



SADC e-Mobility Outlook: Accelerating Low Carbon Transport Futures

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EXECUTIVE SUMMARY

The Southern African Development Community (SADC) is host to countries with stark disparities in development ranging from least developing such as Malawi to middle income such as South Africa. The regional development agenda is therefore highly country specific given each member states' specific priorities. Transport in Southern Africa is acknowledged as a foundation to regional economic development and integration which attests to SADC's Regional Indicative Strategic Development Plan (RISDP) emphasising transport infrastructure investment. Of the estimated 567 Mt CO₂ attributed to fuel combustion by SADC member states in 2014, the transport sector is responsible for 17% or 94 Mt CO₂ of which road transport is the primary contributor. South Africa accounts for approximately 60% of the SADC road fleet and consumed approximately 60% of final fuel demand for SADC transport (1190 PJ) in 2018. Domestically, its road fleet accounts for 90% of Green House Gas (GHG) emissions and final fuel consumption. Presently, the contribution of transport to South Africa's national energy-related CO₂ emissions is estimated to be approximately 14%.

South Africa's 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 domestic emitting sector by mid-century.

The SADC population, currently at 363 million, is projected to exceed 700 million by 2050. Should regional development and investment in transport infrastructure reflect South Africa's present trajectory, regional emissions and energy demand will increase dramatically and challenge the implementation of member states' climate change commitments. It is therefore imperative to decarbonise the SADC transport sector to realise the vision of the Green Economy Strategy and Action Plan for Sustainable Development (GESAP) and the Nationally Determined Contributions (NDC) member states have pledged. The urgency for action given Southern Africa's acute vulnerability to the adverse impacts resulting from Climate Change requires a vision in accordance with the Paris Agreement.

Transport in South Africa in 2050: regional lessons

Owing to its regional predominance in energy supply, consumption and GHG emissions, a quantitative assessment of the South African transport sector with a focus on road transport was undertaken to explore future domestic impacts and regional ramifications regarding vehicle technology and fuel supply choices. 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 stimulates electricity demand driving investment in the power sector: in South Africa this could translate to a 20% increase in electricity demand by 2050. In rural areas, e-micromobility presents a synergistic opportunity to expand the deployment of microgrids.

The investment in power generation to support e-mobility replaces the need to upgrade existing refineries to improve fuel quality. No additional investment in new crude-oil refinery capacity would be warranted if the transport fleet is electrified. Angola is presently the SADC member most at risk in this context as petroleum product is its chief export commodity.

Corridor freight heavy vehicles present an opportunity for a hydrogen supply chain in Southern Africa. Hydrogen as a transport fuel could displace diesel in the SADC corridor freight fleet. The level of hydrogen demand is dependent on both the choice of road vehicle technology and investment in rail infrastructure. In South Africa, in conjunction with road-to-rail modal shifting along corridor routes, hydrogen could account for 6% to 17% of total vehicle-kilometres driven.

Shifting road vehicle-kms to rail is key to achieving substantial energy savings. A low carbon and functional transport system should therefore also include public transport system at its core, with the rehabilitation of rail systems a priority. A continued reliance on road vehicles will require additional revenue for both new road capacity and functional maintenance. In South Africa alone a backlog of road maintenance is estimated to cost R417 billion.¹

The SADC Green Economy Strategy and Action Plan (GESAP provides) a framework for charting a path towards climate resilient and low carbon transport that could drive greener inclusive economic growth via the creation of new manufacturing value chains spanning the region. The GESAP promotes low carbon alternatives but potentially counterproductive measures are tabled in complementary policy formulation such as the Regional Indicative Strategic Development Plan (RISDP). Continued investment in conventional oil and gas infrastructure may defer or avoid investment in zero GHG emissions alternatives due to the likelihood of technology and supply chain infrastructure lock-in.

¹ Townsend M. and Ross D. "The road maintenance backlog in South Africa", <u>https://www.academia.edu/36885537/The road maintenance backlog in South Africa</u> (accessed October 15, 2020)

Key objectives for an ambitious transition in transport as indicated in this study are summarised in Table 1.

Table 1: Key recommendations	for a reaional low carbon	and eneray transport system in 2050
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Target	Measures and Interventions
Freight	Prioritise rail systems along corridor routes.
	Investigate the potential for advancing hydrogen energy infrastructure in SADC: draft a regional hydrogen roadmap which considers the assembly or manufacture of hydrogen fuel-cell heavy vehicles and hydrogen gas for regional and global export markets.
Public transport	Harmonise transport policies and strategies within national climate and socio-economic imperatives (i.e. spatial development incorporating housing and affordable and efficient transport).
	Strategic investment with a 50-year horizon in efficient rail, minibus and micromobility infrastructure.
Electric Vehicles	Establish a regional automotive value chain spanning mineral extraction to component manufacture prioritising the portfolio of electric vehicles comprising battery, hydrogen and micromobility technologies.
	Utilise public investment vehicles to provide green manufacturing incentives to avoid investment in stranded fossil-fuel infrastructure and technology lock-in.
	Deploy e-micromobility such as e-bikes and e-scooters to accelerate rural mobility and stimulate mini-grid investment to address national electrification goals.
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.
	South Africa's synfuel complex should be assessed for its potential as a green hydrogen-based supply of transport fuel and chemicals; potentially in partnership with Mozambique exploiting its natural gas resource with carbon capture and utilisation.
	Scale investment in diverse renewable energy (RE) sources such as solar, wind and geothermal to decarbonise the Southern African Power Pool (SAPP) establishing a multi-corridor RE-SAPP that facilitates a SADC e-mobility transition and enables economic diversification of SADC member states.

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 CO2 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 CO2 emissions should reach net zero² 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.

Previous mitigation analyses aimed at limiting emissions to 2050,³ 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 Green House Gas (GHG) emissions (hereafter referred to as "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. In addition, to also identify sectors and/or subsectors in which this is currently not possible and to explore future technology options, in the context of sustainable development challenges in the overall economy.

How then does this affect southern African countries? This paper takes a closer look at land transport in the Southern African Development Community (SADC) with emphasis on South Africa, as the largest contributor to emissions in the region, to explore the role of transport and the synergies that exist with the power sector in decarbonising the region. Comparative

 $^{^{\}rm 2}$ 'Net zero' means that globally, we reach a point at which CO2 sources equal CO2 sinks.

³ 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.

examples from Angola, the Democratic Republic of the Congo (DRC), Mozambique and Zambia are used to highlight key transitional risks and opportunities.

SADC is estimated to account for 2%-3% of global GHG emissions from fossil fuel combustion totalling 594 MtCO₂e in 2014.⁴ South Africa contributes the majority share of 82%, with Angola the second largest GHG emitter with 8% of the SADC total (Figure 1). Within the limitations of available data for the region, all member states tend to exhibit large shares of GHG emissions from fuel combustion for transport services, for which South Africa's transport sector has the lowest contribution at 12% in 2014.





Except for Angola all member states have registered NDCs, signalling a commitment to transformational development that integrates climate change mitigation.⁵ As the second largest economy on the continent, South Africa's economy accounts for half of the SADC Gross Domestic Product (GDP).⁶ Owing to its coal intensive economy, South Africa's emissions represents almost half the region's emissions and therefore has a preeminent role in the SADC decarbonisation agenda.

DECARBONISED TRANSPORT: THE IMPERATIVE OF A SUSTAINABLE TRANSPORT TRANSITION

⁴ World Bank, "World Development Indicators", <u>https://databank.worldbank.org/</u> (accessed October 11, 2020)

⁵ UNFCCC, "NDC Registry (Interim)", https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx (accessed, October 8, 2020)

⁶countryeconomy.com, "SADC - Southern African Development Community" <u>https://countryeconomy.com/countries/groups/southern-african-development-community</u> (accessed, October 8, 2020)

The transport sector is responsible for roughly a quarter of energy-related CO₂ emissions globally, but transport emissions are increasing at a rate faster than other energy-end-use sectors.⁷ Road vehicles account for the bulk of transport emissions, approximately three quarters of global transport emissions.⁶ In South Africa, this figure is even higher, with more than 90% of transport emissions arising from road transport.⁸ Globally, despite advances in vehicle efficiency, alternative fuels and alternative mobility technologies, road transport emissions continue to increase – offsetting mitigation savings.⁹ 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 of the transport transition.

In 2015 the SADC vehicle population was estimated at 16 million vehicles with passenger vehicles accounting for ~65% of the fleet (Figure 2). The SADC motorisation rate,¹⁰ excluding South Africa, is similar to the continental average of ~40 vehicles per 1000 persons compared to the global average of 180.¹¹ South Africa, Mauritius, and Botswana are exceptions having similar motorisation rates to the global average. South Africa's vehicle population represents 60% of the SADC fleet and when combined, results in a higher SADC motorisation rate of 50. Motorisation is influenced by income and access to vehicles with wealthier countries typically exhibiting much higher rates; the USA, for example having the highest rate of 820 relative to the European average of 470. Total vehicle demand in Sub-Saharan Africa (SSA), in 2017, was 1.7 million¹² vehicles compared to the South African (ZA) market of 557,704.¹³ Although the ZA market comprised a third of continental demand, income growth could see demand for 2.1 million units by 2035 in SSA with consequences on fuel demand and emissions.

Figure 2: Estimated vehicle population in SADC and motorisation rates.^{11,53}

⁷ IEA [International Energy Agency]." Tracking Transport". https://www.iea.org/reports/tracking-transport-2019

⁸ WWF [World Wildlife Fund], "Low Carbon Frameworks: Transport". http://awsassets.wwf.org.za/downloads/

wwf_2016_transport_emissions_in_south_africa.pdf (accessed, October 8, 2020)

⁹ ITF [International Transport Forum]. "Transport Outlook 2019".

¹⁰ Motorisation rate unless defined otherwise is the ratio of the total vehicle fleet to the resident population (,000s persons)

¹¹ OICA [International Organization of Motor Vehicle Manufacturers], "Vehicles in Use" <u>http://www.oica.net/category/vehicles-in-use/</u> (accessed, October 8, 2020)

¹² Justin Barnes, "Driving African industrialisation: Establishing a Sub - Saharan African Automotive Pact",

¹³ NAAMSA [National Association of Automobile Manufacturers of South Africa], "Domestic New Vehicle Sales",

https://www.naamsa.co.za/NewVehicleStatistics.aspx (accessed, October 8, 2020)



*Figure 3: Vehicle ownership vs income (2007)*¹⁴



Specific, ambitious and actionable transport-related policies and targets are lacking at the regional and regional level, undermining climate objectives and the net zero targets outlined in the IPCC Special Report. According to the International Transport Forum⁹ 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 CO₂ 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

¹⁴ IPPC (Intergovernmental Panel on Climate Change), Mitigation – Fourth Assessment Report, Chapter 5 "Transport and its infrastructure"

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.

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 a bus rapid transit (BRT) system. Popular measures for each lever are captured in Figure 3 below.

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.

Figure 4:Transport Transition Levers & Measures



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 ITF⁹ high ambition scenario results in global CO₂ emission reductions in the transport sector of 30% by 2050 – from 7 200 MtCO₂ eq in 2015 to 5 000 MtCO₂ eq 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.

A TRANSPORT TRANSITION FOR SOUTH AFRICA WITH REGIONAL IMPLICATIONS

In this paper, we focus our analyses on the potential to decarbonise the South African transport sector, the largest in region, 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-motorised 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.

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.¹⁵ 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 South Africa's National Development Plan.¹⁶

The transport sector within SADC is similarly encumbered by the difficulties facing South Africa albeit with differing historical socio-economic development trajectories. Expensive, unreliable transport services coupled with insufficient energy supply have been identified as a major hurdle to regional growth.¹⁷ Like South Africa, road transport is the primary means of land transport in the region. The SADC Regional Infrastructure Master Plan's (RIDMP) Transport Sector Plan outlines measures to integrate and harmonise transport policy across the region to better facilitate regional trade. Of these, the road network is identified as a vital component to the vision of a seamless integrated regional transport system. Vehicle technology and fuel choice are critical pillars in realising this vision and presently the region lacks standardised fuel quality specifications and tariff mechanisms governing the sales of new and used vehicles, especially with regard to energy efficiency and emissions standards.^{18,19}

In terms of trade volumes and value, South Africa, Angola, Zambia, the DRC and Mozambique represent close to 80% of the annual SADC GDP. The global energy transition is of particular consequence to these countries as economic activity is concentrated in either fossil-fuel or new energy minerals and technologies as illustrated in Figure 4. Angola's export revenue is almost entirely dependent on petroleum products (90%) while importation of refined petroleum products totalled 13% of import costs. Similarly, Mozambique's export revenue

https://www.unenvironment.org/events/workshop/sadc-regional-framework-harmonisation-low-sulphur-fuels-and-vehicle-emission (accessed October 9, 2020)

¹⁵ PricewaterhouseCoopers, "Africa Gearing Up: Future prospects in Africa for the transportation & logistics industry"

¹⁶ South Africa, "National Development Plan 2030 - Our Future-Make It Work", https://www.nationalplanningcommission.org.za/assets/Documents/ndp-

²⁰³⁰⁻our-future-make-it-work.pdf (accessed October 8, 2020) ¹⁷ SADC, "Regional Infrastructure Development Master Plan- Executive Summary"

¹⁸ UN Environment Programme, "SADC Regional Framework for Harmonisation of Low Sulphur Fuels and Vehicle Emission Standards",

¹⁹ Anas Abdoun, "Fuel Quality and Emission Standard Developments in Africa"

comprises mainly coal and gas while being reliant on importing petroleum products. In contrast, in the spectrum of economic transition, the DRC and Zambia by scale of trade represents the bulk of SADC trade in key minerals for the new energy transition in particular to electric vehicles. South Africa's economy is in comparison relatively diversified by portfolio and magnitude of trade. Platinum, manganese, coal, and vehicles are key export segments (27%) while vehicle components and petroleum products are key import segments (18%). Noteworthy is the reciprocal importation of vehicles and vehicle components by its SADC neighbours and as shown in Figure 5 the similar flow of petroleum fuels between member states.



Figure 5: Trade of key energy commodities and vehicles and components for selected SADC member states⁶ (2018)

Figure 6: Southern Africa petroleum fuel flows (2010-2013)²⁰



Concerning the regional trade in vehicles and fuel, the ICCT²⁰ notes that:

"Limitations on importation of second-hand vehicles vary across the subregion. Angola allows individuals to import any aged vehicle but not motor companies. Botswana prohibits import of vehicles with more than 100,000km of mileage. Age limits for second-hand imports are set in Lesotho (8 years) and Mozambique (5 years for cars; 9 years for vans), while South Africa bans all second-hand vehicles with a few exceptions. South Africa is a major manufacturer of vehicles and has the second highest motorisation rate in Sub-Saharan Africa (after Congo-Brazzaville).

When comparing fuel and vehicle standards Mozambique can implement at least Euro 2 vehicle emission standards, based on current fuel quality. Once South Africa implements its 10ppm standard for both gasoline and diesel, it plans to set a Euro 5 vehicle emission standard. Given that Mozambique and South Africa supply most of Southern Africa's fuel, it is conceivable that all the countries could likewise implement higher vehicle standards to match the fuel quality".

https://theicct.org/sites/default/files/CCAC%20Africa%20Clean%20Vehicles%20and%20Fuels%20RFP.pdf (accessed October 8, 2020)

²⁰ ICCT [International Council on Clean Transportation], "Fuel and vehicle flows in Western and Southern Africa",

Status and Trends in Transport Sub-Sectors

Public & Private Passenger Transport

Unlike South Africa, most SADC member states lack regular detailed statistical censuses specific to transport utilisation and modal choices.^{21,22,23} Selected case studies on public transport however suggest similar trends and indicators across the region.^{24,25,23}

The South African public transport system is characterised by inefficiency and inequality. 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.

Long commute times and the cost of public transport are key barriers to further patronage.^{26,27} In 2013, lower income groups spent >20% of their monthly household income on transport.²⁸ Despite the fact that rail is significantly cheaper than mini-bus taxis and buses, both which are substantially more affordable than private car use, the trend away from public transport (specifically rail) reveals the increasing dysfunctionality of the South African public transport system.^{27,28,29}

With respect to passenger vehicles, from 2013 to 2018 the motorisation rate (thousands of vehicles per person) is estimated to have increased 6%, from 120 to 130 revealing an increasing trend in private motorised travel over the past decade.²⁶ 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 multipliers₃) and employing 113,532 people across assembly, components, and tyre manufacturing sub-sectors. This presents additional policy challenges and opportunities regarding technology choices for future road vehicles.^{30,31,32}

With an estimated population of 60 million (2020), South Africa accounts for 16% of the SADC population of 363 million; of which the DRC comprises the largest population share at 25%.⁵³ The SADC population is projected to increase to ~700 million by 2050 with South Africa reaching ~75 million (10%). In light of the current unsustainable practices, a holistic regional approach to reversing these trends is necessary.

²¹ United nations economic and social council, "Africa Review Report on Transport"

²² International Association of Public Transport, "Report on statistical indicators of public transport performance in Africa"

²³ Ajay Kumar and Fanny Barrett, "Stuck in traffic: Urban transport in Africa"

²⁴ Engineering for Change, "The African commute: city transport trends" <u>https://medium.com/impact-engineered/the-african-commute-city-transport-trends-</u> cf369e5106bd (accessed October 9, 2020) ²⁵ Infrastructure Consortium for Africa, "Urban Transport in Sub-Saharan Africa"

https://www.icafrica.org/fileadmin/documents/Publications/ICA Urban Transport Study - Summary Oct16.pdf (accessed October 9, 2020)

²⁶ Statistics South Africa, "National Household Travel Survey. South Africa"

²⁷ Luke and Heyns, "Public transport policy and performance: The results of a South African public opinion poll."

²⁸ Philip van Ryneveld, "Urban Transport Analysis for the Urbanisation Review"

²⁹ Londeka Ngubane, "The state of public transport in South Africa" https://www.saferspaces.org.za/understand/entry/the-state-of-public-transport-in-southafrica (accessed October 10, 2020)

³⁰ Statistics South Africa, "Discussion Document on South Africa's Motor Trade Industry" ³¹ Johannes Jordaan et al. "Economic and socio-economic impact of SA automotive industry"

³² Anthony Dane et al. "Exploring the Policy Impacts of a Transition to Electric Vehicles in South Africa"

Commercial Transport & Freight: Road, Rail & Maritime Transport

In South Africa, the commercial transport and freight sector accounts for the majority (85%) of transport is via road with existing rail capacity not fully utilised at significant cost and losses associated with inefficiency.^{33,34} 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). SADC trade is inextricably linked to South Africa for whom intra-regional exports comprise ~60% of trade, followed by Angola, Namibia, Zimbabwe and the DRC which each account for 6% to 7% of intra-trade facilitated primarily via road.³⁵ Fuel and lubricants are unsurprisingly the most significant operating cost, accounting for on average 40% of vehicle operating costs.³⁵

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 in South Africa is estimated to cost R417 billion.³⁶ To put this into perspective, this is almost double the annual health expenditure in South Africa for 2019.³⁷ 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.³⁸

Similar to the SADC situation, 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.^{35,39,40} Although land and air transport dominates intra-state trade within the region, maritime transport and associated ports are a vital economic backbone to regional development owing to the substantial international trade by member states. Most regional exports are via the South African port of Durban emphasising the current critical enabling role of the land transport sector.³⁹ With more than 95% (by volume) of South Africa's imports and exports shipped by sea, maritime shipping and transport plays a critical role yet South African ports are "characterised by high costs and substandard productivity relative to global benchmarks".¹⁶ The maritime shipping industry is dominated by international companies – but includes a small portion of South African shipping companies operating through off-shore subsidiaries.⁴¹ 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.⁴²

³³ Jan v. Havenga, "The importance of disaggregated freight flow forecasts to inform transport infrastructure investments."

³⁴ Jan v. Havenga et al., "A Logistics Barometer for South Africa: Towards sustainable freight mobility."

³⁵ Alexis Habiyaremye, "Fast tracking the SADC integration agenda to unlock regional collaboration gains along growth corridors in Southern Africa"

³⁶ Townsend and Ross, "The road maintenance backlog in South Africa":

³⁷ National Treasury (South Africa), "National Budget, Estimates of National Expenditure"

³⁸ Department of Transport (South Africa) "Draft Green Transport Strategy: (2018-2050)"

³⁹ SADC, "Transport" <u>https://www.sadc.int/themes/infrastructure/transport/</u> (accessed October 10, 2020)

⁴⁰ Jan Havenga and Anneke de Bod, "Sub-Saharan Africa's rail freight transport system: Potential impact of densification on cost"

⁴¹ Department of Transport [South Africa], "SA Maritime Transport Sector Study" (2011)

⁴² Department of Transport [South Africa], "Comprehensive Maritime Transport Policy" (2017)

Aviation: Passenger & Cargo

The OR Tambo International airport in South Africa is the largest SADC aviation hub. The airport hosted the majority of the 74% of passenger traffic (32 million) and 62% of freight traffic (1,160 million ton-km) estimated for South Africa's activity as a SADC member for 2018.⁴ Similarly to other segments of the transport sector, aviation 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.³⁸ 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.⁴³ However, only about 10% of South Africans currently use air transport, which reflects broader trends in income inequality and transport use. When it comes to airfreight, international traffic dominates – accounting for 83% of all volumes, the majority (55%) of which is inbound.⁴³ 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.

Transport Emissions Profile

Oil products (e.g. gasoline, diesel, kerosene) are the primary SADC transport fuel, estimated at 99% (1177 PJ) of the final energy consumption by transport (1190 PJ) with road transport responsible for 93% of the total consumption by mode (Figure 6).

Figure 7: Estimated SADC final fuel consumption by mode and key fuels (2018) ⁴⁴ Note: Other includes domestic maritime navigation

⁴³ Department of Transport [South Africa], "National Airports Development Plan" (2015)

⁴⁴ IEA [International Energy Agency], "Data and statistics" <u>https://www.iea.org/data-and-statistics/</u> (accessed October 11, 2020)



As the largest energy consumer in the region, in 2015, emissions from the transport sector in South Africa were estimated to account for 10.8% of the country's total GHG emissions, and 14% of energy related CO2 emissions. Upstream emissions from the production, refining and transportation of liquid fuels (not included in the transport sector) also contribute significantly to South Africa's 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.⁴⁵ 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 and 93.1% of the sector's emissions, it is the area with the greatest mitigation potential (Figure 7).

Figure 8: Transport fuel commodity split for South Africa (2015)⁴⁶

⁴⁵ Department of Environmental Affairs [South Africa], "GHG inventory for South Africa 2000-2015"

⁴⁶ Bruno Merven et al. "Road freight and energy in South Africa" <u>https://sa-tied.wider.unu.edu/article/road-freight-and-energy-in-south-africa</u> (accessed October 11, 2020)



Green Transport Futures

The SADC Green Economy Strategy and Action Plan for Sustainable Development⁴⁷ (GESAP) is the central framework for member states charting the community's vision for green industrialisation as the core of regional economic integration and cooperation. Promulgated in 2012, the GESAP provides guidance for 10 sectors deemed regionally significant outlining specific measurable targets by which to implement the adopted strategies. Transport, as the backbone to economic integration is one such sector for which several challenges, as highlighted earlier, are identified. The Regional Infrastructure Development Master Plan [Transport Sector Plan]³⁹ and the Regional Indicative Strategic Development Plan⁴⁸ (RISDP) 2020-30, which prioritises transport infrastructure provides a foundation for the GESAP's transport strategies and targets which are summarised in Table 1. The strategies, a synthesis of regional and national planning policies outlines 3 transport themes which address infrastructure and climate change; green multimodal passenger and freight transport; and regional low carbon vehicle trade.

	Strategies	Action List	Time Frame
T1	Promote investments in climate- resilient transport	T1.1. Establish incentive schemes for the promotion of innovative materials for road, railway and airport infrastructure in order to increase resilience to floods, storms, coastal erosion and higher temperature.	Long Term
	infrastructure	T1.2. Conduct assessment studies on the adaptation of key transport infrastructure highly exposed to climate change impacts (e.g., to sea level rise).	Medium Term
Т2	Promote green public transport	T2.1. Encourage the establishment of public-private sector models to invest in and operate green transport systems.	Short Term

Table 2. Green Econom	v Stratogy and A	ction Dlan	for Suctainable	Dovolonment	Transport Action Dlan47
TUDIE 2. GIEEN LLUNUIN	y Strutegy unu A			Development.	Παποροπι Αυτιοπ Επαπ

⁴⁷ SADC, "Green Economy Strategy and Action Plan For Sustainable Development"

https://www.sadc.int/files/4515/9126/1250/SADC Green Economy Strategy and Action Plan-English.pdf (accessed October 8, 2020) ⁴⁸ SADC, "Regional Indicative Strategic Development Plan, 2020-2030 Blue Prints, 4th Draft" <u>https://imanidevelopment.com/wp-</u>

content/uploads/2020/03/4th-Draft_RISDP-2020-30-Blue-Prints2.pdf (accessed October 8, 2020)

	networks and multimodal	T2.2. Promote investments in "green ports"	Long Term
	Transport	Long Term	
	T2.4. Increase access to public transport, especially the poor and marginalised.		Short Term
		T2.5. Conduct assessment studies for multimodal transport	Short Term
	Encourage regional trade in low-	T3.1. Harmonise regulations on vehicle emissions and vehicle import bans.	Medium Term
em veł T3	emitting vehicles.	T3.2. Provide incentives to the regional trade in low- emitting vehicles, e.g. through custom tax rebates or exemptions.	Short Term
		T3.3. Encourage the reduction (or reform) of harmful subsidies on gasoline and diesel (based on assessments of economic implications of the reallocation of the subsidies).	Medium Term

Similar to the GESAP strategic vision for transport, 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 2050⁴⁹ (NATMAP), the primary policy basis for transport planning in South Africa.

Building from the NATMAP and in response to the National Climate Change Response Policy,⁵⁰ which advocates a climate-resilient and low carbon economy by 2050, the revised Green Transport Strategy, was published in 2018.³⁸ The Strategy, in accordance with the GESAP, 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. These are captured in Table 2 below.

⁴⁹ Department of Transport (South Africa), "National Transport Master Plan (NATMAP) 2050 Synopis Report", <u>https://www.transport.gov.za/natmap-2050</u> (accessed October 12, 2020)

⁵⁰ Department of Environmental Affairs (South Africa) "National Climate Change Response Policy (2011)"

Implementation Themes	Strategic Pillars
Climate Change Response Norms & Standards	 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	 Shift car users from <i>individual</i> private passenger cars to public transport, including rail.
	 Provide infrastructure to promote non- motorised transport and eco-mobility transport.
	 Provide transport infrastructure in a manner supportive of the eco-system, while not clearly compromising generations to come.
Green Rail	 Extend the rail network to provide reliable, safe, and affordable high- speed transport while switching to renewable energy trains.
Green Transport Technologies	 Reduce the carbon footprint of over- reliance on petroleum based fuels, by decarbonising the transportsector.
	 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	 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.

Table 3: Green Transport Strategy Themes & Pillars (South Africa)

Box 1: Green Transport Strategy Short-term Strategic Targets

- 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.
- 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.
- 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.
- Invest in sources of green energy infrastructure, such as biogas filling stations, electric car charging points, GIS integratorICTtechnologyplatformsforlocating stations, regulating future pricing and providing statistics.

MODELLING AN AMBITIOUS TRANSITION IN TRANSPORT

To explore possible transport futures for their regional impact, a quantitative assessment of the South African road transport sector is conducted. Owing to the relatively good record of historical data and its significant role in the region in terms of emissions, vehicle fleet size, fuel consumption and supply, and vehicle production, a South African specific modelling platform is utilised. 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.⁵¹ The composition of mobility services are primarily a function 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 8, the technological and policy landscape is thus defined by:

1) Vehicle Technology (horizontal axis):

a. <u>Non-EV automotive sector</u>: South Africa's auto industry remains a laggard in switching to Electric Vehicle (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 Internal Combustion Engine (ICE) technology. Domestic production of hybrid-ICE vehicles are cost competitive alternatives. Policies to encourage a shift to EVs (including cars, buses, minibus taxis and light commercial vehicles) are not pursued. A continuation of the existing fuel consumption pattern and vehicle technologies in the region would persist with the associated fossil-fuel infrastructure.

b. <u>EV automotive sector:</u> 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). A reorientation of regional manufacturing is implied towards new energy technologies and key commodity value chains anchored in the extraction and beneficiation of local resources such as copper, lithium (Zimbabwe), cobalt and manganese.

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

a. <u>Road vehicle emphasis</u>: 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. <u>Modal shift and transit-oriented development:</u> 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.

⁵¹ Stone, A., Merven, B., Maseela, T. and Moonsamy, R. "Providing a foundation for road transport energy demand analysis: The development of a vehicle parc model for South Africa", https://doi.org/10.17159/2413-3051/2018/v29i2a2774 (accessed October 3, 2020)

Figure 9:Transport carbon pathways towards 2050



MODAL SHIFT & TRANSIT ORIENTED DEVELOPMENT

Table 4: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 the NDC pledges by South Africa and its member states, 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 8Gt - representing South Africa's lower NDC range- and for which previous analysis⁵² suggested the budget as the economically sustainable threshold that the country could sustain. 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.

Exploring the technical feasibility of an ambitious transition

Growth Factors

The primary drivers of growth in transport services are GDP and population growth. The SADC population of approximately 363 million (2020) is expected to reach ~700 million by 2050.⁵³ The South African population estimated at ~60 million (2020) is projected to increase to 75 million by 2050 accounting for approximately 15% - 10% of the SADC population over the period.

Population growth projected for SADC is contrasted against growth for South Africa and other



against Figure 10: Projected population growth for SADC with key countries⁵³

key populous SADC member states in Figure 9. The DRC (27%) and the United Republic of Tanzania (18%) may account for nearly half the SADC population by 2050 with Angola and Mozambique sharing similar status with South Africa. 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 a conservative assumption about a potential reduction in passenger motorised travel in 2050 is adopted⁵⁴ which by proxy is in agreement with the SADC RISDP infrastructure objective pertaining to the *Industrialisation-Urbanisation-Mobility Nexus* in the context of smart cities to "reduce congestion and greenhouse gas emissions and create liveable cities in the SADC region".⁴⁸

⁵² McCall B., Burton J., Marquard A., Hartley F., Ahjum F., Ireland G. and Merven B, "Least-cost integrated resource planning and cost-optimal climate change mitigation policy: Alternatives for the South African electricity system"

⁵³ UN Dept. of Economic and Social Affairs, "World Population Prospects 2019" <u>https://population.un.org/wpp/Publications/Files/WPP2019_DataBooklet.pdf</u> (accessed February 18, 2020)

⁵⁴ Pye S. and Daly H. 2015. Urban transport modal shift: an energy systems approach. 34th International Energy Workshop, June 03–05, Abu Dhabi.

Economic growth (GDP) for the SADC region, for the period 2010-2018, averaged ~3% per annum.⁴⁸ For the analyses, we adopt a similar growth rate on average over the period 2020-2050 for the South African economy (~ 50% of SADC GDP) which also aligns to domestic aspirations.⁵⁵ Economic growth between 2018 and 2022 is based on medium term projections^{56,57} as depicted in Figure 10.



Figure 11: Projected population and economic growth for South Africa

Fuel Supply

South Africa, Angola and Zambia

hosts the only crude oil refining capacity in SADC. With a total production capacity of 718,000 barrels/day (oil equivalent) South Africa hosts ~84% of crude-oil refining capacity and ~90% when including synthetic fuel production from coal. The majority of South Africa's liquid fuels are refined from imported crude oil with approximately half of imported crude originating from Nigeria and Angola. Domestic production via coal liquefaction (CTL) is also another important source of liquid fuels and petrochemicals.⁵⁸ A transition will have a dramatic impact on both the domestic liquid fuels supply chain⁵⁹ and regionally.²⁰

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 CO₂ emissions.

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 which would align with the SADC GESAP Strategy (Table 1) to improve vehicle emissions (T3). Gazetted in 2017 and estimated to cost R41 billion (2015 Rands)⁶⁰,⁶¹ the fuel specification has however not as yet been implemented 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 South African 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 also included as an

⁵⁵ Department of Energy (South Africa), "Integrated energy plan. Annexure B: Macroeconomic assumptions. (2016)"

⁵⁶ National Treasury (South Africa) "Medium Term Budget Policy Statement (2018)"

⁵⁷ International Monetary Fund, "World Economic Outlook: Challenges to steady growth (2018)"

⁵⁸ South African Petroleum Industry Association, "Annual Report (2018)", <u>https://www.sapia.org.za/Publications</u> (accessed June 26, 2020)

⁵⁹ KPMG, "The petroleum industry's contribution to South Africa (2017)", <u>https://www.sapia.org.za/doc/SAPIA 15 November Final.pdf</u> (accessed February 18, 2020)

⁶⁰ Department of Energy (South Africa), "Discussion document on the review of fuel specifications and standards for South Africa (2011)"

⁶¹ South African Petroleum Industry Association, "Cleaner Fuels II", <u>http://www.sapia.org.za/Key-Issues/Cleaner-fuels-II</u>, (accessed February 18, 2020)

option rather than assumed as a fixed investment.⁶² 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 South African transport sector.

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.⁶³ 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.⁵⁵ 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. The Southern African Power Pool (SAPP), founded in 1995, was established to strengthen the transmission network and increase energy security to facilitate economic growth for all member states. By installed capacity South Africa is the largest operator with 81% (48 467 MW) of the SADC capacity (59 991 MW); and in terms of demand also the largest consumer responsible for 90% of local generation and 85% of the SADC demand market.⁶⁴ Consequently, as the largest SAPP member, South Africa's coal intensive electricity generation results in the region having a disproportionately high GHG emissions factor of ~1kg CO₂eq/kWh.⁶⁵ Renewable Energy (RE) installations in SADC has however grown sharply in the last decade from 12 000 MW to 21 000 MW (2008 -2017).⁶⁶ Hydropower projects remain the largest RE technology by



Figure 12: Schematic of the existing SAPP with planned additions. Circles sizes are indicative of power system size (2016).⁶⁴

capacity, despite impressive growth of Solar-PV and Wind technology portfolios of 72% during this period.

Challenges remain to electrify the region which is still home to the lowest energy access rates and supply reliability in the world. The SADC average electricity access in 2016 was 48% with a sharp distinction between rural (32%) and urban populations (75%) (Figure 12). In contrast,

http://dx.doi.org/10.17159/2413-3051/2018/v29i4a5581, (accessed October 12, 2020) ⁶⁵ Mayuresh Sarang, "Grid Emission Factor for the South African Power Pool (2016)",

⁶² Africa Oil and Power, "CEF Partners with Aramco for New Refinery", <u>https://www.africaoilandpower.com/2019/11/15/cef-partners-with-aramcofor-new-refinery/</u> (accessed February 18, 2020)

⁶³ International Energy Agency, "Tracking Transport" France. Online: https://www.iea.org/reports/tracking-transport-2019

⁶⁴ Jarrad Wright and John van Coller, "System adequacy in the Southern African Power Pool: A case for capacity mechanisms"

<u>https://unfccc.int/files/na/application/pdf/module 3 2.sb case studies.pdf</u> (accessed October 12, 2020)

⁶⁶ SADC "Renewable Energy and Energy Efficiency Status Report 2018" https://www.ren21.net/wp-content/uploads/2019/05/SADC_2018_EN_web.pdf (accessed October 11, 2020)

South Africa's average electricity access rate was estimated at 86% (2016) with 93% access for urban dwellers and 68% for the rural population.

Box 3: Micromobility and Minigrids

Mobility in rural areas suffer from a lack of adequate transport infrastructure, such as poorly maintain roads, and infrequent motorised alternatives due to remote locations (affecting fuel cost and supply) and the cost of provisioning regular transport services to communities characterised by low population densities owing to the expansive geographic locales they inhabit. The introduction of motorcycle taxis along with mobile phones are credited with significantly improving the livelihoods of rural communities via the connectivity these technologies provide to a range of services both physical and virtual.⁶⁷ Within Africa, Rwanda has pioneered the introduction of micro-mobility with the introduction of electric-bicycles (e-bikes) while in South Africa e-scooters form part of the road transport mosaic. Apart from alleviating congestion and deferring road infrastructure investment in urban regions, e-bikes as a form of micromobility enables the provision of transport services to remote communities when coupled to reliable source of electricity for which alternative transport fuel supplies are erratic and costly.

Cognisant of the disparities in electrification rates between urban and rural communities, all SADC member states have formulated rural electrification strategies. However implementation rates have not matched those of urban districts due to numerous difficulties which include the cost optimal expansion of the central network- sometimes over vast geographic territories - lacking basic infrastructure to service energy constrained communities.⁶⁷ Enabled by dramatic reductions in the cost of renewables, mini-grids have emerged in the last decade as a cost-effective alternative to the "central grid expansion" paradigm wherein mini-grid systems can be deployed initially and integrated into the supply network as the system expands. The World Bank defines a mini-grid, typically ranging in capacity from the 10 kW to 10 MW scale, as "electric power generation and distribution systems that provide electricity to just a few customers in a remote settlement or bring power to hundreds of thousands of customers in a town or city."

Currently, Tanzania is the only SADC member with an official mini-grid electrification policy to address rural electrification.⁶⁹ As of 2016, 109 systems totalling 158 MW served 184, 000 customers. These minigrids are however predominantly composed of fossil-fuel technologies (46%) with Biomass (33%) and Hydro (21%) providing the bulk of the RE share: Solar at 0.234 MW account for only 0.15% of installed capacity.⁷⁰ Noteworthy is that within the DRC - SADC's most populous member which rivals Malawi as having the lowest electrification rates.

⁶⁷ Gina Porter, "Mobilities in Rural Africa: New Connections, New Challenges" <u>http://dx.doi.org/10.1080/00045608.2015.1100056</u> (accessed October 13, 2020)

⁶⁷ Worldbank, "Investing in Mini Grids Now, Integrating with the Main Grid Later: A Menu of Good Policy and Regulatory Options" http://hdl.handle.net/10986/31772 (accessed October 13, 2020)

 ⁶⁸ Worldbank, "Mini Grids for Half a Billion People : Market Outlook and Handbook for Decision Makers" http://hdl.handle.net/10986/31926
 ⁶⁹ Stockholm Environment Institute, "Renewable energy mini-grids: An alternative approach to energy access in southern Africa"
 <u>https://mediamanager.sei.org/documents/Publications/SEI-DB-2016-SADC-mini-grids.pdf</u> (accessed October 11, 2020)

⁷⁰ International Renewable Energy Agency, "Policies and Regulations For Renewable Energy Mini -Grids"

https://www.irena.org/publications/2018/Oct/Policies-and-regulations-for-renewable-energy-mini-grids (accessed October 13, 2020) ⁷¹ Babalwa Bungane, "DRC: Green mini-grid programme to reduce energy poverty" <u>https://www.esi-africa.com/industry-sectors/renewable-energy/drc-green-mini-grid-programme-to-reduce-energy-poverty/</u> (accessed October 13, 2020)

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: 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 13. The GHG emissions intensity⁷² 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 14: South Africa's Power Sector: Total Installed Generation Capacity (2020 - 2050)

South Africa as a Case Study: Transport Transition Scenarios

As introduced in earlier sections, we focus the quantitively analysis on the South African road transport sector to explore the implications for road transport in SADC and the concomitant impact on energy supply. Referring to Table 3, four scenarios with an emphasis on road transport were introduced. The Spatial Planning and Modal Shift pathway results in a lower demand for passenger transport when compared to the Road Vehicle Emphasis pathway (Figure 14). 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. 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

⁷² 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.



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 15).

Figure 15: Modal split of passenger-km demand by technology

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 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.



Figure 16: Freight modal shares of tonne-km

Emissions

In Figure 16, 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 MtCO₂eq and 0.008 MtCO₂eq in 2050, respectively.

In contrast, for the non-EV Fossil-Car scenario, emissions would peak at ~70 MtCO₂eq and fluctuate at about 65 MtCO₂eq 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.



MtCO2eq

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 17). An electric pathway benefits in the medium term as a noticeable decline in emissions would occur from 2025 (5 MtCO₂eq) to 2030 (7 MtCO₂eq), with cumulative avoided emissions totalling 80 MtCO₂eq. In contrast, emissions in the fossil fuel scenarios would benefit from a modal shift in the latter period 2030 (9 MtCO₂eq) to 2050 (15 MtCO₂eq), with cumulative savings of 145 MtCO₂eq. 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, Impacts on Fuel Supply and Power Sector)

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 18 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 19: 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 19 and Figure 20, respectively. A domestic EV market has the potential to be fully electrified in 2050, whereas a non-EV market would prefer 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.



Figure 20:Private passenger road vehicles by population and technology

Figure 21: Public transport road vehicles by population and technology

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 20), with a combination of rail and buses (including BRT) displacing minibus taxis by 2050 (Figure 21)



Figure 22: Modal composition of public transport by technology



Figure 23: 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. Previous analyses⁴⁶,⁷³ 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 IEA⁷⁴ reports that freight services are

⁷³ Ahjum F., Hartley F., and Merven B, "An assessment of the GHG mitigation potential of land transport pathways presented in the Green Transport Strategy for South Africa and their economywide impact (2019)"

⁷⁴ International Energy Agency, "The Future of Trucks: Implications for energy and the environment" <u>https://webstore.iea.org/the-future-of-trucks</u> (accessed February 19, 2020)

correlated to economic growth, which as seen in Figure 22, 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 18, 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 and including light trucks, account for 94% of vkm driven in 2050 with fuel-cell heavy



Figure 22: Freight transport road vehicles by population and technology

Table 5: 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-	Oil product	100%	93%
Efficiency	Electric	0%	0%
	Hydrogen FC	0%	7%
EcoMobility	Oil product	82%	0%
	Electric	15%	94%
	Hydrogen FC	3%	6%

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 15. This is also evident when comparing v-km by technology shares for the Fossil-Efficiency and Fossil-Car scenarios in Table 4.

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 23). Aviation fuel accounts for the remaining 25% and comprise the bulk of emissions in 2050 (Figure 16).

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.



Figure 24: Total transport energy consumption and fuel composition in 2050 for the scenarios

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 24a). A cost-optimal power sector would effectively become lowcarbon by 2050 and, in the absence of a national GHG emissions budget, its emissions trajectory is essentially invariant to the transition in transport (Figure 24b). 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 24b, 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 for the EcoMobility scenario would persist until 2045. In the Fossil-Car scenario, a 8 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.



Figure 25: Power sector: a) electricity supply; and b) associated GHG emissions (including a 8 Gt Carbon Cap case)

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 25). 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.



Figure 26: The total power sector capacity required for the Fossil-Car scenario: displayed with the additional capacity required for the other scenarios

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 of product per annum. Of the total output, 83% is liquid fuels (i.e. 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 MtCO₂eg annually. The facility has an assumed technical life of another 20 years which, in the modelled scenarios, sees it retire at the earliest by 2040.

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 26). 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 Figure 28: Refinery emissions fuel generally stagnate over the period



Figure 27: Total refinery capacity in 2050 for the scenarios



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 18). 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 27). In 2050, emissions equate to 5 MtCO₂eq for the EcoMobility scenario (solely from hydrogen production); in contrast to the 22 MtCO₂eq in the Fossil-Car scenario for which hydrogen is responsible for 16 MtCO₂eq 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).





Box 2: Hydrogen: Black to Green

Interest in hydrogen's role in the transition to a global net-zero energy system, specifically in applications for industrial and transport systems has increased in recent years. Multiple low and zero-carbon proof-of-concept projects are underway ranging from the production of steel and ammonia to public transit and corridor transport. Multiple production process routes for hydrogen exists and in order to distinguish conventional processes such as coal gasification from net-zero alternatives, a colour classification scheme has been adopted which has been suggested could provide a basis for net-zero production certification. The World Bank's Energy Sector Management Assistance Program⁷⁵ (ESMAP) describes the colour coding as follows:

Black hydrogen—Hydrogen produced from coal via coal gasification and extraction.

Brown hydrogen—Hydrogen produced from lignite.

Gray hydrogen—This term usually refers to hydrogen produced via steam methane reforming (SMR), and it is the most common type of hydrogen produced globally. Gray hydrogen can also refer to hydrogen that is created as a residual product of a chemical process—notably, the production of chlorine from chlor-alkali plants.

Blue hydrogen—This term is used for hydrogen produced using low-carbon processes. It is almost exclusively used to refer to hydrogen produced via natural gas or coal gasification but combined with carbon capture storage (CCS) or carbon capture and use (CCU) technologies in order to reduce carbon emissions significantly below their normal levels for these processes. It can, however, also refer to hydrogen produced via pyrolysis, by which hydrogen is separated into hydrogen and a solid carbon product colloquially called "carbon black."

Green hydrogen—This term is used for hydrogen produced from 100 percent renewable sources. It most commonly refers to hydrogen created from a process called electrolysis, which can use 100 percent renewable power and water to create pure hydrogen and oxygen. Other green hydrogen production methods include hydrogen extraction from reformed biogas and hydrogen extraction from waste.

⁷⁵World Bank, "Green Hydrogen in Developing Countries" <u>https://openknowledge.worldbank.org/bitstream/handle/10986/34398/Green-Hydrogen-in-</u> <u>Developing-Countries.pdf</u> (accessed October 03, 2020)

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 South African road transport sector towards 2050. Assuming an average annual economic growth rate of ~3% over the period (2020-2050) with the population reaching 75 million in 2050, four scenarios were modelled. The scenarios contrasted policy choices about vehicle technology (Fossil-Car vs Electric-Car); modal shifting for passenger and freight road transport; as well as considerations of improved urban planning via Transit Oriented Development (Fossil-Efficiency vs EcoMobility). The scenarios as they compare for GHG emissions and energy demand are summarised in Figure 29.



Figure 30: Key outcomes in 2050 for the South African transport scenarios

Given the current levels of energy demand and emissions of the South African transport sector (897 PJ and 60 MtCO₂eq, respectively) the Fossil-Car scenario represents the most energy intensive future, with a total demand of 1117 PJ and GHG emissions of 65 MtCO₂eq 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 MtCO₂eq 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 a 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 MtCO₂eq. The residual emissions comprise aviation and maritime emissions, which contribute 9 and 0.08 MtCO₂eq 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 MtCO₂eq. 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 16 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.

South Africa's vehicle fleet could potentially double by 2050, influenced largely by passenger vehicle adoption with low occupancy factors. Although, SADC member states would possess unique circumstances determining local private vehicle ownership; income remains a key determinant. The SADC population is likely to near double by 2050 and inline with the GESAP, economic growth aspirations would suggest an increasing motorisation rate for the region. From present day estimates, the SADC vehicle fleet is comparable to South Africa's at ~15 million vehicles (assuming a motorisation rate of 40 vehicles per 1000 persons). By 2050 the SADC vehicle fleet could conservatively equate to treble the South African fleet if the motorisation rate doubles. This would have major implications for fuel supply and vehicle technology choices as the region seeks greater economic integration and harmonisation of vehicle emissions standards and fuel quality.

While the South African vehicle market nears saturation, SADC member states have been identified as emerging markets with most new vehicles sales occurring outside South Africa. SADC industrialisation within the RISDP framework, could therefore include a regional expansion of the automotive manufacture and fuel supply chain. South Africa is a major global exporter of vehicles and platinum while the DRC and Zambia have global monopolies on cobalt and copper resources. The results indicate that electric vehicles (i.e. battery and hydrogen fuel-cell technology), could form the basis of a regional value chain spanning both battery and fuel-cell vehicles given the regional resource endowment and infrastructure (Figure 4). Corridor freight via road at present is the economic arterial link between member states owing to a lack of investment in rail infrastructure. The results suggest that while rail investment is an important component to reducing GHG emissions and energy consumption,

road vehicles will persist providing flexibility to the logistic sector. The span of distances between major freight hubs mimics the spatial structure of South Africa's economy and hydrogen fuel-cell heavy vehicles (HFCVs), in this transport segment, may complement battery electric vehicles in the vehicle fleet. The deployment of HFCVs would additionally be dependent on the pace and investment in alternative hydrogen fuels.

The future of crude-oil 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. As the largest refiner in the region, and 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 26). Angola, which depends on oil products for more than 90% of export revenue (41 US billion in 2018) is most at risk from a transition to electric vehicles. Key markets such as China, exist beyond the SADC boundaries compounding the risk as globally electric vehicles are increasingly eroding new vehicle sales of conventional diesel and gasoline vehicles. Angola's renewable energy resources remain largely unexploited, with sizable solar resources (5%-6%) and hydropower potential (17% of large hydro) in SADC, electrification could enable economic diversification.

Regarding energy supply options for the South African transport sector, 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 25). 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 24b). 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. The Southern African Power Pool (SAPP) is dominated by South Africa's generation capacity and a future cost optimal expansion that favours renewable energy would decarbonise the grid and facilitate a green regional economic corridor.

Hydrogen as a future transport fuel could significantly displace diesel in the corridor freight fleet by 2030. The level of hydrogen demand is dependent on both the choice of road vehicle technology and modal shift (Figure 28). 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 27).

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. Mozambique's abundant natural gas resource may present a transitional opportunity as a source of hydrogen as an enabler of cleaner transport and green hydrogen. SAPP remains coal intensive with renewable energy additions not yet at scale comparable to the region's available resource. Such a strategy would align with the RISDP regional infrastructure development pertaining to Oil and Gas. However, in isolation, and without the strategic inclusion of Carbon Capture and Utilisation (CCU), such a path presents a high investment risk as globally, the trend of divestment from fossil-fuel and GHG emissions intensive activity gathers pace. The regional integration of infrastructure may however offer a means to exploit the resource if considered in tandem with South Africa's synfuel infrastructure. Similar in magnitude to total transport sector emissions, the future of South Africa's CTL facility post 2040 is contentious given the high CO₂ emissions intensity of its operation. Further analysis is beyond the scope of this study although it is recognised that the existing infrastructure currently provides an ideal proposition for hydrogen production and high value chemicals via CCU; perhaps providing a foundation for the establishment of the region's first green industrial estate. Based on South Africa's demand, future aviation fuel demand could account for 10%-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.

The SADC Green Economy Strategy and Action Plan for Sustainable Development identified the poor state of existing infrastructure and need for climate resilience in future infrastructure. The continent's high susceptibility to the adverse impacts resulting from Climate Change⁷⁶ is a clarion call to safeguard livelihoods and regional economic prosperity. The transport sector is pivotal to the industrialisation of the region via its coupling to the energy supply infrastructure and as a conduit of regional economic integration. Addressing future transport growth, 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. Incentivising the adoption of alternative vehicle technologies is shown to be the prime lever with which to satisfy SADC's Green Transport Growth objective. Specifically, the electrification of transport in tandem with a low-carbon power sector offer the most benefit. Furthermore, while not the focus of this analysis, e-micromobility, in conjunction with minigrids, is seen as a particularly attractive intervention to address both rural transport and electrification.

⁷⁶ Michelle Barnard, "SADC's response to climate change – the role of harmonised law and policy on mitigation in the energy sector" <u>http://dx.doi.org/10.17159/2413-3051/2014/v25i1a2685</u> (accessed October 13, 2020)

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