An energy-economic critique of electric vehicle penetration in South Africa with emphasis on passenger vehicles

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1. Glossary:

CGE: Computable General Equilibrium (model)

eSAGE: (energy extended) South Africa General Equilibrium model

EV: Electric Vehicle

GDP: Gross Domestic Product

Hybrid: An ICE vehicle with auxiliary battery (e.g. Toyota Prius)

ICE: Internal Combustion Engine

SATIM: South Africa TIMES model

SATIMGE: linked SATIM:eSAGE model

2. Abstract:

A global transition to electric motorised transportation is evident with new electric vehicle sales forecast to rapidly increase, competing with and potentially displacing conventional petroleum fuelled passenger vehicle sales. In South Africa passenger electric vehicles are, at present, imported and subject to a 25% tariff. South Africa presently has a large domestic automotive industry which is presented as a key engine of future economic growth. A revised linked energy-economy model, SATIMGE, was utilised to investigate the economy wide implications of a global shift to electric vehicles in which local industry remains non-EV and the 25% tariff remains for imported vehicles. The impact on local crude oil refineries was also investigated given a scenario of declining future demand. The results suggest that future passenger vehicles in 2050 may comprise a mixture of electric and hybrid vehicles with the composition highly dependent on the purchase cost as a 25% impost would result in a negligible passenger EV share. The economic impact of a large EV share in the case of cost competitiveness is positive despite declining local automotive production with an average real GDP 6.7% higher than one without EVs. Furthermore local crude oil refineries are deemed uneconomic should the Euro-5 fuel standard be implemented.

3. Introduction

In South Africa a trend of increasing private vehicle ownership is observed with consequent demand for supporting infrastructure and energy supply (StatsSA, 2014; eNATis 2019; DoT 2014). Of the road vehicle fleet, private passenger vehicles, at 65%, represent the largest segment; consuming approximately 40% (~290 PJ) of road transport fuel at present. Given a trajectory of increasing demand for passenger vehicles, Ahjum et al. (2018) indicated that a 14% to 80% fleet composition of electric passenger vehicles from 2030 to 2050 has the potential to decrease fuel demand by 93 PJ to 290 PJ respectively. This equates to a reduction of 11% and 30% of total road transport fuel from 2030 to 2050 based on assumptions of average economic growth of 3% annual GDP for the period.

By 2025-2030, purchase price parity with conventional internal combustion engine (ICE) vehicles is forecasted with demand for EVs anticipated to accelerate as a result without subsidy support {REF: BNEF, 2018 et al.}. This is mainly due to the lower total cost of comparative vehicle ownership and progressive improvement in driving range. The motor vehicle industry forms a key part of industrial policy in South Africa with a total contribution to national GDP estimated at between 1% and 7% of total GDP (Jordaan et al., 2018; StatsSA, 2014). National accounts data from StatsSA indicates that direct motor vehicle production (including parts and accessories) accounts for 0.8% of total value added (StatsSA, 2014). Since 1995 industrial policy has promoted the sector as a source of export revenue with key markets in Europe, Africa, North America, Brazil and Japan (StatsSA, 2018). Initial EV adoption has stemmed primarily from the European, North American and Japanese markets. However, EV deployment has recently surged in China where sales of 600,000 units accounted for 2.3% of the passenger vehicle market in 2017 and total sales in 2018 surpassed 1 million vehicles to comprise approximately 4% of market share (EV-volumes, 2018). India and South American countries have also implemented EV adoption policies (UNEP, 2016). The rise in EV sales in these regions has implications for South African motor vehicle exports which consist only of ICE vehicles.

Locally, it is estimated that less than 1000 EVs have been sold to date. Although lagging global adoption rates, historical sales suggest a trend of increasing future demand (WattEV2Buy, 2018). Ahjum et al. (2018) suggested that EVs could potentially comprise 80% of new sales of vehicles by 2045. Policy based incentives to promote the adoption of zero emissions vehicles has predominantly centred on global action to reduce greenhouse gas emissions and improve local air quality. This has resulted in, presently, electric vehicles (EVs) being the technology of choice by market share. The combined change in global and potential local demand for EVs presents an opportunity for the South African automotive sector to diversify production to include EV manufacture. Such a diversification would assist in maintaining global market shares and also mitigate a potential increase in imports as a result of a local shift toward EVs and away from conventional ICE technology.

Previous studies (Altieri et al., 2016; Caetano et al., 2017; Ahjum et al., 2018) have assessed the energy, emissions and economic impacts of an increase in EV penetration in South Africa. It was found that the increasingly lower cost of decarbonisation of the electricity system encourages demand sectors to electrify. If least-cost modelling assumptions incorporate low-emissions generation technologies such as solar-pv and wind then, in the transport sector, this provides an opportunity for a large-scale switch to e-mobility technologies such as battery electric vehicles.

Caetano et al. (2017) and Ahjum et al. (2018) modelled scenarios comprising: an escalating crude oil price of US$100 - US$125 per barrel; and a low oil price of US$80 per barrel over the period 2030 - 2050. Since the publication of these studies the global crude oil price has declined with forecasts for prices now ranging between US$100 and US$30 per barrel (BNEF, 2018a; DBEIS, 2018; EIA 2017). A decline in crude oil prices may advantage conventional and hybrid ICE vehicles which may result in a lower domestic level of EV penetration. Slower uptake domestically also has the potentially to influence the domestic motor vehicle industry and its ability to maintain its global market share. This along with the continued importing of crude oil fuels would have negative implications on the current account balance of the country.

This paper builds on the studies of Ahjum et al. (2018), Stone et al. (2018) and Caetano et al. (2017) by assessing the energy and economic impact of electric vehicle penetration in South Africa. The analyses is conducted for an unconstrained GHG emissions case to investigate the economy wide techno-economic ramifications of a low or high EV fleet share. It complements the previous research by incorporating lower crude oil price assumptions, more conservative vehicle fuel efficiency improvements and examines the impact on the domestic motor vehicle industry (and the economy) from a decline in global motor vehicle market share. Furthermore the linked energy-economic model (SATIMGE) utilised by Altieri et al. (2016) and Caetano et al. (2018) was revised, linking the transport energy supply chain to the wider economy. It is believed the revised integrated modelling approach therefore better represents EV penetration in South Africa as expenditure in the economy and the links to energy supply and demand are improved.

Methodology and assumptions

The Energy Research Centre's linked energy economic model, SATIMGE, is used in this paper to assess the potential uptake of electric vehicles in the country. Unlike other energy-economic models which include either a simplified version of an economic model into an energy model or vice versa, SATIMGE combines a bottom-up integrated full sector energy systems model, SATIM, with eSAGE a detailed dynamic recursive computable general equilibrium model for South Africa (Arndt et al. 2016). By combining these detailed models of different aspects of the country, SATIMGE is able to consistently capture all the technical detail needed for full sector energy systems analysis and assess the impact across various agents in the economy accounting for behavioural responses to relative price changes.

SATIMGE links the SATIM and eSAGE models in an iterative process (see Figure 1) that mimics South Africa's energy planning process in which energy investment and pricing decisions (in the case of electricity) are taken outside of the market. New energy and electricity investment is determined by the state Department of Energy, while electricity prices are set by the National Energy Regulator of South Africa. Specifically, given initial sector and household income growth projections, SATIM is used to compute the least-cost energy technology mix for the country including the resulting investment plan and electricity price. This information, along with information on fuel efficiency and fuel switching by agents is passed on to eSAGE which is run to incorporate the new energy supply and demand composition. To facilitate the exogenous electricity price, the sales tax on electricity is made endogenous. This provides the eSAGE model with sufficient room for electricity demand to respond to changing electricity prices over the horizon. All other energy prices are endogenous in the eSAGE model. Updated sector and household income growth projections are then passed back to SATIM which optimises based on this new information. This iterative process continues until the model converges such that energy utilization (and associated CO2 emissions) in both models are aligned and internally consistent in terms of demand, price and technology mix. In the first iteration electricity and refinery sector investment is not imposed on the eSAGE model to circumvent the problem of electricity demand not responding to price changes. The SATIM and eSAGE models are calibrated based the 2012 energy balance and social accounting matrix (van Seventer et al. 2016) respectively.

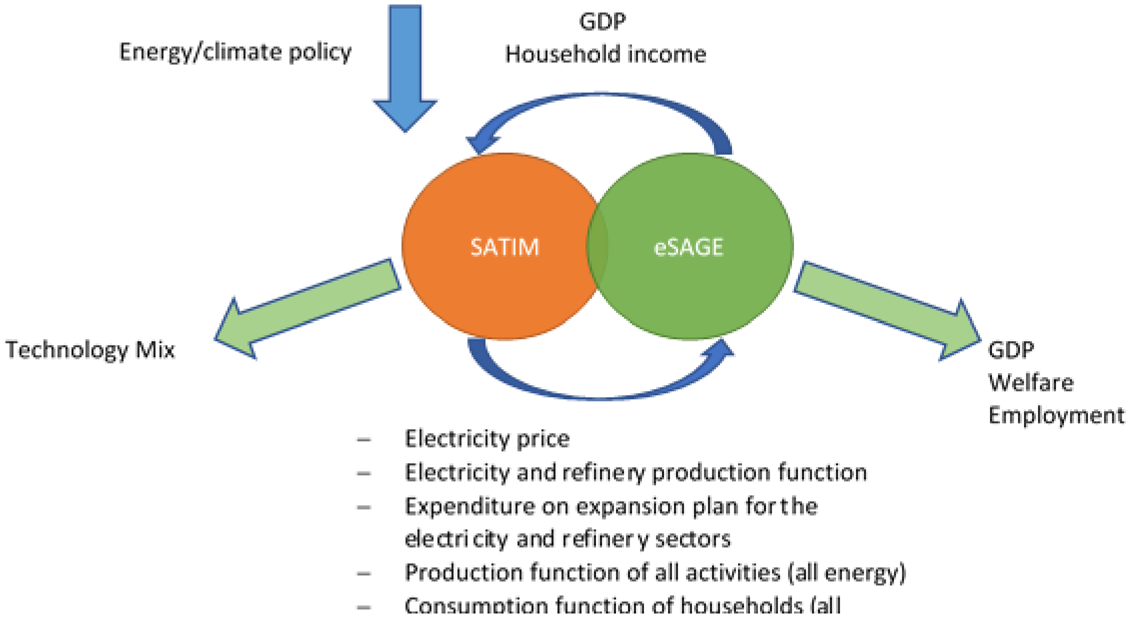

Figure 1: Iterative approach used in SATIMGE (Updated from Arndt et al. 2016)

The existing stock of technologies (e.g. power plants, refineries, vehicle parc), and committed build to 2022, are included in the SATIM model with existing power plants retired as specified by government (DOE IRP 2016). Technology costs are aligned to that used in national government planning (DOE IRP 2016) except for renewable energy costs which are outdated. Conservative costs by Ireland and Burton (2018) are used for solar PV and wind. Demand profiles for all end-uses are assumed to be fixed over time. Fuel switching for thermal and transportation energy services is allowed. The overall demand profile seen by the grid will vary over time because of differing growth rates by different sectors, fuel switching to and away from electricity, and distributed generation and storage installations. System adequacy is insured by imposing an overall reserve margin of 15% of firm capacity over peak demand. Thermal plants (including CSP with storage), hydro, pump storage and batteries are given a full capacity credit. PV is given no capacity credit while wind is given a 15% capacity credit. PV and wind profiles are aggregated to the 8 time slices used in this model from the profiles used in (Wright et al. 2017, Reber et al. 2018). Coal and nuclear based technologies are given limited flexibility in that they are not permitted to vary their output during the day. Crude oil refineries are modelled as flexible, for example, permitting retirement if the investment to comply with Euro 5 fuel standards is deemed uneconomic (DoE, 2011). Stone et al. (2018) describes the method for the vehicle parc model calibration - in particular the disaggregation of the freight fleet- while Ahjum et al. (2018) describes the incorporation of potential future vehicle technologies.

Key model revisions are summarised below:

- Revised energy balance from 2006 to 2012
- Differentiated petroleum products, i.e. transport versus non-transport in economy model
- Time slice electricity demand included for passenger vehicles
- Assumptions for vehicle efficiency progress adjusted from Ricardo-AEA (2012) to conform with the Integrated Energy Plan (DoE, 2016)
- Refinery refinery production and investment are linked between the energy and economy models

The freight fleet is the largest consumer of petroleum product (Stone et al., 2018) but the passenger vehicle fleet, by size, is the largest market for EV penetration. Electric and hydrogen fuel cell vehicle (HFCV) penetration in the freight and public fleet was investigated in previous research and is the basis for a sector specific future research. In this paper emphasis is given to the private passenger fleet but it should be noted that the economic model currently considers the transport sector holistically and the penetration of EVs and HFCVs, predominantly in the freight sector, would also induce economy wide impacts. However given the relative magnitude of the private passenger fleet, the discussion of the economic impacts that follows, with respect to the influence of EVs, remains relevant.

Scenarios and assumptions

Two core scenarios are considered in this paper. In the reference scenario electric vehicle technology costs become competitive with internal combustion engines by 2030 as suggested by the literature (Bloomberg, 2018b). In this scenario real GDP grows at an average annual rate of 3.1% with a median global crude oil price of US$80/barrel during 2030-2050. We assume that the motor vehicle industry is progressive and adapts to changes in vehicle class demanded. The external and domestic market share of the South African motor vehicle industry therefore does not change as a result of changes in vehicle class preferences. The scenario is considered the most techno-economically favourable towards EV adoption.

In the reference scenario, real GDP growth in the CGE model is targeted to meet actual growth between 2012 and 2017, whilst growth between 2018 and 2022 are based on projections from the National Treasury (MTBPS 2018) and International Monetary Fund (WEO October 2018). Longer term growth projects are aligned to meet the Department of Energy's planning growth rate of 3.1% to 2050. The structure of the economy does not shift dramatically although the share of mining in Gross Value Added (GVA) decreases, while manufacturing and services increase marginally. The supply of labour is assumed to increase in line with population growth (~0.56%, UNEP 2016), although upward sloping labour supply curves are assumed for all skill categories, given the long-term nature of the analysis. Government spending and foreign savings increase by 3% per annum, although the increase in foreign savings decreases over time as debt is repaid. Total factor productivity is adjusted to reach the 2016 Draft IRP moderate growth forecast. The macroeconomic closures included are aligned to the stylized facts for South Africa; it is assumed that investment is driven by the total level of savings in the economy; government savings are flexible, and no fiscal rule is imposed; and the exchange rate is flexible. Existing capital is assumed to be fully-employed and activity specific. Elasticities used in the CGE model are based on the most recent published estimates for South Africa: income elasticities (Burger et al. 2015); armington trade elasticities (Saikonnen, 2015); and factor elasticities (Kreuser et al. 2015).

The contrasting scenario is distinguished from the reference scenario by higher retail costs for EVs). In this scenario EVs remain uncompetitive with traditional transport technologies due to import duties, captured by the SATIM model in the increased investment cost of electric vehicle technologies relative to ICE technologies at ~25% from 2030 -2050.

Results

Electricity could account for approximately 50% of energy use by 2050 for motorised private passenger travel.

We contrast the reference, EV cost competitive scenario, with the EVHiCost scenario (higher retail costs). In the reference scenario, the use of electricity as a transport fuel increases over time (see Figure 1). The uptake is driven by the decrease in electric vehicle technology costs which become equivalent to that of internal combustion engines by 2030; and the lower cost of electricity versus traditional fuels. By fuel share, electricity comprises 5% - 50% of total energy use in the private passenger transport sector during 2030- 2050 replacing conventional crude oil product (petrol and diesel). Private motorists may continue to use oil product until 2050 (Figure 1) although at reduced demand (~50%) compared to present consumption levels of near 100%. Whilst comprising 80% of the vehicle fleet in 2050, fuel consumption by EVs in this segment is 92 PJ or 25 TWh (~50%) in contrast to the 91 PJ (~50%) of liquid fuel demanded by the residual ICE and hybrid fleet accounting for the remaining 20% (Figure 2).

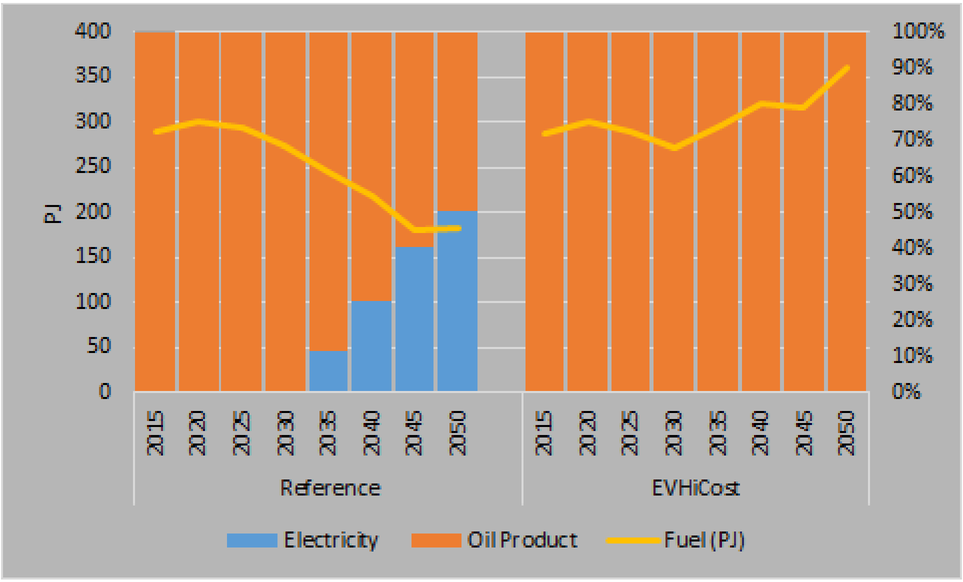

Figure 1: Passenger vehicle fuel consumption for the reference and increased EV cost scenarios.

With increased EV costs, within the private fleet, electricity consumption is predominantly via two-wheeled transport (Figure 2). In the reference, cost competitive scenario, hybrid ICEs appears as an interim bridging technology to EV adoption whereas in the EVHiCost scenario hybrids could emerge as the dominant technology in 2050 with subsequent higher fuel demand (Figure 1).

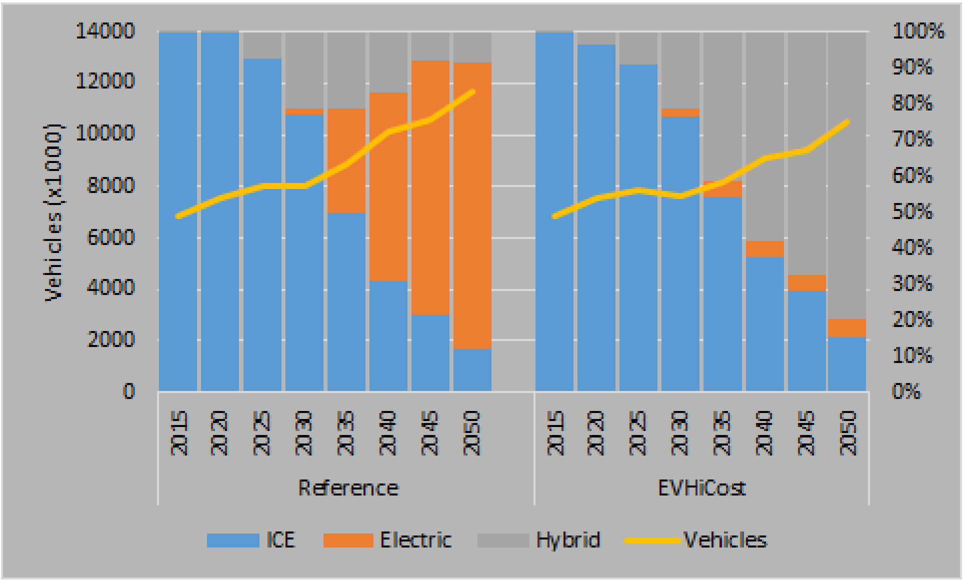

Figure 2: Primary competing technologies for the private vehicle category.

Ahjum et al. (2018) highlighted that the advantageous well-to-wheel efficiency of EVs in the South African supply-to-service chain deferred investment in new liquid fuel supply capacity. The shift away from traditional technologies and fuels results in a decrease in traditional refinery production (see Figure 3) with no new coal to liquid or gas to liquid capacity added to the energy system over the period. Figure 3 suggests that given the range of crude oil price futures (50-80 $US/bbl) the investment option to upgrade the crude oil refineries to Euro 5 fuel is not economic as fuel demand by either a hybrid or residual ICE fleet are met via imported product.

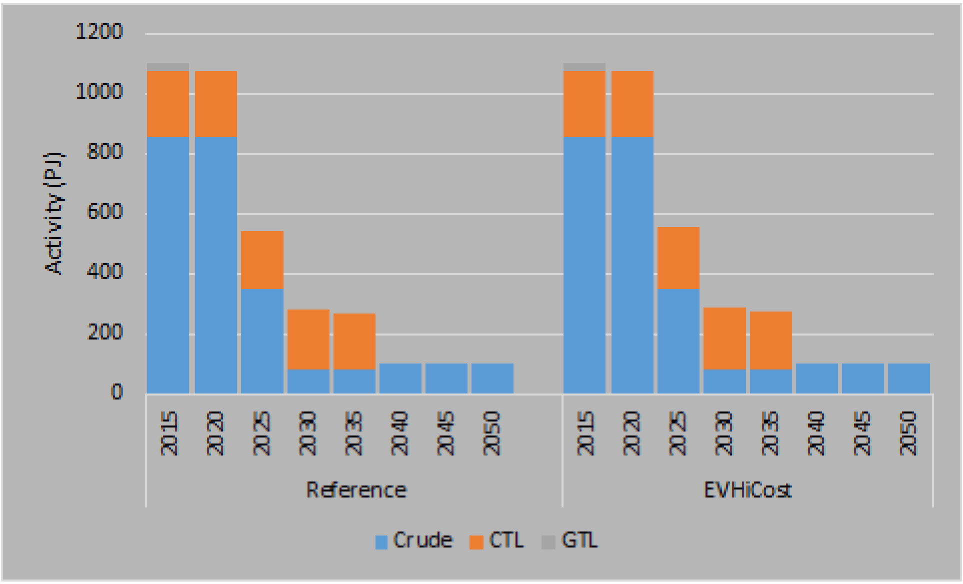

Figure 3: Domestic liquid fuel production

When domestic EV costs are kept artificially high through import duties, as in the EVHiCost scenario, a shift to increased electricity use in the private passenger transport sector is deferred (see Figure 1 & Figure 2). Within the private passenger transport sub-sector, motorists become more reliant on oil product as hybrid vehicles are the primary transport technology in the sector.

Economic impact of elevated domestic EV costs

In the reference case, real Gross Domestic Product (GDP) grows at an annual average rate of 3.1%. The structure of GDP remains relatively the same in 2050 as in 2015, although the share of mining in total GDP decreases with small increases experienced in the manufacturing and services sectors (see Figure 4). Employment grows at an average annualised rate of 3.0% over the period with sector employment aligned to GDP.

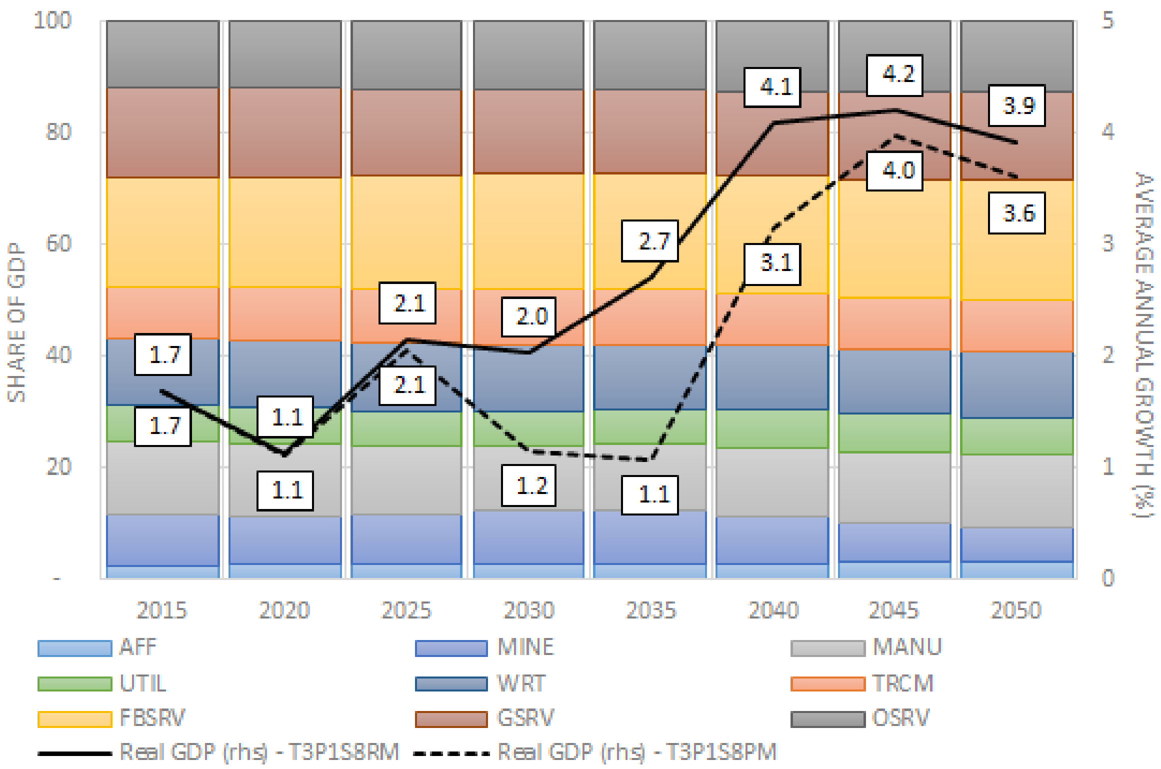

Figure 4: Real GDP

Under the increased EV cost scenario real GDP growth is lower relative to the reference case. Between 2045 and 2050 the average annual real GDP growth rate is 0.3 percentage points lower. The level of real GDP is 18.2% lower by 2050. The lower level of real GDP is the result of slower growth in the services and manufacturing sectors. Within the services sector, the largest declines in GDP are experienced in the financial and business services sub-sector although declines are experienced across all sectors. Manufacturing sub-sectors which experience the largest declines in GDP are the basic and other chemicals; food and beverages; and metal products sub-sectors. The petroleum sub-sector experiences an increase in production.

The EVHiCost scenario examines the impact of EV cost as a driver of adoption. In line with the lower level of real GDP, a lower level of employment is also experienced in the EVHiCost scenario. The total level of employment is 20% lower by 2050 relative to the reference case. This translates into 215 thousand fewer jobs being created per annum under the EVHiCost scenario. Lower levels of employment are concentrated in the services and manufacturing sectors and span across skill levels.

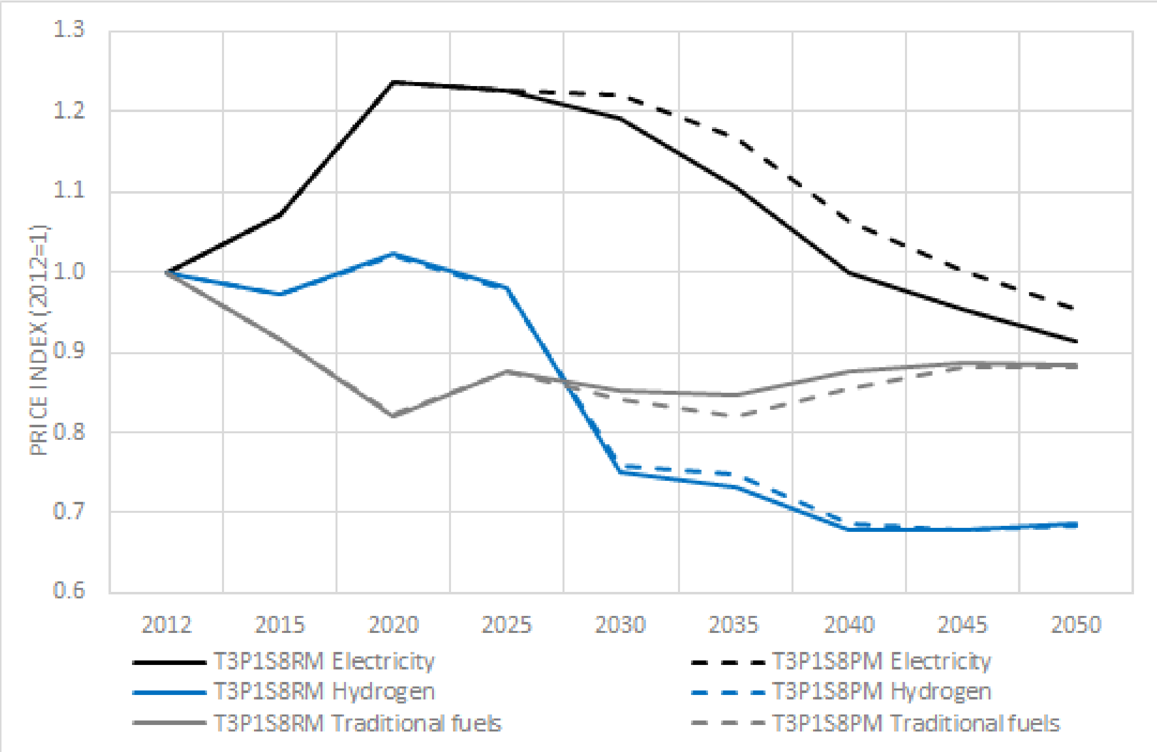

Figure 5: Land transport costs

The lower level of GDP experienced under the EVHiCost scenario is driven by the higher cost of land transport in this scenario relative to the reference case which, due to the importance of moving goods and services, has knock-on effects throughout the economy. Land transport (including the purchase of fuel for transport) accounts for nearly 4% of production costs and 1.5% of final product costs through moving goods and services to final consumers. Land transport costs also account for 6% of household final expenditure. Figure 5 presents the difference in traditional land transport fuel costs and new transport fuel costs (i.e. hydrogen and electricity). The higher electricity price, relative to the reference case, also discourages economic activity and household consumption as it raises the cost of production and in the case of households, crowds out demand for other goods and services. Real household consumption, a measure of welfare, decreases relative to the reference case and is 19.4% lower by 2050 (Figure 6).

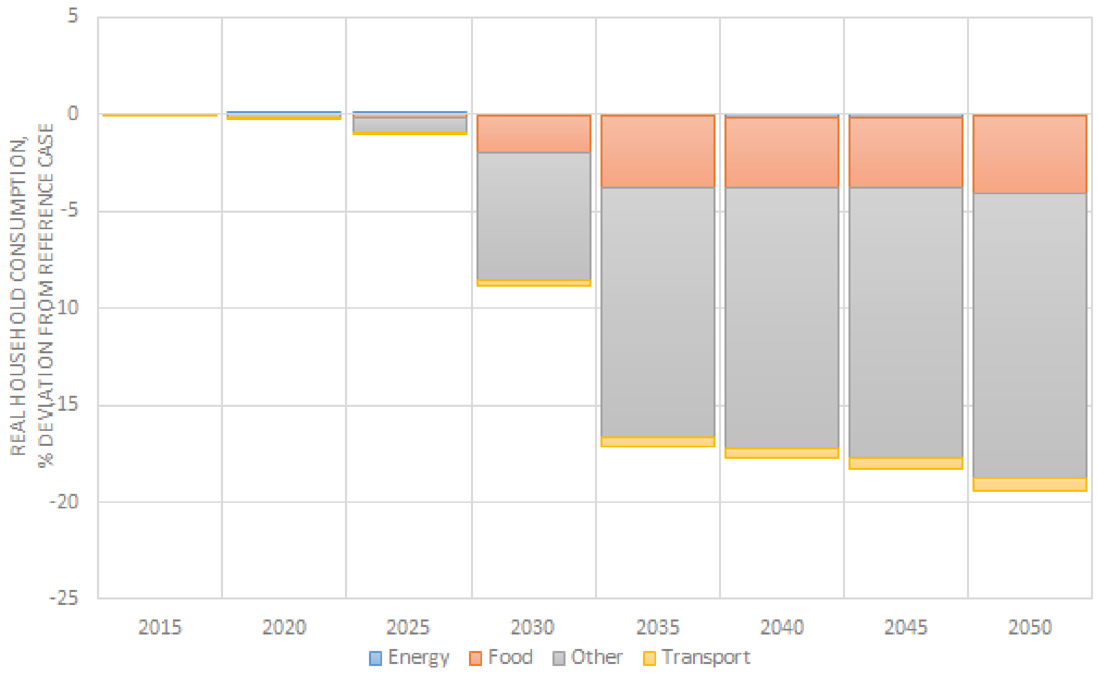

Figure 6: Household consumption

In the reference scenario the shift toward electric vehicles reduces South Africa's foreign dependence on crude oil and petroleum products, improving energy security. Crude oil and petroleum imports decline by more than 50% between 2018 and 2050. This decreases the share of energy imports to GDP from 4.3% in 2018 to 1.5% in 2050. Overall imports decline from 31% of GDP to 28%. Under artificially higher EV costs, this improvement is slightly eroded as crude oil and petroleum imports only decline by 18% by 2050. Energy imports is 2.1% of GDP by 2050 (total imports are 29%).

Sensitivity analysis

While the uptake of electric vehicles is dependent on the cost of electric vehicle technology (captured by the core scenarios), the scale and timing of implementation is also sensitive to the demand for transport services and running costs of alternative technologies, which comprises largely of fuel costs. For this reason, we also conduct sensitivity analysis on two key determinants of technology and fuel choice in the transport sector. Specifically, we consider the state of the economy and the cost of imported crude oil and petroleum product prices. In the former, we consider the outcomes for the reference case but where the average annual real GDP growth rate is a) higher and b) lower than in the reference case. The average annual real GDP growth is 4.1% and 2.1% in the high growth and low scenarios respectively. In the latter, we assume that the global crude oil price is US$30/barrel lower than in the reference case. Global petroleum product prices are also lower in line with the lower global crude oil price. The scenarios analysed under the sensitivity analysis is reported in Table 1.

Table 1: Sensitivity analysis scenarios

Scenario	Sensitivity	Description
T3P1S8RH	Real GDP growth	This scenario is the same as the reference case but the average annual growth rate is assumed to be 4.1% instead of 3.1%.
T3P1S8PH	Real GDP growth	This scenario is the same as T3P1S8PH but with artificially higher domestic EV technology costs.
T3P1S8RL	Real GDP growth	This scenario is the same as the reference case but the average annual growth rate is assumed to be 2.1% instead of 3.1%.
T3P1S8PL	Real GDP growth	This scenario is the same as T3P1S8PL but with artificially higher domestic EV technology costs.
T3P1S5RM	Crude oil price	This scenario is the same as the reference case but the crude oil price is assumed to be US$50/barrel. Global petroleum product prices are adjusted in line.
T3P1S5PM	Crude oil price	This scenario is the same as T3P1S5PM but with artificially higher domestic EV technology costs.

Real GDP growth

The average annual real GDP growth rate affects the level of energy demanded by the transport sector via household income and freight services. These changes are however small between the three growth scenarios considered in this paper. Figure 7b presents the total level of energy demanded by the transport sector across the three scenarios while Figure 7a presents the fuel composition of this demand. Note that hydrogen consumption in transport is observed primarily in the heavy vehicle freight segment and is discussed in detail by Ahjum et al. (2018). It is included in this discussion as its utilisation influences the economic model growth trajectory.

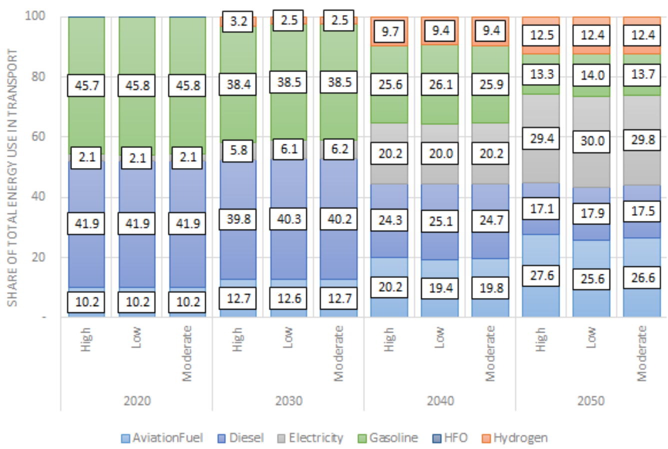

Figure 7a: Share of fuel in energy demand

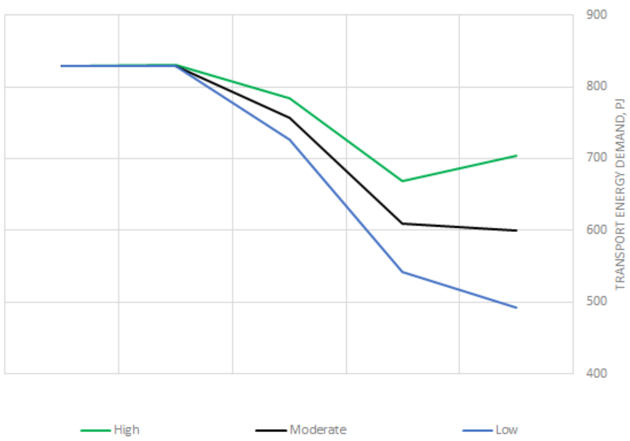

Figure 7b: Energy demand

Lower global crude oil prices

Total energy demanded by the transport sector is 11.8% higher in the low global crude oil price scenario (T3P1S5RM) as a result of the lower crude oil and petroleum product prices which enables faster economic growth and hence a larger demand for transport services. The average annual real GDP growth rate is 0.4 percentage points (%pts) higher than in the reference scenario. As a result, the level of electricity demanded by the transport sector is higher over the period relative to the reference case. This is also true for all other fuels demanded by the sector although the increases in petroleum and diesel demand are larger than the increases in hydrogen and electricity. As a share of total energy use, the uptake of electricity in the transport sector is slower but by 2050 roughly the same as in the reference case scenario (see Figure 8).

No new refinery capacity is added under this scenario as it becomes cheaper to import petroleum products than produce them domestically. Domestic refinery production is 16.5% lower than in the reference case. New hydrogen capacity added to the system is higher than in the reference case totalling 90.5PJ. Increased imports of petroleum products (and hence lower production) results in lower domestically produced emissions than in the reference case to 2040. Thereafter emissions in the low crude oil price scenario increases by more than in the reference case as a result of higher economic growth with the emissions intensity of GDP, measure as CO2eq/R, decreasing relative to the reference case.

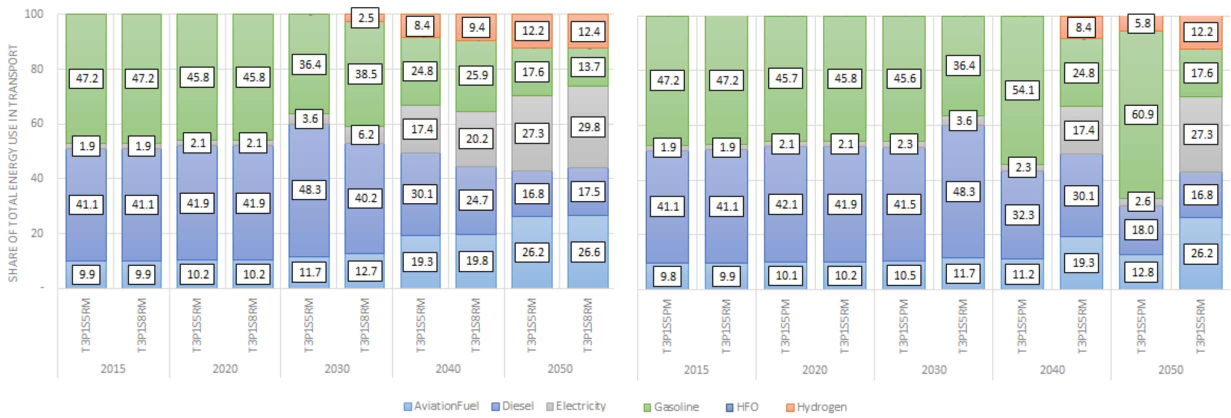

Figure 8: Energy use in transport

Under a high EV technology cost scenario (i.e. T3P1S5PM) the uptake of electricity in transport is lower reaching only 2.6% of total energy demand relative to 27.3% in T3P1S5RM. The bulk of energy used in the transport sector comes from petrol which accounts for more than two thirds of energy use by 2050. The share of hydrogen also decreases relative to T3P1S5RM reaching only 5.8% by 2050 (T3P1S5RM: 12.2%). As in the core scenarios discussed above, real GDP is lower under the pessimistic EV cost scenario. Average annual real GDP is 0.7 %pts lower in the T3P1S5PM scenario while 250 thousand fewer jobs are created per annum.

Transport technology and the domestic motor vehicle industry

While the motor vehicle industry[1] is a relatively small contributor to total GDP and employment (0.8% and 0.4%), it does comprise a larger share of GDP and employment in the manufacturing sector (6% and 3.2%) and shares strong links with other manufacturing sub-sectors. In 2012, the

[1] The motor vehicle industry includes motor vehicle parts and accessories.

motor vehicle industry accounted for 35%, 23% and 13% of total domestic demand for leather products, non-ferrous metals, and iron and steel products respectively. In 2012, the domestic output multiplier for the sub-sector is estimated to be 1.31 (median: 1.6) with an employment effect multiplier of 2.5 (median: 3.2).[2]

The sector has also been identified as a key exporter. In 2012, motor vehicle exports accounted for 5.3% of total exports and 11.8% of manufactured exports. Key export destinations include Europe (specifically Germany and the UK), which accounts for 52% of total motor vehicle exports; SADC (16%) and the United States (12%). The global competitiveness of the motor vehicle sector is, however, dependent on government regulations and policies such as the Motor Industry Development Program with rising support necessary as imports become cheaper.

South Africa's motor vehicle industry focuses on the production of internal combustion engines to feed both domestic and internal demand. The change in global and local preferences toward electric and hydrogen vehicles suggests that if this sector does not adapt it will lose market share as foreign customers will find other suppliers and domestic customers will switch to imports. Local production would thus suffer with potential negative impacts on the rest of the economy. In this section we therefore analyse the core scenarios presented above under a non-adaptive motor vehicle industry. This is modelled by decreasing the share of motor vehicle exports and increasing the share of imports accounting for the level of EV adoption in each scenario. The results are compared to corresponding scenarios where the motor vehicle industry is adaptive.

The results show that if the motor vehicle industry does not adapt to the changes in vehicle preferences production in the sector declines. This however leads to the release of resources, lowering the relative prices of capital and labour that are used more productively in other sectors of the economy. The price of imported motor vehicles are also lower than those domestically produced thus the switch lowers the cost of purchasing a vehicle resulting in increased purchasing power for businesses and households. As a result the level of real GDP is 6.7% higher under reference EV technology costs and 6.4% higher under pessimistic EV costs. The increase in GDP is concentrated in the services sector although all sectors in the economy experience an increase in GDP. Employment increases in line with real GDP gains. Total employment in the economy is 7% and 6.4% higher in the non-adaptive scenarios. The increase in employment is larger than the increase in GDP as the economy becomes more labour intensive relative to the non-adaptive scenario. In line with the increase in real GDP and employment, household welfare (measured by real household consumption spending) also increases relative to the adaptive motor vehicle sector scenarios. Larger welfare gains are experienced in higher income households who are also the largest purchasers of motor vehicles. Both exports and imports are higher by 2050 under the non-adaptive scenario although the rise in imports is higher than in exports. This results is a slight deterioration (0.1%pts) in the trade deficit as a share of GDP.

Discussion and Conclusions

Ahjum et al. (2018) and Tara et al. (2017) had previously investigated the implications of migrating to alternative transport fuels and technologies for road transport and highlighted the preference for electricity and hydrogen as a future road transport fuel. In particular, the private passenger vehicle

[2] The output multiplier implies that for a R1 million increase in demand for outputs from the motor vehicle industry, total output in the economy increases by R1.31 million with R0.31 million being indirect through the sector's links with other sector in the economy. Similarly the employment effect multiplier means that for every R 1 million increase in demand for outputs from the motor vehicle industry, 2.5 direct and indirect jobs will be created.

market, given its size was a key segment identified for electrification while hydrogen featured in heavy vehicle transportation. In addition, mode switching particularly for the passenger segment was also identified as an important transport intervention. The economic analyses focused primarily on the impact different rates of decarbonisation ambition had on transport sector migration to alternative technologies and the resultant impact on economic growth.

In this paper, an energy-economy model was utilised to examine the economy wide impacts of transport electrification with an emphasis on private passenger electric vehicle adoption. In particular the effect of a relatively higher purchase cost of an EV was investigated and subject to variations in assumptions of future GDP from an average rate of 2.1% to 4.1% and crude oil prices of $US 50 and $US 80 per barrel by over the period 2030 - 2050. Key improvements to the linked model are a low or conservative fuel-efficiency improvement across the vehicle technology portfolio over the modelling period as reflected in the Integrated Energy Plan (DoE, 2016) and capturing refinery investment in the economic model rather than only fuel prices to better reflect capital redirection with regard to national expenditure.

The research conducted in this study indicates that the purchase cost remains a key driver of EV penetration with the preference for either hybrid ICEs or EVs are primarily based on the initial purchase cost. A ~25% premium on the purchase cost of an EV would preference hybrid ICEs resulting in a lower GDP growth trajectory of 0.3% points. The uptake of electric vehicles has a larger positive impact on economic growth and employment. This result is evident in the comparison of the reference case and EVHiCost scenarios as well as the T3P1S5RM and T3P1S5PM scenarios. The uptake of electric vehicles results in lower electricity prices as the additional demand results in a larger share of electricity production coming from cheaper wind and solar PV alternatives. This has a positive impact on the economy as it reduces the costs of moving goods, services and people around. The lower electricity price also has further reaching impacts on the economy as it is used directly by households and within production processes. Increased electric vehicle penetration also reduces any energy security risk faced by South Africa as the country becomes less dependent on imported fuels.

If the present Euro-2 fuel standard is altered to the proposed Euro-5 standard, the investment estimated at ~ Rbil 40 (2015) is avoided opting instead for the importation of finished product instead. The selection of either hybrid or EV technology has no impact on domestic liquid fuel supply production. On a techno-economic basis, continued operation of crude oil refineries would be largely dependent on subsidisation as the investment required for a Euro-5 fuel standard is not economic. A decrease in refinery production does not translate into a decrease in manufacturing or overall economic growth. In the EVHiCost refinery production is marginally higher than in the reference case yet both manufacturing and overall economic growth is lower. This is also the case when comparing the reference case and the T3P1S5RM scenarios. In the T3P1S5RM scenario refinery production is lower than in the reference case as demand is satisfied through cheaper imports, manufacturing and economic growth are however higher. This result however assumes that the production of petroleum products and chemicals are not dependent on each other apart from the consumption of intermediate inputs. If the reality is that chemical manufacturers, largely Sasol, cannot produce chemicals at current costs without producing large scale liquid fuels a decline in refinery capacity may also result in a decline in chemicals production. This may have broader impacts on the economy and exports. Further research into the links between these industries is needed.

Should the automotive industry remain a non-exporter of EVs to traditional markets, then a decline in motor vehicle production (in its current form), as a result of a non-adaptive industry occurs. However the decline in automotive production, does not result in a decline in economic growth or employment as resources that would have been used within the industry is reallocated to more productive and employment intensive sectors of the economy. The trade deficit however deteriorates marginally as a share of GDP as motor vehicle imports increase to meet demand.

In this study we have modelled the motor vehicle industry as a collective and as represented by the supply and use tables published by StatsSA. We have also assumed that an adaptive industry will continue to function in the same way as the current industry. This may however not be the case. If in adapting to changing vehicle class demand the motor vehicle industry becomes more integrated with the rest of the economy, less dependent on imported components and more productive it could have a larger positive impact on the economy and employment. A more detailed analysis of what a potential EV production industry would look like and the potential for productivity improvements in the motor vehicle industry is needed.

Although this study has focussed on vehicle technology choices, a holistic approach to mobility challenges is acknowledged. Further research into urban non-motorised planning; freight and public transport and co-benefits of alternate technology adoption; and grid integration of a large electric vehicle population is included as part of the continued transport research programme at the centre.

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