South African National Energy Development Institute (SOC) Ltd.

Quantifying the energy needs of the transport sector for South Africa: A bottom-up model

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Executive summary

Transport is a large consumer of energy in South Africa and vital for economic development. Currently the transport sector consumes 28% of final energy, the bulk of which, 97%, is in the form of liquid fuels. As the population grows and becomes wealthier, so the demand for passenger transport and private vehicles increases; similarly, rising GDP drives the demand for freight transport. Supply interruptions are costly to the economy and careful long-term planning is required to ensure that there is sufficient infrastructure to support the efficient functioning and growth of the transport sector in the future.

Long-term planning requires an accurate depiction of the status quo regarding the demand for passenger and freight transport in different transport modes. It also requires projections of future demand for passenger and freight transport, and a translation of demand for transport into a demand for fuel and infrastructure requirements. With this in mind the project attempted to answer the following questions:

1. What are the medium-to-long-term trends in demand for passenger and freight transportation under different scenario assumptions?
2. What is the resulting demand for liquid fuels under different scenario assumptions?
3. What are the emissions associated with each of the scenarios?

The project focused on the development of a number of models which, when combined, can be used to develop scenarios to answer these and other questions around the likely future energy and infrastructure requirements of the transport sector and its major influences in terms of both energy and emissions. The future energy demand of the transport sector was calculated in terms of services performed ('useful' energy) as well as the amount of energy supplied ('final' energy). This allows analysis of the substitution between alternative energy forms and modes, as well as an appraisal of the evolution of the technological improvements in vehicles.

A number of modelling techniques have been combined in this study to provide a novel and rigorous methodology for estimating the current and future vehicle parc and the associated energy demand. In the end, five models were employed in the study: a vehicle parc model; a time budget model; a computable general equilibrium model; a freight demand model; and a fuel demand model. Data with which to populate transport sector models is sparse in South Africa, and a broad range of input assumptions are made which are discussed in detail in the report.

The vehicle parc model developed is calibrated over seven years from 2003–2009, and was largely developed to fill knowledge gaps around vehicle usage patterns in South Africa. The model provides a comprehensive picture of the baseline vehicle parc and its activity, disaggregated by vehicle class and technology. Due to the nature and spatial distribution of the demand for fuels by the transport sector, the vehicle parc model was developed and calibrated at a provincial scale.

The vehicle parc model draws on estimates of scrapping curves, vehicle sales, annual vehicle mileage for each vehicle class and decay of mileage as vehicles age. In order to calibrate the vehicle parc model against known fuel usage, the evolution of vehicle fuel efficiency over the lifetime of the vehicle is included in the model. Primary sources of data for the vehicle parc model are eNATIS, NAAMSA, Department of Transport and SAPIA, in addition to several smaller local studies and international studies which were used as benchmarks. Base year technology penetration, fuel economy and vehicle mileage were validated outputs of the vehicle parc model.

Energy demand in the transport sector is driven by the distance travelled and the energy required for each passenger or ton kilometre travelled. Average fuel economy is influenced by several variables: for instance, the fuel economy of vehicles decreases as they age but new cars are becoming more efficient, and new cars tend to cover higher annual mileages than older vehicles. Efficiency improvements occur due to technology becoming more efficient but also from reductions in vehicle mass and engine capacity. Significant improvements in vehicle efficiency are possible in new vehicles, and an estimated annual improvement of 1% was adopted for the model, based on studies in the United Kingdom and elsewhere.

Vehicle occupancy and load factor assumptions are critical for calculating passenger kilometres and ton kilometres travelled. Data around vehicle occupancy rates in different modes is sparse, it was assumed that passenger vehicles have an average occupancy of 1.4 passengers, minibus' 14 passengers and Diesel bus' 25 passengers. Light commercial vehicles (LCVs) were assumed to carry an average load of 0.5 tons, and medium commercial vehicles (MCVs) and heavy commercial vehicles (HCVs)are assumed to carry loads of 2.5 and 15 tons respectively.

Annual vehicle mileage can vary markedly from vehicle to vehicle and moreover tends to, on average, decline as the vehicle ages. Estimates of average mileage for vehicles in their first year of operation and for all operating vehicles are however useful indicators of activity. The vehicle parc model estimates that on average passenger cars travel 16 630 kilometres per year and heavy commercial vehicles travel around 50 000 kilometres per year with new vehicles, on average, travelling over 70 000 kilometres in their first year. Similarly, the average vehicle mileage estimated for minibus taxis was 32 000 kilometres with new vehicles, on average, travelling 50 000 kilometres in their first year of operation. This is however one of the major uncertainties in the vehicle parc model. Minibus mileage estimates have a large effect on the model calibration due to their high modal share, and the accuracy of the model would be greatly enhanced if reliable data for the minibus taxi industry was available. The model generated activity data for passenger and freight transport is shown in Table A, and in general calibrated vehicle parc model fuel sales in the provinces align well with actual sales, the notable difference being Gauteng and Natal, which reflects the difficulty in apportioning diesel consumption provincially with the high volume of freight transported along the corridor between these two provinces.

Table A: Model-generated passenger transport data for South Africa (2006)

	Total vehicles	**Total veh-km**	**Activity**	**Modal share**	**NATMAP[a] (2005)**
	(1000 veh.)	(billion veh-km)	(billion p.km)	(%) of p.km	(%) of trips
Public (excl. air)	291.4	9.01	**147**	53%	59%
Private	5253.2	85.12	**118.6**	43%	40%
TOTAL (excl. air)			**265.5**		

Table B: Model-generated freight transport data for South Africa (2006)

Vehicle type	**Total vehicles**	**Total veh-km**	**Activity**	**Modal share**
	(1000 veh.)	(billion veh-km)	(billion ton.km)	(%) of ton.km
LCV	1803.9	28.8	14.4	10%
MCV	137.4	3.64	9.1	6%
HCV	198.1	8.0	120.1	84%
TOTAL	2139.4		143.6	

Time-use and travel surveys from numerous cities and countries throughout the world suggest that travel time budget is on average approximately 1.1 hours per person per day across the spectrum of per capita income (Schafer & Victor, 2000). The time budget model used this estimate, along with an estimate of average speed of different modes and waiting and walking time, to develop a profile of demand for passenger kilometres travelled in different modes.

The time budget model was disaggregated into three income groups representing low-, medium- and high-income households.[1] Motorisation generally increases more or less linearly with GDP/capita, until saturating. In South Africa, the number of registered vehicles has tracked GDP more closely than population and growth in registered vehicles and GDP has been around 3–4% whilst population growth has been around 1.2–1.5%. Per capita vehicle ownership is low in South Africa at around 180 vehicles per 1000 people; even in Gauteng, a vibrant economic hub, ownership is around 314 vehicles per 1000 people, less than the 500–800 average for developed countries, and therefore allocation of travel time to different modes as incomes increase is an important component of the model.

The evolution of income groups as GDP and population grows in the future was done using a CGE model. The model indicates that with a moderately high-income growth of 3.9% household income groups change dramatically over the period. By 2025 all but the lowest income decile of households will exceed the threshold for the medium-income group.

As the economy grows, so does the transport of freight. Currently the services sector is forming a larger portion of GDP and if this trend continues, the elasticity of freight demand to GDP is likely to be less than 1. In the absence of alternative sources an elasticity of 0.8 was used. Even with this conservative estimate, freight transport increases threefold by 2050.

The future energy demand of the transport sector was modelled for a reference case which represents a business as usual outcome with a modestly high growth rate and an alternative case that assumed a number of energy saving policy interventions. These interventions are not implausible, even in combination, but can be considered optimistic and so the two scenarios provide an envelope of future transport sector energy demand, vehicle parc size and emissions. This envelope indicates that:

- Transport energy demand under business as usual will double by 2050.
- The vehicle fleet will have grown to exceed 24 million road vehicles by 2050 from a baseline of 8.2 million in 2010. Of these, over 17 million will be private vehicles, excluding light commercial vehicles.
- It is possible to constrain the increase in energy demand to less than 30% with a trend towards stabilisation through policy instruments. This relies, amongst other things, on a 2% annualised improvement in fuel economy across vehicle types compared to the 1% assumed under business as usual.
- Similarly to the energy demand results, CO_2 emissions from transport were projected to more than double by 2050 for the Reference Case but only increase by 11% for the Alternative Case. The large CO_2 mitigation for the Alternative Scenario arises because of the shift to public transport and fuel economy improvements which results in a drop of 24% for private passenger CO_2 emissions between 2010 and 2050.
- The simulated shift from road freight to rail freight and higher fuel economy improvements results in the alternative case CO_2 emissions for 2050 being 46% lower than for the reference case in 2050. This accounts for 42% of the total transport sector mitigation in CO_2 emissions in the alternative scenario.

Future developments in modeling in the transport sector should focus on data as well as model development. Data could initially focus on accurate assessments of the use of minibus taxis, the

[1] Low-income households have a household income of under R19 000 in 2007, middle-income households had an income between R19 000 and R76 800 in 2007.

refinement of estimates of average loading of commercial vehicles in different weight categories both intra and intercity. A refinement in average speed, private car ownership, waiting times for public transport and travel time and vehicle occupancy would improve the calibration of the models developed during this study and the accuracy of scenarios.

Modelling of intracity and intercity travel within and between provinces would allow the calculation of future transport fuel use for each province, which will aid decision-making around infrastructure investment and opportunities for alternative transport modes. Further disaggregating the higher income group in the model and adding a link between car ownership and household income would refine the representivity of car ownership and therefore demand for private p.km in the model. Both Input data and results would be greatly improved through studies focusing on elasticity of freight demand (ton.km) in relation to transport GDP and overall GDP. Having developed the suite of models, a full life cycle costing of infrastructure required for road vs rail should be carried out.

Finally, collaboration between researchers in South Africa working in the transport sector would greatly enhance both base year data and transport sector modelling. For instance, collaboration with the CSIR could help to understand and reconcile the differences between their estimated road freight demand for ton.km and that of the vehicle parc model in this study.

This report is written in three sections, the first two presenting two papers. The first paper outlines the development of a calibrated vehicle parc model, the second develops projections of demand for passenger and freight transport up until 2030 and presents the results of the business as usual and alternative case based on these projections. The third section reports on two stakeholder meetings that were held over the course of the project. Conclusions and recommendations are included at the end of Section 1 and Section 2.

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Section 1

Working paper 1:
A vehicle parc model for South Africa

Abstract

Transport is an important component of any economy. As economies and populations grow, so too does the demand for passenger and freight transport. Meeting the energy requirements of a growing transport sector requires investment in infrastructure, failure to invest can have far reaching negative economy impacts as witnessed in South Africa during the 2006 supply disruptions.

This paper focuses on the development of a suite of models which combined can be used to develop projections of demand for energy and emissions from passenger and freight transport in South Africa until 2050. Given that there are large uncertainties in projecting energy services into the future, the models include many attributes, which allow the testing of the impact of a broad range of assumptions on future demand. Two scenarios are developed in the paper, a base case scenario, in which demand for energy in transport increases fivefold over the planning period, and a more efficient transport scenario in which several opportunities to improve energy efficiency, ranging from improvements in private vehicle efficiency to modal shifts, halve the projected increase in demand for fuel in 2050. The paper demonstrates the important influence which careful planning and investment in infrastructure can have on both energy demand and future emissions of this important economic sector.

Introduction

The energy consumption of the transport sector in South Africa is large, totaling around 28% of total final consumption (TFC) in the national energy balances. The bulk of this energy demand (97%) is in the form of liquid fuels, which itself is the bulk of the national liquid fuel demand (84%) (DoE, 2009) (IEA, 2011). The evolution of transport demand, both in terms of its magnitude and form (carrier) is very uncertain and has large implications for infrastructure requirements.

A successful and productive economy is founded not only on a reliable energy supply for current needs but also on the ability of that supply to respond sustainably to changing needs. Due to the reliance on liquid fuels for transport, disruptions to liquid fuels supply to the transport sector can have large economic impacts. A study on strategic stocks of liquid fuels conducted by the then Department of Minerals and Energy in 2006, estimated that R925 million a day could be lost as the result of a fuel supply disruption (DoE, 2006). Ensuring that such disruptions do not occur requires that the appropriate energy infrastructure, such as refineries, pipelines and power stations are in place.

The energy infrastructure required to meet liquid fuel needs, and transport liquid fuels from the point of supply to the point of demand involves large investments and long lead-times. In addition, the choice of primary energy and the transformation process can have substantial impacts on society and the environment. Investment decisions must therefore be informed by planning processes, such as a national integrated energy plan. A first step in the planning process is to develop an understanding of the current demand for mobility of passengers and freight in the economy and the drivers of mobility in the transport sector and how these will evolve over time. The need for mobility is not something that can be directly measured or observed and therefore requires estimation based on a number of observable variables, for instance how much people are driving and the quantity of goods being moved around in the current economic environment or how many vehicles are on the road/rail network.

This paper describes the development of a calibrated model of the vehicle fleet and its characteristics, often called a 'vehicle parc model', which can be used to characterise liquid fuel consumption in the transport sector in South Africa. The model developed for this research includes both passenger and freight transport, and different transport modes, and is calibrated for each province. However, due to the dominance of liquid fuels in the transport sector, characterising liquid fuels demand is the major focus. The output of the model can be used to develop projections of demand for passenger and freight transport in South Africa's transport sector in order to inform decisions related to infrastructure planning such as the location of refineries and pipelines. Very broadly, the modelling approach followed two steps; firstly available historic data was used to develop a picture of the 'base' year use of energy for transport, by fuel and mode. Secondly, demand for passenger and freight transport was projected into the future under different plausible scenarios. The calibration of the 'base' year of the model is discussed in this paper.

Overview of transport in South Africa

South Africa is characterised by regional extremes in climate, population and economy. The arid Northern Cape province, the largest of the nine provinces, accounting for 30.5% of the total land area, contributes just 2.3% of South Africa's GDP and is home to around 7% of the population (1.06 million people) (Stats SA, 2012). The industrial powerhouse of Gauteng, located 560km from the nearest coastline, on the other hand has just 1.4% of total land area, produces 33.7% of South Africa's GDP and is home to roughly 22% of the population (more than 10 million people). The three provinces of Gauteng, Kwazulu-Natal and the Western Cape combined account for just 20% of the total land area, but they produced 64% of South Africa's GDP in 2010 and are home to 55% of the population (Stats SA, 2012). These geographic and socio-economic differences result in distinct nodes of high transport demand and high traffic volumes that are spatially remote from each other within South Africa.

The aggregate statistics for the distribution of vehicles in the provinces in South Africa are shown below in Table 1. In 2010 Gauteng had a motorisation level of 314 vehicles per thousand people, far above the national average and more than 3.5 times higher than the 85 vehicles/1000 of the least motorised province, Limpopo (eNaTiS, 2012).

Table 1: Motorisation of South Africa's provinces compared to GDP and land area share

Province	Population (2011)	Total self-propelled vehicles (Dec 2011)	Share of vehicles (%)	Motorisation (veh/1000 persons)	Contribution to national GDP (2010)	Land area share (%)
Eastern Cape	6 829 958	628529	7%	92	7.7%	13.8%
Free State	2 759 644	478546	5%	173	5.5%	10.6%
Gauteng	11 328 203	3560678	39%	314	33.7%	1.4%
KwaZulu-Natal	10 819 130	1268984	14%	117	15.8%	7.7%
Limpopo	5 554 657	474225	5%	85	7.2%	10.3%
Mpumalanga	3 657 181	585628	6%	160	7.0%	6.3%
Northern Cape	1 096 731	195094	2%	178	2.3%	30.5%
North West	3 253 390	457286	5%	141	6.7%	8.7%
Western Cape	5 287 863	1485018	16%	281	14.1%	10.6%
TOTAL	50 586 757	9133988	100%	181	100.0%	100.0%

In general, even in Gauteng, vehicle ownership is low compared to developed countries. Towards the end of 2011 the National Traffic Information System (eNaTiS) reported around 9.1 million vehicles in South Africa of which nearly six million were passenger cars (eNaTiS, 2012). This translates to a motorisation rate of around 180 vehicles per thousand people compared to a range of 500 to 800 for developed countries and an average of around 40 for Africa (The World Bank, 2011). As is the case with much of Africa however, much of the demand for passenger transport is still met by walking (23% of trips) as reported by the results of the 2003 National Household Travel Survey (NHTS) (DoT, 2003). Also typical of the continent is the high modal share of minibus taxis (25% of trips) which are estimated to number upwards of 120 000 of the 280 000 registered minibus taxis. Although more expensive, minibus taxis still dominate the other public transport modes of bus (9% of trips) and train (6% of trips) because they are more accessible and flexible and thus offer the lowest overall trip time (DoT, 2003).

Road trucks have come to dominate the transport of general goods and their net annual utilisation is reported to have reached 260 billion ton.km in 2008 (Havenga, Simpson, & van Eeden, 2011). The export of bulk goods particularly iron ore and coal has, however, maintained the rail freight industry as by far the largest in Africa, sustaining over 100 billion ton.km per annum over the last 10 years and reaching 130 billion ton.km in 2008 (Havenga, Simpson, & van Eeden, 2011). Much of the freight is therefore between mines and ports through which goods are exported, or on routes between Gauteng and the other economic hubs in the country. The Richards Bay Coal Line and the Sishen-Saldanha iron ore line alone accounted for 48% of all rail freight in 2007 and these two lines combined with the Cape-Gauteng and Durban- Gauteng corridors accounted for 70% of all rail freight in 2007 (Transnet, 2009).

Recent years have seen record vehicles sales peaking at 714,315 total vehicle sales in 2006 with the sales of all types of vehicles increasing (NAAMSA, 2012). Sales dropped with the global recession in 2009 but have quickly risen again to the 600 000 unit mark in 2011 and possibly exceeding it, given that Mercedes Benz SA did not submit their data for that year.

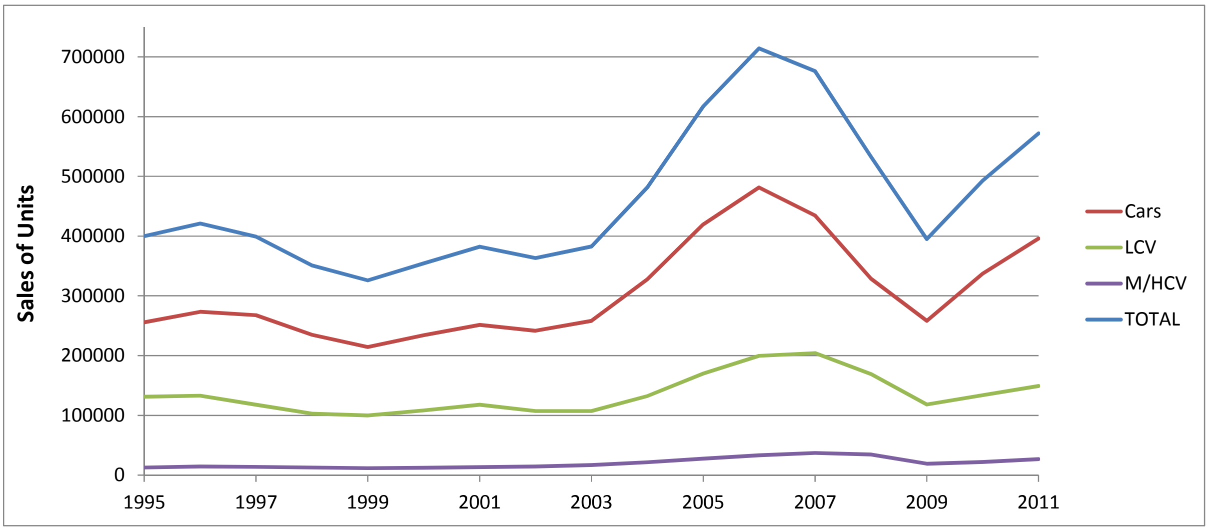

Figure 1: Vehicle sales in South Africa (1995–2011) – includes non-NAAMSA

In line with the above vehicle sales growth, the last decade has seen steady growth in gasoline consumption (1% pa) but somewhat sharper diesel consumption growth at around 5% per annum. Thus, emulating trends in Europe, the gasoline to diesel ratio has steadily swung in favour of diesel and is now around 1.2 (SAPIA, 2011). Dieselisation of the passenger car parc has, however, been slower than in many European countries, with diesel cars making up about 10% of the current passenger car fleet and 15% of current sales (NAAMSA, 2012). The average diesel car fraction of the passenger car fleet in the European Union (EU), grew from 25% in 2001 to 41% in 2007, led by France, Austria and Luxembourg with diesel car fractions of over 50% in 2007 (Eurostat, 2012). The relative lag in South Africa likely reflects that it is in general not possible to pay back the premium in the price of a diesel car with fuel savings within the useful lifetime of the car. Thus in South Africa growth in diesel use seems to rather reflect a growth in freight demand and more recently the growth in demand for peaking and back-up electrical power supply.

Growth in transport demand in South Africa is largely a result of both population growth and economic growth, however there are other factors which characterise the growth of energy demand in the transport sector in South Africa and are included in the vehicle parc model such as the ratio of vehicles using diesel and petrol, long freight haulage distances and high road freight demand. Other factors which translate transport demand into fuel consumption, such as the age of the vehicle fleet, which impacts energy efficiency, are also included in the model.

The critical role of road transport in particular has been summed up by Haw and Hughes (2007) as follows:

> *"Passenger transport over land is the largest consumer of energy followed by land freight. Road transport is a larger sub-sector than rail and air (DME 2001). Energy intensities are high in this sector due to an ageing vehicle fleet, low occupancy rates and poor maintenance of vehicles. Historically segregated residential patterns result in large commuter communities which increases fuel consumption and resultant emissions. Loading and maintenance regulations are poorly enforced and public transport systems*

> *are crowded and unreliable. This leads to high smog levels, road damage, increased road fatalities and reduced productivity as people spend more time and money on commuting."*

Much of the modelling effort has therefore gone into profiling this diverse sector and this paper will attempt to lay out the many assumptions and methodologies that have been employed to capture the road transport sector's typology and activity patterns in a model of fuel demand.

Modelling transport demand

There are several different approaches that have been used to model the transport sector. In the early 1970s, projections were made for energy demand based on macroeconomic forecasting that essentially extrapolated past energy-economy relationships into the future. These projections indicated very high energy demand growth and typically led to plans for large expansion of energy supply capacity. However, energy demand did not develop accordingly, prompting research into the discrepancies between model projections and behaviour in reality. (IAEA, 1984). Subsequent studies formed the basis of the bottom-up approach to energy analysis, which involves disaggregated analysis of the systems that deliver energy services. By calculating energy demand in terms of services performed ('useful' energy) as opposed to amount of energy supplied ('final' energy), a better study of the substitution between alternative energy forms is allowed, as well as an appraisal of the effect that evolution of the technological improvements has on demand.

In a bottom-up approach, energy consumption by any transport sector is directly driven by two factors: vehicle-km travelled, and conversion efficiency of the vehicle (referring to a road, rail or air vehicle).

The vehicle-kms travelled are in turn driven by the needs of society and the economy to move people and goods around. Conversion efficiency depends mostly on the underlying technology, i.e. type of vehicle, fuel and vintage that makes up the vehicle parc and to some degree the patterns of utilisation of that technology. It is useful to treat passenger transport and freight transport separately, as the need for mobility by people and goods have slightly different drivers and technologies.

Armenia, Baldoni, Falsini, and Taibi (2010) proposed a detailed systems dynamics model, shown in Figure 2, to represent the demand for mobility and energy consumption of passenger transport. The model includes a number of the drivers and interactions which define energy consumption in passenger transport and illustrates the complex interactions and extensive data needs required to effectively model this sector. A diagram for road freight transport would be very similar but for instance where environmental policies drive vehicle occupancy in the passenger diagram, environmental and safety policies would drive maximum vehicle load in a freight diagram. The major economic and policy drivers are however similar for both the road and rail transport modes and the outcome of the system, fuel consumption, is still the direct result of vehicle km travelled and vehicle fuel efficiency.

Several of the elements in Figure 2 are included in the calibrated vehicle parc model discussed in this paper. These are the distance travelled per vehicle, the total kilometres travelled, fuel consumption, fuel efficiency, the total vehicle fleet, and the average age of vehicles. Certain factors in Figure 2 affecting the vehicle km travelled and fuel efficiency, for instance traffic congestion, are difficult to quantify as they are not well understood due to the limited availability of data. To accommodate the unknown influences the model is calibrated by adjusting the variables until the output matches the known fuel sales data. Once calibrated, we can be reasonably sure that the model returns realistic estimates of the number of operating vehicles and their annual distance travelled. By making an informed assumption regarding the average occupancies of different vehicle types we can then estimate total private travel demand.

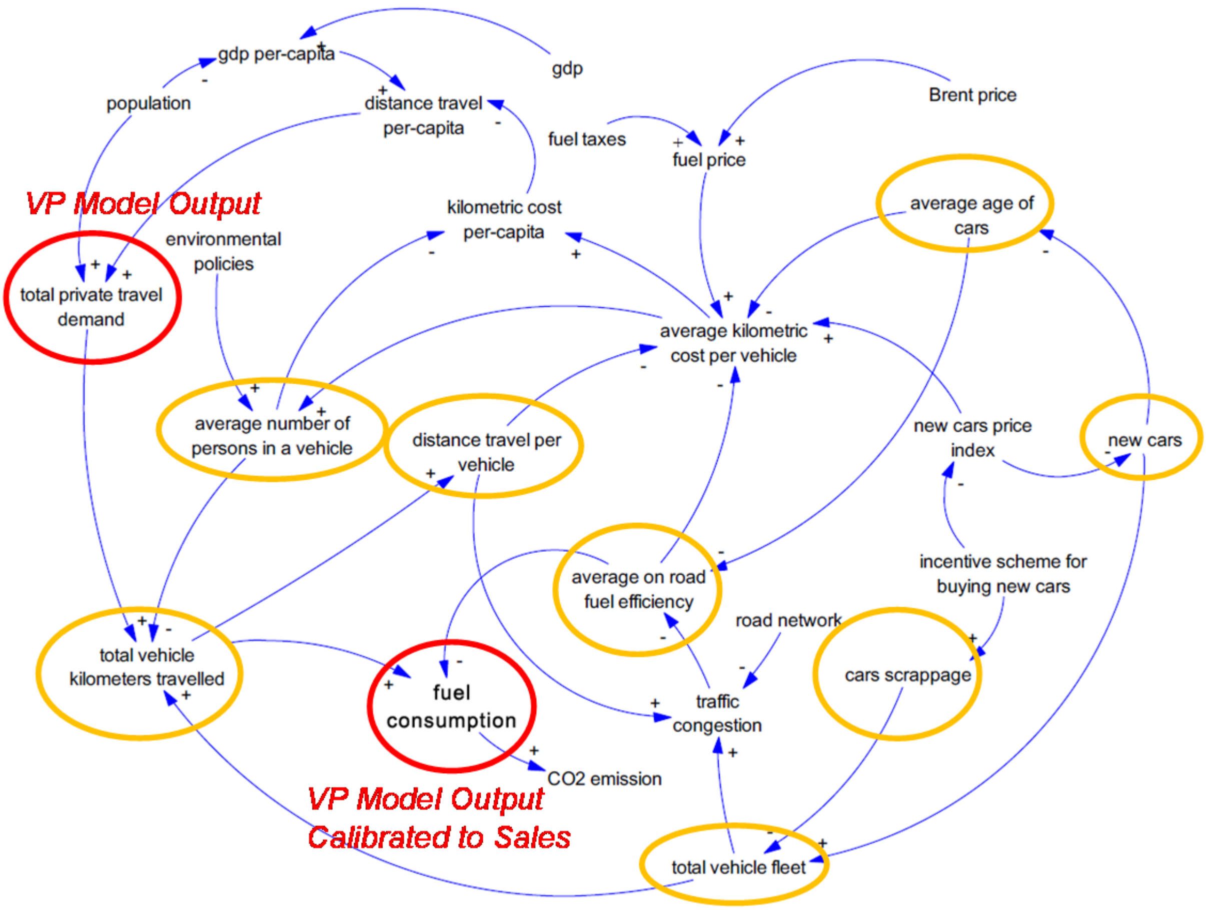

Figure 2: Causal diagram for energy needs for passenger transportation
Adapted from Armenia et al. (2010)

Research methodology

Model choice

While this paper discusses the compilation of a calibrated baseline transport sector model, the ultimate goal of projecting energy demand bears brief discussion because it influenced the selection of the software platform in which the model was developed. Overall, the conceptual methodology was to compile a model on a 'bottom-up' basis that could be used to project future energy demand based on a projected demand for passenger-km and ton-km. The model is economically focused in the sense that both passenger-km and ton-km demand are driven by the transition of households between income groups based on economic projections. The model would ideally be scalable to include new system elements as national and regional data improves.

The Analytica software platform was selected for developing the model as it lends itself to a systems approach, catering for feedback relationships between system elements and both deterministic and stochastic outputs from elements. A graphical interface allows the system elements to be set out in a comprehensible network and thus adding new system elements to an existing model is easier than in, say a spreadsheet, because in Analytica it only requires a simple addition to the model framework. Some of the advantages of a spreadsheet are retained in that data tables, for instance of base year vehicle category fuel economy, can be quickly entered or accessed from the system diagram as shown in Figure 3.

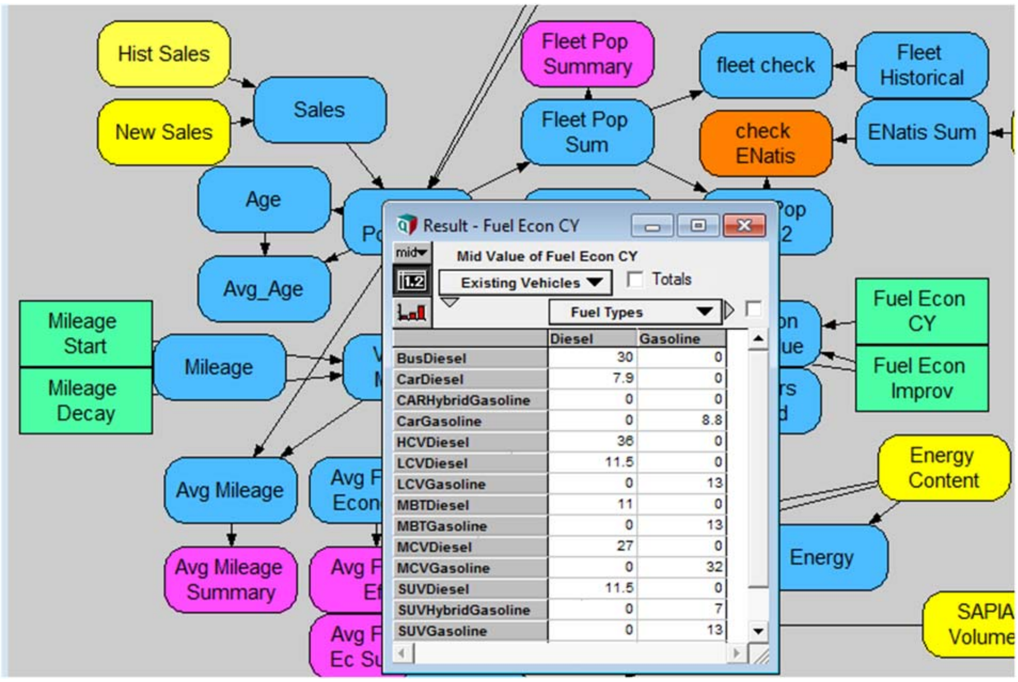

Figure 3: System diagram and data table features of analytical platform

Calibration

Given the gaps in our knowledge around vehicle utilisation in South Africa, the model had to be calibrated with great care, testing the plausibility of any assumptions. To this end it was decided to calibrate the model over seven years, spanning the period from 2003 to 2009, our base year. This gives some reassurance that the model's sensitivity to assumptions is unlikely to cause any unrealistic divergence in the results. In essence, the calibration involves iterating the most uncertain variables like annual mileage and fuel economy until the model predicts the observed fuel sales for the calibration years. Clearly, if errors are large, given reasonable values for these variables relative to available empirical data, there would be something structurally wrong with the model and therefore these iterations require a judicious assessment at each step.

The vehicle parc model was calibrated for both passenger and freight vehicles firstly for South Africa as a whole, and then by province. The set-up and calibration of the critical variables defining the utilisation of vehicles and their efficiency in the model proceeded as follows:

1. Historic vehicle sales data for cars, buses and commercial vehicles was used along with scrapping curves to derive an estimate of the stock of vehicles of different vehicle types, the sum of stock by type was compared with the eNaTiS registration database for calibration purposes.
2. Vehicle mileage estimates were calculated for both passenger and freight vehicles, assuming that the annual mileage travelled by vehicles decays as they age.
3. Fuel demand was calculated by multiplying the kilometres travelled, the vehicle technology fuel efficiency and the number of vehicles in the vehicle technology segment as shown in the equation below. The technology segment fuel demands were summed to yield the vehicle parc demand and compared to the recorded fuel sales for calibration purposes.

$$D_{f,k} = \sum_{j=Y1}^{j=k} \sum_{i=1}^{i=C} N_{i,j} \times FC_{i,j} \times VKT_{i,j}$$

…(Eq. 1)

$D_{f,k}$ = Demand for fuel f in year k

$N_{i,j}$ = The number of vehicles in technology segment i with model year j (Y1 being the first model year), where technologies numbered 1 to C all use fuel f.

$FC_{i,j}$ = Estimated fuel consumption for technology segment i with model year j

$VKT_{i,j}$ = Vehicle kilometres travelled per vehicle in technology segment i with model year j

4. The fuel demand was calibrated to match the known fuel sales data by first getting broad agreement by scaling the kilometres travelled per vehicle and then fine tuning with adjustments to the fuel economy assumptions.

A schematic representation of the vehicle parc model and its data inputs and validations is shown in Figure 4.

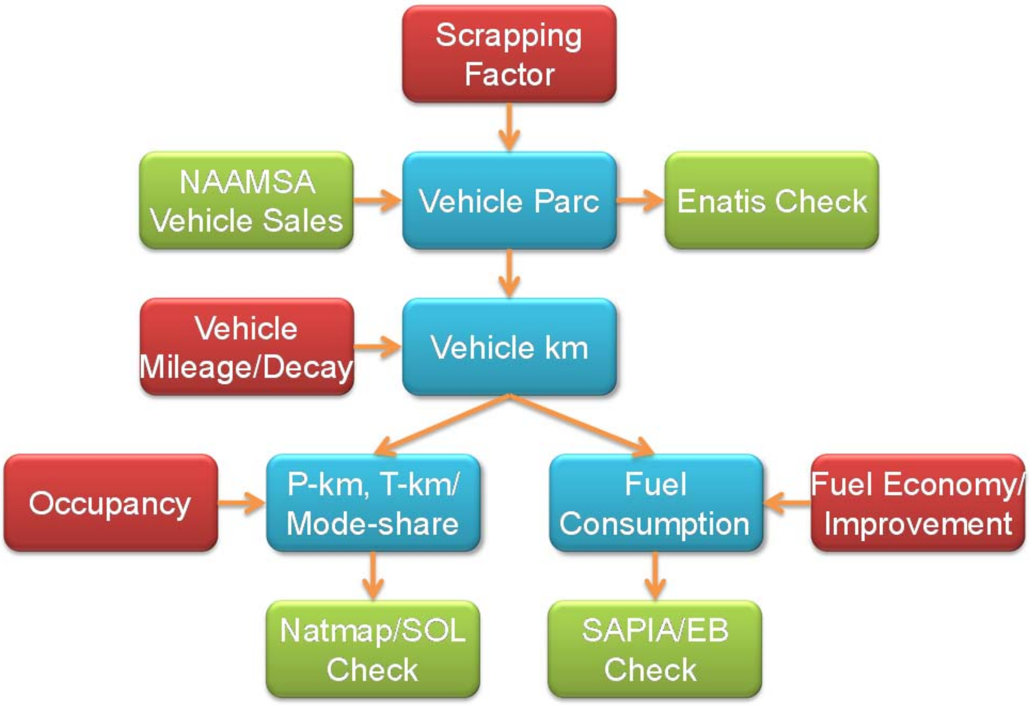

Figure 4: Schematic representation of the vehicle parc model and its data inputs and validations

Data and assumptions

Developing transport sector models and projecting demand into the future is challenging in the South African context because there is a paucity of data on vehicle utilisation and therefore assumptions had to be made around the scrapping factors, vehicle mileage, occupancy and fuel economy inputs. The vehicle parc model developed required disaggregated data on the current vehicle population, efficiency and utilisation for both passenger and freight transport.

Data on the total registered vehicle population in South Africa is captured by the electronic national administration traffic information system (eNaTiS). The eNaTiS vehicle registration data includes six vehicle classes, namely: motorcars and station wagons; minibus; buses trains and midi-buses; light duty vehicles, panel vans and other light vehicles (less than 3500kg); trucks larger than 3500kg; and other self-propelled vehicles. The eNaTiS data is more aggregate than the historic vehicle sales data available from the National Association of Automobile Manufacturers of South Africa (NAAMSA). NAAMSA publishes 14 vehicle classes cross referenced to technical data that could be used to disaggregate the eNaTiS data into additional subcategories. However, NAAMSA data records only vehicle sales and therefore does not directly translate into vehicles on the road. Determining the count of vehicles in the vehicle classes shown in Table 2 therefore required some mapping between sources.

Table 2: Vehicle classes adopted for the model

Vehicle types	Fuel type	Model ID*
Passenger car	Diesel	CarDiesel
Passenger car	Gasoline	CARHybridGasoline
Passenger car	Gasoline	CarGasoline
Bus	Diesel	BusDiesel
Heavy commercial vehicle	Diesel	HCVDiesel
Medium commercial vehicle	Diesel	MCVDiesel
Medium commercial vehicle	Gasoline	MCVGasoline
Light commercial vehicle	Diesel	LCVDiesel
Light commercial vehicle	Gasoline	LCVGasoline
Minibus taxi	Diesel	MBTDiesel
Minibus taxi	Gasoline	MBTGasoline
Sport utility vehicle	Diesel	SUVDiesel
Sport utility vehicle	Gasoline	SUVHybridGasoline
Sport utility vehicle	Gasoline	SUVGasoline
Motorcycle	Gasoline	MotoGasoline
* *These IDs are used in graph legends below*		

Estimates of freight utilisation in ton.km have been available in the public domain through the annually published State of Logistics reports (Havenga, Simpson, & van Eeden, 2011) since 2004. Estimates of the demand for passenger transport in passenger.km are not readily available but could potentially be inferred by analysis, for example from the trip data generated by the National Transport Master Plan model (DoT, 2009).

In order to check the model calibration, regional data on fuel sales was required. While aggregate fuel consumption by the transport sector is available through the national energy balances published by the DoE, there were challenges in apportioning fuel consumption to passenger and freight transport as fuel use in transport is not disaggregated in the energy balances. The South African Petroleum Industry Association (SAPIA) records disaggregated fuel sales data by province under several categories, one of which is 'Freight' however this contains only diesel sales to depots. Long haul trucks frequently obtain fuel from retail outlets (classified as 'retail' by SAPIA) and therefore the recorded use of diesel for the 'freight' category designated by SAPIA accounts for less than half of the actual freight consumption of diesel.

The fuel demand calculation and model calibration process required a number of assumptions to populate the three variables in Equation 1, N the number of vehicles, VKT, their mileage and FC their fuel economy. The assumptions required are:

1. a vintage profile derived from realistic scrapping curves;
2. an assessment of annual vehicle mileage for each vehicle class and the rate at which this decays as the vehicle ages; and
3. estimates of the fuel economy of each vehicle class and how this is changing with time.

Vintage profile

To project the energy consumption of a vehicle parc and how it may evolve over time, a vintage profile of the current vehicle parc was established. This is important, as newer vehicles may have better fuel economy and higher vehicle mileage than older vehicles and, as newer vehicles enter the parc and older ones are driven less and are scrapped, the average fuel economy of the parc changes.

The rate at which vehicles have been scrapped was defined in the model by scrapping curves which estimate the probability of a vehicle surviving as a function of its age. This allows us to convert historical sales data into stock data. The Weibull cumulative distribution function, shown below, was used for this purpose.

If: x = age of the vehicle
$f(x)$ = the probability of the vehicle remaining operational
α = a constant
β = a constant

$$f(x) = e^{-\left(\frac{x}{\beta}\right)^{\alpha}} \qquad \text{...(Eq. 2)}$$

Multiplying the total sales of a vehicle type in a particular year (vintage) by the appropriate scrapping factor on the curve will yield the probable population in a future base year. Thus historical sales data can be converted to an approximation of stock in the vehicle parc for a given year by substituting the result of Equation 2, the probability of a vehicle being scrapped, in Equation 3.

If: Y_S = The year of sale
Y_P = The year for which the vehicle park is being characterised
V_P = The stock of vehicles in the vehicle parc in year Y_P sold in year Y_S
V_S = The number of vehicles sold in year Y_S
$f(Y_P - Y_S)$ = The function estimating the probability of the vehicle being scrapped

$$V_P = f(Y_P - Y_S)\, V_S \qquad \text{...(Eq. 3)}$$

The scrapping curves were calibrated by iterating the parameters for the scrapping curves until a target population was reached. This was done until the converted historical detailed vehicle sales data from NAAMSA matched the more aggregated total vehicle population data from eNaTiS for a calibration year while maintaining an average vehicle age for the model that accorded with published data and was continuous with other calibration years. The Weibull constants used for the vehicle parc model and the resulting average age of vehicle categories in the model for the 2010 calibration year are presented below including data from previous studies for comparison.

Table 3: Vehicle class Weibull coefficients & resulting average ages for the calibrated model compared to other studies a sources

<table>
<tr><th>Source</th><th colspan="3">This model</th><th colspan="3">SA national octane study
Bellet al (2003)</th><th>Moodley & Allopi (2008)</th><th>Stone & Bennett (2001)</th></tr>
<tr><th>Year</th><th colspan="3">2010</th><th colspan="3">2002</th><th>2005</th><th>2000</th></tr>
<tr><th>Vehicle category</th><th>β</th><th>α</th><th>Avg. Age</th><th>β</th><th>α</th><th>Avg. Age</th><th>Avg. Age</th><th>Avg. Age</th></tr>
<tr><td>Diesel car</td><td>22</td><td>3.0</td><td>5.0</td><td>20.2</td><td>3.2</td><td>4.2</td><td rowspan="2">10</td><td></td></tr>
<tr><td>Gasoline car</td><td>23</td><td>2.0</td><td>11.8</td><td>20.2</td><td>3.2</td><td>10.4</td><td></td></tr>
<tr><td>Hybrid gasoline car</td><td>22</td><td>3.0</td><td>2.2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Diesel SUV</td><td>22</td><td>3.0</td><td>5.2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hybrid gasoline SUV</td><td>22</td><td>3.0</td><td>0.7</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Gasoline SUV</td><td>22</td><td>3.0</td><td>6.9</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Diesel LCV</td><td>22</td><td>3.0</td><td>7.8</td><td>20.2</td><td>3.2</td><td>7.2</td><td></td><td rowspan="2">9.3</td></tr>
<tr><td>Gasoline LCV</td><td>22</td><td>1.4</td><td>12.4</td><td>20.2</td><td>3.2</td><td>9.9</td><td></td></tr>
<tr><td>Diesel MCV</td><td>24</td><td>3.0</td><td>8.5</td><td></td><td></td><td></td><td rowspan="3">12</td><td rowspan="3">11.9</td></tr>
<tr><td>Gasoline MCV</td><td>24</td><td>3.0</td><td>19.1</td><td></td><td></td><td></td></tr>
<tr><td>Diesel HCV</td><td>24</td><td>3.0</td><td>9.6</td><td></td><td></td><td></td></tr>
<tr><td>Diesel MBT*</td><td>23</td><td>3.0</td><td>3.5</td><td></td><td></td><td></td><td rowspan="2">13.0</td><td></td></tr>
<tr><td>Gasoline MBT*</td><td>23</td><td>3.0</td><td>13.0</td><td>20.0</td><td>3.2</td><td>11.3</td><td></td></tr>
<tr><td>Diesel bus</td><td>30</td><td>3.0</td><td>15.4</td><td></td><td></td><td></td><td>11</td><td></td></tr>
<tr><td>Motorcycle</td><td>16</td><td>3.0</td><td>5.5</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9">* MBT: Minibus Taxi</td></tr>
</table>

There is a wide range of average ages between vehicle classes but the younger classes, for example diesel cars, diesel minibus-taxis and hybrids reflect recent sales that are a lot higher than historical sales. The established vehicle classes such as gasoline cars, LCVs and HCVs all have average ages of around 10 or more years. The scrapping curve for each vehicle class in the model plotted using the Weibull coefficients is shown in Figure 5 below.

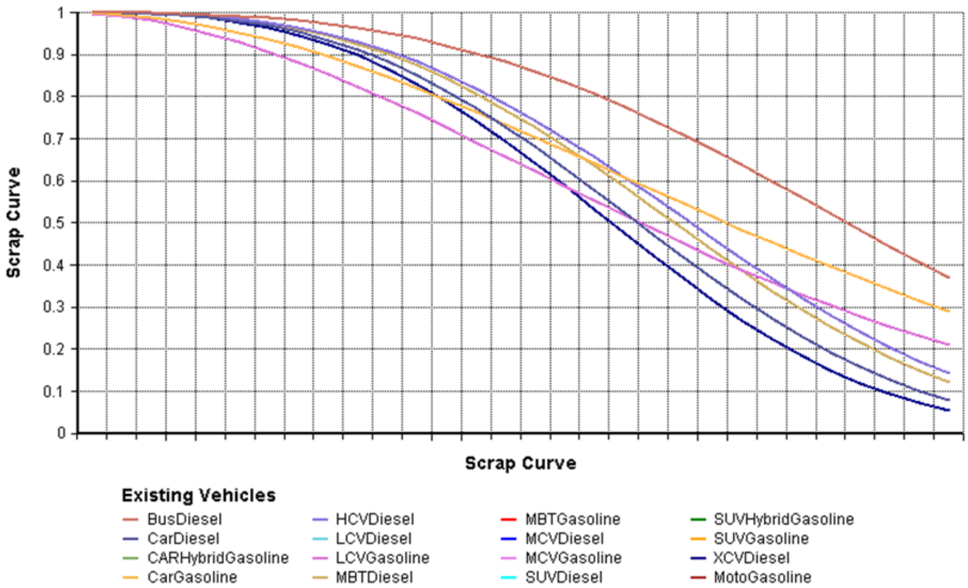

Figure 5: Base year scrapping curves for the vehicle technology types in the vehicle parc model

Vehicle mileage

The process of developing mileage assumptions for the model, that would be both plausible and allow for the calibration of model fuel demand with fuel sales, requires an assumption around the initial annual mileage of 'new vehicle' annual mileage. The assumed 'new vehicle' mileage was based on national and international literature. The annual mileage of vehicles has been observed to, on average, decay steadily from this initial value for each year of operation. The US EPA's MOBILE 6 model assumes a constant rate of decay compounding annually that is specific to vehicle type (Jackson, 2001) as shown in Figure 6. In general (buses being the exception), the rate of decay assigned is higher for vehicles with a higher initial mileage, heavy truck mileage for example decays at 10.9% per annum while for light-duty vehicles the default rate in Mobile 6 is 4.9% annual decay in annual mileage per annum. Although the latter rate has been observed to be both higher and lower for specific areas within the United States (Yu, Qiao, Li, & Oey, 2002), good agreement was shown with a parked car study covering a number of sites in Nairobi (University of California at Riverside, Global Sustainable Systems Research, 2002) where initial mileage was lower but the rate of decay very similar.

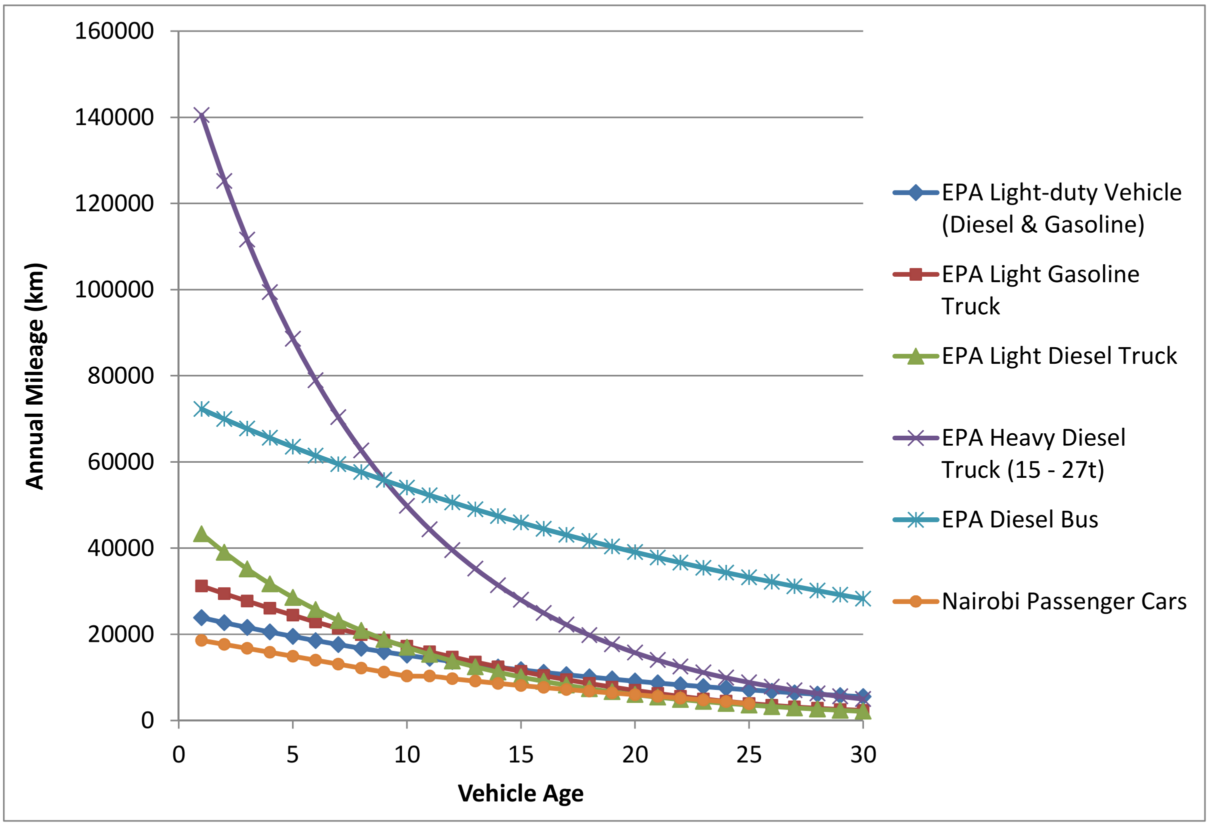

Figure 6: EPA Mobile 6 annual mileage decay assumptions compared to results of vehicle activity study for Nairobi Kenya

Lacking even rudimentary mileage accumulation data for South Africa, the value of 4.9% was used as the rate of mileage decay for the South African vehicle parc model across all vehicles classes. The rate of decay combined with the assumption of an initial 'new vehicle' mileage and the age profile of the model parc resulting from the scrapping assumptions discussed above results in an estimate of average annual mileage for each vehicle class. Clearly, if recent vehicle sales have been low then this will reduce the average mileage of that class because older vehicles which cover less mileage contribute disproportionately. After model calibration, these assumptions resulted in average mileages for the model vehicle classes that are reasonably consistent with previous studies and local and foreign data as shown below in Table 4.

Table 4: Assumed average vehicle mileage (km/annum)

Region	**South Africa**									**North America**	**OECD – Europe & Pacific**	**non-OECD**
Source	**This model – new vehicle mileage**	**This model – average mileage of stock**	**SAPIA PDSA[1]**	**RTMC[2]**	**LTMS[3]**	**National Octane Study Model – 45 km/h[4]**	**National Octane Study Model – 34 km/h[4]**	**Stone & Bennett[5]**	**Stone - Coastal KZN[6]**	**IEA/SMP Model (2010)[7]**		
Year	**2006**	**2006**	**2008**	**2007**	**2003**	**2002**	**2002**	**1998**	**2002**	**2010**	**2010**	**2010**
Diesel car	24 000	21 254	19 000	14 644	15 000	23 467	19 778		18 873	17 600	11 250	10 875
Gasoline car	24 000	16 169	19 000		14 575	17 647	14 872		14 016	17 600	11 250	10 875
Hybrid gasoline car	24 000	23 678										
Diesel SUV	24 000	20 314										
Hybrid gasoline SUV	24 000	24 000										
Gasoline SUV	24 000	19 128										
Diesel LCV	25 000	19 202	19 500	18 806	15 000	25 196	21 143		20 577			
Gasoline LCV	25 000	16 662	19 500		14 575	21 046	17 660		16 552			
Diesel MCV	45 000	33 417		42 901				39 933	34 211	32 000	25 000	21 125
Gasoline MCV	25 000	13 575							38 229	32 000	25 000	21 125
Diesel HCV	70 500	48 403						52 583	72 354	60 000	60 000	50 000
Diesel MBT	50 000	43 474		27 480	70 000					35 000	35 000	40 000
Gasoline MBT	50 000	30 927	30 000		70 000	92 365	92 365		70 332	35 000	35 000	40 000
Diesel bus	40 000	22 072		35 227	28 912				61 985	60 000	60 000	40 000
Motorcycle	10 000	8 340		6 124						5 000	7 500	7 500

1: (NAAMSA / SAPIA Working Group, 2009)
2: (Road Traffic Management Corporation, 2009)
3: (DEAT, 2007)
4: (Bell, Stone, & Harmse, 2003) – This model used the speed dependent COPERT equations to calculate fuel economy so the calibration with fuel sales required adjustment of annual mileage if average speed was changed.
5: (Stone & Bennett, 2001)
6: (Stone, 2004)
7: (IEA, 2011)

The large range of minibus-taxi annual mileage estimates is of interest because this vehicle class has a large effect on the model calibration due to its high modal share. The discrepancy in mileage between the various studies reflects to some degree the respective author's struggles with calibrating their models in the absence of good activity data for these vehicles. Recent published data for African cities (International Association of Public Transport & African Association of Public Transport, 2010) presented in Table 5 suggests minibus-taxi mileages are high.

Table 5: Average annual mileage per vehicle for passenger modes in various African cities

City	Passenger car (km/annum)	Diesel bus (km/annum)	Minibus-taxi (km/annum)
Abidjan	12 000	60 049	86 400
Accra	19 200	29 952	79 872
Addis Ababa	25 357	53 924	57 350
Dakar	7 500	45 582	58 006
Dar es Salaam	25 000		70 000
Douala	15 000	40 000	50 000
Johannesburg	*21 900*	*27 260*	*64 680*
Lagos	4 260	73 920	72 000
Nairobi	8 133	15 000	18 000
Windhoek	15 863	15 000	

The value of vehicle parc models would be greatly enhanced if reliable data for the minibus taxi industry was available, a relatively low-cost exercise given that there are relatively few vehicles of this type which operate within a commercial structure, albeit sometimes semi-formal. Good data for minibus taxis would improve the calibrated model outputs for other vehicle classes.

Fuel economy

Fuel economies for each vehicle class and each model year were generated by assuming a 1% annual improvement in fuel economy of the vehicle classes in the vehicle fleet relative to their 2010 fuel economy according to the aggregate manufacturer's data available for representative car models in each vehicle class. Average vehicle fuel economy is a factor of several variables, as vehicles age the efficiency decreases, but the fuel economy of new vehicles tends to improve over time as shown in Table 6 below. This is the result not only of technology becoming more efficient but also because regulation is reducing vehicle mass and engine capacity. The South African vehicle parc is dominated by models from Europe and Japan, so given the data shown in Table 6 we might expect a higher annual improvement but given the slower rate of scrapping in South Africa and the lower value of 0.4% for the short period reviewed by the IEA, it was decided that 1% is a reasonable historical improvement in the absence of local reliable data. This assumption is also supported by a British study (Kwon, 2006), which suggests that new passenger vehicles and light commercial vehicles had an improved vehicle efficiency of 0.9% per annum between 1979 and 2000 in Britain, a much longer period than the period coved by the studies reviewed below.

Table 6: Improvements in passenger car fuel economy in world markets 2000–2010

	ICCT (2011)		Cuenot & Fulton (2011) (International Energy Agency)	
Country	**Period**	**Annual fuel economy improvement**	**Period**	**Annual fuel economy improvement**
US	2000–2010	1.60%	2005–2008	1.90%
Canada	2000–2008	1.28%	-	-
EU	2000–2010	1.90%	2005–2008	1.90%
Japan	2000–2009	2.81%	2005–2008	2.20%
South Africa	-	-	2005–2008	0.40%

Data for the fuel economy improvement of heavy-duty vehicles over the calibration period was not found and therefore an assumption of 1% was applied to these vehicle classes as well. The resulting historical fuel economy trajectory for the vehicles classes in the model is presented in Figure 7. Given the blanket 1% assumption, the fuel economy of all vehicle classes increases by just over 22% over the 20 year period shown. Clearly, in certain instances the fuel economy data for some technologies are extrapolated back to before those technologies entered the market, gasoline hybrid SUVs for instance, but this does not affect the model if no stock of these vehicles exists.

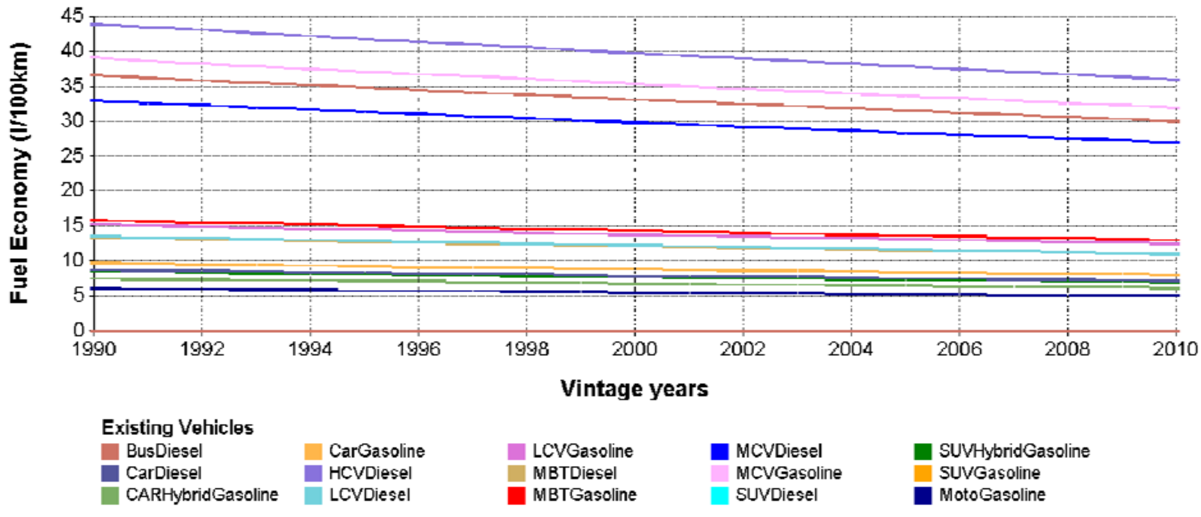

Figure 7: Assumed historical evolution of vehicle fuel economy in the model

The calibration process involved first adjusting the initial annual mileage assumed to the final values shown above in Table 4 and then adjusting the 2010 fuel economy estimates slightly until a good match was obtained between the data for historical fuel sales to the transport sector and the fuel demand of the vehicle parc model. The adjusted new vehicle 2010 fuel economy assumptions and the resulting fuel economy of stock in that year for the calibrated model are compared to other local and international studies and models in Table 7.

Table 7: Calibrated model fuel economy (l/100km) by vehicle class compared to other studies and sources – Part 1

Region	**South Africa**									**North America**	**OECD – Europe & Pacific**	**non-OECD**
Source	**This model – new vehicle fuel economy**	**This Model – average fuel economy of stock**	**Vander-schuren[1]**	**SAPIA PDSA[2]**	**LTMS[3]**	**National Octane Study Model – 45 km/h[4]**	**National Octane Study Model – 34 km/h[4]**	**Stone & Bennett [4]**	**Stone - Coastal KZN[5]**	**IEA/SMP Model (2010)[6]**		
Year	**2006**	**2006**	**2010**	**2008**	**2003**	**2002**	**2002**	**1998**	**2002**	**2010**	**2010**	**2010**
Diesel car	7.5	7.7	8.2	6.3	7.7	5.9	6.7		6.8	9.5	7.4	9.1
Gasoline car	8.3	9.1	10.5	8.4	9.3	7.5	8.6		10.8	11.6	8.9	11.1
Hybrid gasoline car	6.4	6.4										
Diesel SUV	11.5	12.0										
Hybrid Gasoline SUV	7.3	7.3										
Gasoline SUV	13.0	13.7										
Diesel LCV	11.5	12.2		10.5	11.2	7.7	9.0	8.7	10.6			
Gasoline LCV	13.0	14.2		13.8	14.7	10.8	13.3		12.5			
Diesel MCV	28.1	30.0						17.4	17.2	25.6	23.7	28.0
Gasoline MCV	33.3	38.7							31.4			
Diesel HCV	37.5	40.7						31.6	47.5	41.9	36.1	33.1
Diesel MBT	11.4	11.8	10.5		11.2							
Gasoline MBT	13.5	15.1	11.4	14.4	12.7	15.4	15.4		16.0	18.0	18.0	16.0
Diesel bus	31.2	35.5	36.0		36.1				27.9	33.0	33.0	28.0
Motorcycle	5.2	5.4								4.5	3.5	2.3

1: (Vanderschuren, 2011)
2: (NAAMSA / SAPIA Working Group, 2009)
3: (DEAT, 2007)
4: (Bell, Stone, & Harmse, 2003) – This model used the speed dependent COPERT equations to calculate fuel economy so the calibration with fuel sales required adjustment of annual mileage if average speed was changed.
5: (Stone & Bennett, 2001)
6: (Stone, 2004)
7: (IEA, 2011)

Occupancy and load factor

Less data was available to guide the assumptions for vehicle occupancy and load factor which are critical for calculating the demand for passenger.km and ton.km in the model. A statistical review of transport in African cities published by the International Association of Public Transport (2010) offers a regional perspective and suggests, given the figures for Johannesburg compared to other cities presented below, that occupancy in South Africa is generally lower than the rest of Africa.

Table 8: Average occupancy per vehicle for passenger modes in various African cities

City	Passenger car (pass/veh)	Diesel bus (pass/veh)	Minibus-taxi (pass/veh)
Abidjan	2.0	60	18
Accra	2.0	68	18
Addis Ababa	3.7	80	11
Dakar	2.0	66	35
Dar Es Salaam	1.9	45	29
Douala	2.3	45	17
Johannesburg	*1.4*	*37.1*	*8.5*
Lagos	1.8	43	18
Nairobi	1.7	70	18
Windhoek	1.3		

The final occupancy and load factors selected for the model are compared to other studies and sources below.

Table 9: Model occupancy and load factor by vehicle class compared to other studies and sources

Region		South Africa			North America	OECD – Europe & Pacific	non-OECD
Source		**This model**	**Vander-schuren[1]**	**LTMS[2]**	**IEA/SMP Model[3]**		
Year	**Units**	**2006**	**2010**	**2003**	**2010**	**2010**	**2010**
Diesel car	pass/veh	1.4	1.40	2.10	1.47*	1.61*	1.77*
Gasoline car	pass/veh	1.4	1.40	2.10	1.47*	1.61*	1.77*
Hybrid gasoline car	pass/veh	1.4					
Diesel SUV	pass/veh	1.4					
Hybrid gasoline SUV	pass/veh	1.4					
Gasoline SUV	pass/veh	1.4					
Diesel MBT	pass/veh	14	12	35	6.00	8.40	10.70
Gasoline MBT	pass/veh	14	12	15	6.00	8.40	10.70
Diesel bus	pass/veh	25	40	35	12.00	16.70	22.00
Motorcycle	pass/veh	1.1			1.20	1.20	1.40
Diesel LCV	ton/veh	0.5		2.10			
Gasoline LCV	ton/veh	0.5		2.10			
Diesel MCV	ton/veh	2.5			2.20	1.60	1.70
Gasoline MCV	ton/veh	2.5			2.20	1.60	1.70
Diesel HCV	ton/veh	15.00			10.00	8.00	6.30

*Data for LDVs which include cars and light trucks/vans/suvs
1: (Vanderschuren, 2011)
2: (DEAT, 2007)
3: (IEA, 2011)

Provincial disaggregation

Once the scrapping factors, vehicle mileage and mileage decay parameters, and fuel economy parameters had been estimated nationally, they were transferred to a provincially disaggregated version of the model. In the provincially disaggregated version, the scrapping factors determined in the national model are applied to the provincially disaggregated NAAMSA vehicle sales data to obtain an initial estimate of the vehicle population in each province. The result was compared to the provincially disaggregated eNaTiS vehicle parc figures to calculate a correction factor to explain the 'net-migration' of cars across provinces after they are sold. For example, it is observed from the vehicle population estimates that a number of cars sold in Gauteng (around 10%) end up in the other provinces. The mileage and fuel economy estimated nationally are then applied to the 'corrected' provincial vehicle population to obtain an estimate of the provincial fuel consumption, which was then be compared to the SAPPIA sales figures in each province.

Results

Aside from the results of the fuel demand calibration which validate the model, the model also generated some interesting aggregate statistics allowing for the profiling of the South African vehicle parc by vehicle class fraction, shown in Table 10, and the share of fuel type, shown in Table 11. These data are shown for 2010, rather than the calibration base year of 2006 used for the other results because the calibration model could generate the later more relevant data for vehicle numbers.

Table 10: Vehicle class as a fraction of the total road vehicle parc for 2010

Vehicle class	Count of vehicles (2010)	Fraction
Diesel car	184 407	2.3%
Gasoline car	4 455 038	54.5%
Hybrid gasoline car	1 107	0.0%
Diesel SUV	279 222	3.4%
Hybrid gasoline SUV	331	0.0%
Gasoline SUV	442 621	5.4%
Diesel MBT	13 976	0.2%
Gasoline MBT	260 577	3.2%
Diesel bus	30 033	0.4%
Motorcycle	366 162	4.5%
Diesel LCV	700 265	8.6%
Gasoline LCV	1 103 608	13.5%
Diesel MCV	131 425	1.6%
Gasoline MCV	5 991	0.1%
Diesel HCV	198 134	2.4%
TOTAL	**8 172 897***	**100.0%**

** This total is not calibrated to include the 'Other self-propelled vehicles' category in the eNaTiS registration database*

Table 11: Split of selected vehicle types by fuel (2010)

Vehicle class	Diesel fraction	Gasoline fraction
Cars & SUVS	9%	91%
MBT	5%	95%
LCV	39%	61%
MCV	96%	4%

The model generates total vehicle km which when combined with assumptions of occupancy, as discussed above, enables the calculation of demand for passenger.km by the different passenger model. This further allows us to calculate a modal spilt for passenger transport which can be compared to other studies as a further validation of the model. The modal split shown in Table 12 shows good agreement with Department of Transport data for 2005 (DoT, 2009).

Table 12: Model generated passenger transport data for South Africa (2006)

	Total Vehicles	Total veh-km	km per veh	Occup-ancy	Activity	Modal Share	NATMAP[a] (2005)
	(1000 veh.)	(billion veh-km)	(000 km)	(pers/veh, %)	(billion p.km)	(%) of p.km	(%) of trips
Public							
Large Bus	22.1	0.63	28.5	25	15.7	6%	10%
MBT	269.3	8.38	31.1	14	117.4	42%	40%
Train*					13.9[b]	5%	8%
Air*		14.30[c]		80%[d]	11.4	4%	1%
TOTAL					**158.4**		
Private							
Pass. Car	4488.5	73.2	16.3	1.4	102.5	43%	40%
SUV	498.4	9.7	19.5	1.4	13.6		
M/cycle	266.3	2.22	8.3	1.1	2.4		
TOTAL					**118.6**		
Grand total					**276.9**		

**: Train and air transport figures are from literature not the model*
a: (DoT, 2009)
b: Intra-city data only for 2006/2007 (Metrorail, 2007) – data for inter-city is not published by the respective vendors
c: 2007 data from The World Bank (Gwilliam, 2011)
d: Author's assumption

The total vehicle km generated by the model by vehicle types also allows us to estimate the utilisation of the road freight fleet in ton.km per annum for the base year as shown below in Table 13. The estimate of total road freight utilisation for 2006 of 144 billion ton.km differs quite substantially from the State of Logistics estimate for that year of 230 billion ton.km (CSIR, 2007). The load factors and mileages assumed in the model, shown above in Table 5 and Table 9, however seem relatively conservative relative to other studies and models. Higher mileages would of course compromise the diesel fuel sales calibration and it's thus likely that the discrepancy between the models stems from load factor assumptions. Total load factors even in Europe, where fuel costs put pressure on margins, are generally in the region of 50% (Leonardi, Rizet, Browne, Allen, Pérez-Martínez, & Worth, 2009), (IFEU Heidelberg, Öko-Institut, IVE, RMCON, 2011) and very variable for the type of freight and are thus difficult to assess. It is also not known whether the State of Logistics figure includes ton.km of freight moved around on private roads within mines and farms which would be a considerable amount. Further work should include an attempt to reconcile the two models.

Table 13: Freight utilisation for 2006 estimated from model output

Vehicle type	Freight utilisation (2006)
	(billion ton.km)
LCV	14.4
MCV	9.1
HCV	120.1
TOTAL	**143.6**

The most important validation is a comparison of the model fuel demand with actual fuel sales for the calibration years. The results for calibrating the model for the years 2003–2009 showed excellent agreement for both petrol and diesel use as shown below in Figure 8.

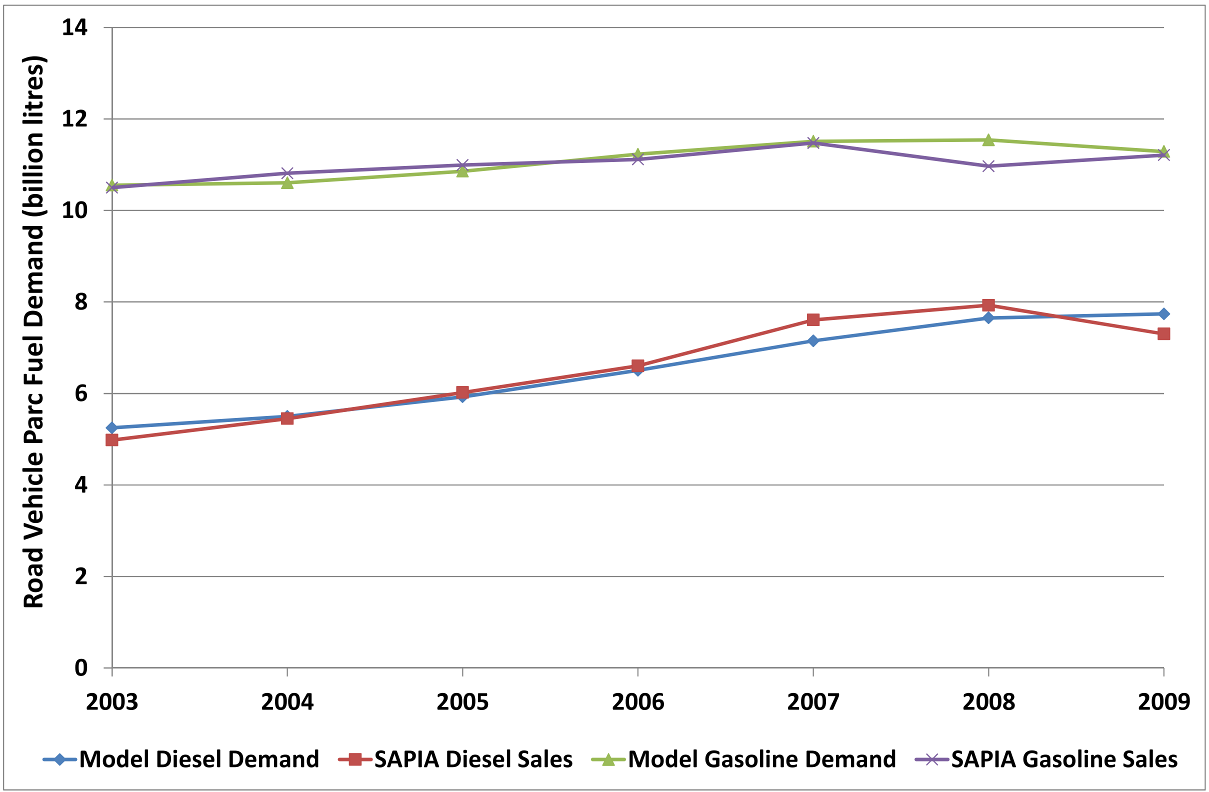

Figure 8: Model fuel demand vs actual fuel consumption for 2003 to 2009

The discrepancy between the petrol sales calculated by the model and actual sales for 2008 may well relate to a spike in price for that year as shown below in Figure 9. The same effect is possibly not seen for diesel because the industrial and freight consumers are less price sensitive than private consumers in the short term. Indeed price elasticity for diesel in South Africa has been reported to be small and less than gasoline (Boshoff, 2012). The calibrated result suggests that adding fuel price elasticity to the model will be a useful attribute particularly in enhancing a response to future fuel price scenarios.

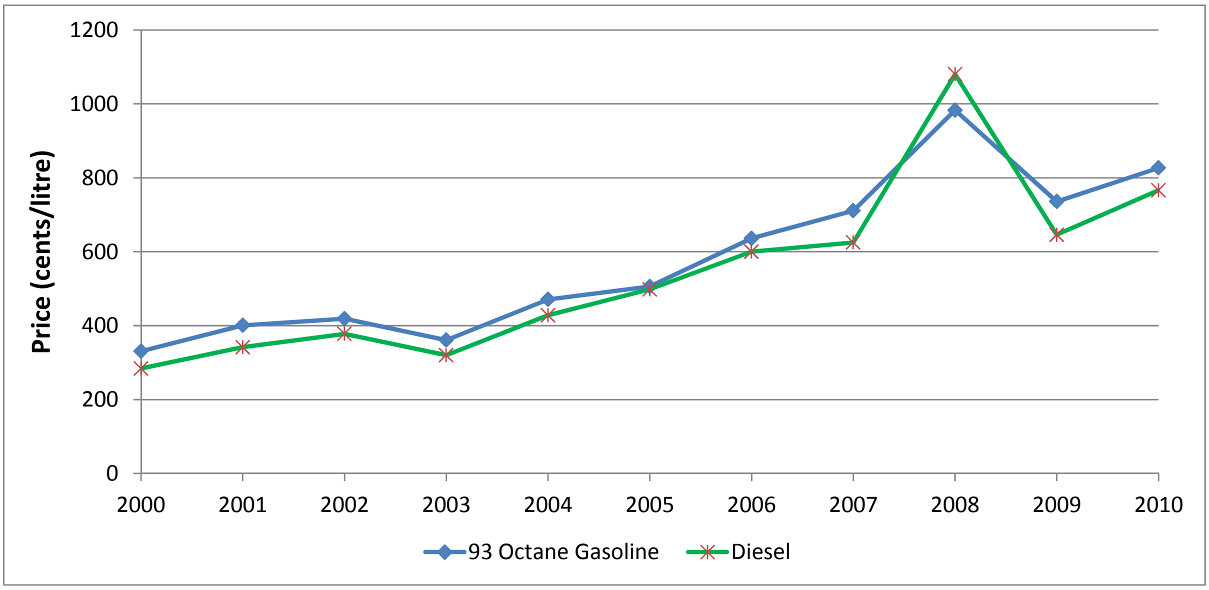

Figure 9: Change in gasoline and diesel prices in South Africa 2000–2010

The provincially disaggregated fuel calibration results, shown below in Figure 10 and Figure 11 for 2006, also indicated a good agreement between model and actual data, predictably with more variation, given the greater uncertainties and data challenges.

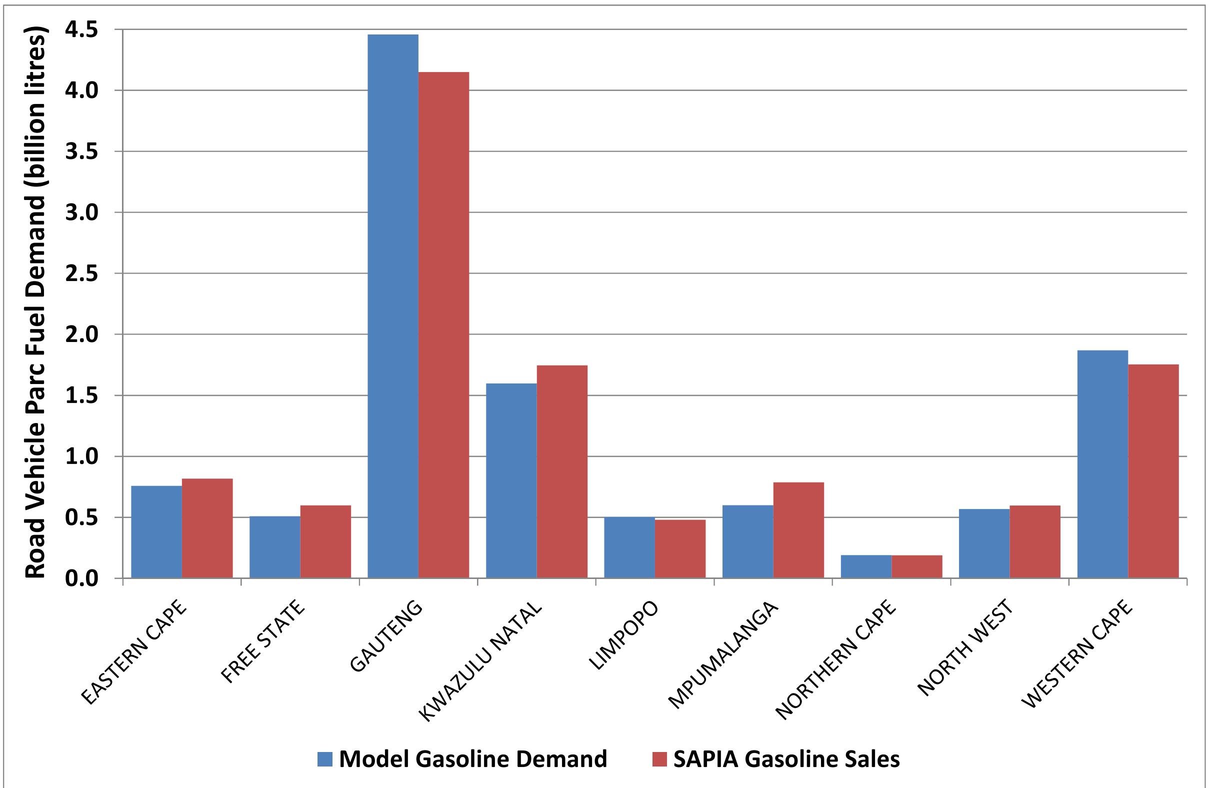

Figure 10: Model gasoline consumption vs actual gasoline consumption for 2006 disaggregated by province

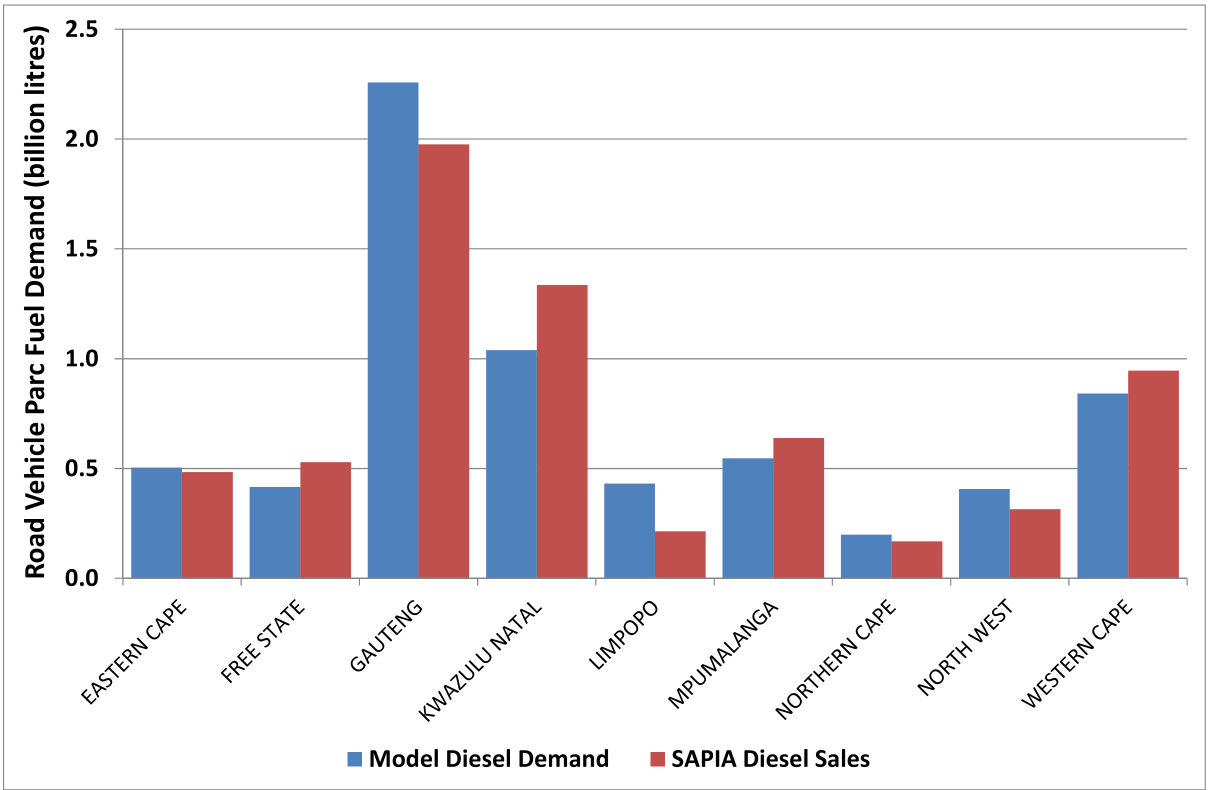

Figure 11: Model diesel consumption vs actual diesel consumption for 2006 disaggregated by province

The largest discrepancies in the provincial data were for diesel consumption in Gauteng and Kwazulu-Natal which reflects the difficulty in apportioning diesel consumption provincially with the high volume of freight transported along the corridor between these two provinces from the harbor in Durban to the industries of the Vaal Triangle.

Conclusions

A vehicle parc model with energy demand calibrated over seven historical years from 2003–2009 has been compiled for South Africa. Calibration results at national level appear excellent while at provincial level they are good with some minor errors in diesel consumption for Gauteng and Kwazulu-Natal, reflecting the heavy freight traffic along the corridor between these two provinces. Essentially the results reflect that a disproportionate number of heavy vehicles operating on the corridor and refueling in Kwazulu-Natal, are registered in Gauteng.

The means to improve this part of the model could be through the use of the extensive vehicle count data for major corridors available in the public domain. Other useful data that potentially could be extracted by extending the study in this direction are:

- freight fuel use disaggregated by corridor;
- useful estimates of actual vehicle utilisation by weight class and configuration; and
- calibration of scrapping curves for heavy vehicles by weight class.

As shown above, an effect of diesel price elasticity can also be seen in the calibration results and a further improvement envisioned for the model will be to integrate this in the vehicle km demand function.

This type of vehicle parc model, if maintained, can be a national resource for optimising the planning of large infrastructure projects. Through the ongoing improvements proposed for the model, the goal is to produce a powerful source of information on transport energy use patterns and trends for all stakeholders.

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Section 2

Working paper 2: A model for the analysis of future scenarios of energy demand in the transport sector in South Africa

Abstract

In many respects the greatest impact of the advent of the industrial age on the lives of ordinary people has been that of motorized transport, beginning with passenger rail in the 19th century and diversifying into progressively cheaper and more reliable passenger cars and also air travel in the 20th century. The range of movement of people, even those of quite modest means, has extended from a radius of a few kilometres in a lifetime to thousands of kilometres. This in turn has accelerated trade and the exchange of skills, ideas and labour between regions driving the pace of change even faster. Aside from the obvious needs of a growing population, therefore, the demand for transport and the energy it requires is intimately linked both with the economy, on the level of its need to move people and goods, and on the level that a growing economy facilitates private travel.

In many countries, the considerable infrastructure required for a multi-modal transport system is taken for granted as a feature of daily life and yet as populations and economies grow the demands on this infrastructure, its extent and complexity, all grow too. This places increasing stress on infrastructure planning and drives the necessity for ever improved projections of the future demand for transport and the energy required to meet that demand. This paper describes the development of projections of demand for transport in South Africa. The projections were made by deploying a number of modeling strategies to capture the many economic and engineering interactions in the transport sector.

Introduction

It seems sensible that growth in population and the economy drive demand for transport. To gain an overall perspective of the relationship between population, the economy and demand for transport historical data for economic growth, population growth, growth in the vehicle parc and growth in vehicles sales for South Africa was compared (as shown below in Figure 12). It would seem that the number of registered vehicles has tracked GDP more closely than population and that the growth in registered vehicles and GDP at around 3–4% annualized has outstripped population growth at around 1.2–1.5% annualised. Given that the vehicle parc is dominated by passenger cars, this suggests that a greater proportion of people are shifting to this mode for their transport needs. Vehicle sales, not being such an aggregate variable, are of course more volatile than population and GDP and show a high sensitivity to small percentage changes in GDP, although these small changes inevitably represent large amounts of money. The vehicle parc still grows when sales are depressed, albeit more slowly, suggesting that in some periods consumers keep their cars for longer, slowing the rate at which cars move down the chain of the secondhand market, thus causing the vehicle parc to age.

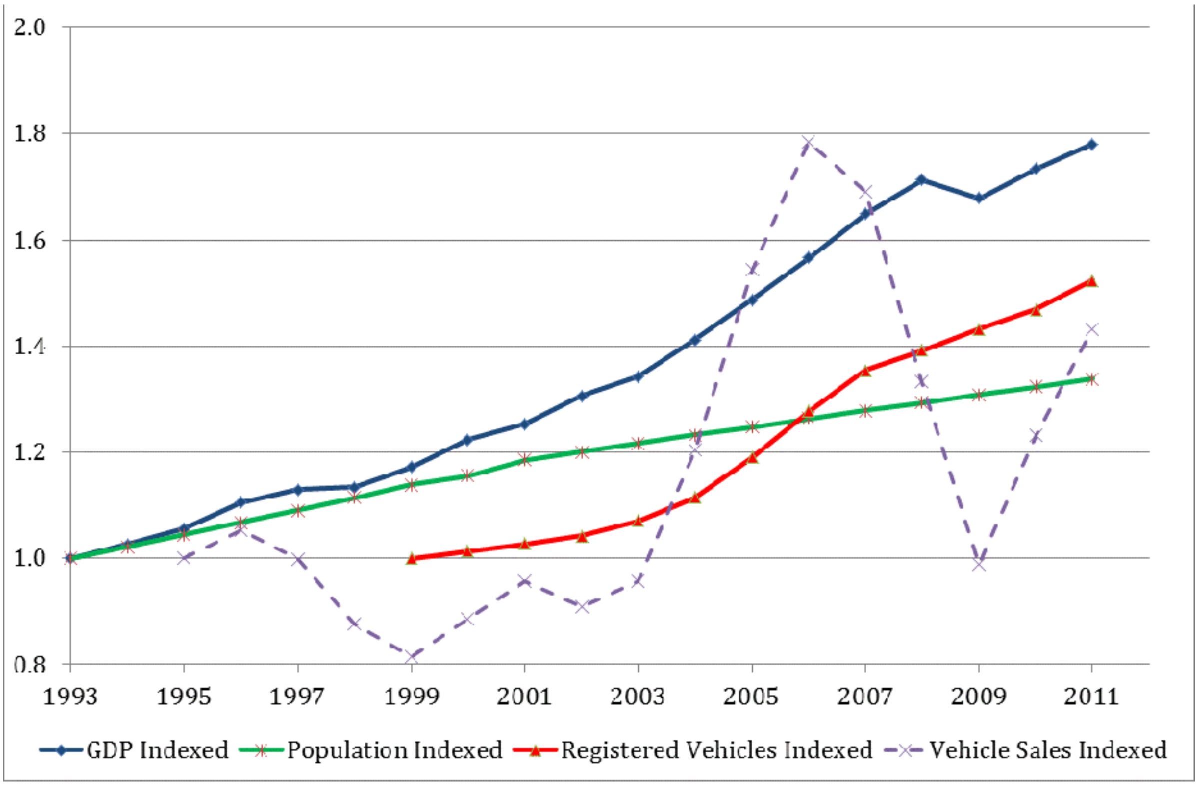

Figure 12: Historical trends in the drivers of the demand for transport in South Africa

The energy demand of the growing pool of registered vehicles is driven by two factors: the distance travelled by vehicles and their energy conversion efficiency. The distance travelled is in turn driven by the needs of society and the economy to move people and goods around. Conversion efficiency depends mostly on the underlying technology, i.e. type of vehicle, fuel and vintage that makes up the vehicle parc and to some degree the patterns of utilisation of that technology. It is useful to treat passenger transport and freight transport separately, as the need for mobility by people and goods have slightly different drivers and technologies. On the other hand, while private travel is evidently growing, South Africa's light vehicle motorisation is only around 160 vehicles/1000 persons (and around 180 vehicles/1000 persons for all private vehicles) – clearly many people do not have access to a private vehicle and use public transport or walk.

From this brief analysis it is evident that if we were to model the future energy demand for transport we would need to broadly do the following:

- Profile the current vehicle parc by its technology types and activity levels.
- Profile the current population by their use of private and public transport probably within typical income groups.
- Assume a population growth rate.
- Project economic growth and its impact on household income and link this to changes in the use of private and public transport.
- Make assumptions about the future energy conversion efficiencies of the vehicles that will be used for private and public transport.
- Make assumptions about the future activity patterns of vehicles, for instance lower speeds due to congestion or higher mileages due to larger conurbations.

The first of these was tackled by the development of an extensive vehicle parc model described in detail in the first section of this report. The vehicle parc model is briefly outlined again in the Methodology section of this paper. The paper goes on to describe the development of a time budget model model which is used to populate scenarios with the goal of answering the following questions spanning a period to 2050:

1. What are the future trends in demand for road, rail and air passenger transportation in South Africa, with a focus on road transportation?
2. What are the future trends in demand for road and rail freight transportation in South Africa?
3. What is the resulting demand for liquid fuels in South Africa up to 2050?
4. What are the CO_2 emissions associated with this demand?

Modelling future demand for liquid fuels by the transport sector lends itself to scenario analysis given the many assumptions required and the great number of permutations which are possible. This study presents the results of one scenario and a base case in order to demonstrate the versatility of the methodology. Future work will extend the scenario analysis.

Factors affecting the growth in demand for energy in the transport sector

The last century has seen exceptionally rapid growth in the human population and its demand for resources, particularly energy. It might be argued that this rate of change results from the availability of cheap and accessible energy. Clearly, predicting future consumption patterns, particularly in the context of climate change and the diminishing abundance of oil, is a very challenging task. In building up the components of a model, the developer will typically look for patterns or consistencies in the behaviour of the critical aspects of the system to which the outcomes are most sensitive. Aspects of transport systems investigated in the development of this model include:

- the evolution of the number of vehicles per capita, called motorization (vehicles/1000 people) with changing income per capita;
- the total time people spend travelling per day, called the Travel Time Budget (TTB); and
- the future improvement of the energy conversion efficiency of vehicles, which we shall term fuel economy, due to technological change, environmental regulations and possible sharp increases in oil price. It should be borne in mind that large improvements in fuel

economy are possible with current technology by manufacturing smaller and less powerful cars.

Clearly, future energy demand will be highly dependent on the number of vehicles, how much they are driven and their energy conversion efficiencies and as such selected literature dealing with the system variables above are discussed in the following section.

Motorisation

The relationship between motorisation (vehicles per 1000 population), particularly passenger car motorisation, and GDP/capita is well documented. In general motorisation increases more or less linearly with GDP/capita until saturating and is thus usually modelled with the s-shaped Gompertz curve, an example of which is shown below fitted to the historical motorization and per-capita income data for some developed economies (Dargay, Gately, & Sommer, 2007).

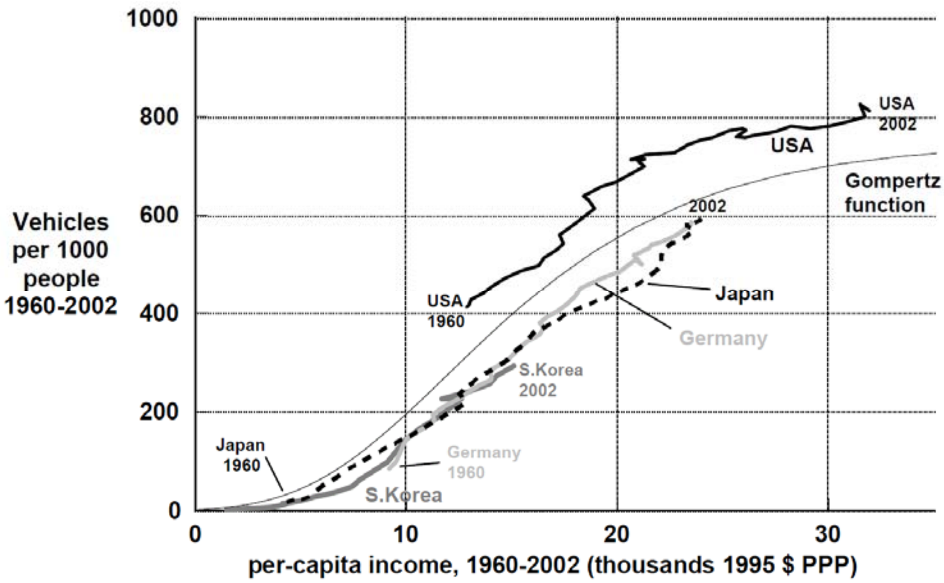

Figure 13: Gompertz Curve model of the correlation of motorisation with income per capita
Dargay et al. (2007)

The curve takes the following form.

If:
V = motorisation in vehicles / 1000 people
GDP = GDP/Capita
α = a constant
β = a constant that determines the per capita income level where saturation occurs.
ϒ = a constant that reflects the level at which motorization will saturate

Then:

$$V = \Upsilon \times e^{\alpha e^{(\beta \times GDP)}} \qquad \textbf{...(Eq. 4)}$$

A study using the Gompertz approach for vehicle parc projections (Dargay, Gately, & Sommer, 2007) pooled an extensive dataset from 45 countries representing 75% of the world's population to derive constants for the Gompertz curve in Equation 1 above for major current and future vehicle markets. They found a good fit to their data set by varying β and fixing the other constants with a fixed value of ϒ being set to 852 but adjusted by a factor dependent on population density and rate of urbanization. The goal of the study was to estimate world motorisation in 2030 but country data, including that for South Africa was also published which is presented below compared to selected results for other countries.

Table 14: Selected study results of a Gompertz Curve model projection of world motorisation in 2030
Dargay et al. (2007)

	Motorisation (vehicles/1000 pers.)			Total vehicles (millions)			Population (millions)			Income /capita (thou. 1995 $ PPP)
Country	**2002**	**2030**	**Growth pa (%)**	**2002**	**2030**	**Growth pa (%)**	**2002**	**2030**	**Annual growth (%)**	**Growth pa (%)**
United States	812	849	0.2	234	314	1.1	288	370	0.9	2.1
Germany	586	705	0.7	48.3	57.5	0.6	83	82	0.0	1.7
Australia	632	772	0.7	12.5	18.4	1.4	20	24	0.7	2.3
Brazil	121	377	4.1	20.8	83.7	5.1	171	222	0.9	2.9
Egypt	38	142	4.9	2.5	15.5	6.7	68	109	1.7	2.3
South Africa	***152***	***395***	***3.5***	***6.9***	***16.7***	***3.2***	***45***	***42***	***-0.3***	***2.7***
China	16	269	10.6	20.5	390	11.1	1285	1451	0.4	4.8
India	17	110	7.0	17.4	156	8.1	1051	1417	1.1	3.5
Total World	130	254	1.6	812	2080	3.4	6237	8199	1.0	1.7

Of the selected countries, only South Africa was modelled as having a negative population growth rate, an outcome that now seems highly unlikely considering the population has since grown to exceed 50 million. If our recent historical population growth rate of 1.2% were to persist till 2030, the resulting population would be nearly 63 million. The motorisation predicted by this model would return a vehicle population of 24.8 million vehicles, implying an annual growth rate of vehicles of 4.7% per annum. By comparison the average annualised growth rate in registered vehicles in South Africa between 1999 and 2010 was 3.6%.

We have seen that historically, as societies become wealthier they acquire more vehicles, mostly passenger cars until households are either almost completely motorized which saturates growth. This saturation level tends to be lower for more densely populated areas.

The daily travel time budget

Time-use and travel surveys from numerous cities and countries throughout the world suggest that the travel time budget is on average approximately 1.1 h per person per day across the spectrum of per capita income (Schafer & Victor, The Future Mobility of the World Population, 2000).

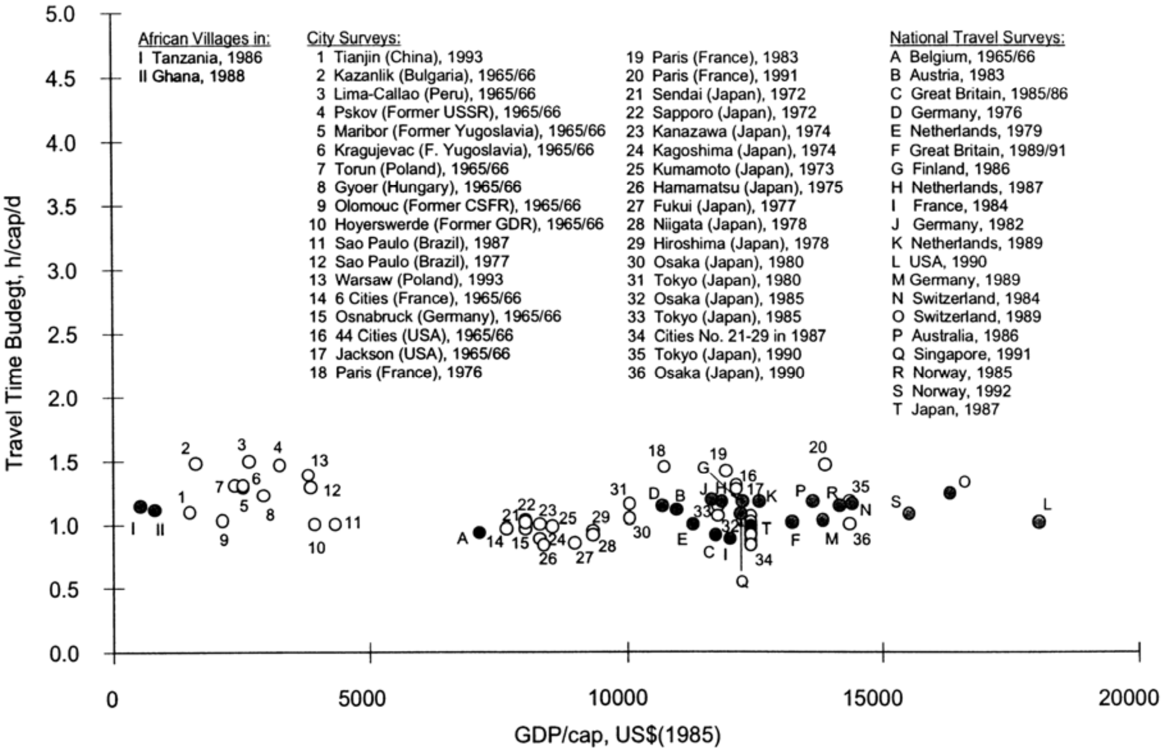

Figure 14: Average per-capita travel budget for various localities and regions across the GDP spectrum
Schafer & Victor (2000)

South African cities are not notably dense, and the poor tend to live in satellite 'townships' far from employment nodes, which suggests that the travel time budget in South Africa may be different. Victor and Schafer however argue that the share of travellers to total population tends to be lower in low-income groups and therefore the time budget when converted to an average per person in the population is similar to high-income groups. This has been eloquently expressed by Schafer as follows (Schafer, 2006):

> Although the amount of time spent traveling is highly variable on an individual level, large groups of people spend about 5 percent of their daily time traveling….. On average, residents in African villages, the Palestinian Territories, and the suburbs of Lima spend between 60 and 90 minutes per day traveling, the same as for people living in the automobile dependent societies of Japan, Western Europe, and the United States.

Schafer and Victor raise the caveat that the stability of average travel time budget holds only for travel by all modes and that time spent in motorised modes rises with income and mobility as people shift from slow non-motorised modes to motorised travel. As this shift tends to completion, however, total motorised travel approaches 1.1 hours. Thus an analysis across income groups must consider that at the lower income end the time budget will include some non-motorized transport, walking for instance which would be less, at the upper income end of the scale but for a large population the average time budget for all income groups will be around 1.1 hours.

Future improvements in vehicle fuel economy

Average vehicle fuel economy is a factor of several variables, as vehicles age the efficiency decreases, but the fuel economy of new vehicles has in recent years tended to improve over time, as shown in the table below.

Table 15: Improvements in passenger car fuel economy in world markets 2000–2010

	ICCT (2011)		Cuenot & Fulton (2011) (International Energy Agency)	
Country	**Period**	**Annual fuel economy improvement**	**Period**	**Annual fuel economy improvement**
US	2000–2010	1.60%	2005–2008	1.90%
Canada	2000–2008	1.28%	–	-
EU	2000–2010	1.90%	2005–2008	1.90%
Japan	2000–2009	2.81%	2005–2008	2.20%
South Africa	-	-	2005–2008	0.40%

This is the result not only of technology becoming more efficient but also because regulation is reducing vehicle mass and engine capacity. The 2008 European Impro-Car project (Nemry, Leduc, Mongelli, & Uihlein, 2008) indicated that fuel economy improvements of 7% (they quote CO_2 emission reductions) could be attained by a 12% vehicle mass reduction and improvements of 18% for a 30% vehicle mass reduction. Aggressive reduction of engine capacity by 30% but maintaining power by turbocharging was expected to reduce fuel economy by 7% for diesel cars and 12% for gasoline passenger cars. These two measures combined could therefore account for a 1% annualized improvement for about 20 years for gasoline cars. Giving way on engine capacity and power together, conceding performance will offer even greater potential benefits if this were to be driven by legislation.

A Joint Transport Research Centre study (JTRC, 2008) that modelled CO_2 emissions from the world transport fleet using the IEA's MoMo model adopted a 29% fuel economy improvement between 2005 and 2050 as the most likely scenario which equates to a 0.75% annualized improvement. Their model however indicated that for world vehicle fleet CO_2 emissions to stabalise a 56% improvement between 2005 and 2050 would be necessary, which is equivalent to a 1.8% annualized improvement.

For the purposes of a general perspective, a series of hypothetical fuel economy improvements between 2012 and 2050 are tabulated below, showing net and annualised quantities and the end-point in 2050 given a representative fleet fuel economy for gasoline passenger cars in 2012 of 8.6 l/100 km. These are compared to the combined cycle fuel economy for two of the current most efficient small car models, scaled up by 10% to account for the reported difference of the European test cycle with real world fuel economy (Pelkmans & Debal, 2006) (Kwon, 2006).

Table 16: Hypothetical fuel economy improvement scenarios for gasoline passenger cars compared to the current efficient non-hybrid gasoline passenger cars

Annualised fuel economy improvement	Total improvement 2012 – 2050	2012 (l/100km)	2050 (l/100km)
-0.5%	-17%	8.6	7.0
-1.0%	-32%	8.6	5.8
-1.5%	-44%	8.6	4.7
-2.0%	-54%	8.6	3.8
-2.5%	-62%	8.6	3.1
Fiat 500 (1.2 l) + 10%[a]		5.6	?
Kia Rio (1.2 l) + 10%[b]		5.9	?
a: (Fiat, 2012)			
b: (Kia, 2012)			

The South African vehicle parc is dominated by models from Europe and Japan, so given the data for those markets shown in Table 6 above we might expect a higher annual improvement than the low value of 0.4% for the short period reviewed by the IEA. This may reflect a slower rate of scrapping and a preference for larger vehicles in South Africa. It was decided that 1% was a reasonable historical improvement for the calibration of the vehicle parc model in the absence of local reliable data. This assumption is also supported by a British study (Kwon, 2006), which suggests that new passenger vehicles and light commercial vehicles had an improved vehicle efficiency of 0.9% per annum between 1979 and 2000 in Britain, a much longer period than the period coved by the studies reviewed above.

It was similarly decided that a future sustained annualised improvement of 1% in fuel economy for existing technology types was a reasonable base case. As shown by Table 16 this is feasible with current technology for gasoline non-hybrids given a complete shift in consumer preference to small cars. A 2% annualised improvement seems far more challenging but plausible and so this was deemed an appropriate rate for a high efficiency improvement scenario.

Overall research methodology

The future energy demand of the transport sector was calculated in terms of services performed ("useful" energy) as opposed to amount of energy supplied ("final" energy). This allows analysis of the substitution between alternative energy forms, as well as an appraisal of the evolution of the technological improvements in vehicles.

A baseline for transport energy services was established with a carefully calibrated vehicle parc model. This provided a good foundation from which to project future fuel demand by the transport sector when augmented with the following key assumptions:

- Projected total passenger and commercial vehicle sales.
- The percentage of different technology types within those sales. In the case of passenger vehicles these would include gasoline, diesel, hybrid gasoline, hybrid diesel, natural gas, fuel cell and electric vehicles.
- The projected fuel economy of the technology types.
- The evolution of annual vehicle km travelled due to growing cities and possibly growing affluence.

The base year technology penetration rates, fuel economies and vehicle mileages were validated outputs from a vehicle parc model. The following two steps were then used to project energy demand:

1. Using household income, population and GDP demand for mobility is projected for different modes and transport classes.
2. Given projected demand for mobility for each mode, a mix of technologies is established to meet this demand, based on techno-economic criteria.

Once the number of vehicles of each technology type, their fuel economy and activity level have been estimated, the calculation of energy demand is relatively trivial. There are 5 sub-models that interact to produce projected energy demand:

1. A vehicle parc model.
2. A time budget model used to calculate passenger travel demand.
3. A computable general equilibrium model used to determine the evolution of household income .
4. A freight demand model.
5. A fuel demand model.

These are described in more detail below.

Creating a base case: the vehicle parc model

A vehicle parc model, calibrated over seven years from 2003 to 2009, was developed to provide a comprehensive picture of the baseline vehicle parc, the disaggregation of vehicle classes and technologies and the activity level of those classes and technologies. This model has been described in detail in Section 1 but a brief review here is warranted. Fuel demand was calculated by multiplying the kilometers travelled, the vehicle technology fuel efficiency and the number of vehicles in the vehicle technology segment as shown in the equation below. The technology segment fuel demands were summed to yield the vehicle parc demand and compared to historical fuel sales for calibration purposes.

$$D_{f,k} = \sum_{j=Y1}^{j=k} \sum_{i=1}^{i=C} N_{i,j} \times FC_{i,j} \times VKT_{i,j}$$

...(Eq. 5)

$D_{f,k}$ = Demand for fuel f in year k

$N_{i,j}$ = The number of vehicles in technology segment i with model year j (Y1 being the first model year), where technologies numbered 1 to C all use fuel f.

$FC_{i,j}$ = Estimated fuel consumption for technology segment i with model year j

$VKT_{i,j}$ = Vehicle kilometres travelled per vehicle in technology segment i with model year j

The fuel demand calculation and model calibration process therefore required a number of assumptions to populate the three variables in Equation 1, N the number of vehicles, VKT, their mileage and FC their fuel economy:

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

The assumptions required an extensive review of literature and data sources to estimate plausible initial values. The model was calibrated so that the model's vehicle population matched the vehicle registration database and the model fuel demand matched the fuel sales data for the calibration years. The fuel demand was calibrated to match the known fuel sales data by first getting broad agreement by means of scaling the kilometres travelled per vehicle and then fine tuning the calibration by adjustmenting the fuel economy assumptions. The final step of estimating demand for passenger.km for personal travel and ton.km for freight required assumptions around average vehicle occupancy for passenger modes and load factor for freight modes. The calibrated results for the base year 2006 for passenger modes and freight modes are shown in Table 127 and Table 139. The model passenger modal share is compared to the National Transport Master Plan modeling results for validation purposes.

Table 17: Model generated passenger transport data for South Africa (2006)

	Total Vehicles	**Total veh-km**	**km per veh**	**Occup-ancy**	**Activity**	**Modal Share**	**NATMAP[a] (2005)**
	(1000 veh.)	(billion veh-km)	(000 km)	(pers/veh, %)	(billion p.km)	(%) of p.km	(%) of trips
Public							
Large bus	22.1	0.63	28.5	25	15.7	6	10
MBT	269.3	8.38	31.1	14	117.4	42	40
Train*					13.9[b]	5	8
TOTAL (excl. air)					**147.0**		
Private							
Pass. car	4488.5	73.2	16.3	1.4	102.5	43	40
SUV	498.4	9.7	19.5	1.4	13.6		
M/cycle	266.3	2.22	8.3	1.1	2.4		
TOTAL					**118.6**		
GRAND TOTAL (excl. air)					**265.5**		
GRAND TOTAL					**276.9**		

**: Train and air transport figures are from literature not the model*
a: (DoT, 2009)
b: Intra-city data only for 2006/2007 (Metrorail, 2007) – data for inter-city is not published by the respective vendors
c: 2007 data from The World Bank (Gwilliam, 2011)
d: Author's assumption

Table 18: Base year freight utilisation (2006) estimated from vehicle parc model output

Vehicle type	Annual mileage of a new vehicle	Average annual mileage of stock	Load factor (ton/vehicle)	Vehicle stock (thou. Vehicles)	Freight utilisation (billion ton.km)
Diesel LCV	25 000	19 202	0.5	566.1	5.4
Gasoline LCV	25 000	16 662	0.5	1 070.4	8.9
Diesel MCV	45 000	33 417	2.5	106.2	8.9
Gasoline MCV	25 000	13 575	2.5	7.9	0.3
Diesel HCV	70 500	48 403	15	165.4	120.1
TOTAL					**143.6**

Projecting demand for passenger travel on land: the time budget model

The projection of energy demand for land transport required an exogenous input of future passenger travel, in passenger.km, into the time budget model. The method used to calculate the demand for passenger travel can be summed up as follows:

- Passenger demand for road and rail was modelled for three income groups representing low-, medium- and high-income households. This was done because growth of private transport over low speed public modes is strongly related to household income. The low-income group includes households with income of up to R19 000 per annum (in 2007 rands), the middle-income group includes households with an income between R19000 and R76 800 and the high-income group the remainder.
- Motorisation (car ownership) per capita for each of the income groups was estimated for the base year using survey data (DoT, 2005).
- Assumptions around ratios of public and private transport, average speed and travel time budget were made for each of the income groups and used to calculate their net demand for passenger travel. Due to the sparseness of activity data the model was calibrated to match the vehicle parc model for only two modes, private and public, for the base year of 2006.
- Mobility not met by private transport was assumed to be met by public transport (for example minibus, bus, metrorail, BRT or rapid train) and distributed between modes according to anticipated investment in infrastructure supporting each of the modes.

Population projections under each income group were used to project the travel time budget of each income group in the future. The calculation of travel demand was made as follows where i is one of 3 income groups and j is one of two modes, public or private:

$$PKM = \sum_{i=1}^{i=3}\sum_{j=1}^{j=2} (F_{ij} \times S_j \times T_i \times N_{ij}) \qquad \text{...(Eq. 6)}$$

PKM = Total passenger.km per year
F_{ij} = Fraction of annual time budget spent travelling in motion on mode j by income group i. This excludes time spent walking and waiting to make use of mode j.
S_j = Average speed of mode j
T_i = Travel time budget per person per year for income group i
N_{ij} = Number of people in income group i using mode j

The variable F_{ij} is the fraction of time spent actually travelling and must therefore be adjusted to exclude time spent walking and waiting to make use of the mode as follows:

$$F_{ij} = (1 - F_{w\_ij}) \times F_{T\_ij} \quad \text{...(Eq. 7)}$$

F_{ij} = Fraction of annual time budget spent travelling in motion on mode j by income group i. This excludes time spent walking and waiting to make use of mode j.

F_{w_ij} = Fraction of time spent walking and waiting when using mode j

F_{T_ij} = Total Fraction of annual time budget spent travelling in on mode j by income group i.

N_{ij}, for the private travel mode, which is the number of people with access to a private vehicles in each income group, was estimated based on the National Household Travel Survey undertaken in 2003 (DoT, 2005). The survey found that 75% of households in the high-income group had access to a car but that only 26% of households across all income groups had access to a car. The critical assumptions in Table 19 below are:

- Car ownership/access – the % of people in an income group with access to a car.
- Cars per person with access to a car – the number of cars per person having access to a car.

If we assume these remain constant over the projection period we can estimate the number of cars for each future year as the population in each income group changes over time.

Table 19: Assumptions and checks used to estimate access to private vehicles by income groups – base year (2006)

		Traveller group					
Model variable	**Unit**	**Low-income**	***Middle-income***	**High-income**	**Comp./ gov/car rental**	**Total /avg**	**Calib. check**
Annual income (percentile)	(%)	50%	30%	20%			
Population	million	23.44	14.06	9.37		46.88	
Car ownership/access	***% of pers***	***7%***	***23%***	***78%*** [a]		***26%***	***26%*** [b]
Cars per person with access to car	***cars/pers***	***0.25***	***0.30***	***0.40***			
Calculated total cars	m veh	0.41	0.96	2.94	0.68	4.987	4.987 [c]
M/cycle ownership	% of pers	0.1%	0.4%	1.4%			
Total m/cycles	m veh	0.03	0.06	0.13	0.05	0.27	0.27 [c]
Persons with access to a private vehicle		7%	23%	79%			
Private vehicles/person with access to vehicle	veh/pers	0.25	0.31	0.41			
Persons with access to a private vehicle	million pers.	**1.67**	**3.24**	**7.44**			
Persons without access to a private vehicle	million pers.	**21.77**	**10.82**	**1.94**			

a: The NHTS (DoT, 2005)*had 5 income categories rather than the 3 of this study. The 2 highest together accounted for just over the 20th percentile of the population of households and had an average access rate to a car of 75% which has been increased slightly to take account of the lapse of 3 years since the study.*

b: NHTS (DoT, 2005)

c: Fleet size of the Vehicle Parc Model. See Table 12 above.

There is a sparsity of data which shows representative average speeds of traffic on South African roads. Clearly local circumstances as regards congestion and road type are enormously variable, and establiishing average speeds on all roads would be an immense undertaking. In a study which developed a speed based emission inventory model for the City of Johannesburg Goyns (2008) sampled the speed of thirty vehicles for a total of 716 hours covering 29 587 km in 2006/2007. The results indicated an average trip duration of 17 minutes, an average trip distance of 11.5 km and an average speed of 41 km/h (Goyns, 2008). The time budget model was, however, as one would expect, very sensitive to average speed and the speeds measured by Goyns did not allow for a time budget as high as 1.1 hours. A compromise was made by assuming the average speed $S_{private}$ of private transport to be 34 km/h, the average speed of the NEDC emissions test cycle (Dieselnet, 2000) used in Europe which is meant to be representative of urban driving including a portion of highway driving.

Table 20: Total distance, time and speed for the new European drive cycle

Phase	**Distance**	**Time**	**Average Speed (km/h)**
	(km)	[sec]	
1 (ECE 15)	4.052	780	18.7
2 (EUDC)	6.955	400	62.6
NEDC: ECE15 + EUDC	11.007	1180	**33.6**

The speed of public transport S_{public} was assumed to be significantly lower at 20 km/h. Thus to calibrate the time budget model, F_{ij} the fraction of the annual time budget spent on mode j by income group i was varied until the passenger travel demand and total vehicle km for each mode matched that of the vehicle parc model. Table 21 presents the estimates of the variables for Equation 3 and Equation 4. A good calibration was attained for reasonable values of F given our assumptions for time budget T and average speed S. It may well be that average speeds in South Africa are higher and that for the time being the time budget of private travelers in particular is moderately less than 1.1 hours per day but it is proposed that a calibrated time budget model with at least plausible estimates for the variables will give a better estimate of future passenger.km than simple extrapolation of demand into the future.

Table 21: Time budget model assumptions for calculating passenger travel demand for public and private modes

Variable	Traveller group				Total	Calib. check
	Low-income	Middle-income	High-income	Comp./ gov/car rental		
1. All modes						
T_i (hours/day/person)[b]	1.1	1.1	1.1			
Annual travel days[c]	300	300	300			
T_i (hours/year/person)	330.00	330.00	330.00			
2. Public – no access to car						
F_{w_ij} [d]	42%	42%	42%			
F_{T_ij}	100%	100%	100%			
F_{ij}	58%	58%	58%			
S_j (km/h)	20	20	20			
N_i (10^6 persons)[e]	21.77	10.82	1.94			
PKM_{ij} (10^9 p.km)	83.34	41.42	7.41		132.17	
3. Public – access to car						
F_{w_ij} [d]	42%	42%	42%			
F_{T_ij}	75%	48%	11%			
F_{ij}	44%	28%	6%			
S_j (km/h)	20	20	20			
N_i (10^6 persons)[e]	1.67	3.24	7.44			
PKM_{ij} (10^9 p.km)	4.79	5.96	3.13		13.9	
Total public PKM (10^9 p.km)	**88.13**	**47.38**	**10.54**		**146.1**	**147.0[a]**
4. Private						
F_{w_ij}	0.00	0.00	0.00			
F_{T_ij} [d]	25%	52%	89%			
F_{ij}	25%	52%	89%			
S_j (km/h)	34	34	34			
N_i (10^6 persons)[e]	1.67	3.24	7.44			
PKM_{ij} (10^9 p.km)	4.6830	18.92	74.26	18.87[f]	116.7	118.6[a]
Total PKM (10^9 p.km)	**92.81**	**66.30**	**84.80**	**18.87**	**262.8**	**265.5[a]**

a: p.km output of the Vehicle Parc Model for 2006. See Table 12 above.
b: See (Schafer & Victor, The Future Mobility of the World Population, 2000)
c: Author's assumption
d: Author's assumption adjusted so that time budget model calibrates to vehicle parc model for 2006
e: See Table 19 above for the estimate of these numbers
f: Estimated from the number of these vehicles in Table 12 and fixed assumptions of 18,000 km annual mileage and occupancy of 1.4 persons/vehicle

To summarise: the time budget model allowed us to generate passenger travel demand for each year of the projection from exogenous values of future population and income. Essentially the premise of the model is that private vehicle passenger demand will increase not only with population growth but also as the proportion of the population in the middle and higher income groups increases. The rate of increase will saturate if the high income group becomes dominant. The time budget model also affords the flexibility to investigate scenarios such as:

- a scenario of reduced average speeds due to congestion;
- a scenario of higher public transport speed due to implementation of brt and high speed rail;
- time budgets specific to income groups; and
- a scenario of public mode walking and waiting time.

While this sub-model could arguably be more disaggregated it is appropriate to local data availability and is a great improvement on the assumption of simple linear growth of passenger travel demand with population growth that underpins many projections of transport energy demand.

Projection of income group splits – the computable general equilibrium model

Computable general equilibrium (CGE) models have been used for policy analysis in many countries including South Africa. The premise of these models is to simulate the functioning of a market economy by modeling the interactions of producers across all sectors, households, government and the rest of the world through prices and capital flows. Their general application is to assess the impacts of a policy or project that affects the output or cost of one good or service on the economy as a whole, across all these sectors.

A CGE model for South Africa has been developed to study the economic implications of introducing carbon taxes in South Africa for the purpose of greenhouse gas emissions mitigation (Alton, et al., 2012). Our study used this CGE model to estimate the probable future evolution of household income in South Africa, for the 3 income groups used by the travel time budget model, given a moderate and stable GDP growth of 3.9% between 2010 and 2025.

The CGE base case required a number of assumptions regarding the future South African economy including, for instance the effects of technical changes, skilled labour supply growth, labour market rigidities and growth in public sector consumption which are described in detail in Alton, et al (2012). The authors however sum up the general outcomes of their base case as follows:

> Total labour employment grows at 2.6 per cent per year, implying an employment growth elasticity of 0.67 and a gradual decline in the national unemployment rate (given annual population growth of 1.5 per cent). GDP growth is fairly even across sectors as a result of uniform productivity growth and mobile labour. Overall, the baseline scenario provides a reasonable economic trajectory for South Africa.

The CGE model's time horizon extended only to 2030, so it was necessary to extrapolate the trend in population change in income groups to 2050. As the CGE model presents results in 14 deciles so it was necessary to map the results to the three groups required for the time budget model. Figure 15 below presents the income group growth projected by the CGE model from 2005 to 2030. Household consumption has been plotted on a log scale because the Rand value of the upper decile is so much higher than the bottom eight deciles. The two income thresholds used to split the population of households into the three groups we need are shown as dashed lines.

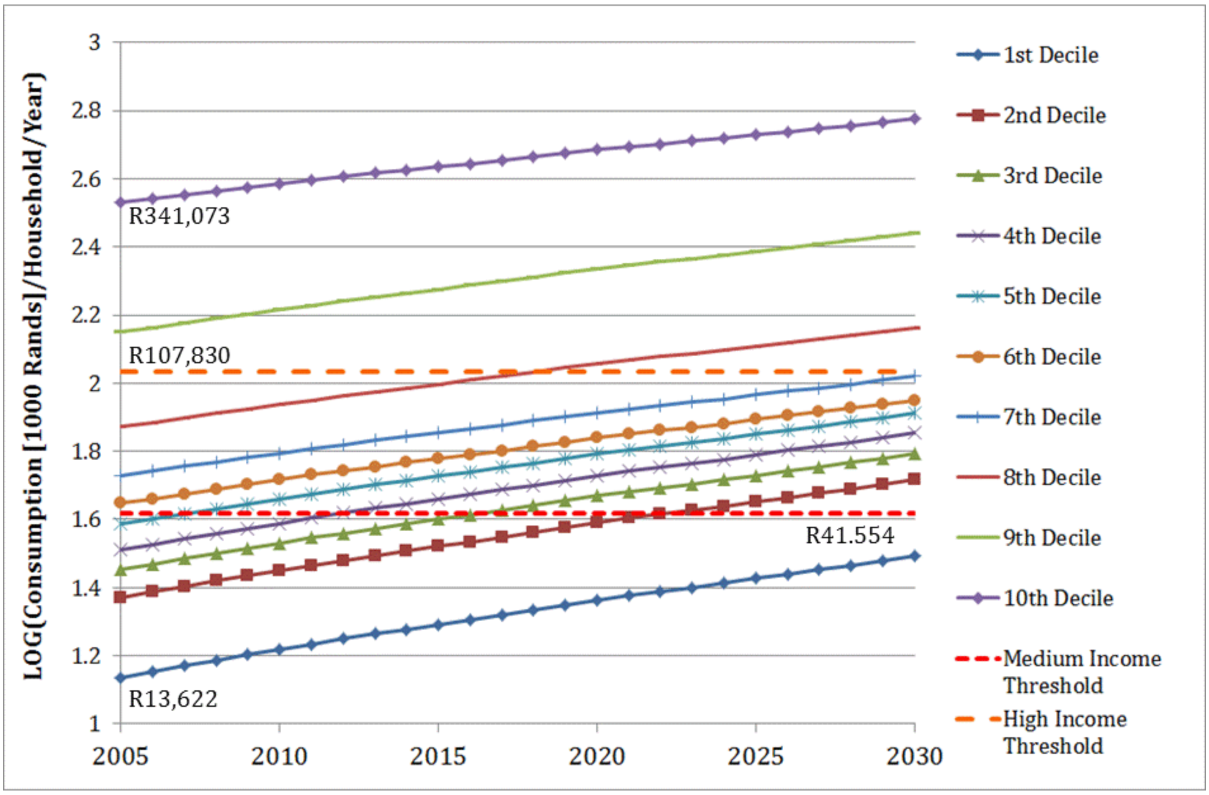

Figure 15: CGE model output for annual household consumption 2005-2030 by deciles of households

Author's calculations using data from Alton et al. (2012)

It is evident from Figure 15 that by 2025 all but the lowest income decile of households will exceed our threshold for the Medium Income Group and that this decile will be on course to exceed it within the following decade. Likewise by 2030 the 7th and 8th household deciles will have transitioned to the high-income group. Little narrowing in relative wealth seems likely but wealth in absolute terms increases with vast numbers of people acquiring more buying power which has important implications for the growth of private travel as modelled by our time budget model.

The household consumption thresholds shown in Figure 15 were set to map the CGE split of households to the the National Household Travel Survey which furnished some of the most critical assumptions in the time budget, specifically those around access to private transport. Table 22 shows the mapping of the five groups in the National Household Travel Survey to the 3 groups in the time budget model and the quintiles in the CGE model. The lower income threshold was therefore set to the average consumption of the 5th and 6th deciles (R41 554) and the upper threshold to the average consumption of the 8th and 9th deciles (R107 830).

Table 22: Mapping of income and expenditure categories for cge modelling results and supporting studies to the three categories of the time budget model

<table>
<tr><th colspan="3">Community survey – 2007[a]</th><th colspan="3">Nhts – 2003[b]</th><th colspan="3">Cge model – 2005[c]</th></tr>
<tr><th>Annual
Income bracket</th><th>Fraction of h/holds (%)</th><th>Three group split</th><th>Annual income bracket</th><th>Fraction of h/holds (%)</th><th>Three group split</th><th>Avg. H/hold cons.</th><th>Fraction of h/holds (%)</th><th>Three group split</th></tr>
<tr><td>No income</td><td>9.1%</td><td rowspan="5">46%</td><td rowspan="2">< R6,000</td><td rowspan="2">24%</td><td rowspan="5">49%</td><td>R 13 662</td><td>10%</td><td rowspan="5">50%</td></tr>
<tr><td>R1-R4 800</td><td>5.5%</td><td>R 23 492</td><td>10%</td></tr>
<tr><td>R4 801-R9 600</td><td>9.9%</td><td rowspan="3">R6,000 – R12,000</td><td rowspan="3">25%</td><td>R 28 384</td><td>10%</td></tr>
<tr><td rowspan="2">R9 601-R19 200</td><td rowspan="2">21.1%</td><td>R 32 426</td><td>10%</td></tr>
<tr><td>R 38 645</td><td>10%</td></tr>
<tr><td>R19 201-R38 400</td><td>21.4%</td><td rowspan="3">34%</td><td rowspan="3">R12,001 - R36,000</td><td rowspan="3">29%</td><td rowspan="3">29%</td><td>R 44 464</td><td>10%</td><td rowspan="3">30%</td></tr>
<tr><td rowspan="2">R38 401-R76 800</td><td rowspan="2">13.0%</td><td>R 53 566</td><td>10%</td></tr>
<tr><td>R 74 354</td><td>10%</td></tr>
<tr><td>R76 801-R153 600</td><td>8.7%</td><td rowspan="6">20%</td><td rowspan="3">R36,000 – R72,000</td><td rowspan="3">11%</td><td rowspan="6">22%</td><td>R 141 306</td><td>10%</td><td rowspan="6">20%</td></tr>
<tr><td>R153 601-R307 200</td><td>6.1%</td><td>R 208 067</td><td>2%</td></tr>
<tr><td>R307 201-R614 400</td><td>3.3%</td><td>R 244 258</td><td>2%</td></tr>
<tr><td>R614 401-R1 228 800</td><td>1.1%</td><td rowspan="3">>R72,000</td><td rowspan="3">11%</td><td>R 292 088</td><td>2%</td></tr>
<tr><td>R1 228 801-R2 457 600</td><td>0.4%</td><td>R 364 406</td><td>2%</td></tr>
<tr><td>R2 457 601 or more</td><td>0.3%</td><td>R 596 546</td><td>2%</td></tr>
<tr><td colspan="9">a: (StatsSA, 2007) – Author's Calculations scaled to take account of non-respondents in sample
b: (DoT, 2005)– Author's Calculations scaled to take account of non-respondents in sample
c: Author's Calculations Using Data from Alton et al., 2012</td></tr>
</table>

Thus in the first year of the CGE model our 3 income groups contain 50%, 30% and 20% of all households but as the consumption of deciles rises in future years and they exceed the fixed threshold of the income group, more households will migrate from the lower to the middle group and from the middle income to the higher income group as shown in Figure 16.

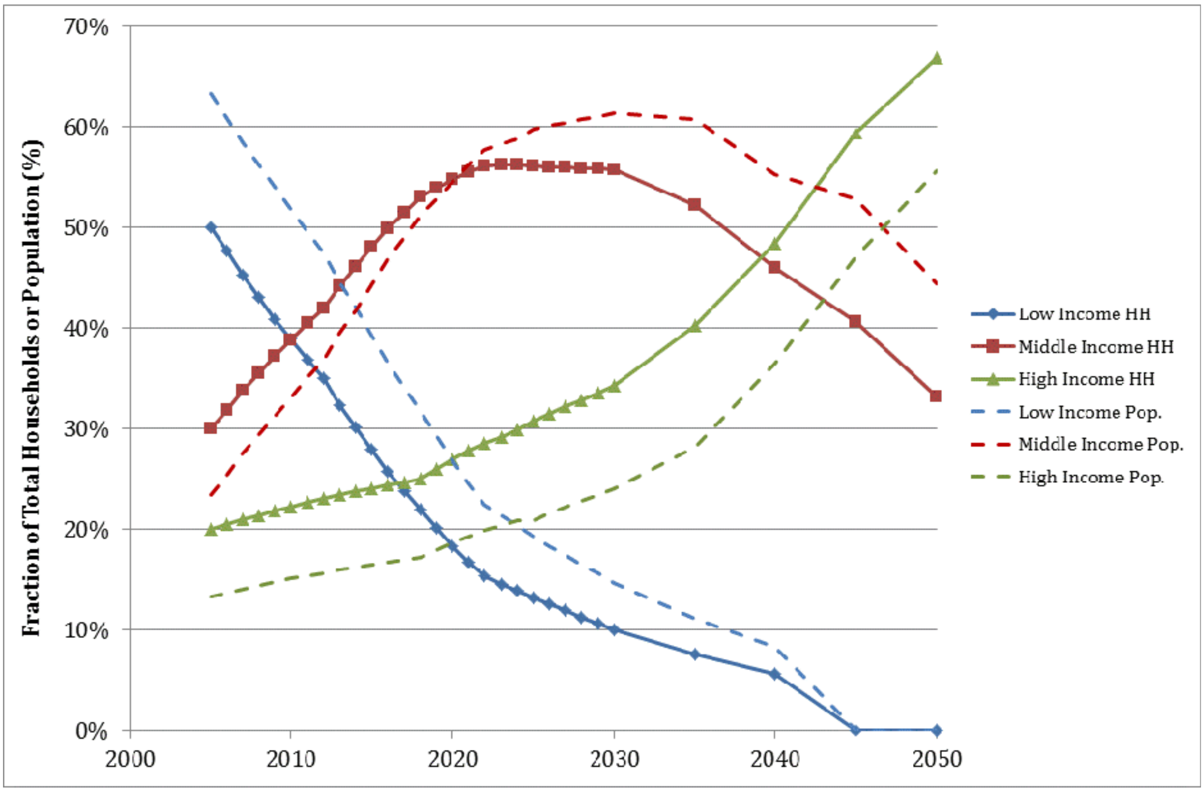

Figure 16: Migration of the south african population between three income groups defined by a fixed threshold as projected by CGE modelling till 2030 and extrapolated to 2050

The household consumption projections therefore indicate that there will be no people left in the lower income group by 2045 and that the high income group will dominate with nearly 70% of households by 2050. Our time budget model requires population not households and therefore conversion of the household fraction into a population fraction is required. This was done using the assumptions for household size of deciles from the StatsSA 2005 Income and Expenditure Survey (StatsSA, 2006). Lower income households are larger so that population leads household fraction for the low income group but lags it for the high income group while the middle income group population fraction transitions from lagging to leading household fraction as the large low income households cross our lower threshold.

Projecting demand for freight on land

The sector GDP projections of the CGE model also formed the basis for the freight model. Clearly as GDP grows the quantity of goods that must be transported grows proportionally and we can model this simplistically as follows:

$$TKM_i = e_i \text{ X } (1 + GR_{GDP})_i \text{ X } TKM_{i-1} \qquad \textit{...(Eq. 8)}$$

Where:

TKM = demand for freight transport in units of ton.km

e_i = the elasticity of freight demand with respect to transport GDP

= (1 + % change in freight demand)/(1 + % change in GDP)

GR_{GDP} = transport GDP growth rate

The sectors relevant to freight demand (transport, mining and iron and steel) were projected to grow as shown in Figure 17 by the CGE model base case until 2030, the CGE projections are extrapolated from 2030 to 2050.

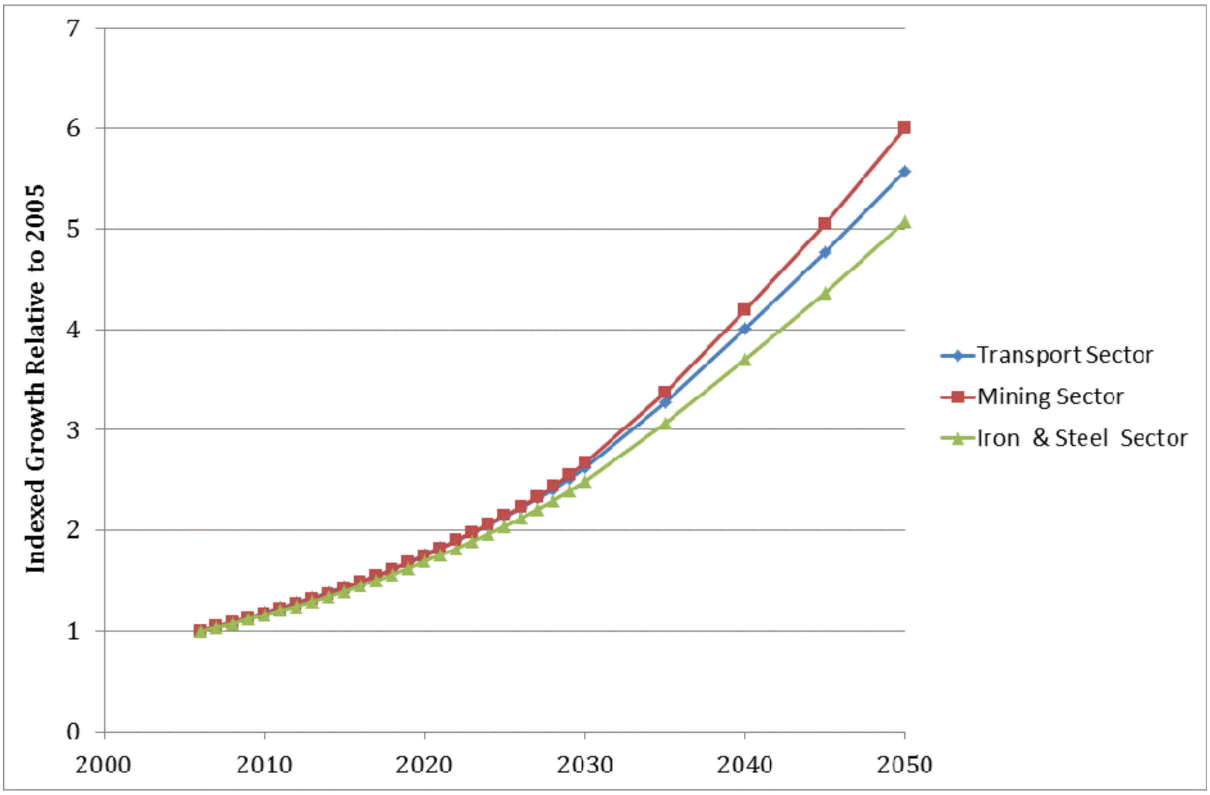

Figure 17: CGE model output for annual household consumption 2005-2030 by deciles of households

Author's calculations using data from Alton et al. (2012)

Their difference in growth is small in the projection window, only diverging after 2030. Therefore transport sector GDP growth was taken as GR_{GDP} for the land freight modes, road and rail.

Data was not available for the elasticity of demand for freight e_i and this was taken as 0.8. This results in a threefold increase in the demand for freight transport between 2005 and 2050. This is an area where future research can contribute to better estimates of growth in freight demand. A particular concern is that a transition to a less energy intensive service economy could translate to a long-run elasticity significantly less than 0.8.

The freight demand for rail in the base year of 2006 was assumed to be that published in the CSIR's State of Logistics Report (Ittmann, King, & Havenga, 2009) disaggregated into corridor, rural, urban and bulk mining freight. This was combined with the road freight demand estimated by the vehicle parc model as shown in Table 13 and the road/rail splits for corridor and for rural/urban freight estimated as shown below. The base case assumed that these remain the same till 2050 and an energy efficient scenario that included a shift back from road to rail could be modeled.

Table 23: Organisation of road and rail freight demand such that the road/rail split can be kept constant for the base case

Mode	Freight 2006 (t.km)	Road / rail split 2006 (%)	Assumed base case road / rail split 2050 (%)
Transport freight by road – LCV	14		
Road vs rail – rural/urban freight#			
Transport freight by road – MCV	9	26%	26%
Transport freight by rail – other	26	74%	74%
Road vs rail – corridor freight#			
Transport freight by road HCV*	120	81%	81%
Transport freight by rail corridor	28	19%	19%
Transport freight – rail export (bulk mining)	67		
Total	**265**		

** In practice a portion of this NAAMSA category are rigid trucks active in urban/rural freight.*

 # The total of road and rail freight is grown with exogenous GDP estimate and then disaggregated by the road/rail split

Social, economic and technological scenario development

Future demand for liquid fuels is determined on the basis of scenarios. The general approach is to setup a base case, reference, or "business as usual" scenario where past and current trends are simply extrapolated over the period of study. In the base case, conversion efficiencies improve at current rates, economic growth trends persist, consumer preferences and habits don't change resulting in unchanged fractional shares of different transport modes and energy prices.

Once the reference case is established, one can develop a multitude of different scenarios to express/explore a range of possible futures, and their consequences, mainly in terms of demand for fuels/energy carriers and associated emissions. Examples of scenarios include: different assumptions about economic growth, urbanisation rates, consumer preferences, improvements in conversion efficiencies, modal shifts, and energy prices that possibly result in demand changes.

There are a large number of possible scenarios but for this study a generalized alternative "high efficiency" scenario was developed to reflect the possible outcome of the following basket of interventions:

- Corridor freight and to a lesser extent rural/urban freight shifts to rail.
- Public transport encouraged through taxing of private vehicles or further subsidy of public transport or both results in lower car ownership.
- Special lanes for higher occupancy vehicles increases average occupancy.
- Higher fuel taxes/prices cause people to drive less.
- More BRT lanes are set up and more high speed Gautrain type trains implemented.
- Taxes are increased on SUV's causing a shift back to cars.
- Improved routes and other incentives for public transport increase vehicle occupancy.
- Vehicle fuel economy improves by 2% per annum instead of 1% per annum for the base case across vehicle types.
- Incentives are put in place for:
    - diesel, hybrid and electric cars;

- diesel and hybrid SUVs;
- diesel and hybrid MBTs;
- electric and CNG BRTs;
- diesel LCVs;
- CNG HCVs.

The proposed effects of these interventions on the underlying assumptions of the model, relative to the reference case are summarized in Table 33, Table 34,Table 35 and Table 36 in the appendix.

Calculation of future energy demand and CO_2 emissions

The calculation of the energy demand is carried out differently for road and rail.

Road vehicles

First a projection for vehicle-km is calculated for each demand using an occupancy (passenger/veh for passenger vehicles) or load factor (tons/veh for freight):

$$Passenger\ VKM_{ti} = \frac{\text{PKM}_{ti}}{O_{ti}} \qquad \textbf{...(Eq. 9a)}$$

$$Freight\ VKM_{ti} = \frac{\text{TKM}_{ti}}{L_{ti}}, \qquad \textbf{...(Eq. 9b)}$$

Where:

VKM_{ti} = vehicle-km projection for demand *i* in year *t*,
PKM_{ti} = passenger-km projection for passenger demand *i* in year *t*,
TKM_{ti} = ton-km projection for freight demand *i* in year *t*,
O_{ti} = vehicle occupancy for passenger demand *i* in year *t*,
L_{ti} = loading for freight demand *i* in year *t*.

Then, each year, the shortfall in vehicle-km capacity for each demand *i* (e.g. private cars) is calculated by taking the difference between the capacity of the vehicle parc for demand *i* in that year and the vehicle-km demand projection for that year, and used to calculate the total vehicle sales for vehicles that year. Since vehicle vintages are tracked, the 'sales' calculation is for the vintage for that year.

$$S_{ti} = \frac{\text{VKM}_{ti} - (\text{P}_{tiv} \times AF_{tiv})}{AF_{ti}} \qquad \textbf{...(Eq. 10)}$$

Where:

S_{ti} = Sales in year t for vehicles vintage t that can meet demand i,
P_{tiv} = Population of vehicles vintage v in year t that can meet demand i (this changes each year as vehicles from the vintage are scrapped),
AF_{tiv} = Average km/year that vehicles vintage v is expected to drive (this decreases as the vehicles get older).

Then shares of the sales for technologies competing for a particular demand are imposed (different ones for different ones for different scenarios) exogenously. Assuming that all technologies for a particular vintage have the same capacity (drive the same number of km per year) and that their capacity will be fully utilized allows us to calculate the fuel used by each technology as follows:

$$F_{tijv} = P_{tijv} \times AF_{tiv} \times E_{tijv} \times 100$$ ***...(Eq. 11)***

Where:

F_{tijv} = Fuel used in year t to meet demand i by technology j, vintage v,
E_{tijv} = Fuel economy (l/100km) for technology j, vintage v, in year t to meet demand i.

The total fuel consumption for each year is calculated simply by summing F across i, j and v. The CO_2 emissions are simply calculated as follows:

$CO_2E_{tf} = F_{tf} \times EF_f$, ***...(Eq. 12)***

Where:

CO_2E_{tf} = the CO_2 emissions from fuel f in year t,
F_{tf} = the total consumption of fuel f in year t,
EF_f = the emission factor for fuel f.

Results

Table 24 shows the evolution of the passenger travel demand that results from the assumptions described in the previous section for the two scenarios considered. It shows that the shift to more public transportation modes in the Alternative case results in a 7% drop in p.km demand by 2030, which further reduces by 13% relative to the Alternative case by 2050. When this is combined with some shifting to rail and vehicle occupancy improvements the drop in passenger vehicle-km is over 20% by 2020 and over 40% by 2050 compared with the Reference case. Figure 18 and Figure 19 show a graphical representation of the same results, where the overall drop in p.km and the mode-shifts that occur are more apparent.

Table 25 shows the evolution of the freight travel demand that results from the assumptions described above. The mode shift measures cause a drop in total vehicle-km of around 3% in 2030 and 5% in 2050. Figure 20 and Figure 21 provide a graphical representation of the same information showing more clearly the impact of the measures on the mode shares for freight.

Table 24: Passenger demand projection

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Annual passenger travel demand projections (bil p-km)**									
Car	114.8	147.0	207.8	281.2	375.4	114.8	133.2	169.7	206.6	244.4
SUV	15.3	19.5	27.6	37.4	49.9	15.3	15.1	17.2	18.4	21.7
Motorbike	2.7	3.5	5.0	6.7	9.0	2.7	3.1	3.9	4.7	5.6
Bus	16.2	17.8	18.5	12.6	5.8	16.2	18.5	19.6	13.1	3.3
Minibus	121.4	133.4	138.6	116.5	90.1	121.4	138.2	146.8	120.8	84.4
BRT	0.0	6.6	17.1	28.4	32.5	0.0	6.6	23.9	59.9	108.7
Rail	14.4	15.8	16.5	16.8	16.9	14.4	16.4	17.5	17.4	18.0
Gautrain	0.0	1.0	1.3	1.7	2.1	0.0	1.0	4.4	12.0	22.9
Total	**284.8**	**344.6**	**432.3**	**501.2**	**581.7**	**284.8**	**332.2**	**402.9**	**452.9**	**509.0**
Variable	**Annual passenger road vehicle-km projections (bil veh-km)**									
Car	82.0	105.0	148.4	200.9	268.2	82.0	92.8	115.4	137.1	158.2
SUV	10.9	14.0	19.7	26.7	35.6	10.9	10.6	11.7	12.2	14.1
Motorbike	2.0	2.5	3.5	4.8	6.4	2.0	2.2	2.7	3.1	3.6
Bus	0.6	0.7	0.7	0.5	0.2	0.6	0.7	0.7	0.5	0.1
Minibus	8.7	9.5	9.9	8.3	6.4	8.7	9.4	9.5	7.5	5.2
BRT	0.0	0.3	0.7	1.1	1.3	0.0	0.3	0.9	2.1	3.8

Table 25: Freight demand projection

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Annual freight demand projections (bil ton-km)**									
Lcv	16	23	31	44	57	16	23	31	44	57
Mcv	10	14	20	28	36	10	14	18	24	30
HCV (corridor)	137	189	261	366	478	137	179	235	314	389
Rail corridor	32	44	61	85	111	32	53	86	138	200
Rail other	30	41	56	79	103	30	42	58	83	110
Rail export	67	76	105	147	212	67	76	105	147	212
Total	**292**	**386**	**534**	**750**	**998**	**292**	**386**	**534**	**750**	**998**
Variable	**Annual road freight vehicle-km projections (bil veh-km)**									
LCV	33	45	62	88	114	33	45	62	88	114
MCV	4	6	8	11	15	4	5	7	10	12
HCV (corridor)	9	13	17	24	32	9	12	16	21	26

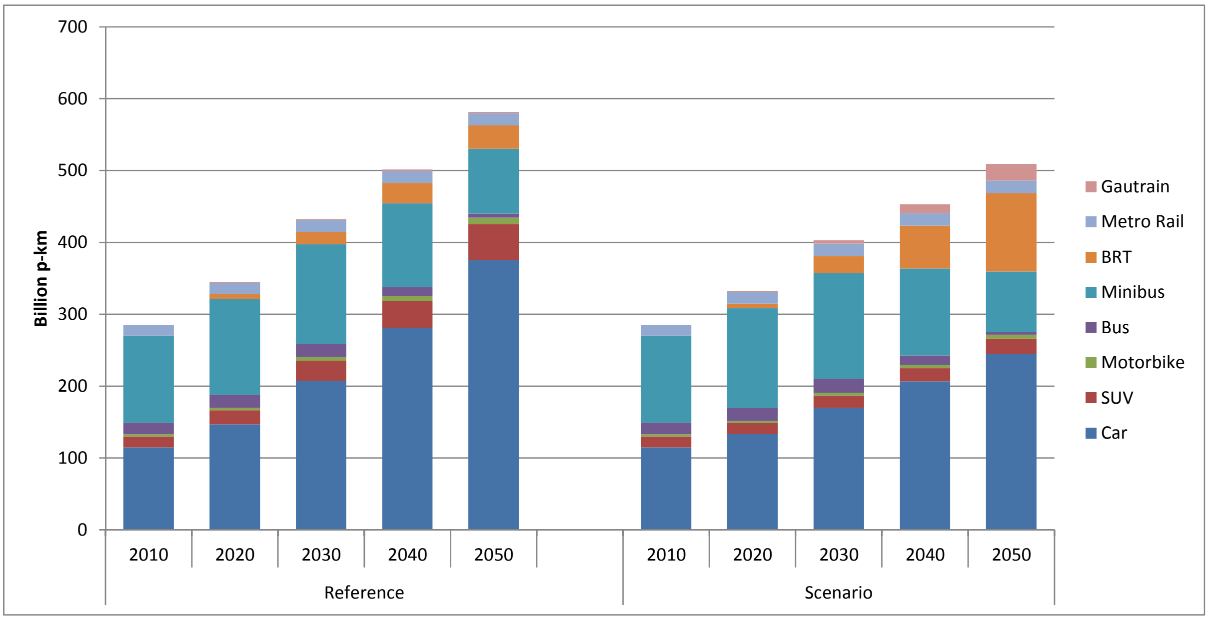

Figure 18: Projection of passenger transport demand (pkm) by mode

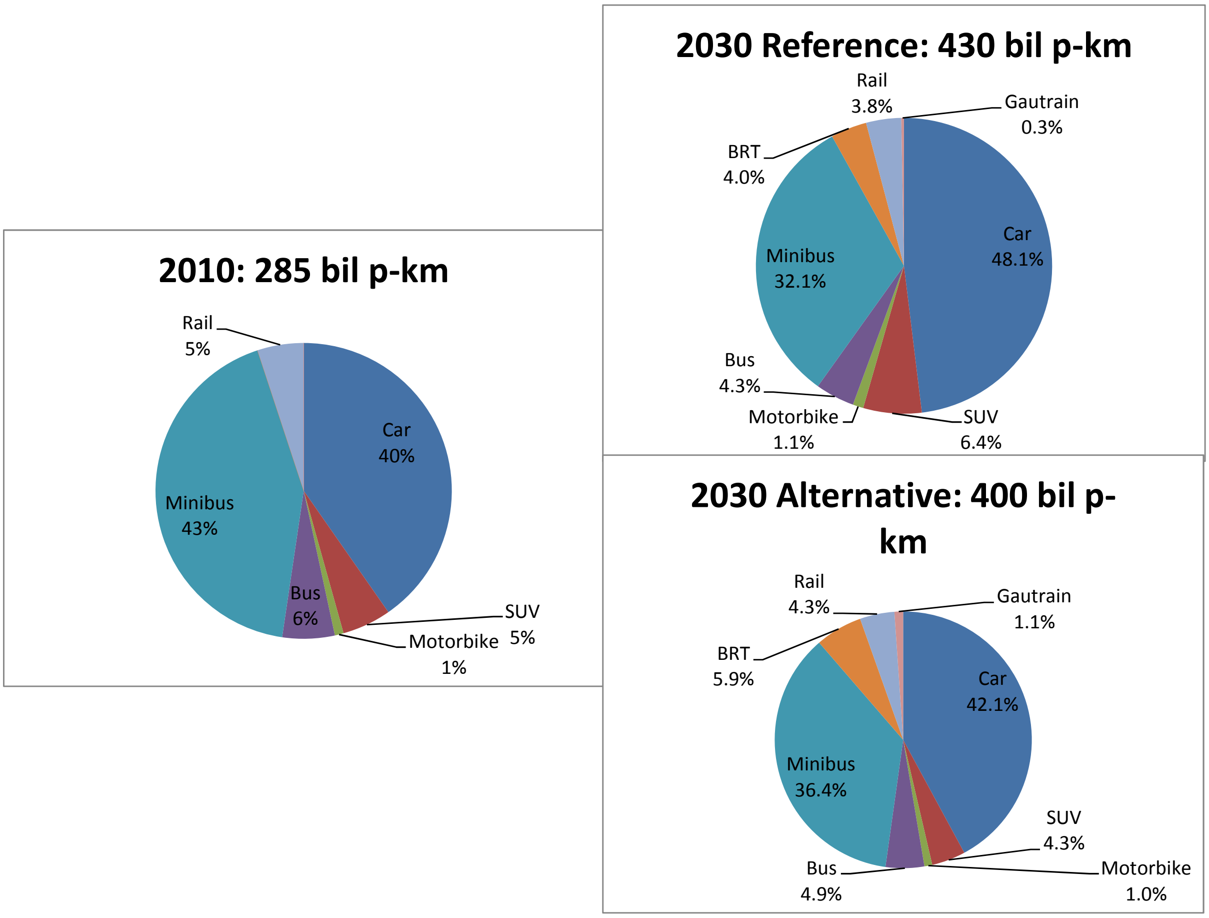

Figure 19: Share of passenger-km

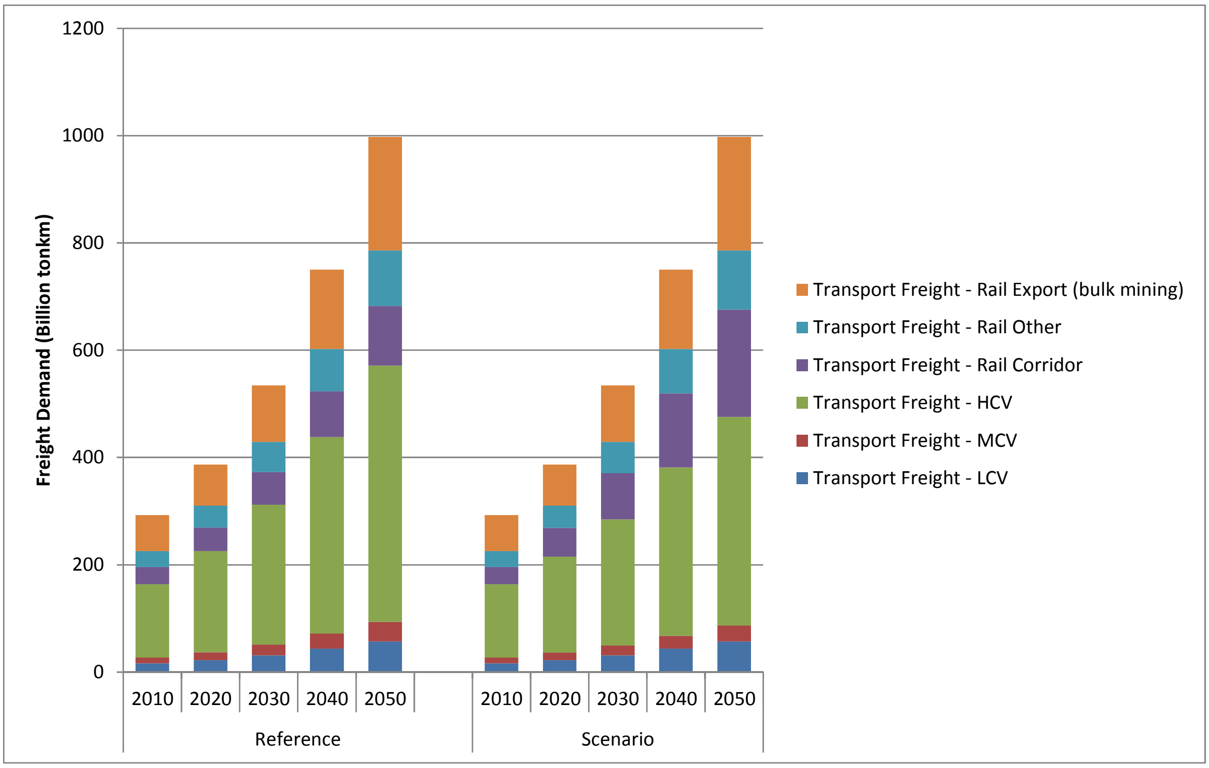

Figure 20: Projection of freight transport demand (pkm) by mode

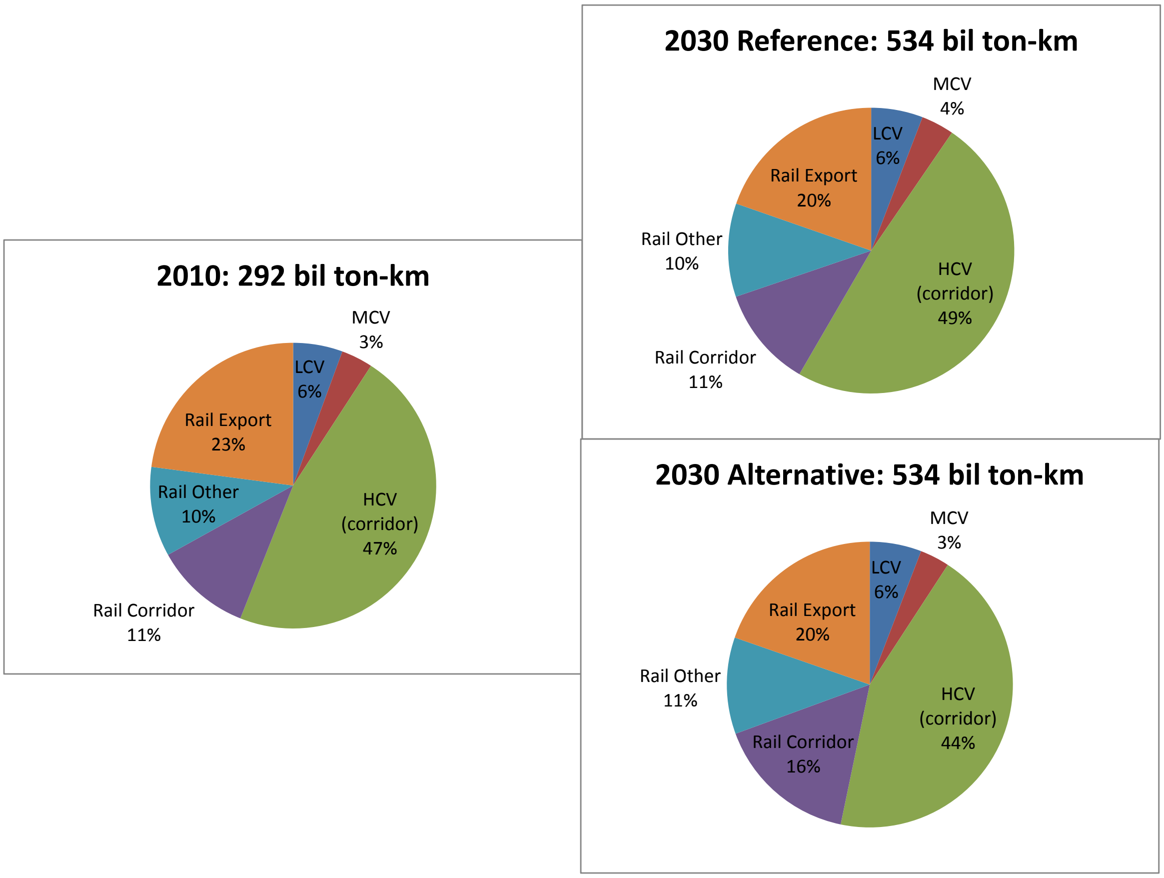

Figure 21: Share of freight ton-km

Table 26 shows the projection of road vehicle sales by mode based on equation 10 which takes into account the difference between the capacity of the parc (where vehicles are scrapped each year) and the p.km or t.km demand. The results show that the annual total vehicle sales would almost reach 1m vehicles by 2030 in the Reference case, whereas in the Alternative case, the 1m annual vehicle sale figure would only be reached in 2050.

Table 26: Vehicle sales projection ('000 vehicles)

	Reference Case					Alternative Case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Car	222	308	743	1008	1352	222	300	597	740	887
SUV	49	35	81	110	144	49	37	44	49	62
Motorbike	10	22	47	64	85	10	20	38	46	55
Minibus	7	13	23	18	13	7	15	21	15	10
Bus	0.5	0.7	1.6	0.8	0.3	0.5	0.7	1.6	0.7	0.2
BRT	0.0	0.5	1.9	3.0	2.9	0.0	0.5	2.6	5.9	10.0
LCV	96	134	327	468	608	96	134	327	468	608
MCV	8	9	21	30	39	8	8	19	26	31
HCV	12	12	30	42	55	12	12	27	36	44
Total	**288**	**379**	**898**	**1203**	**1598**	**288**	**373**	**705**	**857**	**1024**

Table 27 shows the vehicle parc size taking into account the sales of new vehicles and scrapping of older vehicles. It shows that in the Reference case there would be more than 10m cars somewhere between 2030 and 2040, whereas the slower growth in the Alternative case causes this figure to only be reached in 2050. Figure 22 shows a detailed view of the car parc, which shows that the car parc would be dominated by gasoline vehicles in both cases.

Table 27: Vehicle parc ('000 vehicles)

	Reference Case					Alternative Case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Cars	4 955	6 596	8 592	11 240	14 860	4 955	6 017	7 281	8 559	10 046
SUVs	578	782	966	1227	1601	578	627	625	610	704
Motorbikes	250	337	454	606	810	250	305	370	441	524
Minibuses	271	288	277	230	178	271	282	269	208	145
Buses	28.2	30.6	30.9	21.9	10.6	28.2	30.3	29.9	20.0	6.9
BRTs	0.0	8.7	24.3	41.6	50.4	0.0	8.3	29.9	72.8	136.4
LCVs	1864	2592	3366	4513	5821	1864	2592	3366	4513	5821
MCVs	130	188	243	330	430	130	181	221	284	351
HCVs	185	261	338	461	600	185	249	307	396	491
Total	**6 081**	**8 043**	**10 345**	**13 367**	**17 510**	**7 200**	**7 269**	**8 604**	**9 911**	**11 564**

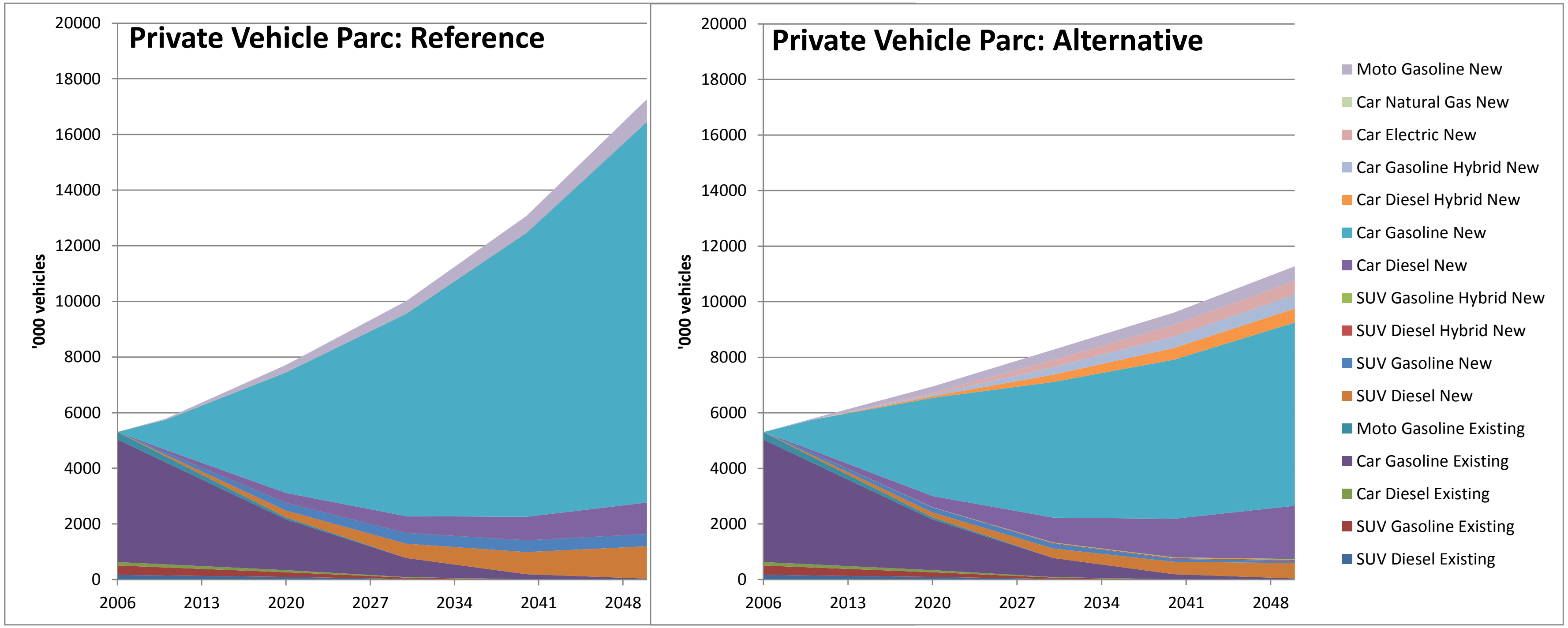

Figure 22: Private vehicle car parc

Table 28 shows the passenger vehicle parc average fuel economy, which takes into account the mix of vehicle vintages and their corresponding fuel economies and annual mileages. It shows that the 2% annual efficiency improvements of the Alternative case helps the gasoline car parc reach an average of 6.2 L/100km by 2040 and 4L/100km by 2050, whereas in the Reference Case, the 1% annual improvement results in a parc average of 7.5 L/100km in 2030 and 6.1L/100km in 2050.

Table 28: Fuel economy for passenger vehicles

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Gasoline cars	9.0	8.4	7.5	6.7	6.1	9.0	7.8	6.2	4.9	4.0
Diesel cars	7.5	7.0	6.2	5.6	5.1	7.5	6.1	4.8	3.9	3.2
Gasoline SUVs	13.4	12.3	10.8	9.7	8.7	13.4	11.9	9.3	6.9	5.4
Diesel SUVs	11.5	10.3	9.0	8.1	7.3	11.5	9.7	7.5	5.9	4.9
Gasoline motos	5.4	4.9	4.4	3.9	3.6	5.4	4.5	3.5	2.9	2.4
Diesel bus	33.9	30.0	26.7	24.0	21.9	33.9	28.6	23.4	19.1	16.0
Diesel MBT	11.3	10.3	9.3	8.4	8.0	11.3	9.2	7.4	6.1	5.5
Gasoline MBT	14.5	12.8	11.2	10.0	9.0	14.5	12.0	9.4	7.5	6.1

Table 29 shows the freight road vehicle parc average fuel economy, which also takes into account the vehicle vintages. Similar trends to what happens in the passenger side are observed on the freight side.

Table 29: Fuel economy for road freight vehicles

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Diesel HCV	39.1	34.8	30.7	27.5	24.8	39.1	32.5	25.5	20.3	16.6
Diesel MCV	28.7	25.4	22.1	19.7	17.9	28.7	23.7	18.4	14.6	11.9
Diesel LCV	11.7	10.4	9.1	8.2	7.4	11.7	9.6	7.4	6.0	4.9
Gasoline LCV	13.9	12.5	11.1	9.9	8.9	13.9	11.6	9.2	7.3	5.9

Table 30 shows the resulting projected fuel sales. Given the above, gasoline is set to grow by 33% by 2030 and 85% by 2050 in the Reference case. In the Alternative case, however, a very different picture arises, where a drop in projected sales of gasoline is observed, dropping by 22% in 2030 and over 35% by 2050. This is driven by the combination of measures, which shift passengers from private to public, road to rail and the incentives put in place on diesel, CNG and electric vehicles. In the Reference case, diesel grows by 57% and 143% in 2030 and 2050 respectively. The growth in the Alternative case is more moderate at 26% and 40% in 2030 and 2050 respectively.

Kerosene (jetfuel) has no measures affecting it, and so remains the same in both scenarios. Electricity consumption grows by 80% by 2030, doubling by 2050 in the Reference gase. In the Alternative gase, there is even higher electricity consumption, with doubling occurring before 2030 and consumption increasing by a factor of 3.25 by 2050. This is mainly driven by the mode shift to rail, which is assumed to be entirely electrified and also a shift of some of the passenger vehicles to electricity. Natural gas displaces some of the diesel in HCVs and BRTs. By 2030, 0.5 billion m^3 (17.3PJ) is consumed, which is roughly 15% of the amount imported from Mozambique in 2010 and this further grows to 1.2 billion m^3 (45PJ) in 2050.

Table 30: Fuel sales

	Reference Case					Alternative Case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Gasoline (bil.litres)	11.9	13.3	15.9	18.8	22.0	11.9	10.8	9.4	8.4	7.5
Diesel (bil.litres)	7.6	9.5	12.0	15.0	17.8	7.6	8.4	9.2	9.9	10.2
Kerosene (bil.litres)	2.5	3.2	4.1	4.4	4.6	2.5	3.2	4.1	4.4	4.6
Electricity (TWh)	4.1	5.5	7.3	10.0	13.0	4.1	6.0	9.0	13.0	17.4
Natural Gas (bil.m3)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.9	1.2

Figure 23 shows more clearly the evolution of the energy consumption by fuel for the transport sector, and the large range between the two scenarios.

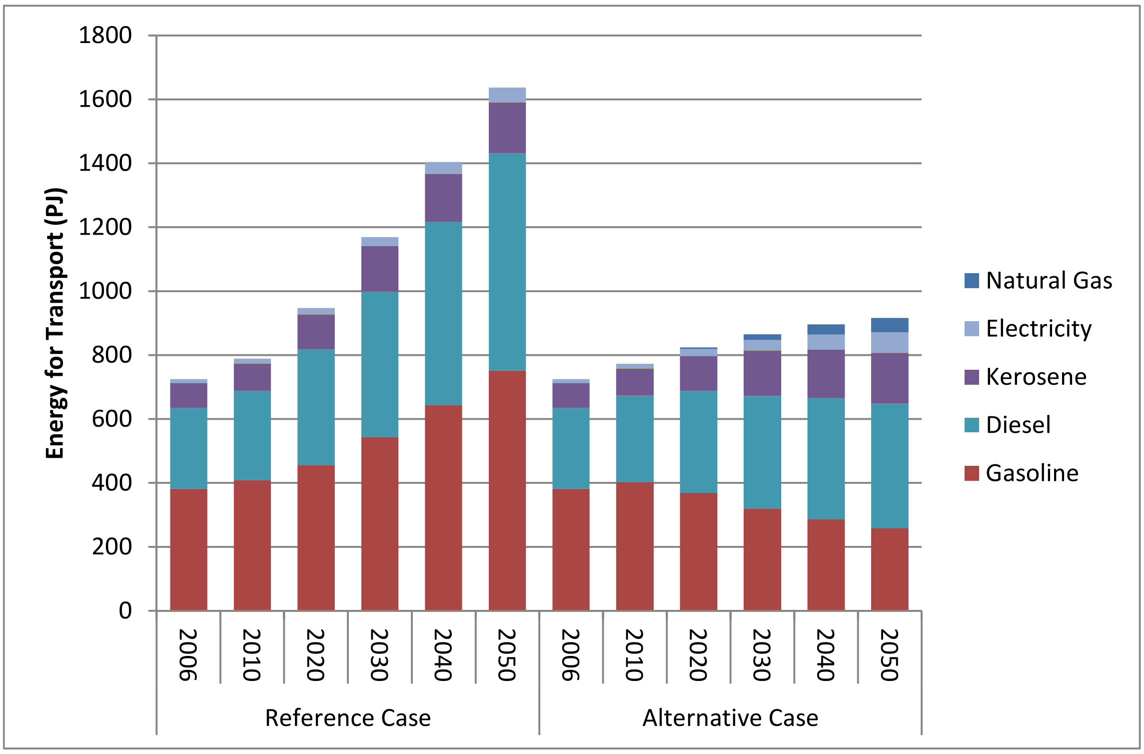

Figure 23: Energy consumption – transport sector

Table 31 shows the resulting CO_2 emissions for private passenger transport, public passenger transport and freight. Note that this is CO_2 emissions at the point of combustion, and that the total CO_2 footprint would be much higher when taking into account upstream emissions, depending on share of CTL in the supply of liquid fuel products.

Table 32 shows the CO_2 intensity for passenger and freight transportation for the two scenarios. In the Reference case, the intensity for passenger transport only drops by 3% and 5% by 2030 and 2050 respectively, despite the 1% annual fuel economy improvements. This is largely because of the higher motorisation rates that are seen. The intensity improvements are much more significant in the Alternative case, at 28% and 47% by 2030 and 2050 respectively. In freight, however, the intensity improvements in the Reference case are more significant (18% and 35% in 2030 and 2050). The improvement is even more significant in the Alternative scenario.

Table 31: CO_2 emissions (Mton CO_2)

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Passenger private	21.2	25.2	31.7	38.5	46.5	21.2	19.8	18.5	17.1	16.1
Passenger public	9.7	11.4	13.8	13.8	13.6	9.7	11.1	13.1	13.1	13.2
Freight	24.2	29.7	36.2	45.5	53.7	24.2	26.5	27.8	30.4	31.5
Total	**55**	**66**	**82**	**98**	**114**	**55**	**57**	**59**	**61**	**61**

Table 32: CO_2 Intensity for transport sector

	Reference Case					Alternative Case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Passenger (kg CO_2/pkm)	108.6	106.2	105.2	104.5	103.4	108.6	92.9	78.6	66.7	57.6
Freight (ton CO_2/tkm)	82.8	76.8	67.7	60.7	53.8	82.8	68.5	52.0	40.5	31.5

Conclusions and proposed future development

The future energy demand of the transport sector was modelled by a Reference case which represents a business as usual outcome with a modestly high growth rate. This was compared to an Alternative case that assumed a number of energy saving policy interventions. These interventions are not implausible even in combination but can be considered optimistic and so the two scenarios can be considered an envelope of future transport sector energy demand, vehicle parc size and emissions. This envelope indicates that:

- Transport energy demand in the case of a business as usual outcome was projected to more than double by 2050.
- It is estimated that this demand will be consumed by a vehicle fleet that has grown to exceed 24 million road vehicles by 2050 from a baseline of 8.2 million in 2010. Of these, over 17 million will be private vehicles excluding LCVs used as private vehicles.
- If a raft of interventions are made however, all of which are conventional policy instruments, it appears possible to constrain the increase in demand to less than 30% with a trend towards stabilisation.
- The vehicle parc in the Alternative scenario was 25% smaller than the reference scenario in 2050 at 18.2 million vehicles of which 11.3 were private vehicles. The difference in vehicle numbers between the scenarios is therefore 98% attributable to fewer private vehicles.
- The large mitigation in energy demand for the Alternative scenario is, however, contingent on European and Japanese vehicle manufacturers maintaining a 2% annualised improvement in fuel economy across vehicle types for the study period and South Africa consistently importing this technology in a similar vehicle mass and engine capacity mix.
- Similarly to the energy demand results, CO_2 emissions from transport were projected to more than double by 2050 for the Reference case but only increase by 11% for the Alternative case.
- The large CO_2 mitigation for the Alternative scenario arises because of the shift to public transport assisted by fuel economy improvements which results in a drop of 24% for private passenger CO_2 emissions between 2010 and 2050.
- The simulated shift from road freight to rail freight and higher fuel economy improvements results in the Alternative case CO_2 emissions for 2050 being 46% lower than for the Reference case in 2050. This accounts for 42% of the total transport sector mitigation in CO_2 emissions assuming the Alternative scenario.

Future developments in modeling in the transport sector should focus on data as well as model development. On the data side, the following is proposed:

- Refinement of estimates of average loading of commercial vehicles, if possible estimating this for each NAAMSA weight category so that a better average loading per vehicle type can be calculated.
- Refinement of the assumptions in the time budget model, including average speed assumptions for travel modes, car access and usage rates in income groups and walking and waiting times for public transport.
- Refinement of the freight model by sub-dividing the NAAMSA HCV Category into rigid trucks active in urban and rural areas and articulated trucks active in corridors. This analysis will make reconciliation with CSIR State of Logistics data easier.

In terms of model development, integrating the fuel or energy demand calculation into the Analytica vehicle parc model would allow easy calculation of both fuel and emissions for a range of different scenarios, and the exploration of uncertainties and probabilities in different scenarios in the vehicle parc model. This would allow the calculation of future transport fuel use for each province which will aid decision making around infrastructure investment. Further disaggregating the higher-income group in the model and adding a link between car ownership and household income would refine the reflection of car ownership within the model and therefore demand for private p.km in the model. Both input data and results would be greatly improved through studies focusing on elasticity of freight demand (ton.km) in relation to transport GDP and overall GDP.

Provincial results would be enhanced through the use of a provincial CGE model (available through UN WIDER) to drive provincial growth, although some effort will be required to calibrate the provincial SAM. The inclusion of freight corridor demand in either a provincial model, or the vehicle parc model would enhance results, particularly relating to infrastructure requirements and opportunities for alternative transport modes to be developed. At the outset it was envisaged that the base year calibrations and scenario projections would be useful for infrastructure development, in terms of supply as well as infrastructure for different transport modes. Having developed the suite of models, a full life cycle costing of infrastructure required for road vs rail should be carried out.

Finally, collaboration between researchers in South Africa working in the transport sector would greatly enhance both base year data and transport sector modeling. For instance, collaboration with the CSIR could help to understand and reconcile the differences between their road freight demand for ton.km and that of the vehicle parc model in this study.

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Section 2 Appendix

Table 33: Projected effect of alternative case interventions on the reference case assumptions underlying passenger transport demand

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Fraction of households with private vehicle (%)**									
Intervention	**Public transport encouraged through taxing of private vehicle or further subsidy of public transport or both results in lower car ownership**									
Low-income	7%	7%	7%	7%	7%	7%	6%	5%	4%	4%
Mid-income	23%	23%	23%	23%	23%	23%	22%	21%	20%	19%
High-income	79%	79%	79%	79%	79%	79%	75%	72%	68%	65%
Variable	**Vehicles/person for households with private vehicle**									
Intervention	**Public transport encouraged through taxing of private vehicle or further subsidy of public transport or both results in lower car ownership**									
Low Income	0.25	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.21	0.2
Mid. Income	0.31	0.31	0.31	0.31	0.31	0.31	0.3	0.28	0.27	0.25
High Income	0.41	0.41	0.41	0.41	0.41	0.41	0.39	0.37	0.35	0.34
Variable	**Private vehicle occupancy for persons with private vehicles (persons/vehicle)**									
Intervention	**Special lanes for higher occupancy vehicles increases average occupancy**									
Occupancy	1.4	1.4	1.4	1.4	1.4	1.4	1.43	1.47	1.5	1.54
Variable	**Public mode road vehicle occupancy (persons/vehicle)**									
Intervention	**Routes improved to improve occupancy + other incentives on public transport**									
Bus	25	25	25	25	25	25	26.3	27.6	28.9	28.9
MBT	14	14	14	14	14	14	14.7	15.4	16.2	16.2
BRT	25	25	25	25	25	25	26.3	27.6	28.9	28.9
Variable	**Private vehicle mileage by Income Group (000 km/year)**									
Intervention	**Higher fuel taxes/prices gets people to drive less**									
Low-income	8.1	8.1	8.1	8.1	8.1	8.1	7.7	7.4	7	6.6
Mid-income	13.6	13.6	13.6	13.6	13.6	13.6	13	12.3	11.7	11.1
High-income	17.7	17.7	17.7	17.7	17.7	17.7	16.8	16	15.2	14.4
Other *	18	18	18	18	18	18	17.1	16.2	15.4	14.7
Variable	**Modal share by income group for persons with access to a private veh (%)**									
Intervention	**More BRT lanes setup and more high-speed Gautrain type trains implemented**									
BRT (LI)	0%	2%	5%	10%	15%	0%	2%	7%	15%	25%
Gautrain (LI)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRT (MI)	0%	2%	5%	10%	15%	0%	2%	7%	15%	25%
Gautrain (MI)	0%	0%	0%	0%	0%	0.0%	0.2%	1.0%	2.0%	3.0%
BRT (HI)	0%	2%	3%	4%	4%	0%	2%	3%	5%	10%
Gautrain (HI)	0%	1%	1%	1%	1%	0%	1%	1%	3%	5%

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Modal share per income group for persons without access to a private vehicle (%)**									
Intervention	**More BRT lanes are set up and more high-speed Gautrain-type trains implemented**									
BRT (LI)	0%	2%	5%	10%	15%	0%	2%	7%	20%	40%
Gautrain (LI)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRT (MI)	0%	2%	5%	10%	15%	0%	2%	7%	20%	40%
Gautrain (MI)	0.0%	0.2%	0.2%	0.2%	0.2%	0.0%	0.2%	1.0%	2.0%	3.0%
BRT (HI)	0%	2%	3%	3%	3%	0%	2%	7%	20%	40%
Gautrain (HI)	0%	1%	1%	1%	1%	0%	1%	1%	3%	5%
Variable	**Modal share of total private pkm (%)**									
Intervention	**Taxes are increased on SUV's causing a shift back to cars**									
Car	86%	86%	86%	86%	86%	86%	88%	89%	90%	90%
SUV	11%	11%	11%	11%	11%	11%	10%	9%	8%	8%
Motorcycle	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Variable	**Annualised rate of fuel consumption improvement (%)**									
Intervention	**EU reduces fuel economy of vehicles enough to stabalise transport sector CO_2 and the technology is transferred to South Africa**									
All Vehicles	1%	1%	1%	1%	1%	2%	2%	2%	2%	2%

LI: Low income 0 – R19,200 per annum (2005 Rands)
MI: Middle Income R19,201 – R76,800 per annum (2005 Rands)
HI: High Income > R76,801 per annum (2005 Rands)
**Other Private vehicles (government, rental, company)*
#: In practice road freight has a much bigger share of urban and rural ton.km because a lot of rigid trucks active there are classified as HCV (> 8,500 kg) GVM by NAAMSA. Better disaggregation by vehicle type would make for a more realistic road rail comparison but the accuracy of reference case total ton.km is not affected

Table 34: Projected effect of alternative case interventions on the Reference case assumptions underlying freight transport demand

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Ton.km share of rail corridor vs road corridor (%)**									
Intervention	**Freight rail industry recaptures market share from road freight**									
Road freight – corridor (HCV)	81%	81%	81%	81%	81%	81%	77%	73%	70%	66%
Rail main – corridor	19%	19%	19%	19%	19%	19%	23%	27%	30%	34%
Variable	**Ton.km share of rail vs road for urban & rural freight (%)**									
Intervention	**Freight rail industry recaptures market share from road freight**									
Road freight urban & rural (MCV)#	26%	26%	26%	26%	26%	26%	25%	23%	22%	21%
Rail freight branch line	74%	74%	74%	74%	74%	74%	75%	77%	78%	79%

Table 35: Passenger vehicle annual sales shares

	Reference Case					Alternative Case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Shares of car sales**									
Intervention	**Diesel, hybrid and electric cars incentivized**									
Diesel	8%	8%	8%	8%	8%	8%	11%	15%	17%	20%
Gasoline	92%	92%	92%	92%	92%	92%	81%	70%	68%	65%
Diesel hybrid	0%	0%	0%	0%	0%	0%	3%	5%	5%	5%
Gasoline hybrid	0%	0%	0%	0%	0%	0%	3%	5%	5%	5%
Electric	0%	0%	0%	0%	0%	0%	3%	5%	5%	5%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Variable	**Shares of SUV Sales**									
Intervention	**Diesel and hybrid SUVs incentivized**									
Diesel	42%	51%	60%	68%	75%	42%	54%	65%	78%	80%
Gasoline	58%	49%	40%	32%	25%	58%	41%	25%	12%	10%
Diesel hybrid	0%	0%	0%	0%	0%	0%	2%	5%	5%	5%
Gasoline hybrid	0%	0%	0%	0%	0%	0%	2%	5%	5%	5%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Variable	**Shares of MBT Sales**									
Intervention	**Diesel MBTs incentivized**									
Diesel	20%	25%	30%	35%	40%	20%	34%	53%	69%	79%
Gasoline	78%	74%	70%	65%	60%	80%	63%	40%	23%	14%
Diesel hybrid	0%	0%	0%	0%	0%	0%	3%	7%	8%	8%
Total	**98%**	**99%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Variable	**Shares of BRT Sales**									
Intervention	**Infrastructure for electric and CNG vehicles made available**									
Diesel	100%	100%	100%	100%	100%	100%	87%	75%	62%	50%
Comp. natural gas	0%	0%	0%	0%	0%	0%	6%	13%	19%	25%
Electric	0%	0%	0%	0%	0%	0%	6%	13%	19%	25%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 36: Freight vehicle annual sales shares

	Reference case					Alternative case				
	2010	***2020***	***2030***	***2040***	***2050***	***2010***	***2020***	***2030***	***2040***	***2050***
Variable	**Shares of LCV sales**									
Intervention	**Diesel LCVs incentivised**									
Diesel	42%	44%	44%	44%	44%	42%	46%	50%	55%	60%
Gasoline	58%	56%	56%	56%	56%	58%	54%	50%	45%	40%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Variable	**Shares of MCV sales**									
Diesel	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Gasoline	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Variable	**Shares of HCV sales**									
Intervention	**Natural gas made available to HCV vehicles**									
Diesel	100%	100%	100%	100%	100%	100%	94%	87%	81%	75%
Comp.Natural Gas	0%	0%	0%	0%	0%	0%	6%	13%	19%	25%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Section 3

Stakeholder engagement

Stakeholder consultation

Stakeholder consultation workshops took place on two occasions, firstly at an inception workshop which was held on 21 October 2009, and secondly at a stakeholder scenario workshop which took place on 9 November in Cape Town and 11 November in Johannesburg. A brief desctiption of both workshops follows in this section.

Inception workshop

The proposed project scope and methodology was presented to stakeholders at the Inception Workshop. The stakeholder group included representatives from SANERI, Chevron, Engen, PetroSA, Sasol, Shell, CEF, SAPIA, Transnet, SASDA, DEAT, ARUP, NERSA, DME, DOT and the CSIR. The workshop was simultaneously held at the University of Cape Town and at SANERI offices in Johannesburg linked-up via video-conferencing. After a presentation of the methodology and discussion of the proposed scope, stakeholders were given the opportunity to provide input on the identification of the most important drivers of demand for mobility and the factors that need to be considered when computing the resulting demand for energy.

The modelling team consisting of students and researchers from the Energy Research Centre and the Centre for Transport Studies at the University of Cape Town then proceeded with the task of establishing the base-year (2003) demand for mobility and base-year energy calibration.

The passenger demand for mobility by province was established using the National Household Travel Survey. The road freight demand for mobility along the 18 most important corridors for 12 goods-categories was established using the national freight roadside survey data. The rail freight demand for mobility was established using Transnet data for the same 12 goods categories. The demand for mobility was checked and calibrated against fuel sales data provided by SAPIA.

The modelling team then proceeded with the initial development of a model for projecting demand for mobility and the resultant energy demand. The model takes into account the main drivers of mobility and other important factors affecting energy demand. The platform chosen for the model is Analytica because of its ability to handle multi-dimensional data. Analytica also has a built-in facility for handling uncertainty in variables using probability distributions, the latter offering interesting possibilities for extensions to this project.

Scenario workshop

The base-year calibration data and initial model skeleton were presented at the second stakeholder workshop held on 9 (Cape Town) and 11 (Johannesburg) November 2010. After a brief summary of the model development and calibration, stakeholders were given the opportunity to give input on the model characterisation and scenarios to be modeled.

Four broad scenarios were defined as follows:

1. High economic growth with minimum efficiency improvements
2. High economic growth with strong efficiency improvements
3. Low economic growth with minimum efficiency improvements
4. Low economic growth with strong efficiency improvements

Points raised during the scenario discussion are summarised below :

Cape Town	
Model scope:	• Time-Frame ending at 2030 possibly too short may be worthwhile to extend to 2050.
Data issues:	• Bunker fuel data could possibly be obtained from Transnet. • Sapia stopped publishing data now published by DME 2011 should be more detailed.
Model issues:	• Efficiency of car park can only be tracked by more detailed car park model • Congestion on corridors difficult because of time of travel and impact of passenger vehicles. • Behaviour is influenced by socio-economic group, further disaggregation into income group may be useful.
Scenarios:	• Important to separate model inputs and outputs. • Scenario axes: High growth/low growth vs with measures and without measures.
Johannesburg	
Model scope:	• Title of project misleading if other liquid fuels sectors not included in analysis, so should be clarified. • Horizon also discussed and extension is a good idea.
Data issues:	• Possibly under-reporting of road haulage SAPIA data. • The 45-55% split of petrol/diesel fuel sales may have changed considerably from 2003, with current diesel vehicle sales share around 20%. • Significant fuel under 'general' could be sold to transport sector in rural areas with pumps attached to small shops. • Total sales figures from Sapia are reliable but the detailed breakdown is not as reliable, and results must be presented with this caveat. • N3 tkm looks low. • Coal transport to power stations doesn't appear to be covered by the corridors as a lot of it happens on minor roads – this needs further investigation. • Bunker-fuel is supply constrained rather than demand driven. • NPA should be able to provide data (at a cost of R3000). • In 2007 diesel car market share as per IER model are 10% in 2007 and 30% in BAU for Gauteng. • Pkm for Gauteng (IER Enerkey model) grows from 150 to 300 by 2040. • Historical annual efficiency improvement for new cars are around 1%.
Scenarios:	• It would be useful to identify which measures will have the most impact for the least cost. • IER Enerkey model: 100% pkm increase by 2040, 120% increase of tkm by 2040, but 55% energy increase. • We must be careful that the measures that are implemented do not have major impacts or are inconsistent with scenario assumptions about e.g.

	GDP growth. • Useful past studies on technology penetration: o European coorporation in science and technology o Sustainable mobility project (WBCSD) o Also look at DeLoittes study on bottlenecks and constraints o Look for Treasury/Presidency scenarios

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