Climate Transparency

A LOW-CARBON TRANSPORT FUTURE FOR SOUTH AFRICA:

TECHNICAL, ECONOMIC AND POLICY CONSIDERATIONS

POLICY PAPER

MARCH 2020

KEY POINTS

- Electrification of transport is key to dramatically reducing transport emissions.
- Hydrogen could feature as the primary fuel for long distance heavy vehicles.
- Public transport and Transit Oriented Development are crucial to a resource efficient transportation system, requiring effective integrated land and transport planning and co-coordination between the multiple tiers of government to streamline legislative frameworks.
- A low carbon transport transition will necessitate the decarbonisation of aviation (and maritime) transport fuels.
- A low carbon transport transition will depend on the decarbonisation of the power sector.
- A just transition requires policies that address disruptions in the existing (fossil) liquid–fuels supply chain and in particular the linked chemicals sector.
- The Green Transport Strategy should outline a coherent approach to address climate change in the context of SA's commitment to the Paris Agreement.

Authors:

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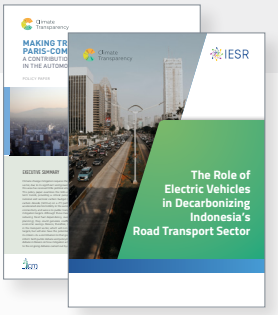


This paper is part of the efforts of the Climate Transparency Initiative, an international partnership of 14 research organisations and non-governmental organisations (NGOs) analysing G20 climate actions. It is part of a series examining the status, opportunities and challenges in decarbonising the transport sector in G20 countries. Other papers on this topic can be downloaded from the Climate Transparency's website: **www.climate-transparency.org**

GLOSSARY

BRT	Bus Rapid Transit
CF2	Clean Fuels (Phase) 2
CTL	Coal-To-Liquids
EV	Electric Vehicle
GHG	Greenhouse Gas
GTS	Green Transport Strategy
HFCV	Hydrogen Fuel-Cell Vehicle
HCV	Heavy Class Vehicle (e.g. truck)
ICE	Internal Combustion Engine
LCV	Light Commercial Vehicle
MCV	Medium Class Vehicle (e.g. light delivery trucks)
Mt	Mega-ton
NATMAP	National Transport Masterplan
NDC	Nationally Determined Contribution
PA	Paris Agreement
P-KM	Passenger-Kilometre
SATIM	South Africa TIMES Model
SYNFUEL	Synthetic Fuel
T-KM	Tonne-Kilometre
TOD	Transit Oriented Development
V-KM	Vehicle-Kilometre

EXECUTIVE SUMMARY

In South Africa, the contribution of transport to national energy-related CO_2 emissions is estimated to be approximately 14%. Road transport is responsible for approximately 90% of transport emissions and 90% of total fuel consumption in transport.

The population, currently at 57 million, is projected to reach 75 million by 2050. An increasing motorisation rate along with a defection from public transport is evident. If South Africa achieves high economic growth rates without low carbon and resource efficient alternatives, transport energy demand and emissions will grow to 2050. The sector could become the largest emitting sector by mid-century.

It is therefore imperative to decarbonise the transport sector if South Africa is to reach its Nationally Determined Contributions (NDC) in accordance with its commitment to the Paris Agreement.

Transport in South Africa in 2050

A least cost optimisation modelling framework of the South African economy was used to contrast four potential transport pathways to 2050. The analysis considered future road vehicle technology pathways and policy levers targeting modal shifts and a reduction in motorised travel (see Figure 3). The findings show that:

Electric vehicles confer substantial reductions in GHG emissions and energy demand compared to internal combustion engines (ICEs), with the potential for zero direct emissions from road transport at less than half the energy supply requirement when compared to an ICE vehicles.

The purchase cost of an EV is the key barrier to widespread adoption. Policy incentives to reduce the cost of ownership of EVs should therefore be prioritised with public-private participation targeting public transport.

A large electric vehicle fleet leads to a 20% increase in electricity demand by 2050. The corresponding investment in power generation replaces needs to upgrade existing refineries to improve fuel quality. No additional investment in new crude-oil refinery capacity would be warranted.

In the context of South Africa's NDC, an electric vehicle fleet, with zero tail-pipe emissions, potentially provides for a more equitable decarbonisation of the power sector by allowing the extended operation of existing coal plants in the near term. The increase in emissions from the power sector are balanced in the long term (2040-2050) by a zero GHG emissions road fleet.

Corridor freight heavy vehicles present an opportunity for a hydrogen supply chain in South Africa. Hydrogen as a transport fuel mainly replaces diesel in the corridor freight fleet. The level of hydrogen demand is dependent on both the choice of road vehicle technology and modal shift accounting for 6% to 17% of total vehicle-kilometres driven in freight road transport.

Shifting road vehicle-kms to rail is key to achieving substantial energy savings. A low carbon and functional transport system should therefore include public transit at its core, with rehabilitation of the rail system a priority. A backlog of road maintenance exists and, excluding urban roads, is estimated to cost R417 billion (Townsend and Ross 2018). A continued reliance on road vehicles will require additional revenue for both new road capacity and functional maintenance.

South Africa's Green Transport Strategy (GTS) is the current policy roadmap for informing low carbon transport policy in South Africa; and should therefore strive for a coherent and consistent approach to address emissions mitigation. The GTS promotes low carbon alternatives but potentially counterproductive measures are tabled which may defer or avoid investment in zero GHG emissions alternatives due to the likelihood of technology and supply chain infrastructure lock-in.

A transition to a low carbon and energy efficient transport future would result in disruptions to the existing liquid fuel supply chain. An implementation strategy spanning provincial and municipal boundaries is necessary to: minimise the disruption associated with restructuring of the fuel supply industry; and facilitate urban planning that promotes public transport and non-motorised travel. This requires streamlined vertically and laterally integrated development frameworks that conform to the strategic national objective of an affordable low carbon and energy efficient transport system. Key objectives for an ambitious transition in transport as indicated in this study are summarised in Table 1.

Table 1 **Key recommendations for a low carbon and energy transport system in 2050**

Target	Measures and Interventions
Freight	Prioritise rail systems along corridor routes.
	Investigate the potential for advancing the hydrogen fuel-cell value chain in South Africa. A hydrogen roadmap which considers the assembly or manufacture of hydrogen fuel-cell heavy vehicles for domestic and export markets.
Public transport	Streamline and integrate national and regional land and transport development policies.
	Harmonise transport policies and strategies within national climate and socio-economic imperatives (i.e. spatial development incorporating housing and affordable and efficient transport).
	Priority investment in rail, BRT and minibus infrastructure with a 50 year planning horizon.
	Deploy EVs in the public transport system. Schemes such as the Taxi Recapitalisation Programme and Carbon Tax revenue could provide a means for the subsidisation of electric public passenger vehicles.
	BRT systemic integration into the road network, prioritizing high speed BRT corridor lanes.
Electric Vehicles	Capacitate local auto-industry for an EV transition to reduce the risk of public investment in stranded infrastructure and technology lock-in. Incentives for the manufacturing of electric minibus taxis and light commercial vehicles as a catalyst for a domestic EV market.
Fuel Supply	Additional investment, in the near term, in the existing crude-oil refineries for the Euro-2 to Euro-5 standard is required for a continuation of ICE vehicle deployment. A holistic policy of electricity sector decarbonisation and EV deployment would not require the above investment in refinery refurbishment or new refineries. The domestic synfuel complex should be assessed for its potential as a green hydrogen-based supply of transport fuel and chemicals.

1. INTRODUCTION

The landmark 2015 Paris Agreement includes a long-term temperature goal of "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" (Paris Agreement Article 2.1 (a)). In the same decision (1/CP.21), countries requested the Intergovernmental Panel on Climate Change (IPCC) to produce a special report on the impacts of global warming above 1.5°. In response, in 2018 the IPCC produced the Special Report on Global Warming of 1.5°. The Report makes it very clear that a) we are already facing climate impacts; b) that these will be significantly worse at 2° than at 1.5°; and that global CO_2 emissions pathways consistent with keeping global temperature within the 1.5° limit require rapid global emissions reductions – 45% by 2030 (in relation to 2010 levels) and global CO_2 emissions should reach net zero[1] by 2050 (IPPC, 2018).

The findings of the report formed the basis of the call by the UN Secretary General to countries, to take urgent additional climate action at the UN Climate Action Summit, held ahead of COP 25 in 2019. The conclusions to COP 25 urged all countries, in the light of their responsibilities and respective capabilities, to address the "emissions gap" between current mitigation commitments (in NDCs, and from Cancun, for 2020) and what is required, in their NDC updates in 2020.

Existing Nationally Determined Contributions (NDCs) under the Paris Agreement will result in global warming of 2.9-3.4°C (UNEP 2019). Countries will need to significantly increase their mitigation ambition in their NDCs updated in 2020, and in subsequent NDCs communicated in 2025, in order to keep the global effort to address the climate crisis on track.

What does this mean for a country such as South Africa? Previous mitigation analyses aimed at limiting emissions to 2050[2], based on mitigation potential (in turn based on available technologies and their costs). In the longer term, the Paris Agreement in its Article 4.1, requires countries to achieve peak GHG emissions as soon as possible, and "to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty".

This provides all countries with an envelope for not only limiting emissions, but reducing emissions to net zero before 2100. The IPCC's SR15 requires this to occur globally around 2050 for CO_2, and for there to be "deep reductions" in other gases. Long-term planning therefore should consider how to reduce emissions to zero in each sector of the economy, where this is feasible, and identify sectors and/or subsectors in which this is currently not possible, to look at future technology options, in the context of sustainable development challenges in the overall economy.

This paper therefore takes a closer look at the transport sector in South Africa in this context, to explore what the future GHG emissions of the sector will likely be under a number of scenarios featuring different policy options, and what would be necessary to decarbonize this sector in South Africa.

1. 'net zero' means that globally, we reach a point at which CO_2 sources equal CO_2 sinks.
2. For instance the Long-Term Mitigation Scenarios (LTMS - 2007) and the Mitigation Potential Analysis (MPA – 2014) both explored options to limit South Africa's emissions to 2050. While the LTMS did underpin South Africa's "Peak, Plateau and Decline" emissions benchmark range, which proposes emissions peaking between 2025 and 2035, neither analysis addresses the question of sectoral or national decarbonisation or of net zero emissions.

2. DECARBONISED TRANSPORT: THE IMPERATIVE OF A SUSTAINABLE TRANSPORT TRANSITION

The transport sector is responsible for roughly a quarter of energy-related CO_2 emissions globally, but transport emissions are increasing at a rate faster than other energy-end-use sectors (IEA 2019). Road vehicles account for the bulk of transport emissions, approximately three quarters of global transport emissions (IEA 2019). In South Africa, this figure is even higher, with more than 90% of transport emissions arising from road transport (WWF 2016). Globally, despite advances in vehicle efficiency, alternative fuels and alternative mobility technologies, road transport emissions continue to increase – offsetting mitigation savings (ITF 2019). Thus, while switching to less carbon intensive fuels and less energy intensive technologies is critical, politically ambitious policy responses which address institutional, infrastructural and behavioural inertia will determine the pace and cadence of the transport transition.

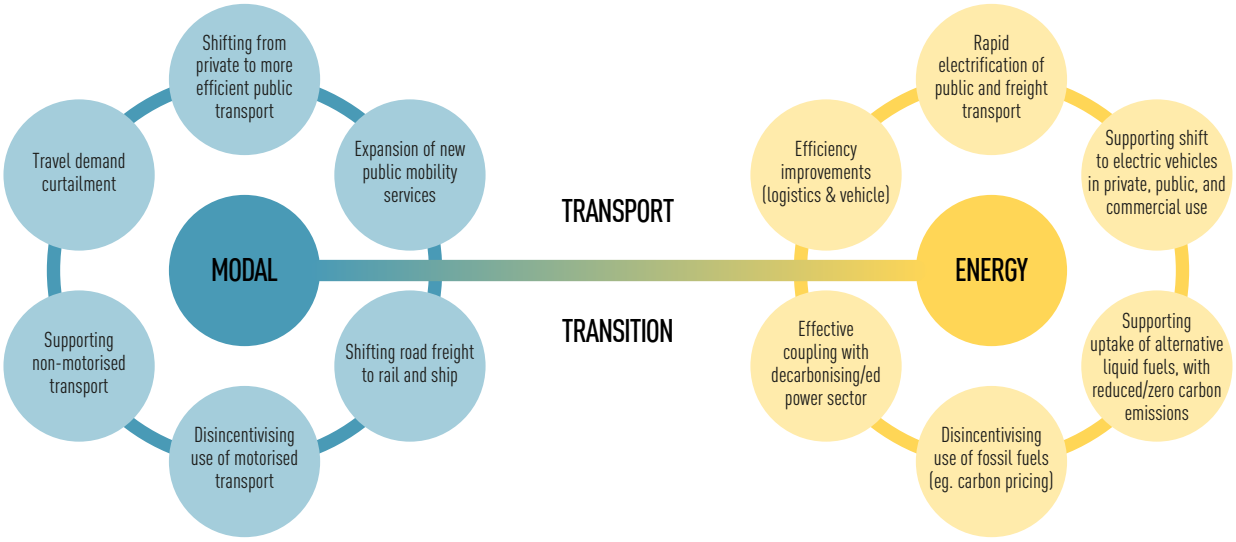
Specific, ambitious and actionable transport-related policies and targets are lacking at the national and international level, undermining climate objectives and the net zero targets outlined in the IPCC Special Report. According to the ITF Transport Outlook (2019), worldwide transport emissions are set to grow by 60% by 2050, even if current and announced mitigation policies are implemented. While the importance of decarbonising the transport sector is widely acknowledged, the path to decoupling transport activity from CO_2 emissions is far from clear. At the same time, as our analysis indicates, there are strong economic imperatives which will over the next three decades drive the transport sector towards more efficient and lower-emitting technologies such as hybrid and electric vehicles. This transition will not necessarily drive sustainable development outcomes such as the universal provision of affordable mobility services, and will also not necessarily drive the transition at the speed necessary to meet overall mitigation goals. Moreover, the transition will also involve considerable disruption to both the supply of liquid fuels, vehicle manufacture and to the transport sector itself – these also need to be mitigated via policy. These three objectives will require a suite of policy responses to support a just transition in the transport sector.

2.1 Taking the Imperative to Policy: Driving Decarbonisation in the Transport Sector

Policies which aim at decoupling transport from emissions are necessary to achieve climate objectives, while also enabling economic activity and meeting passenger mobility needs. Demand for transport is driven by changes in GDP, population, trade, technology and geography/urban design. Supply and demand-side interventions to shape demand trends and plan for decarbonisation therefore rest on two major levers.

1. Modal Shifting: The first relates to changes in mobility that contribute to reduced energy consumption, while meeting mobility demand. For example, a private car user switching to public, electrified transport to meet the same transport needs. These changes are associated with significant gains in relation to sustainable development objectives in the transport sector. Coupled with urban design that focuses on mobility and accessibility, modal switching can contribute to the enhancement of low pollution and congestion public transport systems to the benefit of all.
2. Fuel Switching: The second relates to changes in energy use or the energy mix in transport, i.e. meeting energy needs more efficiently while generating less emissions. For example, the electrification of bus rapid transit (BRT). Popular measures for each lever are captured in Figure 1 below.

Figure 1: **Transport Transition Levers & Measures**



These levers relate to broad policy areas which impact how people and businesses use transport within communities and economies. For example, urban planning that supports densification is an important lever for better service delivery in cities, including transport - where demand is reduced and transport needs are more equitably provided for, supporting better economic and social outcomes. Policy mechanisms to effect such changes, include:

- financial and pricing instruments (subsidies, taxes, direct payments, etc.);
- mandatory standards and regulations;
- infrastructure investment and support programmes for new/non-motorised technologies and/or low-carbon fuels;
- public education and marketing; and
- national capacity building.

While the main levers and many of the policy measures and mechanisms are known, the feasibility of selecting the right mix of interventions and implementing them at pace to achieve a rapid low carbon transport transition by 2050 requires attention. This is compounded by the interlinkages between transport and other sectors, most importantly electricity and liquid fuel production, as well as important considerations relating to sustainable and inclusive development. Where the ITF (2019) high ambition scenario results in global CO_2 emission reductions in the transport sector of 30% by 2050 – from 7 230 $MtCO_2eq$ in 2015 to 5 026 $MtCO_2eq$ in 2050, decarbonising the transport sector in accordance with the PA will require more ambitious targets which our analysis suggests could be facilitated via a policy of electrification of transport.

3. A TRANSPORT TRANSITION FOR SOUTH AFRICA

In this paper, we explore the potential to decarbonise the South African transport sector through exploring a combination of two packages of interventions, as outlined above. The first of these consists of vehicle technology shifts – from the current dominance of internal combustion engines to various forms of electric and hybrid vehicles. The second is a concerted set of policy interventions resulting in lower transport demand (spatial planning, transport avoidance, promotion of non-motorized transport options), and a modal shift of freight and passenger transport. We use a full-sector energy model to understand the implications of these shifts for GHG emissions in the transport sector, in energy supply sectors, and in the overall economy.

3.1 South African Transport Sector Overview

South Africa has the most developed transport and logistics sector in Sub-Saharan Africa, reflected in its relatively modern infrastructure and effective trade facilitation (PWC 2014). Though road transport dominates, the country also operates regionally important ports and hosts the largest rail and air network on the continent.

The transport sector faces significant challenges which encumber inclusive economic development and incur significant environmental, health, and safety externalities. Primary challenges include:

- An unequal and inefficient public transport sector, partly the legacy of its underdevelopment during apartheid,
- the migration of freight from rail to road, and
- underinvestment in infrastructure resulting in ageing infrastructure with an increasing maintenance backlog.

In South Africa, the imperatives of a transport transition stem not only from the need to reduce emissions to abate climate change but also from the need to create a more equitable and efficient transport system. Many of the core elements of a transport transition – including improved, integrated public transport systems, urban densification, shifting freight from road to rail, and electrification – have the potential to address the socio-economic and environmental ambitions of the country as espoused in the National Development Plan (RSA, 2011)

3.2 Status and Trends in Transport Sub-Sectors

Public & Private Passenger Transport

The South African public transport system is characterised by inefficiency and inequality. Under apartheid, transport infrastructure development and polices were used to enforce racially segregated cities and rural/urban divides, leaving the country with the legacy of a fragmented, unequal and inefficient public transport system. According to the 1996 White Paper on National Transport Policy, this contributed to a pattern of "low

density development, spatially dislocated settlements and urban sprawl [which resulted] in inordinately long commuting distances and times, low occupancy levels, high transport costs and low cost recovery" (RSA 1996). For urban and rural poor, access to school, work, and public services continues to entail long commutes i.e. higher demand for passenger kilometres (km). Informal and poorly integrated transport networks also necessitate long walks to, from, and in-between public transport options – increasing already lengthy commutes. Furthermore, embedded inefficiencies in the allocation of urban space (giving priority to private vehicles) contributes to continued exclusion and inaccessibility, as well as high levels of congestion and urban pollution.

Travel times and costs are increasing, along with congestion and pollution (TomTom 2019; IEA 2016). Hitge & Vanderschuren (2015) indicated that South Africans generally spend more time than the global average commuting via motorised travel (90 mins vs 70 mins for private travel) with travel times via public transport at an average of 110 mins. An ongoing trend of commuters migrating to mini-bus taxis and cars away from rail has increased road congestion with negative economic consequences (StatsSA 2019b; KPMG 2014). Long commute times and the cost of public transport are key barriers to further patronage (StatsSA 2014; Luke & Heyns 2013). Van Ryneveld (2018) states that, in 2013, lower income groups spent >20% of their monthly household income on transport. Despite the fact that rail is significantly cheaper than mini-bus taxis and buses, both which are substantially more affordable that private car use, the trend away from public transport (specifically rail) reveals the increasing dysfunctionality of the public transport system (Luke & Heyns 2013; Ngubane 2017; Van Ryneveld 2018).

The 2013 National Household Travel Survey, revealed an increasing trend in private motorised travel over the past decade (StatsSA 2014). With respect to passenger vehicles, from 2013 to 2018 the motorization rate (thousands of vehicles per person) is estimated to have increased 6%, from 119 to 126. The private vehicle fleet comprises the largest share in terms of vehicle population and transport emissions. While public transport is an important mode, largely informed by travel time and cost, a trend of increasing travel by private vehicle is evident. Furthermore, South Africa has a well-developed local automotive manufacturing industry - reportedly responsible for 7.5% of GDP (including multipliers[3]) and employing 113,532 people across assembly, components and tyre manufacturing sub-sectors. This presents additional policy challenges and opportunities with regard to technology choices for future road vehicles (StatsSA 2018; Jordaan et al. 2018; Dane et al. 2019).

With the population projected to increase to 75 million by 2050, a holistic national approach to reversing these trends is required.

Commercial Transport & Freight: Road, Rail & Maritime Transport

In the commercial transport and freight sector, the majority (85%) of transport is via road with existing rail capacity not fully utilised at significant cost and losses associated with inefficiency (Havenga 2013; Havenga et al. 2016). Increased demand for freight transport has – to a large extent – been met by an increase in heavy vehicles, in part due to deregulation which has contributed to the underutilisation of rail (DoT 2018). This trend contributes not only to higher GHG and air pollutant emissions, but also to the faster deterioration of roads and increased maintenance costs. Excluding urban roads, the current backlog of road maintenance is estimated to cost R417 billion (Townsend & Ross 2018). To put this into perspective, this is almost double annual health expenditure for 2019 (NT 2019). Approximately 78% of South Africa's road network is thought to be older than its original design life, and 30% of the road infrastructure is rated as being in either 'poor' or 'very poor' condition (DoT 2018).

South Africa's rail infrastructure and rolling stock is also ageing, poorly maintained, and deteriorating rapidly in the face a significant capital investment and maintenance backlog.

With more than 95% (by volume) of the country's imports and exports shipped by sea, maritime shipping and transport plays a critical role for the South African economy – yet South African ports are "characterised by high costs and substandard productivity relative to global benchmarks" (RSA 2011). The maritime shipping industry is dominated by international companies – but includes a small portion of South African shipping companies operating through off-shore subsidiaries (DoT 2011). This reflects international trends associated with the globalisation of the shipping industry in a free trade environment. Nevertheless, the shipping industry is of critical importance to the South African economy, requiring "massive investment in infrastructure, innovative technology, and proper management" of ports and integrated transport systems and effective regulation of the shipping industry (DoT 2017).

Aviation: Passenger & Cargo

Similarly to other segments of the transport sector, aviation[4] demand is increasing yet the sub-sector faces challenges when it comes to the aging air fleet and lack of funding for retrofitting the current fleet, limited scope for continued fiscal support, and a lack of integrated transport planning (DoT 2018).

In terms of passenger transport, scheduled domestic traffic dominates – accounting for ~24 million passenger trips a year, followed by scheduled international flights at 10.3 million passenger trips per year (IATA 2014 cited in DoT 2015). However, only about 10% of South Africans currently use air transport, which reflects broader trends in income inequality and transport use.

3. This is inclusive of retail and aftermarket repair activities, although the manufacturing contribution represents most this amount (DTI 2018)

4. Aviation includes passenger and cargo transport, as well as non-commercial activity (eg. private sports, recreation, & private flights).

When it comes to airfreight, international traffic dominates – accounting for 83% of all volumes, the majority (55%) of which is inbound (DoT 2015). Demand for both passenger and freight aviation is forecast to grow at a level slightly above to ~2x GDP of the growth rate over the next 30 years.

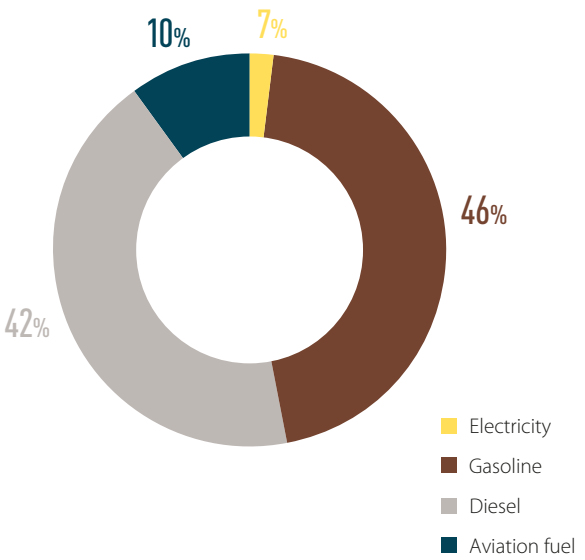
3.3 Transport Emissions Profile

In 2015, emissions from the transport sector were estimated to account for 10.8% of the country's total GHG emissions, and 14% of energy related CO_2 emissions. Upstream emissions from the production, refining and transportation of liquid fuels (not included in the transport sector) also contribute significantly to GHG emissions, largely emanating from the emissions-intensive coal-to-liquids conversion process, which accounts for 7.7% of national emissions while meeting only 20% of the country's petrol and diesel needs (DEA 2013). The emission intensity of liquid fuel production and the electricity sector highlight the importance of integrated energy supply chain transitions. With road transport accounting for the majority of fuel demand (Figure 2) and 91.2% of the sector's emissions, it is the area with the greatest mitigation potential.

3.4 The Green Transport Strategy 2018-2050

South African transport policy underscores the importance of transitioning to an accessible, cost-reflective and affordable low carbon transport system. This is evident in the National Transport Master Plan 2050 (NATMAP 2050), the primary policy basis for transport planning in South Africa. Building from the NATMAP and in response to the National Climate Change Response Policy (2011), which advocates a climate-resilient and low carbon economy by 2050, the Green Transport Strategy was published in 2018[5]. The Strategy considers various policy interventions that could contribute to substantially reducing "GHG emissions and other environmental impacts from the transport sector by 5% by 2050", while promoting economic growth and inclusive development (DoT 2018). These are captured in Table 2 below.

Figure 2: **Total transport fuel consumption by fuel type**



Merven et al. 2019

Table 2 **Green Transport Strategy Themes & Pillars**

Implementation Themes	Strategic Pillars
Climate Change Response Norms & Standards	1. Develop norms & standards for climate change response at National, Provincial and Local level to ensure that there is consistency in the way climate change responses are implemented across different jurisdictions.
Green Roads	2. Shift car users from *individual* private passenger cars to public transport, including rail. 3. Provide infrastructure to promote non-motorised transport and eco-mobility transport. 4. Provide transport infrastructure in a manner supportive of the eco-system, while not clearly compromising generations to come.
Green Rail	5. Extend the rail network to provide reliable, safe, and affordable high-speed transport while switching to renewable energy trains.
Green Transport Technologies	6. Reduce the carbon footprint of over-reliance on petroleum based fuels, by decarbonising the transport sector. 7. Promote alternative fuels, such as compressed natural gas (CNG) or biogas, and liquid biofuels as transport fuels. 8. Promote electric and hybrid-electric vehicles.
Green Fuel Economy Standards	9. Develop "Green Procurement Guidelines" to promote efficient and low-carbon vehicle technologies. 10. Provide norms, standards, and regulations that promote green fuel economy in vehicles and improve emissions standards of fuel in South Africa.

DoT 2018

5. For an overview of the legislative and policy basis for climate change mitigation in the transport sector, see section 4.2 of the Green Transport Strategy (2018)

The Strategy also outlines six short-term strategic targets or "quick-wins", to be implemented within 5-7 years, captured in Box 1 below.

Previous analysis of the Green Transport Strategy found that the implementation of strategic targets and measures contained in the plan resulted in an emission reduction of ~70% in the transport sector by 2050, with a positive impact on economic growth and employment (Ahjum et al. 2019). The most important factor identified was a shift to electric vehicles, assuming costs become comparable with internal combustion engines: EVs being solely responsible for an emissions reduction of ~50% in transport relative to a scenario in which ICE vehicles predominate.

Box 1: Green Transport Strategy Short-term Strategic Targets

1. To achieve modal shifts in the transport sector that reduce GHG emissions and other harmful emissions, reduce transport congestion and improve temporal, spatial and economic efficiency in the transport sector. In particular, achieve a 30% shift of freight transport from road to rail by a 20% shift of passenger transport from private cars to public transport and eco-mobility transport.
2. To convert 5% of the public and national sector fleet in the first seven years of the implementation of this strategy and an annual increase of 2% thereafter, to cleaner alternative fuel and efficient technology vehicles (ideally powered through renewable energy) and environmentally sustainable low carbon fuels by 2025, including the use of CNG, biogas and biofuels and the use of renewable energy to provide electricity for transport.
3. To reduce fossil-fuel related emissions in the transport sector by promoting norms and standards for fuel economy and putting in place regulations that promote improved efficiency in fossil fuel powered vehicles and improved environmental performance of fossil fuels.
4. To promote strategies and standards for delivering transport infrastructure, integrated transit planning and systems that build climate resilience in urban and rural communities, whilst minimising the environmental impact of transport infrastructure.
5. To develop best practice guidelines to ensure that integrated, climate- friendly transport options are incorporated into land use and spatial planning at national, provincial and local levels.
6. Invest in sources of green energy's infrastructure, such as biogas filling stations, electric car charging points, GIS integrator ICT technology platforms for locating stations, regulating future pricing and providing statistics.

DoT 2018

4. MODELLING AN AMBITIOUS TRANSITION IN TRANSPORT

The South Africa TIMES (SATIM) model allows for the interrogation of transport futures to gauge their influence on energy supply and demand, and their consequent economic and environmental impact (Appendix A). As highlighted in Section 1, the composition of mobility services are a function primarily of technology and spatial form. As such, vehicle technology and spatial planning, in tandem with modal shifting of transport services – an outcome of both land and transport development policy, form two key axes from which four transport scenarios are derived. As depicted in Figure 3, the technological and policy landscape is thus defined by:

1) Vehicle Technology (horizontal axis):

a. Non-EV automotive sector: South Africa's auto industry remains a laggard in switching to EV manufacture, and the current EV importation tax remains over the period such that the purchase cost of an EV remains at a premium to competing ICE technology. Domestic production of hybrid-ICE vehicles are cost competitive alternatives. Policies to encourage a shift to EVs (including cars, buses and LDVs) are not pursued.

b. EV automotive sector: A transition in the domestic auto-industry towards EVs occurs. In South Africa, EVs reach cost parity with ICE and Hybrid-ICE technology by 2030.

Since South Africa contains more than 80% of the world's known reserves of platinum, a shift towards mineral beneficiation is assumed which would result in a local hydrogen supply chain stimulating the production or assembly of hydrogen fuel-cell heavy vehicles (HFCVs).

2) Spatial Planning and Modal Shift (vertical axis):

a. Road vehicle emphasis: Development without a specific policy regarding modal shifting in freight or passenger transport, results in a transport sector in which passenger transport is dominated by the use of private vehicles and freight transport is dominated by road freight.

b. Modal shift and transit-oriented development: spatial planning and resource efficiency policies address increasing road congestion and local air pollution. Ambitious modal shifting in freight and passenger transport is implemented. Furthermore, Transit Oriented Development (TOD) reduces motorised transport demand.

The four transport futures are based on the interplay of these two sets of interventions. The accompanying modelling assumptions are described in Table 3.

Figure 3: **Transport carbon pathways for South Africa towards 2050**

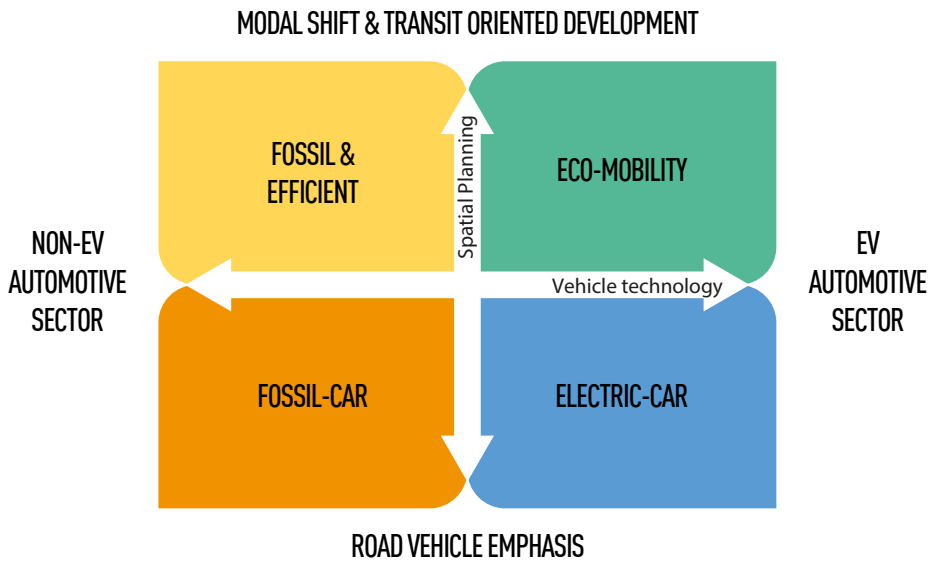


Table 3 **Summary of transport scenarios with key model assumptions**

Transport Pathway	Policy Narrative	Policy Levers	Technologies
Fossil-Car	■ Non-EV local Industry ■ No imperative for public transport and Road-to-Rail migration	■ Expensive EV: cost at 25% premium to ICE technology in 2050 ■ No change in rail share of corridor freight ■ Declining public transport patronage	■ Hybrid-ICE /ICE cost competitive vehicles ■ Late development of HFCV for Heavy Vehicles (e.g. Buses, Trucks)
Fossil & Efficient	■ Non-EV local Industry ■ Public transport and Road-to-Rail migration ■ Reduction in motorised travel via TOD	■ Expensive EV: cost at 25% premium to ICE technology in 2050 ■ 70% of freight road corridor migration to rail by 2050 (DEA 2014) ■ Reversal of public transport defection to ~ 2012 modal share of rail ■ TOD reduces motorised travel demand by 10% in 2050	■ Hybrid-ICE /ICE cost competitive vehicles ■ Late development of HFCV for Heavy Vehicles (e.g. Buses, Trucks) ■ Migration to rail in freight and passenger transport
Electric-Car	■ EV local Industry ■ No imperative for public transport and Road-to-Rail migration	■ Cost parity for electric drivetrains by 2030 ■ No change in rail share of corridor freight ■ Declining public transport patronage	■ EV/HFCV cost competitive by 2030
Eco-Mobility	■ EV local Industry ■ Public transport and Road-to-Rail migration ■ Reduction in motorised travel via TOD	■ Cost parity for electric drivetrains by 2030 ■ 70% of freight road corridor migration to rail by 2050 ■ Reversal of public transport defection to ~ 2012 modal share of rail ■ TOD reduces motorised travel demand by 10% in 2050	■ EV/HFCV cost competitive by 2030 ■ Migration to rail in freight and passenger transport

While cognisant of South Africa's NDC pledge, the transport scenarios are modelled in the absence of a national GHG emissions constraint to gauge the direct impact of tabled measures on transport emissions. The results are contrasted with additional modelling which limits cumulative economy wide-emissions over the 2015-2050 period to a carbon budget of 7.75Gt. McCall et al. (2019) had previously suggested that an economy-wide budget of 7.75 Gt was the lowest emissions threshold that the country could sustain without negative economic impacts. For clarity, the Fossil-Fuel and Eco-Mobility scenarios are compared with this carbon budget as these comprise the two extreme contrapuntal emissions pathways for transport.

4.1 Exploring the technical feasibility of an ambitious transition

Growth Factors

The primary drivers of growth in transport services are GDP and population growth.

The South African population is currently estimated at ~57 million people and is projected to increase to 75 million by 2050 (UN 2019).

The economy is forecast to grow at approximately 3% per annum on average over the period 2020-2050. Economic growth between 2018 and 2022 is based on medium term projections from the National Treasury MTBPS (NT 2018a) and the International Monetary Fund (2018). Longer term growth projects are aligned to meet the Department of Energy's planning growth rate of ~3% to 2050 (DoE 2016)

These are captured, as represented in Figure 4, in the SATIM model. Densification and Transit Oriented Development (TOD) which would decouple the rate of demand for passenger motorised travel with population growth is an additional factor to consider. In this study, owing to a lack of local studies, the results of Pye and Daly (2015), based on a UK analysis, is adapted to provide a conservative assumption about a potential reduction in passenger motorised travel in 2050 for South Africa.

Fuel Supply

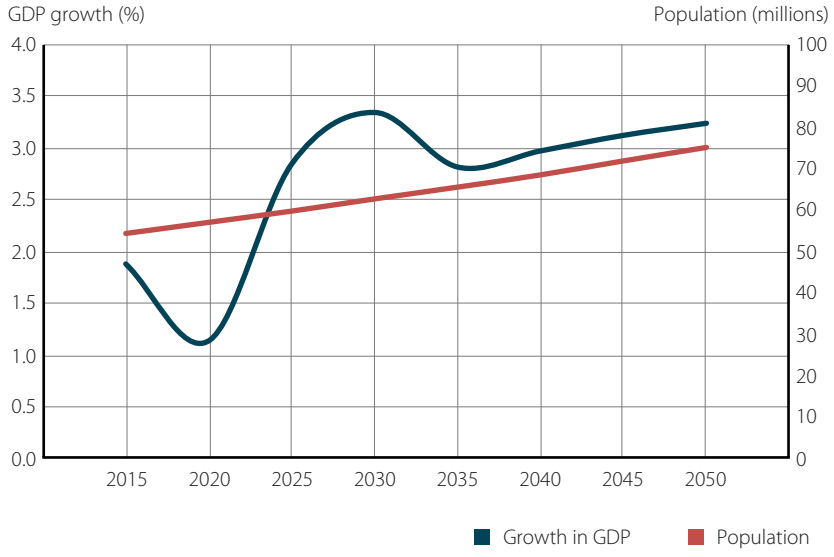
With a total production capacity of 718,000 barrels/day (oil equivalent) South Africa produces the majority of its liquid fuels from imported crude oil and domestic coal via liquefaction (SAPIA 2018).

A transition will have a dramatic impact on the domestic liquid fuels supply chain (KPMG 2017).

In 2012, South Africa gazetted the Cleaner Fuels 2 (CF2) regulations to improve the quality of local fuels from the current Euro 2 standard to the Euro 5 standard, to become effective in 2017 and estimated to cost R41 billion (2015 Rands) (DoE 2011; SAPIA 2017). Its implementation has however reached an impasse with industry and government in disagreement regarding the responsibility for financing the refurbishment of the refineries. Nonetheless, in this model we assume that the CF2 regulations will be effectively implemented by 2030. Existing crude oil refineries will either need to invest in refurbishment or cease production to observe these regulations. The establishment of a new, large refinery is included as an option rather than assumed as a fixed investment (Africa Oil and Power 2019). A median global crude oil price is modelled at US $80/barrel (2015 prices) over the period 2030-2050.

In addition, we assume that South Africa's existing coal-to-liquid (CTL) facility (see Box: 2) - retires in 2040. It is worth noting that this single development in the liquid fuels supply sector has a mitigation impact comparable to the decarbonisation of the entire transport sector.

Figure 4: **Projected population and economic growth for South Africa**



Box 2: CTL Fuel Supply

South Africa operates a large coal-to-liquids facility - 150,000 bbl/day oil equivalent - which is responsible for close to a third of domestic liquid fuel supply on average. Operating with an efficiency of ~30%, its emissions are comparable in magnitude to the transport sector accounting for 12% of energy-related CO_2 emissions.

Vehicle Efficiency, Speed & Occupancy Factors

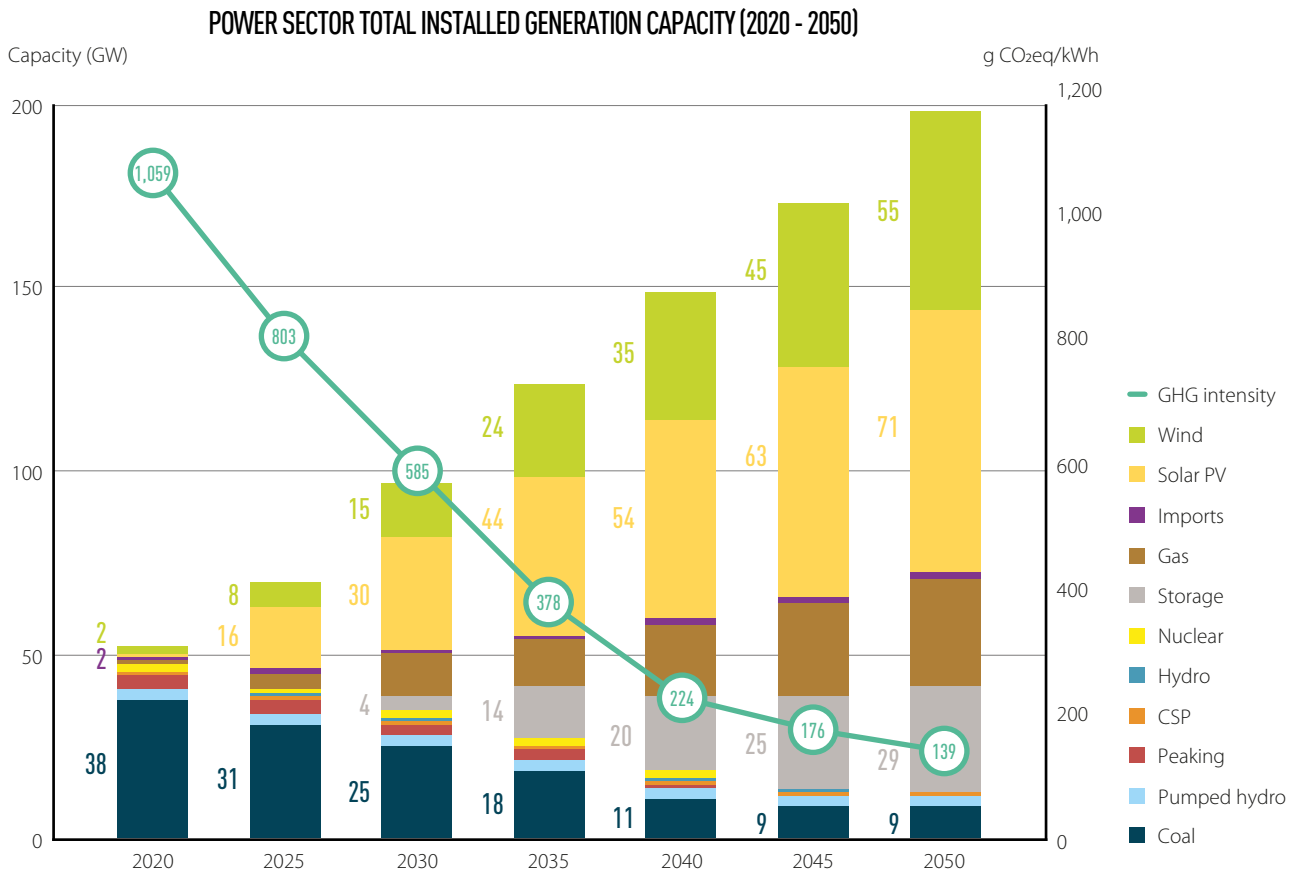
An increase in vehicle efficiency is an important mechanism to decrease emissions in the transport sector. However, we maintain conservative assumptions as reported in real world testing of road vehicles (IEA 2019). The model assumes, conservatively, an annual vehicle fuel efficiency improvement of 0.5% and 0.1% for public and freight road vehicles, respectively, as is modelled in the Integrated Energy Plan (DoE 2016). Average vehicle speeds and passenger occupancy factors are assumed to be constant across the period.

The Power Sector

Decarbonisation of the power sector will determine, to a large extent, the feasibility of a low carbon transport transition if such a transition will primarily rely on the electrification of mobility. SATIM, being a full-sector energy model, provides a detailed representation of the power sector for South Africa with technology options for new generation, and accounts for any additional emissions in the power sector arising from transport electrification. In this work, the following assumptions are made for the development of the power sector, as adapted from McCall et al. (2019): Minimum Emissions Standards requirements for the coal fleet are implemented from 2025; limits on the total new capacity of renewable energy technology until 2030 after which there is no limit; and a stipulation that battery storage capacity needs to be supplemented with natural gas-fired generation capacity for added reliability. The result is that all new generation capacity is in the form of either wind, solar PV, or gas, with large amounts of battery storage to compliment the variability of the RE capacity (Figure 5).

The GHG emissions intensity[6] of the grid declines from 1141 g/kWh in 2015 to 139 g/kWh in 2050, as older coal plants are decommissioned with some coal retiring early. By 2030, 51% of generation capacity is RE, and by 2050 this grows to 76%.

Figure 5: **The SATIM cost-optimal expansion of the power sector**



6. The intensity is calculated by accounting for all GHG emissions from electricity generation, and the total delivered electricity at the point of use after transmission and distribution losses.

4.2 Transport Transition Scenarios

The Spatial Planning and Modal Shift pathway results in a lower demand for passenger transport when compared to the Road Vehicle Emphasis pathway (Figure 6). Measured in passenger kilometres (p-km), the TOD intervention encourages a shift towards non-motorised travel. In contrast to the current captive modality experienced by low-income households, the TOD reduces demand for motorised travel by 10% in 2050. Also public transport, in particular rail, is prioritised over private travel with public transport reaching a 50% modal share in 2050 with rail travel accounting for almost 20% of total passenger travel. Within the freight sector the volume of goods transported, measured in tonne-kilometres (t-km), remains constant but road corridor freight experiences a shift to rail from a share of approximately 15% to 70% in 2050 (Figure 7).

The significance of modal switching highlights the interdependencies of the transport sector and upstream sectors, specifically the electricity sector, given significant increases in rail share in both freight and passenger demand. This also raises important questions not only about infrastructure investment decisions, but also behavioural shifts and associated communication and incentive strategies. In other words, emission reductions will depend to a large extent on changing the way that people and businesses make decisions around and utilise transport infrastructure.

Emissions

In figure 8, the GHG emissions associated with the Fossil-Efficient and Eco-Mobility scenarios are compared. Overlaying the graphs, total emissions associated with the Fossil-Car and Electric-Car Scenarios are also compared. Both EV scenarios demonstrate the potential for the rapid decoupling of transport activity from emissions in South Africa. By 2050, aviation and maritime transport contribute the residual 9 $MtCO_2eq$ and 0.008 $MtCO_2eq$ in 2050, respectively.

In contrast, for the non-EV Fossil-Car scenario, emissions would peak at ~70 $MtCO_2eq$ and fluctuate at about 65 $MtCO_2eq$ in the case of no modal shift and TOD. This is due to the switch to Hybrid ICE passenger cars, which would gain a sizeable market share by 2030. Increased demand in the period 2045 to 2050 contributes to an increase in emissions by 2050, and highlights the limited potential for decarbonisation offered by fossil-fuelled hybrid vehicles.

Figure 6: **Modal split of passenger-km demand by technology**

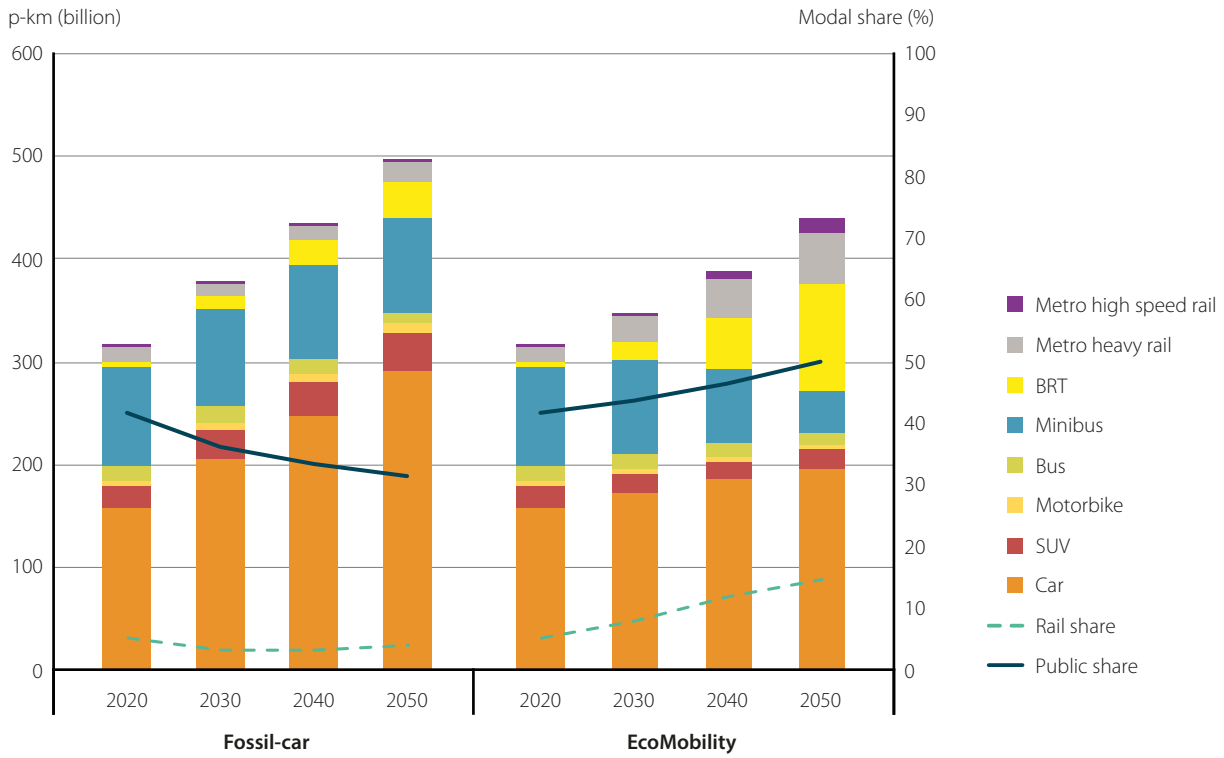


Figure 7: **Freight modal shares of tonne-km**

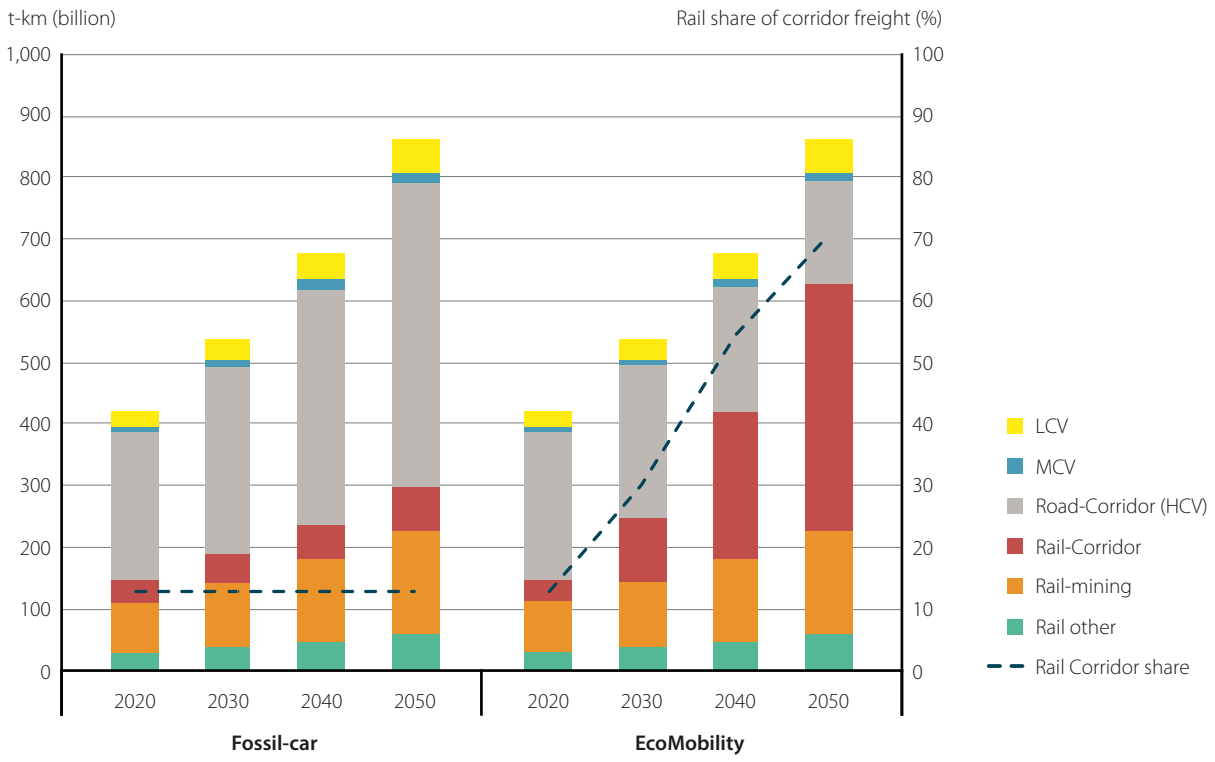
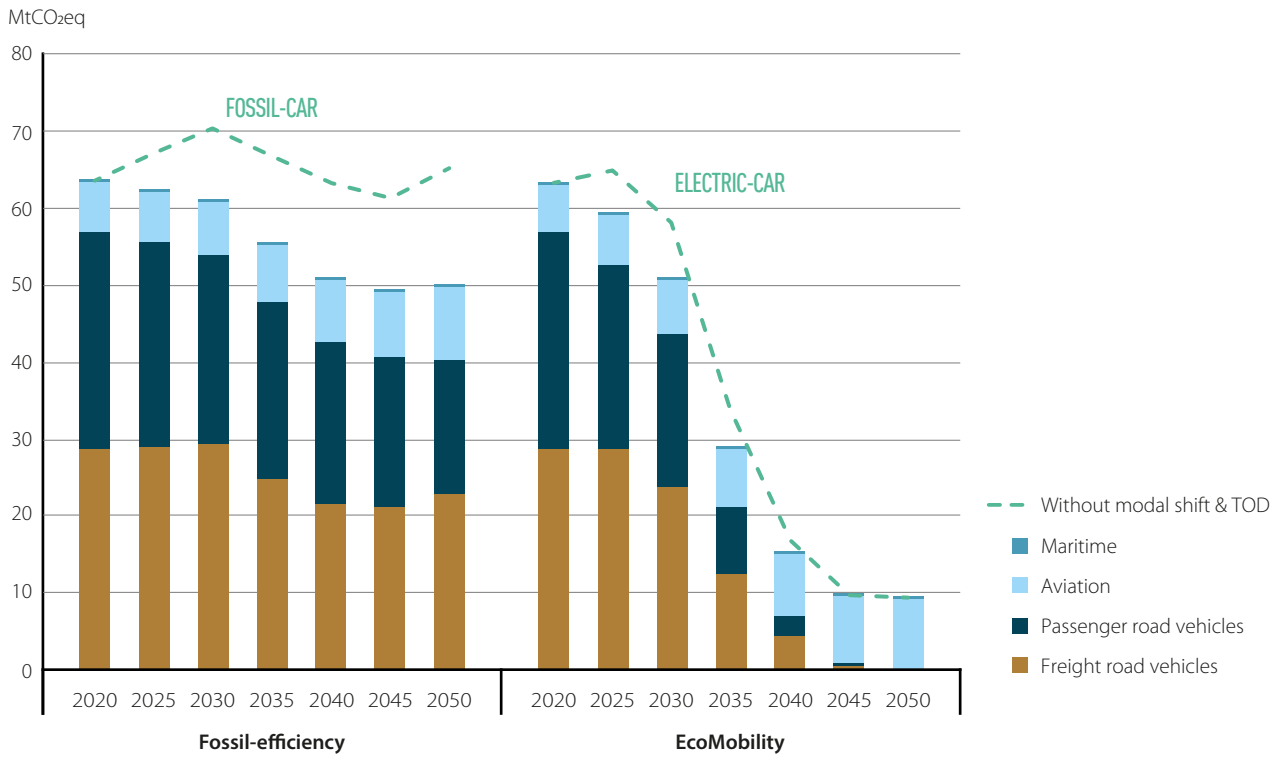


Figure 8: **Emissions from the transport sector**



Demand and Modal Shift

Modal switching has a substantial impact on direct emissions for the fossil fuel pathways but minimal impact for the electrified pathways in the transport sector (Figure 9). An electric pathway benefits in the medium term as a noticeable decline in emissions would occur from 2025 (5 $MtCO_2eq$) to 2030 (7 $MtCO_2eq$), with cumulative avoided emissions totalling 80 $MtCO_2eq$. In contrast, emissions in the fossil fuel scenarios would benefit from a modal shift in the latter period 2030 (9 $MtCO_2eq$) to 2050 (15 $MtCO_2eq$), with cumulative savings of 145 $MtCO_2eq$. The large difference between the two technology pathways reflects the impact of a transition to electric vehicles. The impact of both technology choice, fuel switching and modal shift is however important when quantifying energy supply for transport. Modal shifting is crucial to reducing final energy demand and improve both resource and economic efficiency (see *Impacts on Fuel Demand, Power Sector and Refineries*)

In contrasting the scenarios, modal shifting and TOD emerge as important interventions for long-term decarbonisation of both freight and passenger transport when considering the fuel supply chain. Figure 10 depicts the use of major transport fuels in each of the scenarios. Despite the negligible effect on emissions in the EV scenarios, one effect of considering the dimension of spatial planning is to reduce the net fuel demand.

Figure 9: **The impact of modal switching on direct transport emissions**

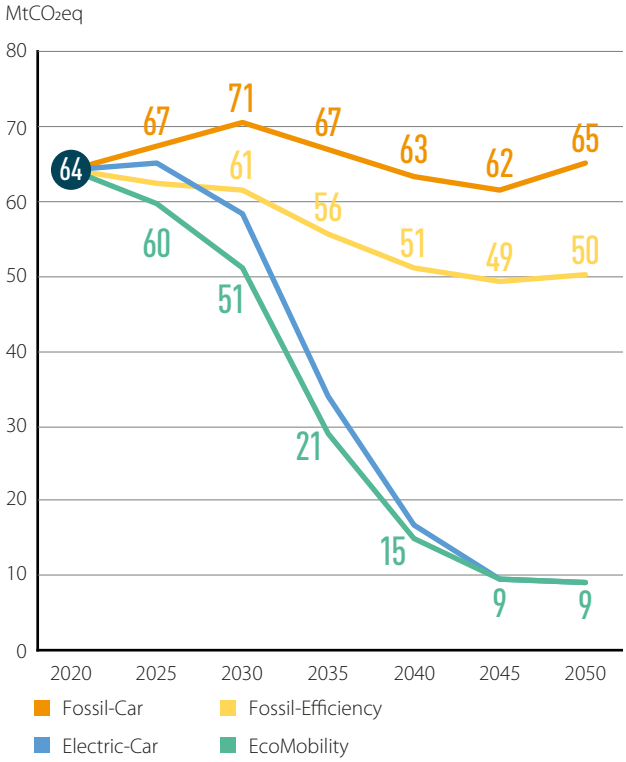
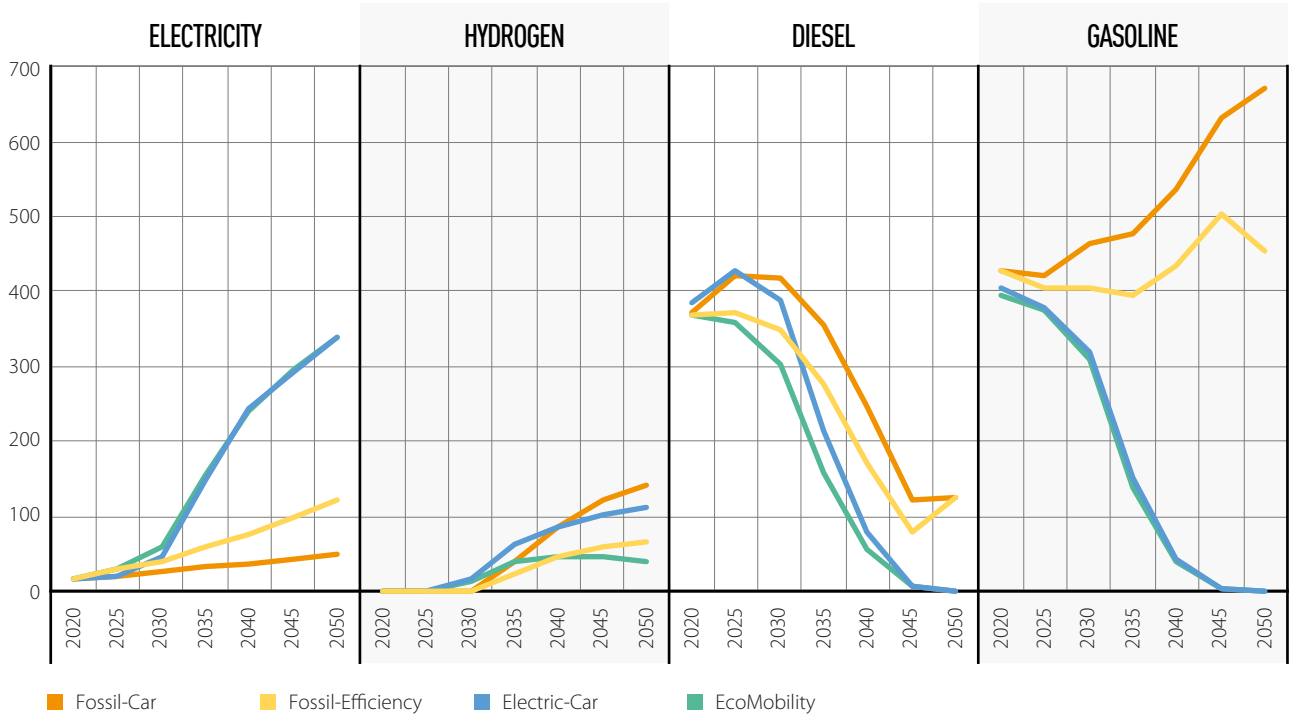


Figure 10: **Transport fuels**



In the EV scenario, liquid fuel demand for diesel is reduced in the early period as road to rail migration in freight occurs shifting fuel consumption to electricity. A modal shift also reduces the potential hydrogen demand in heavy vehicles towards electricity via rail. A progressive decline in diesel results mainly from a switch to hydrogen for heavy vehicles in corridor freight transport. The notable dramatic shift in the petrol/diesel ratio in the non-EV scenarios would have a significant impact on the economics of domestic liquid fuels production.

We compare potential vehicle technologies and population size as reflected in the scenarios, for private and public transport sub-sectors in figure 11 and 12, respectively. A domestic EV market has the potential to be fully electrified in 2050, whereas a non-EV market would have a preference for Hybrid-ICE vehicles in the private fleet, as well as hydrogen in the public fleet.

The key impact of modal shifting is to reduce the private passenger fleet size. A pathway with a road-vehicle emphasis results in a passenger vehicle population of approximately 13 million in 2050; nearly doubling from the current registered population of 7.4 million. In contrast, modal migration and TOD could reduce the vehicle population to approximately 8 million in 2050.

A decrease in the private passenger fleet is interestingly matched with a decrease in public transport vehicles to meet passenger demand: 250,000 compared to 225,000 (Figure 12), with a combination of rail and buses (including and BRT) displacing minibus taxis by 2050 (Figure 13).

Figure 11: **Private passenger road vehicles by population and technology**

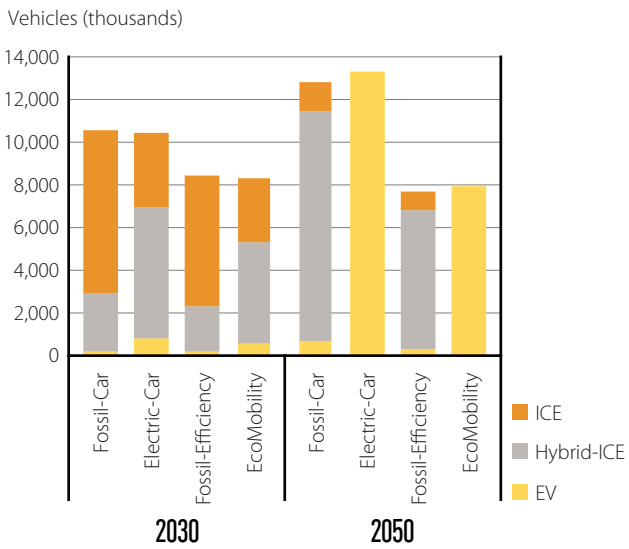


Figure 12: **Public transport road vehicles by population and technology**

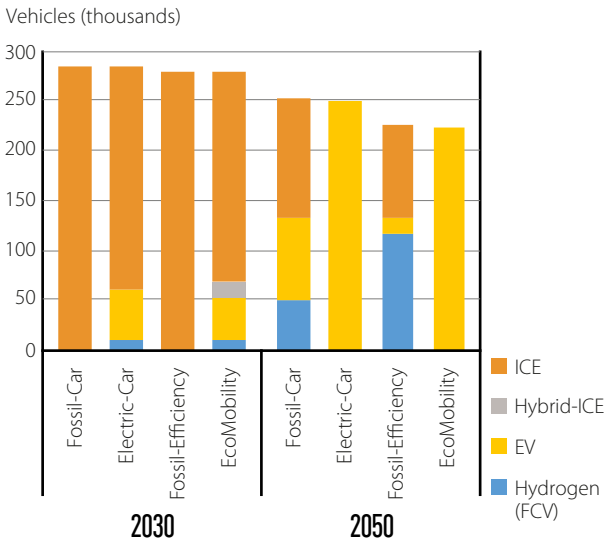


Figure 13: **Modal composition of public transport by technology**

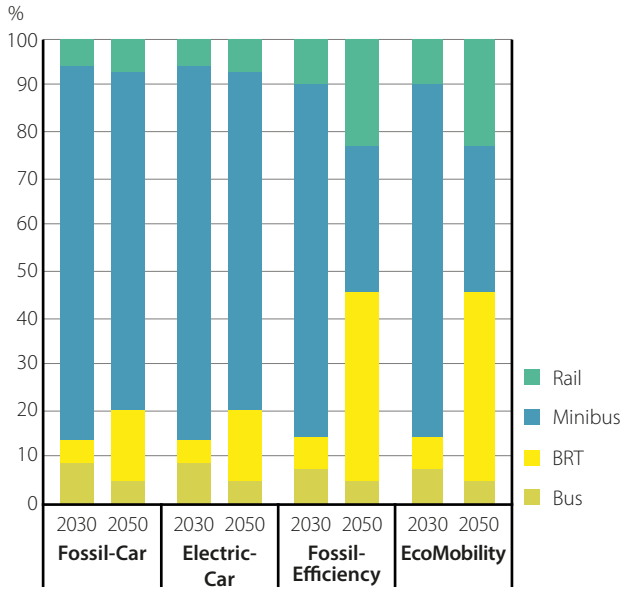
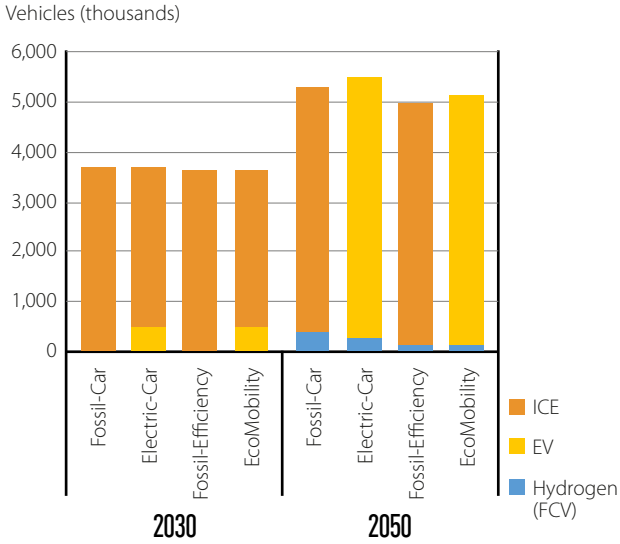


Figure 14: **Freight transport road vehicles by population and technology**



Fuel Switching in Freight Transport

In the freight sector, the EV pathways result in the full electrification of LCVs and small to medium trucks in 2050. Merven et al. (2019) and Ahjum et al. (2019) indicated that the electrification of transport would result in higher GDP growth relative to non-EV scenarios. This is due to the reduction in fuel demand per vehicle-km (v-km) travelled relative to ICE vehicles and the concomitant decrease in national expenditure on fuel supply. The IEA (2017) reports that freight services are correlated to economic growth, which as seen in Figure 14, results in an increase in the fleet size for the EV scenarios relative to their comparative *Fossil* scenarios.

For the Fossil-Car scenario, LCVs (which comprise the bulk of the freight road fleet population) continue to consume oil product. Refineries produce a set ratio of both diesel and gasoline for which the LCV vehicles are the primary consumers of the diesel product. Escalating demand for gasoline as shown in Figure 10, beyond which local refineries can supply would subsequently require imported product. The decline in diesel consumption is largely due to the switch to fuel-cells for road corridor heavy vehicles where the bulk of diesel is consumed. This is due to the comparative high consumption of diesel for extended vehicle-kms along corridor routes where hydrogen fuel cells would present the cost optimal choice in the period 2030-2050.

In terms of technology utilisation, as shown in Table 4, the Fossil-Car scenario would have 17% of total v-km driven via hydrogen fuel-cell with the remainder fuelled by diesel. In contrast, for the EcoMobility scenario, the LCV fleet is electrified accounting for 96% of v-km driven in 2050 with fuel-cell heavy vehicles comprising the remaining 6%. The reduction in corridor v-km when compared to the Electric-Car scenario (13%) is as a result of the road-to-rail migration as indicated in Figure 7. This is also evident when comparing the Fossil-Efficiency and Fossil-Car scenarios in Table 4.

Figure 14: **Freight transport road vehicles by population and technology**

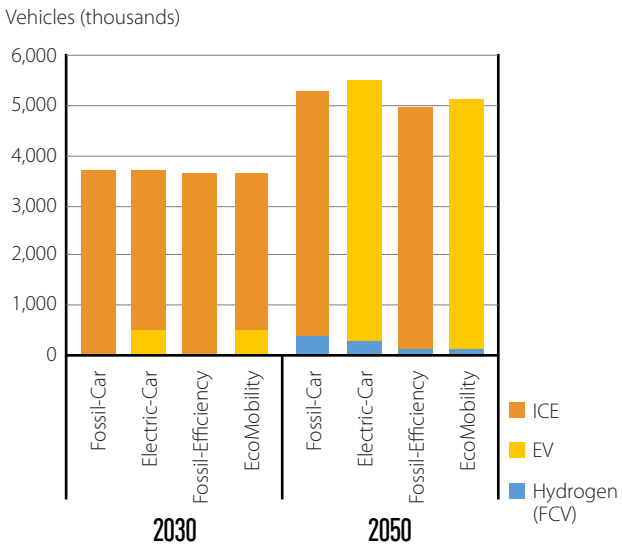
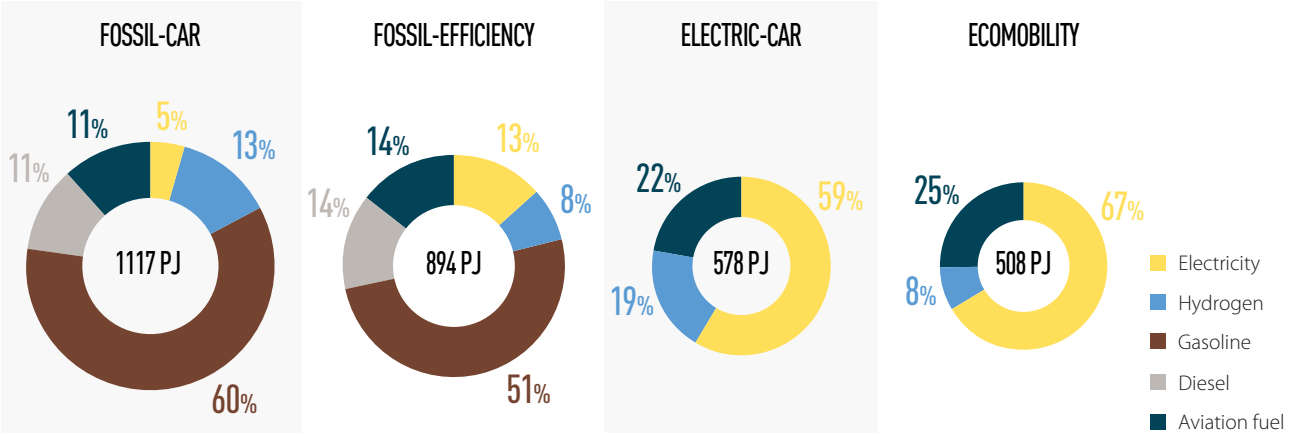


Table 4 **Share of freight vehicle-km by fuel type**

Scenario	Technology Type	2030	2050
Fossil-Car	Oil product	100%	83%
	Electric	0%	0%
	Hydrogen FC	0%	17%
Electric-Car	Oil product	82%	0%
	Electric	15%	87%
	Hydrogen FC	3%	13%
Fossil-Efficiency	Oil product	100%	93%
	Electric	0%	0%
	Hydrogen FC	0%	7%
EcoMobility	Oil product	82%	0%
	Electric	15%	94%
	Hydrogen FC	3%	6%

Figure 15: **Total transport energy consumption and fuel composition in 2050 for the scenarios**



Impacts on Fuel Demand

In the EcoMobility scenario, fuel demand is not only significantly lower, decreasing to 55% of the current fuel demand, but the transport sector's energy needs are also primarily met by electricity (67%) and hydrogen (8%) (Figure 15). Aviation fuel accounts for the remaining 25% and comprise the bulk of emissions in 2050 (Figure 8).

In contrast, for the Fossil-Car scenario fuel demand increases by 30% in 2050, of which a sizable portion is still met by fossil fuels. However, a greater share of hybrid vehicles substantially limits growth in fuel demand for a vehicle population which near doubles by 2050. Nevertheless, electric drivetrains, owing to their higher well-to-tank efficiencies, in tandem with modal switching confer greater savings in 2050.

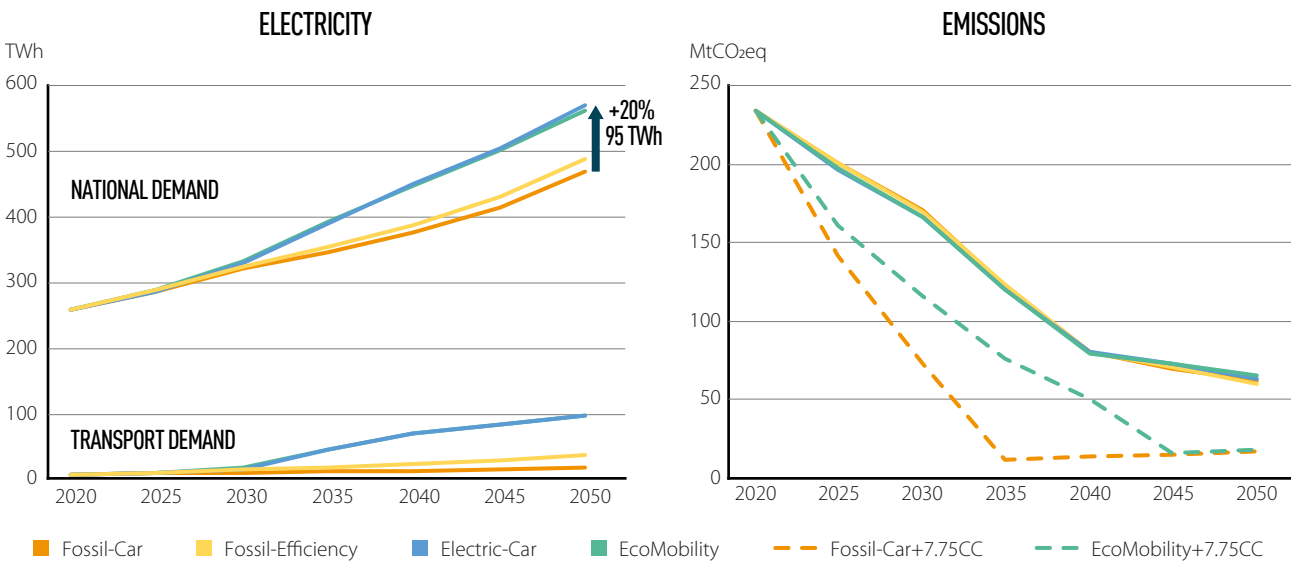
Marine vessel fuel usage is negligible at 0.1 PJ for both cases.

Impacts on Fuel Supply

Power Sector

An electrified vehicle fleet, servicing a population of 75 million people in 2050, would require an additional 20% or 95 TWh (including transmission and distribution losses) for the EcoMobility scenario (Figure 16a). A cost-optimal power sector would effectively become low-carbon by 2050 and, in the absence of a national GHG emissions budget, its emissions trajectory is essentially invariant to the transition in transport (Figure 16b). However, when an emissions budget is applied to the economy, as would be the case when South Africa commits to its NDC, we note that, as depicted in Figure 16b, an ambitious transport electrification policy would result in increased emissions from the power sector relative to the Fossil-Car scenario. Higher emissions from the power sector

Figure 16: **Power sector: a) electricity supply; and b) associated GHG emissions (including a 7.75 Gt Carbon Cap case)**



for the EcoMobility scenario would persist until 2045. In the Fossil-Car scenario, a 7.75 Gt carbon budget requires earlier decarbonisation whereas in the EcoMobility scenario, due to the deployment of zero-(GHG) emissions vehicles, additional carbon space is allocated in the budget allowing for an extended decarbonisation period. Effectively, the EcoMobility scenario results in the increased utilisation of the existing coal plants in the medium term and shows that there are sectoral trade-offs. Transport technology policy could thus alter the timing of closures of other emitting infrastructure even under ambitious mitigation scenarios.

When compared to the Fossil-Car scenario, the additional capacity required to support an ambitious switch to EVs would, in 2050, require an additional 41 GW for the Eco-Mobility scenario and 45 GW for the Electric-Car scenario (Figure 17). In 2030, without an economy-wide emissions budget, the EV scenarios result in a decrease in the utilisation of existing coal capacity (-1GW) switching to renewables instead. The Fossil-Efficiency scenario also increases demand for electricity for rail transportation, requiring an additional 9 GW in 2050 compared to the Fossil-Car scenario.

Refineries

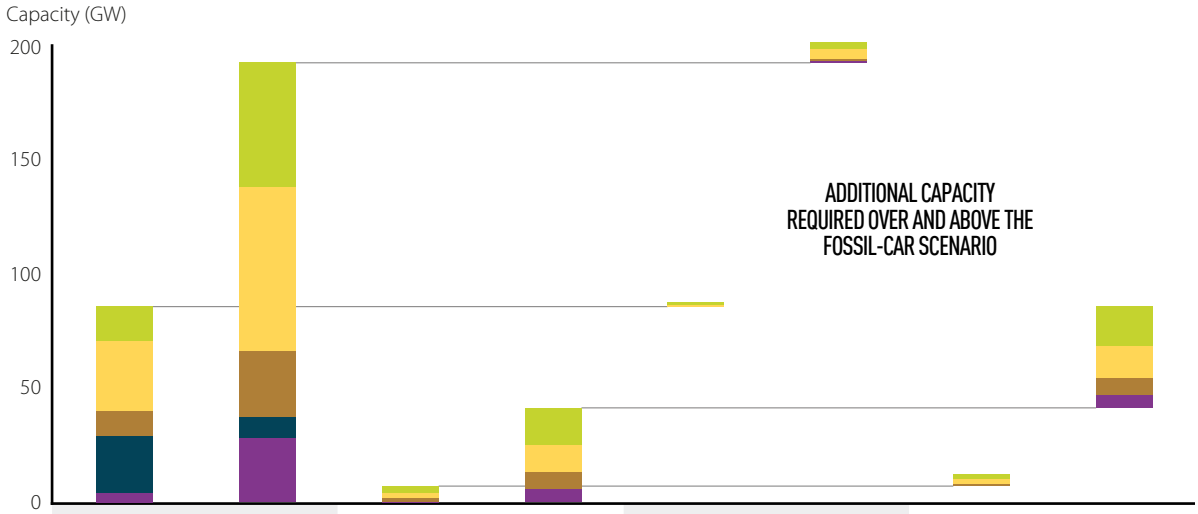
The existing coal-to-liquids (CTL) facility primarily consumes coal. Although the coal feedstock is supplemented with natural gas, the amount of gas that is able to displace coal is limited by plant design. The total CTL capacity in South Africa is approximately 150,000 barrels of oil equivalent per day, or roughly 246 PJ per annum. Of the total output, 83% is liquid fuels (i.e. jet fuel or kerosene, gasoline and diesel) with the balance consisting of other commodities (e.g. alcohols, waxes, methane rich gas). The facility is reported to emit on average approximately 55 $MtCO_2eq$ annually. The facility has an assumed technical life of another 20 years which would see it retire at the earliest by 2040. Supplying close to 30% of annual transport fuel, it is responsible for a much higher carbon footprint in the South African fuel supply chain when compared to Europe (Table 5).

Table 5 **Comparison of embedded CO_2eq for diesel and petrol for South Africa and Europe.**

Fuel	Country	Well-to-Tank	Well-to-Wheel
		kg CO_2/litre	
Diesel	South Africa*	1.5	4.3
	Europe**	0.6	3.2
Petrol	South Africa	2.6	5.2
	Europe	0.5	2.9

* SATIM model (excludes emissions associated with crude-oil extraction);
** EN16258, Kamdar (2019)

Figure 17: **The total power sector capacity required for the Fossil-Car scenario: displayed with the additional capacity required for the other scenarios**



	Fossil-Car 2030	Fossil-Car 2050	EcoMobility 2030	EcoMobility 2050	Fossil-Efficiency 2030	Fossil-Efficiency 2050	Electric-Car 2030	Electric-Car 2050
Wind	15	55	3	16	1	3	2	17
PV	30	71	2	12	1	4	2	14
Gas	11	29	1	7	1	1	1	7
Coal	25	9	-1	0	0	0	-1	0
Battery	4	29	1	7	0	1	1	7

Figure 18: **Total refinery capacity in 2050 for the scenarios**

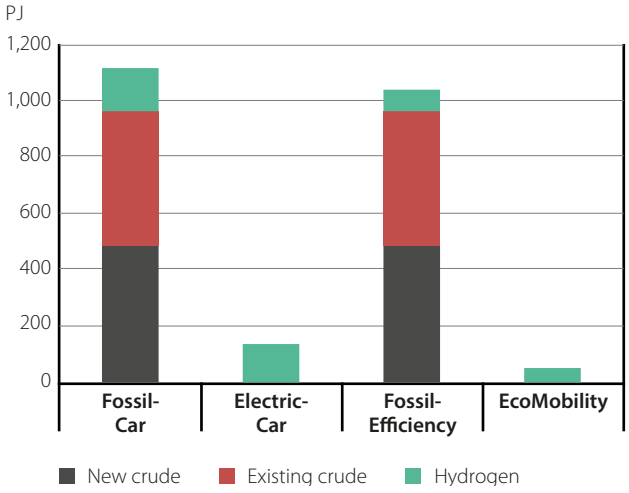
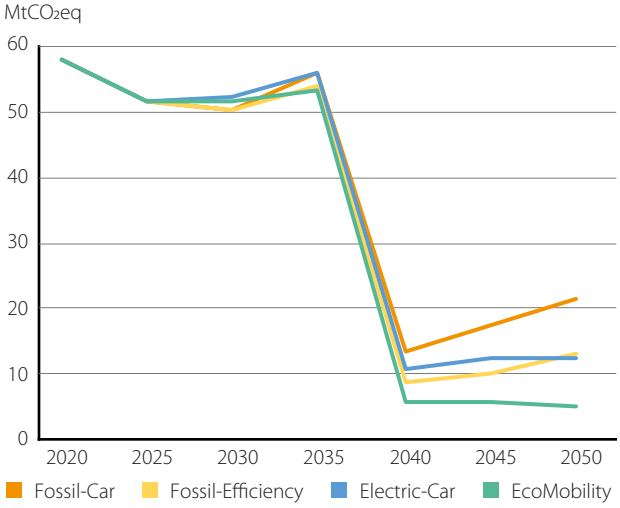


Figure 19: **Refinery emissions**



The Euro 2 to 5 fuel standard implementation (Clean Fuels Phase 2, CF2) would require the refurbishment of 50% of existing domestic crude refining capacity, with the remaining refineries decommissioned due to the investment cost. In the Fossil-Car and Fossil-Efficiency scenarios, an additional crude oil refinery with capacity of the order of 300,000 barrels per day may be required in 2050 to supplement increased demand (Figure 18). In this case, the new refinery would replace the forgone capacity as liquid fuel demand increases toward 2050.

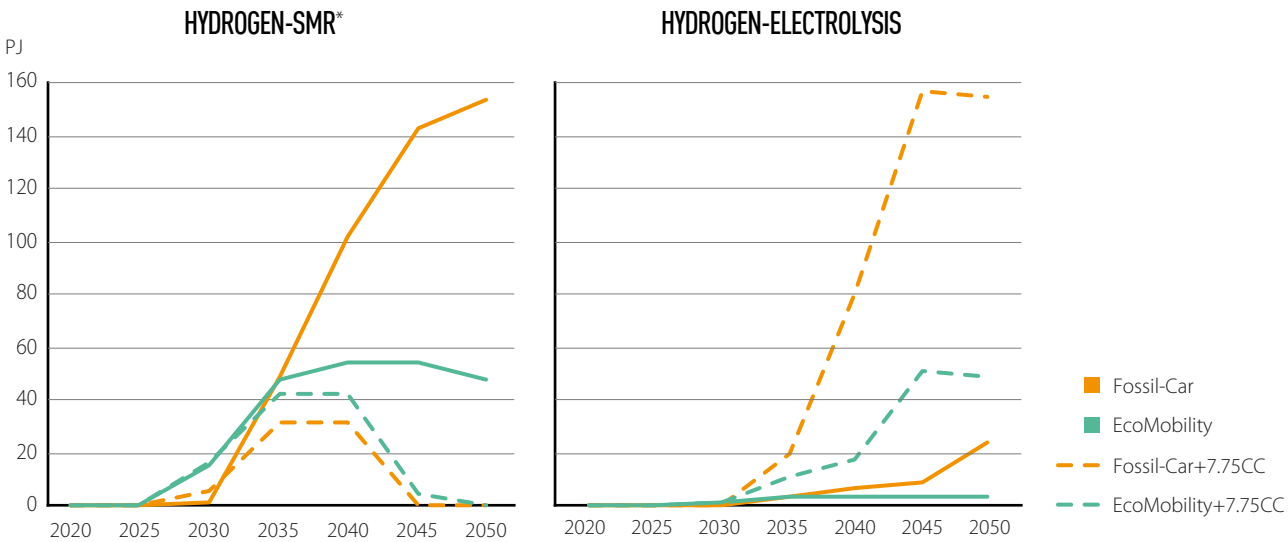
All in all, the two fossil fuel scenarios would see total domestic liquid fuel generally stagnate over the period 2030-2045 with a shift in the local diesel:petrol consumption ratio requiring importation to balance local production.

However, the two EV scenarios would negate the requirement for domestic production as liquid fuel demand for transport would progressively decline (Figure 10). Also of note is the level of hydrogen production that would be curtailed if ambitious road-to-rail modal switching is implemented for freight transport: a reduction, in 2050, of 50% and 20% respectively for the Fossil-Efficiency and EcoMobility scenarios, when compared to the Fossil-Car scenario.

The existing CTL facility is assumed to retire in 2040 and emissions from the refineries are, post CTL, primarily driven by the choice of process route for the production of hydrogen (Figure 19). In 2050, emissions equate to 5 $MtCO_2eq$ for the EcoMobility scenario (solely from hydrogen production); in contrast to the 22 $MtCO_2eq$ in the Fossil-Car scenario for which hydrogen is responsible for 16 $MtCO_2eq$ and the remainder from crude-oil processing.

The emissions resulting from hydrogen production are due to the economic preference for natural gas via Steam-Methane-Reforming (SMR) in the absence of an emissions constraint. As illustrated in Figure 20, when an emissions constraint is applied, the choice of hydrogen supply switches from natural gas SMR to electrolysis. The electrolysis production route instead requires electricity with lower associated production emissions from a decarbonised power sector (Figure 5).

Figure 20: **Hydrogen supply: the impact of an emissions constraint on the preferred process route: i.e. natural gas vs electricity**



* Steam Methane Reforming (SMR)

5 CONCLUSION

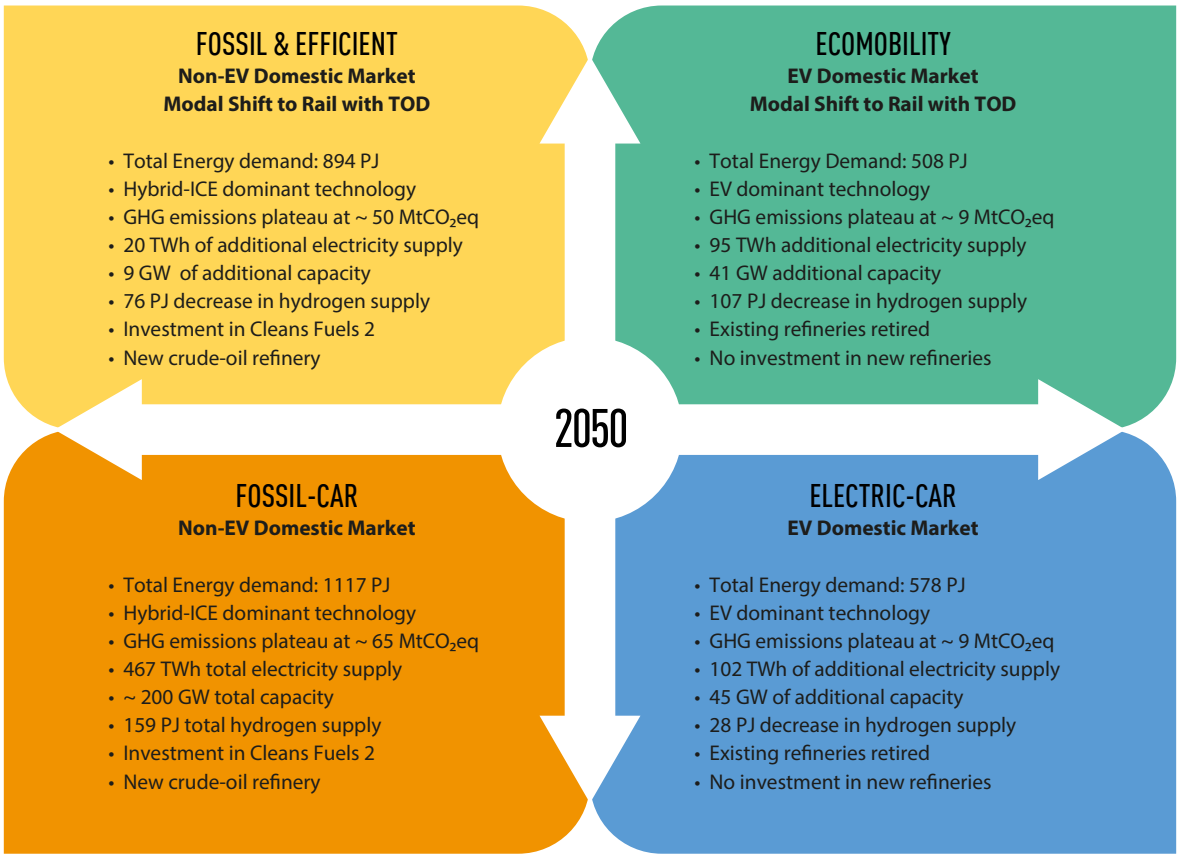
A full sector representation of the South African economy in a least cost modelling framework (SATIM) was utilised to assess the resultant economy-wide energy and GHG emissions for the transport sector towards 2050. Assuming an average annual economic growth rate of 3% over the period (2020-2050) with population reaching 75 million in 2050, four scenarios were modelled. The scenarios contrasted policy choices about vehicle technology (Fossil-Car vs Electric-Car) and urban planning with respect to modal shifting in passenger road transport and freight; as well as transit oriented development (Fossil-Efficiency vs EcoMobility). The scenarios as they compare for GHG emissions and energy demand are summarised in Figure 21.

Given the current levels of energy demand and emissions of the transport sector (897 PJ and 60 $MtCO_2eq$, respectively) the Fossil-Car scenario represents the most energy intensive future, with a total demand of 1117 PJ and GHG emissions of 65 $MtCO_2eq$ in 2050. In contrast, the Fossil-Efficiency scenario implements a modal shift which leads to: a shift in corridor freight with a 70 % rail share; an approximate 50% share of motorised travel between public and private travel, in combination with TOD (reducing motorised passenger travel demand by 10%). This has the effect of reducing the energy supply requirement (net of losses) to 894 PJ and emissions to 50 $MtCO_2eq$ representing a 20% decrease in energy demand and 23% decline in emissions relative to the Fossil-Car scenario. The Fossil-Efficiency scenario effectively plateaus growth in energy and emissions for transport, relying on Hybrid-ICE vehicle technology in combination with the above measures.

In the absence of modal shift and TOD, a technological shift towards EVs as represented by the Electric-Car scenario would require 578 PJ, with transport emissions totalling 9 $MtCO_2eq$. The residual emissions comprise aviation and maritime emissions, which contribute 9 and 0.08 $MtCO_2eq$ since, by 2050, the vehicle fleet is electric with zero tail-pipe emissions. This includes hydrogen-fuel-cell vehicles in the freight sector, which are essentially electric-drive trains. Compared to the Fossil-Car and Fossil-Efficiency scenarios, the reduction in energy demand is 48% and 35% respectively; and for emissions a reduction of 86% and 82%, respectively, would result.

The EcoMobility scenario which comprises both a technological shift towards EVs and a modal shift with TOD similar to the Fossil-Efficiency scenario, results in the lowest energy demand for transport services. The energy demand totals 508 PJ with emissions of 9 $MtCO_2eq$.

Figure 21: **Key outcomes in 2050 for the transport scenarios**



Relative to the Fossil-Car and Fossil efficiency scenarios, the reductions in energy demand are 55% and 43% respectively. The comparative emissions are similar to that of the Electric-Car scenario due to the electrification of the vehicle fleet. However, compared to the Electric-Car scenario, a reduction of 12% in energy demand results for a similar emissions profile. This is attributed to the effect of a modal shift with TOD.

Figure 8 depicts transport emissions for the Fossil-Efficiency and EcoMobility scenarios by sector composition in which the emissions of the Fossil-Car and Electric-Car scenarios (exhibiting similar emissions composition by sector) are also contrasted. The importance of targeting decarbonisation in both freight and passenger transport is highlighted by the measurable contribution to emissions of both sectors.

The future of the domestic refineries is contingent on the future choice of vehicle technology. Both the Fossil-Car and Fossil-Efficiency scenarios require similar investment in the existing refineries to meet Euro-5 standards. With a switch to more fuel efficient Hybrid-ICE vehicles, approximately only half of the existing crude-oil refineries are refurbished with the remaining capacity retired. If the economy grows at an average rate of 3% over the horizon, a new refinery would be required in 2050. The capacity of the new refinery would be in the order of 300, 000 bbl/day (Figure 18).

In contrast, both the Electric-Car and EcoMobility scenarios would not need any further investment in the existing crude-oil refineries or require new capacity. Instead investment would be diverted to the power sector which would require an additional 102 TWh or 45 GW and 95 TWh or 41 GW of capacity, respectively, when compared to the Fossil-Car scenario (Figure 17). A cost-optimal expansion of the power sector would result in a rapid decarbonisation of the electricity sector post 2030 if no limitations are placed on investment in renewable energy. This would in turn facilitate the widespread adoption of EV technology with minimal impact on power sector emissions (Figure 16).

Although the emissions for the EcoMobility and Electric-Car scenarios are similar, the difference in energy demand, translates into an additional 7 TWh of electricity and 4 GW of supply capacity in the form of Solar PV and Wind for the Electric-Car scenario in which no modal shift or TOD measures are implemented.

McCall et al. (2019) suggested a 7.75 Gt carbon budget represents a lower threshold to decarbonising the economy without negative economic consequences. If such an emissions constraint is applied to the analysis, both EV scenarios would result in increased emissions from the power sector until 2045 compared to the fossil fuel scenarios (Figure 16). This however suggests that EVs, a zero GHG emitting technology, facilitates an extended period of decarbonisation of the power sector by extending the operation of the existing coal plants and deferring early investment in renewable energy.

The future of the CTL facility post 2040 is contentious given the high CO_2 emissions intensity of its operation. Similar in magnitude to total transport sector emissions, its retirement reduces refinery emissions from 53-56 $MtCO_2eq$ in 2035 to 13-6 $MtCO_2eq$ in 2040 (Figure 19).

Future aviation fuel demand could account for 11% -25% of total transport fuel demand in 2050. Given the nature of the synthetic fuel manufacturing process, an opportunity to extend the facility's operational life potentially exists for aviation fuel production via hydrogen and provides a means to a less disruptive transition in transport. However, it is acknowledged that the repurposing of the CTL facility requires further research beyond the scope of this study.

Hydrogen as a transport fuel mainly replaces diesel in the corridor freight fleet. The level of hydrogen demand is dependent on both the choice of road vehicle technology and modal shift (Figure 18). With modal shifting, hydrogen demand is displaced by electricity as rail is prioritised, whereas the non-EV scenarios, in the absence of EV alternatives, result in a preference for fuel cell vehicles in public transport. The scale of hydrogen production and associated emissions is largely reflected in the refinery emissions post 2040, when it is assumed the CTL facility retires (Figure 19).

The emissions associated with hydrogen production are due to the economic preference for natural gas as feedstock in the absence of an economy–wide emissions constraint. However coupled with a decarbonising power sector, electricity via electrolysis would be the preferred fuel if an economy-wide GHG emissions budget is implemented.

In accordance with the Green Transport Strategy's (GTS) vision of a resource efficient transport system, the analysis has revealed that passenger modal shifting and freight road-to-rail measures are interventions of significance in reducing the energy requirement for transport in 2050. However, in this study, incentivising the adoption of alternative vehicle technologies is shown to be the prime lever with which to satisfy the GTS mission "to substantially reduce GHG emissions and other environmental impacts from the transport sector". Specifically, the electrification of transport in tandem with a low-carbon power sector offer the most benefit. A preference for EVs would exceed the GTS mitigation benchmark. Furthermore, in light of continued technological innovation, the analysis indicates that the transport sector is able to contribute an order of magnitude higher to emissions reductions if policy encourages the adoption of economic and resource efficient technological alternatives, and behavioural changes towards public transport.

APPENDIX A: MODELLING TRANSPORT WITH THE SOUTH AFRICA TIMES (SATIM) MODEL

SATIM is a least-cost optimisation model which incorporates a technology rich representation of the economy. The economy wide energy supply chain for energy services demanded across all economic sectors is optimised for the least system cost: i.e. lowest cost to the economy. SATIM is calibrated to a national energy balance and the optimisation is predicated on assumptions about future technology costs and energy prices (Figure 22).

Within SATIM, the transport model is composed of a number of sub-models, a schematic representation of which is illustrated in Figure 23.

The vehicle parc model (Figure 24) - described by Stone et al. (2018) - is used to establish the characteristics of the vehicles in operation from 2000–2014 for South Africa. The vehicle categories analysed include private, public and freight vehicles.

The vehicle kilometres model captures distance demand for freight and passenger. Freight vehicle kilometres are derived from an economic model, which provides a GDP growth forecast and demand for freight services in ton-km. Vehicle kilometres are then calculated from load factor estimates for each vehicle type.

Estimating passenger travel demand is more complex and is based on local estimates and inferences from international literature of travel time by income group, vehicle speeds for public and private vehicles, and occupancy (Figure 25).

Modal shares for road and rail for both freight and passenger transport are derived from local literature with future shares exogenously expressed. Behavioural determinants which would encourage households to preference public transport are not modelled, but are instead expressed as exogenous factors based on local historic trends. A reduction in passenger kilometres (p-km) due to urban densification and transit oriented design (TOD) is not explicitly captured in the modelling but inferred from similar international modelling analyses (Pye and Daly 2015).

Aviation and maritime transport are incorporated as aggregate fuel demands with no technology representation: demand is correlated to projected GDP growth.

Figure 22: **Overview of the Energy Systems Model (SATIM)**

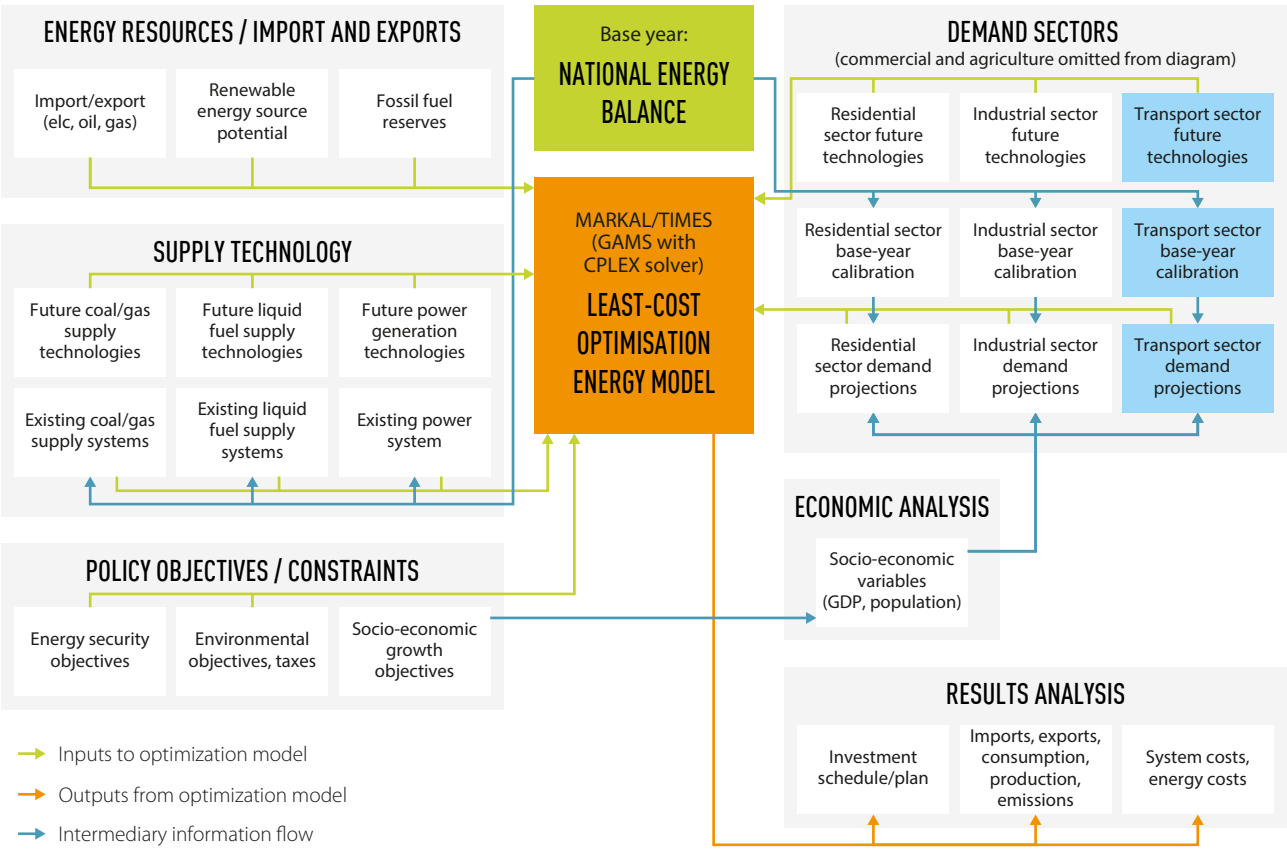


Figure 23: **A schematic of the SATIM transport model**

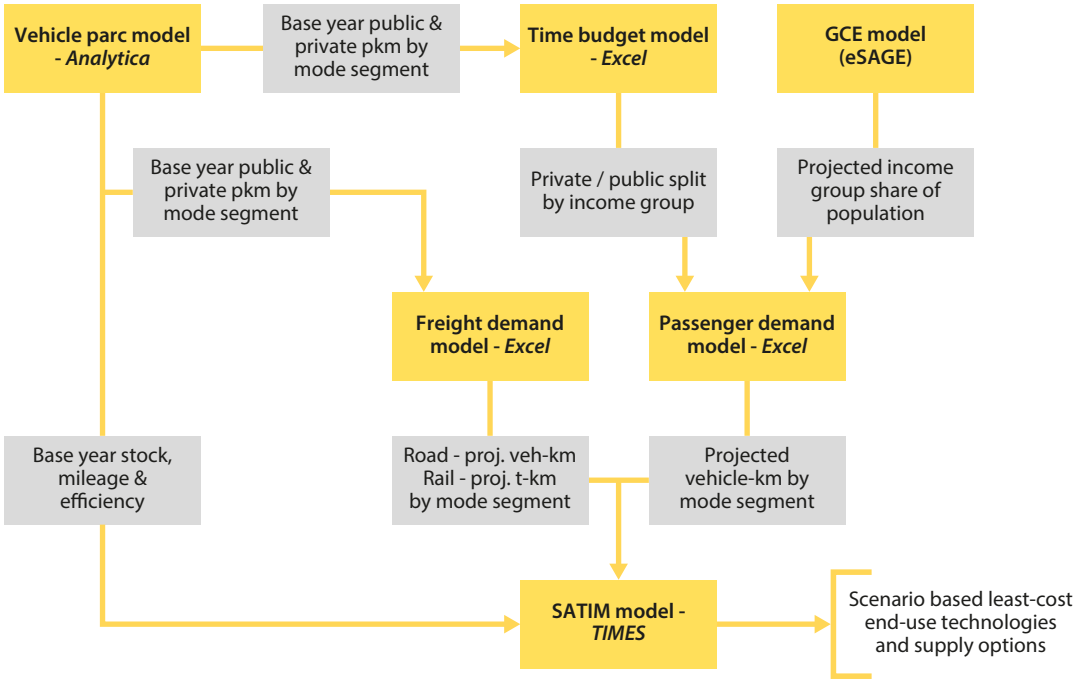


Figure 24: **Vehicle parc and fuel calibration in SATIM**

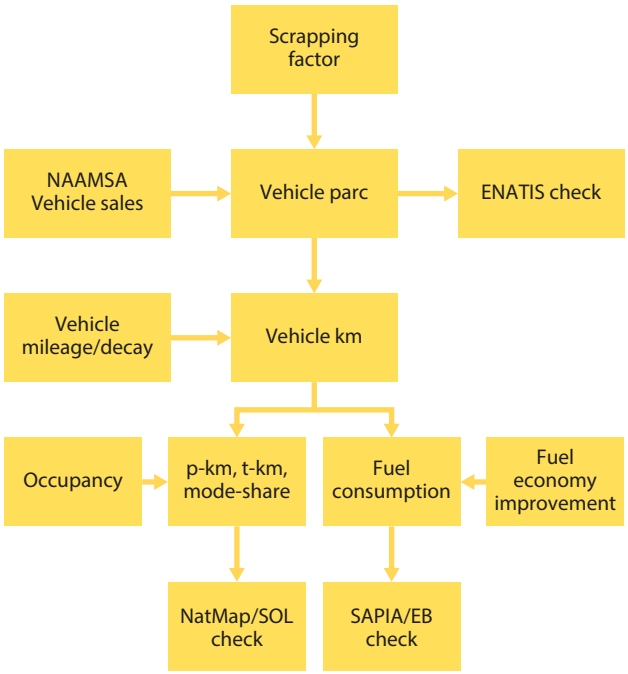
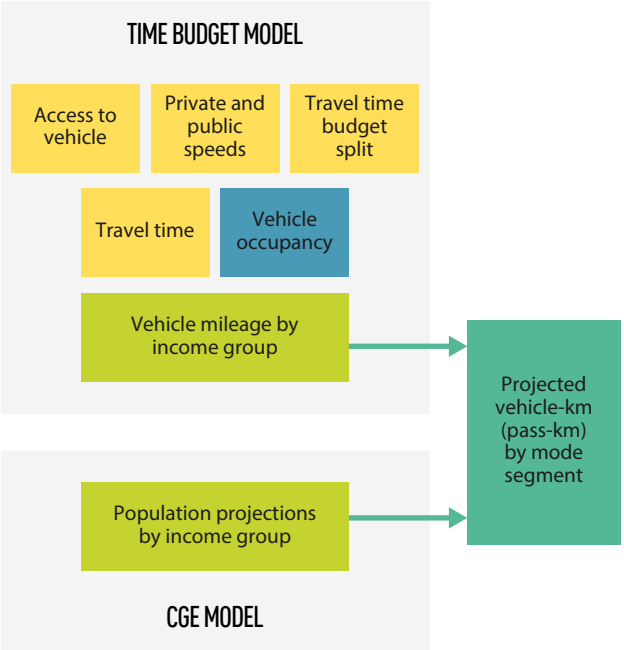


Figure 25: **Summary of the Passenger Demand Model**



The vehicle parc was estimated utilising public vehicle sales and national registration data. Scrapping factors are derived from Weibull distributions, which were determined for each vehicle class to reconcile registry data. Vehicle mileage decay (which is required for vintaging the vehicle parc) and fuel economy and occupancy factors (load factors for freight t-kms) were estimated from the literature, as local data on these factors is limited.

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