An assessment of the GHG mitigation potential of land transport pathways presented in Green Transport Strategy and their economy-wide impact

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Abstract

This paper assess the emissions and economic impact of the 2018 Green Transport Strategy using a linked energy-economic model. The transport sector is the second largest emitter of emissions in South Africa. Decarbonisation of the sector is therefore needed to reach the country's Nationally Determined Contributions. The key findings from this paper is that the implementation of the GTS results in significant declines in emissions with positive impact on economic growth and employment. The key driver behind the decline in emissions is the shift to electric vehicles as costs become comparable with traditional internal combustion engines.

Keywords

Energy, Economy, Policy, Transport, Modelling

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Glossary

CGE	Computable General Equilibrium (model)
BRT	Bus Rapid Transit System
eSAGE	energy extended South Africa General Equilibrium model
EV	Electric Vehicle
GDP	Gross Domestic Product
GTS	Green Transport Strategy
Hybrid	An ICE vehicle with auxiliary battery (e.g. Toyota Prius)
ICE	Internal Combustion Engine
NAMAs	Nationally Appropriate Mitigation Actions
PJ	Peta-Joule
SATIM	South Africa TIMES model
SATIMGE	linked SATIM:eSAGE model

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1. Introduction

The National Transport Master Plan 2050 (NATMAP 2050), is the cornerstone policy instrument which outlines key transport planning themes. It emphasises the preservation of the environment in tandem with accessible, cost reflective and affordable transportation services. In accordance with NATMAP 2050 and in response to the National Climate Change Response Policy (DEA, 2011) white paper, which advocates a climate-resilient and low carbon economy by 2050; the Green Transport Strategy (GTS) was drafted. The purpose of the GTS is to serve as an implementation plan tabling interventions which would contribute equitably to meet the national objective of a low carbon transport sector. As such, the strategic vision of the GTS is "to substantially reduce GHG emissions and other environmental impacts from the transport sector by 5% by 2050", while maximising the role of transport in promoting economic growth.

Mobility as a service connects every facet of society from the movement of individuals to that of physical goods which underpin economic activity. The transport sector is estimated to emit approximately 60 MtCO2eq or 14 % of national emissions associated with energy utilisation (ERC, 2018); similar in magnitude to present day industrial emissions and larger if emissions attributed to transport fuel supply are included. Similarly, the energy demand of ~ 894 PJ is comparable to industrial consumption (1294 PJ).

The National Household Travel Survey (StatsSA, 2013) revealed an increasing motorisation rate with a migration away from public transport and non-motorised travel. The population is forecast to reach 65 million by 2050 and by vehicle population and transport emissions share, the private passenger fleet is the largest. In the freight sector, the majority of transport is via road with existing rail capacity not fully utilised. If economic growth as forecast until 2050 is achieved in the absence of low carbon resource efficient solutions, transport sector emissions will continue on an increasing emissions and energy demand trajectory. This would potentially, regarding direct emissions eclipse industrial emissions to become the largest emitting sector if the power sector decarbonises (ERC, 2019; CSIR, 2017). Decarbonising the transport sector is therefore necessary for South Africa to reach its Nationally Determined Contributions as well as the Paris Agreement.

The emissions and economic impact of the 2017 Green Transport Strategy (DoT, 2017) has been previously assessed in the Policies And Measures Study (ERC, 2018). This paper builds on this work by considering the implications of the 2018 GTS (DoT, 2018) using an updated linked energy-economic model which better aligns the refinery sector in the energy and economic models. In addition, the updated linked model includes a revision of technology characteristics and typology and commodity costs (Merven et al., 2019; Hartley et al., 2019). This paper mainly addresses land transport interventions presented in the 2018 GTS which is also the predominant focus of the GTS. The key findings from this paper is that the implementation of the GTS results in significant declines in emissions with the impact on economic growth and employment being positive. The key driver behind the decline in emissions is the shift to electric vehicles as costs become comparable with traditional internal combustion engines.

2. Research Method

The Energy Research Centre's linked energy-economic model, SATMGE, is used in this study. The linked model combines the bottom-up technology rich South Africa TIMES (SATIM) energy model with a detailed dynamic recursive computable general equilibrium model for South Africa (SAGE). The latter is calibrated such that the energy volumes in the model, measured in PJ, match those presented in the ERC energy balance. The individual models (i.e. SATIM and SAGE) as well as the linked model are described by Arndt et al. (2016) and Merven et al. (2017). Figure 1 presents a simplified schematic of the linked model. Energy/environment scenarios are constructed in the energy model, SATIM. An iterative process in which energy prices, investment expenditure and energy demand changes (including efficiency gains) is passed to the economic model, SAGE, which returns, in response to the latter information, expected GDP and household income/expenditure. The economic information moderates the expansion determined by SATIM for energy supply such as electricity generation and liquid fuels, as well as demand for energy commodities by the economic sectors such as freight transport services for example. Iteration occurs until economic growth converges in both models.

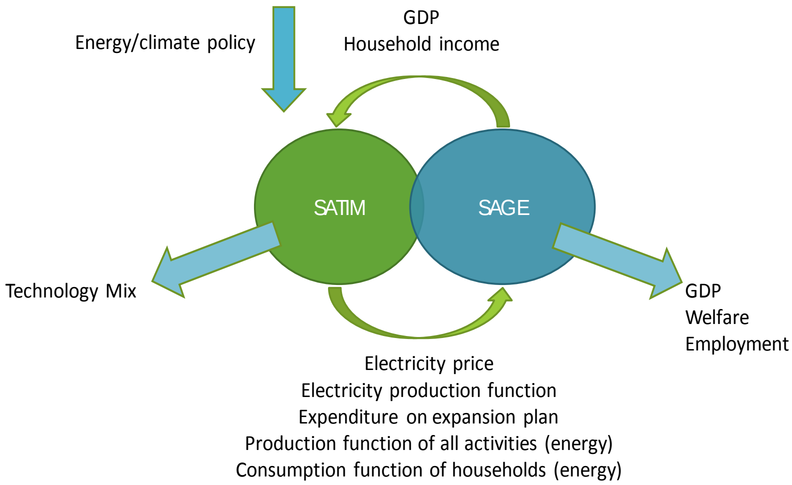


Figure 1: SATIMGE illustrating the iterative exchange of data between the energy and economic models

Transport in the energy model of the linked model is modelled in detail using a vehicle parc model. This model is depicted schematically in Figure 3 and described in Stone et al. (2018) and Ahjum et al. (2018).

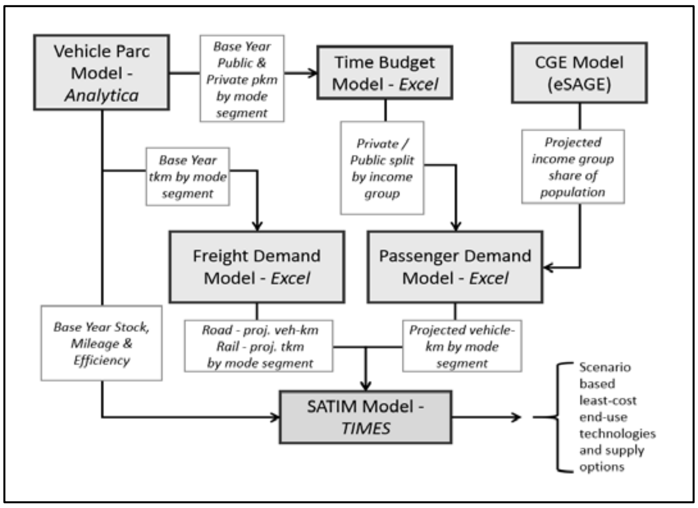


Figure 2: Transport sector model (SATIM)

3. Scenarios and Assumptions

The GTS consists of 10 strategic pillars with 6 short-term strategic targets (see Table 1). These pillars and measures provide objectives for the transport sector but do not necessarily indicate how these will be achieved or specify targets or deadline for achieving them. For this reason, the measures the GTS modelled primarily include those related to land transport which have sufficient information to be quantitatively assessed and/or can be further defined using other stated government targets. The scenarios modelled are presented in Table 2 and explained in more detail below. The GTS measure promoting the use of liquid biofuels is not modelled in this analysis due to the near non-existent national supply chain despite regulations in force since 2015 (DoE, 2014) and the negligible energy and economic impact of biofuels blending programme at national scale (ERC, 2018).

The impact of measures from the 2018 GTS are modelled to assess the emissions and economic impact of individual measures as well as of the measures combined relative to a reference scenario. The “5% by 2050” emissions target for transport, in the analyses presented, compares both a 5% reduction in transport emissions relative to the reference scenario; and a 5% reduction in the national total attributable to transport.

Table 1: GTS Strategic pillars and short-term strategic targets (DoT, 2018)

Strategic pillar	Short-term strategic targets
Develop norms and 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.	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.
	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.
Shift car users from individual private passenger cars to public transport, including rail.	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.
Provide infrastructure to promote NMT and eco-mobility transport.	
Provide transport infrastructure in a manner supportive of the eco-system, while not clearly compromising generations to come.	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.
Extend the rail network to provide reliable, safe and affordable high-speed transport while switching to renewable energy trains.	
Reduce the carbon footprint and over-reliance of petroleum-based fuels by decarbonising the transport sector.	

<table>
<tr><td>Promote alternative fuels such as Compressed Natural Gas (CNG) or biogas, and liquid biofuels as transport fuels.</td><td rowspan="3">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.</td></tr>
<tr><td>Promote electric and hybrid-electric vehicles</td></tr>
<tr><td>Develop “Green Procurement Guidelines” to promote efficient and low carbon vehicle technologies.</td></tr>
<tr><td>Provide norms, standards and regulations that promote green fuel economy in vehicles and improve emissions standards of fuel in South Africa.</td><td>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.</td></tr>
</table>

Table 2: A summary of the GTS portfolio of interventions modelled describing salient features

GTS	Scenario Name	Key Feature
	Reference	Baseline scenario with EV premium at 25% relative to conventional present-day technology. Rail share of land corridor freight constant at 13% (2016 share)
1	FreiRail	30% road corridor migration to rail by 2030 reaching 50% by 2045
2	PassMode	20% relative shift to public transport by 2030 reaching 50% by 2050
3	AltVeh	Cost parity for all alternate vehicle technologies by 2030 (e.g. electric or fuel-cell)
4a	MinBusDual	Minibus taxi fleet converted to bi-fueled gas-petrol by 2030
4b	MetBusGas	Urban bus fleet converted to gas only fleet by 2030

The manner in which each of these scenarios are modelled is discussed below.

1) **Migrate road freight to a rail alternative within 7 years (FreiRail).** The DEA (2014) freight road to rail report indicates aspirational shares of 30%, 50% and 70% for corridor rail activity by 2045 with the 30% and 70% shares suggested as low and high targets respectively. These targets are adopted in this study. Specifically, we assume that rail accounts for 30% of freight by 2030 in line with the NAMAs. A further progression to a 50% share by 2045 is modelled to conform to the DEA (2014) moderate ambition.

2) **20% shift of passenger transport from private cars to public transport and non-motorised transport within 7 years (PassMode).** The shift is based on the GHG Mitigation Potential Analysis (DEA, 2014) which draws upon the Western Cape Infrastructure Framework study (PDG, 2013). Therefore a shift to public transport approach is modelled with emphasis on public rail and BRT as suggested in the Western Cape study. In the modal shift scenario the growth in private travel is reduced to 1.5% per annum during 2020-2030 with negligible growth until 2050 as a migration to public transport is reversed. The decline in the share of public transport during the period 2020-2030 in the reference case is stabilised such that the ratio is similar (56:44). This represents an 18% shift from private travel relative to the reference case. It is presumed that the migration towards public transport continues towards 2050 (e.g. implementation of incentives such as a congestion tax) such that the private to public travel ratio reaches a 50% share each.

3) **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 (AltVeh).** Public sector passenger vehicles comprises less than 1% of the national vehicle parc while the size of public sector freight road vehicles is unknown. Therefore the national vehicle population is used to gauge the share of alternative vehicle technologies shares. The modelling presumes that levies against electric vehicles are removed such that cost parity is reached by 2030 for freight and private road vehicles. Noting that light commercial vehicles are the largest segment of the freight fleet and the primary candidate for electric alternates. The model is allowed to optimise the road fleet without market share requirements for a specific fuel-based technology and compared to the GTS ambition. Relative costs of alternate vehicle technology are informed by the Ricardo-AEA (2012) study.

4) **Foster a conducive environment for the conversion of public and quasi-public transport vehicles to be converted to dual-fuel vehicles within 10 years**.

    a. (**MiniBusDual**) The presumption is that bi-fuel vehicles are referred to and apply only to minibus taxis only as alluded to in the GTS 2018, with target achieved by 2030. The bi-fuel system comprising natural gas and petrol.

    b. (**MetBusGas**) The GTS 2017 referred to the gas conversion of the metro-bus fleet and this is included under the compressed natural gas (CNG) for transport initiative in the GTS (2018). Presently trialled in Gauteng, the term “metro-bus” is presumed to refer to bus fleets in urban regions used for public transport purposes. Since there is no data to delineate buses operating in areas which have the potential for natural gas reticulation, the proportion of the national passenger bus fleet which could be converted to CNG is based on an urban/rural population split. Urban passenger-kms serviced by buses are wholly met by CNG buses by 2030.

The modelling analyses presumes, conservatively, that all scenarios experience 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 constant across the period. The median global crude oil price is US $80/barrel (2015 prices) during 2030-2050. The revision incorporates:

- Clean Fuels Phase 2 with the option to refurbish the crude-oil refineries, invest in new capacity or retire domestic production;
- The Coal-to-Liquid facility retires after 2040, operational throughout its technical life.
- As detailed by McCall et al. (2019) utility scale lithium-ion battery storage becomes competitive post 2030 reflecting literature cost projections and competes with gas to balance the intermittency of solar and wind renewable energy in the power sector.

No GHG emissions constraints are imposed in order to gauge the efficacy of the GTS in achieving the targeted GHG reduction in transport.

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% to 2050 (DoE, 2016). The structure of the economy does not shift dramatically over time 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 economic forecast growth targets for the reference case. 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, investment and government expenditure are however fixed shares of absorption resulting in a balanced savings-investment closure; government savings are flexible, and no fiscal rule is imposed. The exchange rate is flexible. Existing capital is assumed to be fully employed and activity specific.

Considerations of additional infrastructure, such as road network capacity, and indirect induced economic restructuring owing to the displacement of present-day technology by alternatives, such as changes in vehicle manufacturing due to increased use of hydrogen fuel-cell and electric vehicles, are not addressed here due to the limitations of data and time. It is assumed that future investment expenditure on these types of infrastructure and changes in production processes is the same as that for existing technologies. This does not apply to the electricity and refinery sectors which are modelled in more detail such that these changes are accounted for. Economy-wide impacts are assessed in this study through changes in the production processes of energy technologies, the associated investments required for these and the price impacts faced by final consumers. Changes in energy efficiency is also accounted for in the economic modelling through information passed from the energy model.

The reference demand for passenger and freight transport is shown in Figure 3. It assumes a transport pathway status quo with no current policy amendments. Passenger demand growth from 378 billion passenger.km (b.pkm) in 2020 to 450 b.pkm in 2050 is primarily met by private passenger vehicles. The share of public transport declines from ~ 26% to ~13% in 2030 due to an increase in private vehicle ownership in line with existing trends. The public transport share rises to 18% in 2050 due to wider adoption of the BRT system. Demand for freight, based on reference case growth projections from the economic model, increases from 423 billion ton.km (b.tkm) in 2020 to 776 b.tkm in 2050. The rail share of land corridor freight remains constant at 15% and the growth is largely in the corridor heavy vehicle segment.

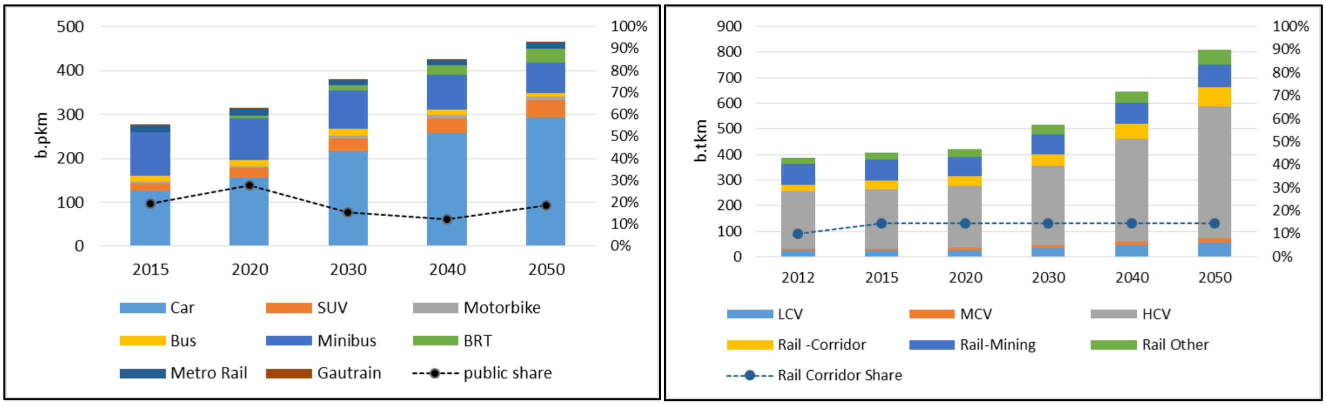


Figure 3: Reference scenario transport growth trajectories for (a) Passenger; and (b) Freight

4. Results and discussion

Figure 4 depicts both national energy emissions and the contribution of the transport sector to the total. In the reference case, total energy emissions increase to 2025 as South Africa continues to produce electricity using coal. As coal power plants are decommissioned and replaced with cheaper renewable energy, overall energy emissions decrease (McCall et al. 2019). This trend is experienced across all the scenarios modelled as the power sector is the largest driver of emissions in South Africa. Transport emissions plateau in reference case where none of the GTS measures are imposed. With full implementation of the GTS measures included, emissions in the transport sector declines markedly by 18% by 2030 relative to the reference scenario. Overall energy emissions decline by ~ 13 MtCO2eq or 3% relative to the reference scenario. By 2050, the national energy inventory is reduced by 56 MtCO2eq or 20%; similar in magnitude to present day emissions from transport. This translates to a reduction of 70% in direct transport emissions from 73 to 24 MtCO2eq.

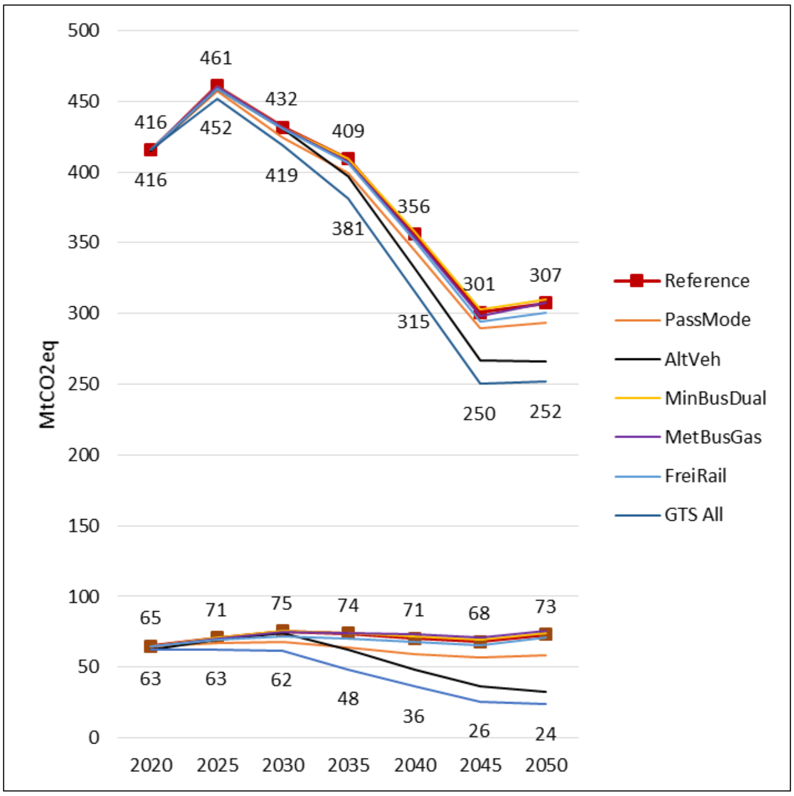


Figure 4: Total economy-wide and direct transport emissions trajectories resulting from GTS measures

A modal shift to public transport provides the largest near term (2030) gain followed by a migration to rail corridor freight (Table 3 and 4). Presuming cost parity by 2030, alternate vehicle technologies provide the largest gains during 2030 -2050 (7%-13%) with a modal shift intervention the second largest contributor (3%-5%). Rail freight transport contributes 2% of the emissions savings. The dual-fuel conversion of minibus taxis and the gas fuel conversion of Metro-buses achieve negligible national emissions savings. That the avoided emissions in 2030 are solely attributed to direct transport activity indicates that the supply chain impacts are negligible during the near-term implementation horizon. To 2050, however, supply chain impacts are more pronounced.

In terms of cumulative emissions avoided - for which the accounting period is 2018-2050 - all measures implemented would avoid a total of 870 MtCO2eq or 6%. Of this, alternative technology vehicles contribute 3% with passenger and freight interventions, 2% and 1% respectively (Table 5).

Table 3: National emissions with relative GTS contribution (MtCO2eq & Percentile)

Reference	2020	2025	2030	2035	2040	2045	2050
	416	461	432	409	356	301	307
PassMode	0	-4	-8	-10	-11	-11	-14
AltVeh	-1	-2	-1	-12	-24	-34	-41
MinBusDual	0	-1	0	1	2	2	3
MetBusGas	0	-1	0	-2	-2	-2	0
FreiRail	0	-2	-1	-3	-5	-7	-7
GTS All	0	-9	-13	-28	-41	-50	-56
PassMode	0%	-1%	-2%	-2%	-3%	-4%	-5%
AltVeh	0%	0%	0%	-3%	-7%	-11%	-13%
MinBusDual	0%	0%	0%	0%	0%	1%	1%
MetBusGas	0%	0%	0%	0%	-1%	-1%	0%
FreiRail	0%	0%	0%	-1%	-1%	-2%	-2%
GTS All	0%	-2%	-3%	-7%	-11%	-17%	-18%

Table 4: Transport emissions with relative GTS contribution (MtCO2eq & Percentile)

Reference	2020	2025	2030	2035	2040	2045	2050
	65	71	75	74	71	68	73
PassMode	0	-4	-7	-10	-11	-11	-15
AltVeh	-2	-1	-1	-12	-22	-31	-40
MinBusDual	0	0	0	1	1	1	1
MetBusGas	0	-1	0	0	3	3	2
FreiRail	0	-2	-3	-4	-3	-3	-3
GTS All	-2	-8	-14	-25	-34	-42	-49
PassMode	0%	-6%	-10%	-13%	-16%	-16%	-20%
AltVeh	-3%	-2%	-2%	-16%	-31%	-46%	-55%
MinBusDual	0%	0%	0%	1%	1%	2%	2%
MetBusGas	0%	-1%	0%	0%	4%	4%	3%
FreiRail	0%	-3%	-5%	-5%	-4%	-4%	-3%
GTS All	-4%	-12%	-18%	-34%	-49%	-62%	-68%

Table 5: Cumulative national emissions with relative GTS contribution (MtCO2eq & Percentile) (2018-2050)

Reference	2020	2025	2030	2035	2040	2045	2050
	4632	6938	9096	11141	12921	14425	15347
PassMode	2	-19	-56	-105	-162	-218	-260
AltVeh	-3	-12	-16	-76	-197	-367	-491
MinBusDual	0	-4	-6	-3	5	17	26
MetBusGas	0	-6	-8	-16	-25	-36	-36
FreiRail	-1	-11	-17	-32	-55	-88	-109
GTS All	1	-45	-110	-250	-453	-705	-872
PassMode	0%	0%	-1%	-1%	-1%	-2%	-2%
AltVeh	0%	0%	0%	-1%	-2%	-3%	-3%
MinBusDual	0%	0%	0%	0%	0%	0%	0%
MetBusGas	0%	0%	0%	0%	0%	0%	0%
FreiRail	0%	0%	0%	0%	0%	-1%	-1%
GTS All	0%	-1%	-1%	-2%	-4%	-5%	-6%

4.1 Emerging Technologies and Fuels

The reference scenario is compared to the GTS all measures; and alternative vehicle technologies scenarios for the three main vehicle categories, namely freight, private and public (Figure 5).

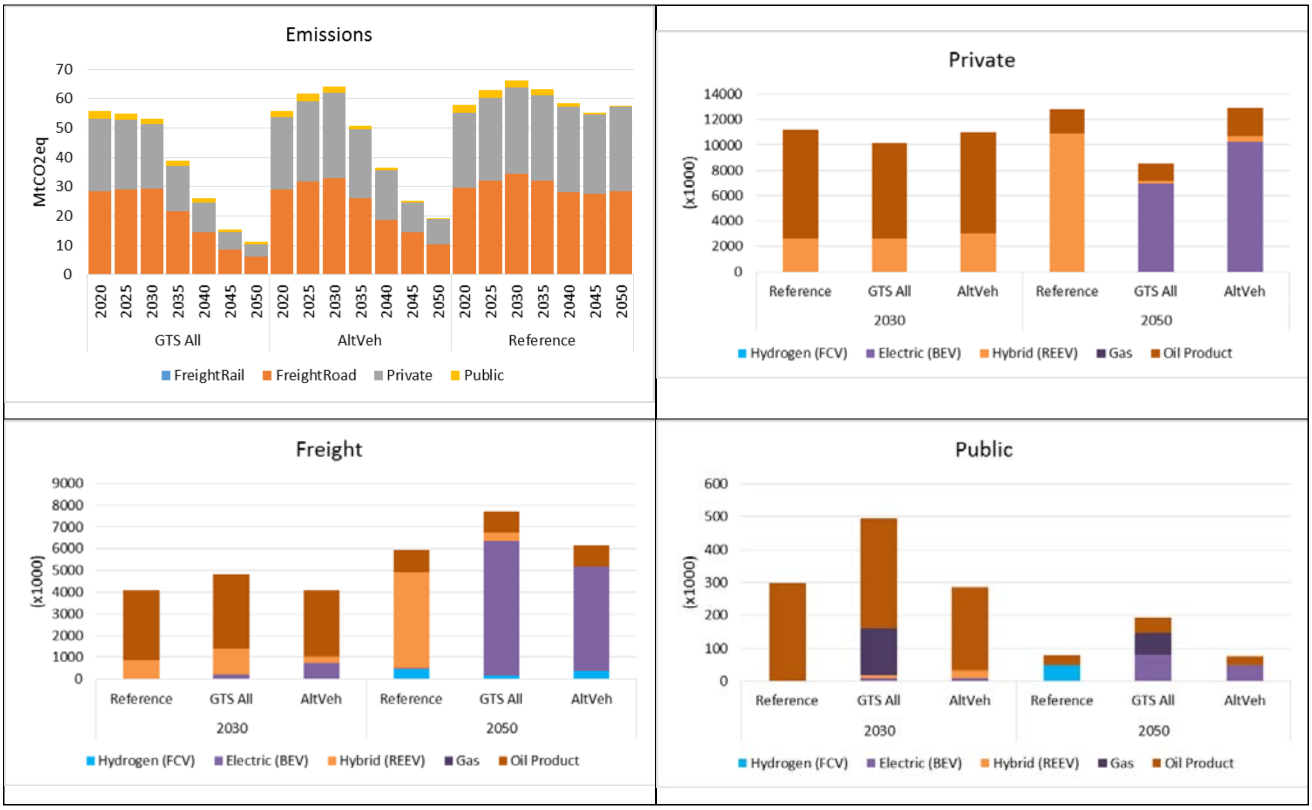


Figure 5: Vehicle population by sector, technology and emissions share

The primary competing technologies are electric and hybrid vehicles which dominate both the freight and private fleet. In freight, hybrid/electric technology is used in the light commercial fleet whereas hydrogen fuel-cells feature in the corridor segment in heavy vehicles. The GTS results in a marked reduction in private vehicle ownership with a corresponding increase in public vehicle capacity. Gas as a transport fuel dominates as a result of the GTS measure to convert minibus taxis and buses to gas fuel. This measure effectively displaces hydrogen in public transport as observed when compared to the reference scenario (Figure 6).

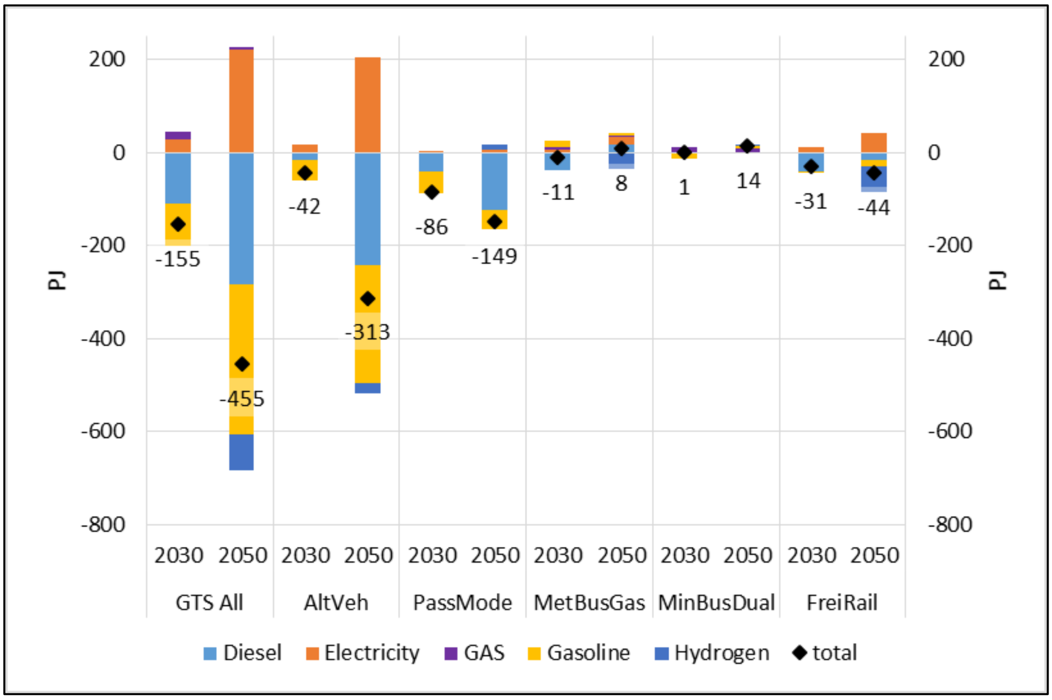


Figure 6: Fuel consumption relative to the reference scenario

The metro-bus and minibus conversions result in a net increase in fuel consumption in 2050 of 8 PJ and 14 PJ respectively. The GTS All combined portfolio would reduce fuel demand by 455 PJ (2050). Alternate vehicles, that is a shift towards electric vehicles, contributes the largest individual saving of 313 PJ (2050) followed by passenger modal shifting (149 PJ) and road to rail migration (44 PJ). Diesel and gasoline are the main fuels displaced across the measures with electricity becoming the preferred fuel. Hydrogen fuel in the freight sector is also displaced by electricity (medium to light truck categories).

The largest additional electricity requirement totalling 220 PJ (61 TWh) would amount to an additional 10% of future demand (McCall et al. 2019) which requires approximately 8 GW of additional electrical storage capacity; 14 GW of Wind; and 9 GW of Solar PV (Figure 7).

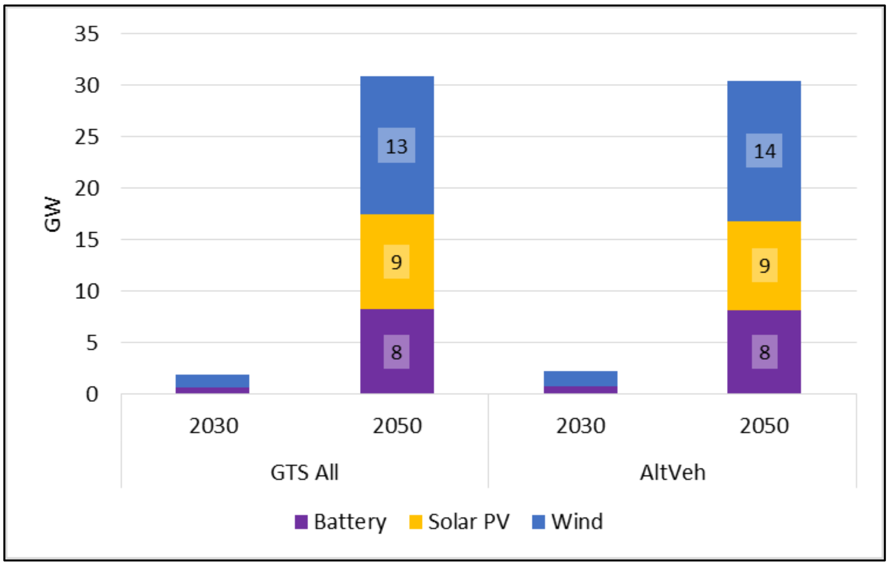
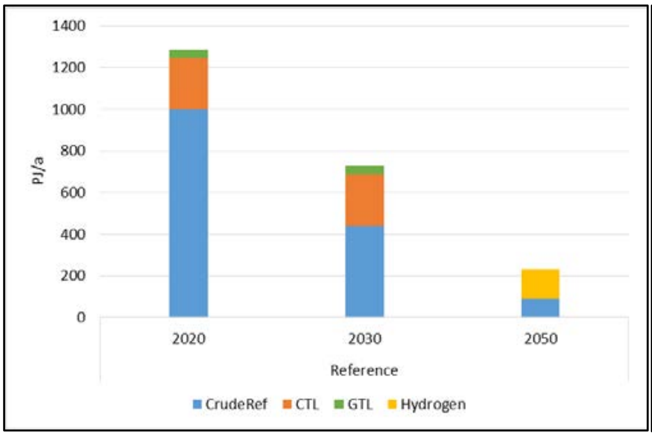


Figure 7: Difference in power sector capacity relative to reference scenario

4.2 Refineries and Liquid Fuel Supply

In the reference scenario, the Coal-to-Liquids (CTL) facility retires beyond 2040 with no new CTL economical. If the drafted Clean Fuels Phase 2 policy is required by 2030, crude oil refinery capacity would commence retirement by 2030 with practically no domestic production by 2050 (Figure 8a). Importation of fuels meeting Euro-5 standard is instead preferred. The reduction in demand for liquid fuels resulting from the GTS measures decreases the volume of imports. The GTS portfolio has no impact on the activity of conventional refineries (Figure 8b).

Demand for hydrogen in transport results in the development of domestic production capacity of ~140 PJ per annum in 2050, in the reference scenario. The implementation of the GTS curtails this demand by 84 PJ. The largest curtailment of an individual GTS measure is the corridor road to rail freight migration (62 PJ) and the metro-bus conversion (39 PJ). As indicated earlier, public transport buses and freight heavy vehicles are the prime candidate consumers of hydrogen fuel and therefore these GTS measures have the largest impact.



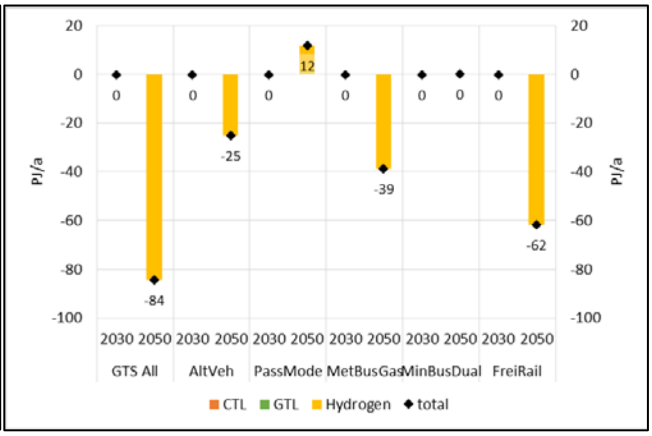


Figure 8: Domestic refinery capacity (a); and the relative impact with the GTS (b)

4.3 The Green Transport Strategy and Economic Development

The implementation of the GTS measures analysed here illustrate that decarbonising the transport sector and ensuring continued economic development are no longer mutually exclusive. The macroeconomic results from this study shows that relative to the reference case, the implementation of the GTS measures leads to an increase in economic growth and employment in both the short and long term. By 2030, average annual real GDP growth is 0.04 percentage points (%pts) higher and an additional ~229 000 jobs are created in the economy. The level of real GDP is 0.7% higher than in the reference case. By 2050, the benefits to the economy are larger with average annual growth increasing by 0.17 %pts relative to the reference case (or 3.8% in level terms) and employment increasing by 1.6 million (see Figure 9).

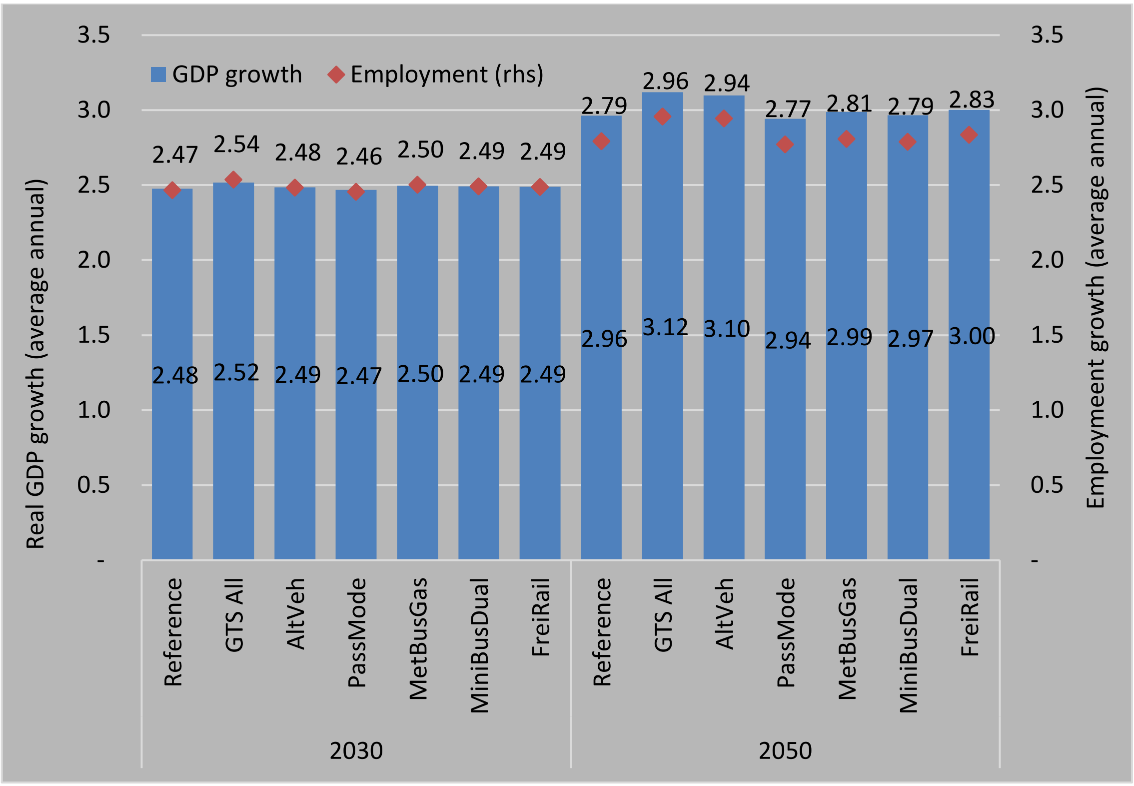


Figure 9: Real GDP and employment growth by scenario

The key links with the energy model ensures that the impacts of changes in energy investment, demand (including changes in energy efficiency) and prices are assessed in the economy-wide model. Declines in renewable energy technologies are expected to significantly decrease the costs of electricity enabling the use of power in other sectors in the economy, including the transport sector (see Figure 10c). By 2030 and 2050, the electricity price is 0.14% and 1% lower when the GTS is implemented relative to the reference case. The decline in the electricity prices offset the increase in electricity investment (Figure 10a) required due to increased demand resulting from the switch in the transport sector as well as higher economic growth. Refinery investment is lower in the GTS All scenario due to the decline in traditional liquid fuel demand.

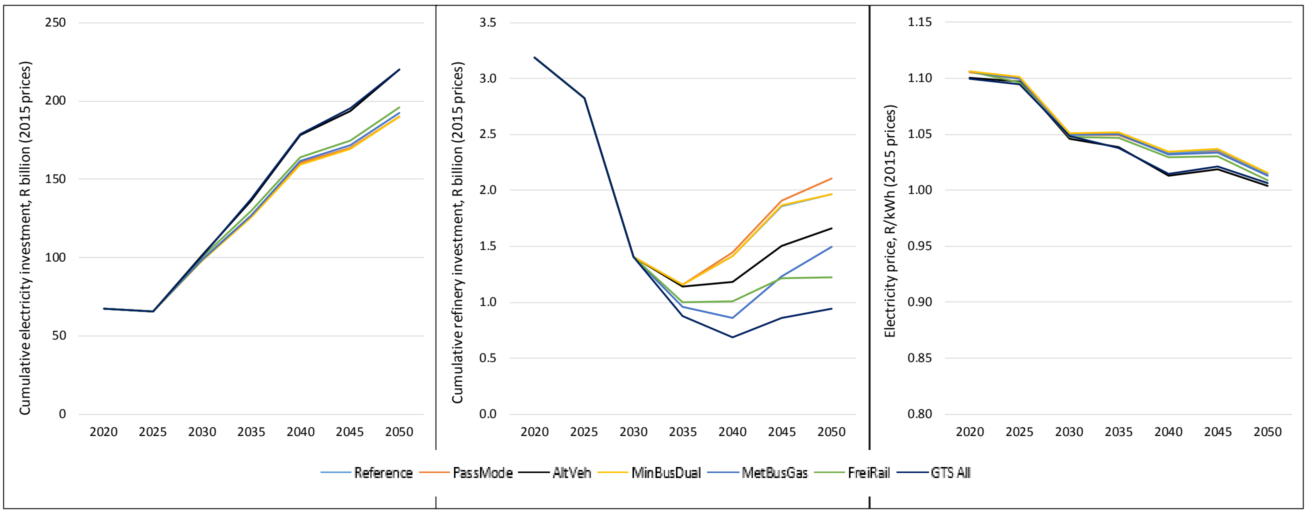


Figure 10: Cumulative investment (a – electricity; b - refinery) and c- electricity price

Fuel security improves under the implementation of the GTS as the shift away from traditional fossil fuels reduces South Africa's dependence on global markets for crude oil and refined product. By 2050, crude oil and petroleum imports decrease from 0.6% of GDP in the reference case to 0.4% in the GTS All scenario. In 2015, crude oil and refined product imports are ~3% of GDP. The decrease in dependence on foreign markets can be seen in the real exchange which improves over the period, as well as the rise in the trade balance as a share of GDP (see Figure 10). Lower dependence on foreign markets for transport fuels reduces the risk of global shocks to the economy.

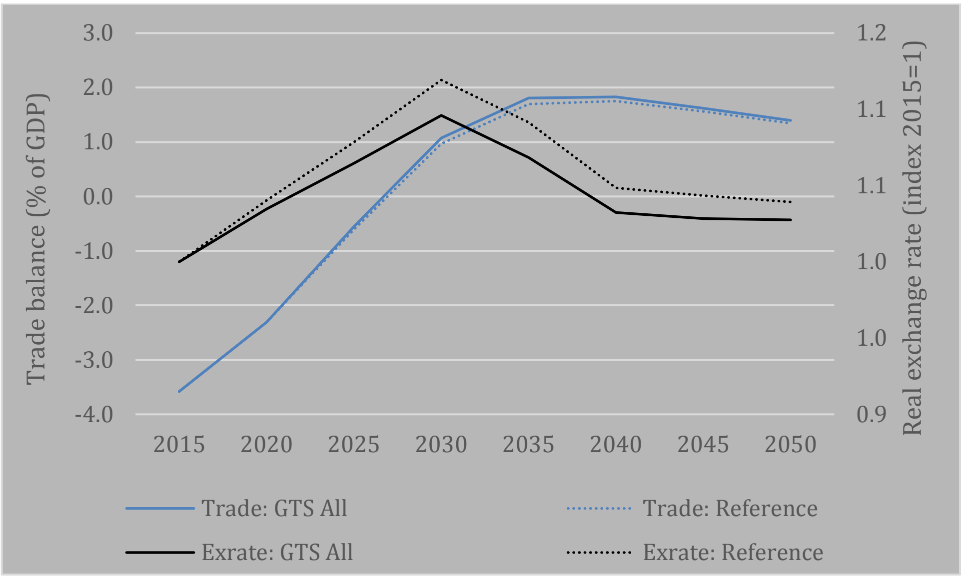


Figure 11: Trade balance and real exchange rate movements

In the short term (i.e. 2030) the key drivers of improved economic growth and employment under the implementation of the GTS is the MetBusGas, MiniBusGas and FreRail measures. Under these scenarios the price of freight and passenger transport declines due to the use of cheaper input fuels. The lower price increases the demand for these services which has positive knock-on impacts in the economy. Over the long term (to 2050), the improvement in growth and employment is primarily driven by the AltVeh scenario, i.e. the shift to electric vehicles. Significant electricity price declines are experienced under this scenario (0.6% relative to the reference case) having broad reaching positive impacts on the economy. It is important to note that in this analysis we do not account for structural changes and investments that may need to take place in the motor vehicle manufacturing sector but rather assume that the sector will continue to produce vehicles to meet the local market demand. Such an analysis requires a further assessment of the motor vehicle industry which falls outside the scope of this study.

The PassMode scenario, interestingly, is found to have a negative impact on economic growth and employment in both the short and long-term (-0.01, ~-36,000 and -0.02, -219,000). This result is due to rising demand for public passenger transport which increases the price of the service but also the result of increased demand for liquid fuels products, specifically diesel, by the public transport sector which both increases imports in the medium term and requires additional refinery capacity investment to allow for higher production in the longer term. The direct link between the energy and economic model for the passenger transport sector currently only takes place through changes in energy use. Future improvements to this may result in a different outcome.

Implications for transport support infrastructure, potential productivity improvements or structural changes in non-energy sectors are not included in this study as detailed micro economic assessments of these are required to inform relationships in the model and fully understand the implications of these changes within the sector and its links to the rest of the economy. Improvements in labour productivity resulting from less congestion, cleaner air and improved health are also not accounted for.

Table 6 Sector contribution to average annual real GDP growth by scenario

		Reference	GTS All	AltVeh	FreiRail	MetBusGas	MiniBusDual	PassMode
2030	**GDP**	**2.521**	**2.487**	**2.491**	**2.497**	**2.491**	**2.468**	**2.477**
	Agriculture	*0.09*	*0.09*	*0.09*	*0.09*	*0.09*	*0.09*	*0.09*
	Mining	*0.20*	*0.17*	*0.19*	*0.19*	*0.18*	*0.19*	*0.19*
	Manufacturing	*0.30*	*0.30*	*0.30*	*0.31*	*0.30*	*0.30*	*0.30*
	Other industry	*0.13*	*0.14*	*0.14*	*0.13*	*0.13*	*0.13*	*0.13*
	Services	*1.76*	*1.83*	*1.77*	*1.77*	*1.80*	*1.79*	*1.76*
2050	**GDP**	**3.119**	**3.097**	**3.000**	**2.987**	**2.966**	**2.943**	**2.964**
	Agriculture	*0.09*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*	*0.09*
	Mining	*0.20*	*0.19*	*0.19*	*0.20*	*0.21*	*0.21*	*0.20*
	Manufacturing	*0.37*	*0.38*	*0.38*	*0.37*	*0.37*	*0.37*	*0.37*
	Other industry	*0.17*	*0.20*	*0.20*	*0.18*	*0.18*	*0.17*	*0.17*
	Services	*2.12*	*2.24*	*2.23*	*2.15*	*2.14*	*2.12*	*2.10*

The sector impacts under each scenario are presented in Table 6. As illustrated the largest improvement in sector growth occurs in the services sector in which freight and passenger transport services are presented. The level of GDP in the land freight transport sector increases by 0.4% by 2030 and 4.5% by 2050 relative to the reference case scenario. Passenger transport services experience faster growth gains in the short term with the level of real GDP in the sector increasing by 24%, although positive gain are also experienced in the longer term. Faster growth is also experienced in the utilities (larger power) and manufacturing sectors despite the decline in production by traditional refinery producer. Within manufacturing, energy intensive users are the largest beneficiaries of the lower electricity price. The mining sector is the only sector that experiences a decrease in GDP. This however is driven more by the strengthening of the exchange rate which has a slows the growth of exports.

Household welfare increases under the GTS All scenario in both the medium and long-term. The impact is particularly positive for low income households which experience an increase in real consumption in the GTS All scenario (relative to the reference case) due to lower prices in the economy.

5. Conclusions

The Department of Environmental Affairs' Policies and Mitigation (2018) study investigated the Green Transport Strategy (2017) for its emissions mitigation efficacy and energy-economy impact. The GTS (2017) had outlined interventions which required implementation by 2022. As in this study, the Energy Research Centre's linked energy-economy model SATMGE was utilised. A passenger modal shifting programme was identified as the prime intervention for achieving the GTS vision. Furthermore, it was observed that the economic impact over the period 2022- 2050 resulted in an increase in real GDP of 0.1% – 0.2% with a saving of 14 MtCO2eq in 2050 which equated to 2%-5% reduction of national emissions and 20% reduction of transports emissions; if the strategy was enacted.

A comprehensive revision of the SATMGE model has provided an opportunity to expand upon the previous research and consider the updated GTS which was promulgated in 2018. The current ~25% tariff on the purchase of electric vehicles is included in the reference scenario and contrasted with the tabled GTS interventions. A practical implementation horizon as tabled in the NAMAs is also modelled.

In contrast to the GTS ambition of a 5% reduction in transport GHG emissions by 2050, the modelling analysis presented in this study suggests that there exists potential for reducing transport emissions by ~70% in 2050. This would reduce national GHG emissions emanating from energy utilisation by 18%. This reduction in emissions can be achieved with an improvement in economic growth and employment and positive impact on the exchange rate and trade balance. It is important to note the caveats mentioned earlier in this paper, in that associated benefits or costs related to productivity improvements or supporting transport infrastructure is not included in the economic assessment. Neither is the positive impact of improved air quality on health and labour productivity.

As with the previous analysis, passenger model shifting, and freight road-to-rail measure are revealed as interventions of significance; presenting effective migration gains in accordance with GTS vision. However, in this study, incentivising the adoption of alternative vehicle technologies are shown to be the prime agent with which to satisfy the GTS vision. Specifically, the electrification of transport in tandem with the deployment of low carbon power systems offer the most benefit. A preference for EVs would exceed the GTS 5% mitigation benchmark. The GTS alternative vehicle technology intervention as modelled in this study is dominated by electric vehicles in the passenger and light commercial fleet. The model assumes that tariffs are removed to encourage adoption and that by 2030 cost parity is achieved with conventional vehicles (BNEF, 2018). The electrification of transport could solely reduce transport emissions by 55% in 2050 with a corresponding reduction in national emissions of 13%.

The dual-fuel minibus taxi and metro-bus conversion to gas fuel is again confirmed to offer negligible GHG mitigation, with the conversion of metro-buses to gas fuel displacing the preference for hydrogen as fuel: up to 39 PJ in 2050.

Further considerations for improving the assessment of low carbon transport strategies include:

- improvements in energy and economic model links in the transport sector;

- a comprehensive analysis of supporting infrastructure costs and that of induced and indirect economics impacts (e.g. the effect on industrial sectors such as Chemicals and Manufacturing);
- establishing a regionally accurate vehicle parc model with appropriate air quality emissions factors to address local air pollution;
- municipal scale analysis to investigate local opportunities to offset emissions, where liquid biofuels or biomethane may provide tangible economic and environmental benefits;
- quantifying the role of the aviation and maritime sectors in reducing transport emissions; and
- establishing a reference baseline emissions trajectory that is used to quantify sector mitigation potential. The baseline trajectory would require annual revision to maintain its utility.

The GTS could achieve substantial GHG mitigation in transport and the national inventory if interventions are implemented as tabled. Furthermore, in light of continued technological innovation, the ”5% by 2050” mitigation goal appears conservative. The analysis indicates that the transport sector is able to contribute an order of magnitude higher if policy encourages the adoption of economic and resource efficient technological alternate, and behavioural changes towards public transport

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