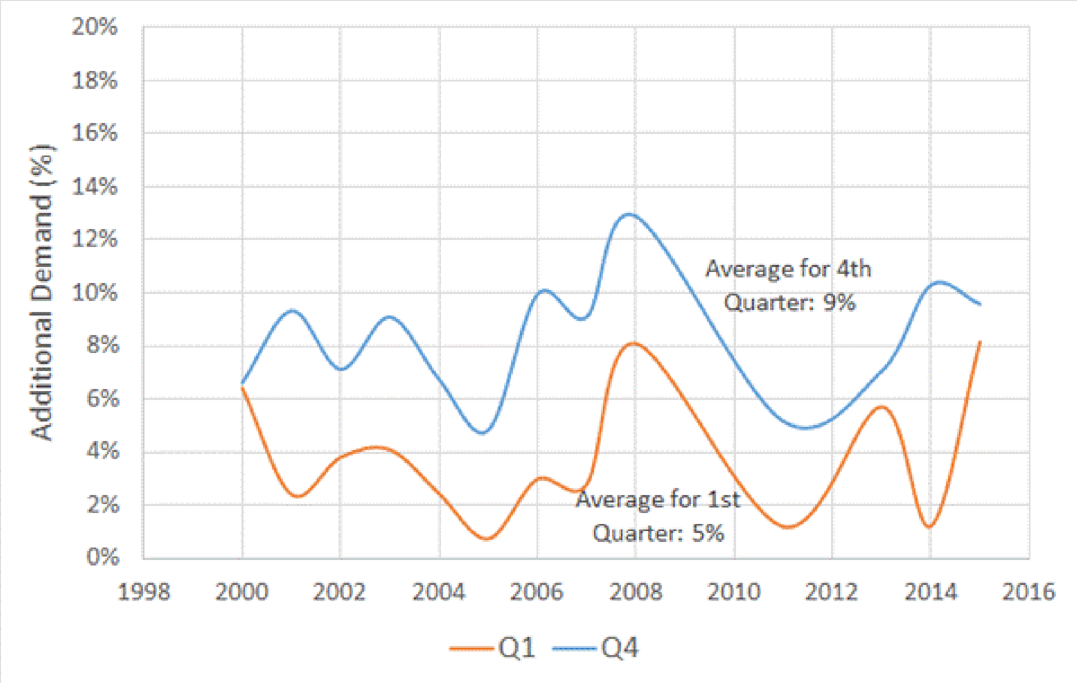
Source: Author's calculations based on (DoE, accessed 2018)

Figure 8: Seasonally adjusted (to 2000 equivalent) petrol demand in the City of Cape Town Metropolitan Municipality 2000-2016[8]

Relative to the winter Quarters 2 and 3, additional demand for petrol tends to be higher (9% on average) in the Christmas period 4th quarter than in the ensuing 1st quarter (5% on average) as shown below in Figure 9.

[7] https://www.southafrica.net/gl/en/corporate

[8] Demand data shows a pronounced inflection for 2010 – 2013 which distorts the seasonality adjustment calculation for 2010 and 2012. This marks the transition from SAPIA custodianship of the liquid fuels data to that of DoE and this data might reasonably be assumed to be questionable particularly at disaggregate level.

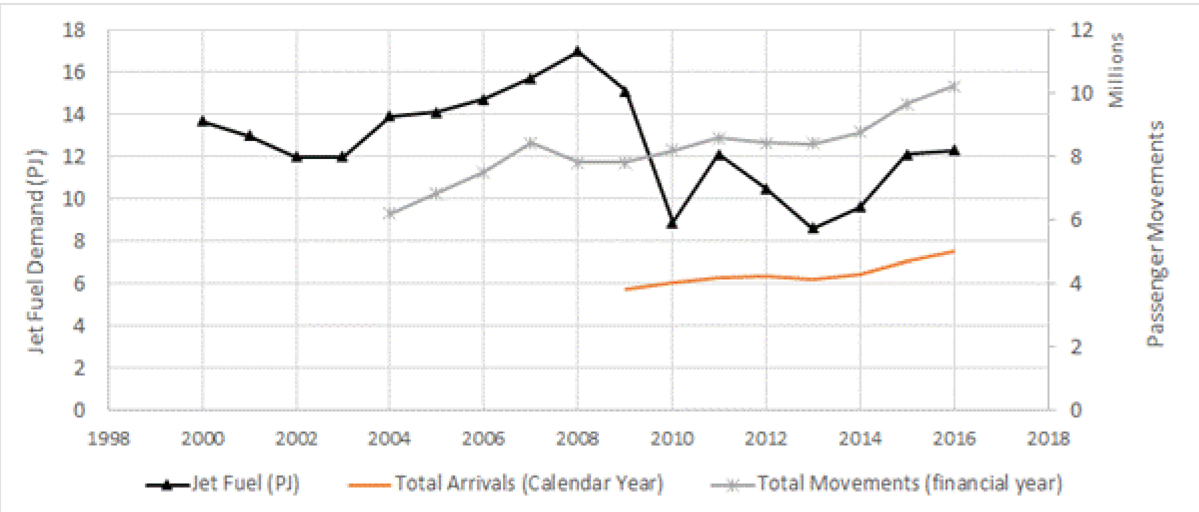


Source: Author's calculations based on (DoE, accessed 2018)

Figure 9: Quarter 1 and 4 Seasonal elevations in petrol demand relative to the average of Quarters 2 and 3 in the City of Cape Town Metropolitan Municipality 2000-2016[9]

5.2 Air Passenger Transport Movements and the Demand for Jet Fuel in the Western Cape

Historical air traffic movements as reported by ACSA for Cape Town International Airport are compared to DoE data for jet fuel consumption in the Western Cape in Table A- 17, Appendix A. As shown below there is poor agreement between reported fuel volumes and air passenger movements between 2008 and 2013.



Source: ACSA and Department of Energy

Figure 10: Reported Jet Fuel Supply for the Western Cape compared to Reported Passenger Movements at Cape Town

[9] Excludes 2009 (no quarterly data), 2010 and 2012 (large inflection and suspect data)

This corresponds to the period where the usual seasonality is not evident in Figure 8 above and may therefore be simply attributable to error. Reported volumes in 2016 however have not returned to previous highs despite that there are far more flights, even accounting for increased aircraft efficiency.

Given this uncertainty, the actual consumption of jet fuel in the province can't be stated with confidence without more investigation but could be as high as 20 PJ and as low as 12 PJ and growing robustly at 3 – 4% annually.

6 Freight Transport in the Western Cape

South Africa has been described as having a 'spatially challenged' economy (CSIR, 2013) with road transport on the corridors between the major cities dominating the demand for general freight (excluding mining commodities) as shown in Table A- 23 for the Western Cape case.

Estimated freight energy demand by road transport mode and fuel for the Western Cape is presented below in Figure 11. Around three quarters of energy demand is for diesel, and the remaining quarter is petrol. Diesel fuelled Heavy Commercial Vehicles (HCV) account for around half freight energy demand while demand from petrol and diesel LCVs are around a quarter each even though they don't move a high share of ton.km (Table A- 15 and Table A- 16) due to shorter trip distances. This is because their energy intensity (MJ/tkm) is around 5 to 10 times higher than an HCV depending on operating conditions. . The activity level plotted in Figure 12 below is calculated as the product of the assumed mileage of a mode and the assumed average load factor (tonnes per vehicle). The load factor assumptions can be viewed as more certain than passenger mode occupancies because they are based on an exercise that calibrated a vehicle parc model that included detailed HCV sub-categories with the total tonne-km output of the University of Stellenbosch, Department of Logistics, Freight Demand Model (FDM) (Stone, Maseela, & Merven, 2018) (Havenga J. , Simpson, de Bod, & Braun, 2016)[10].

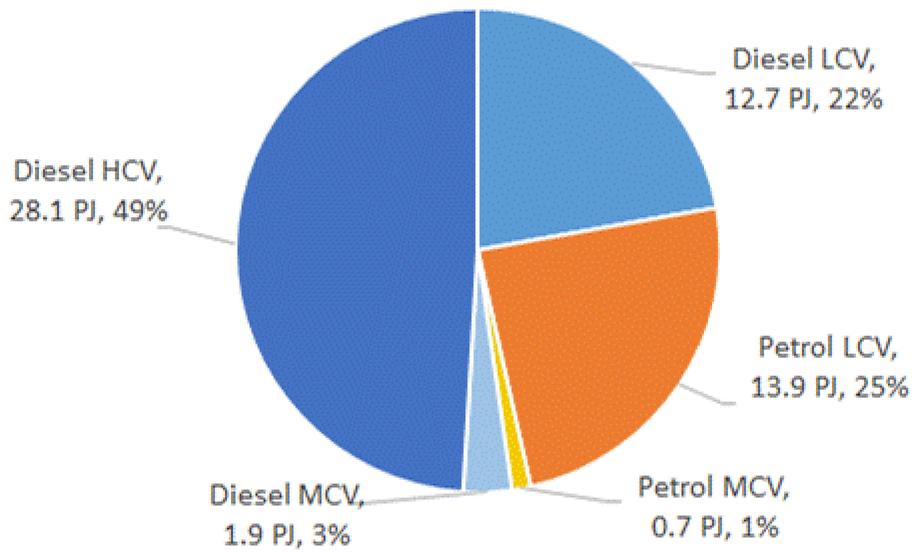


Figure 11: Freight Transport Energy Demand (PJ) by mode and fuel for the Western Cape, 2016 [6]

[10] The FDM is a 'gravity' model that balances freight flows between freight 'generators' and 'attractors'. It has been developed over more than a decade and is supported by a great deal of ongoing empirical research and direct survey of freight operators.

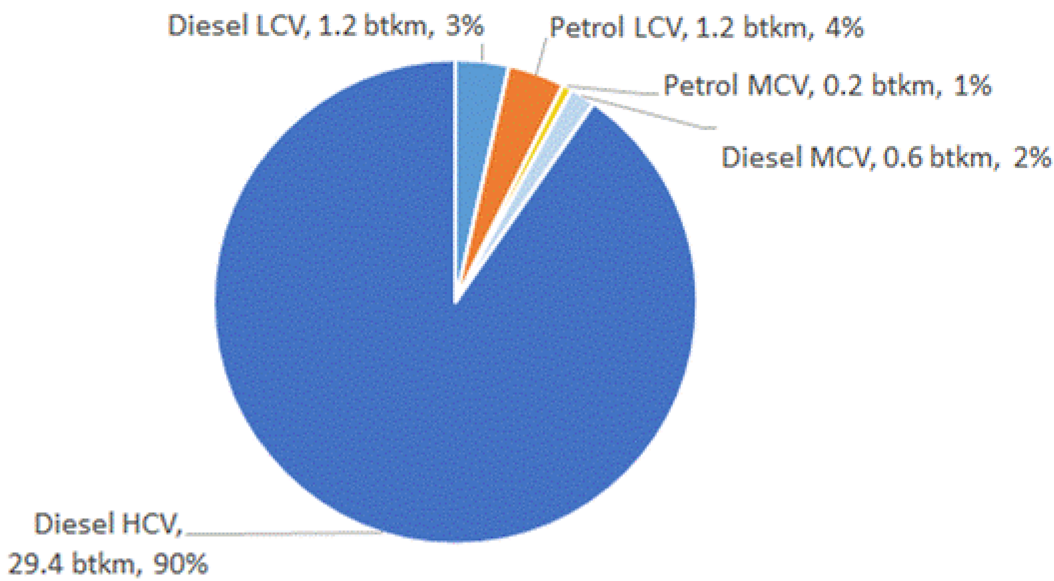


Figure 12: Freight Transport Activity (btkm) by mode and fuel for the Western Cape, 2016 [6]

As shown in Figure 13 below the freight flows between the Western Cape and the other provinces are dominated by flows with the other two large provinces, Gauteng and Kwazulu-Natal, with export to Gauteng the largest single flow. On a tonnes basis, the exchange with Gauteng is heavily skewed towards export from the Western Cape. This is likely influenced by the high density of beverages which are a major export from the province (Simpson, 2018).

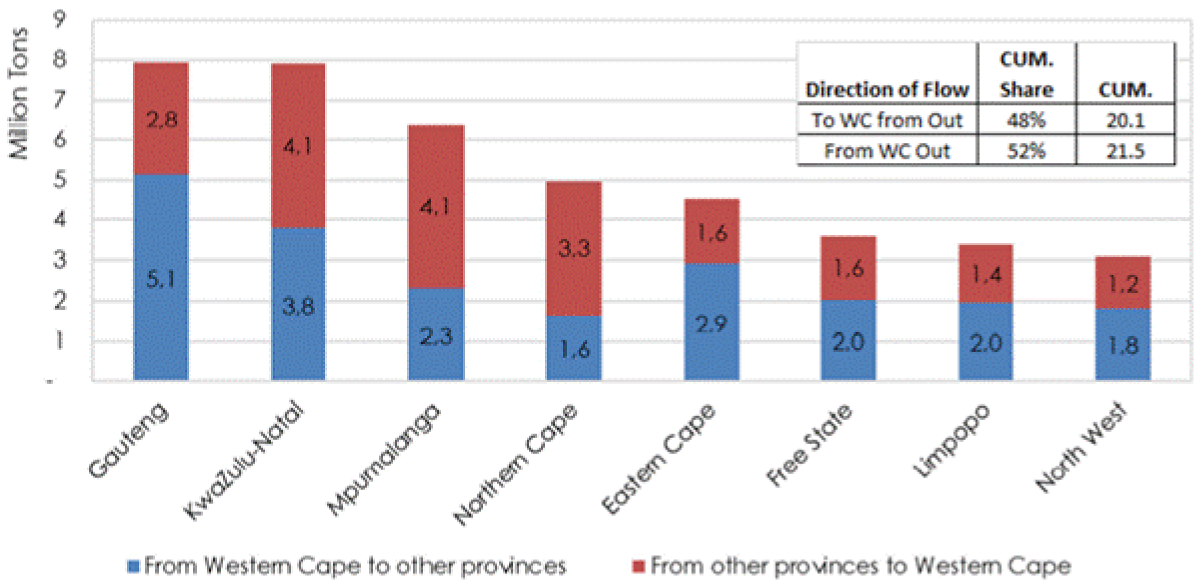


Figure 13: Freight Flow between the Western Cape and other Provinces (WCG, 2018)

The flows above are reflected in the concentration of road transport freight on the N1 corridor shown in Table A- 23 which accounts for 45% of all tkm in the province. This raises the possibility of increased use of rail to reduce logistics costs. Rail market share has however rather been diminishing with time as shown below.

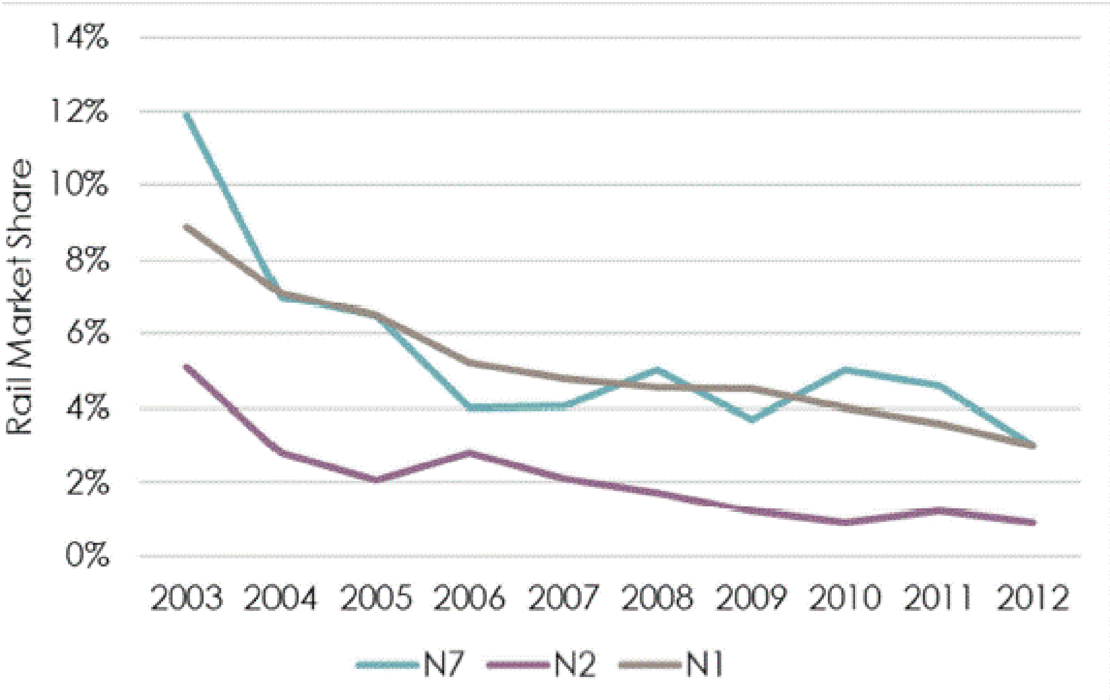


Figure 14: Rail Market Share of Freight on Western Cape Corridors (WCG, 2018)

'Rail friendly' freight that could be easily diverted (back) to rail has been identified on these corridors as shown in Table A- 23. This has the potential to shift the current rail tkm share of corridor freight from 8% up to 28%.

While a detailed sectoral breakdown of freight flows was unfortunately not made available to this project, the public data as presented in Table A- 24 reflects that Fast Moving Consumer Goods (FMCG) are the single largest commodity group in terms of flows and are concentrated on the N1 corridor. Processed food and beverages have historically been the largest component of this commodity group and also contribute around 4.1% to the provincial GDPR, ranking 6th of 12 of the freight and passenger flows ranked in Table A- 24[11]. Combined with its key intermediate Agriculture however, the Food and Beverages sub-sector represents a contribution of over 8% to GDPR moving its ranking to 3rd behind public transport and redistribution of goods to retail. These latter flows are not however strongly margin generating, are highly dispersed and not easily tractable to policy.

More importantly, Figure A- 2 and Figure A- 3 show that Agriculture and the Food and Beverages manufacturing sector are large employers have been extremely valuable generators of employment growth. Other large freight flows that are key to the provincial economy include Construction and its non-metallic mineral inputs and Chemicals and petroleum products, particularly the latter on a province wide view. Smaller flows that are still key to the real economy are Paper and Wood Products and 'Other Manufactured Products' which includes furniture, textiles and electronics (see Figure A-4).

[11] In ranking flows in terms of contribution of GDPR the approach has been to simply indicate the contribution of the sector which the flow is a part. The value add share of the flow itself to the sector or sub-sector GDPR will clearly vary greatly but the number is used in the sense that the transport flow is a critical enabler of the sector activities.

7 Off-Road and Stationary use of Diesel Fuel in the Western Cape

Significant volumes of diesel are used in off-road and stationary applications in addition to road transport. Indeed, if calibration of a vehicle parc model such as that described in Appendix C is attempted by targeting total diesel sales without correcting by an estimate of off-road and stationary use, the resulting annual mileages and / or fuel economies that must be assumed as inputs are generally not credible.

Off-road and stationary consumption of diesel commonly occurs in the following areas of the economy:

1. Agriculture: For working cultivated lands including ploughing, planting, reaping, treating with pesticide and baling. (Louw, 2018) reports that over a 20 year period the energy intensity of cultivation for grain crops has improved from 100 litres/cultivated hectare to around 65 litres/cultivated hectare. Of this no more than 5% is diverted to road transport by the farmer for the transport of materials and product. The improved energy intensity is due the following drivers:
    - Increased 'no till' farming
    - Improved efficiency of machines
    - Improved economies of scale with larger farms
    - Multi-purpose implements e.g. furrow cut, plant and compact in one pass with one machine.
2. Construction: Earth moving machines for site preparation and diesel generators for on-site electricity.
3. Mining: Various machines undertaking earth and rock breaking, removal of ore to processing facility etc.
4. Manufacturing: forklifts
5. Air Transport: Airport local distribution of passengers and goods.
6. Commercial and manufacturing activities that require high levels of reliability like hospitals may use significant quantities of diesel in supplying back-up power.

As shown below, the national energy balances have suggested that the off-road share of diesel has been diminishing over time from around 35% to around 20% with Mining displacing Agriculture as the dominant off-road consumer (Stone, Maseela, & Merven, 2018).

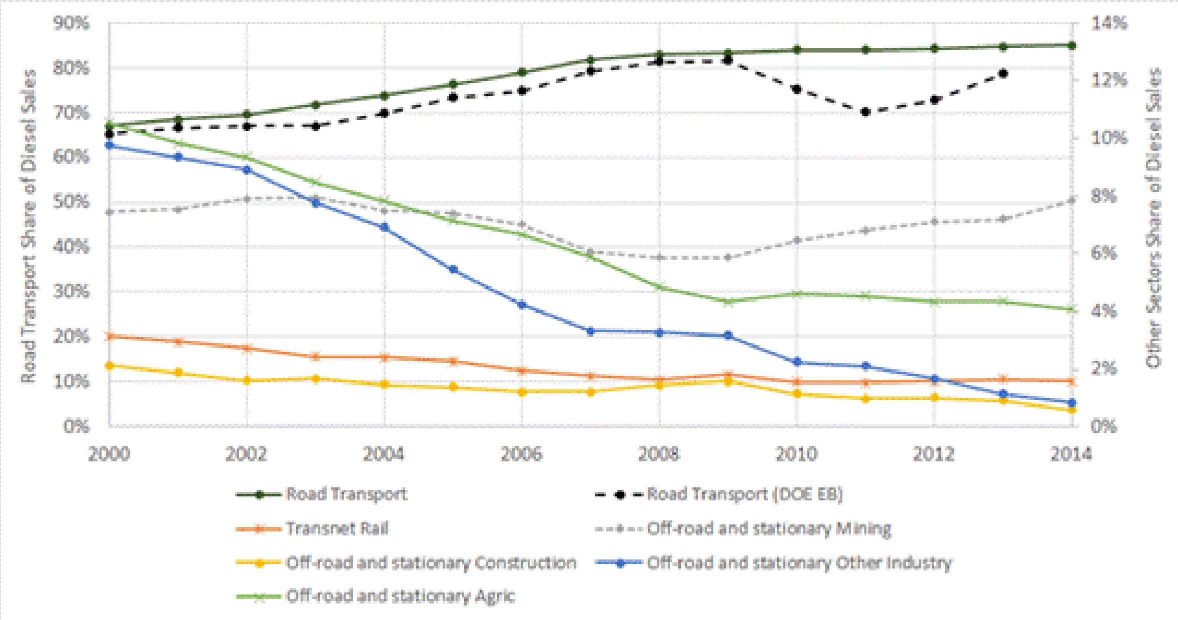


Figure 15: Off-road and Road Transport Shares of Diesel Supply 2000 – 2014 Based on an Analysis of National Energy Balances (Stone, Maseela, & Merven, 2018)[12]

As is suggested by the high attribution to Agriculture and low attribution to mining indicated in Table A- 8, for many municipalities it might be expected that Agriculture would dominate off-road diesel demand in the Western Cape. A key consideration is that these figures being derived from the Department of Energy's Trade Category data do not distinguish between off-road (on-farm) activities and road transport of agricultural produce (agri-freight). This is because this data is derived by surveys sent to the major oil companies who presumably fill them in based on a system of customer classification. They are not based on direct survey of the sector. The analysis described below attempted, using a bottom-up check, to estimate a share of diesel consumption for the Western Cape for "on-farm" activities.

A tool was developed for this project to balance fuel supply and vehicle activity in each local municipality. The methodology is described in Appendix B2 and requires an input of the diesel consumption for each municipality that is off-road ("on-farm") agricultural activities. Initially these inputs were based purely on assumptions derived as follows:

1. Table 2 below presents the assumptions for off-road diesel share of demand in the "functional metro" of Cape Town, Stellenbosch and Swartland and the "rural" rest of the Western Cape. As would be expected the "off-road" share of the rural and secondary Western Cape is much higher than the metropole and dominated by Agriculture – 38% of 43%.
2. These are assumptions are calculated by aggregating the "Agriculture' data in Table A- 8 but assume that the road transport share of these volumes is 25% on the basis that local rural transport companies and transport functions within co-operatives likely buy the diesel, using it for road transport but also selling it on to farmers, but are classified as wholly 'Agriculture'. The scale of this number largely arises from trading-off inputs so that a sensible fuel balance is achieved. It has no empirical basis.

[12] It's important to note that these shares are adjusted to exclude the assumed share of Agriculture Sector diesel consumption that is used to transport produce on roads. The "Off-road and Stationary Agric" line is for "on-farm" activities. These assumptions are not well supported because no metadata is published by DoE with its Fuel Statistics and the energy balances are supported by limited metadata on sectoral splits.

3. Thus the average share of off-road agriculture in the Western Cape in this scenario is 16% of demand (22% minus 6%) or around 10.6 PJ for 2016.

Table 2: Off Road Assumptions for Input to the Municipality Level Fuel Balance Tool (see Appendix B2)

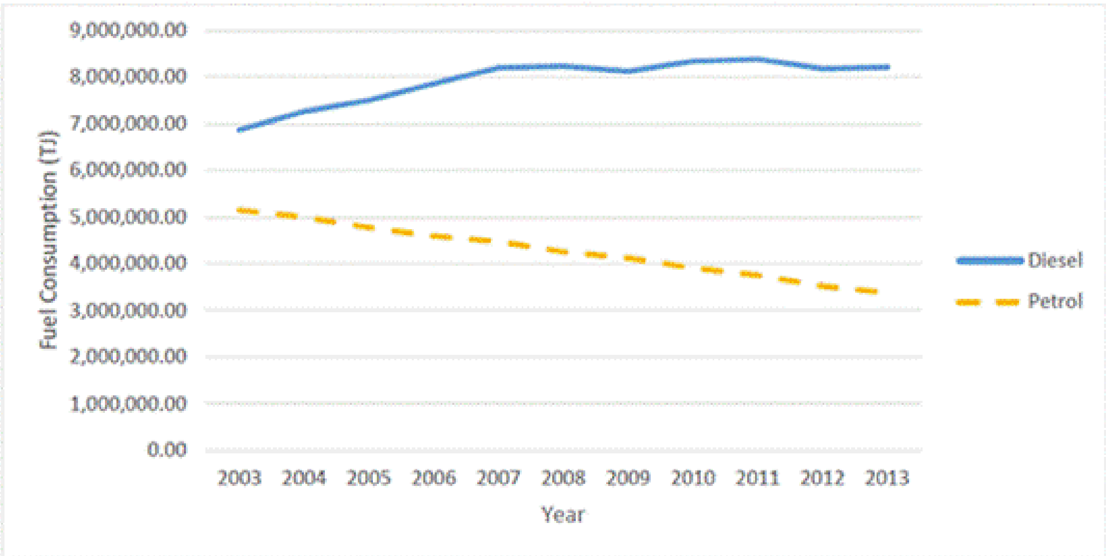
	Functional Metro	Rural	WC Average
Diesel Demand (PJ)	43.12	24.68	67.80
Off-Road Share	10%	43%	22.0%
Assumed Non-Agric. Portion of Off-Road	7%	5%	6.0%

These assumptions were validated using the arable hectares in the province and the figures from Grain SA discussed above (Louw, 2018) as a starting point. These calculations are presented in Appendix B3.

It was concluded that the estimates of off-road agriculture made for this investigation are of the right order of magnitude but that the energy intensity of agriculture and other sectors that use significant volumes of diesel in off-road applications needs to be better understood in the future to have more certainty about off-road demand. Similarly, credible local energy intensities per unit output are required for construction and mining activities in order to improve our understanding of how diesel is used.

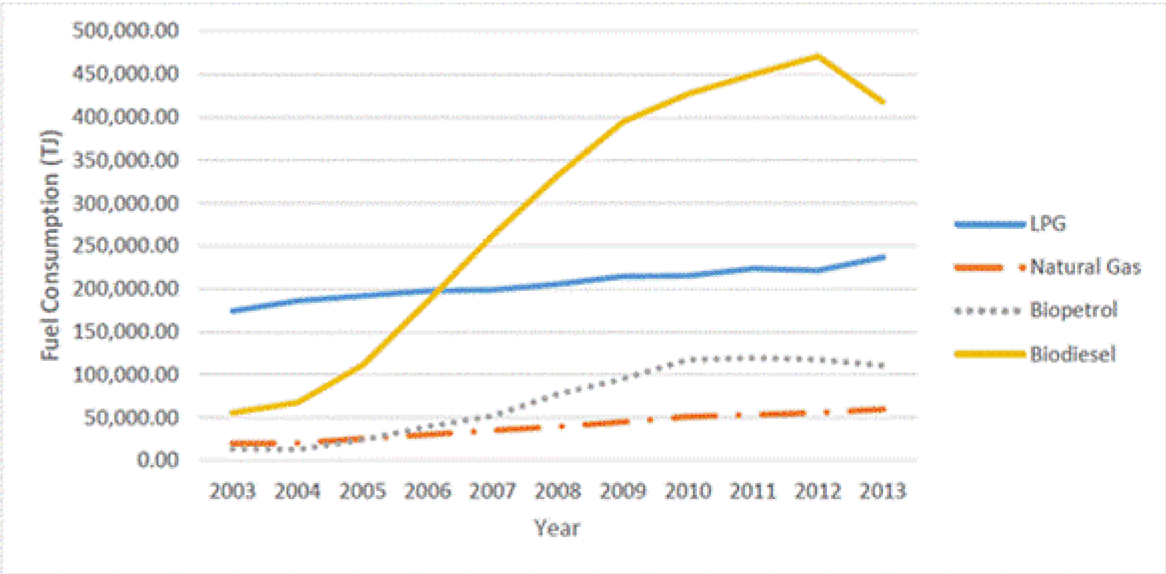
8 Evolution of Natural Gas Transport Sector Demand in the EU and US Markets

In assessing the potential for fuel switching of the demands surveyed in this report, the perspective of the evolution of transport fuel demands in developed economies is useful. The demand for petroleum fuels over time in the US and EU is presented in Appendix A, Table A- 25 and Table A- 26vand in Figure 16 to Figure 18 below. Natural gas transport sector demand as a share of total transport sector demand is similarly small in the US (0.2%) and EU (0.5%). Demand is however growing strongly off this low base particularly in the US over the last 5 years (CAGR of 10.4%).



Source: Ricardo calculations based (Eurostat, 2013) and (UNFCCC, 2015)

Figure 16: Evolution of the Demand for Petrol and Diesel by Road Transport in the EU 2003 - 2013 excluding blended biofuel (Ricardo-AEA, 2016)



Source: Ricardo calculations based (Eurostat, 2013) *and* (UNFCCC, 2015)

Figure 17: Evolution of the Demand for Gaseous Fuels and Biofuels by Road Transport in the EU 2003 - 2013 (Ricardo-AEA, 2016)

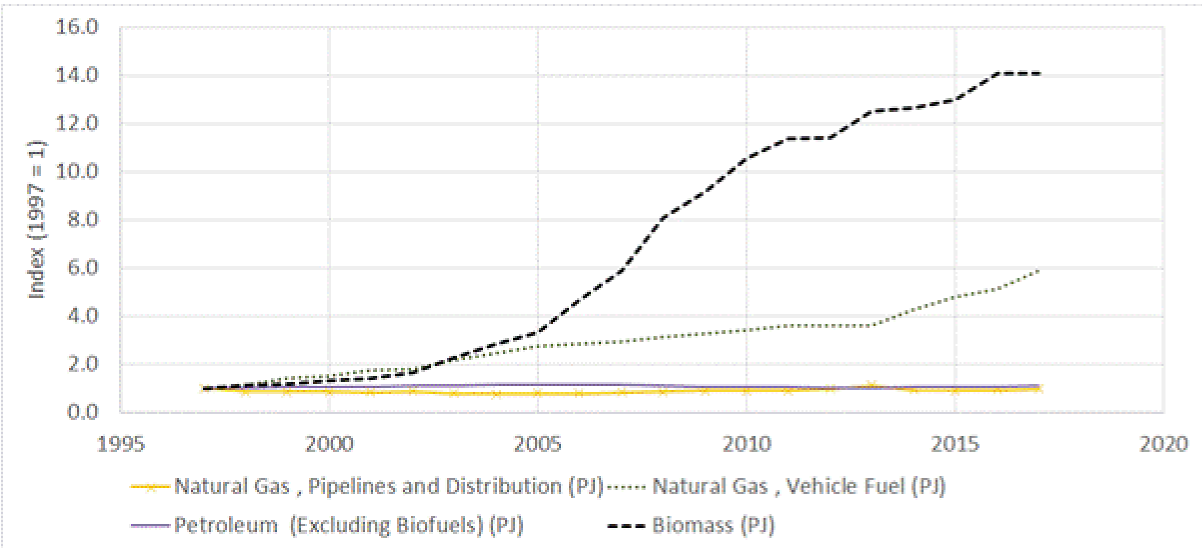


Figure 18: Evolution of the Demand for Petroleum Fuels, Natural Gas and Biofuels by Road Transport in the US 1997 - 2017 (EIA, 2018)

9 Analysis of Gas Uptake by Mode

The cross-cutting phase of literature review and interviews (see Figure 1) made it clear that each mode is different with respect to the potential for natural gas as a fuel substitute and the barriers to uptake. Each mode was therefore separately analysed by combining the following steps and criteria:

- A sensitivity analysis was performed using the payback calculator described above in Appendix D considering both the option of retrofits and new vehicles fuelled by natural gas.
- Any insights obtained from interviewing stakeholders were incorporated.

- The maturity of competing technologies like battery electric vehicles or fuel cell vehicles was considered.
- A perception of the degree to which a mode may have the formal systems and business practices to successfully fuel switch was considered.
- Subsidy for environmental reasons was not considered realistic. Short-term subsidy including limited tax holiday was considered as an option for market stimulus but the scope for this in the case of South Africa, the case of Gautrain notwithstanding[13], should be considered extremely limited in our view.
- The final range of uptake was the opinion of the project team based on a qualitative assessment of the above factors. The project team has been conservative in their assessments on the basis that technical and economic viability are the lesser barriers to fuel switching compared to institutional barriers.

The key features of the analysis of each mode and the final range of uptake potential is presented below following consideration of the likely regulation process for the price of gas.

9.1 The Price of Natural Gas for Transport

The National Energy Regulator (NERSA) has a mandate to regulate **maximum** piped-gas prices in terms of the Gas Act, 2001 (Act No.48 of 2001) which empowers NERSA to set a maximum price in the event that there is "inadequate" competition. This was deemed the case in a NERSA decision of 20 February 2008. NERSA does not set actual prices but prices must fall below the maximum price. NERSA therefore accept a "willingness to pay" approach in principle but sets a maximum price in the current market because it is still deemed monopolistic. The value chain will require licensees for the transmission, distribution and trading phases and these licensees will need to report to NERSA using the Regulatory Reporting Manuals (RRMs) provided, in a similar way to what is currently required for licensees of liquid fuel storage (NERSA, 2011) (NERSA, 2014). The maximum price granted to a licensee is set by either of two methods:

- Energy Price Indicators Approach which references to price indicators of certain relevant energy sources (i.e. coal, electricity, Heavy Fuel Oil, Liquefied Petroleum Gas and Diesel) using weightings prescribed by the Department of Energy. According to NERSA, "*The formula recognises the fact that no single fuel is a perfect substitute for gas. Furthermore, the formula allows maximum prices to be determined at a level that reflects the balance between encouraging new entry and equitable sharing of any economic surplus between consumers and producers.*" Once the maximum price of gas is arrived at, all other charges (tariffs and levies) mentioned above shall be included to arrive at the 'total gas charges' to be invoiced by a licensee." (NERSA, 2011)
- The 'pass-through of costs' approach which requires a cost-based price build-up, including the cost of the procured or produced gas, tariffs from further up the value chain including transportation or regasification costs as follows (NERSA, 2011):

    Total Price = Max price for Gas Energy + transmission and distribution network tariffs + transmission and distribution trading service tariffs + storage tariffs + trading margin + levy.

As is the case with storage licensees, the trader's margin (as a percentage) will be calculated in nominal terms. The nominal Weighted Average Cost of Capital (WACC) of the trader will be the trading margin

[13] Gautrain is highly subsidised (National Treasury, 2014)

(%), since all other expenses are allowed to the licensee as a pass-through. The regulation as it stands therefore seems sector agnostic. If a licensee specialises in supplying the transport sector they can apply for a maximum price that passes through their costs and a margin that reflects "financially efficient" use of capital and equity but charge less than this (forgo margin) for reasons of market stimulation. Crucially, the current regulations make provision for a levy that could, and in the view of the consultants, should ultimately be made equivalent, in the case of transport sector supply, to petrol and diesel levies. This is recognising that a short-term tax holiday could be justified to develop a market until better of economies of scale are attained.

A payback calculator, discussed in Appendix D, was used to explore the viability of different mode and gas technology combinations under scenarios of relative prices for petrol, diesel and natural gas. The model for the gas price assumed a 'pass-through of costs approach' with an assumed conservative trading margin on the dispensing infrastructure of 35% but no explicit margin assumptions on transmission and distribution although the R45/km assumption for trucking distribution would include margin. In this instance it is not clear if this kind of distribution would be subject to NERSA's regulations as they are specific to 'piped gas' although these refer to "transportation" in the build-up of costs. The purpose of this model was however to gain high level insights into the cost benefit of natural gas substitution of petrol and diesel not exhaustively simulate a planned system.

Future work should add more detail on margins in the value chain based on NERSA's methodology liasing with them on the likely amendments for truck or based distribution of LNG. The model was shared with the Western Cape Government and can form the basis for this.

9.2 Passenger Cars

The following are the factors that were considered in the assessment of the potential for natural gas uptake in the passenger car mode:

- Battery electric cars have considerable momentum behind them. While battery electric vehicle vehicles still only accounted for around 0.3% of sales in OECD countries in 2017, sales growth was 63% (IEA, 2018) compared to 2016. There are now 40 battery electric vehicle models available in California in a regime of very large subsidies that sees large electricity utilities like PG&E[14], the state government and federal government all simultaneously offer generous rebates and subsidies for switching to an electric vehicle.
- Given South Africa's small market it is hard to see dedicated gas-powered passenger cars being imported into the country with support for maintenance and sales unless there are very extreme gas / crude oil price differentials.
- The payback calculator (Appendix D) indicated that, under price conditions of $3/MMBtu Henry Hub and $75/bbl Brent Crude, the payback on CNG bi-fuelled conversions would be just over 7 years. However, the investment in distribution infrastructure for private transport would be prohibitive.
- Realistically, the potential uptake in this mode is likely restricted to retrofits in captive fleets.

In the view of the project team potential uptake in the passenger car mode is not beyond 0.5 – 2% under favourable conditions

[14] https://www.pge.com/en_US/residential/solar-and-vehicles/options/clean-vehicles/electric/clean-fuel-rebate-for-electric-vehicles.page

9.3 Minibus Taxis

The following are the factors that were considered in the assessment of the potential for natural gas uptake in the minibus taxi mode:

- The payback calculator (Appendix D) indicated that retro-fitting petrol minibus taxis (92% of the fleet) has the most favourable payback of fuel switching of any mode because of the high mileage and low conversion cost. At $3/MMBtu Henry Hub and $75/bbl Brent Crude, payback on CNG bi-fuelled conversions would be around 1.7 years for an annual usage of 35,000 km.
- An existing pilot run by the Industrial Development Corporation (IDC) in Gauteng which converted the 500 vehicles of members of the SUNTACO taxi association has been modestly successful (Emslie, Taylor, & Goosen, 2014) but the participants are frustrated by 'lack of access to the value chain' and this threatens the project (Emslie, 2018).
- Previous pilots in Mitchell's Plein, Cape Town have however failed in attempts to integrate minibus operators into the conventional fuel value chain. The challenge appears to be the resulting division of business focus of these small-medium type enterprises in concurrently undertaking two very challenging operational businesses with completely divergent requirements in safety and due diligence (McLachlan, 2018).
- Maintaining the conversions and infrastructure of the SUNTACO project has been a challenge and around 300 vehicles of the original 500 are still operating on gas (Emslie, Interview, 2018).
- Registered minibuses are falling in number (see Table A- 11) while formal transport networks in the large cities are expanding underwritten by Public Transport Infrastructure Grants (PTIG) from national treasury (National Treasury, 2014).
- It is unclear what the spectrum of informality is across the whole minibus taxi industry but the lived experience of any motorist speak to it being very wide. The "so-called" buy-in / buy-out schemes whereby municipal bus operators partnered with former minibus operators in bus rapid transit expansion (Von Der Heyden, Hastings, & Leitner, 2014) will have taken a significant number of the more formal players out of the space over the last ten years. Some of the remaining operators will likely transition to formal feeders of mass transit in the evolving public transport networks of major cities (City of Cape Town, 2016) while others remain at the margins legally and economically.
- While economically very attractive even if gas is taxed, it will take specific sector expertise, extensive stakeholder engagement and concerted market development with a strong black economic empowerment bias to unlock this potential.
- The business model development of the small enterprises undertaking maintenance of the retrofits and the structure of their contracts would be one of the most important drivers of sustained success.

In the view of the project team the potential range of substitution is 3 – 30% under favourable price conditions and active market development.

9.4 Light Commercial Vehicles (LCV)

The following are the factors that were considered in the assessment of the potential for natural gas uptake in the LCV mode:

- Similarly to minibus taxis, retro-fitting petrol LCVs (57% of the LCV fleet) also has a potentially favourable payback (see Appendix D) because of the typically high mileage and low conversion cost for spark-ignition engines.

- For a price regime of $3/MMBtu Henry Hub and $75/bbl Brent Crude, payback on CNG bi-fuelled conversions would be around 2.1 years for a usage of 30,000 km per annum.
- Dual-fuel conversions of diesel fuelled LCVs are too capital intensive for this type of vehicle and would not be viable. Diesel LCV penetration of the LCV mode grew at over 4% year on year from 2000 to 2014 (DoE, accessed 2018) and so the pool of petrol LCVs has been diminishing. Presumably however, with the restrictions on diesel vehicles emerging in cities in the EU[15] this trend may reverse in time.
- The challenge in expanding natural gas into this mode is the sheer diversity of operators involved in the redistribution of goods and the transport of materials.
- Battery electric vehicles are definitely challengers in this space particularly for light courier services. The EPA's Alternative Fuel Vehicle database[16] indicates that in the US market 7 models of battery electric van and 9 models of hybrid electric van were available in 2017/18 compared to 11 models of CNG and CNG compatible van.

In the view of the project team the potential range of substitution is 5 – 15% under favourable price conditions and active market development.

9.5 Commuter Buses

The following are the factors that were considered in the assessment of the potential for natural gas uptake in the Commuter Bus mode:

- In principle, municipal bus fleets are ideal for fuel switching because they are captive fleets with central refueling and drive high annual mileage which will result in fuel savings paying back quicker.
- Dual Fuel Retrofits are however expensive and dedicated gas vehicle capex premiums are quite high at around 12% for CNG with LNG storage a further 16% (Short & Goldblatt, 2017) (Berg, 2012).
- Conventional commuter buses are diesel fuelled which is cheaper per unit energy than petrol (Table D- 1) so the rate of payback is slower than for the petrol fuelled vehicles discussed above. As such the payback on dedicated CNG 18 m buses with a 48,000 km annual mileage as estimated in this investigation only approaches 5 years at oil prices of over $95/bbl and Henry Hub gas price of below R1.50/MMBtu if the comparison excludes taxes and levies.
- LNG is however a far better economic prospect paying back for an 18m bus covering 48,000 km per annum in under 5 years for a Brent oil price of $75/bbl and a Henry Hub gas price of $3/MMBtu.
- The City of Johannesburg (CoJ) undertook an extensive program of gas-diesel dual fuel (DDF) retrofits and procurement of buses with dual fuel technology. 150 buses in total have DDF capability but are not deemed cost effective in the current operational circumstances (Bihman, 2018). The Diesel Dual Fuel experiment by CoJ will could discourage more attempts unless the value proposition is very convincing.
- CoJ undertook a cost benefit analysis of its options which concluded that battery electric buses were competitive with diesel options in terms of the cost of ownership and emissions externality costs (Short & Goldblatt, 2017). This has resulted in CoJ viewing electric buses as their best option for future procurement of low emission buses (Bihman, 2018).

[15] https://www.express.co.uk/life-style/cars/925353/Germany-diesel-ban-fuel-Europe-cars
[16] www.fueleconomy.gov

- An Atlantic based company, CA components, producing gas powered CHP units could convert Cape Town's Golden Arrow bus company's fleet to gas as their base engines have a common mounting footprint with most of the fleet (Myburg, 2018). A ballpark price estimate is however around R400,000 per conversion which is very capital intensive for this application unless prices are very favourable.
- Cape Town is running a large pilot of 11 battery electric buses[17] supplied by Chinese manufacturer BYD. While TDA have said they are open to gas as a fuel (Jobanputra, Covary, Sasman, & Haw, 2018) the logistic burdens of a third fuel and the city's commitment to net zero carbon emissions by 2050[18] make gas uptake in this city a challenge.
- Tour bus potential was roughly estimated as part of this project as around 65 TJ per annum (Section 5.1) with these fleets relatively small compared to the commuter fleets. The potential may however exist to develop this market as "green tourism"

In the view of the project team the potential range of substitution is 3 – 20% under favourable price conditions and active market development.

9.6 MCV and HCV Metropolitan Freight

The following are the factors that were considered in the assessment of the potential for natural gas uptake in the Metropolitan Freight mode:

- Metropolitan freight has a similar payback regime to commuter buses for CNG requiring high price differentials if the comparison excludes taxes and levies.
- But LNG dual fuel retrofits could payback in 4 years at $3 Henry Hub and $75/bbl Brent Crude in cases where mileage is as much as 100,000 km.
- South African breweries have indicated they will go gas with some of their fleet to be supplied by Free State based helium producers Renergen in 2019 (Leidke, 2018).
- Scania are also looking to initiate a CNG pilot in the Gauteng area (Templeton, 2018).
- Metropolitan freight redeploys a lot of so-called 2nd life trucks and so penetration of new dedicated gas vehicles would be relatively slow (Templeton, 2018).

In the view of the project team the potential range of substitution is 5 – 30% under favourable price conditions and active market development.

9.7 HCV Long Haul Freight

The following are the factors that were considered in the assessment of the potential for natural gas uptake in the Long Haul HCV mode:

- Unless oil / gas price differentials are very high, CNG typically doesn't readily pay back in this space and the low range of CNG trucks is in any event prohibitive without massive investment in refuelling stations. This is in turn contingent on an established transmission infrastructure.
- Increased ranges are offered by new long haul LNG truck products such as the Iveco Strialis (up to 1600 km) and Volvo FH LNG and FM LNG (up to 1000 km). The implication is that in the Western

[17] https://www.tda.gov.za/en/news-and-events/press-releases/articles/multiple-tests-confirm-electric-buses-meet-Citys-expectations-on-all-route-profiles-be-it-downhill-or-uphill/page-1/

[18] https://www.lifegate.com/people/news/25-cities-zero-emissions-2050-c40

Cape scenario, one corridor refuelling node should be sufficient to support gas fuelled long haul trucking on the N1 route to Gauteng. Potentially this could be supplied by rail either extending this rail fuel transport all the way to Gauteng or building a small scale liquefaction plant in Gauteng taking gas from the SASOL pipeline as input. The latter is however potentially quite expensive at around an additional $11/MMBtu on the gas price (see Appendix G).

- The advantage of this mode is trucks turn over quickly (1st life) due to the very high annual mileages of as much as 150,000 km per annum (RFA, 2009)
- This is a highly competitive industry with tight margins and no room for error in logistics. It is therefore not easy to do pilots but local project developer Volco Power indicated that they have a long haul LNG pilot customer in the Western Cape which they are looking to supply with LNG imported in adapted containers (Olivier, 2018).
- Fuel price volatility would be highly impactful on end users and contract terms in the fuel supply would be very important. Market stimulation may require a sovereign fund that would bridge periods of unfavourable prices so that contracted prices can be guaranteed.
- A major barrier to implementation is whether the OEMs will get the ball rolling by bringing in gas fuelled models to such a small market where there is limited support for the technology. Locally Iveco and Scania however seem to be looking for market differentiation through gas but project developers should not look to OEMs to put significant money into pilots.

In the view of the project team the potential range of substitution is 5 – 50% under favourable price conditions and active market development.

9.8 Rail

The following are the factors considered in the assessment of the potential for natural gas uptake in the Freight Rail and Long Distance Passenger Rail mode:

- Unfortunately the rail utility Transnet did not want to engage on the issue of fuel switching of their diesel locomotives.
- The local agency of engine manufacturer MTU who supply Transnet with engines do however have an interest in gas because their parent company (Rolls Royce) is investing heavily in R&D in the medium speed engine space (Collair, 2018).
- The technology will therefore be available but locomotives have long lives and the country has just made a very large and very public procurement[19]
- Short and medium term potential would likely be mostly through dual fuel retrofits (MTU recommended Gauteng based FAR Diesel Power Services as agents for conversion kits for this size engine)
- A possible barrier is that Transnet would have to have an appetite for handling this fuel across their integrated network.

In the case of rail gas uptake potential seemed highly uncertain at this stage and was not quantified. Historical data, while of poor quality[20], suggests that around 1 – 2 PJ of diesel is used by rail in the Western Province.

[19] https://www.railjournal.com/locomotives/transnet-south-africa-orders-1064-locomotives/

[20] Transnet publishes its energy demand but does not indicate a regional split. Wholesalers made early inroads into supplying diesel to Transnet and so the DoE data attributed to rail is not reflective of actual volumes.

9.9 Marine

A more detailed assessment of marine demand potential than discussed here is presented in Appendix H. In the longer term, with two large ports in the Western Cape, this is seen as a significant opportunity by the project team. The following are, in brief, the factors considered in the assessment of the potential for natural gas uptake in Marine Bunkering:

- Marine bunkering in Cape Town has dropped from 50 PJ in 2009 to 1.5 PJ in 2016 (Table A- 5). The reasons for the collapse of the industry are briefly discussed in Appendix H4.
- The International Bunker Industry Association (IBIA) recognises natural gas as a longer term shipping fuel but they and other local industry players are not of the view that natural gas is going to be a significant marine fuel for some time. This is in spite of the impending MARPOL[21] regulations limiting sulphur emissions. The view is that scrubbers and distillate blending will be the means by which sulphur emissions are mitigated for some time to come (Murphy, 2018) (Pillay, 2018).
- Against this, engine supplier MTU (Rolls Royce), a big player in the medium speed engine space is moving R&D from diesel into gas including for marine applications (Collair, 2018). This suggests that growth in LNG fuelled shipping may be quicker than IBIA anticipate.
- Stakeholders engaged at the Astron Refinery expressed a view that immediate demand after the MARPOL 2020 sulphur emissions regulation limit[21] commencement will be satisfied by distillate blending and scrubbers. They plan to mitigate and not invest on this basis, rather adopting a wait & see strategy over what may be as long as a 5 – 10 year disruption period (Pillay, 2018).
- Beyond MARPOL the shipping industry is committed to reduce its CO_2 emissions by half by 2050 (Murphy, 2018).

In the view of the project team a marine bunkering LNG uptake potential of 20 - 50 PJ on a 20 - 30-year view is possible depending on:

i. **A steadily growing rate of LNG penetration into the global fleet displacing distillate dilution of high sulphur residual fuels and the use of scrubbers to meet emissions regulations.**
ii. **An aggressive bunkering industry recovery plan pursued and bought into by all stakeholders. This will need to start with recovering the traditional residual fuel market but now complaint to MARPOL and so the Astron Refinery will be a key partner.**

10 Key Output 1: An Estimate of the Range of Natural Gas Potential by Mode

The ranges of potential natural gas market penetration by mode were combined with the base case projections of the vehicle parc described in Appendix C to build-up upper and lower outcomes for natural gas uptake in energy terms into the future from the contributions of each mode. The results are presented below in Figure 19 and Note: *See* Figure C- 20 *for data table*

Figure 20. These are combined into a range, shown in Figure 21 into which, in the opinion of the consultants, the demand from the transport sector will probably fall given a natural gas supply at scale.

[21] http://www.imo.org/en/mediacentre/hottopics/ghg/documents/faq_2020_english.pdf

The uncertainties are viewed as large and the value of this exercise is seen as developing a plausible range of what the transport sector could contribute to a natural gas energy economy in the Western Cape.

The dotted line shown in Figure 21 shows one of many possible pathways. By way of example, a possible storyline for that pathway would be a delayed ramp up in demand due to infrastructure development but then successful market development in one or more modes with quite rapid curtailment nearing 2050 due to aggressive global action against climate change and competing electro-mobility technologies in the heavy-duty modes. The intention of this exercise is not however to develop such scenarios because currently there is not enough information to give one precedence over another. Rather the point is to convey a sense of scale of both the potential uptake and its uncertainty as well as the drivers of a low or high pathway. The following are important features of the upper and lower limits.

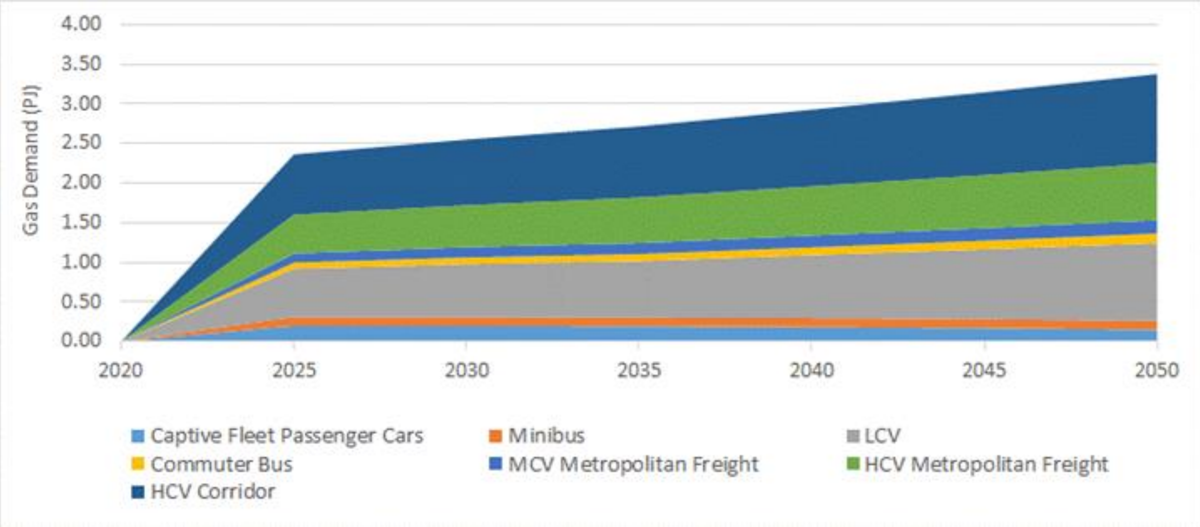
- They have been calculated by multiplying the percentage penetration ranges estimated in Section 9 above by the relevant mode demand (e.g. Petrol LCV but not Diesel LCV) as projected by the vehicle parc model (see Appendix C6) for each year of the projection. This converts the percentage penetration into a demand for energy.
- In Section 9 above the primary considerations in deriving an estimated potential were economic feasibility of that mode given a range of typical price differentials between natural gas and petroleum fuels, infrastructure demands for that mode and any institutional barriers. The final numbers were therefore the result of expert opinion after review of both quantitative and qualitative data. The upper and lower limits in energy units presented below should be understood in the same way.
- A range is proposed not only to reflect large uncertainties such as price and competition from other new technologies but also the level of active market development by both public and private sectors. The following storylines illustrate the drivers of an outcome tending either to the upper or lower limits:
    - In the short and medium term, given that a bulk LNG supply is present and if natural gas remains cheaper than petrol or diesel, the outcome will plausibly tend towards the upper end of the range with active market development, favourable policy and the debottlenecking of approvals and licenses. The availability of heavy-duty truck models in South Africa at premiums no higher than the parent markets is also extremely key to this outcome and the co-operation of the OEMs in this regard should not be assumed.
    - Low oil prices relative to gas, failure of stakeholders to work together and regulatory gatekeeping will skew outcomes to the lower end. Given the pivotal role of heavy commercial demand, the realisation of competitive pressure from alternatives such as battery electric vehicles, fuel cell vehicles, fuel cell-battery electric hybrids and catenaries would make the lower demand scenario more likely. The risk of this is far higher after 2030.

The upward sloping dotted arrow in *Note: See* Figure C- 20 *for data table*

- Figure 20 illustrates the possible, but at this stage highly uncertain, additional potential uptake of natural gas by marine bunkering discussed in detail in Appendix H. The findings of this section draw the following conclusion, "*A potential of 20 - 50 PJ on a 20 - 30-year view may not be unreasonable depending on the rate of LNG penetration into the global shipping fleet.*" This has not been added as a wedge on the basis that it can be considered to balance the risk of fuel cells and/or battery technologies displacing gains in gas penetration after 2030.

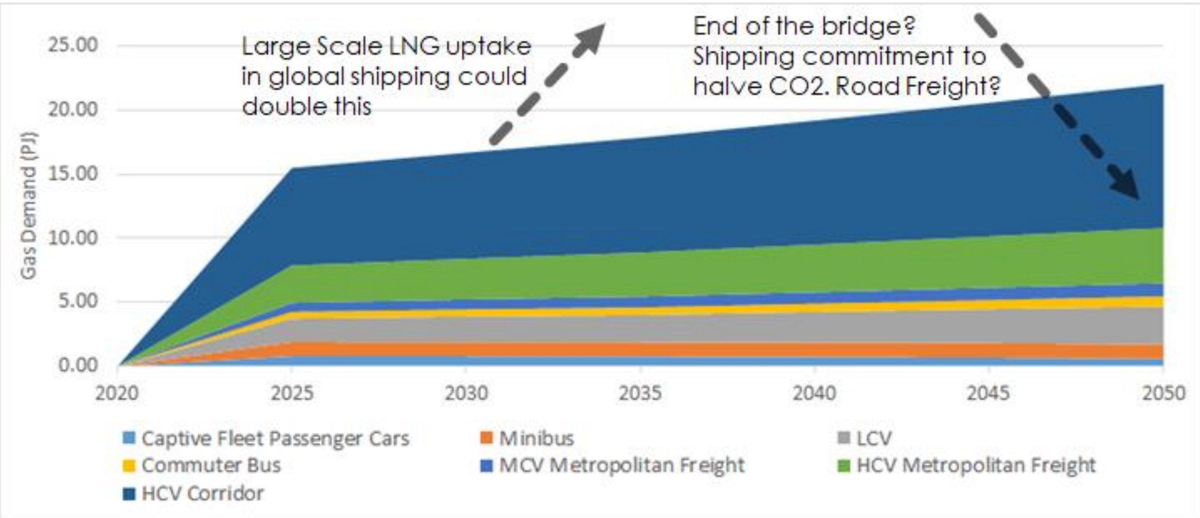
- The downward sloping dotted arrow serves as a warning of the often quoted idea of natural gas being a bridge fuel to a low or zero carbon future. The marine bunkering demand is especially susceptible to a hard end to this bridge because it is driven purely by international markets over which local policy exercises no control. Beyond the MARPOL sulphur regulations, the International Maritime Organisation (IMO) has committed the shipping industry to reduce its CO_2 emissions by half by 2050 (Gabbatiss, 2018) (Murphy, 2018)

- The ramp up of demand between 2020 and 2025 is similarly not deterministic and is premised simply on gas becoming available in 2020, possibly only at small scale with the supply maturing until 2025 to the point of an LNG terminal with associated transmission and distribution infrastructure being in place. The range of penetration rates presented in Section 9 are applied from 2025 onwards and interpolated between 2020 and 2025 assuming zero uptake in 2020.



Note: See Figure C- 19 for data table

Figure 19: Build-up of Lower Natural Gas Uptake Estimate (Moderate oil price and Moderate Gas Price but enough differential for CNG retrofits and bulk LNG; inactive Market Development)



Note: See Figure C- 20 *for data table*

Figure 20: Build-up of Upper Gas Uptake Estimate (High oil price and Low gas Price; Highly Active Market Development)

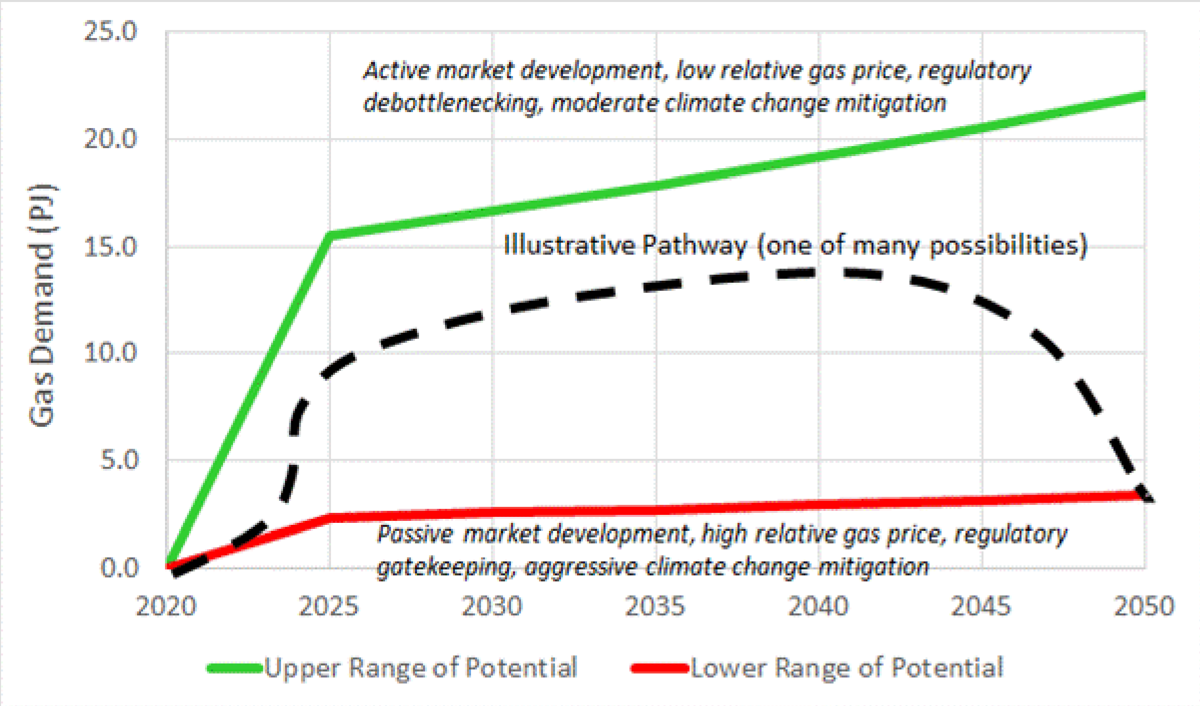


Figure 21: Combination of Upper and Lower Potential Estimates into a Probable Range of Natural Gas Uptake by the Transport Sector

The purpose of considering these numbers, as perceived by the project team, is to act to realise them should a bulk LNG supply project need this demand to be more economically viable. While the project team may not necessarily start from the viewpoint that natural gas is beneficial to the transport sector on a stand-alone basis, there appears to be a strong case that an LNG supply is positive for the provincial economy in general.

In the longer term, the outcomes of the electro-mobility disruption, including the emergence of cost competitive hydrogen fuel cells for heavy duty applications, and the aggression with which climate change mitigation may be pursued globally are the largest uncertainties. There is however a reasonable possibility that marine bunkering supply could fill the gap of a shift to electro-mobility in the heavy duty truck space in the medium term.

11 Findings

Focus Area A of the Terms of Reference defined a wide range of transport, energy and economic statistics as deliverables. These were required to define the parameters of the transport landscape in the Western Cape that faces potential disruption and offers potential for natural gas substitution. An extensive data collection exercise supported by modelling informed the detailed statistical annex presented in Appendix A. In line with the project methodology (see Figure 1) this exercise then informed an analysis of demand that was intended to feed into the key project outputs as follows:

- **Key Output 1:** An estimated range of LNG Potential by Mode
- **Key Output 2:** A summary of key risks, consequences and potential mitigations

- **Key Output 3:** A general Assessment of the viability of LNG uptake in the Western cape transport sector
- **Key Output 4:** An Actions Timeline for the Western Cape to stimulate LNG uptake in the Transport Sector
- **Key Output 5:** Other Actions and Insights coming out of the analysis

Report 2 will synthesise all the outputs but this report in addition to **Key Output 1** presented in Section 10 presents findings that inform **Key Output 3** and **Key Output 5** below.

11.1 Findings Relating to Key Output 3: General Assessment of the Viability of Natural Gas Uptake in the Transport Sector

- The Western Cape economy, in common with the rest of South Africa has a freight intensive economy with goods concentrated on corridors, in particular the N1 which accounts for over 50% of total tonne-km of freight activity in the province (see Table A- 23) Metropolitan distribution with heavier vehicles accounts for about 5% of tonne-km due to shorter trip distance.. This concentration on corridors and the scale of logistics companies that have developed to provide freight services in this environment provide the largest opportunity for liquid fuel substitution by natural gas
- The statistics show most current corridor fuelling actually happens in Cape Town and so a corridor gas fuelling station would likely only need one refuelling point in the case of LNG trucks. Current models have claimed ranges of 1000 km (Volvo FH LNG and FM LNG) to 1600 km (Iveco Strialis – see Appendix E), the latter comparable to diesel truck ranges. CNG trucks having much lower range, are more suited to local (intra-metropole) freight distribution (see Appendix D2 for detail). An LNG refuelling station would need to be within 1000 km of both Cape Town and Gauteng (vicinity of Colesburg) and near the railway line so that LNG supply could be railed.
- The Food and Beverages manufacturing sector is highly freight intensive and an important exporter of goods to Gauteng and provider of employment growth. This sector could be a key target for market stimulation of natural gas fuel switching or shifting to rail where viable.
- The substitution of petrol offers significantly better paybacks than diesel because its cost per unit energy is higher. Retro-fit technology is also cheap and typically pays back in a year or two for most price scenarios. Captive petrol fleets exist in the minibus taxi industry and in LCV applications like courier companies.
- There are current pilots in the metropolitan freight space but CNG paybacks don't seem attractive unless prices are very favourable and the fuel is not taxed (see Appendix D2 for detail on Cost Benefit Analysis). A tax holiday would effectively be a subsidy and not sustainable or equitable in the long term (see Report 2, Task D – Socio Economic Impacts). LNG may be an option in metropolitan freight for operators that can accommodate this technology and the extra capital cost.

11.2 Findings Related to Key Output 4: An Actions Timeline for the Western Cape to stimulate natural gas uptake in the Transport Sector

- The scale of freight operations on the N1 corridor therefore make it ideal for a long-haul pilot but LNG rather than CNG fuelling is required to make practical use of long range gas truck technology. The existing gas supply in Gauteng is compressed so a pilot would need either to rail up LNG to both a midway station and to the end point in Gauteng or else deploy a small-scale liquefaction plant in Gauteng. This decision would require a detailed feasibility study but indicative costs are presented in Appendix D2 and Appendix G and can be summarised as follows:

  - Dispensing Costs (Corridor & Gauteng Station): +/- R30/GJ
  - Rail Costs (Corridor Station): +/- R45/GJ @ R2/tkm[22]
  - Rail Costs (Gauteng Station): +/- R67/GJ @ R2/tkm
  - Small Scale Liquefaction Plant including dispensing, storage and transport: +/- R150/GJ

- These estimates are far from conclusive but suggest that if LNG was needed in Gauteng it might be competitive to rail it from the coast particularly Richard's Bay. If landed costs were low enough a pilot might even be able to pass the full amortised costs of the installation to the customer.
- Fortunately, the IDC has initiated a large minibus taxi pilot in Gauteng which provides many useful lessons but has also highlighted the barriers to success. It would make sense to leverage this project and those who worked on it as much as possible in planning for natural gas transport sector market development.
- In the case of petrol minibuses and LCVs which have the most attractive economics if they can be centrally fuelled, this is a case of trying to reach many niches and market stimulus in this space will require targeted information and a rapidly deployable turnkey solution for providing the fuel and the conversion kits.
- Large logistics companies supplying long-haul services turn over truck stock quickly (1st life) before selling vehicles on for other uses (2nd life). Building a market therefore requires targeting these companies early on to build market momentum. A contracted gas price that guarantees operational costs over the 1st life of a new LNG truck would be a powerful incentive to fuel switching.

11.3 Findings Relating to Key Output 5: Other Actions and Insights Coming out of the Analysis

- Agriculture and moving around agricultural products and derivatives is far more important to the Western Cape economy even than the 8% sector share of GDPR suggests. Agriculture and the Food and Beverages manufacturing sector are large employers have been extremely valuable generators of employment growth against a backdrop of a shrinking manufacturing sector.

- Real petrol and diesel prices have escalated in line with oil at around 2.9% p.a. (in $ terms) on a 30 year view and are highly correlated to oil price and rand/dollar (R^2 = 93-95%). While taxes and levies have returned to previous highs in 1988, in general fuel prices track the oil price and the rand dollar exchange rate quite closely.

- Tourism in the Western Cape is very car centered and petrol demand is highly seasonal. Targeting this market could create a small but significant boost for sustainable transport. The Uber e-hailing service is seeing very rapid growth with tourists and could provide opportunities for promoting 'green' tourism.

- This demand for passenger transport by the tourism sector is significant at just over 6% of total demand estimated for the province and is of the order of the entire Metro Rail system demand in 2012 (Table A- 16).

[22] SA fleet average in 2013 was 90c/tkm with rail generally cheaper for bulk commodities. Source: CSIR (2013), State of Logistics 2013 – Bold Steps Forward

- Furthermore, as shown in Table A- 24 in a comparison to the freight demand and GDPR contribution of economic sectors, tourism contributes over 4% to provincial GDPR, similar in scale to key sectors such as Food and Beverage manufacture and Agriculture. It is clear that planning and policy making for tourism transport is important.
- This is reflected in the wealth of statistics collected by South African Tourism[23], Cape Town Tourism and Stats SA. These surveys could be far better leveraged for more technically useful data with little effort which would be useful, when combined with appropriate tourist orientated marketing and ticketing solutions in shifting the current tourist transport demand away from passenger cars.

- Modelling using the tool described in Appendix B2, suggests that the official fuel sales data provides quite a poor picture of fuel demand on a regional basis. The results suggest that the true demand for Cape Town lies somewhere in the range from the DoE figure down to 25% less, Mossel Bay ranges down to 70% less and the other municipalities from 50% less to as much as 100% higher. Langeberg Municipality is an example of a municipality where attributed fuel volumes seem particularly low.

- In general, the data landscape has improved relative to previous years in terms of the scope of sources and the professionalism of personnel charged with a data mandate. The following general data problems however persist:
    - In most cases there is a complete lack of scientifically relevant metadata
    - Data is often poorly validated
    - Data is published in non-machine-readable formats in discreet files for short time periods making repurposing very difficult
    - Organisations without a data mandate have a poor culture of transparency and are reluctant to respond to requests for data. The prevailing principle is that all data is proprietary until there is a compelling reason or explicit external instruction to make it public rather than the reverse. A competitive economy and indeed a healthy society however require a strong public data culture.
- This project has unequivocally demonstrated that it is now no longer possible to produce an accurate greenhouse gas inventory at local or regional level for South Africa due to supply side data quality. This is not unique to South Africa as Uganda has over 50 fuel suppliers. Model based imputation is the standard industry alternative but this is not simply a question of leveraging existing traffic models. Energy modellers and transport modellers are interested in different things and their models typically don't reconcile without quite a lot of engagement. This engagement needs to happen and in the context of far greater positive engagement around data quality between stakeholders.
- The energy intensity of agriculture and other sectors that use significant volumes of diesel in off-road applications needs to be better understood in the future to have more certainty about off-road demand. Similarly, credible local energy intensities per unit output are required for construction and mining activities in order to improve our understanding of how diesel is used. This type of bottom-up data will be needed to compensate for the lack of credible supply-side data in order to adequately quantify national, regional and local level energy demand and emissions in the future.
- The possibility of rapid penetration of BEV vehicles into the passenger car market, such that they account for 100% of sales by 2035, has the potential to reduce petrol demand by half by 2040

[23] https://www.southafrica.net/gl/en/corporate

while diesel will likely still grow. This storyline implies not only cost parity between EVs and ICE vehicles in the global market by around 2025 but that sufficient models representing this market are available in South Africa. This result accounts for a high average vehicle age diluting the penetration of EVs into the market even though sales are high. The implications are serious in terms of the balance of products (slate) produced by local refining capacity given that diesel could still grow strongly.

- A Ride-sharing disruption combined with a shift to lower carbon transport has the potential to reduce demand for petrol by over 20% by 2040 relative to today even though demand for transport will have grown significantly. This would however require the urban bus system to attain and maintain passenger-km supply growth rates of 4.5% annualized and the rail system to recover and attain and maintain passenger-km supply growth rates of 2.5% annualised. The use of SUV's would have to decline by 1% annualized although this is against the trend now seen in the United States for example (Bloomberg, 2018). Realistically, there is neither the will not the money currently to approach these mode shifts but ride-sharing is a potentially low-cost rapidly deploying game changer that can reduce passenger-km and therefore, potentially energy demand, by 30% relative to baseline (not today's demand) or around 14 PJ by 2040[24].

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[24] Estimated using the ratio of occupancies with and without ride sharing - see Table C- 4 above: 1 – (1.4/1.995) = 30%

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Appendix A Statistical Abstract

Appendix A1 Selected Socio-Economic Data for the Western Cape

Table A- 1: Population Growth in the Western Cape and the City of Cape Town (1996 – 2017)

Year	City of Cape Town	Western Cape	Source
1996	2,562,277	3,956,875	(Stats SA, 2014)
2001	2,892,243	4,524,335	(Stats SA, 2014)
2011	3,740,026	5,822,734	(Stats SA, 2014)
2014		6,082,849	(WCG, 2014)
2017	4,232,276	6,510,000	(WCG, 2017a)
CAGR (2011-2017)	**2.1%**	**1.9%**	

Table A- 2: Census Data for Population in the Local Municipalities of the Western Cape 1996, 2001 and 2011

District & Local Municipality	1996	2001	2011	CAGR 1996-2001	CAGR 2001-2011	Share 2011
West Coast	**234,952**	**282,672**	**391,766**	**3.8%**	**3.3%**	**6.7%**
Matzikama	43,906	54,199	67,147	4.3%	2.2%	1.2%
Cederberg	31,704	39,559	49,768	4.5%	2.3%	0.9%
Bergrivier	37,485	46,538	61,897	4.4%	2.9%	1.1%
Saldanha Bay	56,557	70,261	99,193	4.4%	3.5%	1.7%
Swartland	65,301	72,115	113,762	2.0%	4.7%	2.0%
Cape Winelands	**563,783**	**630,284**	**787,490**	**2.3%**	**2.3%**	**13.5%**
Witzenberg	76,386	89,087	115,946	3.1%	2.7%	2.0%
Drakenstein	186,334	194,417	251,262	0.9%	2.6%	4.3%
Stellenbosch	103,996	118,709	155,733	2.7%	2.8%	2.7%
Breede Valley	129,984	146,387	166,825	2.4%	1.3%	2.9%
Langeberg	67,083	81,684	97,724	4.0%	1.8%	1.7%
Overberg	**158,862**	**203,729**	**258,176**	**5.1%**	**2.4%**	**4.4%**
Swellendam	24,579	28,285	35,916	2.8%	2.4%	0.6%
Theewaterskloof	74,582	93,276	108,790	4.6%	1.6%	1.9%
Overstrand	36,686	55,012	80,432	8.4%	3.9%	1.4%
Cape Agulhas	23,015	27,155	33,038	3.4%	2.0%	0.6%
Eden	**380,887**	**454,924**	**574,265**	**3.6%**	**2.4%**	**9.9%**
Kannaland	21,190	23,971	24,767	2.5%	0.3%	0.4%
Hessequa	38,553	44,114	52,642	2.7%	1.8%	0.9%
Mossel Bay	59,789	71,494	89,430	3.6%	2.3%	1.5%
George	120,148	149,436	193,672	4.5%	2.6%	3.3%
Oudtshoorn	79,181	84,692	95,933	1.4%	1.3%	1.6%
Bitou	18,427	29,182	49,162	9.6%	5.4%	0.8%
Knysna	43,599	52,035	68,659	3.6%	2.8%	1.2%
Central Karoo	**56,114**	**60,483**	**71,011**	**1.5%**	**1.6%**	**1.2%**

Laingsburg	5,913	6,680	8,289	2.5%	2.2%	0.1%
Prince Albert	9,508	10,512	13,136	2.0%	2.3%	0.2%
Beaufort West	40,693	43,290	49,586	1.2%	1.4%	0.9%
City of Cape Town	**2,562,277**	**2,892,243**	**3,740,026**	**2.5%**	**2.6%**	**64.2%**
Western Cape	**3,956,875**	**4,524,335**	**5,822,734**	**2.7%**	**2.6%**	**100%**

Source: (Stats SA, 2014)

Table A- 3: Share of Economic Output of Districts in the Western Cape

District Municipality	Share of Economic Output (2015)
West Coast	5%
Cape Winelands	11%
City of Cape Town	72%
Overberg	3%
Central Karoo	1%
Eden	8%

Source: (WCG, 2017b)

Table A- 4: Share of GDPR and CAGR of GDPR by Sector for the City of Cape Town and the Western Cape

Sector	City of Cape Town[1]			Western Cape[2]	
	Share of GDPR (%) 2015	CAGR (2005-2015)	CAGR (2010-2015)	Share of GDPR (%) 2015	CAGR (2010-2015)
Primary Sector	**1.5%**	**3.1%**	**3.9%**	**4.6%**	**2.6%**
Agriculture, forestry and fishing	1.3%	3.7%	4.1%	4.3%	2.6%
Mining and quarrying	0.2%	-0.1%	3.1%	0.3%	2.9%
Secondary Sector	**23.6%**	**1.9%**	**1.3%**	**21.5%**	**1.3%**
Manufacturing	15.0%	1.6%	1.2%	15.2%	1.1%
Electricity, gas and water	3.0%	-0.7%	-0.5%	1.9%	-0.4%
Construction	5.6%	5.2%	2.8%	4.4%	2.9%
Tertiary Sector	**74.9%**	**3.2%**	**2.8%**	**74.0%**	**3.0%**
Wholesale and retail trade, catering and accommodation	16.9%	2.6%	2.7%	16.1%	2.9%
Transport, storage and communication	11.6%	2.6%	2.2%	10.2%	2.4%
Finance, real estate and business services	27.8%	3.8%	3.0%	30.1%	3.3%
General government	11.8%	3.9%	3.8%	10.8%	3.5%
Community and social services	6.7%	2.0%	1.8%	6.7%	2.0%
Total	**100**	**2.9%**	**2.5%**	**100.0%**	**2.6%**

1: Source - (WCG, 2017a)

2: Source - (WCG, 2017b)

Figure A- 1: The Share of the Real Economy Sectors in the Western Cape (TIPS, 2016)

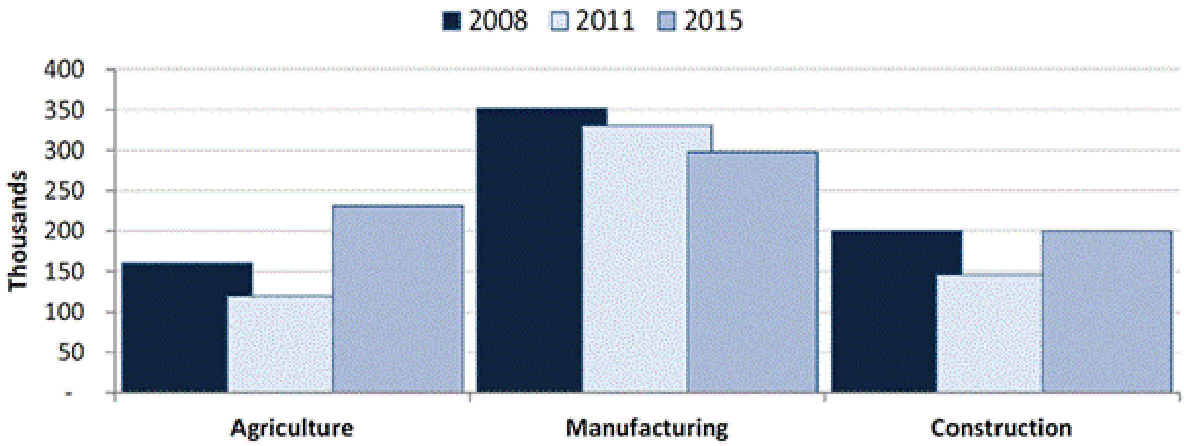


Figure A- 2: Western Cape Employment in Main Sectors of the Real Economy 2008, 2011 and 2015 (TIPS, 2016)

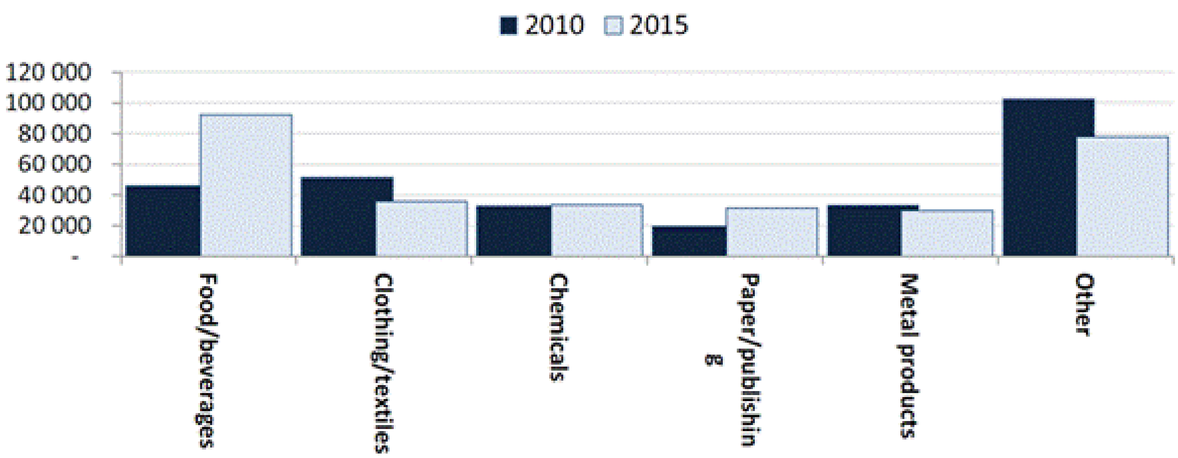


Figure A- 3: Western Cape Employment in Manufacturing by Industry (TIPS, 2016)

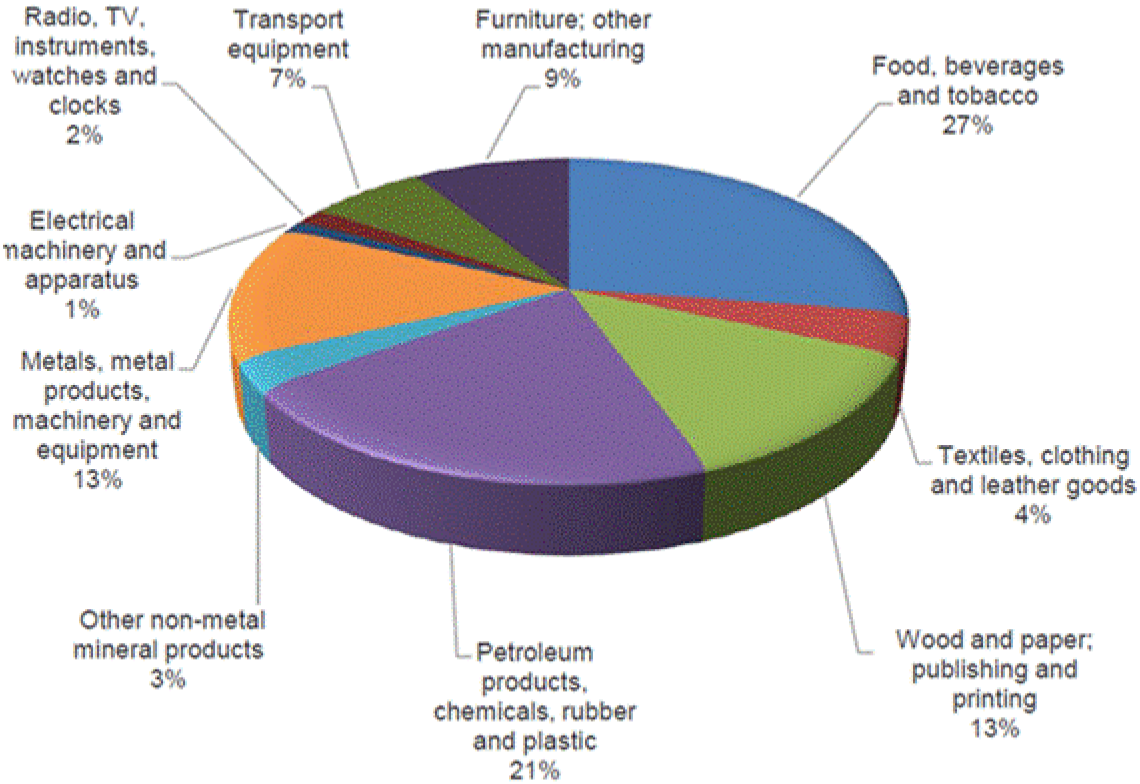


Figure A- 4: Sub-Sector Breakdown of Cape Town's Manufacturing Sector 2015 (Wesgro, 2016)

Appendix A2 Energy and Transport Data for the Western Cape

Table A- 5: The Evolution of Demand for Petroleum Transport Fuels in the Western Cape 2000 - 2016[1]

Year	Jet Fuel (PJ)	Aviation Gasoline (PJ)[2]	Diesel (PJ)[3]	Petrol (PJ)	Marine Fuel Oil (PJ)[4]
2000	13.7	0.12	48.6	56.7	57.0
2001	13.0	0.13	47.6	56.6	68.6
2002	12.0	0.11	45.1	57.0	52.0
2003	12.0	0.11	45.2	58.2	49.8
2004	13.9	0.12	49.3	59.5	45.8
2005	14.1	0.13	51.8	60.2	48.0
2006	14.7	0.09	53.1	60.7	35.0
2007	15.7	0.09	70.0	61.5	42.4
2008	17.0	0.07	71.1	58.6	59.7
2009	15.1	0.07	50.5	58.9	50.4
2010	8.9	0.07	42.1	52.0	5.6
2011	12.1	0.07	61.3	66.3	4.1
2012	10.5	0.08	65.0	64.5	4.3
2013	8.6		59.4	58.0	3.8
2014	9.6	0.07	89.5	58.1	2.8
2015	12.1	0.08	111.8	59.1	2.2
2016	12.3	0.08	71.7	61.8	1.5
CAGR 2000 -2008	**2.7%**	**-6.3%**	**4.9%**	**0.4%**	**0.6%**
CAGR 2008 - 2016	**-4.0%**	**0.8%**	**0.1%**	**0.7%**	**-36.7%**
CAGR 2000 - 2016	**-0.7%**	**-2.8%**	**2.5%**	**0.5%**	**-20.2%**

1: Source - (DoE, accessed 2018)*. Data excludes the magisterial district Heidelberg (Gauteng) which is incorrectly allocated to the Western Cape in the DoE data*

2: The 2013 data was implausibly high and was omitted

3: This includes Eskom purchases for the Ankerlig and Gourikwa open cycle gas turbines during the electricity supply shortages of 2007 – 2015. See below for estimated correction.

4. The order of magnitude of this drop in demand was confirmed by (Lockhart-Barker, 2018) *and others in the industry.*

Table A- 6: The Evolution of Petrol Demand Attributed to Local Municipalities in the Western Cape 2000 - 2016

Local Municipality	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2016 Share	CAGR 2000 - 2016	CAGR 2000 - 2008	CAGR 2008 - 2016
City of Cape Town Metropolitan Municipality	38.8	39.0	39.1	39.8	40.8	41.4	41.9	42.3	40.4	41.0	38.0	49.6	48.3	42.7	43.4	44.6	47.3	77%	1.2%	0.5%	2.0%
Mossel Bay Local Municipality	1.23	1.27	1.34	1.50	1.46	1.54	1.56	1.63	1.58	1.82	1.47	1.72	1.97	2.52	2.59	2.69	3.25	5.3%	6.2%	3.2%	9.4%
Stellenbosch Local Municipality	2.42	2.41	2.42	2.46	2.51	2.53	2.52	2.58	2.57	2.66	2.31	2.59	2.62	2.46	2.42	2.44	2.49	4.0%	0.2%	0.7%	-0.4%
Drakenstein Local Municipality	1.57	1.58	1.57	1.61	1.68	1.72	1.74	1.71	1.60	1.60	1.35	1.50	1.44	1.16	1.13	1.15	1.16	1.9%	-1.9%	0.2%	-3.9%
George Local Municipality	1.38	1.36	1.41	1.51	1.49	1.55	1.54	1.57	1.44	1.42	1.10	1.36	1.19	0.94	0.91	1.01	1.01	1.6%	-1.9%	0.6%	-4.4%
Swartland Local Municipality	1.11	1.11	1.10	1.16	1.16	1.17	1.22	1.31	1.11	1.16	1.04	1.20	1.13	1.14	1.07	0.93	0.93	1.5%	-1.1%	0.0%	-2.3%
Breede Valley Local Municipality	1.12	1.07	1.14	1.19	1.18	1.15	1.11	1.10	1.02	0.84	0.66	1.03	1.02	0.97	0.88	0.84	0.62	1.0%	-3.7%	-1.3%	-6.0%
Saldanha Bay Local Municipality	0.82	0.82	0.83	0.87	0.89	0.93	0.94	0.96	0.97	0.95	0.70	0.92	0.88	0.76	0.68	0.58	0.58	0.9%	-2.1%	2.2%	-6.3%
Theewaterskloof Local Municipality	0.80	0.78	0.74	0.77	0.78	0.80	0.88	0.92	0.94	0.90	0.62	0.64	0.64	0.58	0.57	0.60	0.53	0.9%	-2.6%	1.9%	-6.9%
Hessequa Local Municipality	0.54	0.54	0.53	0.54	0.55	0.54	0.53	0.53	0.49	0.49	0.44	0.45	0.43	0.42	0.42	0.46	0.48	0.8%	-0.8%	-1.3%	-0.3%
Overstrand Local Municipality	0.78	0.81	0.87	0.88	0.90	0.92	0.94	0.94	0.90	0.90	0.62	0.82	0.75	0.64	0.58	0.46	0.46	0.7%	-3.3%	1.8%	-8.2%
Beaufort West Local Municipality	0.79	0.76	0.75	0.74	0.72	0.67	0.65	0.64	0.60	0.59	0.46	0.57	0.51	0.45	0.42	0.42	0.42	0.7%	-3.9%	-3.4%	-4.3%
Oudtshoorn Local Municipality	0.70	0.66	0.66	0.69	0.71	0.73	0.72	0.78	0.74	0.70	0.36	0.52	0.50	0.46	0.44	0.44	0.39	0.6%	-3.6%	0.7%	-7.7%
Witzenberg Local Municipality	0.54	0.51	0.47	0.48	0.48	0.48	0.47	0.50	0.47	0.42	0.32	0.34	0.34	0.32	0.36	0.45	0.37	0.6%	-2.3%	-1.6%	-3.0%
Knysna Local Municipality	0.66	0.66	0.66	0.69	0.74	0.73	0.70	0.73	0.70	0.69	0.51	0.62	0.53	0.40	0.36	0.33	0.31	0.5%	-4.5%	0.8%	-9.6%
Bitou Local Municipality	0.58	0.59	0.58	0.61	0.66	0.65	0.62	0.65	0.62	0.62	0.45	0.55	0.47	0.35	0.32	0.29	0.27	0.4%	-4.8%	0.8%	-10.1%
Bergrivier Local Municipality	0.40	0.42	0.42	0.44	0.46	0.47	0.47	0.48	0.47	0.48	0.35	0.45	0.44	0.39	0.36	0.32	0.26	0.4%	-2.6%	1.9%	-7.0%
Matzikama Local Municipality	0.46	0.44	0.43	0.43	0.43	0.41	0.41	0.42	0.39	0.33	0.27	0.26	0.26	0.24	0.22	0.21	0.21	0.3%	-4.9%	-2.0%	-7.7%
Cape Agulhas Local Municipality	0.26	0.24	0.23	0.24	0.24	0.25	0.26	0.27	0.23	0.19	0.14	0.14	0.13	0.13	0.12	0.16	0.18	0.3%	-2.0%	-1.3%	-2.7%
Langeberg Local Municipality	0.49	0.46	0.57	0.55	0.49	0.48	0.48	0.48	0.46	0.39	0.24	0.34	0.32	0.40	0.27	0.24	0.15	0.2%	-6.9%	-0.6%	-12.8%
Laingsburg Local Municipality	0.26	0.24	0.23	0.23	0.21	0.20	0.18	0.18	0.17	0.16	0.15	0.16	0.15	0.14	0.14	0.14	0.14	0.2%	-3.9%	-5.6%	-2.2%
Cederberg Local Municipality	0.31	0.31	0.30	0.30	0.31	0.31	0.32	0.31	0.29	0.24	0.16	0.18	0.16	0.12	0.12	0.12	0.10	0.2%	-7.0%	-1.0%	-12.6%
Kannaland Local Municipality	0.13	0.11	0.12	0.12	0.13	0.13	0.13	0.14	0.11	0.11	0.09	0.13	0.13	0.12	0.07	0.09	0.09	0.1%	-2.1%	-1.4%	-2.8%
Swellendam Local Municipality	0.37	0.36	0.36	0.37	0.36	0.36	0.33	0.33	0.28	0.21	0.11	0.19	0.18	0.20	0.14	0.08	0.08	0.1%	-8.9%	-3.1%	-14.4%
Prince Albert Local Municipality	0.13	0.11	0.09	0.08	0.08	0.08	0.07	0.07	0.06	0.05	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.04%	-9.6%	-8.7%	-10.5%
TOTAL Western Cape	**56.7**	**56.6**	**57.0**	**58.2**	**59.5**	**60.2**	**60.7**	**61.5**	**58.6**	**58.9**	**52.0**	**66.3**	**64.5**	**58.0**	**58.1**	**59.1**	**61.8**	**100%**	**0.5%**	**0.4%**	**0.7%**

Notes: 1. These disaggregate figures should be considered approximate and YoY changes may not reflect changes in actual local demand. See Appendix B for discussion on distortions due to the growth in wholesalers and the unknown patterns of distribution from these entities and oil company storage depots.

2. Fuel Sales statistics are published by magisterial district. The above data were mapped assuming intersecting areas with local municipalities are proportional to demand.

Table A- 7: The Evolution of Diesel Demand Attributed to Local Municipalities in the Western Cape 2000 - 2016

Local Municipality	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2016 Share**	**CAGR 2000 - 2016**	**CAGR 2000 - 2008**	**CAGR 2008 - 2016**
City of Cape Town Metropolitan Municipality	30.2	29.2	26.8	26.2	29.6	31.0	31.4	37.0	43.2	29.7	26.4	40.8	44.0	39.7	57.9	67.6	49.8	69.5%	3.2%	4.6%	1.8%
Estimated Ankerlig OCGT Demand	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*4.34*	*2.83*	*0.58*	*1.35*	*2.26*	*10.1*	*25.6*	*28.6*	*40.3*	*0.24*	*0.3%*			
Mossel Bay Local Municipality	2.28	2.14	2.61	3.03	3.14	3.60	3.86	9.15	7.96	5.27	4.54	5.89	5.95	7.62	17.40	29.48	8.96	12.5%	8.9%	16.9%	1.5%
Estimated Gourikwa OCGT Demand	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*4.21*	*3.41*	*0.23*	*0.57*	*1.77*	*5.88*	*12.9*	*13.6*	*21.7*	*0.15*	*0.2%*			
Swartland Local Municipality	1.59	1.97	1.66	1.62	1.82	1.91	2.23	7.20	5.40	2.52	1.48	1.82	3.10	3.17	2.94	3.88	2.08	2.9%	1.7%	16.5%	-11.2%
Stellenbosch Local Municipality	1.03	1.03	1.03	1.04	1.08	1.17	1.20	1.13	1.19	1.14	0.93	1.10	1.15	0.89	1.22	1.32	1.38	1.9%	1.8%	1.8%	1.8%
Breede Valley Local Municipality	1.39	1.47	1.71	1.91	2.02	2.30	2.00	1.90	1.53	1.41	0.89	1.16	1.22	0.98	1.16	1.12	1.13	1.6%	-1.3%	1.2%	-3.7%
Drakenstein Local Municipality	1.22	1.23	1.18	1.20	1.31	1.48	1.47	1.18	1.35	1.44	1.09	1.24	0.88	0.64	0.81	0.77	0.78	1.1%	-2.8%	1.3%	-6.6%
George Local Municipality	1.04	0.95	0.91	0.95	0.85	0.91	0.90	0.96	0.87	0.83	0.58	0.80	0.78	0.54	0.75	0.75	0.77	1.1%	-1.8%	-2.2%	-1.5%
Matzikama Local Municipality	1.15	0.86	0.73	0.65	0.77	0.68	0.66	0.67	0.68	0.63	0.66	0.61	0.62	0.66	1.17	0.69	0.74	1.0%	-2.7%	-6.4%	1.1%
Saldanha Bay Local Municipality	1.20	1.83	1.70	1.69	1.66	1.69	1.94	2.62	1.65	1.22	0.48	1.81	1.64	1.10	0.95	0.72	0.72	1.0%	-3.1%	4.0%	-9.8%
Theewaterskloof Local Municipality	0.83	0.75	0.57	0.58	0.48	0.46	0.66	0.92	0.92	0.81	0.66	0.73	0.76	0.61	0.77	0.97	0.71	1.0%	-0.9%	1.3%	-3.2%
Hessequa Local Municipality	0.49	0.45	0.46	0.47	0.46	0.46	0.46	0.55	0.48	0.42	0.38	0.51	0.50	0.43	0.63	0.76	0.59	0.8%	1.3%	-0.1%	2.6%
Beaufort West Local Municipality	1.26	1.18	1.31	1.64	1.87	1.90	2.02	1.95	1.60	1.53	1.33	1.39	1.07	0.56	0.55	0.53	0.57	0.8%	-4.9%	3.1%	-12.2%
Cape Agulhas Local Municipality	0.28	0.28	0.14	0.12	0.12	0.12	0.13	0.16	0.15	0.13	0.10	0.10	0.11	0.09	0.13	0.21	0.56	0.8%	4.5%	-7.6%	18.1%
Cederberg Local Municipality	0.49	0.52	0.57	0.58	0.62	0.64	0.62	0.68	0.57	0.48	0.36	0.44	0.45	0.37	0.58	0.57	0.47	0.7%	-0.3%	1.8%	-2.3%
Bergrivier Local Municipality	0.59	0.56	0.52	0.54	0.57	0.56	0.59	0.68	0.59	0.49	0.27	0.54	0.50	0.35	0.41	0.43	0.41	0.6%	-2.3%	-0.2%	-4.3%
Overstrand Local Municipality	0.32	0.31	0.28	0.30	0.31	0.34	0.41	0.46	0.43	0.41	0.29	0.34	0.35	0.26	0.36	0.33	0.36	0.5%	0.7%	3.7%	-2.2%
Witzenberg Local Municipality	0.75	0.55	0.46	0.45	0.43	0.42	0.39	0.39	0.34	0.26	0.20	0.24	0.26	0.22	0.32	0.38	0.35	0.5%	-4.7%	-9.4%	0.3%
Oudtshoorn Local Municipality	0.43	0.37	0.40	0.36	0.34	0.35	0.37	0.41	0.40	0.32	0.14	0.25	0.25	0.19	0.27	0.27	0.25	0.3%	-3.4%	-1.0%	-5.8%
Laingsburg Local Municipality	0.20	0.19	0.20	0.20	0.22	0.23	0.22	0.24	0.24	0.09	0.35	0.21	0.21	0.15	0.20	0.22	0.24	0.3%	1.1%	2.1%	0.2%
Knysna Local Municipality	0.28	0.29	0.31	0.33	0.33	0.34	0.35	0.40	0.39	0.35	0.23	0.29	0.28	0.18	0.24	0.22	0.22	0.3%	-1.4%	3.9%	-6.5%
Bitou Local Municipality	0.24	0.25	0.26	0.29	0.29	0.30	0.31	0.35	0.34	0.31	0.20	0.25	0.24	0.16	0.21	0.18	0.19	0.3%	-1.4%	4.5%	-7.1%
Swellendam Local Municipality	0.42	0.40	0.32	0.33	0.33	0.33	0.33	0.34	0.25	0.18	0.06	0.27	0.27	0.24	0.26	0.14	0.17	0.2%	-5.5%	-6.4%	-4.7%
Langeberg Local Municipality	0.47	0.43	0.42	0.42	0.37	0.37	0.34	0.30	0.29	0.22	0.13	0.20	0.21	0.18	0.17	0.13	0.12	0.2%	-8.1%	-5.8%	-10.3%
Kannaland Local Municipality	0.20	0.17	0.16	0.17	0.13	0.08	0.09	0.11	0.18	0.16	0.20	0.11	0.10	0.08	0.07	0.09	0.09	0.1%	-5.1%	-1.4%	-8.6%
Prince Albert Local Municipality	0.24	0.23	0.32	0.13	0.12	0.13	0.15	0.15	0.15	0.11	0.16	0.15	0.13	0.08	0.08	0.08	0.04	0.1%	-10.3%	-6.0%	-14.4%
TOTAL Western Cape	48.6	47.6	45.1	45.2	49.3	51.8	53.1	70.0	71.1	50.5	42.1	61.3	65.0	59.4	89.5	111.8	71.7	100.0%	2.5%	4.9%	0.1%
Eskom estimated procured ex WC[3]	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*8.55*	*6.24*	*0.81*	*1.92*	*4.03*	*4.13*	*0.00*	*23.15*	*41.82*	*0.38*				
Corrected TOTAL Western Cape	48.6	47.6	45.1	45.2	49.3	51.8	53.1	61.4	64.9	49.7	40.2	57.2	60.9	59.4	66.4	70.0	71.3		2.4%	3.7%	1.2%

Notes: 1. These disaggregate figures should be considered approximate and YoY changes may not reflect changes in actual local demand. See Appendix B for discussion on distortions due to the growth in wholesalers and the unknown patterns of distribution from these entities and oil company storage depots. 2. Fuel Sales statistics are published by magisterial district. The above data were mapped assuming intersecting areas with local municipalities are proportional to demand. 3. It appears as if substantial share of diesel for Eskom's OCGTs was procured from entities that may have registered the sale to another province, possibly the company registration address, in the DoE surveys of the oil majors.

Table A- 8: Sectoral Allocation of Diesel Demand for Local Municipalities in the Western Cape (2016)

Local Municipality	Agriculture	Commerce and Public Services[2]	Construction	Domestic Air Transport	Food and Tobacco	Machinery	Mining and Quarrying	Non-Metallic Minerals	Non-specified (Industry)	Non-specified (Other)	Paper Pulp and Print	Rail	Road	TOTAL
City of Cape Town	14%	49%	0%	0.0%	0.2%	0.1%	2.3%	0.0%	0.3%	0.1%	0.0%	1.2%	32.4%	100%
Mossel Bay	16%	73%	0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.3%	100%
Swartland	50%	24%	2%	0.0%	0.0%	0.0%	1.9%	0.6%	0.0%	0.0%	0.0%	0.4%	20.7%	100%
Stellenbosch	20%	6%	3%	0.0%	0.1%	0.0%	0.3%	0.0%	0.7%	0.0%	0.0%	0.0%	70.2%	100%
Breede Valley	41%	3%	1%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	52.6%	100%
Drakenstein	34%	3%	2%	0.0%	0.4%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	60.9%	100%
George	20%	9%	0%	0.2%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	69.6%	100%
Matzikama	51%	0%	0%	0.0%	0.0%	0.0%	18.7%	0.0%	0.0%	0.0%	0.0%	4.8%	25.2%	100%
Saldanha Bay	33%	8%	1%	0.0%	0.1%	0.0%	16.8%	0.0%	0.0%	0.0%	0.0%	0.2%	40.3%	100%
Theewaterskloof	87%	0%	0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%	0.0%	11.1%	100%
Hessequa	30%	12%	0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	56.8%	100%
Beaufort West	45%	0%	0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	55.4%	100%
Cape Agulhas[3]	5%	78%	0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	16.5%	100%
Cederberg	87%	0%	1%	0.0%	0.0%	0.0%	2.6%	1.9%	0.0%	0.0%	0.0%	0.0%	7.0%	100%
Bergrivier	19%	0%	11%	0.0%	0.0%	0.0%	3.9%	20.2%	0.0%	0.0%	0.0%	0.0%	45.8%	100%
Overstrand	45%	21%	1%	0.0%	0.2%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	32.6%	100%
Witzenberg	36%	12%	0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	50.9%	100%
Oudtshoorn	7%	2%	0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	90.4%	100%
Laingsburg	45%	0%	0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	54.9%	100%
Knysna	35%	2%	1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	60.8%	100%
Bitou	37%	2%	1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	59.7%	100%
Swellendam	30%	20%	0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	49.4%	100%
Langeberg	82%	0%	0%	0.0%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.1%	100%
Kannaland	84%	15%	0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	100%
Prince Albert	100%	0%	0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	100%

Notes: 1.DoE do not make Trade Category data public and there is ongoing effort to improve the representation of sectors in the surveys for instance with the addition of ISIC sectors such as 'Food & Tobacco'. For the time being these figures should be considered indicative.

2. This category is equivalent to the former trade categories "Remainder of General Trade" and "Independent LPG Suppliers" and is presumably where much of the independent wholesaler portion resides. As such there is likely considerable redistribution to road transport and other sectors

3. Agriculture would be expected to dominate Cape Agulhas but a large wholesaler Moov Oil is resident in the constituent Bredasdorp Magisterial District and this has been indicated as 'Commercial' sales by the supplying oil company in the DoE Survey. This is an example of how this level of data should be interpreted with caution.

Table A- 9: Historical Fuel Prices

Year	Coastal 95 ULP (Dec 2016 cents/litre)	Coastal Diesel 0.005% (Dec 2016 cents/litre)	Coastal Diesel 0.05% (Dec 2016 cents/litre)	Gauteng 93 ULP & LRP (Dec 2016 cents/litre)	Gauteng Diesel 0.05% (Dec 2016 cents/litre)	Europe Brent Spot Price FOB (Dec 2016 Dollars per Barrel)	Henry Hub Natural Gas Spot Price (Dec 2016 Dollars per Million Btu)	Diesel Fuel Levy	Diesel Road Accident Fund Levy	Diesel Total Imposts	Petrol Fuel Levy	Petrol Road Accident Fund Levy	Petrol Total Imposts	Petrol - Share of Levies of the Price	Diesel - Share of Levies of the Price
1988				643	596	31		145.9	15.4	241.9	167.9	26.4	274.9	43%	41%
1989				763	742	34		199.7	13.4	283.0	202.9	22.9	295.7	39%	38%
1990				707	665	32		174.7	11.7	247.6	177.5	23.4	262.1	37%	37%
1991				675	680	35		160.1	11.5	224.4	224.8	20.1	297.7	44%	33%
1992				686	659	35		206.6	17.4	271.9	239.3	27.0	314.2	46%	41%
1993				718	664	28		188.8	15.9	248.5	242.5	36.6	323.0	45%	37%
1994				700	635	29		194.0	21.8	259.5	221.3	33.4	303.4	43%	41%
1995				649	597	25		181.4	20.4	242.5	213.6	31.2	290.4	45%	41%
1996				711	656	30		191.0	18.0	236.9	222.0	32.6	283.7	40%	36%
1997				647	617	28	3.3	186.1	19.9	226.5	224.1	36.6	273.6	42%	37%
1998				657	575	18	3.2	204.0	27.6	263.8	232.1	38.9	303.2	46%	46%
1999				709	598	28	3.4	199.7	27.0	258.2	237.7	38.0	307.3	43%	43%
2000				832	714	40	5.6	194.1	25.3	229.2	234.6	35.6	280.0	34%	32%
2001	924			950	809	34	4.3	190.1	38.7	238.2	230.0	38.7	278.2	29%	29%
2002	895			919	829	35	4.0	169.1	38.6	216.1	204.6	38.6	251.6	27%	26%
2003	723			741	657	37	6.6	176.9	44.7	229.9	210.2	44.7	263.2	36%	35%
2004	936			956	869	49	7.6	191.0	53.3	252.3	223.1	53.3	284.5	30%	29%
2005	976			999	984	72	9.5	194.1	61.2	263.1	225.2	61.2	294.1	29%	27%
2006	1175		1104	1194	1130	88	7.4	183.3	66.9	257.5	212.6	66.9	305.2	26%	23%
2007	1231		1075	1248	1099	90	7.3	176.9	69.9	253.8	203.8	69.9	297.6	24%	23%
2008	1540		1690	1556	1712	147	12.3	195.7	71.6	276.1	195.7	71.6	291.5	19%	16%
2009	1075		936	1089	956	73	3.8	195.9	92.9	299.3	217.7	92.9	335.5	31%	31%
2010	1168		1071	1176	1090	84	5.2	214.2	101.1	325.4	235.3	101.1	360.5	31%	30%
2011	1344		1226	1363	1254	126	4.8	214.7	105.7	329.9	234.5	105.7	362.8	27%	26%
2012	1451		1345	1474	1376	109	3.1	227.8	109.9	346.7	246.6	109.9	377.8	26%	25%
2013	1461		1349	1478	1382	113	3.8	234.3	113.9	356.7	252.1	113.9	386.3	26%	26%
2014	1548		1417	1569	1452	109	4.1	235.9	117.1	357.8	252.8	117.1	385.9	25%	25%
2015	1407		1234	1423	1270	58	2.9	257.0	164.9	426.3	273.0	164.9	453.1	32%	34%
2016	1305	1118	1114	1324	1153	45	2.9	270.0	154.0	428.3	285.0	154.0	453.3	34%	37%
2017	1269	1092	1088	1296	1126	48	3.0	287.1	156.0	447.2	301.4	156.0	471.1	36%	40%
2018	1417	1283	1277	1448	1322	72	2.9	295.1	176.9	476.0	308.9	176.9	498.9	34%	36%
CAGR (1988 -2018)				**2.8%**	**2.7%**	**2.9%**		**2.4%**	**8.6%**	**2.3%**	**2.1%**	**6.6%**	**2.0%**	**-0.7%**	**-0.4%**
CAGR (2001 -2008)	**7.6%**			**7.3%**	**11.3%**	**23.4%**	**16.4%**	**0.4%**	**9.2%**	**2.1%**	**-2.3%**	**9.2%**	**0.7%**	**-6.2%**	**-8.2%**
CAGR (2008 -2018)	**-0.8%**			**-0.7%**	**-2.6%**	**-7.1%**	**-13.5%**	**4.3%**	**9.8%**	**5.8%**	**4.8%**	**9.8%**	**5.7%**	**6.5%**	**8.7%**

Table A- 10: Seasonally Adjusted Petrol Demand in the City of Cape Town Metropolitan Municipality 2000-2015 (litres)

Year	Q1	Q2	Q3	Q4
2000	291,816,093	276,138,989	272,284,967	292,327,319
2001	281,884,886	274,744,114	275,810,769	300,946,129
2002	284,870,290	268,416,312	280,442,373	293,965,408
2003	282,976,479	271,292,726	272,432,438	296,576,094
2004	282,603,320	272,195,636	279,572,189	294,480,757
2005	280,674,074	277,967,418	279,302,331	292,056,024
2006	281,915,934	276,180,567	271,339,144	300,978,260
2007	288,135,229	273,498,274	287,246,816	305,849,563
2008	297,971,807	279,784,839	271,555,067	311,199,897
2010	282,992,574	255,582,772	243,117,271	246,485,025
2011	285,545,949	275,018,334	289,352,567	296,760,235
2012	282,214,706	286,793,971	316,687,945	303,346,368
2013	288,614,879	277,238,140	268,833,310	292,278,099
2014	277,747,462	272,776,699	276,098,884	302,663,348
2015	296,628,848	274,683,106	273,869,449	300,552,038

Note: The seasonal adjustment calculation removes YoY growth from the data so the above can be thought to be adjusted to year 2000 equivalent terms

Table A- 11: Registered Vehicle Population for the Western Cape 2006 – 2018 (eNatis, Accessed 2018)

Vehicle Type	**2006/12/31**	**2010/12/31**	**2016/12/31**	**2018/07/31**	**2018 Share**	**CAGR (2006 - 2018)**
Motor cars and station wagons	900,848	992,686	1,219,373	1,269,333	70.0%	3.0%
Minibuses	35,165	35,024	33,966	36,141	2.0%	0.2%
Buses, bus trains, midibuses	4,835	5,061	6,831	7,048	0.4%	3.3%
Motorcycles, quadrucycles, tricycles	54,248	72,743	85,456	85,255	4.7%	4.0%
LDV's, panel vans, other light load veh's GVM <= 3500kg	245,738	273,261	315,717	330,935	18.3%	2.6%
Trucks (Heavy load vehicles GVM > 3500kg)	33,076	34,432	42,909	44,639	2.5%	2.6%
Other self-propelled vehicles	30,821	31,259	37,647	39,115	2.2%	2.1%
Total self-propelled vehicles	**1,304,731**	**1,444,466**	**1,741,899**	**1,812,466**	**100.0%**	**2.9%**
Caravans	16,783	16,448	17,513	18,114	4.8%	0.7%
Light load trailers GVM <= 3500kg	101,995	116,980	140,001	146,353	38.8%	3.2%
Heavy load trailers GVM > 3500kg	10,988	12,225	19,832	21,752	5.8%	6.1%
Total Trailers	129,766	145,653	177,346	186,219	49.4%	3.2%
All other and unknown vehicles	2,791	4,666	4,520	4,417	1.2%	4.0%
Total Trailers & Unknown	**262,323**	**295,972**	**359,212**	**376,855**	**100.0%**	**3.2%**

Table A- 12: Registered Vehicle Population for the Western Cape by Local Municipality 31st July 2018 (eNatis, 2018)

Local Municipality	HCV (GVM>3500 kg equip to draw)	HCV (GVM>3500 kg, not to draw)	Bus	LCV	Passenger Cars	Motorcycle	Special Vehicle	Unknown	Grand Total	Share of All Vehicles	Share of Heavy Vehicles	Share of Light Vehicles
Beaufort West	86	83	75	2116	4550	358	189	2	7459	0.4%	0.3%	0.4%
Bergrivier	437	233	205	4621	8834	684	1754	8	16776	0.9%	1.2%	0.8%
Bitou	188	89	217	2828	9151	881	214	10	13578	0.7%	0.7%	0.8%
Breede Valley	1107	578	566	8687	23519	1622	2384	11	38474	2.1%	3.1%	2.0%
Cape Agulhas	246	163	91	3373	6435	598	995	4	11905	0.7%	0.7%	0.6%
Cederberg	381	227	142	3627	4879	345	1840	4	11445	0.6%	1.0%	0.5%
City of Cape Town	18904	6219	20216	193293	929306	56310	7550	459	1232257	68.0%	62.6%	69.3%
Drakenstein	2083	754	1074	14404	45985	2458	2402	27	69187	3.8%	5.4%	3.7%
George	1196	402	781	13763	39689	3821	1540	21	61213	3.4%	3.3%	3.4%
Hessequa	470	178	117	5167	9426	922	1466	5	17751	1.0%	1.1%	0.9%
Kannaland	181	79	81	1532	2611	225	303	7	5019	0.3%	0.5%	0.3%
Knysna	336	138	337	5009	16361	1771	338	9	24299	1.3%	1.1%	1.4%
Laingsburg	25	22	8	510	606	45	63	1	1280	0.1%	0.1%	0.1%
Langeberg	658	551	349	5962	12078	974	1765	7	22344	1.2%	2.1%	1.1%
Matzikama	465	269	209	4535	6840	456	1483	9	14266	0.8%	1.3%	0.7%
Mossel Bay	558	225	493	9249	26151	2722	742	9	40149	2.2%	1.8%	2.2%
Oudtshoorn	346	123	300	4872	12509	1438	842	4	20434	1.1%	1.1%	1.1%
Overstrand	332	162	306	8213	25805	2234	451	19	37522	2.1%	1.1%	2.1%
Prince Albert	20	24	11	653	982	158	108	1	1957	0.1%	0.1%	0.1%
Saldanha Bay	703	188	516	8025	21914	1797	605	11	33759	1.9%	1.9%	1.9%
Stellenbosch	747	358	604	8699	31209	2168	1732	28	45545	2.5%	2.4%	2.5%
Swartland	1166	368	303	7541	17164	1359	3114	16	31031	1.7%	2.5%	1.5%
Swellendam	366	107	96	2890	4593	529	1039	1	9621	0.5%	0.8%	0.5%
Theewaterskloof	679	364	387	6453	13495	851	2896	5	25130	1.4%	2.0%	1.2%
Witzenberg	777	278	346	4927	10625	529	2580	3	20065	1.1%	1.9%	0.9%
Grand Total	**32457**	**12182**	**27830**	**330949**	**1284717**	**85255**	**38395**	**681**	**1812466**	**100.0%**	**100%**	**100.0%**

Table A- 13: Estimated Demand for Passenger and Freight Balanced by Fuel for Road Transport for Local Municipalities in the Western Cape

Municipality	Estimated Road Transport Passenger Demand (bpkm)[6]	Estimated Road Transport Freight Demand (btkm)[6]	Estimated Road Transport Diesel Demand (PJ)[1]	Estimated Road Transport Petrol Demand (PJ)	Estimated Diesel Share that is Off-Road Agriculture[2]	Assumed Corridor Diesel Sales and/or Wholesaler Redistribution (PJ)[3]	Assumed Corridor Petrol Sales and/or Wholesaler Redistribution (PJ)	Intersecting Corridors
Cape Town	31.73	20.62	35.3	45.8	1.4%	high	high	N1, N2,N7
Mossel Bay	0.59	0.43	0.8	1.0	12.3%	0.2	0.1	N2
Stellenbosch	1.01	0.97	1.5	1.6	15.3%	high		N1
Drakenstein	1.15	1.55	2.2	1.8	25.2%			N1
George	0.92	0.80	1.4	1.6	15.2%			N12, N2,N9
Swartland	0.53	1.11	1.5	1.0	37.6%	high		N7
Breede Valley	0.64	0.79	1.2	1.0	30.6%			N1
Saldanha Bay	0.50	0.43	0.7	0.9	24.5%			
Theewaterskloof	0.37	0.54	0.8	0.6	65.4%			N2
Hessequa	0.20	0.32	0.5	0.4	22.1%	0.3	0.1	N2
Overstrand	0.52	0.29	0.6	1.0	34.0%			
Beaufort West	0.10	0.10	0.2	0.2	33.5%	0.4	0.2	N1, N12
Oudtshoorn	0.31	0.24	0.4	0.5	39.8%			N12
Witzenberg	0.29	0.52	0.7	0.5	26.8%			
Knysna	0.38	0.27	0.5	0.6	26.5%			N2
Bitou	0.21	0.16	0.3	0.4	28.0%			N2
Bergrivier	0.22	0.34	0.5	0.4	14.2%			N7
Matzikama	0.18	0.38	0.6	0.4	38.5%			N7
Cape Agulhas	0.14	0.22	0.3	0.3	39.8%			
Langeberg	0.34	0.62	0.9	0.5	61.7%			N2
Laingsburg	0.01	0.03	0.0	0.0	33.8%	0.2	0.1	N1
Cederberg	0.13	0.30	0.4	0.3	65.6%			N7
Kannaland	0.07	0.14	0.2	0.1	62.9%			
Swellendam	0.11	0.23	0.3	0.2	22.9%			N2
Prince Albert	0.02	0.03	0.0	0.1	74.7%			N1, N12
Corridor (Rural & Secondary only) *4*	0.28	1.05	1.0	0.5	15.6%			N1, N2,N7
TOTAL	**41.0**	**32.5**	**53.0**[5]	**61.7**	**16%**			

NB: These data are model generated (see Appendix B2)

1: Calibrated from a bottom up model with the registered vehicles population and assumed fuel economies and mileages as input. The functional metropole of Cape Town, Swartland and Stellenbosch are assumed to have higher activity levels and were calibrated separately (see Appendix B2).

2: Shares for Cape Agulhas and Oudtshoorn were corrected to the average of other rural and secondary municipalities. Most diesel sold in Oudtshoorn is indicated as sold to retail stations (Table A- 8) but the low figure for Agriculture can be considered questionable.

3: These are localities where significant fuel is sold that is not explained by the population of registered vehicles. This can't be separated for the functional metropole of Cape Town, Swartland and Stellenbosch by this analysis but the very high activity levels required to calibrate indicates that most corridor fuelling is happening here especially for long haul trucks. Where numbers are indicated these can be considered minimum values as these are derived from surveys of the oil majors only and wholesalers are likely supplying additional volumes.

4: This row sums the volumes in the corridor columns so that the fuel totals for the province are correct.

*5: While petrol is calibrated to that sold (*Table A- 6*), diesel consumption by road transport is calibrated to about 80% of total sales (*Table A- 7*) according to the analysis in* (Stone, Maseela, & Merven, 2018)*. This therefore assumes that on average about 20% of diesel is used in off-road and stationary applications. These calibration totals assume a scenario of redistribution by wholesalers where 3.6 PJ of diesel and 0.2 PJ of petrol are exported out of the province (Table B- 2).*

6: bpkm – billion passenger.km; btkm – billion tonne.km

Table A- 14: Activity Levels (VKT) Required to Balance Fuel Sales for the Functional Metropolitan Area Compared to Rural and Secondary Municipalities

	All Vehicles	Diesel Vehicles		Petrol Vehicles	
Mode	**Average Calibration Mileage (km)[3]**	**Metro[1] Mileage (km)**	**Rural & Secondary[2] Mileage (km)**	**Metro Mileage (km)**	**Rural & Secondary Mileage (km)**
HCV	78,732	99,452	66,936	-	-
MCV	27,859	35,191	23,685	28,079	20,384
LCV	18,432	23,283	15,671	18,578	13,486
Passenger Car	14,125	17,843	12,009	14,132	10,259
Motorcycles	7,549	9,536	6,418	7,609	5,524
Minibus	30,515	39,050	25,943	32,605	23,669
Bus	26,398	33,345	22,442	-	-

NB: These data are model generated (see Appendix B2)

1: The functional metropolitan area of City of Cape Town, Stellenbosch and Swartland

2: All other Western Cape municipalities

3: From provincial vehicle parc model calibrated for 2006, 2010 and 2015

Table A- 15: Demand for Freight and Passenger Travel Required to Balance Fuel Sales for the Functional Metropolitan Area Compared to Rural and Secondary Municipalities

	All Vehicles		Diesel Vehicles		Petrol Vehicles	
Mode	**Metro (btkm)**	**Rural & Secondary (btkm)**	**Metro (btkm)**	**Rural & Secondary (btkm)**	**Metro (btkm)**	**Rural & Secondary (btkm)**
HCV	21.21	8.14	21.21	8.14	0	0
MCV	0.55	0.21	0.40	0.15	0.15	0.06
LCV	1.71	0.68	0.84	0.32	0.87	0.36
Total	**23.5**	**9.0**	**22.4**	**8.6**	**1.0**	**0.4**

	All Vehicles		Diesel Vehicles		Petrol Vehicles	
Mode	**Metro (bpkm)**	**Rural & Secondary (bpkm)**	**Metro (bpkm)**	**Rural & Secondary (bpkm)**	**Metro (bpkm)**	**Rural & Secondary (bpkm)**
Passenger Car	19.16	4.24	2.80	0.58	16.36	3.66
Motorcycles	0.49	0.15	0	0	0.49	0.15
Minibus	10.63	2.13	0.99	0.18	9.64	1.95
Bus	3.24	0.95	3.24	0.95	0	0
Total	33.5	7.5	7.0	1.7	26.5	5.8

NB: These data are model generated (see Appendix B2)

btkm: billion tonne.km

bpkm: billion passenger.km

Table A- 16: Demand for Freight and Passenger Travel Required to Balance Fuel Sales Compared to non-Petroleum Modes for the City of Cape Town Local Municipality

Mode	**Freight Transport Demand (btkm)[5]**	**btkm Share[5]**	**Petrol (PJ)**	**Diesel (PJ)**	**Electricity (PJ)**	**Total (PJ)**	**Energy Share (%)**	**Year**	**Source**
HCV	18.6	90%	0.0	18.4		18.4	48.9%	2016	Fuel Balance[6]
MCV	0.48	2%	0.5	1.2		1.67	4.4%	2016	Fuel Balance[6]
LCV	1.5	7%	9.1	8.5		17.6	46.7%	2016	Fuel Balance[6]
Total	**21**	**100%**	**10**	**28**	**0**	**38**	**100.0%**		

Mode	**Passenger Transport Demand (bpkm)[5]**	**bpkm Share[5]**	**Petrol (PJ)**	**Diesel (PJ)**	**Electricity (PJ)**	**Total (PJ)**	**Energy Share (%)**	**Year**	**Source**
Passenger Car	18.1	50%	31.69	4.70		36.39	81.7%	18.1	Fuel Balance[6]
Motorcycles	0.5	1%	0.79	0.00		0.79	1.8%	0.5	Fuel Balance[6]
Minibus	10.1	28%	3.71	0.33		4.05	9.1%	10.1	Fuel Balance[6]
Bus	3.1	8%	0.00	2.14		2.14	4.8%	3.1	Fuel Balance[6]
myCiti	*0.11[6]*			*0.07*		*0.07*	0.2%	2017	CoCT[1]
Golden Arrow	*0.75[6]*			*0.50*		*0.50*	1.1%	2013	WCG[2]
TPM Bus Services				*0.40*		*0.40*	0.9%	2013	WCG[2]
Metro Rail	3.05	8%			0.19	0.19	0.4%	2012	CITP 2016[3]
Bicycle	0.02	0.1%				-		2012	Kane[4]
Walk	1.3	4%				-		2012	Kane[4]
Total	**36.11**		**36.19**	**8.14**	**0.19**	**44.52**	**100.0%**		

1: (City of Cape Town , 2018)

2: (Visagie, 2013)

3: City of Cape Town EMME Model Output for 2014 - 488,111 passengers per working day with an average trip distance of 23 km (City of Cape Town, 2016). *30% load assumed for weekends was added to this. Disruptions to the rail industry suggest that this usage may have dropped to half this.*

4: Calculations for (Kane, 2017). *Access provided by author. Based on City of Cape Town Household Travel Survey 2013*

5: Includes long distance transport and possibly a significant amount of activity outside of commuting corridors not accounted for in the City of Cape Town's trip estimate figures. The high activity levels estimated for all buses relative to the large operators like myCiti and Golden Arrow suggest some of this diesel may rather be used by commercial vehicles at a higher energy intensity than that assumed but the detailed investigation required to resolve this was beyond the scope of this project.

6. Estimated bottom-up from data in (City of Cape Town, 2015) *for GABS and* (City of Cape Town , 2018) *for myCiti. See file "Public Transport CO2 Intensities Cape Town.xlsx" in the project data submission*

Table A- 17: Passenger Throughput at Cape Town International Airport 2004 – 2017 compared to Jet Fuel Supply Attributed to all Western Cape Municipalities

Year	Jet Fuel (PJ)	Domestic Arrivals	Regional Arrivals	International Arrivals	Total Arrivals (Calendar Year)	Total Movements (Financial year)
2004	13.9					6,214,903
2005	14.1					6,834,173
2006	14.7					7,518,543
2007	15.7					8,426,618
2008	17					7,813,170
2009	15.1	3,142,886	62,003	643,862	3,848,751	7,810,069
2010	8.9	3,333,886	61,142	632,319	4,027,347	8,200,547
2011	12.1	3,471,056	64,708	669,093	4,204,857	8,576,338
2012	10.5	3,489,755	73,590	667,814	4,231,159	8,434,799
2013	8.6	3,415,763	72,259	667,250	4,155,272	8,392,989
2014	9.6	3,513,794	76,895	707,783	4,298,472	8,755,872
2015	12.1	3,823,249	85,366	770,834	4,679,449	9,659,589
2016	12.3	4,030,151	101,275	891,945	5,023,371	10,211,390
2017		4,122,302	106,754	1,078,220	5,307,276	10,752,246
CAGR 2009 - 2016	**-2.9%**	**3.6%**	**7.3%**	**4.8%**	**3.9%**	**3.9%**
CAGR 2004 - 2016	**-1.0%**					**4.2%**

Source: ACSA data published in various sources

Table A- 18: Foreign Tourist Arrivals and Bed Nights Stayed in the Western Cape 2016

	2016
Arrivals Q1	455,266
Bed Nights Stayed (million)	4,698,700
Arrivals Q2	304,660
Bed Nights Stayed (million)	3,458,700
Arrivals Q3	344,100
Bed Nights Stayed (million)	3,648,400
Arrivals Q4	475,200
Bed Nights Stayed (million)	4,937,600
Arrivals (Air & Land)	**1,579,226**
Average Stay (days/nights)	**10.6**
Bed Nights Stayed (million)	**16,743,400**

Table A- 19: Use of Modes by Foreign Tourists Visiting Cape Town and South Africa

	SA[1]			Cape Town[2]
Mode	**2016**	**2017**	**2018**	**2014**
Minibus taxi	1.90%	2.60%	2.00%	
Private car or van	42.60%	41.80%	36.90%	
On foot or bicycle	5.50%	7.40%	3.90%	
Other Taxi	16.30%	11.00%	8.30%	
Rental car	25.20%	28.10%	35.00%	26%

Aeroplane	40.50%	39.70%	36.70%	
Uber[3]	0.00%	11.90%	19.40%	
Tour bus	12.50%	13.00%	11.20%	25.0%
Truck or lorry	0.40%	0.20%	0.40%	
Commercial bus	3.50%	3.20%	2.50%	
Private hotel shuttle	10.40%	10.20%	6.00%	
Train	2.90%	3.60%	3.50%	
Ship/Boat	5.60%	3.80%	1.00%	
Motorcycle	0.10%	0.40%	0.20%	

1: Data is for 4th Quarter for 'Air Markets' which are more relevant to the Western Cape (South African Tourism, 2018)

2: (Womack, J, 2015)

3: Note the rapid growth in Uber preference

Table A- 20: Comparison of Domestic Tourist Arrivals for the Western Cape as Published by SAT and StatsSA

	SAT (2017)[1]	**Stats SA (2016)[2]**
Q1	400,000	
Q2	540,000	
Q3		
Q4		
TOTAL	1,880,000 [3]	2,475,000
AVERAGE	**2,177,500**	
Length of Stay (nights)	7.5	5
AVERAGE	**6.25**	

1: (South African Tourism, 2018)

2: (Stats SA, 2017)

3: Projected. This is included because the SAT reports note that the Stats SA surveys have a small sample size at provincial level and should be used with caution sub-nationally.

Table A- 21: Combination of Arrivals, Mode Preference and Stay Length Data with Trip Frequency and Distance Assumptions to Derive pkm Estimates for Foreign Tourism in 2016 for the Western Cape

	Share of Arrivals	**Assumed Trips using this mode**	**Assumed Trip Distance (km)**	**Assumed Stay Distance (km)**	**million pkm**	**pkm Share**
Minibus taxi	3.47%	4	8	32	1.75	0%
Private car or van	42.60%	20	18	360	242.19	47%
On foot or bicycle	5.50%	8	1.5	12	1.04	0%
Other Taxi	16.30%	15	8	120	30.89	6%
Rental car	25.20%	20	22	440	175.10	34%
Uber	0.00%	15	8	120	-	0%
Tour bus	23.88%	1.5	100	150	56.57	11%
Commercial bus	3.50%	3	8	24	1.33	0%
Private hotel shuttle	10.40%	2	20	40	6.57	1%
Train	2.90%	2	20	40	1.83	0%
Motorcycle	0.10%	20	15	300	0.47	0%
TOTAL Passenger Car					**448**	**87%**
TOTAL Bus					**58**	**11%**
TOTAL Minibus					**8**	**2%**
TOTAL All Modes					**518**	**100%**

Table A- 22: Combination of Arrivals, Mode Preference and Stay Length Data with Trip Frequency and Distance Assumptions to Derive pkm Estimates for Domestic Tourism in 2016 for the Western Cape

Mode	**Share of Arrivals**	**Assumed Trips using this mode**	**Assumed Trip Distance (km)**	**Assumed Stay Distance (km)**	**million pkm[1]**	**pkm Share**
Minibus taxi	9.66%	4	8	32	42	2%
Private car or van	77.71%	10	18	180	1,904	79%
On foot or bicycle	5.50%	4	1.5	6	4	0%
Other Taxi	5.00%	3	8	24	16	1%
Rental car[2]	12.65%	10	22	220	379	16%
Uber	0.00%	3	8	24	-	0%
Tour bus	3.00%	1	100	100	41	2%
Commercial bus	3.50%	2	8	16	8	0%
Private hotel shuttle	1.00%	2	20	40	5	0%
Train	2.90%	1	20	20	8	0%
Motorcycle	0.10%	10	15	150	2	0%
TOTAL Passenger Car					**2,299**	**95%**
TOTAL Bus					**48**	**2%**
TOTAL Minibus					**47**	**2%**
TOTAL All Modes					**2,409**	**100%**

1: Estimates are only for overnight domestic tourism and excludes day trips

2: All air arrivals were assumed to rent cars. In practice many will make use of private cars.

Table A- 23: Estimated Split of Freight Demand by Mode and Corridor for the Western Cape for 2016

Route	Road tonnes (million) [1]	Rail tonnes (million) [1]	Assumed Trip Distance Road	Assumed Trip Distance Rail	btkm Road	btkm Rail	Share of General Freight tonnes	Share of General Freight tkm	Additional Rail Friendly Freight (btkm)	Notes
Total Flow	189.11									
Bulk Exports		49.2				49.2				This is mostly Sishen-Saldanha iron ore line
General Freight Total	**132.8**	**7.1**			**28.6**	**2.16**				
N1	26.7	1	573	558	15.3	0.56	20%	52%	3.61	Trip distances not from source – they are approximately distances to provincial borders for the N1 and halfway to the borders for the N2 and N7.
N2	7.7	0.06	437	501	3.4	0.03	6%	11%	0.39	
N7	3.1	2.9	280	329	0.9	0.95	4%	6%	0.13	
Metro (Distribution)[2]	22.2	0.05	76	57	1.7	0.003	16%	5%		Mostly HCV, some MCV
Rural	23.1	3.1	186	200	4.3	0.62	19%	16%		Mostly HCV, some MCV
Redistribution	50	-	62	-	3.1	-	36%	10%		Estimated from vehicle parc model. Highly uncertain

1: Source – tons moved data from (WCG, 2018) *except for "Redistribution" which has been used as a balancing item such that total ton.km matches that of the vehicle parc model described in Appendix C. This was based on consultation with the authors of the base data who confirmed that the gravity model (Freight Demand Model) from which this data was generated does not reflect 'redistribution' of goods well because it's based on movement between main nodes* (Simpson, 2018).

2: This is mostly heavy vehicle metropolitan freight where goods are moved from regional distribution centres where corridor freight is unloaded to local distribution centres from which it is 'redistrubuted' (Simpson, 2018)

3: This is trip distance within the province only. Most corridor freight trips are longer and cross provincial boundaries

tkm: tonne-km of freight activity; btkm: billion tonne-km of freight activity

Table A- 24: Estimated Split of Freight Demand by Sector – Comparison of 2009 and 2012 Data

2012 Data			2009 Data		Ranking (Based on 2015 GDPR of Sectors		
Commodity	**All WC Freight Flows (tonnes)[2]**	**N1 Corridor (tonnes)[2]**	**Commodity**	**N1 Corridor (tonnes)[1]**	**GDPR Sector or sub-Sector Used for Ranking**	**Share of GDPR (2015)**	**Rank[4]**
FMCG	21.87	15.93	Processed foods	8.1	Food, Beverages & Tobacco	4.1%	6
			Beverages	3.4			
Other Agriculture	15.37	8.64	Other Agriculture	0.8	Agriculture	4.3%	4
Fruit	3.66	1.19					
Grain	2.16	0.93					
Chemicals	3.96	2.8	Other Chemicals	2.2	Petroleum Products, chemicals, rubber and plastic	3.2%	7
			Fertilizer	1.5			
Energy	12.76	4.32	Fuel & Petroleum products	1.3			
			Coal	3.5	*unranked*	-	-
Construction	13.21	1.02	Non-metallic mineral products	1.6	Other non-metallic mineral products	4.8%	3
					Construction		
Metal Industries	3.96	1.1	Iron & Steel	0.9		2.0%	9
Other Mining	1.19	1.1	Other Mining	3.2	Mining and quarrying	0.3%	12
Other Manufactured Products	7.16	4.83	Other commodities	7.8	Rest of Manufacturing	2.4%	8
Automotive	0.3	0.25			Transport Equipment	1.1%	11
			Wood & Wood Products	1.3	Wood & paper publishing & printing	2.0%	10
			Paper & Paper Products	0.7			
Redistribution	35				Wholesale and retail trade, catering and accommodation	16.1%	1
FREIGHT TOTAL	**120.6**	**42.1**		**36.3**			
PASSENGER FLOWS (FOR COMPARISON)							
Tourism (2016)	2.9	bpkm			Tourism	4.2%	5
Public Transport (2016)	16.9	bpkm			Transport, storage and communication	10.2%	2

1: *Source* - (Havenga J. , Simpson, Fourie, & de Bod, 2011)
2: *Source* - (Havenga, Goedhals-Gerber, de Bod, & Simpson, 2015)
3: FMCG (Fast Moving Consumer Goods) was not split into constituent commodities in the 2012 data but given that processed food and beverages were together 32% of the total 2009 flows reported for the N1 corridor, it can reasonably be assumed their share of freight remains high.
4: In ranking flows in terms of contribution of GDPR the approach has been to simply indicate the contribution of the sector which the flow is a part. The value add share of the flow itself to the sector or sub-sector GDPR will clearly vary greatly but the number is used in the sense that the transport flow is a critical enabler of the sector activities.

Appendix A3 Fuel Use in the Transport Sectors of the US and EU

Table A- 25: US Transportation Sector Energy Consumption by Fuel (PJ)

Year	Natural Gas (Excluding Supplemental Gaseous Fuels)	Natural Gas , Pipelines and Distribution	Natural Gas Vehicle Fuel	Petroleum (Excluding Biofuels)	Total Fossil Fuels	Biomass	Total Primary	Electricity Retail Sales to the Transportation Sector	Transportation Sector Electrical System Energy Losses	Total
	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)
1997	823	814	9	25096	25920	108	26027	18	40	26085
1998	703	693	10	25734	26437	119	26556	18	40	26614
1999	713	700	13	26447	27159	124	27284	18	42	27344
2000	709	695	14	27062	27771	142	27913	19	44	27977
2001	694	679	16	26778	27472	150	27622	21	46	27688
2002	737	721	16	27305	28042	179	28221	20	44	28285
2003	662	642	20	27379	28042	242	28284	25	54	28362
2004	635	613	22	28336	28971	306	29277	26	57	29360
2005	658	633	25	28716	29375	358	29732	27	59	29818
2006	659	634	26	29034	29694	501	30195	26	57	30278
2007	700	673	27	28975	29675	635	30310	29	63	30403
2008	730	702	28	27246	27976	870	28846	28	59	28933
2009	754	725	29	26289	27043	987	28030	28	59	28117
2010	759	728	31	26527	27286	1134	28420	28	58	28505
2011	774	742	32	26076	26850	1222	28072	28	57	28157
2012	823	790	32	25517	26339	1226	27566	26	53	27645
2013	936	904	33	25827	26763	1348	28111	27	55	28194
2014	802	763	38	26206	27008	1363	28371	28	56	28455
2015	786	743	43	26592	27377	1399	28776	27	54	28858
2016	799	753	46	27116	27915	1513	29428	27	52	29507
2017	843	789	53	27313	28155	1515	29670	27	52	29750
Share 2017	**3%**	**3%**	**0.2%**	**92%**	**95%**	**5%**	**100%**	**0%**	**0%**	**100%**
CAGR 10Y	**1.9%**	**1.6%**	**7.1%**	**-0.6%**	**-0.5%**	**9.1%**	**-0.2%**	**-0.8%**	**-1.9%**	**-0.2%**
CAGR 5Y	**0.5%**	**0.0%**	**10.4%**	**1.4%**	**1.3%**	**4.3%**	**1.5%**	**0.5%**	**-0.4%**	**1.5%**

Source: (EIA, 2018)

Table A- 26: Change in EU Road Transport Energy Demand by Fuel 2003 - 2013

Fuel	Transport Demand 2003 (PJ)	Share 2003	Transport Demand 2013 (PJ)	Share 2013	CAGR	Average Annual Growth (PJ)
Diesel	6,900	56.2%	8,100	65.1%	2%	120
Petrol	5,100	41.6%	3,500	28.1%	-4%	-160
Biodiesel	55	0.4%	420	3.4%	23%	36.5
LPG	175	1.4%	240	1.9%	3%	6.5
Biopetrol	20	0.2%	110	0.9%	19%	9
Natural gas	20	0.2%	65	0.5%	13%	4.5
Total	**12,270**	**100%**	**12,435**	**100%**	**0.1%**	**16.5**

Source: (Ricardo-AEA, 2016)

Appendix B Notes on Statistical Methodology

Statistical data for the demand of transport (petroleum) fuels, registered vehicles and the demand for passenger.km and ton.km are presented above for the Western Cape. Where possible this has been disaggregated by local municipality and by industry sector. The publically available sources were supplemented with the kind assistance of:

- The Department of Energy
- The National Traffic Information System (eNatis)
- Eskom
- The Department of Logistics, University of Stellenbosch

In general the data landscape has improved relative to previous years in terms of the scope of sources and the professionalism of personnel charged with a data mandate in organisations like those above. The following general data problems however persist:

- In most cases there is a complete lack of scientifically relevant metadata
- Data is often poorly validated
- Data is published in non-machine readable formats in discreet files for short time periods making repurposing very difficult
- Organisations without a data mandate have a poor culture of transparency and are reluctant to respond to requests for data. The prevailing principle is that all data is proprietary until there is a compelling reason or explicit external instruction to make it public rather than the reverse. A competitive economy and indeed a healthy society however require a strong public data culture.

Additionally, the transport system is complex and as such data processing required a number of assumptions, estimates and calculations. This appendix presents notes and supporting assumptions for the statistical data tables.

Appendix B1 Petroleum Fuels Sales

Petroleum fuels sales data disaggregated by magisterial district is posted online by the Department of Energy (DoE, accessed 2018). Additional mapping to a sector view called 'Trade Categories' (now expanded to some ISIC categories) was obtained on request (DOE, 2018). The Competition Commission has ruled that this data has the potential to aid uncompetitive behaviour and publically released data must be a year old. The latest full year is therefore 2016.

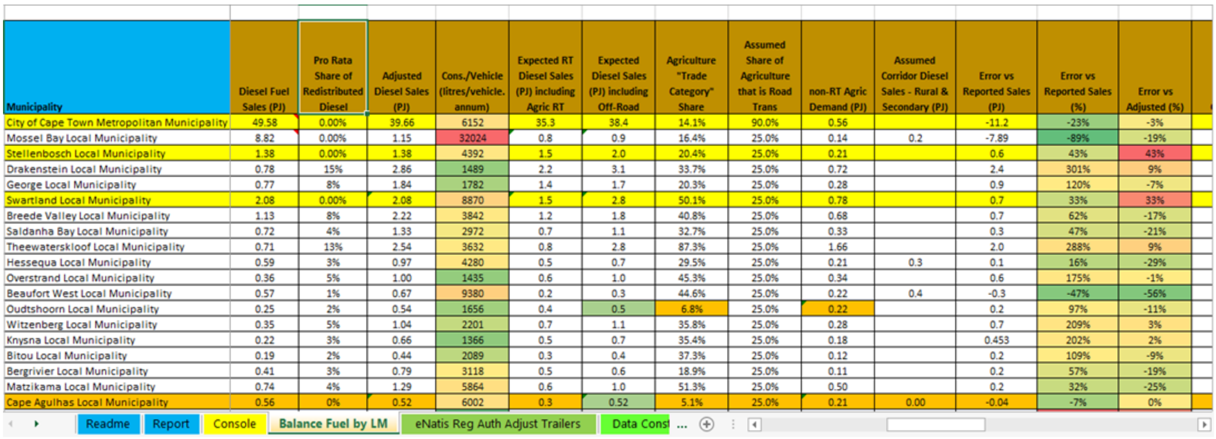
The data was mapped from magisterial districts to local municipalities using GiS software to determine the area overlap. Fuel supply in a local municipality was assumed to be proportional to the intersected area of overlapping magisterial districts. In reality this not so because fuel is supplied to discreet nodes such as commercial customers and storage depots. Furthermore, the arrangements for supply to retail outlets from distribution nodes is not made public and fuel is likely extensively distributed locally across municipal borders. Local municipality level fuel demand can therefore be considered approximate and the determination of transport activity levels from this data is best interpreted as an average of similar municipalities.

Appendix B2 Investigating the Plausibility of the Reported Spatial Disaggregation of Petroleum Fuel Sales

Fuel sales are reported by magisterial district (DoE, accessed 2018) which can be mapped to local municipalities with the caveat that data collection is not in reality very spatially resolved. This project investigated in detail the plausibility of this data at a local municipality level but also in terms of a simple urban/rural split.

A spreadsheet tool was developed to balance the expected demand from the vehicle registration database with fuel sales for each local municipality in the Western Cape given common fuel economy assumptions but distinct annual mileage assumptions for the metropolitan area (urban) and non-metropolitan area (rural and secondary towns and cities)

This tool with filename, “LM Fuel Balance_v3.xlsx”, forms part of the outputs of this project. A screenshot of the balancing calculation sheet is shown below in Figure B- 1.



Municipality	Diesel Fuel Sales (PJ)	Pro Rata Share of Redistributed Diesel	Adjusted Diesel Sales (PJ)	Cons./Vehicle (litres/vehicle. annum)	Expected RT Diesel Sales (PJ) including Agric RT	Expected Diesel Sales (PJ) including Off-Road	Agriculture "Trade Category" Share	Assumed Share of Agriculture that is Road Trans	non-RT Agric Demand (PJ)	Assumed Corridor Diesel Sales - Rural & Secondary (PJ)	Error vs Reported Sales (PJ)	Error vs Reported Sales (%)	Error vs Adjusted (%)
City of Cape Town Metropolitan Municipality	49.58	0.00%	39.66	6152	35.3	38.4	14.1%	90.0%	0.56		-11.2	-23%	-3%
Mossel Bay Local Municipality	8.82	0.00%	1.15	32024	0.8	0.9	16.4%	25.0%	0.14	0.2	-7.89	-89%	-19%
Stellenbosch Local Municipality	1.38	0.00%	1.38	4392	1.5	2.0	20.4%	25.0%	0.21		0.6	43%	43%
Drakenstein Local Municipality	0.78	15%	2.86	1489	2.2	3.1	33.7%	25.0%	0.72		2.4	301%	9%
George Local Municipality	0.77	8%	1.84	1782	1.4	1.7	20.3%	25.0%	0.28		0.9	120%	-7%
Swartland Local Municipality	2.08	0.00%	2.08	8870	1.5	2.8	50.1%	25.0%	0.78		0.7	33%	33%
Breede Valley Local Municipality	1.13	8%	2.22	3842	1.2	1.8	40.8%	25.0%	0.68		0.7	62%	-17%
Saldanha Bay Local Municipality	0.72	4%	1.33	2972	0.7	1.1	32.7%	25.0%	0.33		0.3	47%	-21%
Theewaterskloof Local Municipality	0.71	13%	2.54	3632	0.8	2.8	87.3%	25.0%	1.66		2.0	288%	9%
Hessequa Local Municipality	0.59	3%	0.97	4280	0.5	0.7	29.5%	25.0%	0.21	0.3	0.1	16%	-29%
Overstrand Local Municipality	0.36	5%	1.00	1435	0.6	1.0	45.3%	25.0%	0.34		0.6	175%	-1%
Beaufort West Local Municipality	0.57	1%	0.67	9380	0.2	0.3	44.6%	25.0%	0.22	0.4	-0.3	-47%	-56%
Oudtshoorn Local Municipality	0.25	2%	0.54	1656	0.4	0.5	6.8%	25.0%	0.22		0.2	97%	-11%
Witzenberg Local Municipality	0.35	5%	1.04	2201	0.7	1.1	35.8%	25.0%	0.28		0.7	209%	3%
Knysna Local Municipality	0.22	3%	0.66	1366	0.5	0.7	35.4%	25.0%	0.18		0.453	202%	2%
Bitou Local Municipality	0.19	2%	0.44	2089	0.3	0.4	37.3%	25.0%	0.12		0.2	109%	-9%
Bergrivier Local Municipality	0.41	3%	0.79	3118	0.5	0.6	18.9%	25.0%	0.11		0.2	57%	-19%
Matzikama Local Municipality	0.74	4%	1.29	5864	0.6	1.0	51.3%	25.0%	0.50		0.2	32%	-25%
Cape Agulhas Local Municipality	0.56	0%	0.52	6002	0.3	0.52	5.1%	25.0%	0.21	0.00	-0.04	-7%	0%

Figure B- 1: Screenshot of Tool for Investigating Fuel Distribution in the Western Cape at Local Municipality Level

We would not expect fuel demand to balance closely for every municipality because activity levels vary locally and moreover the split of petrol and diesel vehicles was not known at this level and the provincial split was applied. The high probability that additional unrecorded distribution is happening is however reflected in the very low mileages that must be assumed for the rural and secondary municipalities in order to balance supply and demand as shown below in Table B- 1. The shortfalls in supply even after calibration to these very low mileages are very large especially for diesel and especially for municipalities like Langeberg (-674%), Kannaland (-158%) and Prince Albert (-97%). As expected there is over-supply relative to the local fleet in key corridor refuelling locations such as Beaufort West (+71% for petrol, +81% for diesel) and Laingsburg (+85% for petrol, +89% for diesel). While it was beyond the scope of the study to establish the true volumes of specific localities these levels of over-supply also seem intuitively too low.

Table B- 1: Calibration Mileages of Municipality Level Fuel Balance Model Assuming Magisterial District Fuel Sales as Published (no redistribution by wholesalers)

	All Vehicles	Diesel Vehicles		Petrol Vehicles	
Mode	Average Calibration Mileage (km)*	Metro Mileage (km)	Rural & Secondary Mileage (km)	Metro Mileage (km)	Rural & Secondary Mileage (km)
HCV	78,732	116,797	23,845	-	-
MCV	27,859	41,328	8,437	29,453	12,519
LCV	18,432	27,344	5,582	19,487	8,283

Passenger Car	14,125	20,955	4,278	14,823	6,300
Motorcycles	7,549	11,199	2,286	7,981	3,392
Minibus	30,515	45,861	9,242	34,200	14,537
Bus	26,398	39,160	7,995	-	-

** As calibrated separately in a vehicle parc model of the Western Cape Province*

The most compelling indication of the scale of untracked wholesaler distribution is however for Mossel Bay for which 8.8 PJ of diesel sales and 3.3 PJ of petrol sales were recorded in the magisterial district data for 2016 for an expected demand at the calibration mileages above of 0.3 PJ of diesel and 0.6 PJ of petrol. For Cape Town calibrated passenger transport demand without redistribution of some fuel is also double estimates derived from the 2013 City of Cape Town Household Travel Survey (Nel, 2016).

The 'LM Fuel Balance' tool was used to develop plausible scenarios of fuel redistribution in the province and recalibrate activity levels. The approach included the following features:

- Fuel is redistributed from three local municipalities where wholesalers are known to be based, Cape Town, Mossel Bay and Cape Aghulus to the other local municipalities in the Western Cape.
- Two redistribution strategies, proportional to sales and proportional to supply demand error are available and the user can blend them - The redistribution algorithm does not allow negative distribution. In other words all municipalities other than those identified as origins of wholesaler redistribution are assumed recipients.
- The tool calibrates by comparing adjusted fuel sales (after redistribution) to expected fuel demand.
- Expected fuel demand is calculated as the product of the number of a vehicle type in the municipal registration database, an assumed fuel economy and annual mileage summed for all vehicle types. In the case of diesel an off-road and stationary volume is added back based on the sector shares for Agriculture presented in Table A- 8 above.
- Calibration is performed by adjusting the assumed mileage for metros and rural areas respectively by calibration factors.
- The calibration factors scale mileages from a provincial vehicle parc model average as a starting point.
- Excess fuel in rural and secondary municipalities is assumed to be available to corridor travel.
- The metro certainly includes a large volume of fuel used in corridor travel especially for diesel but in this tool it is not split out.
- In this respect it was found that it was best to treat the Cape Town Metropolitan Municipality and the Stellenbosch and Swartland Municipalities as one "functional" metro especially for diesel.

The scenario of wholesaler fuel redistribution presented below in Table B- 2 was found to give a reasonable balance between urban and rural activity levels, acceptable error at a local municipality level between supply and expected demand and more reasonable agreement between demand for passenger transport in Cape Town compared to travel survey data and modelling.

Table B- 2: Scenario of Wholesaler Redistribution of Petrol and Diesel in the Western Cape from Indicated Municipalities to other Municipalities that Yields More Plausible Activity Data

Local Municipality	**Inside Western Cape**		**Exported out of Western Cape**	
	Diesel	**Petrol**	**Diesel**	**Petrol**
Mossel Bay	75%	60%	12%	5%
Cape Town	15%	5%	5%	0%
Cape Aghulus (Voom)	7%	0%	0%	0%
	Energy Units (PJ)			
Mossel Bay	6.6	2.0	1.1	0.2
Cape Town	7.4	2.4	2.5	0.0
Cape Aghulus (Voom)	0.04	0.00	0.0	0.0

This scenario underlies the synthetic data generated for municipal level vehicle activity and presented in Table A- 13 to Table A- 16. These data therefore represent a likely distribution of fuel and activity but are only partially derived from surveys. The modelled redistribution of the volumes shown in Table B- 2 between the remaining municipalities for this scenario are shown below.

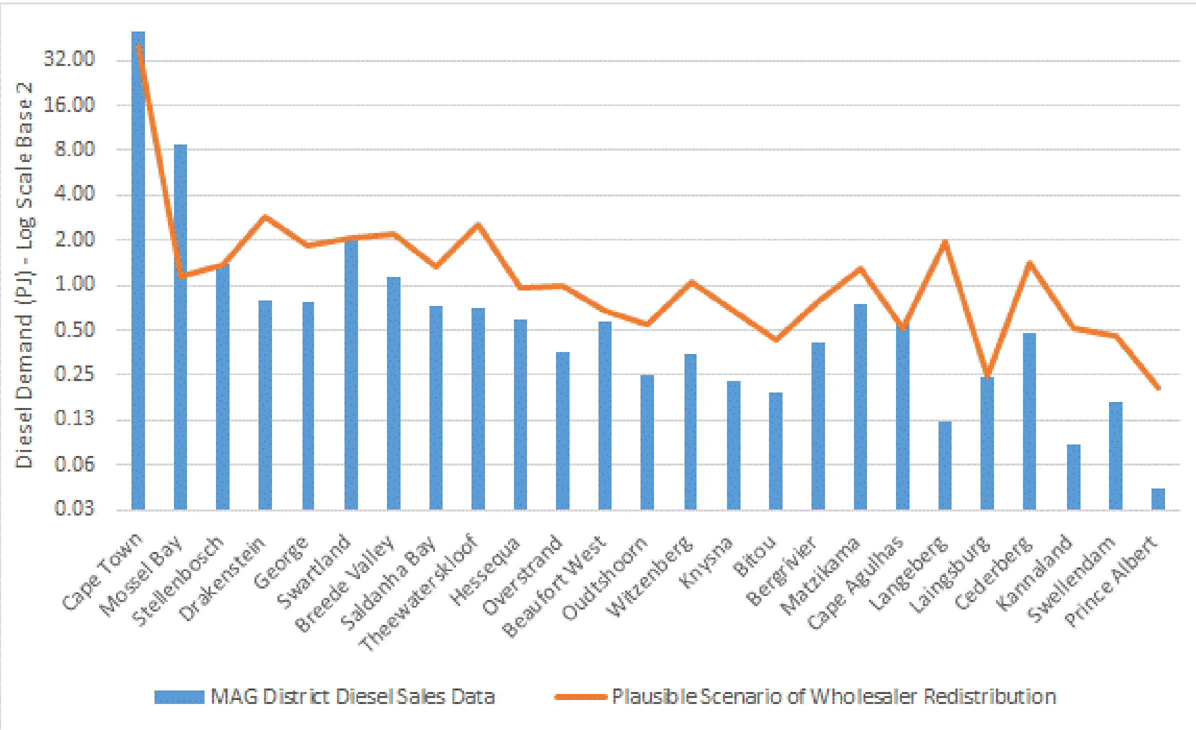


Figure B- 2: Scenario for the Plausible Redistribution of Diesel from Cape Town, Mossel Bay and Cape Aghulus to other Municipalities

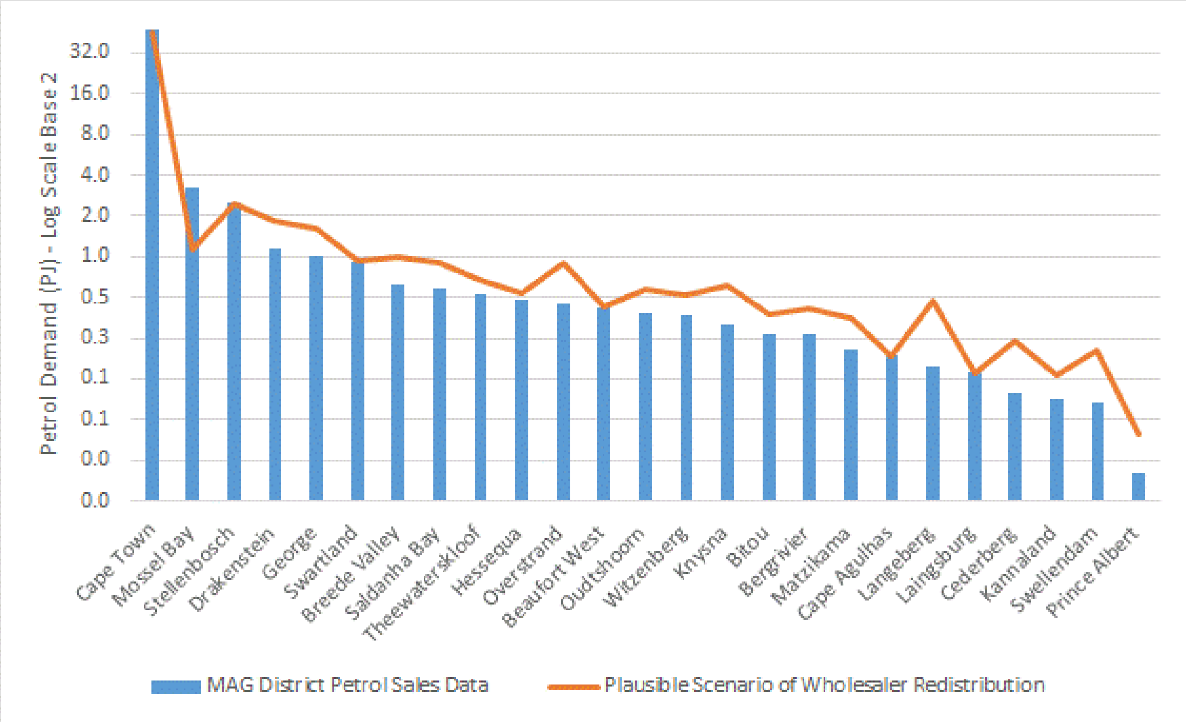


Figure B- 3: Scenario for the Plausible Redistribution of Petrol from Cape Town, Mossel Bay and Cape Aghulus to other Municipalities

Appendix B3 Bottom-up Sense Check of Off-Road Agricultural Diesel Demand

Simple bottom-up calculations were used to sense check the assumed off-road agricultural demand for diesel of 10.6 PJ estimated using DoE data. In the first scenario, this volume was replicated using the assumptions presented in Table B- 3 below as input to the following equation:

Demand = Area [ha] X Energy Intensity [litres diesel/ha] X Utilisation [%] X (1 – Road Transport Share]

Table B- 3: Scenario 1 - Assumptions of Off-Road Agricultural Energy Intensity Required to Reproduce Diesel Consumption Derived from Supply-side Data for the Western Cape

Usage	**Area (ha)[2]**	**Assumed Energy Intensity (litres/ha)[1]**	**Assumed Utilisation**	**Assumed Road Transport Share**	**Calculated Off-Road Demand**
Potentially arable land (19%)	2,454,788	86	100%	3%	205,177,563
Grazing (70.4%)	9,105,821	9	100%	10%	70,616,430
Forestry	198,938	9	100%	20%	1,371,361
				TOTAL VOLUME (litres)	**277,165,354**
				CV Diesel (MJ/litre)	**38.1**
				TOTAL ENERGY (PJ)	**10.6**

1: Grain farming requires inputs of 65 litres diesel /ha having dropped over time from 100 litres diesel/ha (Louw, 2018)
2: Source - (WCG, 2014)

As shown below, in a second scenario, more conservative assumptions yielded a number around half as much. The energy intensity of non-grain crops was not however investigated and may be higher or lower. The energy intensities for grazing and forestry are, at this stage, speculative.

Table B- 4: Scenario 2 – Bottom-up Calculation of Off-Road Agricultural Diesel Consumption based on more Conservative ASsumptions

Usage	Area (ha)[2]	Assumed Energy Intensity (litres/ha)[1]	Assumed Utilisation	Assumed Road Transport Share	Calculated Off-Road Demand
Potentially arable land (19%)	2,454,788	65	70%	5%	106,108,211
Grazing (70.4%)	9,105,821	5	100%	5%	43,252,650
Forestry	198,938	5	100%	30%	696,283
				TOTAL VOLUME (litres)	**150,057,144**
				CV Diesel (MJ/litre)	**38.1**
				TOTAL ENERGY (PJ)	**5.7**

1: Grain farming requires inputs of 65 litres diesel /ha having dropped over time from 100 litres diesel/ha (Louw, 2018)
2: Source - (WCG, 2014)

The conclusion was drawn that the estimates of off-road agriculture made for this investigation are of the right order of magnitude but that the energy intensity of agriculture and other sectors that use significant volumes of diesel in off-road applications needs to be better understood in the future to have more certainty.

Appendix B4 Registered Vehicles by Local Municipality

Registered vehicles by vehicle types for provinces and registering authorities are available online (eNatis, Accessed 2018). Historical per Registering Authority data is however only available online from 2011 onwards and data from previous projects and that kindly forwarded by eNatis (eNatis, 2018) had to be used to supplement the online data to produce Table A- 12. Furthermore, eNatis use different typologies for registering authority and provincial views with trailers and motorised vehicles lumped together in the former. Trailer shares for 2018 were therefore adduced from the detailed data obtained from eNatis and applied to the registering authority data for 2016 to populate the fuel supply demand balancing tool described in Appendix B2 above.

Table 3: Comparison of eNatis Provincial and Registering Authority (aggregated) Views for Vehicle Typologies for the Western Cape Province 31 December 2016

Registering Authority View		Provincial View	
Vehicle Type	Count	Vehicle Type	Count
Heavy load veh (GVM>3500Kg, not to draw)*	29,042	Trucks (Heavy load vehicles GVM > 3500kg)	42,909
Heavy load veh (GVM>3500Kg, equip to draw)*	33,705	Heavy load trailers GVM > 3500kg	19,832
Sub Total GVM > 3500 kg	*62,747*	*Sub Total GVM > 3500 kg*	*62,741*
Light load vehicle (GVM 3500Kg or less)*	457,220	LDV's, panel vans, other light load veh's GVM <= 3500kg	315,717
		Light load trailers GVM <= 3500kg	140,001
Sub Total GVM < 3500 kg	*457,220*	*Sub Total GVM < 3500 kg*	*455,718*
Heavy passenger mv (12 or more persons)	6,919	Buses, bus trains, midibuses	6,831
Light passenger mv (less than 12 persons)	1,219,602	Motor cars and station wagons	1,219,373
Minibus	33,966	Minibuses	33,966
Motorcycle / Motortricycle / Quadrucycle	85,462	Motorcycles, quadrucycles, tricycles	85,456
Special Vehicle	55,186	Other self-propelled vehicles	37,647
Unknown	2,663	Caravans	17,513
		All other and unknown vehicles	4,520
Sub Total Other & Unknown	*57,849*	*Sub Total Other & Unknown*	*59,680*
GRAND TOTAL	*1,923,765*	*GRAND TOTAL*	*1,923,765*

** Note that trailers are not separated out for this data.*

Note: Registering Authority level data for 2016 data was needed to correspond to the available fuel supply data which was latest 2016 for a full year.

Appendix C Projecting Future Demand Under Scenario Using a Vehicle Parc Model

A vehicle parc (fleet) model was used to explore a limited number of scenarios of future energy demand for the Western Cape. This was not a modelling study and therefore this exercise was quite high level and calibration and assumptions were not highly refined. Nonetheless some useful insights were obtained and the working model has been made available to the WCG which provides a useful tool for further explorations. The reference case demand was also directly used for Key Output 1 which assessed a probable range of natural gas penetration in the Transport Sector.

The vehicle parc model was adapted for the Western Cape from a spreadsheet based national vehicle parc model (Stone, Henley, & Maseela, Modelling growth scenarios for biofuels in South Africa's transport sector, 2015). The assumptions were updated with national data from a recent modelling study (Stone, Maseela, & Merven, 2018). The tool had two purposes in this project:

- To represent the population of vehicles in the province and their current activity levels and efficiencies with a fair degree of certainty where empirical data is sparse or non-existent. This was required for the deliverables of Task A of the Terms of Reference which are documented in Appendix A.
- To represent the evolution of demand under scenario so as to better understand the potential for transport disruption and the potential for uptake of LNG by transport going into the future

The vehicle parc model is essentially a stock model that simulates the rate at which vehicles are scrapped and the effects on energy demand. It's value is in simulating scenarios of technology change, accounting for the lag created by the long life of a vehicle in South Africa.

Vehicles are scrapped and replaced with new technologies as the model looks further forward. We try and relate the rate of scrapping and the levels of activity (annual mileage) and efficiencies to the observed real world in one or more base years. We use calibration to ensure the model is realistic within established parameters. The simplified equation used to calculate energy consumption is:

$$\boldsymbol{Energy\ Consumption} = \boldsymbol{no.of\ vehicles} \times \boldsymbol{mileage} \times \boldsymbol{efficiency} \qquad \textbf{\textit{Equation 1}}$$

A number of assumptions are required to estimate the three variables in Equation 1: The number of vehicles; their mileage and their efficiency. These assumptions are as follows:

- A vintage profile derived from realistic scrapping curves that enables vehicle stock to be estimated from sales of historical vehicles disaggregated by vehicle type; the curves were calibrated so that the stock estimate closely matched a vehicle registration database.
- An assessment of annual vehicle mileage for each vehicle class and the rate at which this decays as the vehicle ages.
- Estimates of the fuel economy of each vehicle class and how this will change over time.

The fuel demand is calibrated to match the known fuel sales data by first iterating till approximate agreement by means of scaling the kilometres travelled per vehicle and then fine tuning with adjustments to the fuel economy and sometimes other assumptions. Thus are supply and demand reconciled and we have some level of certainty that our baseline passenger.km and ton.km estimates are reasonable.

This version looks forward to 2050 and is driven by the exogenous input of assumed passenger.km and ton.km demand for the Western Cape. The model determines the number of new vehicles required (sales) based on the demand not met by the residual fleet which is scrapped according to calibrated logistic curves. The share of new technologies using alternative fuels, assumed in the new vehicles sales determines the future demand for these fuels. The proportion of these technologies in the sales is simulated by the user using the interface shown below in Figure C- 1.

2. Penetration Rates of Technologies (% of Sales)

2.1. Passenger Cars — *Array PR_CAR*

Technology	Fuel	2006	2010	2015	2020	2025	2030	2035
Diesel_Conventional	Diesel	11.0%	13.7%	20.0%	15%	10.0%	5%	0.0%
Gasoline_Conventional	Gasoline	89%	86.2%	77.7%	78.0%	73.5%	53.0%	50.0%
Natural_Gas_Conventional	Natural Gas	0.0%	0.0%	0.0%	0%	0.0%	0%	0.0%
Hybrid_Gasoline	Gasoline	0.1%	0.1%	1.6%	3%	10.0%	30.0%	30.0%
Hybrid_Diesel	Diesel	0.0%	0.0%	0.5%	1%	1.5%	2%	0%
Flex_Fuel_Vehicle	E85	0.0%	0.0%	0.0%	0%	0.0%	0%	0%
Fuel_Cell_Vehicle	Hydrogen	0.0%	0.0%	0.0%	0%	0.0%	0%	0.0%
Battery_Electric_Vehicle	Electricity	0.0%	0.0%	0.2%	3%	5%	10%	20%
SUM		**100.000%**	**100.000%**	**100.00%**	**100.000%**	**100.000%**	**100.000%**	**100.000%**

2.2. SUVs — *Array PR_SUV*

Technology	Fuel	2006	2010	2015	2020	2025	2030	2035
Diesel_Conventional	Diesel	40.5%	41.7%	43.0%	30.0%	15.0%	5.0%	0.0%
Gasoline_Conventional	Gasoline	59.5%	58.3%	53.7%	61.8%	59.4%	50.0%	50.0%
Natural_Gas_Conventional	Natural Gas	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hybrid_Diesel	Diesel	0.0%	0.0%	1.1%	2.2%	3.6%	5.0%	0.0%
Hybrid_Gasoline	Gasoline	0.0%	0.0%	2.0%	4.0%	17.0%	30.0%	30.0%

Note: For past years the user sets actual technology penetration from sales data and for past years scenarios of penetration rates. In this case battery electric vehicle sales are assumed to accelerate in market share after 2030

Figure C- 1: Technology Sales Penetration Interface of the Western Cape Vehicle Parc Model

Appendix C1 Calibrating the Vehicle Parc Model

The first calibration step is the rate of scrapping so that the number of vehicles matches that in the registration database (see Table A- 11). The next stage of calibration tries to get the best average fit by scaling primarily annual mileage for different modes from initial values. The methodology doesn’t attempt to take short run elasticities to price, GDP or income into account which is what would be needed to be highly accurate for every one of the calibration years 2006, 2010 and 2015 as these short run effects are not relevant to long term projections. The calibration accuracy for the Western Cape vehicle parc model developed for this project is shown below.

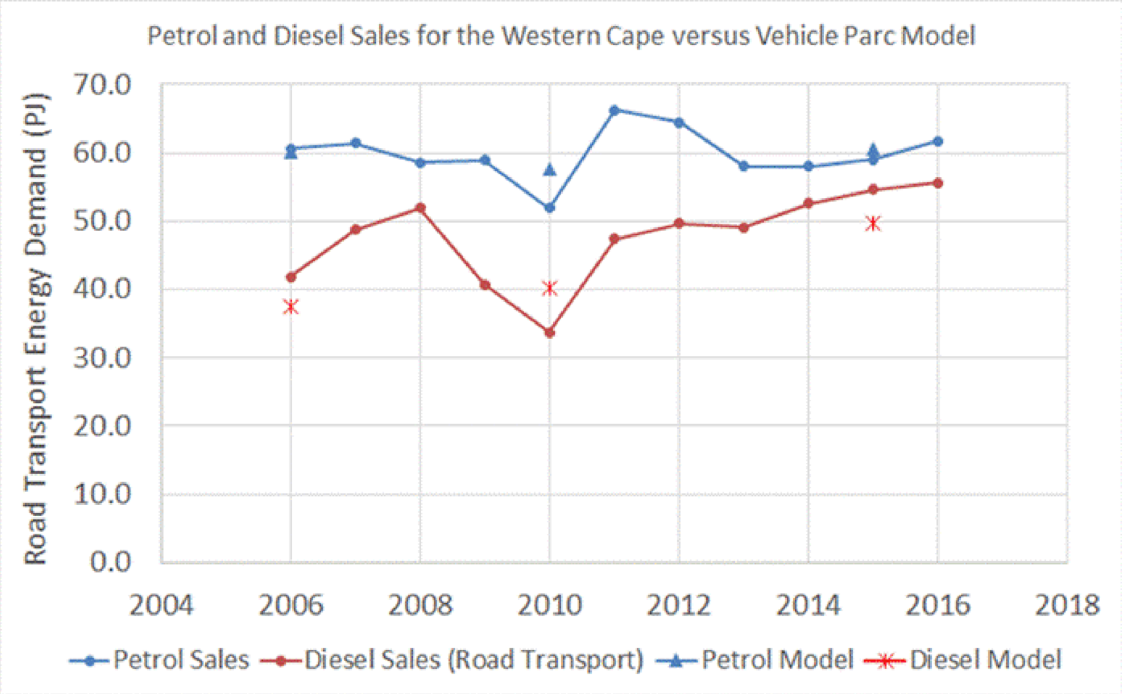


Figure C- 2: Calibration of the Vehicle Parc Model versus Supply Side Fuel Demand Data (DoE, accessed 2018)

Diesel leakage across corridors means it's not worth too much effort massaging the diesel calibration. Calibrating the model gave some useful insights into why petrol demand has levelled off:

1. Steady dieselisation of Cars and LCVs
2. A drop in the number of registered minibuses. Presumably this may have reversed with the crisis in the Metrorail service.
3. Modest efficiency improvements

Appendix C2 The Relationship between Transport Activity and Economic Growth

Energy demand projection models, including the vehicle parc model used for this project, tend to be driven by economic growth assumptions and so the link between economic growth and actual demand for energy services (pkm and tkm) is important to establish. The CSIR assisted by the University of Stellenbosch's Department of Logistics published estimates of tonne-km freight activity between 2003 and 2013. These are presented below and compared to real GDP over the same period. The annualised growth rates are 3.6% for freight activity and 3.3% for real GDP implying an elasticity of tonne-km with respect to GDP of close to 1.

Table C- 1: Growth in tonne-km of freight Activity versus Growth in Real GDP for South Africa (2003 – 2013)

Year	Road				Rail					Total Freight Activity Demand (btkm)	Source[1]	GDP (Rands - constant 2010 prices, seasonally adjusted and annualised)[2]
	Metro (btkm)	Rural (btkm)	Corridor (btkm)	Natcor & CapeCor[3] (btkm)	Corridor (btkm)	Natcor & CapeCor (btkm)	Rural (btkm)	Metro (btkm)	Bulk Export (btkm)			
2003	43	49	92		41		20	2	61	308	2nd SOL	2,143,231
2004	47	58	103		30		23	0.2	73	334.2	3rd SOL	2,240,846
2005	53	62	108		31		23	0.2	75	352.2	4th SOL	2,359,097
2006	60	68	108		28		24	2	67	357	5th SOL	2,491,296
2007	61	68	116		31.5		27	2.5	68	374	6th SOL	2,624,841
2008	61	71	79	52	17	13	13	1.3	68	375.3	7th SOL	2,708,601
2009	58	72	69	53	12	8	18	0.2	75	365.2	8th SOL	2,666,940
2010	62	78	72	60	12	6	18	0.1	76	384.1	9th SOL	2,748,008
2011	61	86	75	75	14	8	19	0.1	83	421.1	10th SOL	2,838,257
2012	61	91	78	71	14	8	25	0.1	82	430.1	10th SOL	2,901,078
2013	60	92	80	73	16	9	25	0.1	85	440.1	10th SOL	2,973,293
									CAGR	**3.6%**	**CAGR**	**3.3%**

1: Source: State of Logistics publications between 2003 and 2013. In 2014 the CSIR ceased this publication and the University of Stellenbosch's Department of Logistics superceded this with the Logistics Barometer at the same time recalibrating the tonne-km estimate and so later data are not consistent with this dataset.

2: Source: Statistics South Africa P0441 – GDP tables

3: NatCor – Corridor between Durban and Gauteng; CapeCor – corridor between Cape Town and Gauteng

This is supported as representative by a regression of international time series undertaken by University College Cork presented below which also suggests an average elasticity of 1 for tonne-km with respect to GDP.

Figure C- 3: Regression of global data for GDP and tonne-km [N = 492] (Mulholland, Teter, Cazzola, & O Gallachoir, 2017)

A similar published time series for passenger.km for South Africa was not found for this study but the European Union publishes the index of passenger transport demand relative to GDP for its member states. The relative change of this index between 2005 and 2015 is presented below and shows that on average passenger transport demand lagged GDP only slightly by 4% in total over a ten year period but with very large variation between member states. This suggests an elasticity of passenger transport activity with respect to GDP approaching 1 but varying far more than is the case for freight for individual observations. Using the number of registered passenger cars in South Africa as a proxy for passenger transport demand, yields a growth from 4,154,593 cars in 2003 to 6,376,733 in 2013[25] equivalent to 4.4% annualised growth. This would imply an elasticity of passenger transport activity with respect to GDP of around 1.3. The vehicle parc model calibration however suggests only 1.2% annualised growth for passenger transport between 2006 and 2015 compared to 2.0% for freight due to stagnation in the supply of passenger transport by Metrorail and minibuses. For the purposes of projecting demand forward it was decided therefore in the absence of better evidence to grow both passenger-km and tonne-km at an elasticity of around 1 with respect to GDP.

[25] Source: National Traffic Information System – data collected for various projects

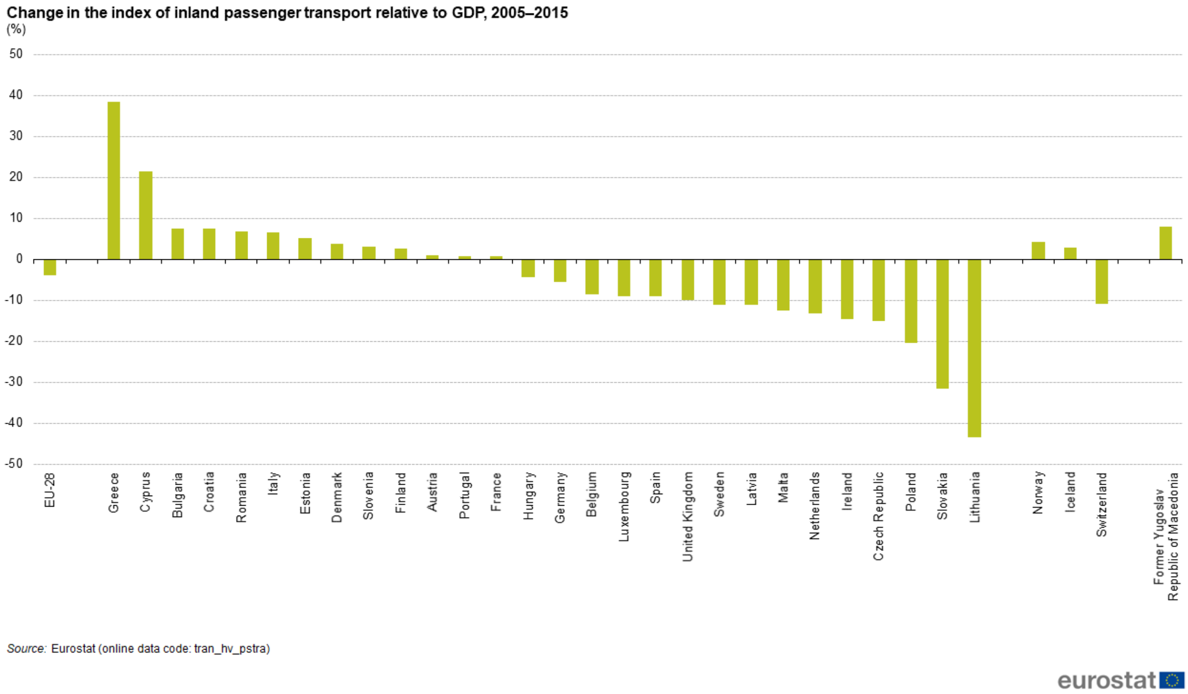


Figure C- 4: Change in the Index of Inland Passenger Transport Demand relative to the Index of GDP for EU Member States 2005 – 2015 (Eurostat, 2018)

Appendix C3 Scenario Development

Two demand scenarios were developed which were overlayed with technology change scenarios. The impact of scenarios of economic growth were not explored and both demand scenarios correspond to a moderate long term real GDP growth rate of between 2 and 2.5%. This was not a dedicated modelling study and the scenario design was limited by the time and resources available. The two demand scenarios were built up from the following assumptions:

1. **Reference Case**: Demand for passenger-km and tonne-km was assumed to carry on growing in a similar pattern to that historically observed as shown below in Table C- 2. The overall growth rate between 2015 and 2050 is 2.2% for passenger.km and 2.4% for tonne-km. This can be considered to correspond to a moderate long term real GDP growth rate of between 2 and 2.5% given the evidence discussed in Appendix C2 above. The resulting passenger-km and tonne-km and the mode shares thereof in 2015 and 2050 are shown in Figure C- 5 and Figure C- 6.

Table C- 2: Assumed Annualised Growth Rates for passenger-km and tonne-km projections for Reference Case

Passenger Mode	2015 - 2020	2020 - 2025	2025 - 2030	2030 - 2035	2035 - 2040	2040 - 2045	2045 - 2050
Car	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
SUV	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Motorbike	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Bus & BRT	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Minibus	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Metro	-5.0%	5.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Cycling	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Walking	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%

Freight Mode	2015 - 2020	2020 - 2025	2025 - 2030	2030 - 2035	2035 - 2040	2040 - 2045	2045 - 2050
LCV	2.5%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
MCV	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
HCV	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Rail Electric	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Rail Diesel	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%

The growth rates assumed above translated to the following shift in modal shares between 2015 and 2050.

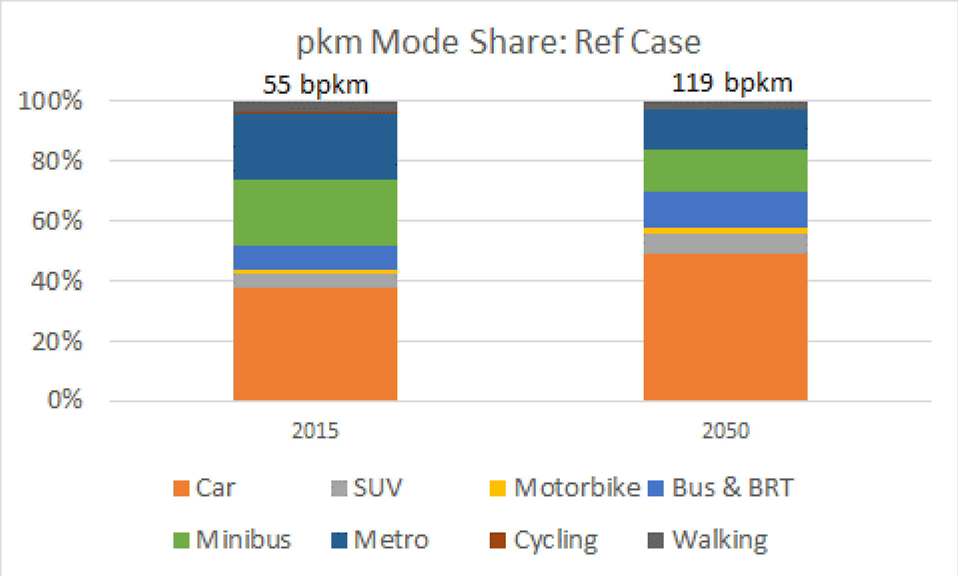


Figure C- 5: Reference Case passenger-km Scenario Shares of Modes in 2015 and 2050 for the vehicle parc model

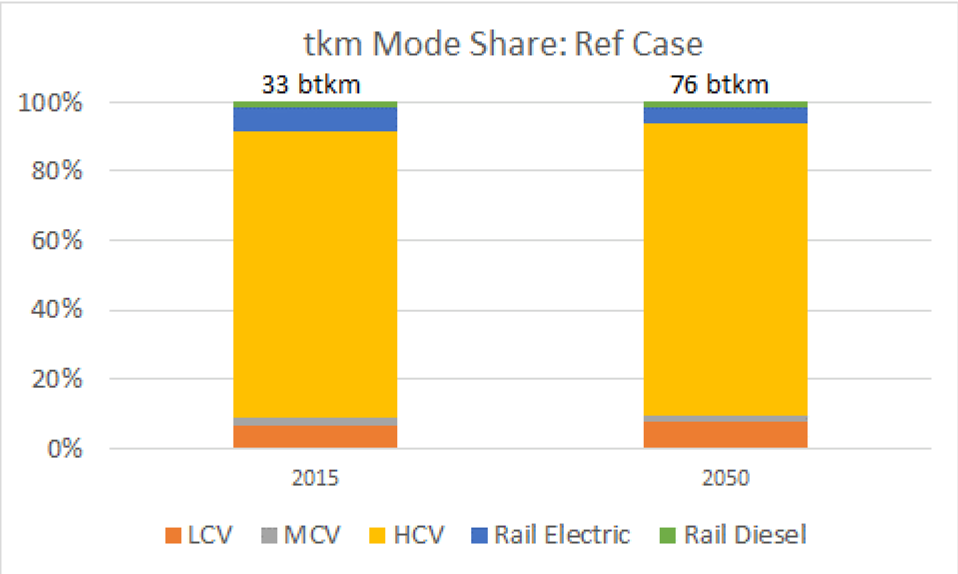


Figure C- 6: Reference Case tonne-km Scenario Shares of Modes in 2015 and 2050 for the vehicle parc model

2. Mode Shift and Ride-sharing: passenger-km and tonne-km are moved from less efficient modes like passenger cars to more efficient modes like buses. Metro rail is assumed to be maintained and expanded with minibuses regenerating as a mode through feeders. In the case of ride-sharing the load factor of passenger cars is increased so that the demand for passenger-km translates to less vehicle-km and so less energy is used. The assumed growth rates per mode are therefore quite different to Business as Usual for the modes SUV, Bus & BRT, Metro, Cycling, Walking and Rail Electric, reflecting a move to less carbon intensive modes but the overall growth rate between 2015 and 2050 is still the same at 2.2% for passenger.km and 2.4% for tonne-km. Ride-sharing was simulated by increasing occupancy as shown in Table C- 3 below. This resulted in less vehicle-km being demanded for the same passenger-km and therefore less energy demand. The resulting passenger-km and tonne-km and the mode shares thereof in 2015 and 2050 are shown in Figure C- 7 and Figure C- 8

Table C- 3: Assumed Annualised Growth Rates for passenger-km and tonne-km projections for Mode-Shift and Ride Sharing Scenario

Passenger Mode	**2015 - 2020**	**2020 - 2025**	**2025 - 2030**	**2030 - 2035**	**2035 - 2040**	**2040 - 2045**	**2045 - 2050**
Car	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
SUV	3.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
Motorbike	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Bus & BRT	3.5%	3.7%	4.0%	4.5%	4.5%	4.5%	4.5%
Minibus	1.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Metro	-5.0%	5.0%	2.5%	2.5%	2.5%	2.5%	2.5%
Cycling	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Walking	1.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Freight Mode	**2015 - 2020**	**2020 - 2025**	**2025 - 2030**	**2030 - 2035**	**2035 - 2040**	**2040 - 2045**	**2045 - 2050**
LCV	2.5%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
MCV	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
HCV	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Rail Electric	1.5%	8.0%	12.0%	12.0%	3.0%	3.0%	3.0%
Rail Diesel	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table C- 4: Assumed Penetration Rate of Ride Sharing in Passenger Car Trips and Effect on Average Vehicle Occupancy

	2015	2020	2025	2030	2035	2040	2045	2050
Average Occupancy	1.40	1.40	1.51	1.62	1.87	1.995	1.995	1.995
Share of Trips	0%	0%	10%	20%	30%	35%	35%	35%

Note: Average occupancy of ride-share trips is assumed to be 2.5 and conventional trips 1.4

The growth rates assumed above translated to the following shift in modal shares between 2015 and 2050.

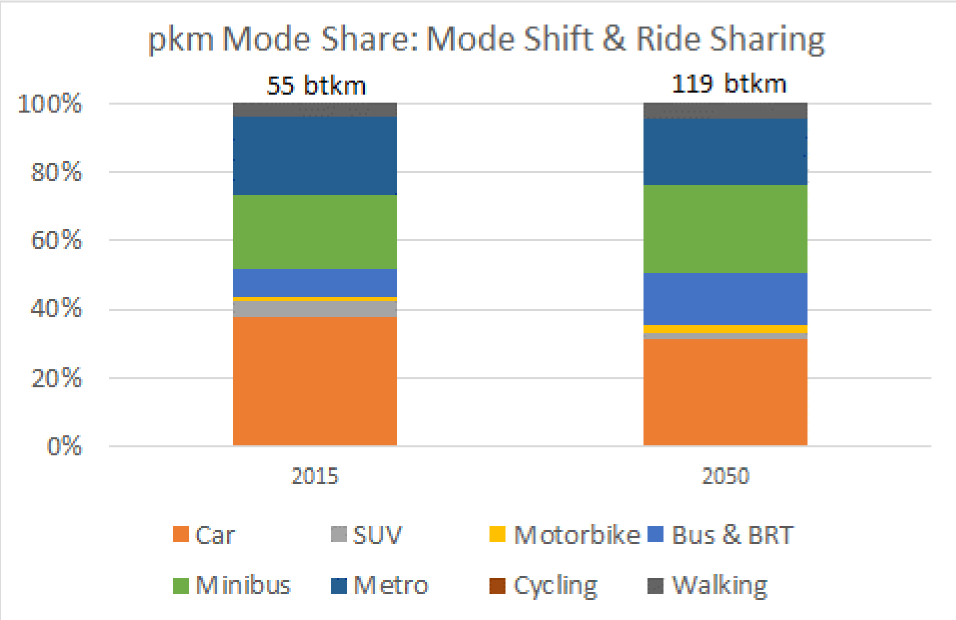


Figure C- 7: Mode Shift and Ride-sharing Scenario passenger-km Shares of Modes in 2015 and 2050 for the vehicle parc model

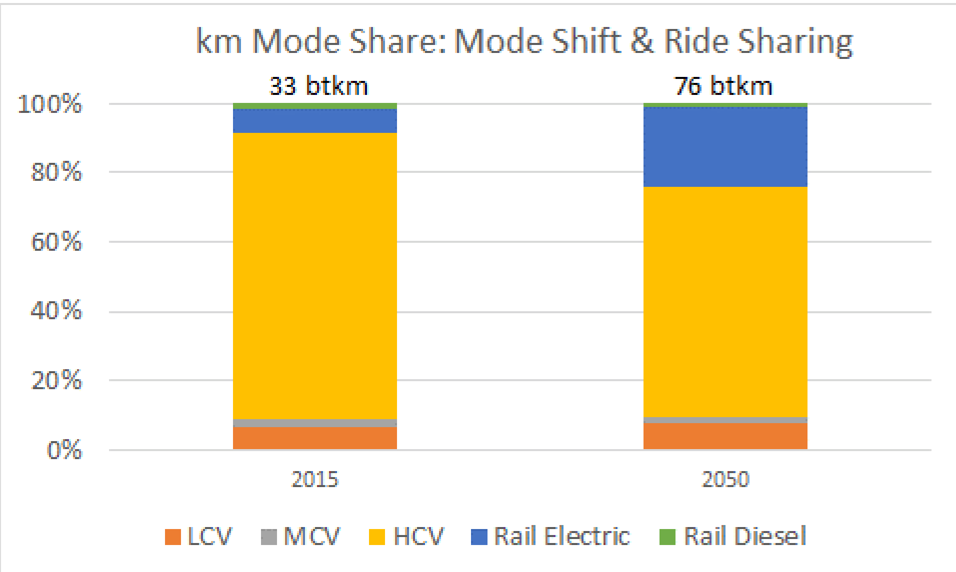


Figure C- 8: Mode Shift and Ride-sharing Scenario tonne-km Shares of Modes in 2015 and 2050 for the vehicle parc model

Scenarios of technology change (sales penetration of new technologies) set using the interface shown in Figure C- 1 were imposed on top of the demand scenarios to form the study scenarios. The following 3 technology change storylines were developed. Where a technology penetration rate is stated to have reached a certain level by a certain date it can be assumed to have been maintained at that level till 2050:

- ***Base Case:* This scenario assume a reverse in the dieselisation of the passenger car fleet knocking on from the emissions scandals, proliferation of hybrids and slow but steady growth of battery electric cars. Commercial vehicle technology retains the status quo.** Sales of conventional diesel internal combustion engine (ICE) passenger vehicles drop to 0% by 2035. Gasoline conventional ICE vehicle sales drop from near 80% of the market in 2020 to 20% in 2050. Gasoline hybrid passenger cars gain 30% of the market by 2030. Battery Electric Vehicle sales reach 10% of the passenger car market by 2030 and 50% by 2050. Similar battery electric penetration is seen in motorcycles but less so in buses which see a 30% penetration. Diesel continues to account for all HCV sales, around half of MCV sales and two thirds of LCV sales.
- ***High Battery Electric Vehicle Penetration*: This scenario assumes rapid assertion of dominance of BEV in the passenger mode.** Battery electric vehicle passenger cars and motorcycles attain 30% of sales by 2025, 80% by 2030 and 100% by 2035. Minibus taxi BEV penetration is slower reaching 5% in 2030 and 25% by 2050. Urban bus BEV penetration is the same as the Base Case attaining 30% by 2030 but remaining at that level till 2050.
- ***Big Gas*: This scenario models successful market development of natural gas switching in transport but stretches it out over time reflecting challenges in building a market. Retro-fits are not explicitly represented and these would be a way to attain initial uptake more rapidly. The bulk of opportunity would however be in dedicated LNG trucks and this would require stock turnover[26].** Bi-fuelled natural gas sales penetration of 3% for passenger cars from 2025 onwards, 30% for mini-buses by 2035, 20% for LCV and MCV by 2030. Dedicated CNG or LNG penetration starting at 5% in 2025 and reaching 30% by 2030 for urban buses. Dedicated CNG or LNG penetration starting at 5% in 2025 and reaching 30% of HCV sales by 2035.

The overlay of demand and technology scenarios combined to form the following scenario matrix:

Table C- 5: Scenario Matrix for Overlay of Demand Scenarios with Technology Change Scenarios

Technology Change Scenarios	***Demand Scenarios***	
	Reference	**Mode Shift/Ride Share**
Base Case	Ref-BaseTech	Shift-BaseTech
High Battery Electric Vehicle Penetration	Ref-HiBEVTech	Shift-HiBEVTech
Big Gas	Ref-BigGasTech	Shift-BigGasTech

Selected results for these scenarios are presented and discussed below.

Appendix C4 Passenger Transport Projections under Scenario

Selected results are presented below in order to give insights into the possible effects of transport disruption and the energy market share of successful but slowly developing natural gas market

[26] The vehicle parc model applies calibrated mileage decay curves based on US EPA curves (Merven, Stone, Hughes, & Cohen, 2012). Newer vehicles therefore contribute more mileage than older ones. The rate of decay is high for HCV and therefore the demand from new gas trucks grows rapidly relative to other fuels once sales are significant.

development. The Ref-BaseTech Scenario results for the energy demand in the passenger transport sector for the Western Cape are presented below. While electricity demand by 2050 looks modest it must be remembered that these vehicles are far more efficient and so the contribution to passenger demand is high.

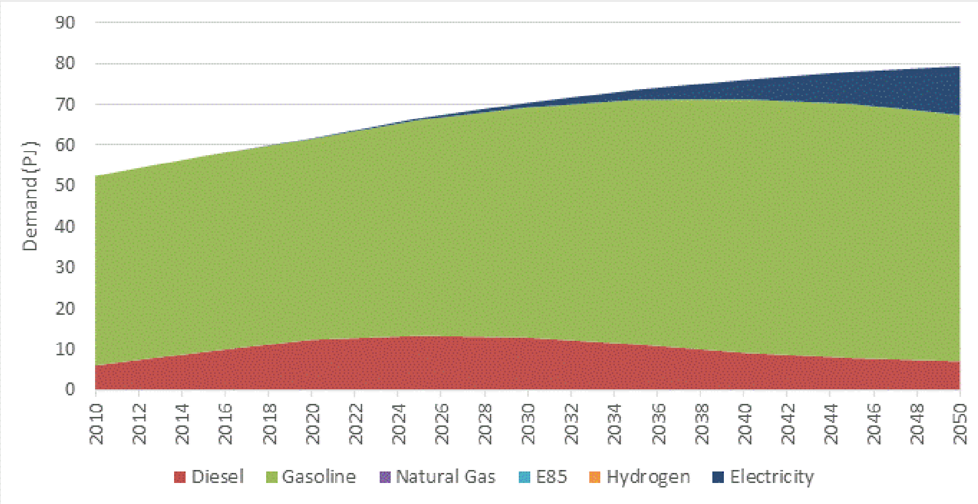


Figure C- 9: Energy Demand from Passenger Transport Ref-BaseTech Scenario 2010 - 2050

The above can be contrasted with the Shift-BaseTech Scenario which shows the large possible energy efficiency (and GHG emissions) gains through the combination of shifting to low carbon modes and increasing passenger car occupancy in the Western Cape.

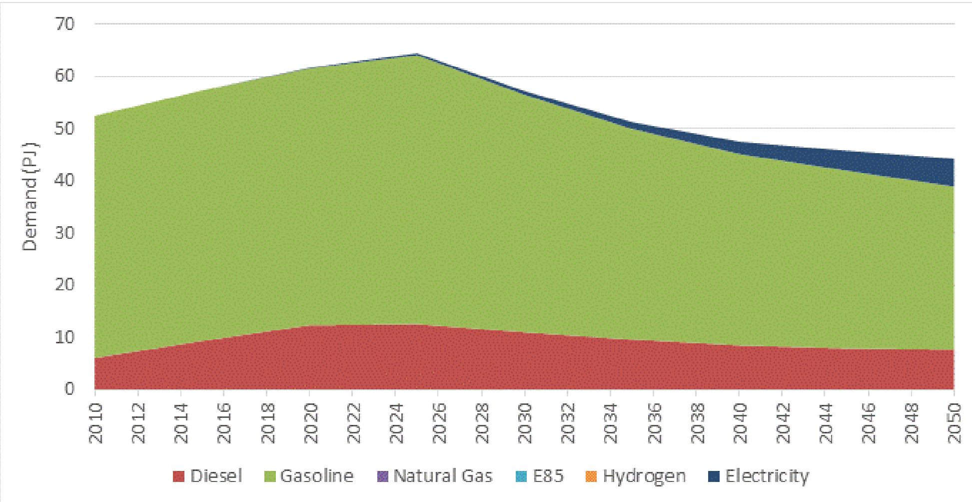


Figure C- 10: Energy Demand from Passenger Transport Shift-BaseTech Scenario 2010 - 2050

As shown by the results for the Ref-HiBEVTech scenario shown below rapid electrification of all passenger cars and motorcycles with significant inroads into public transport can achieve similar total energy demand reduction. Electricity would now however be a significant demand by 2050 of nearly 33 PJ (9 TWh) or around 40% of the Western Cape's electricity demand in 2015/6 (WCG, 2018). The sense of this can be checked as follows: Petrol demand in the province in 2015/16 was 60 PJ. If demand for passenger transport grows at 3% annualised but efficiency of ICE vehicles improves at 1% annualised, fuel demand would grow at around 2% annualised. By 2050 this rate of growth would equate to demand for petrol of 118 PJ. Electric vehicles are around 3.5 times more efficient that ICE vehicles which means that, if we assume similar efficiency gains for EVs, complete substitution of petrol would require electricity supply of around 118/3.5 = 34 PJ. Electricity demands from BEV adoption at scale are therefore highly significant in the longer term.

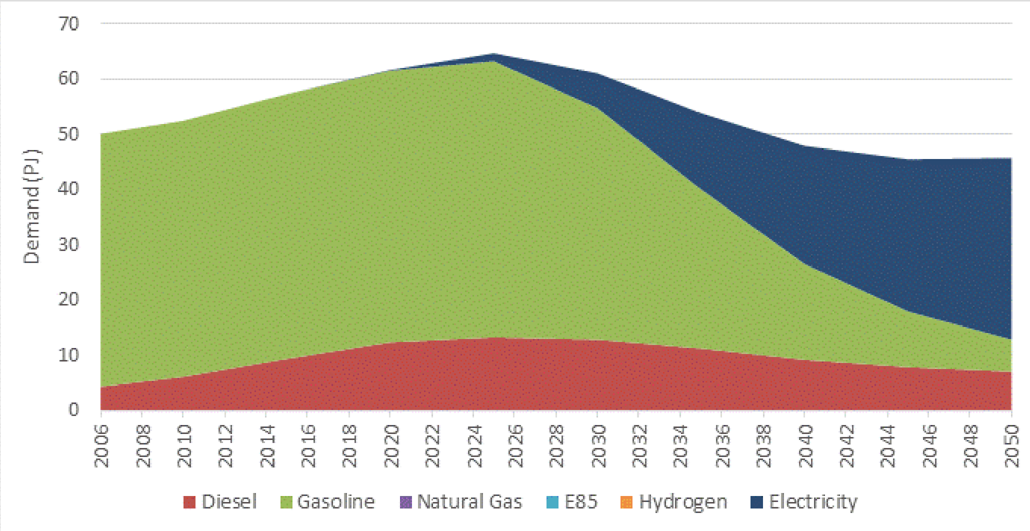


Figure C- 11: Energy Demand from Passenger Transport Ref-HiBEVTech Scenario 2010 – 2050

Combining rapid electrification with mode shift and ride-sharing in Scenario Shift-HiBEVTech gives an idea of the potential scale of disruption on energy demand in the longer term as shown below.

In

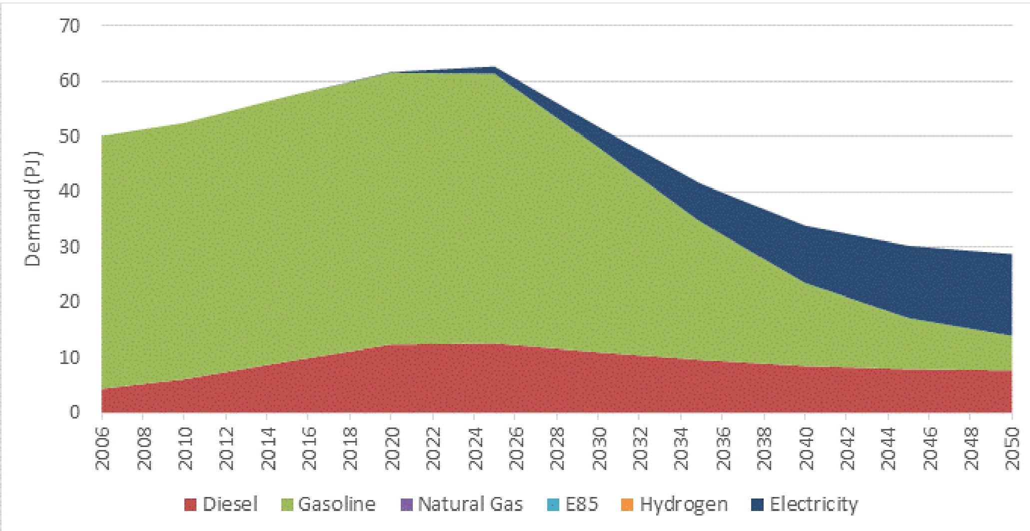


Figure C- 12: Energy Demand from Passenger Transport 'Shift-HiBEVTech' Scenario 2010 - 2050

The 'Ref-BigGasTech' scenario did not assume as much opportunity in the passenger mode as for freight and assumed a 3% penetration of bi-fuelled passenger cars, a 30% penetration of bi-fuelled natural gas minibuses by 2035 and a 30% penetration of new urban buses by 2030 (see scenario descriptions in section above). Bi-fuelled means that the vehicle can switch between petrol and natural gas. These ranges are based on the analysis presented in Section 9 above. Passenger car penetration, in particular, is limited by the need for distribution infrastructure. Minibuses can be retro-fit at low cost and so this penetration could be achieved far quicker than this simulation. This storyline sought to track the path of a slow but steady niche market development which as shown below approaches 5 PJ by 2040 for the passenger opportunity. This graph should be considered along with Figure 21.

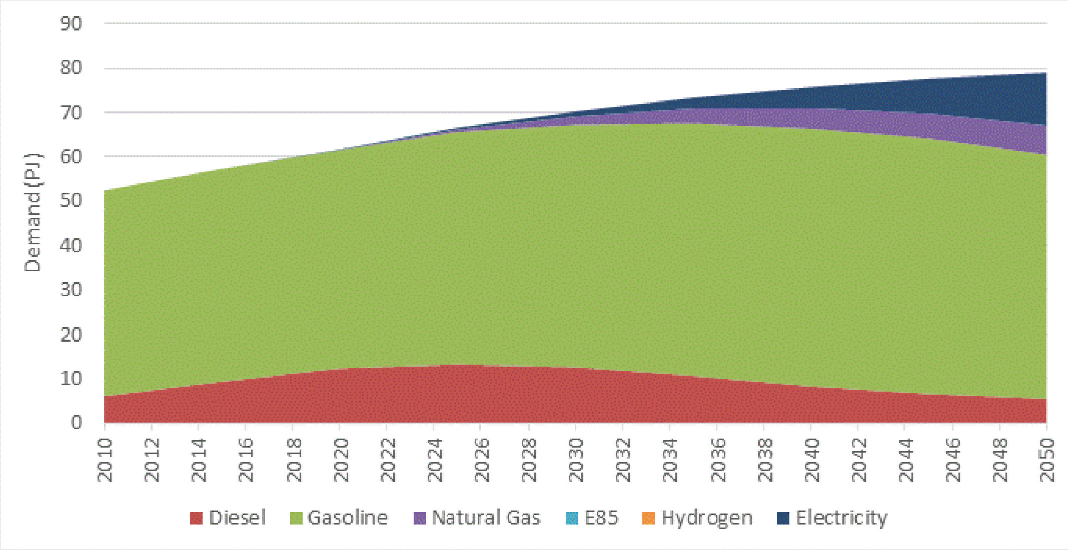


Figure C- 13: Energy Demand from Passenger Transport 'Ref-BigGasTech' Scenario 2010 - 2050

Findings

- The possibility of rapid penetration of BEV vehicles into the passenger car market, such that they account for 100% of sales by 2035, has the potential to reduce petrol demand by half by 2040 while diesel will likely still grow. This storyline implies not only cost parity between EVs and ICE vehicles in the global market by around 2025 but that sufficient models representing this market are available in South Africa. This result accounts for a high average vehicle age diluting the penetration of EVs into the market even though sales are high. The implications are serious in terms of the balance of products (slate) produced by local refining capacity given that diesel could still grow strongly.
- A Ride-sharing disruption combined with a shift to lower carbon transport has the potential to reduce demand for petrol by over 20% by 2040 relative to today even though demand for transport will have grown significantly. This would however require the urban bus system to attain and maintain passenger-km supply growth rates of 4.5% annualized and the rail system to recover and attain and maintain passenger-km supply growth rates of 2.5% annualised. The use of SUV's would have to decline by 1% annualized although this is against the trend now seen in the United States for example (Bloomberg, 2018). Realistically, there is neither the will not the money currently to approach these mode shifts but ride-sharing is a potentially low-cost rapidly deploying game changer that can reduce passenger-km and therefore, potentially energy demand, by 30% relative to baseline (not today's demand) or around 14 PJ by 2040[27].
- Without significant uptake of natural gas by passenger cars, which is very unlikely given the need for a distribution network, even market success in the minibus and urban bus modes does not offer more than a niche opportunity in the passenger transport sector. Given the assumptions for a gas scenario discussed above, a demand of 5 PJ was attained but this could take a long time to reach (2040) if it depended on new vehicles. Retro-fits with 3rd party kits are therefore key in this sector in order to gain some of this niche potential early on in the development of a market.

[27] Estimated using the ratio of occupancies with and without ride sharing - see Table C- 4 above: 1 – (1.4/1.995) = 30%

Appendix C5 Freight Transport Projections Under Scenario

The reference case for freight transport suggests a more than doubling of liquid fuels demand, mostly diesel by 2050 as shown below.

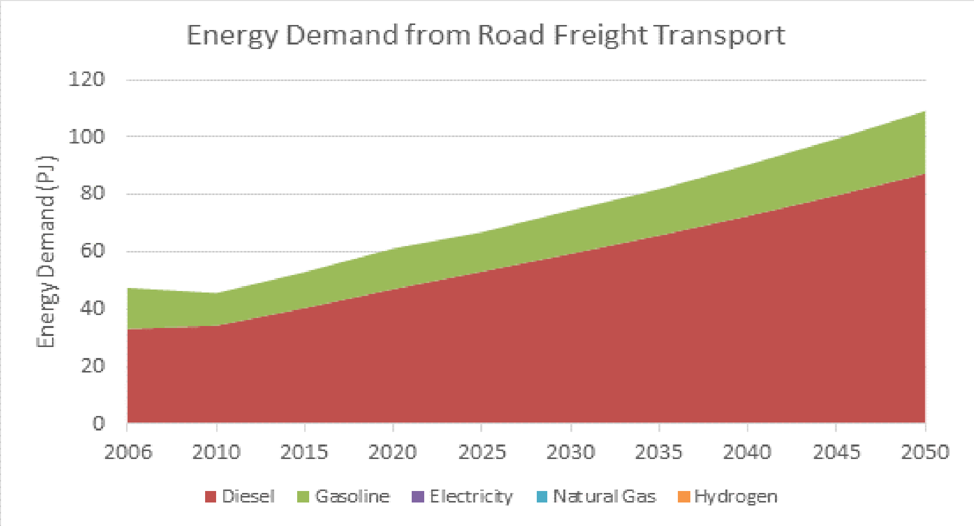


Figure C- 14: Energy Demand from Freight Transport for Ref-BaseTech Scenario 2010 – 2050

The Shift-BaseTech Scenario imposes the shifting of over 13 billion tkm out of a market of 76 billion tkm from road to rail by 2050, relative to the reference scenario. This would require rail's share of general freight to increase from around 9% today to around 24% for a doubling of total demand. As shown below the effect on diesel demand is only around 10% relative to the Ref-BaseTech Scenario because LCV demand continues to grow as before.

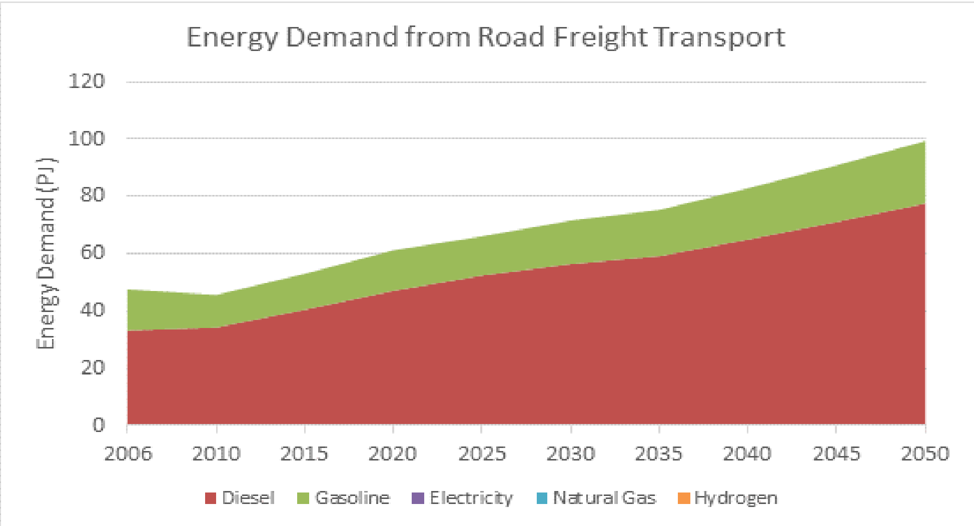


Figure C- 15: Energy Demand from Freight Transport for Shift-BaseTech Scenario 2010 - 2050

The 'Ref-BigGasTech' assumed a 20% penetration of natural gas vehicles into the sales of LCV and MCV modes by 2030 staying constant to 2050 and a 30% penetration into HCV by 2035 maintained to 2050 (see scenario descriptions in section above). This scenario would require fuelling infrastructure on corridors as well as fuelling of captive metropolitan fleets, aspects explored in more detail in Appendix D2 and Appendix G. As shown below demand for natural gas from freight reaches around 5 PJ by 2030, nearly 17 PJ by 2040 and around 25 PJ by 2050.

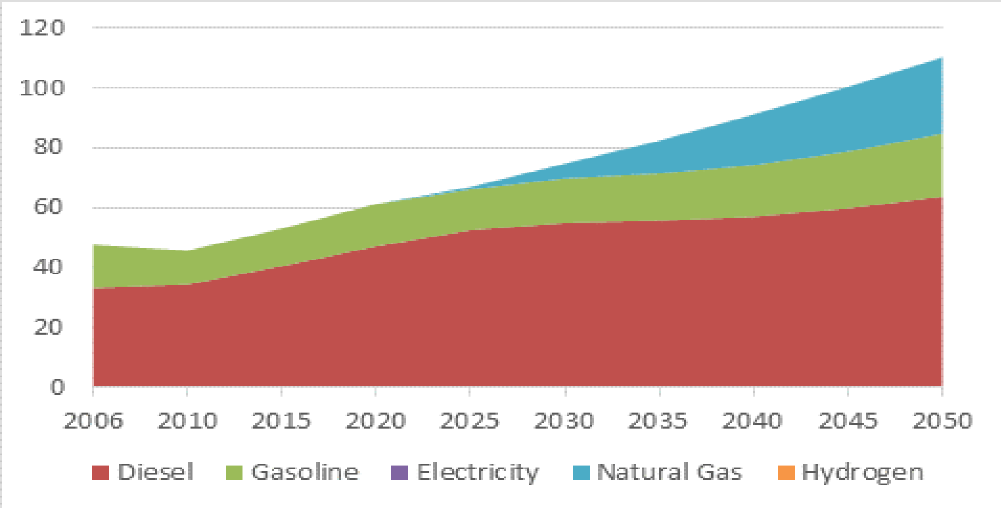


Figure C- 16: Energy Demand from Freight Transport for 'Ref-BigGasTech' Scenario 2010 - 2050

Findings

- The diesel / petrol ratio looks likely to swing further in favour of diesel, even drastically so if battery electric vehicles come to dominate the passenger car mode.
- General Freight Rail would need very large investments and growth relative to road freight to make even a moderate (10%) impact on total demand for diesel by road transport.
- Given the assumptions for a gas scenario (Ref-BigGasTech) discussed above, demand for natural gas from freight reaches around 5 PJ by 2030, nearly 17 PJ by 2040 and around 25 PJ by 2050. Dual-fuel retrofits have limited potential however (Appendix D2) and growth therefore depends on new vehicle turnover. Large logistics companies supplying long-haul services turn over truck stock quickly (1st life) before selling vehicles on for other uses (2nd life). Building a market therefore requires targeting these companies early on to build market momentum. A contracted gas price that guarantees operational costs over the 1st life of a new LNG truck would be a powerful incentive to fuel switching.
- As is discussed in Section 10 above, the key uncertainties around attaining the Ref-BigGasTech scenario scale of demand, approaching 2040 and possibly earlier, are:
  - Stringent action against climate change that would target all fossil fuels including natural gas
  - Either independently or because of this, a shift to hydrogen fuel-cell trucks or hybrid battery electric fuel cell trucks[28]. The primary barrier of a switch to fuel cells is not however the vehicle costs, although commercially viable models are not yet available from established manufacturers, but rather the cost of a hydrogen supply chain (Stone, Merven, & Senatla, 2013). By 2050 however, abundant solar power capacity that would otherwise be curtailed may exist and could produce low cost, zero-carbon hydrogen.

[28] See https://nikolamotor.com/one

Appendix C6 Vehicle Parc Model Base Case Outputs for use in Estimating Ranges of Uptake by Mode

Figure C- 17: Vehicle Parc Model Ref-BaseTech Energy Demand by Mode and Fuel - Passenger

Mode	Technology	Fuel	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car	Diesel_Conventional	Diesel	0.79	1.86	3.80	5.73	6.20	5.67	4.23	2.59	1.47	0.76
Car	Gasoline_Conventional	Gasoline	34.59	35.23	37.11	37.88	39.98	39.86	38.51	36.75	33.94	29.73
Car	Natural_Gas_Conventional	Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Car	Hybrid_Gasoline	Gasoline	0.00	0.01	0.10	0.38	1.19	4.03	8.07	11.49	14.30	16.72
Car	Hybrid_Diesel	Diesel	0.00	0.00	0.03	0.11	0.23	0.41	0.45	0.30	0.19	0.10
Car	Battery_Electric_Vehicle	Electricity	0.00	0.00	0.01	0.10	0.33	0.79	1.77	3.49	5.89	8.99
SUV	Diesel_Conventional	Diesel	1.97	2.34	2.99	3.34	3.12	2.40	1.58	0.85	0.40	0.16
SUV	Gasoline_Conventional	Gasoline	4.74	4.85	5.25	5.62	6.22	6.59	6.89	7.01	6.72	6.00
SUV	Natural_Gas_Conventional	Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SUV	Hybrid_Gasoline	Gasoline	0.00	0.00	0.02	0.09	0.34	0.97	1.69	2.32	2.82	3.25
SUV	Hybrid_Diesel	Diesel	0.00	0.00	0.01	0.05	0.12	0.23	0.26	0.18	0.11	0.05
SUV	Battery_Electric_Vehicle	Electricity	0.00	0.00	0.00	0.01	0.06	0.16	0.37	0.74	1.26	1.92
Motorcycle	Gasoline_Conventional	Gasoline	0.84	1.09	1.18	1.37	1.56	1.76	1.92	2.03	2.08	2.08
Motorcycle	Battery_Electric_Vehicle	Electricity	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.16	0.29	0.45
MBT	Diesel_Conventional	Diesel	0.08	0.29	0.42	0.74	0.89	0.97	0.88	0.65	0.39	0.21
MBT	Gasoline_Conventional	Gasoline	5.57	5.21	4.30	3.86	3.70	3.59	3.66	3.75	3.80	3.74
MBT	Battery_Electric_Vehicle	Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.14	0.23
Bus	Diesel_Conventional	Diesel	1.46	1.54	2.05	2.33	2.60	2.75	2.93	3.18	3.53	3.99
Bus	Battery_Electric_Vehicle	Electricity	0.00	0.00	0.00	0.00	0.03	0.13	0.24	0.35	0.45	0.56

Figure C- 18: Vehicle Parc Model Ref-BaseTech Energy Demand by Mode and Fuel - Freight

Mode	Technology	Fuel	2006	2010	2015	2020	2025	2030	2035	2040	2045	2050
LCV	Diesel_Conventional	Diesel	7.18	9.18	11.91	16.09	19.52	22.88	26.34	30.05	33.98	38.06
LCV	Gasoline_Conventional	Gasoline	14.19	10.90	11.62	12.89	12.15	13.43	14.28	15.92	17.65	19.64
LCV	Flex-Fuel Vehicle	E85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LCV	Natural_Gas_Conventional	Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MCV	Diesel_Conventional	Diesel	2.21	1.88	1.69	1.55	1.50	1.50	1.57	1.64	1.73	1.80
MCV	Gasoline_Conventional	Gasoline	0.17	0.45	0.93	1.27	1.53	1.72	1.84	1.95	2.05	2.17
MCV	Natural_Gas_Conventional	Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCV	Gasoline_Conventional	Diesel	23.73	23.16	26.78	29.34	32.11	34.88	37.78	40.79	43.99	47.39
HCV	Natural_Gas_Conventional	Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCV	Hydrogen_Fuelcell	Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C7 Key Output 1 – Data Tables for the Estimate of the Range of Natural Gas Potential by Mode

Figure C- 19: Data Table for Build-up of Lower Natural Gas Uptake Estimate

Mode	Technology Type	Estimated Lower Substitution Potential	2020	2025	2030	2035	2040	2045	2050
Captive Fleet Passenger Cars	Bi-Fuelled Conversion CNG	0.5%	0	0.20	0.20	0.19	0.18	0.17	0.15
Minibus	Bi-Fuelled Conversion CNG	3.0%	0	0.11	0.11	0.11	0.11	0.11	0.11
LCV	Bi-Fuelled Conversion CNG	5.0%	0	0.61	0.67	0.71	0.80	0.88	0.98
Commuter Bus	Purpose Built New Vehicle Purchase CNG / LNG	3.0%	0	0.08	0.08	0.09	0.10	0.11	0.12
MCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	5.0%	0	0.12	0.13	0.14	0.15	0.16	0.17
HCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	5.0%	0	0.49	0.53	0.57	0.62	0.67	0.72
HCV Corridor	LNG Purpose Built New Vehicle Purchase	5.0%	0	0.76	0.83	0.90	0.97	1.04	1.12
TOTAL			**0**	**2.4**	**2.5**	**2.7**	**2.9**	**3.1**	**3.4**

Figure C- 20: Data Table for Build-up of Upper Natural Gas Uptake Estimate

Mode	Technology Type	Estimated Lower Substitution Potential	2020	2025	2030	2035	2040	2045	2050
Captive Fleet Passenger Cars	Bi-Fuelled Conversion CNG	2.0%	0.00	0.80	0.80	0.77	0.73	0.68	0.59
Minibus	Bi-Fuelled Conversion CNG	30.0%	0.00	1.11	1.08	1.10	1.13	1.14	1.12
LCV	Bi-Fuelled Conversion CNG	15.0%	0.00	1.82	2.01	2.14	2.39	2.65	2.95
Commuter Bus	Purpose Built New Vehicle Purchase CNG / LNG	20.0%	0.00	0.52	0.55	0.59	0.64	0.71	0.80
MCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	30.0%	0	0.70	0.79	0.85	0.91	0.97	1.02
HCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	30.0%	0	2.92	3.17	3.43	3.71	4.00	4.31
HCV Corridor	LNG Purpose Built New Vehicle Purchase	50.0%	0	7.62	8.27	8.96	9.68	10.43	11.24
TOTAL			**0.0**	**15.5**	**16.7**	**17.8**	**19.2**	**20.6**	**22.0**

Appendix D Cost Benefit Analysis of Fuel Switching to natural gas

Appendix D1 Background – The drivers of fuel switching

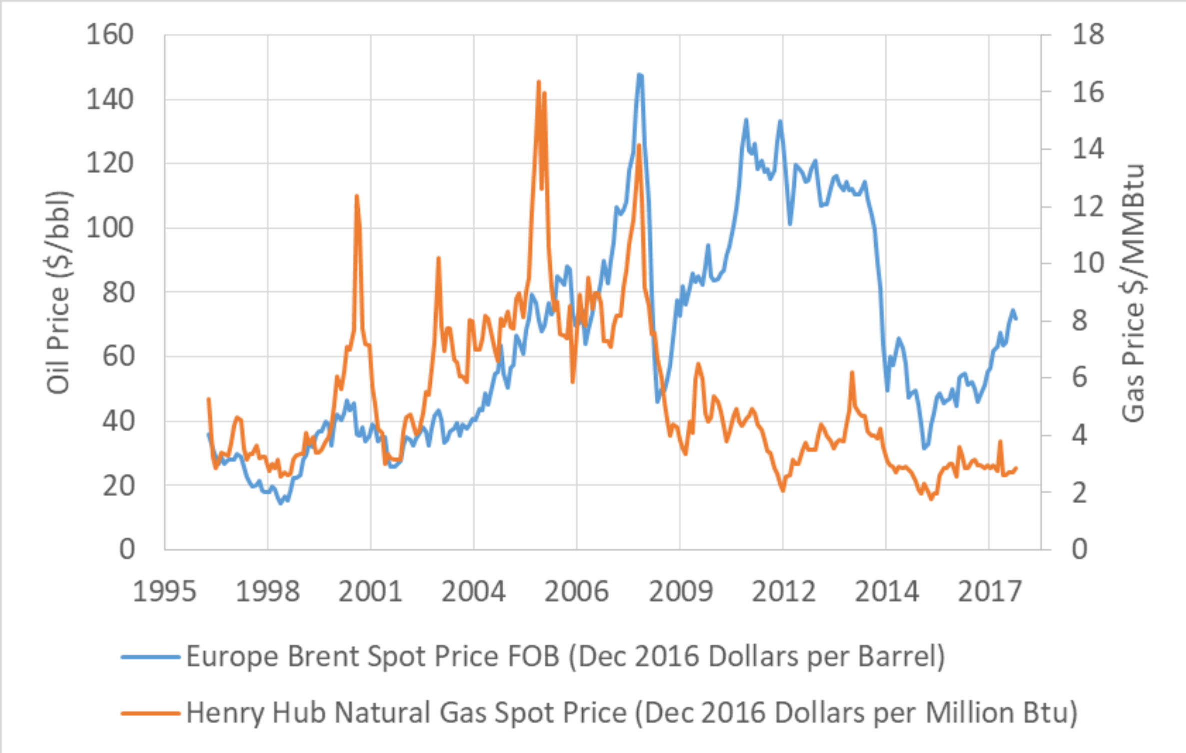
The cross cutting task of literature review and interviews (see Figure 1) strongly suggested that LNG uptake in the private transport space might be limited given the cost of a distribution network and the strong growth in battery electric vehicles for private transport. The major LNG transport opportunity therefore resides in commercial captive fleets (refuel in one or few places). Transport operators are motivated in their technology decisions by the cost of delivering a service, either moving passengers or moving freight. This is influenced by the capital cost of the vehicle and any fuelling infrastructure, usually amortised and the ongoing operation and maintenance costs of which fuel costs are generally the major share.

It is fairly certain therefore that if operational costs are sufficiently reduced by fuel switching then commercial transport operators will respond to the market if they can access the capital to do so. Fuel switching may be achieved by new vehicle purchase, engine and fuel system replacement or engine and fuel system retro-fit. Retro-fit may take the form of:

- Bi-fuelled conversion whereby the engine either runs on natural gas OR petrol at the discretion of the driver. This is usually only practical in a spark ignition engine for which natural gas is suited by virtue of its high octane number.
- Dual-fuel conversion, typically applied to compression ignition (diesel) engines whereby both diesel and natural gas are introduced into the combustion chamber in the same stroke in a ratio that depends on the operating conditions and engine parameters (IEA, 2017). In its simplest form, diesel is injected in the usual way into a pre-mixture of gas and air which is ignited by the diffuse compression ignition of the diesel droplet plume. Injection of both gas and diesel offers much greater scope for optimisation but this is generally only practical in a purpose built dual-fuel engine.

In economic terms this translates into much higher capital and O&M costs for dual fuel conversions compared to bi-fuelled conversions. The decision as to whether to use CNG or LNG also has cost implications. CNG does not require a cryogenic storage tank in the fuelling infrastructure and on the vehicle but requires a fuel tank rated to pressures of 200 – 300 bar (IEA, 2017) and also requires on-site compression of the gas to this pressure (distribution pressure will be much lower) when fuelling the vehicle to attain a practical vehicle range. In local experience these compressors are expensive to maintain (Emslie, Interview, 2018). Even at these high storage pressures, the lower energy density of CNG fuels compared to diesel means required in-vehicle fuel storage volumes are up to six times higher to deliver the same range. LNG fuel being in liquid form only requires double diesel storage volumes for equivalent range, depending on relative vehicle and engine efficiency (IEA, 2017). In general therefore, LNG is a better economic proposition for larger long-range trucks and buses and CNG is more suited to local distribution.

There is a premium to pay for fuel switching therefore that depends on the technology deployed. This premium has to be offset by a price advantage and by far the greatest uncertainty in making a decision whether to invest in LNG infrastructure or switch to LNG as a fuel, is this price advantage. This is illustrated by the time series shown below in Figure D- 1 which shows a long history of price correlation till 2009 and then a period of decorrelation as shale boomed and oil prices escalated followed by brief re-correlation with a low oil price and recent decorrelation. The implication is the price advantage is uncertain and therefore the gains from fuel switching are also uncertain. This suggests that viable fuel switching scenarios need a cushion to absorb negative price outcomes.



Source: EIA

Figure D- 1: The Gas and Oil Prices – Correlation, decorrelation, re-correlation, decorrelation

Appendix D2 Using CBA to Inform Estimates of LNG Uptake Potential

In assessing the LNG uptake potential of a mode, cost benefit is the primary consideration for the end-user and it was decided that a cost benefit tool would be of benefit to be taken into consideration along with the barriers particular to a mode such as the paratransit nature of minibus taxi operations, the recent battery electric procurement decisions in the public bus space and the need for scale if a transport operator were to take delivery of trucked LNG containers.

The calculator used simple undiscounted payback as the indicator of viability as defined by the following equation[29]:

$$\boldsymbol{Payback\ Period\ (years) = \frac{Capex\ Premium\ (Rands)}{Annual\ Fuel\ Savings\ (\frac{Rands}{year})}} \qquad \textbf{Equation 2}$$

Where:

$$\boldsymbol{Annual\ Fuel\ Savings = Annual\ Mileage\ [km] X \frac{Fuel\ Economy\ [\frac{MJ}{km}]}{1000} X \{Current\ Fuel\ Price\ \left[\frac{Rands}{GJ}\right] - Substitute\ Fuel\ Price\ \left[\frac{Rands}{GJ}\right]\}} \qquad \textbf{Equation 3}$$

[29] Data for an opex premium or discount for natural gas vehicles varies. Extended oil drain intervals may be offset by the costs of maintaining fuel storage and metering components particularly for dual-fuel retrofits. Opex costs were assumed equal for ICE and natural gas vehicles for this exercise. The sensitivity to the uncertainty in relative price of fuels far exceeds the influence of this variable.

The petrol and diesel price were linked to the Brent Crude Oil price and the Rand/dollar exchange rate by regressing the data presented in Table A- 9 to give the following equations:

$$D = 176.82 + 15.833 \; X \; RD + 6.525 \; X \; BR \qquad (R^2 = 93\%) \qquad \textit{Equation 4}$$

$$P = 146.73 + 30.862 \; X \; RD + 6.032 \; X \; BR \qquad (R^2 = 96\%) \qquad \textit{Equation 5}$$

Where:

P = Petrol Price (2016 Rand cents/litre) excluding taxes and levies
D = Diesel Price (2016 Rand cents/litre) excluding taxes and levies
RD = Rand/Dollar Exchange Rate
BR = Europe Brent Spot Price FOB (Dec 2016 Dollars per Barrel)

The gas price was built up for CNG and LNG as follows:

- Landed cost was assumed to have a fixed offset, Offset 1, relative to Henry Hub which was set at \$4.50/GJ which represents the sea transport cost and amortised bulk LNG infrastructure [30]
- The distribution cost of piped CNG was modelled as an Offset, Offset 2, between landed cost of gas and cost at CNG pump and was set at 2016 Rands/GJ 110[30].
- CNG Pump Price was calculated as Henry Hub plus the two offsets.
- Trucking distribution costs for LNG were calculated as follows:

$$T_{LNG} = \frac{(D \; X \; OP)}{Cap} \qquad \textit{Equation 6}$$

Where:

T_{LNG} = Trucking Distribution Costs [Metropolitan](R/GJ)
D = transport distance set at 150 km default (assumes delivery from Saldanha Bay to a Cape Town based transport operator)
OP = operating cost of truck [R/km] set by default at R45/km[31]
Cap = Payload of LNG truck set at 911 GJ for a 46,000 litre LNG container (standard size) on a truck

- LNG Dispensing Costs were calculated as follows:

$$D_{LNG} = \frac{(pmt(I,n,Capex) * (1 + Margin) + O\&M \; X \; Capex)}{(fleet \; size \; X \; mileage \; X \; FC)} \qquad \textit{Equation 7}$$

Where:

D_{LNG} = Dispensing Costs of LNG (R/GJ)

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[30] Source: Jurgen Kuhl, Capic – based on project development experience
[31] Source: Jurgen Kuhl, Capic – based on project development experience. This equates to R2.17/tkm. This can be checked against the cost of moving liquid fuels by truck to various localities derived from Central Energy Fund pricing data, for example Kenhardt (R2.30/ton.km) and Phalaborwa (R1.30/ton.km). The average national road freight costs in 2013 were 90c/ton.km (CSIR, 2013). The figure of R45/km can therefore be considered conservative and reflecting the economics of small scale supply. Economies of scale could therefore bring down costs to around R30/ton.km. Against this it should be noted that the distance assumption is loaded distance only and does not account for the likely necessity of an unloaded trip which is what makes transporting fuel more expensive than general freight.

pmt(I, n, Capex) = interest repayment function (I = interest rate, n = loan period)
Capex = Capital Cost of Dispensing Station – estimated at US$200,000 (Mariani, 2016)
Margin = operators margin (set at 35%)
O&M = operation and maintenance rate (set at 2%)
Fleet size = number of captive vehicles being refuelled by station. Set at 15 by default as minimum viable fleet size.
FC = fuel consumption (GJ/km)

- LNG price was calculated as follows:

$$\boldsymbol{LNG\ Price\ at\ Dispenser}\ \left(\frac{R}{GJ}\right) = \boldsymbol{Henry\ Hub} + \boldsymbol{Offset\ 1} + \boldsymbol{T_{LNG}} + \boldsymbol{D_{LNG}} \qquad \textit{Equation 8}$$

Table D- 1 illustrates the price simulation of petrol, diesel, CNG and LNG for local transport use under two scenarios of oil and gas price for a fixed rand/dollar exchange. The project team decided that it was economically correct to compare fuel prices less taxes and levies in the sense that the lost taxes from fuel substitution must be recovered in some form. A tax holiday would effectively be subsidy and there is no strong justification for subsidy, certainly on environmental grounds, in the view of the authors.

Table D- 1: Example of Fuel Cost Simulation for Two Scenarios of Henry Hub Gas and Brent Oil Price

Price Scenario	**Moderate**	**Extreme**
Europe Brent Spot Price FOB (Dollars per Barrel)	$60.00	$100.00
Henry Hub Natural Gas Spot Price (Dec 2016 Dollars per Million Btu)	$3.00	$2.00
Rand / Dollar	14.00	14.00
Offset - Henry Hub to Landed Cost in SA (Dec 2016 Dollars per Million Btu)	$4.50	$4.50
Landed Cost LNG (R/GJ)	R111.30	R96.46
Offset between landed cost of gas and cost at CNG pump (R/GJ)	R110.00	R110.00
Trucking Distribution Costs [Metropolitan] (R/GJ)	R7.41	R7.41
Levelised LNG Dispensing Costs (R/GJ)	R30.27	R30.27
Offset between landed cost of gas and cost at LNG pump (R/GJ)	R37.68	R37.68
Cost of CNG at Pump less Taxes and Levies (R/GJ)	**R221**	**R206**
Cost of LNG at Pump Less Taxes and Levies (R/GJ)	**R149**	**R134**
Cost of Diesel at Pump less Taxes and Levies (R/GJ)	**R207**	**R276**
Cost of Petrol at Pump less Taxes and Levies (R/GJ)	**R275**	**R346**

The payback calculator results for these two scenarios are presented below. A payback of 5 years can be considered moderately attractive while a payback of 2 years or less can be considered highly attractive.

Table D- 2: Payback Calculator Results for Moderate Price Differential Scenario

Vehicle Type	**Passenger Car**	**Minibus**	**Commuter Bus (12 m)**	**Commuter Bus (18 m)**	**Commuter Bus (18 m)**	**LCV**
Retro or New	**Retro**	**Retro**	**New**	**New**	**New**	**Retro**
Base Fuel	Petrol	Petrol	Diesel	Diesel	Diesel	Petrol
Fuel Economy Base (MJ/km)	2.9	4.9	19.8	28.6	28.6	4.7
Form of Gas	CNG	CNG	CNG	CNG	LNG	CNG
Conversion Technology	SI	SI	SI	SI	SI	SI
Fuel Economy Gas (MJ/km)	2.9	4.9	22.0	31.8	31.8	4.7
Conversion Cost / Capex Premium*	23153	23153	384302	455208	531076	23153
Annual Mileage	14125	35000	40000	48000	48000	30000
Base Fuel Cost	11148	46801	164318	284397	284397	38416
Gas Fuel Cost	8968	37652	194862	337261	227048	30906
Fuel Cost Savings	2179	9149	-30544	-52864	57349	7510
Payback	**10.6**	**2.5**	**-12.6**	**-8.6**	**9.3**	**3.1**
Vehicle Type	**Metro-politan HCV**	**Long Haul HCV**	**Metro-politan HCV**	**Long Haul HCV**	**Metro-politan HCV**	**Metro-politan HCV**
Retro or New	New	New	New	New	Retro	Retro
Base Fuel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Fuel Economy Base (MJ/km)	15.0	21.0	15.0	21.0	15.0	15.0
Form of Gas	CNG	CNG	LNG	LNG	CNG	LNG (e.g. Ecodual)
Conversion Technology	SI	SI	SI	Dual Pilot Injection (10% diesel)	Dual Fuel (30% diesel / 70% gas)	Dual Fuel (30% diesel / 70% gas)
Fuel Economy Gas (MJ/km)	16.7	23.3	16.7	21.6	16.7	16.7
Conversion Cost / Capex Premium*	424861	424861	750000	750000	234282	273329
Annual Mileage	35000	100000	35000	100000	50000	100000
Base Fuel Cost	108857	435429	108857	435429	155510	311021
Gas Fuel Cost	129092	516367	86906	335173	175745	267118
Fuel Cost Savings	-20234	-80938	21951	100256	-20234	43903
Payback	**-21.0**	**-5.2**	**34.2**	**7.5**	**-11.6**	**6.2**

**: Sources: conversions* - (Emslie, Taylor, & Goosen, 2014)*; buses* - (Short & Goldblatt, 2017) *including spreadsheet CBA model kindly made available by the City of Johannesburg Transport Department; LNG/CNG dual fuel kits* - (Berg, 2012). *For new trucks the percentage premiums for buses were applied to a base cost of R2.5 million*

Table D- 3: Payback Calculator Results for Extreme Price Differential Scenario

Vehicle Type	**Passenger Car**	**Minibus**	**Commuter Bus (12 m)**	**Commuter Bus (18 m)**	**Commuter Bus (18 m)**	**LCV**
Retro or New	**Retro**	**Retro**	**New**	**New**	**New**	**Retro**
Base Fuel	Petrol	Petrol	Diesel	Diesel	Diesel	Petrol
Fuel Economy Base (MJ/km)	2.9	4.9	19.8	28.6	28.6	4.7
Form of Gas	CNG	CNG	CNG	CNG	LNG	CNG
Conversion Technology	SI	SI	SI	SI	SI	SI
Fuel Economy Gas (MJ/km)	2.9	4.9	22.0	31.8	31.8	4.7
Conversion Cost / Capex Premium*	23153	23153	384302	455208	531076	23153
Annual Mileage	14125	35000	40000	48000	48000	30000
Base Fuel Cost	14007	58805	218607	378358	378358	48270
Gas Fuel Cost	8367	35127	181795	314645	204432	28834
Fuel Cost Savings	5640	23678	36812	63713	173927	19436
Payback	**4.1**	**1.0**	**10.4**	**7.1**	**3.1**	**1.2**
Vehicle Type	**Metro-politan HCV**	**Long Haul HCV**	**Metro-politan HCV**	**Long Haul HCV**	**Metro-politan HCV**	**Metro-politan HCV**
Retro or New	New	New	New	New	Retro	Retro
Base Fuel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Fuel Economy Base (MJ/km)	15.0	21.0	15.0	21.0	15.0	15.0
Form of Gas	CNG	CNG	LNG	LNG	CNG	LNG (e.g. Ecodual)
Conversion Technology	SI	SI	SI	Dual Pilot Injection (10% diesel)	Dual Fuel (30% diesel / 70% gas)	Dual Fuel (30% diesel / 70% gas)
Fuel Economy Gas (MJ/km)	16.7	23.3	16.7	21.6	16.7	16.7
Conversion Cost / Capex Premium*	424861	424861	750000	750000	234282	273329
Annual Mileage	35000	100000	35000	100000	50000	100000
Base Fuel Cost	144822	579289	144822	579289	206889	413778
Gas Fuel Cost	120435	481740	78249	321089	182502	280632
Fuel Cost Savings	24387	97549	66573	258200	24387	133146
Payback	**17.4**	**4.4**	**11.3**	**2.9**	**9.6**	**2.1**

**: Sources: conversions* - (Emslie, Taylor, & Goosen, 2014)*; buses* - (Short & Goldblatt, 2017) *including spreadsheet CBA model kindly made available by the City of Johannesburg Transport Department; LNG/CNG dual fuel kits* - (Berg, 2012). *For new trucks the percentage premiums for buses were applied to a base cost of R2.5 million*

The following insights were gained from this exercise:

- The cost of petrol per unit energy is higher than diesel and so paybacks are very favourable for fuel switching away from petrol fuelled vehicles that do a high mileage like minibus taxis and petrol LCVs. Retrofit conversion of minibuses and LCVs can pay back in under three years even under more moderate oil/ gas price differentials.
- Procurement of natural gas CNG buses is moderately attractive only at quite high price oil/gas price differentials but LNG buses are an attractive prospect across a wide price range but annual mileages need to be quite high (> 40,000 km/year)
- Metropolitan freight is attractive for fuel switching from a business and operational point of view which is why current pilots are targeting this space (Templeton, 2018), (Leidke, 2018). However, unless switching is to LNG not CNG and annual mileage is very high for this type of vehicle (+/- 100,000 km/annum) paybacks are not attractive. These are often so-called second life trucks (Templeton, 2018) and so in many applications we would not expect such a high mileage.
- Long haul HCV fuel switching to LNG can be highly attractive at high price differentials and modestly attractive at moderate price differentials. Given contractual protection and large scale operators it seems likely that this is a viable prospect if the technology can be imported at reasonable premiums and can be supported with parts and maintenance.
- In general, diesel substitution with CNG tended to return negative paybacks (not viable) unless price differentials were extreme.

Appendix E Long Haul LNG Truck Range – Example of IVECO Strialis

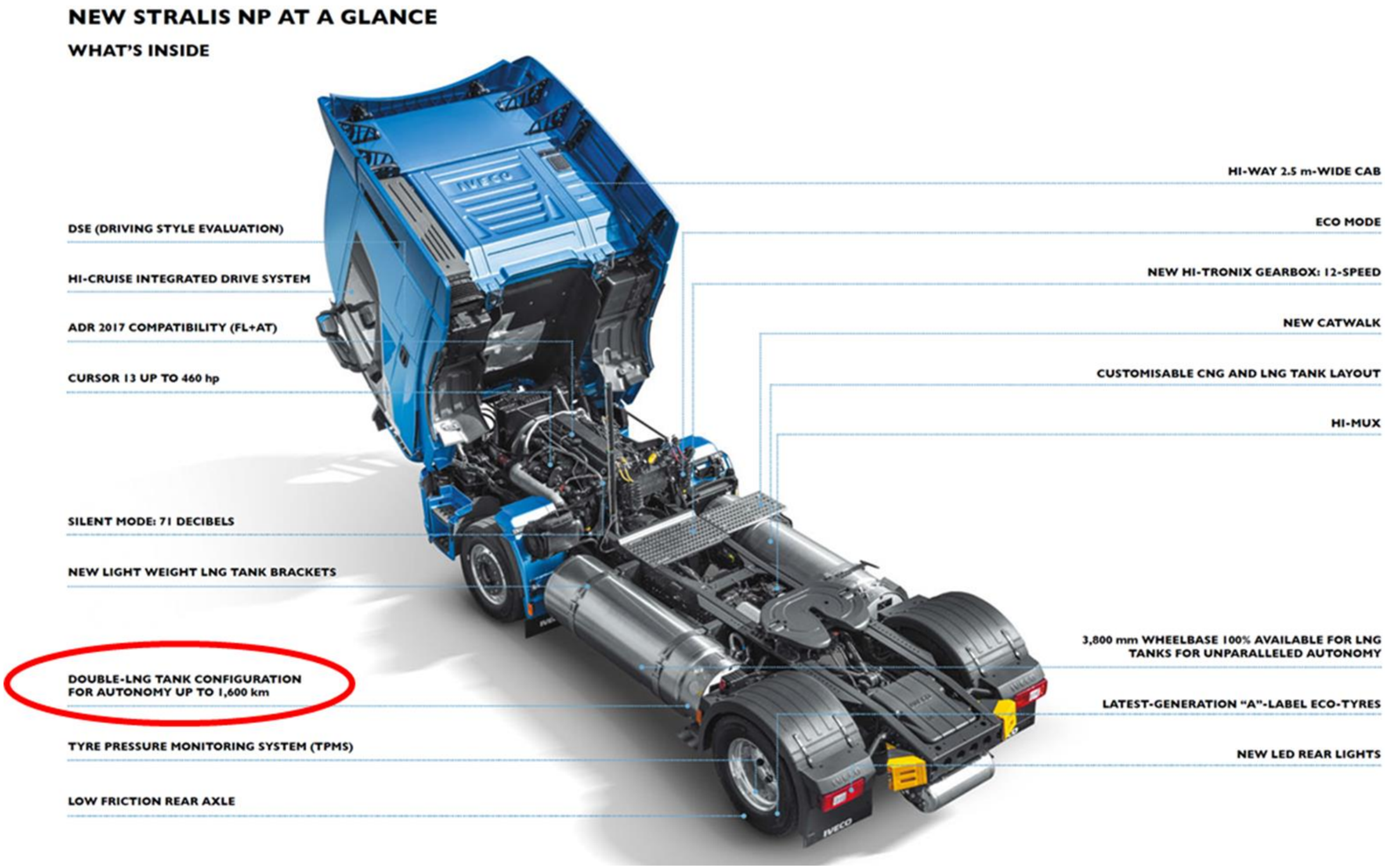


Figure D- 2: Layout of Iveco Strialis NP Truck Tractor showing Double LNG Tank Configuration for 1600 km Range

Appendix F Estimated Range of Road Transport LNG Uptake Potential in the Western Cape

Table F- 1: Lower Range of Road Transport LNG Substitution Potential by Mode 2020 - 2050

Mode	Type	Estimated Lower Substitution Potential	2020	2025	2030	2035	2040	2045	2050
Captive Fleet Passenger Cars	Bi-Fuelled Conversion CNG	0.5%	0	0.20	0.20	0.19	0.18	0.17	0.15
Minibus	Bi-Fuelled Conversion CNG	3.0%	0	0.11	0.11	0.11	0.11	0.11	0.11
LCV	Bi-Fuelled Conversion CNG	5.0%	0	0.61	0.67	0.71	0.80	0.88	0.98
Commuter Bus	Purpose Built New Vehicle Purchase CNG / LNG	3.0%	0	0.08	0.08	0.09	0.10	0.11	0.12
MCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	5.0%	0	0.12	0.13	0.14	0.15	0.16	0.17
HCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	5.0%	0	0.49	0.53	0.57	0.62	0.67	0.72
HCV Corridor	LNG Purpose Built New Vehicle Purchase	5.0%	0	0.76	0.83	0.90	0.97	1.04	1.12
TOTAL			**0**	**2.4**	**2.5**	**2.7**	**2.9**	**3.1**	**3.4**

Table F- 2: Upper Range of Road Transport LNG Substitution Potential by Mode 2020 - 2050

Mode	Type	Estimated Upper Substitution Potential	2020	2025	2030	2035	2040	2045	2050
Captive Fleet Passenger Cars	Bi-Fuelled Conversion CNG	2.0%	0.00	0.80	0.80	0.77	0.73	0.68	0.59
Minibus	Bi-Fuelled Conversion CNG	30.0%	0.00	1.11	1.08	1.10	1.13	1.14	1.12
LCV	Bi-Fuelled Conversion CNG	15.0%	0.00	1.82	2.01	2.14	2.39	2.65	2.95
Commuter Bus	Purpose Built New Vehicle Purchase CNG / LNG	20.0%	0.00	0.52	0.55	0.59	0.64	0.71	0.80
MCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	30.0%	0	0.70	0.79	0.85	0.91	0.97	1.02
HCV Metropolitan Freight	LNG Purpose Built New Vehicle Purchase & Dual Fuel 2nd Life	30.0%	0	2.92	3.17	3.43	3.71	4.00	4.31
HCV Corridor	LNG Purpose Built New Vehicle Purchase	50.0%	0	7.62	8.27	8.96	9.68	10.43	11.24
TOTAL			**0.0**	**15.5**	**16.7**	**17.8**	**19.2**	**20.6**	**22.0**

Appendix G Types and Indicative Costs of Small Scale LNG Filling Stations and Liquefaction Plants

The scale of freight operations on the N1 corridor make it ideal for a long haul pilot but LNG rather than CNG fuelling is required to make practical use of long range gas truck technology. The existing gas supply in Gauteng is compressed so a pilot would need either to rail up LNG to both a midway station and to the end point in Gauteng or else deploy a small scale liquefaction plant in Gauteng. This decision would require a detailed feasibility study but indicative costs are presented below.

There are three general types of small scale refuelling station as shown below:

Figure F- 1: Types of Small Scale Refuelling Stations (Gabl, 2017)

Costs are indicated below but as these are for Europe where there is an established market a considerable premium might be expected to import this technology into South Africa for a pilot.

Table F- 3: Indicative Costs of Small Scale Refuelling Stations (Gabl, 2017)

			Capex			
Type	Fleet Size	Storage Capacity (tonnes)	Lower TEUR (000 EUR)	Upper TEUR (000 EUR)	Lower million Rands	Upper million Rands
Mobile containerised	20 trucks	10 - 18	<	500		8.0
Moveable skidded station	40 trucks	18 - 24	500	600	8.0	9.6
Permanent full scale	150 trucks	40 - 80	1000	2000	16	32

A case study for Indonesia listed the following costs for a small scale liquefaction plant (Semple, 2013):

- Liquefaction: USD 2000 per tonne per year (USD5.1/ mmbtu)
- Opex: 2% of capex (USD 0.75/ mmbtu)
- Tractor and trailer capex: USD 500,000 (USD0.70/ mmbtu)
- Tractor and trailer opex: USD 0.50/mmbtu
- Storage: USD 1,500 cubic metre and 10 days of capacity plus opex: USD 2.2/ mmbtu
- Vaporisation: USD 1.0/mmbtu
- Overheads and marketing: USD0.75/ mmbtu
- **All in USD cost: USD 11.0 /mmbtu (1 mmbtu = 1.06 GJ)**

Appendix H Estimate of WC Bunkering Market Potential

Appendix H1 LNG for Marine Transport

The development of LNG as fuel is accelerating since the introduction in 2000 with passenger ship Gultra operating Norwegian water. It started with small vessels with fixed routes – passenger ships, offshore supply vessels with trading pattern concentrated in Norway. There are 257 confirmed vessels operating globally (124 LNG fueled ships in operation and 133 new ships). Below map shows the trading locations of the LNG fueled ships in operation, though concentrated in Northern Europe, vessels are also operating globally. The trend of the newbuilds is towards larger ships (deep sea container ship, cruise ship and Aframax/Suezmax tankers) and global operation. CMA CGM, one of the largest container liners, is ordering 9 ultra large container vessels for delivery from 2019 onwards. A number of international cruise operators are ordering large cruise ships with 16 ships will be delivered from 2019 onwards. Tankers market will also get additional LNG fueled tankers with 27 orders for delivery next year.

Figure H- 1: LNG fuelled ships as of 11.07.2018 (Source: DNV GL LNGi)

In 2017, 9821 vessels calling at ports in the 4 main ports, ca. 80% of the vessels called at Richards Bay, Cape Town, Durban and Saldanha bay. Durban is the largest bunker ports in the country, in addition to Richards Bay and Cape Town. Dry/liquid bulk vessels, container ships and tankers are the top three vessel segments calling at these ports. These are large deep-sea vessels (see below map) operating between the Indian Ocean and south Atlantic Ocean. In addition, the number of cruise ships calling at the ports is assumed increasing especially if the new terminal in Durban is operating in 2020. MSC Cruise is a key player in the Cape and is currently (2018) ordering 2 LNG fueled cruise ships.

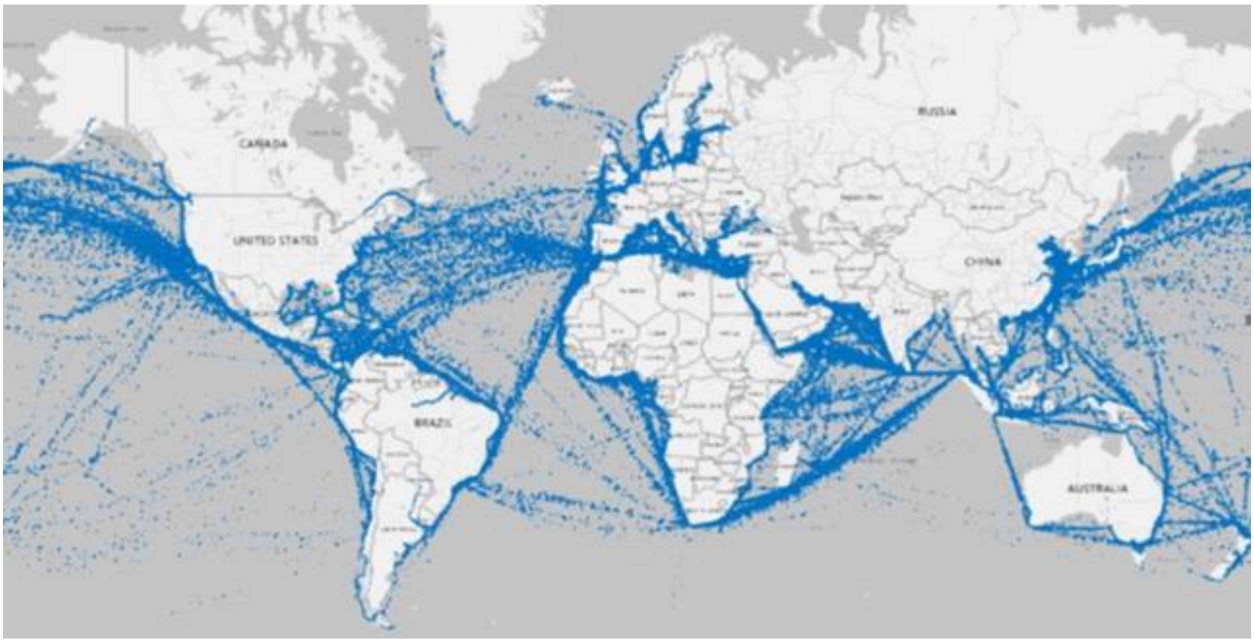


Figure H- 2: Container vessels trading pattern, 2017 (Source: AIS)

Figure H- 3: Illustration of container vessels fuel consumption trading between Singapore and Brazil.

No LNG bunkering activities and infrastructure currently available in South Africa despite the plenty of natural gas supplied from Mozambique. However, the **Cape Route has potential to offer LNG as fuel for ships.** The ports of Cape Town and Durban are highly rated as bunkering locations globally.

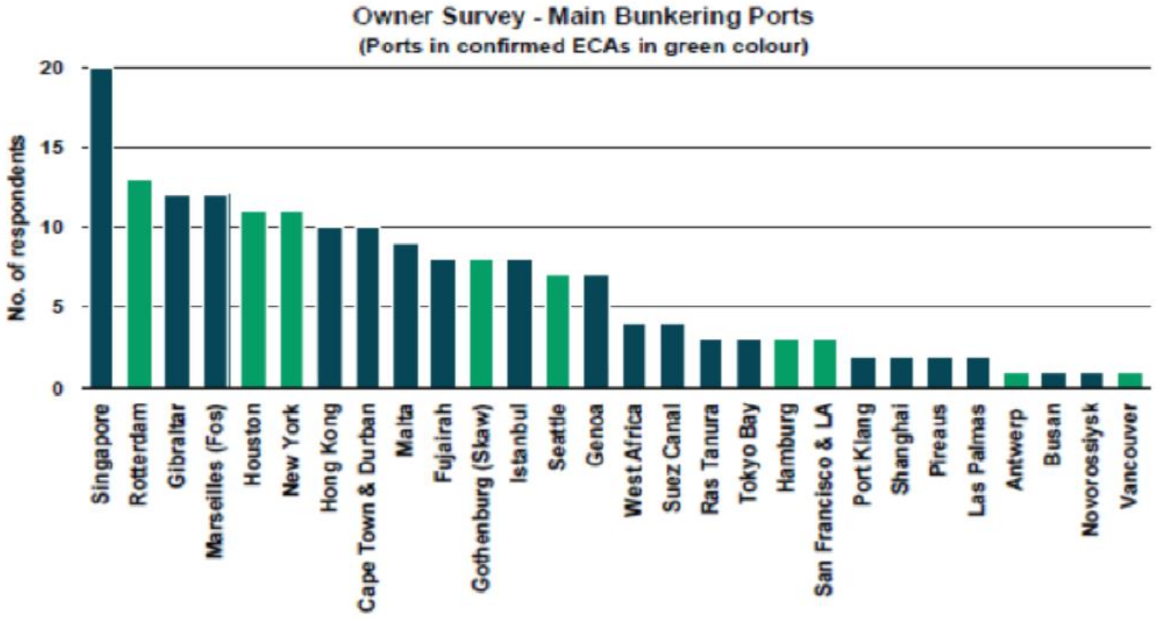
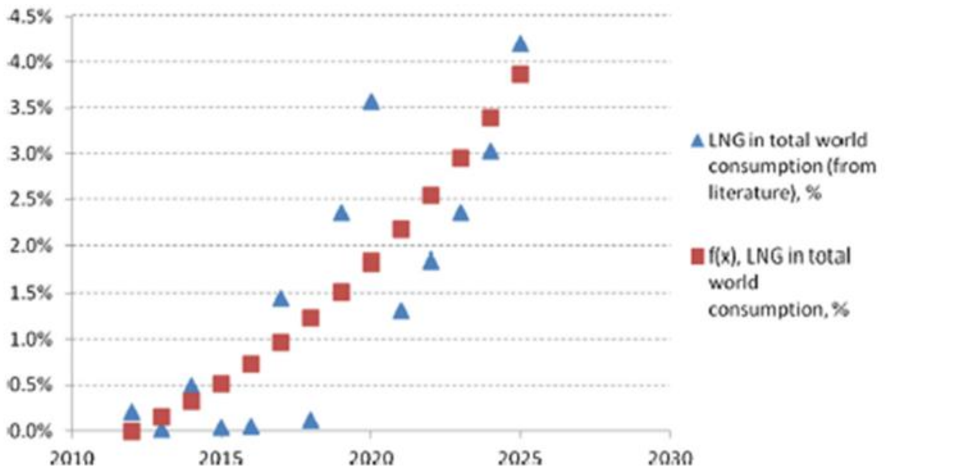


Figure H- 4: Primary bunkering locations from ship owner survey -(Source: Aegesen, 2012)

One the key strength of South Africa that the country is strategically located on the international trade routes, handling ships opting not to use the Suez Canal for Far East-Europe trade, ships servicing Far East-South America on dry bulk trade and container traffic, Middle East/India-South America trade, Far East to west coast of Africa trade and domestic trade (gateway cargoes).

Sea transport is expected to grow which means there will be further demand for bunker supply offered by the country important bunker ports, such as Durban and Cape Town. For ship owners, compliance with international regulations, availability of LNG and price difference between LNG and other alternative fuels are the main drivers for choosing LNG. Ships bound for Europe must comply with the international, regional and local regulations. North Europe and the Baltic Sea is an emission control areas (ECA) where strict regulations apply. Ships sailing from Far East to Northern Europe via the Cape, must use lower Sulphur content when entering the ports in the ECA. Furthermore, the global Sulphur cap from 2020 will likely drive the use of LNG fueled ships in other parts of the world including Asia and South America.



LNG as % of total world bunker market. Source: own calculation based on forecasts in the literature review

Figure H- 5: LNG as a % of total world bunker market (Own calculation))

There is an opportunity to exploit the synergy between LNG for IPP and marine transport bunkering through shared infrastructure.

LNG must be available when the ship needs it. This means LNG infrastructure must be available along the trade routes. Below map shows that a number of LNG bunkering infrastructure are already available in some parts of the world (green), some projects have been decided (darker blue) and some projects are under discussion (light blue). Asia, South America, Middle East/India have or are establishing the infrastructure. However, no discussion yet around the Cape where its location is the midway between Asia and South America. For **Far East-Europe via the Cape**, the bunkering may be done in the Far East (Singapore will have the facility ready by 2020) or somewhere in the western Mediterranean Sea (Gibraltar signed an agreement with Shell for the development of LNG storage and bunkering facility. Enagas is developing a small scale LNG application to supply LNG at Algeciras. For **Far East-South America and Middle East-South America** trades**, Ships** loading in Far East for South America may potentially bunker at the Cape ports. The distance from Singapore to Durban, for instance is approx. midway between Singapore and South America. For **Far East-South Africa** (gateway cargoes). Bunkering may be done in Singapore and/or at the discharge ports in South Africa. For **Far East-west coast of Africa,** bunkering may be done in Singapore and/or at the discharge ports in west coast of Africa or around the Cape.

Furthermore, LNG and dual-fuel engines are a long-term objective mostly for containership and cruise ship owners (Aegesen, 2012). This point is particularly important for Durban and Cape Town ports considering a number of container vessels and cruise ships calling at both ports. In addition, Figure H-6 below provides an indication of trends on the development of the LNG fuelled fleet and shows that the delivery started picking up in 2014 with significant projected increase. This will also contribute to the demand of LNG as marine fuel.

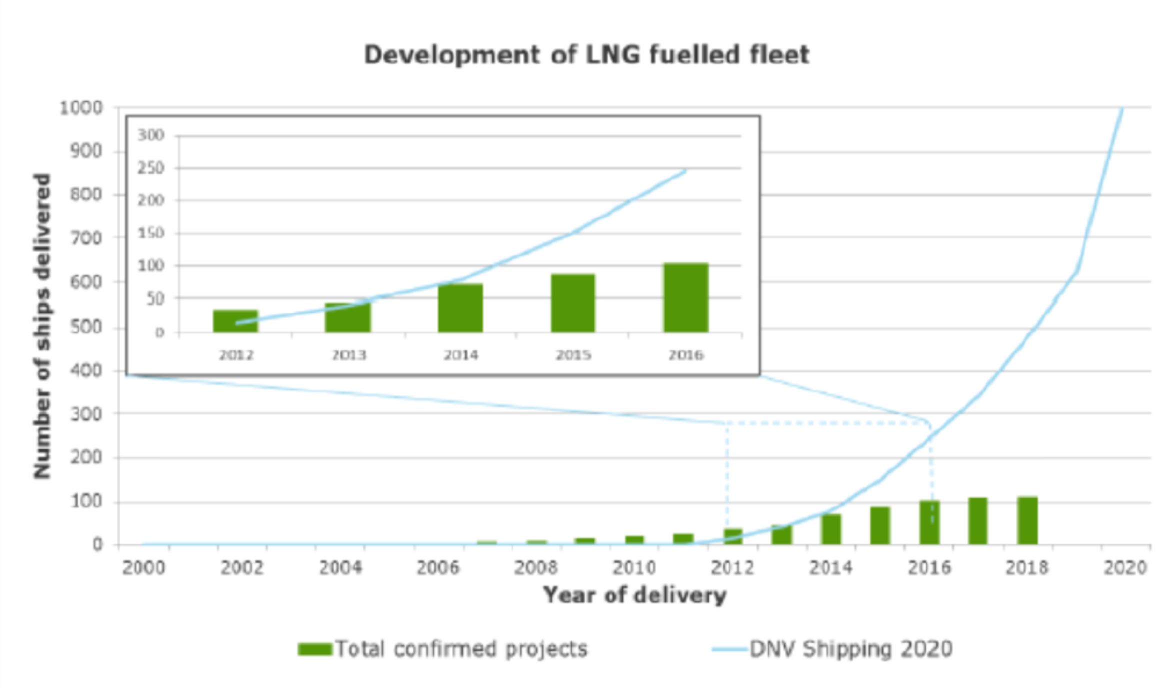


Figure H- 6: Development of LNG fuelled ship fleet (Source: Wuersig, 2014)

Appendix H2 Development of Model to Estimate energy demand from shipping (2017)

Demand is historically made up of Cargo callers (loading and unloading) and bunker only callers. The refuelling potential was modelled for Cape Town and Saldanha using data for ships calling at these ports in 2017. The following was considered in estimating fuel demand:

- Segments
- Ports and Port Calls
- tonnages, voyage lengths for the major trade routes

Segments

To streamline the analysis, the entire fleet in scope was broken down into the following main vessel segments.

Table H- 1: Main Vehicle Segments considered in the analysis

Segments
General Cargo
Bulk Dry
Bulk Liquid
Container-Non-Cellular
Tanker-Oil
Tanker-Chemical
Tanker-LPG
Tanker-Bitumen
Other
Coaster (Bona Fide)

Ports and Port Calls

The number of operators (NO) and gross tonnages (GT) reported at the Cape Town and Saldanha Bay ports are shown in Table H- 2 (Based on Transnet Port Statistics 2017). This represents the cargo arrivals at Cape Town and Saldanha in 2017.

Table H- 2: Port calls to Cape Town and Saldanha in 2017 (Transnet Port Statistics)

	CAPE TOWN		**SALDANHA BAY**	
	NO	**GT**	**NO**	**GT**
General Cargo	130	1 883 269	41	1 403 949
Bulk Dry	147	4 336 514	429	30 516 646
Bulk Liquid	20	317 383	23	1 975 818
Container-Non-Cellular	624	36 153 126	--	
Tanker-Oil	76	1 687 616	17	1 399 922
Tanker-Chemical	68	1 405 272	3	251 161
Tanker-LPG	8	63 237		
Tanker-Bitumen	1	3 923		

Other	6	206 967	6	198 835
Coaster (Bona Fide)	39	497 242		
TOTAL:	**1 119**	**46 554 549**	**519**	**35 746 331**

Estimated Fuel Demand (Modelled)

The fuel demand in 2017 was estimated using estimated using cargo tonnages, voyage lengths for the major trade routes and average energy intensities for each of the above segments.

Table H- 3: Modelled Fuel Demand for Cape Town and Saldanha

	Bunkering Potential (Petajoules)		
	Cape Town	**Saldanha**	**Total**
General Cargo	8.17	2.58	**10.75**
Bulk Dry	12.51	36.50	**49.01**
Bulk Liquid	0.75	0.86	**1.61**
Container-Non-Cellular	69.88	-	**69.88**
Tanker-Oil	3.30	0.74	**4.04**
Tanker-Chemical	3.18	0.14	**3.32**
Tanker-LPG	0.37	-	**0.37**
Tanker-Bitumen	0.03	-	**0.03**
Other	0.08	0.08	**0.16**
Coaster (Bona Fide)	0.30	-	**0.3**
Total:	**99**	**41**	**140**

Appendix H3 Historical Fuel Demand

Marine bunker volumes have been decreasing in recent years and the Western Cape in particular has shown a sharp decrease in volumes mainly as a result of high port charges, unregulated cargo tariffs and low port productivity.

Table H- 4: Historical Marine Bunker Volumes for the Western Cape and Durban

Comparison of Historical Marine Bunker Volumes for the Western Cape and Durban						
	Western Cape (DoE accessed 2017,2018)			**Port of Durban (Prof Trevor Jones, 2017)**		
Year	litres	Million tons	PJ	litres	Million tons	PJ
1991				1795600778	1.767	74.7
1992				2044989775	2.012	85.1
1993				2327630638	2.290	96.8
1994				2439855687	2.401	101.5
1995				3084110596	3.035	128.3
1996				3321030143	3.268	138.2
1997				3749147921	3.689	156.0*
1998				3641079356	3.583	151.5
1999				3516384857	3.460	146.3

2000	1370811142	1.349	57.0	3167240261	3.117	131.8
2001	1648751577	1.622	68.6*	3175553228	3.125	132.1
2002	1249223368	1.229	52.0	3366751459	3.313	140.1
2003	1198292292	1.179	49.8	3163083778	3.112	131.6
2004	1101974409	1.084	45.8	3113205979	3.063	129.5
2005	1152784869	1.134	48.0	2090711091	2.057	87.0
2006	842298710	0.829	35.0	2061615708	2.029	85.8
2007	1019069981	1.003	42.4	2232031523	2.196	92.9
2008	1435065113	1.412	59.7	1941077693	1.910	80.7
2009	1211297173	1.192	50.4	1770661878	1.742	73.7
2010	133913920	0.132	5.6	1654280346	1.628	68.8
2011	99030162	0.097	4.1	1421517283	1.399	59.1
2012	102318210	0.101	4.3	1222006085	1.202	50.8
2013	90322022	0.089	3.8	1080685653	1.063	45.0
2014	66469139	0.065	2.8	1055746754	1.039	43.9
2015	53206898	0.052	2.2			
2016	37205000	0.037	1.5			

* Historical Peak Demand

Appendix H4 Findings and Conclusions

1. Demand is historically made up of Cargo callers (loading and unloading) and bunker only callers
2. In 2006 - 2008 port charges for bunker only callers increased by 9000% and this resulted in a sharp drop in marine bunker volumes especially in the Western Cape.
3. The remaining bunkers can be assumed to be cargo callers that have to take on bunkers and this can be considered a minimum market then of:
   - Around 1-3 PJ in the Western Cape
   - Around 40 - 50 PJ in Kwazulu Natal
4. There are three reasons cited for the decline of the industry (Lockhart-Barker, 2018):
   - The high port charges
   - The unregulated fluctuating cargo tariffs
   - Low port productivity leading to a perception that bunkering was slowing down cargo activities further
5. cargo only ships bunkered extensively at one time because Cape Town had a ring main serving all berths
6. A model of 2017 cargo arrivals at Cape Town and Saldanha suggested a voyage refuelling potential of some 140 PJ for those ships
7. Taking historical demand as a guide for the Western Cape (peaked at 69 PJ in 2001) and Durban (peaked at 156 PJ in 1998 according to Jones) suggest an aggressive WC bunker industry could conceivably capture 50 - 100 PJ again.
8. On a 10-year view however LNG growing off a low base of 0.2% of the fleet would not be a large share
9. Conceivably though a potential of 20 - 50 PJ on a 20 - 30-year view may not be unreasonable depending on the rate of LNG penetration into the global shipping fleet.
10. OEMs are reportedly investing in large gas engine development and this will drive uptake in the longer term.

Marine Natural Gas Potential - Further Work Required

Further study is needed to assess the potential of LNG bunkering around the Cape. The first step is to estimate the future of LNG bunker volume around the Cape Route, for instance up to 2025. The following is proposed:

1. Evaluation of current energy demand of vessels around the Cape (Baseline). The objective is to identify the shipping profile and to calculate the relevant current energy demand from vessels calling at the ports in the time period of June 2016 – June 2018. We propose the use of AIS data for tracking ships movements for different type and age of ships and combine the data with DNV GL data warehouse and other sources. DNV GL uses a unique tool that estimates fuel consumption per vessel by combining operational performance information, e.g. speed patterns, based on AIS data, with vessel data, e.g. dimensions or installed engine.

2. Estimation of development of fuel oil consumption. The objective is to estimate the consumption development for the coming years up to 2025 by analysing the transport volume growth for each vessel segment and development of energy efficiency in the fleet.

3. Assessment of relevance of LNG as fuel for various vessel segment. The objective is to estimate the LNG uptake for various vessel segments by analysing the regulatory and public pressure, LNG fuel pricing system, etc.

4. Forecast LNG fuel demand up to 2025. The objective is to estimate the future LNG demand in the ports up to 2025 for each of the generated scenarios.