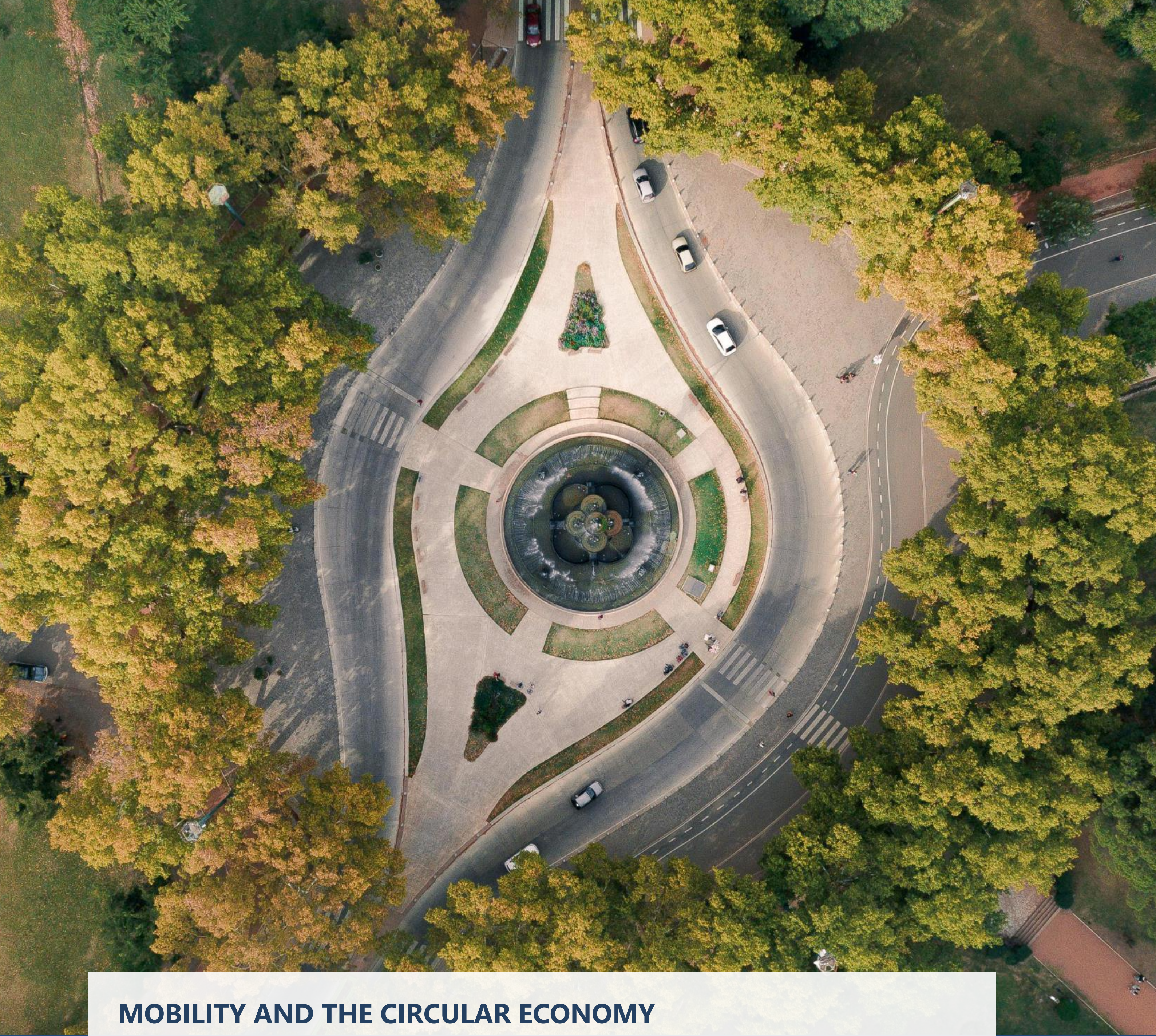

MOBILITY AND THE CIRCULAR ECONOMY

Creating a more effective and efficient mobility sector through a circular economy

February 2025

SCIENCE, TECHNOLOGY AND INNOVATION FOR A CIRCULAR ECONOMY SERIES

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EXECUTIVE SUMMARY

"Circular mobility requires a primary focus on designing for users and goods, instead of for vehicles. Transitioning towards a circular mobility system creates opportunities for improved productivity, efficiency, and reduced costs, with positive spillover effects for other critical sectors of the South African economy."

South Africa's mobility sector accounts for 8% of the nation's GDP and is becoming increasingly unsustainable due to the high reliance on road transport. The decline in rail infrastructure has resulted in 84.3% of all land freight being transported via road networks, leading to increased logistics expenses, congestion and deterioration of road infrastructure. Public transportation faces challenges due to diminishing train and bus ridership, compelling commuters to depend on minibus taxis, despite safety concerns and high associated costs. Apartheid-based spatial planning continues to restrict mobility, compelling low-income workers to endure lengthy and expensive commutes.

Transportation accounts for 19% of national energy consumption, resulting in increasing GHG emissions; yet investment in rail, electric vehicles, and climate-resilient infrastructure is insufficient. Without immediate policy improvements, such as cohesive transport planning, infrastructure investment, and financial incentives for sustainable technologies, South Africa's transport system will remain costly, inefficient, inequitable, and environmentally unsustainable.

South Africa does not have an explicit circular economy strategy for mobility, but several existing policies align with circularity principles. Local, regional and international trends highlight significant opportunities for the uptake of circular practices in the mobility sector.

South Africa's mobility sector can transition towards a circular economy through sustainable urban planning, cleaner transport options, and efficient use of resources. Based on local, regional and global trends, key interventions identified in this report include increased use of public transport systems, dedicated non-motorised transport infrastructure, and ride-sharing that all encourage low-carbon mobility, while concepts like 15-minute cities promote walkability and reduce reliance on private vehicles. Electrification, alternative fuels, and improved vehicle efficiency help cut emissions, while road-to-rail transport shifts can contribute to reducing congestion and logistics costs. Circular supply chains, alternative road materials, and end-of-life vehicle recycling assist in minimising waste and extend resource life cycles. Lastly, climate-resilient infrastructure and sustainable drainage systems ensure long-term durability in the face of environmental challenges.

These trends offer significant opportunities for reducing resource consumption, improving transport efficiency, and lowering South Africa's carbon footprint. However, stronger policy alignment, infrastructure investment, and public-private sector collaboration is needed to accelerate the implementation of circular economy interventions.

The identified interventions were evaluated and ranked by stakeholders via a survey distributed to key stakeholders within the mobility sector. The survey aimed to assess the appropriateness of 17 circular interventions to the South African mobility sector, the sector's level of readiness to adopt, and current levels of implementation.

Survey respondents identified shifting freight from road to rail, climate-resilient transport infrastructure, and hybrid/electric vehicles (EVs), as the most familiar interventions. Stakeholders agreed that circular economy practices would benefit South Africa's mobility sector, with road-to-rail freight shifts, increased public transport use, and climate-resilient infrastructure seen as the most beneficial interventions.

Several interventions were recognised for enhancing resilience and competitiveness, including the use of alternative road materials, local EV component manufacturing, second-life battery use, and process optimisation for logistics. While all interventions were deemed somewhat ready for implementation, flexible working arrangements and Mobility-as-a-Service (MaaS) had the highest readiness scores due to their existing adoption. Sustainable urban drainage systems (SuDS) and climate-resilient transport infrastructure also showed high readiness but remain under-implemented.

The most widely adopted interventions in South Africa are flexible working arrangements, MaaS, and dedicated bicycle and pedestrian facilities. However, stakeholders noted that climate-resilient transport infrastructure is highly ready but underutilised, making it a strong candidate for fast-tracked implementation.

Specific challenges and obstacles to adopting CEIs in the South Africa mobility sector included: the lack of a specific national circular economy policy; fragmentation of policies within and between line departments; lack of infrastructure investment and development, including technological innovation; lack of stakeholder collaboration and public-private partnerships; the lack of financial incentives for green technologies; lack of appropriate skills; lack of investment in research and development to advance new technologies; and inefficiencies in the South African rail sector.

It was agreed by stakeholders that there is a need for a comprehensive sector skills development strategy to reskill workers and ensure that they are equipped for future jobs in the mobility sector, and a clear need for investment in rail infrastructure.

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ACRONYMS

ACSA	Airports Company South Africa
APDP	Automotive Production and Development Program
BRT	Bus Rapid Transit
C&D	Construction and demolition
CE	Circular Economy
CEI	Circular Economy Intervention
CO_2	Carbon Dioxide
CSIR	Council for Scientific and Industrial Research
DFFE	Department of Forestry, Fisheries and the Environment
DoE	Department of Energy
DoT	Department of Transport
DSI	Department of Science and Innovation
dtic	Department of Trade, Industry and Competition
EMF	Ellen MacArthur Foundation
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTS	Green Transport Strategy
ICE	Internal Combustion Engine
LPI	Logistics Performance Index
MaaS	Mobility-as-a-Service
MEIA	Macro-Economic Impact Assessment
MOTE	Manufacturing of Transport Equipment Sector
NEV	New Energy Vehicle
NDP	National Development Plan
NHTS	National Household Travel Survey
NLTSF	National Land Transport Strategic Framework
NMT	Non-Motorized Transport
OEM	Original Equipment Manufacturer
PPP	Public Private Partnership
PRASA	Passenger Rail Agency of South Africa
R&D	Research and Development
SAAM	South African Automotive Masterplan
SADC	Southern African Development Community
SAM	Social Accounting Matrix
SANRAL	South African National Roads Agency
SD	System Dynamics
SIC	Standard Industrial Classification
SOE	State Owned Enterprise
SSA	Sub-Saharan Africa
SuDS	Sustainable Urban Drainage Systems
SuRF	Sustainable Roads Forum
TaS	Transport and Storage
TCH	Transaction Clearing House (SANRAL)
TFR	Transnet Freight Rail

1 Introduction

1.1 Background

An effective and efficient mobility sector is critical to any country's economic development, including South Africa's. It provides access between businesses and their respective markets; households and their places of work and education; and between communities. However, the movement of goods and people is an energy and resource intensive activity, with the transport sector consuming vast resources, accounting for 19% of South Africa's total energy demand (DoE, 2019), exacerbated by extensive travel distances.

Traditional, linear approaches for managing mobility systems, operations and infrastructure are unsustainable as they are a significant contributor to national greenhouse gas (GHG) emissions, lead to the depletion of finite resources, result in congestion, wasted time, decreased productivity, urban heat-island effects, and environmental pollution (EMF, 2019). Road transport (liquid), ranked second out of 30 key categories that have a significant influence on South Africa's total GHG inventory, with transport accounting for 12.7% of the energy sectors emissions in 2020 (DFFE, 2022). The heavy dependence on petroleum products for road transportation and civil aviation, and the steady increase in imports of both petrol and diesel finished products into South Africa (DoE, 2019) has a direct bearing on South Africa's balance of trade.

With 1,047,000 jobs in the third quarter of 2024, the transport sector is responsible for 6.2% of formal employment in the country. Compared to the third quarter of 2023, the transport sector experienced an increase in employment of 8.3% (StatsSA, 2024). The fourth highest growth after the mining sector (18.4%), utilities (12.7%) and Manufacturing (8.4%) (*ibid*).

An estimated 84.3% of land freight is transported via road in South Africa (DoT, 2023) and has been increasing over the past several years, which in addition to consuming significant quantities of fossil fuels, has a direct bearing on national productivity and competitiveness. The heavy reliance on road transport also negatively impacts the condition and maintenance of the national road network (Gain Group, 2020). While South Africa has a sophisticated logistics sector, ranking 33 out of 160 countries in 2018, in terms of the World Bank's Logistics Performance Index (LPI), it is plagued by numerous challenges including the lack of adequate infrastructure investment and maintenance, lack of skills, and high costs, all of which negatively impact system efficiency (*ibid*).

South Africa's resource intensive mobility sector provides the perfect impetus for transitioning South Africa to a more circular mobility system (Figure 1). Applying the three circular economy principles of the Ellen MacArthur Foundation (EMF, 2019) to the South African mobility sector, points to opportunities in:

1. *Optimisation and designing out waste:* e.g., alternative fuel sources, integrated transport systems, shared and multi-modal mobility, remote and flexible working systems, vehicle and infrastructure efficiency, waste management.
2. *Keeping materials and products in use longer*: e.g., durable and resilient design of vehicles and transport infrastructure, use of alternative construction materials, circular construction value chains, design for disassembly, vehicle recycling and remanufacture.
3. *Regenerating natural systems*: e.g., green infrastructure, ecosystem-based transport planning, restoration of natural spaces, wildlife corridors and crossings.

These circular economy principles provide a useful framework through which to explore circular economy opportunities in the South African mobility sector.

Figure 1. Mobility within a circular economy (adapted from SIFA, 2020)

Circular mobility requires a primary focus on designing for users and goods, instead of vehicles – such as planning transport networks that provide reduced travel distance and time per journey. Transitioning towards a circular mobility system creates opportunities for improved productivity, efficiency, and reduced costs, with positive spillover effects for other critical sectors of the South African economy such as agriculture, manufacturing, and human settlements.

1.2 Objective

Adopting a more circular economy, in which economic development is decoupled from resource consumption, has been recognised globally as an economic opportunity. Early drivers of the circular economy in Europe and Asia focused heavily on access to resources and critical raw materials in managing development risks (Godfrey, 2022). The drivers for a circular economy have since progressed to that of mitigating climate, biodiversity and water impacts, and unlocking new socio-economic opportunities, framed within the context of a post-Covid green and circular economic recovery (*ibid*). The latest driver to emerge, given planetary boundaries, is that of sustainable consumption or "sufficiency". The South African Government has recognised the circular economy as an opportunity for a low-carbon, sustainable and resilient economic growth. Providing a means to meet international climate and sustainability commitments, and to address the triple challenges of inequality, poverty, and unemployment (DSI, 2019; DSI, 2022).

This study, which explores the opportunities for greater circularity in the South African mobility sector, is a component of a larger CSIR project titled '*Identifying opportunities for a more circular South African economy – A resource perspective*'. The first phase of this project produced a series of short briefing notes, including one for the mobility sector, titled "*Facilitating sustainable economic development through circular mobility*" (Mokoena *et al.,* 2021). These short briefing notes provide context to the circular economy broadly, as well as within seven resource-intensive sectors of the South African economy (mining, agriculture, manufacturing, human settlements, mobility, energy, and water).

The second phase of the project undertook a more comprehensive assessment of the circular economy in resource-intensive sectors of the South African economy. The technical report on *mining* and the circular economy showed that resource scarcity is a driver for South Africa to transition to a more circular economy (Khan *et al*., 2022). Four further technical studies showed that South Africa has already adopted circular practices in *agriculture*, *manufacturing*, *energy*, and *water*, but that these practices have not (yet) achieved a scale for meaningful impact. As such, the circular economy is not new to these sectors. While for some interventions the levels of readiness to adopt is still low, there is consensus that most of the circular interventions put forward can provide very real economic, social and environmental benefits for the country.

The final stage of the project explores the opportunities to adopt circular practices in two of the most diverse, cross-cutting, and human-centric sectors – that of *human settlements* and *mobility*. These two sectors were left to the end as they include many of the circular interventions already explored through the previous studies. They are also, based on international research, the two sectors that typically provide the greatest opportunities (and benefits) for a circular economy transition.

This report provides a deep dive into Circular Economy Interventions (CEIs) in the South African mobility sector. It seeks to provide further detail on the *current development path* (Chapter 2) of the South African mobility sector, including a high-level overview of the sector; an overview of the current availability and demand for resources; expected trends (assuming little to no major disruption); an analysis of potential resource constraints for future growth of the sector; and the identification of key economic and socio-economic gains and losses associated with the current path. The report then explores a *potential circular development path* for the South African mobility sector, including identifying circular economy interventions based on local and international trends (Chapter 3); assessment of the appropriateness of these interventions for South Africa through engagement with key stakeholders; and a critical assessment of the readiness (including potential obstacles and unintended consequences) to implement these CE interventions in the South African context (Chapter 4). Unlike the previous technical reports, this study goes one step further to model the systemic impacts of selected circular interventions on the transport sector (Chapter 5).

The mobility study also included collaborative efforts with the CSIR's human settlements project team to identify synergistic opportunities across the two sectors.

Together, this series of CSIR publications aim to inform public and private sector responses on South Africa's drivers for a circular economy transition (with a focus on resource scarcity and climate mitigation) (in line with international thinking), and where immediate circular economy opportunities are achievable in various resource-intensive sectors of the South African economy.

1.3 Methodology

The methodology adopted for this study involved collating secondary data through a comprehensive literature review of the mobility sector. This was particularly important in undertaking the trends analysis of circular mobility interventions. A special focus was placed on international circular economy practices not yet used in South Africa, but that could have merit and potential for local adoption.

The literature review was followed by primary data collection through stakeholder engagements, which included the distribution of an online structured questionnaire sent to 100 sector stakeholders, and one-on-one stakeholder interviews. The feedback from these sessions greatly enriched the study and provided a more inclusive response to the circular economy opportunities in the mobility sector.

2 Current development path for South African mobility sector

2.1 Sector overview

Mobility, through various transportation modes, plays a crucial role in connecting businesses with their markets, households and communities in South Africa. The *Transport, Storage and Communications* sector contributes about 8% to the country's GDP, making it a key economic driver (StatsSA, 2024). Overseen by the Department of Transport through six national branches responsible for different modes of transport, including aviation, maritime, rail, road, public transport, and integrated transport planning. Yet, mobility remains a critical challenge, with many South Africans relying on inefficient and resource-intensive transport systems.

The 2020 National Household Travel Survey (NHTS) reveals the essential role of mobility in daily life based on the travel patterns of 45 million South Africans. The use of road-based systems is evident with 10.7 million people using taxis and 6.2 million driving private vehicles. However, "walking all the way" was the main mode of travel for most households, with 17.4 million people walking all the way to their destinations (StatsSA, 2022). 'Walking all the way' was the means of travel for 20.3% of South African workers, including workers with disabilities (22.2%). One of the main reasons given for walking, was that public transport was too expensive (9.6%). This was more often noted as a reason by workers in urban areas (*ibid*).

Public transport systems, primarily taxis, remain the backbone of urban passenger mobility, yet they are plagued by challenges such as high costs and safety concerns. Taxis account for 80% of public transport use among workers, reflecting their critical role despite widespread dissatisfaction over reckless driving and fare increases. Buses and trains have seen a decline in usage, with buses catering to rural commuters and trains largely abandoned due to long travel times and safety issues, particularly in provinces like Gauteng and Western Cape.

Trains were once a crucial mode of transport, but this has declined drastically, with only 0.5 million households using this mode in 2020, compared to 1.4 million in 2013. This decline highlights the growing dependence on road transport due to inefficiencies and safety concerns in the rail sector. Rail suffers from poor operational conditions, leading to a reliance on road transportation for freight. Despite investments in rail infrastructure, operational challenges persist, including locomotive availability, cable theft, vandalism, and port delays (George *et al*., 2018). These challenges within the rail industry also affect how passengers travel by rail which leads to a shift to other forms of transportation like taxis. This puts further strain on road networks which also face their own set of challenges such as underinvestment, lack of maintenance, high costs, and deteriorating conditions resulting from carrying rail-friendly freight on road.

The apartheid system created a legacy of social segregation and spatial inequality, leaving many South Africans disconnected from their workplaces and essential social services (Walters, 2014). This distorted spatial structure continues to influence mobility patterns, with disadvantaged and rural communities often facing significant challenges in accessing transportation and opportunities for socio-economic advancement. Post-apartheid efforts have focused on addressing these geographies of exclusion and inequality by striving to create a more inclusive and effective public transportation system, but progress remains uneven, highlighting the ongoing need for systemic transformation in the mobility sector.

While the sector remains a vital economic contributor, it is characterized by inequities, inefficiencies, and high reliance on fossil fuels. Addressing these challenges indicates a need to lay the foundation for a more sustainable and inclusive mobility system.

2.2 Key resources in the South African transport system

The mobility sector is the second largest energy consumer in the country, accounting for 19% of the country's energy demand (DoE, 2019), with liquid fuels dominating its energy consumption and petroleum products being the primary source. Road infrastructure systems are the most relied upon mode of transport by South Africans and are therefore the leading emitter of GHGs and the largest energy consumer within the sector. The country's significant dependence on fossil fuels, particularly in the transport sector, contributes substantially to GHG emissions.

South Africa boasts an extensive transport network, including roads, rail tracks, ports, and airports. However, there is a high reliance on road travel for freight and passenger transport that contributes to the rapid deterioration of road networks in the country. This heavy reliance on road transport intensifies the sector's contribution to GHG emissions and highlights its resource intensity.

2.2.1 Road Infrastructure

The South African road network functions as the fundamental infrastructure of the country's transport system. South African roads transport over 84.3% of all land freight, which accounts for 81.9% of total land freight revenue (StatsSA, 2024). This imposes a substantial strain on road infrastructure and necessitates considerable financial investments for maintenance and rehabilitation.

As the primary infrastructure connecting the economic centres of our provinces with regional and global markets, the national road network, under the responsibility of SANRAL, serves an indispensable function and has high economic significance.

While the majority of the country's national road system is in a good condition, provincial and municipal road networks are not coping with the normal demand and are poorly maintained (SAICE, 2022). Rather than using proactive and preventative maintenance strategies, maintenance is infrequent and reactive, such as the patching of potholes.

2.2.2 Rail Network

Approximately 16% of land freight is transported via rail and has been steadily declining over the past several years (Figure 2), exacerbated by the pandemic (2020-2022).

State-owned entities, Transnet Freight Rail (TFR) and the Passenger Rail Agency of South Africa (PRASA), manage most of the freight and passenger rail networks respectively, with the Gautrain Rapid Rail Link providing high-speed rail services in Gauteng between Johannesburg, Pretoria and O.R. Tambo International Airport. Most of the rail network in South Africa is owned by TFR and provides a vital network that connects ports, terminals and production hubs in the country.

The lack of maintenance, vandalism and larceny of corridor infrastructure have resulted in most of the rail network remaining in a declining state, except for the Gautrain Rapid Rail Link. The country's rail operational capacity is subsequently diminished, leading to a decrease in volume and safety performance (SAICE, 2022). This, in turn, has a ripple effect by increasing the strain on the road infrastructure.

The White Paper on National Rail Policy, which provides a comprehensive overview of the trajectory of our rail system's development, was approved by Cabinet in March 2022. In addition to establishing policy certainty, this policy implements profound structural reforms within the sector. The primary objective of this White Paper on National Rail Policy is to facilitate investment in our railways, with particular emphasis on harnessing the rail technologies to revitalise the industry. The policy implements secondary interventions that facilitate on-rail competition and effect institutional repositioning. Consequently, additional rail operators will be able to enter the market and vie for customers' attention, thereby enhancing operational efficiency and facilitating the freight industry's pursuit of competitive pricing and service quality.

2.2.3 Ports

South Africa has several significant ports, such as Cape Town, Durban, and Richard's Bay. The operation of these terminals is vital in facilitating international trade and managing the influx and outflow of goods. In 2023, the total annual cargo handled by South African ports was 210.6 million metric tons, where majority (78%) of cargo consisted of exports (DoT, 2023). Major challenges facing the maritime sector include port inefficiencies, congestion and global disruptions, such as the Red Sea tensions, and container shortages which threaten global competitiveness and impact other sectors like agriculture and manufacturing (Palm, 2024). There are also concerns over the operational costs and pricing of marine services which negatively impact the performance of South African ports (Mthembu, 2024). Despite operational challenges, the country's port infrastructure is in a relatively good condition. Major fishing harbours have recently undergone extensive rehabilitation and have seen an improvement in conditions (SAICE, 2022).

The efficiency of South African maritime transport can be maintained through modernising port infrastructure, diversifying supply routes, and addressing stakeholder concerns regarding operational costs.

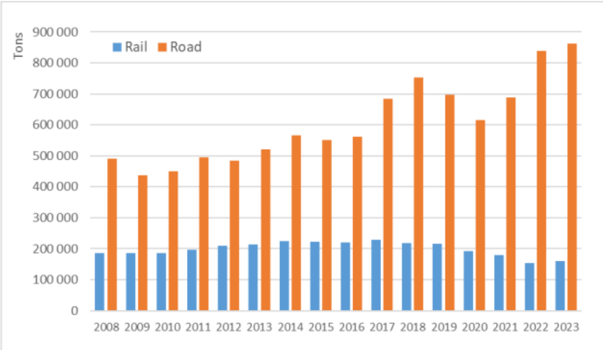

Figure 2. Total freight transportation in South Africa (000 tons) estimates (StatsSA, 2008-2023)

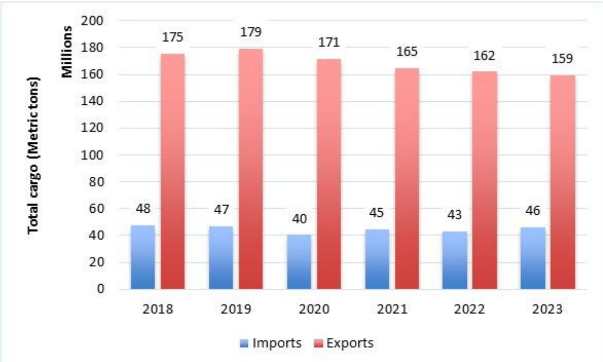

Figure 3. Total cargo imported and exported through South African ports (metric tons) (DoT, 2023)

2.2.4 Airports

South Africa has nine major airports that are owned and managed by Airports Company South Africa (ACSA). According to the SAICE 2022 Infrastructure Report Card for South Africa, the aviation infrastructure owned by ACSA is in a good condition despite deferral of some maintenance and expansion works following the decline in revenue from the Covid-19 pandemic.

These airports facilitate the movement of passengers on both domestic and international routes, serving as vital links between South Africa and the regional and global community. The total number of passengers transported by South African airports was just over 31 million in 2023 and has been steadily recovering since the Covid-19 pandemic (Figure 4).

South Africa has historically held the largest market share of passengers in the continent's air transport system, accounting for almost 30% of all passengers over the last six years. However, Egypt overtook South Africa in 2022, carrying 37.9 million passengers as opposed to 30.1 million in South Africa (ACI, 2022). Air travel represents 6.4% of national business trips, despite private vehicles being the most prevalent mode of transportation for South African business travelers. This is particularly evident in the Western Cape, where air travel constituted 15.3% of business trips (StatsSA, 2022).

Johannesburg's OR Tambo International Airport stands out as the busiest and most significant airport in South Africa. In the 2023 financial year OR Tambo accounted for 42.9% of the country's aircraft movements. This was followed by Cape Town International Airport (21.4%), Chief Dawid Stuurman International Airport in Port Elizabeth (9.2%) and King Shaka International Airport in Durban (8.8%) (DoT, 2023).

The Chief Dawid Stuurman International Airport in Port Elizabeth is often referred to as the "ten-minute airport" given its proximity to the central business district, highlighting the importance of travel time to airports for passengers as well as airport services, which are influenced by local travel patterns and access to airports. As such, reducing travel times is important in enhancing operational efficiency and passenger experience. Larger distances from major cities to airports, such as OR Tambo and King Shaka International Airport, can impact airport inefficiencies and travel times. Traffic congestion on roads as well as the use of a private versus public vehicles also influences the travel time to airports, which tends to increase airport travel time in the country's major cities.

2.2.5 Public Transportation

Public transport services are an indispensable function of mobility by ensuring affordable and convenient transit for South Africans. Despite this, the National Household Transport Survey (2020) showed that most commuters walked all the way to their destination, which has a direct bearing on productivity. Minibus taxis were the second most used mode of public transport (Figure 5), with trains being the least used mode of transport.

2.2.5.1 Passenger buses

Buses are an important mode of transport for South Africans, despite the decline in use over recent years, transporting approximately 12% of households in 2020 compared to 18% in 2013. Even though, on average, buses are cheaper to use than taxis, the main concern for bus commuters is the limited availability and infrequency of buses, particularly in rural areas (StatsSA, 2022). According to Mitizi (2017), many routes are not serviced by bus companies, forcing commuters to either walk considerable distances or utilise alternative modes of transport to reach their destination. Safety and security are also a concern where passengers expressed dissatisfaction with security at bus facilities, overcrowding in buses and the risk of accidents, particularly in Kwa-Zulu Natal and Limpopo (StatsSA, 2022).

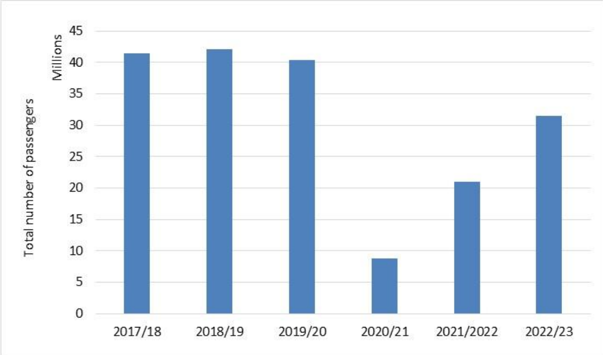

Figure 4. Total number of passengers transported via airports in South Africa (DoT, 2023)

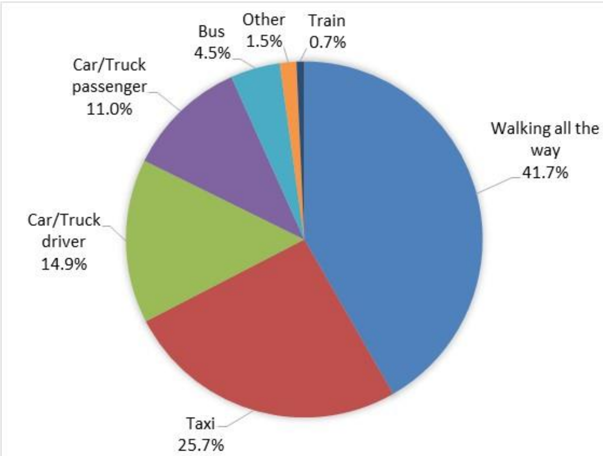

Figure 5. Percentage distribution of household members by mode of travel, (StatsSA, 2022)

2.2.5.2 Minibus taxis

Minibus taxis are the backbone of public transport in South Africa, with 66% of households in the country relying on this mode of transport. Moreover, taxis are increasingly becoming the preferred option as the use of trains and buses is decreasing, given taxis account for 80% of public transport trips for work-related travel. They offer commuters convenience and accessibility, since most South Africans can reach a taxi within 15 minutes of their households. Many South Africans prefer taxis over other forms of transportation, yet commuters continue to face challenges due to rising costs, safety concerns, and dissatisfaction with local taxi services (StatsSA, 2022).

2.2.5.3 *Passenger rail*

Passenger rail has historically played a significant role in South African public transport, particularly for low-income households. However, its use has declined significantly over recent years, given that only 3.2% of workers used trains as their selected mode of transport in 2020 compared to 12.9% in 2013 (StatsSA, 2022). The decline in rail usage is attributed to several concerns from rail commuters including poor service reliability, long waiting times, overcrowding, vandalism, and safety concerns. This has resulted in even more reliance on road-based modes of transport such as taxis and buses, that only exacerbate congestion, travel costs and GHG emissions.

Rail passenger transport directly impacts economic activities, and there is a need to improve the service reliability and integration with other modes of transport to make rail transport a viable mobility solution.

Commuters often prioritise factors such as train security, punctuality of service, and station distance. Some issues highlighted by rail passengers include local Metrorail trains that consistently lack a scheduled structure, making them unreliable. This makes rail an unreliable means of transport for commuters in South Africa. Given this reality, urgent interventions need to be identified and implemented to improve the operation and use of South Africa's rail network – both for passengers and freight.

Passenger rail is a cost-effective mode of transport. The cost of passenger rail is comparable to the cost of bus transport and provides the most affordable mode of transport for most South Africans (StatsSA, 2022).

2.2.6 Technology

The implementation of an electronic fare collection system for the public transport system is making progress. The Department of Transport resolved to pilot the implementation of an integrated, single ticketing system using the SANRAL Transaction Clearing House (TCH) during the 2023 fiscal year. E-toll collections were cleared via the TCH on behalf of a variety of toll operators and toll plazas. The versatility of the TCH has extended its advantages beyond tolls to include cashless parking, fuel payments, vehicle licence renewal payments, and the utilisation of SANRAL's customer service centres for driving licence renewals. Local governments in Polokwane and Rustenburg are conducting a pilot programme to prepare for the implementation of the Integrated Single Ticketing System.

2.2.7 Logistics

Challenges in the logistics sector has a systemic impact on the performance of the economy. While South Africa ranks relatively well in the Logistics Performance Index (LPI), it struggles with poorly performing ports and congested corridors. Port inefficiencies are leading shippers to use alternative ports in the SADC region (most notably Maputo in Mozambique), while congestion at border posts, road transport of native rail freight, and challenges such as speeding, overloading and others, are affecting freight flows on key corridors. The recently released Container Port Performance Index (CPPI) by the World Bank (World Bank, 2023), which ranked the Port of Cape Town as the worst performing in the world, emphasized the need for ongoing performance improvements to remain attractive to international trade. Strategies such as developing dry ports and modernizing infrastructure, aim to enhance overall performance of the logistics system. While inefficiencies in the performance of the system have a significant effect on economic performance, they also provide an opportunity for redesign of key processes and practices, and to transition towards a more circular model of freight transport.

2.3 Intermediate demand sectors

Transport is a crucial intermediate input for the successful function of business as it is needed for the in-bound logistics of raw materials and components from suppliers, transportation of work-in-progress materials within the organisation, as well as the outbound logistics of finished goods to customers and consumers. Figure 6 shows the proportion of the total intermediate input accounted for by transportation services for the 30 Standard Industrial Classification (SIC) sectors with the greatest reliance on transportation.

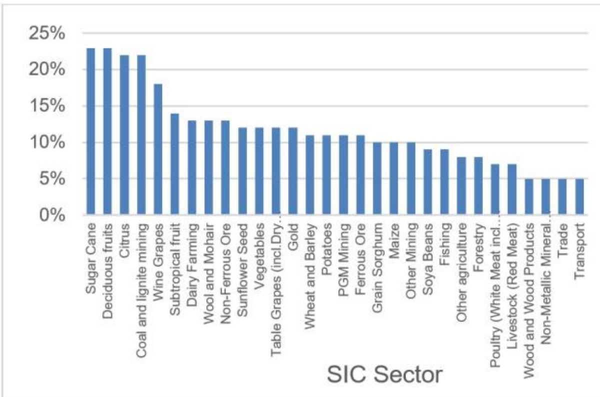

Figure 6. The contribution (%) of transport to the overall intermediate input demand for the 30 highest SIC sectors (Conningarth Economists, 2024)

As shown in Figure 6, more than 20% of the input costs (i.e., costs associated with raw materials and other inputs used by a sector to produce its outputs) for the sugar cane, deciduous fruits, citrus, and coal and lignite mining sectors is comprised of transport-related costs. This confirms the significance of the transport sector as a contributor to the functioning of these sectors. This operational activity translates into externalities such as emissions.

2.4 Current resource constraints

2.4.1 Lack of infrastructure investment

South Africa faces challenges to its economic development primarily due to inadequate investment in new transport infrastructure and the maintenance of existing transport infrastructure, which not only jeopardizes economic development, but also exacerbates issues like traffic congestion, which has profound socio-economic implications.

Projections indicate that travel speeds in Gauteng are expected to decrease from 43km/h to 10km/h, or less, by 2030 if no interventions are made to improve road networks and public transport infrastructure (Steyn, 2022). This would have profound impacts on the movement of goods and people. The situation is further compounded by the lack of climate-resilient infrastructure, evidenced by the recent surge in sinkholes on major highways. This deficit in infrastructure investment and maintenance is attributed to various factors, including insufficient funding, mismanagement, corruption, and a shortage of skilled personnel.

Typical features facing urban transport in many African cities include aging and deteriorating infrastructure, traffic congestion, accidents, lengthy commute times, and the lack of integrated transport and land use policies (Ndebele & Aigbavboa, 2018). Investment in transport infrastructure, whether traditional resource intensive linear approaches, or more sustainable, green and circular mobility solutions, emerges as a critical hurdle that must be addressed to unlock the potential for economic growth in South Africa. Inadequate infrastructure investment is attributed to the waning partnerships between public and private sectors (Ndebele & Aigbavboa, 2018). It is argued that many African governments struggle to present projects in a financially appealing manner to potential investors. Despite the widespread adoption of Public Private Partnerships (PPPs) for infrastructure financing globally, African initiatives in this realm appear to lag behind, despite the recognized infrastructure investment gap (Osei-Kyei & Chan, 2016). However, Osei-Kyei & Chan (2016) note the increasing interest among governments in developing economies, particularly in Sub-Saharan Africa (SSA), in implementing PPP policies to bridge transport investment gaps and alleviate pressure on government budgets. Yet, Osei-Kyei & Chan (2016) also highlight the challenges associated with adopting PPP financing models, such as high toll charges, lack of competition, and complex contractual arrangements, leading to project cancellations and distress. Continued investment is necessary not only in large-scale infrastructure to enhance the formal public transport system but also in its operational systems, including technological advancements to promote public transport adoption over private vehicles, improved security/safety measures, fare systems, travel efficiency, comfort, and responsive operational management (SEA, 2017).

2.4.2 Crime and vandalism in infrastructure development

Escalating crime rates directly impede the utilization of public transport and shared mobility services. Instances include targeted attacks on ride-hailing drivers and passengers, vehicle theft, and hijackings. The notion of safety serves as a major deterrent for numerous commuters who opt to utilize their personal vehicles instead. Moreover, crime and corruption actively dissuade investment in transport infrastructure. According to SEA (2017), despite extensive and intricate negotiations, the 'Go George' public bus service encountered violent disruptions in August 2015, instigated by disgruntled minibus taxi operators. During the unrest, four buses were set ablaze. The grievances expressed by minibus taxi operators centred around perceived livelihood losses.

SEA (2017) further emphasizes that secondary cities undertaking public transport initiatives may face heightened challenges in operational efficiency due to inadequately designed urban layouts. It is imperative to incorporate land use efficiency considerations into urban planning and approval processes as integral components of long-term project planning. This approach fosters public acceptance and reduces the likelihood of vandalism or scepticism, thus enhancing the prospects for successful implementation.

2.4.3 Energy scarcity

South Africa grapples with a critical shortage of electricity generation capacity, resulting in frequent power outages in the form of load shedding, which has inflicted substantial economic losses and job cuts. The transition towards greener energy sources for transport, such as electric vehicles and green hydrogen, is hindered by the country's inadequate electricity generation, particularly in terms of green electricity. This shortfall presents a significant impediment to growth, especially considering the surging global demand for greener transportation alternatives and the substantial increase in electricity generation required to meet these demands. The uptake of EVs is currently slow within South Africa. Pure EVs accounted for only 0.88% of new vehicle sales in 2022 (Lamprecht, 2023).

Furthermore, South Africa faces the challenge of transitioning away from fossil fuels towards more sustainable fuel sources, a move in stark contrast to global trends aiming for net zero emissions by 2050. While the EU proposes bans on new fossil-fuel cars, South Africa's heavy reliance on fossil fuels could lead to fuel shortages and potential vehicle shortages, both commercially and privately. Additionally, the Covid-19 pandemic has exposed the vulnerability of the global economy to shortages of essential minerals and resources, with repercussions on mobility-related sectors due to supply shortages of vital materials like steel, silicon, and minerals required for batteries in electric vehicles. These supply shortages are anticipated to intensify with increasing demand, unforeseen events and system disruption.

2.5 Economic and socio-economic gains and losses

2.5.1 Infrastructural inefficiencies and service delivery decline

The transport-related infrastructure network in South Africa is deteriorating and severely impacting the country's economy. It is estimated that the economy-wide cost impact of Transnet's port and rail inefficiencies alone amounted to about R505 billion in 2022 (almost five times more than that of 2019), which could have supported the creation of 900,000 jobs and helped to alleviate the country's high unemployment rate (Havenga *et al*., 2023).

Reported causes for the inefficiencies and decline in service delivery at Transnet Freight Rail (TFR) include unavailability of maintenance spares and components, theft and vandalism, social unrest, sabotage and contractual disputes (Transnet, 2022). Together, these causes resulted in a 33.9% decline in the total volume of general freight, export coal, and export iron ore transported by the rail operator from 2018 to 2023 (calculated using Transnet (2023) and Transnet (2018)). In turn, this has led to unrealised revenue from mineral exports estimated by the Minerals Council of South Africa to be around R150 billion for 2022 alone (Ngcobo, 2023), as well as a drastic shift of rail freight to the more resource- and carbon-intensive alternative, road transport via trucks. It is believed that some of the theft and vandalism experienced by TFR is direct sabotage from trucking mafias to increase the need for transport via trucks (Ardé, 2024).

2.5.2 Higher demand for road freight

To compensate for the decline in TFR's service delivery, freight owners have started to transport their freight via long-haul trucks. This influx of trucks on the South African road network is adding to congestion, infrastructure degradation, and various social issues. For example, the Lebombo border post bordering South Africa and Mozambique has reportedly experienced a truck arrival increase from 400 to 1800 trucks per day (Mabuza, 2023). The large number of trucks passing through is degrading road conditions, increasing the rate of accidents, and leading to the formation of a pre-border post queue that has been reported to exceed 40km in length. This queue of trucks is blocking entrances to facilities (Walsh, 2023) and causing disruptions for community members trying to go about their daily activities such as leaving for work (Democratic Alliance, 2023), in addition to slowing trade and tourism and attracting crime (Goddard, 2023).

2.5.3 Increased logistics costs and market loss

South Africa's extensive geographical spread places the country at a disadvantage in terms of economic competitiveness due to higher logistics costs, as a result of increased distances travelled. Accordingly, the country and its businesses cannot afford the additional cost increases resulting from the above-mentioned inefficiencies as they impact commodity selling prices, attractiveness on the export market and, ultimately, the South African economy.

2.5.4 Disruption by Electric Vehicles (EVs)

A significant global disruption within the road transport sector is the displacement of Internal Combustion Engine (ICE) vehicles with EVs or hydrogen fuel cell vehicles. The global transition to EVs can pose a threat to the country's automotive manufacturing industry that predominantly manufactures ICE vehicles. This is because more than 60% of locally manufactured passenger vehicles are exported (Lamprecht, 2023), which is concerning given that various export markets have announced plans to ban the sale of ICE vehicles. Given the realisation of these international bans and the failure of South Africa's automotive manufacturing base to transition to new energy vehicles (NEVs) before 2035, the country is expected to lose almost half of its light-vehicle export market. The consequences of this loss include a R199,400 million decrease in GDP and 255,300 fewer job opportunities (unpublished CSIR study).

2.5.5 Cost of fuel consumption and the cost of productive time lost

Car ownership in South Africa rose from 23% to 33% between 2003 and 2013, driven by amongst others increased purchasing power of the middle class (SEA, 2017; Ndebele & Aigbavboa, 2018), resulting in increased traffic, consumption of fuel, and GHG emissions. African cities are considered to have some of the highest rates of annual traffic increases, ranging from 15% to 20% (Ndebele & Aigbavboa, 2018). The mobility sector is a large source of CO_2 emissions and with the recent surge in the volume of traffic in cities because of car ownership, the emissions trajectory is expected to continue to rise (Zhu, 2018). This has a negative impact on air quality and human health.

Research indicates that people generally prefer a daily time budget of about 1.1 hours, which is referred to as the "Marchetti" constant. This tendency appears to exist across cultures and countries. According to surveys, South Africa's typical time budget is 60% longer than this, which indicates an economic "drag" imposed by our transport problems and increasing congestion (SEA, 2017).

2.5.6 Cost of urban sprawl and cost of extending road network to alleviate traffic congestion

South African initiatives such as Bus Rapid Transit (BRT) to improve public transport have not, typically, produced accessible and financially viable public transportation despite their enormous capital costs (SEA, 2017). It is thought that this is mostly because South African urban densities are low. Because of the high costs associated with providing transportation services and conducting business, as well as the low purchasing power of lower income households (that make up most public transportation users), a smaller portion of public transportation costs are recovered than is typically the case globally (SEA, 2017). In the African context, the use of appropriate urban transport planning methodologies and systems has always been difficult due to internal access and circulation issues related to informal settlements. Because of this, marginalization has continued and mobility for most people has worsened (Ndebele & Aigbavboa, 2018).

Low-density, expansive cities need more transportation infrastructure, which usually leads to an increase in the number of vehicles in use (EMF, 2019). This increases traffic, the consumption of energy and resources, and pollution. Ndebele & Aigbavboa (2018) consolidates that socio-economic loss associated with the current mobility approach is attributed to an emphasis on building more highways and roads, which promotes car-centric towns with little to no integration with other modes of transportation like trains and bus lines. Regrettably, this approach has resulted in the creation of ineffective urban areas marked by urban sprawl, ongoing congestion, and other urban transportation-related issues (*link to Gibberd et al. (2025) CSIR Human Settlements Circular Economy report*).

2.5.7 Overwhelmed road freight and increased logistics costs

The energy and emissions intensity of freight transport varies significantly by mode, with rail typically producing a third of the emissions of long-haul road transport and only a tenth of smaller rigid trucks. South Africa's large cities dominate the demand for general freight and are geographically located at a relatively long distance away from the nearest port (a spatially challenged economy). This demand is primarily supplied by road transport, which accounts for 84.3% of transportation (StatsSA, 2024). Metropolitan freight contributes nearly 50% of the total volume of freight demand in tonnes, contrasting with corridor freight at 16%. However, the shorter distances travelled by metropolitan freight reduce its share of total freight tonne-kilometres to approximately 15%. Some corridors exhibit high freight, energy, and emissions intensity, particularly in processed food and petroleum fuels (SEA, 2017).

2.6 Need for inclusive policy reform

Despite South Africa's ongoing efforts to strengthen its transport system, there have been areas of neglect and underinvestment. In addition to inadequate investment, policy stagnation and leadership instability have impeded progress in the transport sector. This predicament has been exacerbated by a complex authority structure that is highly fragmented, in which certain responsibilities are centralised at the national level in state-owned enterprises (SOEs) under various ministries, while others are devolved to provincial and local governments.

This fragmented structure contributes to the varying performance of the transport system throughout South Africa. Certain organisations possess adequate resources, capabilities and management, enabling them to effectively oversee the assets entrusted to them. Conversely, other organisations struggle with inadequate governance structures, a scarcity of technical proficiency, unfunded mandates, and unstable management, all of which have contributed to unsatisfactory outcomes in general. Addressing these disparities requires stronger governance, targeted investment, and improved infrastructure management to ensure equitable transport development across the country.

3 The Circular Economy – A mobility perspective

3.1 Introduction

Currently, South Africa lacks an explicit circular economy strategy for the mobility sector, however, several national policies, strategies and plans contain elements that align with circular economy principles. The *Green Transport Strategy* (GTS) 2018-2050 provides a comparable framework for understanding the government's intentions regarding the future of transportation. The GTS acknowledges that the transport sector contributes significantly to the country's GHG emissions, with road transport accounting for most emissions. Despite ambitious goals, such as a 5% reduction in GHG emissions by 2050, active intervention levels remain relatively low compared to international commitments. The GTS does, however, propose interventions which are aligned with circular economy principles, such as the adoption of cleaner fuels and alternative fuels; shifting passengers from private transport to public transport, and freight from road to rail; adopting alternative energy vehicles; and rethinking and redesigning our cities and towns to safely accommodate cyclists and pedestrians. South Africa's local context will, however, determine the extent to which certain circular economy interventions can be implemented.

This concept of a sustainable public transport system is echoed in the *National Land Transport Strategic Framework* (NLTSF) (DoT, 2023). It recognises the need to reduce travel by motor vehicles, often single occupancy, by shifting to different travel patterns and transport usage, and greater integrated land use and transport systems.

> *"An integrated and efficient transport system supporting a thriving economy that promotes sustainable economic growth, supports a healthier lifestyle, provides safe and accessible mobility options, socially includes all communities and preserves the environment."* (DoT, 2023)

The *White Paper on National Transport Policy* (DoT, 2022) sets the foundation for South Africa's transport policy and aims to ensure equitable, efficient, integrated and sustainable transport systems. Furthermore, this is echoed by the respective policies across the country's various transport modes including the:

- *National Rail Policy (2022)*
- *Comprehensive Maritime Transport Policy (CMTP) (2017)*
- *White Paper on National Civil Aviation Policy (2017)*
- *Integrated Urban Development Framework (IUDF) (2016)*
- *National Freight Logistics Strategy (2005)*
- *National Transport Master Plan (NATMAP) 2050*.

Other relevant policies and strategies include the Department of Trade, Industry and Competition's (dtic) *South African Automotive Masterplan* (SAAM 2021-2035) that supports local manufacturing of automotive components, which could be extended to include EVs and sustainable mobility solutions. The *Automotive Production and Development Program* (APDP), which sets out targets for the development of a competitive automotive industry, which includes opportunities for EV manufacturing and the integration of circular economy principles. The Department of Forestry, Fisheries and Environment's (DFFE) *Extended Producer Responsibility* (EPR) legislation could be expanded to support responsible end-of-life vehicle and battery collection, reuse and recycling.

It was pointed out that while the dtic has developed an *EV Roadmap and Masterplan*, there is still a lack of concrete support mechanisms, such as investment incentives or subsidies, to drive the adoption of EV technology.

The *National Development Plan* (NDP 2030) highlights that poor transport links and infrastructure networks, raises the cost of doing business in South Africa and negatively impacts the standard of living. It therefore recognizes the importance of efficient and affordable public transport to enhance mobility for low-income households, while also emphasizing the need for sustainable economic growth and a shift towards a low-carbon economy. Moreover, the Department of Transport's *Draft White Paper on Roads Policy for South Africa* recognises the need and contribution of sustainable road infrastructure towards an overall sustainable economic system (DoT, 2018). Efforts like the *Sustainable Roads Forum* (SuRF) and government initiatives to localize manufacturing underscore a growing focus on sustainability and job creation, aligning with circular economy principles. The concept of Mobility-as-a-Service (MaaS) is also gaining traction, indicating a shift towards service-based mobility solutions like ride-hailing, which have the potential to reduce personal vehicle ownership and promote more efficient resource use.

Several projects have been implemented under the *Rolling Stock Fleet Renewal Project* which aim to revitalise and modernise South Africa's rail engineering sector through local manufacturing, job creation, and skill development.

There is a policy trend towards sustainable and green mobility in South Africa, with various initiatives and strategies aligning with circular economy principles. However, local, regional and international trends highlight significant opportunities for the uptake of circular practices in the mobility sector. The following sections explore the current international trends in mobility, with the potential to drive circularity. These trends will frame the discussions in Chapter 4.

3.2 Trends analysis

The urban design of a city influences the flow of people, products and resources inside it, as well as the circulation of resources (*link to Gibberd et al. (2025) CSIR Human Settlements Circular Economy report*). Because the urban form can create lock-ins in terms of housing, mobility, and population behaviour, circular economy principles should be considered from the start when making urban design decisions. Urban design has an impact on a city's overall energy and material use, waste generation, system efficiency, and emissions, both operational (coming from traffic or industry) and embodied (generated by the construction of buildings and infrastructure). A city's energy consumption and emissions are essentially dictated by its density, land use mix, connection, and accessibility, all of which are important characteristics of urban form. These factors are inextricably related and must be considered simultaneously when addressing consumption or pollution (Paavola, 2020). That's not to say that circular economy principles can't be adopted within existing cities and towns or guide the future development of our cities and towns, and related mobility systems. According to the World Green Building Council (2022), 80% of the buildings that will stand in Africa in 2050, are still to be built. This provides significant opportunity to rethink our urban design and mobility in a more sustainable, low carbon, and circular way.

3.2.1 15-minute city

The 15-minute city concept aims to make all daily needs accessible within a 15-minute walk or bicycle ride of a person's home. This encourages a change in people's mobility patterns; reduces resource consumption; and can have positive impacts on the environment. The intention of the system is to meet residents' basic needs without the need for motorised transportation. The concept promotes proximity to amenities and access to essential goods, services and well-being opportunities (Staricco, 2022).

The concept can reduce the consumption of resources and lower GHG emissions by reducing the need for long distance travel and the use of private vehicles. Due to shorter supply chains and transportation distances, it also encourages local production and consumption of goods and services while promoting a healthy lifestyle for residents. Table 1 presents the aspects to consider for 15-minute cities.

"The 15-minute city concept prioritises people in its design, rather than basing urban planning on vehicle demands."

3.2.2 Shifting passengers to public transport

A modal shift from private to public transport has the potential to enhance mobility and the quality of life of individuals, as well as the reduction of resource intensity and environmental impacts. The use of single-occupancy private vehicles increases traffic congestion and adds strain on existing road infrastructure. This often results in increased maintenance and rehabilitation needs to accommodate the growing number of vehicles. The environment is also negatively impacted through increased GHG emissions compared to high occupancy vehicles.

A high number of private car users on the roads, results in traffic congestion which impacts the travel time of road users, loss of production, high cost of goods and services, and increases accident rates.

The intention of national government is to make public transport competitive compared to private vehicle use, such that it becomes a viable, and preferred option to private car users. The needs of the users must be clearly understood to entice commuters to shift from the current perceived convenience of private car use to public transport. Especially in South Africa, where public transport is unreliable and limited in the areas serviced. A decrease in travel time is the most enticing factor to promote a shift to public transport. In South Africa, travel time was confirmed to be the most common determinant of transport mode choice (StatsSA, 2014). The second determinant of transport mode choice was the cost of travel (StatsSA, 2014). Driving greater public transport as a circular intervention, must build these two factors into its design.

Table 1. Aspects of 15-minute cities (Staricco, 2022)

Aspect	Function / Contribution
Mixed land-use development	Encourage infrastructure which serve multiple functions, i.e., residential, commercial, government services
Local amenities	Provide services and goods to communities
Green spaces	Improve quality of life and provide recreational options, encouraging public to walk or bike
Community engagement	Involve communities in urban planning to understand their demands and needs
Sustainable transportation	Provide public transportation infrastructures and offer services to encourage non-motorised transport, e.g., bike rental
Walkability and bike ability	Improve accessibility to amenities

The prevalent use of private vehicles has been discouraged by the Department of Transport (DoT), as early as 2007 with the aim of improving public transport and providing a better service (DoT, 2007). There is also a need to change public perception about public transport safety, efficiency, accessibility and affordability. This can be done by considering push and pull measures. The integration of infrastructure development into existing networks can increase public transport use. The expansion of public transport infrastructure and upgrading infrastructure in conjunction with network integration can lead to an exponential increase in public transport use.

3.2.3 Dedicated bicycle and pedestrian facilities

Dedicated bicycle and pedestrian facilities include infrastructure that is specifically designed to increase the viability and safety of bicycling or walking as modes of transport (Scott, 2023; U.S. Department of Transportation, 2019). This intervention also contributes to a circular economy by reducing resource consumption through lower vehicle use and promoting energy efficiency, while also minimising waste and improving public health.

Promoting cycling and walking has a synergistic relationship with some of the other identified circular economy interventions such as a modal shift from private vehicle use and is more feasible in areas where essential goods and services are easily accessible, such as in the 15-minute city concept. Furthermore, dedicated walking and bicycle facilities could help alleviate various transport-related problems in South Africa, where 43.5% of workers make use of private transport as their main mode of travel to work and only 20.3% and 1.1%, respectively, walk or cycle to their destination (StatsSA, 2022).

To ensure their effectiveness, bicycle and pedestrian facilities require continuously linked walkways or bike networks, intersections and crossings that are simplified and considerate of non-motorised transport users, proper illumination and signage, vehicle speed limits where appropriate (i.e., in school zones), the prevention of accident hazards such as vehicles parked on walkways, and walkways through parking areas (Rastogi, 2011). Some of these requirements have been listed as causes for the country's low level of utility cycling (i.e., road safety, insufficient road space, infrastructure and bicycle facilities) in addition to steep slopes, high wind and low status associated with this mode of transport in South Africa (Jennings, 2011), hinting towards the unpreparedness of the country to push this intervention. Bicycle lanes are also frequently used as parking spots or temporary storage (Lekgothoane, 2015), making commutes hazardous for cyclists. Cultural norms and the dominance of car culture in South Africa has been another barrier to promoting cycling and walking as a viable transportation option.

3.2.4 Flexible working arrangements

Flexible work arrangements, which involve part-time or full-time work from home or remote working, gained traction during the COVID-19 global pandemic (Hook *et al.*, 2020). The reduction in air pollution during the COVID-19 pandemic, due to amongst others, decreased land and air transport, were extensively reported in scholarly publications (Lui *et al.*, 2020; Schlosser *et al.,* 2020; UK Department for Transport, 2020).

Flexible working arrangements can contribute to the circular economy by reducing the need for daily commutes, leading to lower fuel consumption and air emissions. This minimizes resource depletion and promotes a more sustainable use of energy. Moreover, urban sprawl can be reduced when employees have flexible work arrangements, thus encouraging the development of more compact, walkable communities.

Since road transportation contributes significantly to energy demand and associated GHG emissions (Witchayaphong *et al.*, 2020), flexible working arrangements and the resultant reduction in travel, or fewer commute trips, offer benefits such as reduced traffic congestion and air pollution (Niles, 1994).

3.2.5 Hybrid or electric vehicles

Hybrid and electric vehicles (EVs) can contribute to the circular economy by reducing reliance on fossil fuels and promoting energy efficiency. Further opportunities also exist in recycling of EV batteries to minimise waste, such as reusing old batteries for stationary storage systems in residential buildings (Cusenza *et al.*, 2019). EVs and hybrids are important in decarbonising the transport sector and can have a meaningful impact in conjunction with the shift to greater public transport. Different types of electrification interventions exist. Battery EVs run solely on electricity stored in batteries and can produce zero tailpipe emissions when recharged using renewable energy. Fuel cell EVs power the electric motor using electricity generated from hydrogen gas as input. Lastly, hybrid EVs combine a traditional internal combustion engine with an electric motor, thereby reducing its reliance on fossil fuels and subsequently lowering emissions (Qadir *et al.,* 2024). Global studies have demonstrated that the most significant impact in reducing tailpipe emissions is a transition to all-electric vehicles powered by a combination of fuel cells and batteries (Thomas, 2004).

The adoption of electric and hybrid vehicles involves several key components, of which the need for a robust charging infrastructure network is likely the most important as it is known to be one of the primary challenges in increasing EV uptake. This is because the lack of sufficient charging stations at key locations and within sufficient distance from each other lead to range anxiety (i.e., the fear of being unable to reach one's destination or a nearby operational charging station). South Africa is reported to have one of the best EV charging network capacities in the world (about 1.8 stations for every 10 EVs on the road) (Labuschange, 2023), however, this is influenced by the modest number of EVs on the country's roads. Fortunately, there are various reports of planned expansions, most of which are driven by public investments (see Labuschagne (2023) and Boonzaier (2024)). However, problems with the existing network (e.g., slower-than-advertised charging speeds, non-functioning or removal of key stations, etc.) have already been reported (Labuschange, 2024).

The effectiveness of EV uptake to decarbonise South Africa's transport industry is hampered by the country's coal-dominated electricity generation mix. Early in 2023, less than 8% of the country's electricity was generated from renewable sources (CSIR, 2023). The consequence is that the environmental benefits associated with EVs will not materialise if these vehicles are recharged from the grid. Furthermore, the frequent implementation of loadshedding within the country due to inadequate electricity supply further increases scepticism regarding the short-term viability of this intervention.

3.2.6 Mobility-as-a-service (MaaS) (ride-share)

Ride-sharing is an innovative on-demand transport service that aims to promote sustainable transport, reduce car utilization, increase vehicle occupancy and public transport ridership by bringing travellers with similar requests together (Mitropoulos *et al.,* 2021). These systems may prove to be significant as private motorized transport poses a major challenge for traffic and the environment. Shared mobility has the potential to increase traffic efficiency, reduce traffic-related environmental pollution (Bierman *et al*., 2023), reduce vehicles on the road, and hence reduce the sectors resource demands. MaaS aims to bridge the gap between public and private transport operators and has the potential to eradicate dependence on private vehicles (Kamargianni, 2017).

MaaS has been available in South Africa for a number of years now, through services such as Uber and Lyft. However, it has faced challenges in carving out a space in the public transport sector, given the pushback from minibus and metered taxis. It has also faced security concerns, both to drivers and passengers, resulting in Uber rolling out the "Follow My Ride" functionality.

3.2.7 Improved vehicle efficiency

Improved vehicle efficiency plays a crucial role in a circular economy by reducing resource consumption and waste throughout a vehicle's lifecycle. By using less fuel or electricity per kilometre driven, efficient vehicles minimize the demand for raw materials used in fuel production and battery manufacturing. This reduced demand, in turn, lessens the environmental impact associated with extracting, processing, and transporting these resources, particularly with light-weighting and reducing the size of vehicles (Hertwich *et al*., 2019). Furthermore, extended vehicle lifespans, enabled by efficient designs and technologies, contribute to a circular economy by delaying the need for new vehicles and reducing the number of vehicles entering the waste stream.

3.2.8 Alternative fuels (bio, hydrogen)

Alternatives to fossil fuels have the potential to reduce externalities, such as environmental impacts. Biofuels and hydrogen fuel are alternative energy sources used to power vehicles, offering lower carbon emissions compared to conventional fossil fuels (Iglesias & Sampson, 2004). Biofuels are derived from organic materials, such as crops, agricultural waste or algae, and can be processed into ethanol or biodiesel to be used in modified internal combustion engines. They are considered renewable since they utilize biological resources that can be replenished over time. Hydrogen fuel, on the other hand, is produced through the process of electrolysis or natural gas reforming, and when used in fuel cells, it generates electricity to power an electric motor. The only byproduct of hydrogen fuel cells is water vapor, making it an environmentally friendly option with zero harmful tailpipe emissions. Both biofuels and hydrogen are seen as viable solutions for reducing the environmental impact of transportation while supporting the shift towards cleaner energy (Ramachandrana & Stimming, 2015; Negi & Mathew, 2018). Green hydrogen has the potential to reduce reliance on fossil fuels in industrial applications such as mining, and in hard-to-abate sectors such as shipping. Local initiatives are underway to develop strategies for the development of the local green hydrogen sector, and to develop pilot solutions (e.g., DSI, 2021).

3.2.9 Shifting freight from road to rail

Rail transport is a key component of economic development due to its lower cost per ton kilometre transported and reduced GHG emissions compared to other modes of land transport (AfDB, 2015). Rail's energy efficiency is also evident, as it accounts for only 2% of the total transport energy demand, despite its large traffic volume (IEA, 2019). This intervention can significantly contribute to a more circular economy through reduced resource consumption, lower emissions and improved air quality.

With the degradation of our rail network and reduction in freight rail capacity, freight owners have shifted their business from rail to road. As such, the road network is currently carrying a disproportionate amount of rail-friendly freight (e.g., Statista, 2024). The impact of this shift is an increased cost of transport per ton-km and an increased cost of logistics to the economy, increased congestion on roads, road degradation, and increased pollution and road accidents.

A movement from road to rail requires, in the first instance, increased rail capacity by improving infrastructure conditions and service availability. This is, in turn, dependent on management of vandalism, infrastructure maintenance and protection, and consideration of alternative operating models. Assuming that a shift is affected, a significant positive impact on the economy is predicted with concomitant improvements in the externalities currently experienced.

3.2.10 Circular supply chains

Reverse logistics comprises a supply chain management function that provides for the return, recycle, repurposing, or disposal of products in the chain. Circular supply chains are a synonymous concept. The focus is on using materials and goods for as long as possible (refurbish and re-sell focus) before discarding them. Take-back schemes is one example, whereby customers are encouraged to return unwanted goods rather than to discard them. These concepts align with circular economy principles in that it facilitates the re-use of materials for different purposes or by different consumers (in case of unwanted sales), and responsible disposal and recycling of goods (which is particularly relevant for environmentally hazardous goods such as batteries, chemicals, and others).

3.2.11 Shorter supply chains

Shorter supply chains aim to reduce the externalities associated with transport by bringing the points of production or manufacture as close as possible to points of consumption. This reduces the distance associated with moving the product through the chain and into the hands of consumers. Elements of the supply chain can also be excluded to reduce the number of role players and transactions. Good examples are found in agriculture, where unused urban spaces (e.g., rooftops) are used to develop gardens, or where households, schools, army barracks, and other institutions are encouraged to grow food locally for own consumption.

In addition to removing or reducing the transport requirement, the need for packaging (and the associated packaging material) is reduced. Similarly, trade directly between farmers and retailers have been shown to reduce the wholesale price (but not the retail price) (e.g., Aysoy *et al*., 2015). Shorter supply chains imply increased localisation of production. To have a positive circular economy effect, gains from reduced transport and logistics needs to be balanced against the relative environmental impact of manufacturing in the localising economy.

Reducing the length of food supply chains can offer several benefits, including a stronger sense of community between consumers and the food production system, less waste generation, and support for local biodiversity through the consumption of traditional foods (Angrisano, 2019).

3.2.12 Process optimisation

Process optimisation (e.g. trip / load optimisation) entails reducing resource inputs and/or inefficiencies that result in wastage. In the freight logistics industry, for example, fuel wastage occurs if delivery routes are suboptimal or if loads are not consolidated. The latter refers to maximising the utilisation of freight trucks to reduce the number of trips required and to, ultimately, minimise fuel usage, emissions, and road degradation. While the related gains might seem negligible per trip, the cumulative impact can be substantial. The benefit of this intervention is that it does not require significant investments and can be implemented on a company-level. Companies have also emerged, that link process optimisation with MaaS, offering an opportunity for load sharing, thereby optimising the vehicle use, and reducing the demand for vehicles on the road.

3.2.13 Alternative road materials

Alternative road materials are a circular economy intervention that focus on reducing the consumption of virgin resources and minimizing waste by repurposing waste materials in road construction and maintenance. Instead of relying on conventional materials such as pure asphalt and natural aggregates, alternative materials like recycled asphalt, construction and demolition (C&D) waste, plastic waste, waste glass, rubberized bitumen from used tyres, coal ash, foundry sand, and steel slag are incorporated into the road-building process. This approach not only diverts waste from landfills but also decreases the environmental footprint associated with extracting and processing virgin materials. By extending the lifecycle of waste materials and promoting their reuse, this intervention has been shown to enhance the durability and performance of road infrastructure, when implemented according to design and construction standards.

3.2.14 End-of-life vehicle refurbishment

End-of-life vehicle remanufacturing and refurbishment involve restoring and upgrading used vehicles, or parts, to extend their useful life, thereby reducing the need for new vehicle production and minimizing resource consumption. This process includes repairing or replacing worn-out parts, reconditioning engines, and upgrading systems to meet modern safety or environmental standards, keeping vehicles in service for longer. A remanufactured product will have all critical components replaced, all to a new specification, while refurbished products typically only have broken or failed components replaced. A remanufactured vehicle engine, for example, is reassembled to the same exacting standards as a new engine. This results in a remanufactured product meeting or exceeding the quality and performance of a brand-new product allowing an original equipment manufacturer (OEM), or its agent, to attach an equal to new warranty to the product (Figure 7).

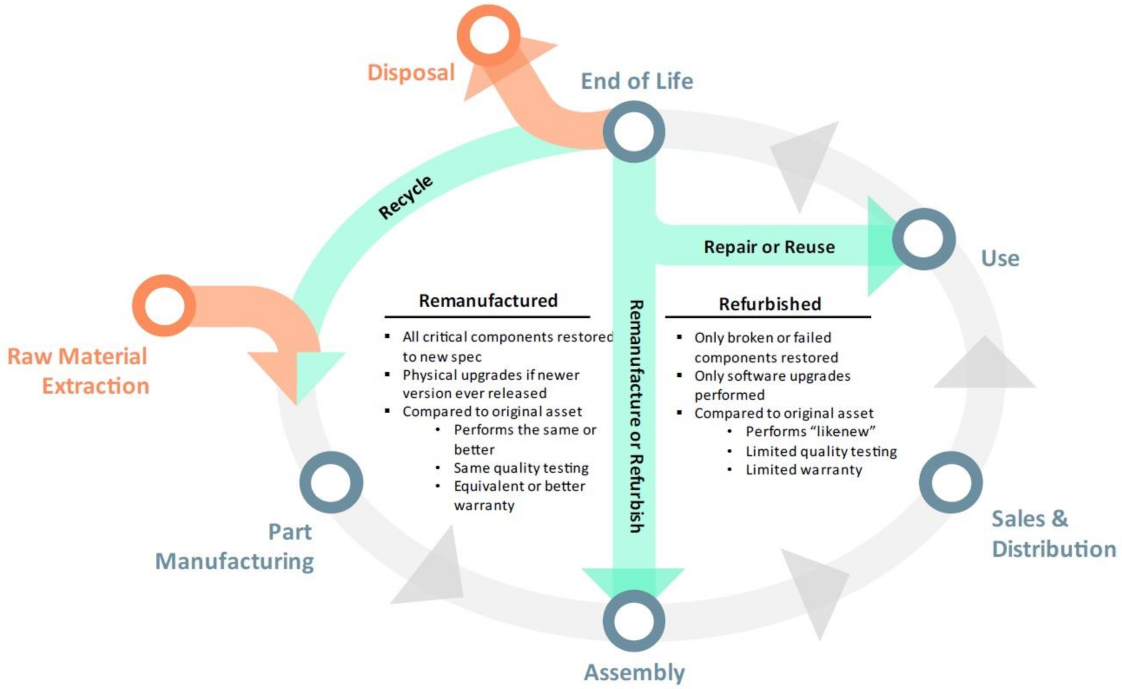

Figure 7. Distinguishing between remanufacturing and refurbishing (Verdantix, 2024)

3.2.15 End-of-life vehicle recycling

End-of-life vehicle recycling focuses on reclaiming valuable materials and components from vehicles that have reached the end of their useful lives, thereby reducing waste and conserving natural resources (Despeisse *et al.*, 2024). This intervention involves dismantling the vehicle to recover materials like metals, plastics and glass. By extracting and processing these materials, the manufacturing sector minimizes the need for virgin resources and reduces the environmental impact associated with mining and manufacturing. This approach keeps resources in use for as long as possible, maximizes the value extracted from each vehicle, and supports the creation of a closed-loop system where materials continuously cycle through production and consumption without becoming waste. In line with the principles of a circular economy, recycling is a less preferred option than reuse, remanufacturing or refurbishment, as the inherent value and utility of the vehicle is lost.

3.2.16 Climate resilient transport infrastructure

Climate shifts in global temperatures, sea-level rise, rainfall patterns and severity of storms will influence the mobility patterns of current transport systems (NASEM, 2014). Due to changing climate patterns, there is a global need to plan, design and construct climate resilient transport systems (Transport & ICT, 2015; Greenham *et al.*, 2022). Climate resilient transport infrastructure is primarily concerned with the reduction of resource consumption and long-term costs through the design, construction, and maintenance of transportation systems that can withstand extreme weather events and adjust to evolving environmental conditions. The advantages of proactively adapting road infrastructure include a more robust and reliable system, reduced vulnerability to climate change impacts, and a reduction in the cost of maintenance (Schweikert *et al.*, 2015), thus contributing a more circular economy through keeping materials in use for longer. Additionally, resilient designs often include the use of natural, regenerative systems like green drainage solutions and permeable surfaces, which work in harmony with the environment to manage stormwater and prevent erosion. This intervention extends the functional life of assets, reducing the environmental impact of infrastructure, and creating transport systems that are more sustainable and capable of supporting economic growth under varying climatic conditions.

3.2.17 Sustainable urban drainage systems (SuDS)

Effective stormwater management is essential for safe, efficient and sustainable transport systems. Urban water management systems are increasingly dealing with issues like water scarcity, flooding and pollution. With the increase of urbanization combined with the effects of climate change, infrastructure constraints are expected to worsen (Saghir *et al.*, 2018). Sustainable stormwater management can be achieved through Sustainable Urban Drainage Systems (SuDS) such as permeable pavements, swales, bioretention systems, filter strips and wetlands. These nature-based solutions contribute to the circular economy through regenerating natural systems by improving water quantity and quality management and enhancing biodiversity through mimicking the natural hydrologic cycle in the built environment (Armitage *et al.*, 2013). In contrast to traditional drainage systems, SuDS often have substantially fewer repercussions in the event of exceedance (Woods-Ballard *et al.*, 2007).


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4 Circular economy development path for the mobility sector

The transition towards a more sustainable and resource-efficient mobility sector is crucial for South Africa as it seeks to balance economic development, improved quality of life and social inclusivity, with environmental protection. With the global shift towards a circular economy, which emphasizes the decoupling of economic development from resource consumption, it has become imperative to identify and implement sustainable and circular interventions that will transform the country's transport infrastructure and vehicle use practices to support a more effective and efficient mobility sector. Drawing from the review of local, regional and international sector trends, this chapter identifies 17 circular economy interventions (CEIs) with the potential to shift the South African mobility sector.

4.1 Circular economy interventions

The proposed CEIs (Table 2) have been selected based on an in-depth analysis of current trends that seek to reduce the mobility sector's dependence on finite resources, minimize waste, and promote sustainable growth. These interventions focus on addressing key challenges such as high carbon emissions; road congestion; poor access to transportation; inefficient use of materials; increasing cost of transport; and the need for resilient infrastructure in the face of climate change. The circular economy can assist South Africa in transforming its mobility sector into one that not only supports economic development but also contributes to environmental sustainability and social equity.

Table 2. Identified Circular Economy Interventions (CEIs) for mobility

Circular Economy Intervention	Description
15-minute cities	15-minute neighbourhoods where facilities used every day, such as schools and retail, can be walked to in 15 minutes, improving efficiency and reducing the requirement for vehicles.
Alternative fuels	Switching to alternative lower-carbon fuel sources such as biofuels and hydrogen fuel cells for private, passenger or freight transport vehicles.
Alternative road material	Alternative road construction material from waste streams such as asphalt, concrete aggregates, green cements and alternative binders, construction and demolition waste, plastic waste, bitumen rubber, waste glass, coal ash, foundry sand, steel slag.
Circular supply chains	Send used or defect products back to manufacturer for repair or recycling (e.g. Reverse logistics, take-back schemes)
Climate resilient transport infrastructure	Climate resilient transport infrastructure that can withstand damage from more extreme and frequent weather events and reduce overall life cycle costs.
Dedicated bicycle and pedestrian facilities	Dedicated bicycle and pedestrian facilities to promote the use of non-motorised transport, reduce traffic congestion and vehicle emissions.
End-of-life vehicle recycling	Vehicle recycling initiatives to reduce landfilled waste from end-of-life vehicles, and return resources (metal, plastic, glass, rubber) back into the economy.
End-of-life vehicle refurbishment	Vehicle remanufacturing & refurbishment initiatives to reduce landfilled waste from end-of-life vehicles, keeping the utility of the vehicle.
Flexible working arrangements	Flexible and remote working arrangements to improve workforce productivity and reduce traffic congestion.
Hybrid or electric vehicles	Adoption of electric or hybrid vehicles to reduce vehicle greenhouse gas emissions and local air pollutants.
Improved vehicle efficiency	Improving the fuel efficiency of vehicles through engine efficiency improvements, hybridisation, lightweighting, reducing rolling resistance, reducing aerodynamic drag.
Mobility-as-a-service	Mobility-as-a-service (MaaS) involves using on-demand services for transportation. A shift away from personally owned modes of transportation towards mobility provided as a service, e.g., ride share
Process optimisation	Optimise production processes, filling of loads, routes to reduce or eliminate waste (energy) (e.g. triptript/load optimisation; reverse logistics)
Shifting freight from road to rail	Shifting freight transport from road to rail to improve the energy efficiency, reduce transportation and infrastructure maintenance costs.
Shifting passenger to public transport	Shifting from the use of private passenger transport to shared mobility systems like public transport.
Shorter supply chains	Produce or manufacture closer to point of consumption, to eliminate or reduce the need for transport (e.g. Peri/Urban agriculture)
Sustainable urban drainage systems (SuDS)	Sustainable urban drainage systems (SuDSSuDSu) are a collection of water management practices that align modern drainage systems with natural water processes, e.g., by mimicking the natural hydrologic cycle

The emphasis on road systems and related interventions is primarily driven by the overwhelming reliance on road transport for both passenger and freight movement across the country. Road transport serves as the backbone of South Africa's economy, facilitating the movement of goods and people within and between cities, connecting rural areas to urban centres, and supporting industries by ensuring the efficient delivery of raw materials and finished products. This dependency on road infrastructure has made it a focal point for the identified CEIs. As the sector transitions towards a more diversified and sustainable transport network, the interventions focused on roads will lay the foundation for broader circular economy practices and long-term sustainability across the South African mobility landscape.

By implementing these interventions, South Africa can position itself as a leader in sustainable mobility on the African continent, while simultaneously enhancing its resilience to global shifts in transportation and environmental policy. The section that follows explores the appropriateness of these interventions to South Africa; our readiness to adopt these interventions; and the current levels of implementation within the sector.

4.2 Appropriateness of circular economy interventions

The assessment of opportunities to implement CEIs within the South African mobility sector was conducted through an online questionnaire followed by targeted stakeholder interviews. The interviews provided in-depth insights into the sector's readiness for adopting circular practices; identified specific areas of opportunity; and highlighted the key challenges faced by the industry. By engaging with industry experts and practitioners, the interviews captured valuable perspectives on how various circular interventions could be effectively integrated into the local mobility sector, supporting sustainable growth and resource efficiency. The findings from these interviews contribute to a nuanced understanding of the potential for circular initiatives and serve as a foundation for developing targeted strategies to transform the mobility sector in South Africa.

The rationale for the stakeholder engagement approach, was recognising that the mobility sector is diverse, with many relevant sub-sectors. Hence, the approach adopted to understand the circular development path needed to provide opportunity for stakeholders from all sub-sectors to participate. A key consideration in the stakeholder engagement component of the project design was to mitigate the potential risk of excluding any important circular economy role-players by not soliciting or inviting their direct inputs and, that the feedback and results from the study needed to be meaningful and representative of this diverse sector. This was essential to provide a sound empirical basis to support proposed recommendations for interventions from the project, whether on a policy or a more practical basis. The results and analysis of the survey are included below and in Appendix1.

4.2.1 Stakeholder engagement

The largest proportion of respondents (53%) were from government, followed by the private sector (32%). In terms of transport branch, the largest group (53%) were from the road transport sector, followed by logistics (16%). Notably, there were no respondents from the maritime or aviation sectors. In terms of their role within the organization, the majority of respondents (22%) are involved in planning and policy development, followed by engineering design and construction (17%). Additionally, it is noteworthy that 74% of respondents have more than 10 years of experience in the mobility sector, bringing a depth of knowledge to this engagement.

In terms of their knowledge of the circular economy, 53% of respondents had a "working knowledge" of the circular economy, with 31% having a good or excellent knowledge of the concept. In terms of actual involvement in circular economy related projects, 61% had less than two years of practical experience. 22% of respondents indicated that they had more than 10 years of circular economy related experience, highlighting that some circular interventions are not new to the mobility sector. CE involvement noted by respondents included, working with alternative fuel sources, such as identifying biomass waste streams to convert into clean energy; producing biogas; the development of electric mobility strategies; feasibility assessments for renewable energy for specific transport systems; the implementation of Integrated Asset Lifecycle Management to ensure long-term preservation and climate resilience; integrated transport planning; utilizing waste ash, plastic, secondary aggregate or non-potable waste in road construction; investigating sustainable asphalt mixes; selecting cost-effective surfacing technologies; and end-of-life vehicle recycling.

In terms of respondents' *familiarity* with CEIs in mobility, the three most familiar interventions were hybrid or electric vehicles (EVs); shifting freight from road to rail; and climate resilient transport infrastructure. The three least *familiar* CEIs were found to be: shorter supply chains (e.g. peri/urban agriculture); 15-minute cities; and circular supply chains (e.g., reverse logistics, take-back schemes).

There was a general consensus amongst stakeholders, that the adoption of circular practices would be beneficial for the South African mobility sector. The three most *beneficial and appropriate* to South Africa, circular mobility interventions included: shifting freight from road to rail; shifting passengers to public transport; and climate resilient transport infrastructure (Figure 8).

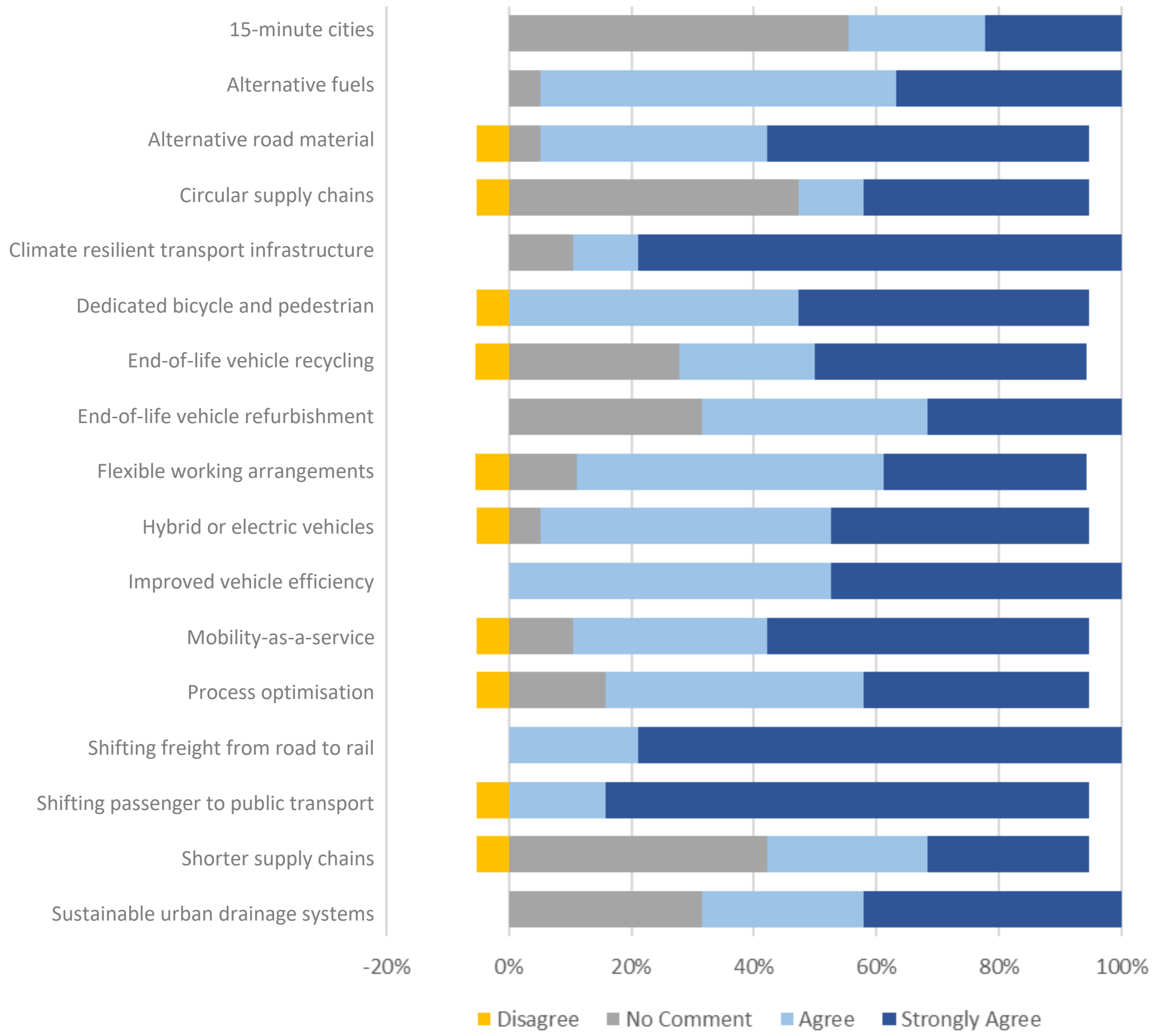

Figure 8. Extent to which circular economy interventions can benefit the South African mobility sector

Shifting freight from road to rail is considered a sustainable mode of transport that can help mitigate the rising costs of road transport per ton-km; reduce road congestion; minimize road degradation; and decrease externalities like pollution and road accidents. However, there are numerous rail infrastructure and inefficiency challenges when moving freight from road to rail in South Africa. Full implementation of Operation Vulindlela, which allows third-party access to rail infrastructure, could increase the readiness level for this shift. However, stakeholders believe vested interests and a lack of political will are significant barriers.

Stakeholders assert that the large public transport industry supports the shift of South African mobility towards public transport, which is associated with lower carbon emissions; increased passenger transport mobility; and improved traffic conditions. However, stakeholders outline that the current public transport systems are way below international norms and emphasize the critical need for public transport improvements, including enhanced comfort, safety and reliability, to attract more users.

New alternative material technologies are believed to be sufficient to support climate-resilient transport infrastructure, potentially mitigating the adverse effects of climate change on roads; reducing the impact of natural disasters; and contributing to sustainable transport infrastructure. However, alternative road materials have not been tested by engineers on any major roads in South Africa to see if it can sustain vehicle axle loads over time.

Meanwhile, the three *least beneficial* circular interventions were suggested to be: 15-minute cities; circular supply chains (e.g. reverse logistics etc.); and shorter supply chains (e.g. peri/urban agriculture). South Africa will face challenges in fully adopting the concept of a 15-minute city, due to the country's history of segregation and resulting unbalanced economic factors; apartheid land reforms; and current levels of crime and safety. Crime can discourage walking or cycling, because these modes of transport make it easier to be a victim in urban areas.

Currently, concepts similar to 15-minute cities are utilised in gated residential estates within South Africa. However, we are seeing new developments emerge which embrace the 15-minute city concept, such as the Menlyn precinct in Pretoria East, the V&A Waterfront Precinct in Cape Town, and Waterfall City in Johannesburg. These are new, upmarket developments that support mixed-use lifestyle living and facilitate greater pedestrian movement.

In terms of shorter supply chains, compared to the energy sector, the food sector provides fewer prospects for urban self-sufficiency. While peri-urban agriculture significantly contributes to urban food supply in various African cities (Cofie *et al*., 2003), literature suggests that South Africa's urban agriculture primarily addresses food security and poverty alleviation (Malan, 2015; Smith *et a*l., 2005; Van Averbeke, 2007) rather than large-scale food production. Peri-urban agriculture can provide an opportunity to shorten supply chains while serving as an essential component of urban food systems, but its impact varies depending on location, policy support, and integration into broader food supply chains. Fruits, vegetables and leafy greens can be successfully produced in urban spaces. Since 40% of the world's cropland is located within 20 kilometres of cities, these peri-urban areas have the potential to generate a significant amount of food.

Stakeholders recognised the following CEIs as being able to *improve the resilience and competitiveness* of the South African mobility sector: shifting freight from road to rail; alternative road materials; climate-resilient transport infrastructure; transitioning to EVs and Hybrid Vehicles, with local manufacturing of EV components; second-life battery use and battery recycling; and process optimization for load and trip management.

4.3 Readiness to implement interventions

Many CEIs have found application in the global north but are yet to find scale or application in developing countries that face their own unique circumstances. Stakeholders were asked to rate the *sector readiness* to implement these CEIs in South Africa (Figure 9) and the *current level of implementation* of the proposed CEIs in the South African mobility sector (Figure 10).

4.3.1 Stakeholder engagement

Stakeholders agreed that all of the identified CEIs have some level of readiness for implementation in South Africa. As expected, given their current level of adoption in South Africa, flexible working arrangements; and mobility-as-a-service (MaaS), were scored by respondents as having the highest levels of readiness to implement. Climate resilient transport infrastructure, and sustainable urban drainage systems (SuDS) also scored high in terms of readiness.

While many South African's have returned to their place or work post the COVID-19 pandemic, working from home; flexible working arrangements; shared office space; and co-working space has found traction in South Africa. This reduces the need for daily commute into work, and/or the distances travelled for work, potentially reducing the number of vehicles on the road.

Stakeholders noted the rapid growth of ride-sharing services like Uber, Bolt and Lyft in South Africa as a successful example of Mobility-as-a-Service (MaaS). However, some stakeholders argue that full-scale implementation of MaaS remains a pipedream in South Africa at this stage, due to the mini-bus taxi industry seeing them as a competitor. MaaS aims to bridge the gap between public and private transport operators on a city, intercity and national level, and envisages the integration of the currently fragmented tools and services a traveller needs to conduct a trip (planning, booking, access to real time information, payment and ticketing). It has the potential to eradicate dependence on private vehicles (Matyas & Kamargianni, 2017).

Meanwhile, the *least ready* to implement circular interventions included: alternative fuels (bio, hydrogen); 15-minute cities; shifting passenger to public transport; and shifting freight from road to rail.

Stakeholders emphasized the need for South Africa to align with global technological shifts, focusing on resource efficiency, cost savings, lower emissions, and minimizing waste to promote economic growth and job creation. They also deem alternative fuels necessary to address current mobility constraints. The readiness of biofuels for mobility depends on making infrastructure accessible to the public, such as storage facilities and legislative readiness, and biofuels may require subsidies.

In terms of *actual implementation*, respondents noted that all identified CEIs had some level of implementation in the South African mobility sector, but not all at a scale for impact (Figure 10). Although the government is aware of these interventions and some initiatives have been trialled through pilot projects, widespread adoption has often been hindered by cultural norms and a lack of necessary incentives. More effective planning and implementation are needed to scale these interventions, with the government playing a stronger role in overcoming these challenges. According to respondents the three *most implemented* CEIs in South Africa are: flexible working arrangements; mobility-as-a-service (MaaS); and dedicated bicycle and pedestrian facilities.

Stakeholders highlighted flexible working arrangements as one of the most promising circular interventions. Since COVID-19, many companies have implemented flexible working conditions, including working from home and flexible hours, which have proven effective. Flexible working arrangements associated with less travel or fewer commute trips offer benefits such as reduced traffic congestion, energy consumption and air pollution (Hook *et al.,* 2020).

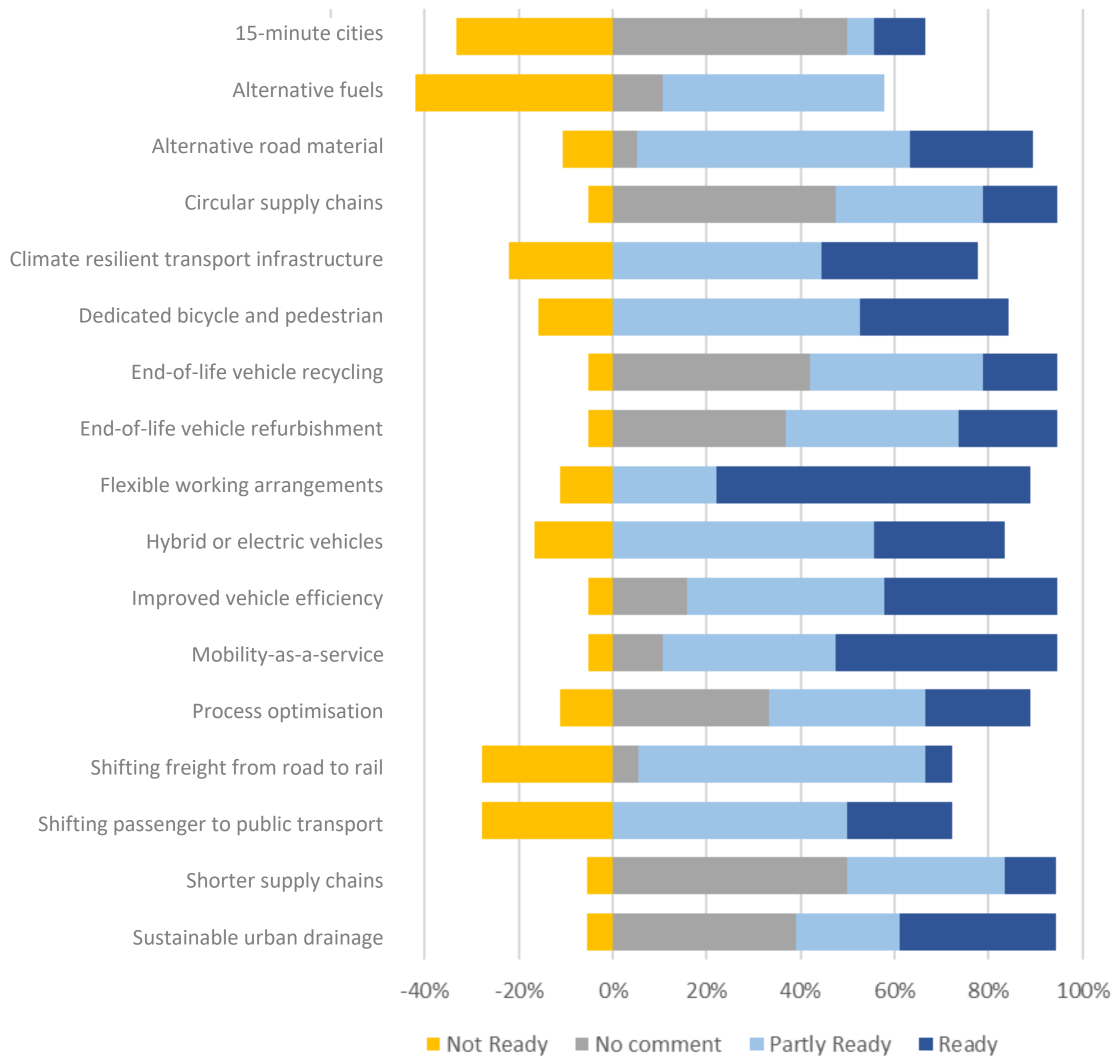

Figure 9. State of readiness to implement circular economy interventions in South African mobility sector

The current South African mobility sector is heavily dependent on energy. Consequently, stakeholders view Non-Motorized Transport (NMT) and dedicated bicycle lanes as an effective CEI. Highlighted projects include NMT initiatives alongside Bus Rapid Transit (BRT) routes and separate projects in Tshwane, with dedicated bicycle lanes in Pretoria East and other areas. Additionally, the City of Johannesburg's NMT strategy includes bicycle and pedestrian lanes in Sandton.

While EVs have begun entering the South African market, their adoption remains slow due to the dominance of fossil fuels. Nonetheless, EVs are seen as a key circular mobility intervention, offering potential emissions reductions and lower vehicle maintenance costs, which could decrease living costs. Stakeholders acknowledge a demand for zero-emissions road freight, and while Volvo has electric trucks in the country, the lack of truck-specific chargers on key corridors limits their use to urban logistics. For electric trucks to be cost-effective, they need to drive more than 18,000 km per month. There is also a need for more promotion and information sharing about the benefits of EVs to encourage broader adoption. However, the turnaround time for implementing EVs may be too long and costly for the average South African.

Other key components to increasing the uptake of hybrid and electric vehicles include government incentives, consumer awareness, technological advancements, and regulatory support. Governments can play a significant role in promoting the adoption of electric and hybrid vehicles through incentives such as tax credits, rebates, and subsidies for purchasing these vehicles, which could help offset the higher upfront costs associated with EVs and hybrids (Diamond, 2009). The most affordable EV on the South African Market (i.e., the pint-sized EVA City Blitz) is currently priced from R 199,900 (as at 2024) (three times cheaper than its closest price competitor), yet still unaffordable for the majority of South Africans (Szutowicz, 2024).

However, shifting commuters to greater use of public transport, must be a priority before shifting single occupancy, internal combustion engine (ICE) vehicles to electric vehicles (EVs_.

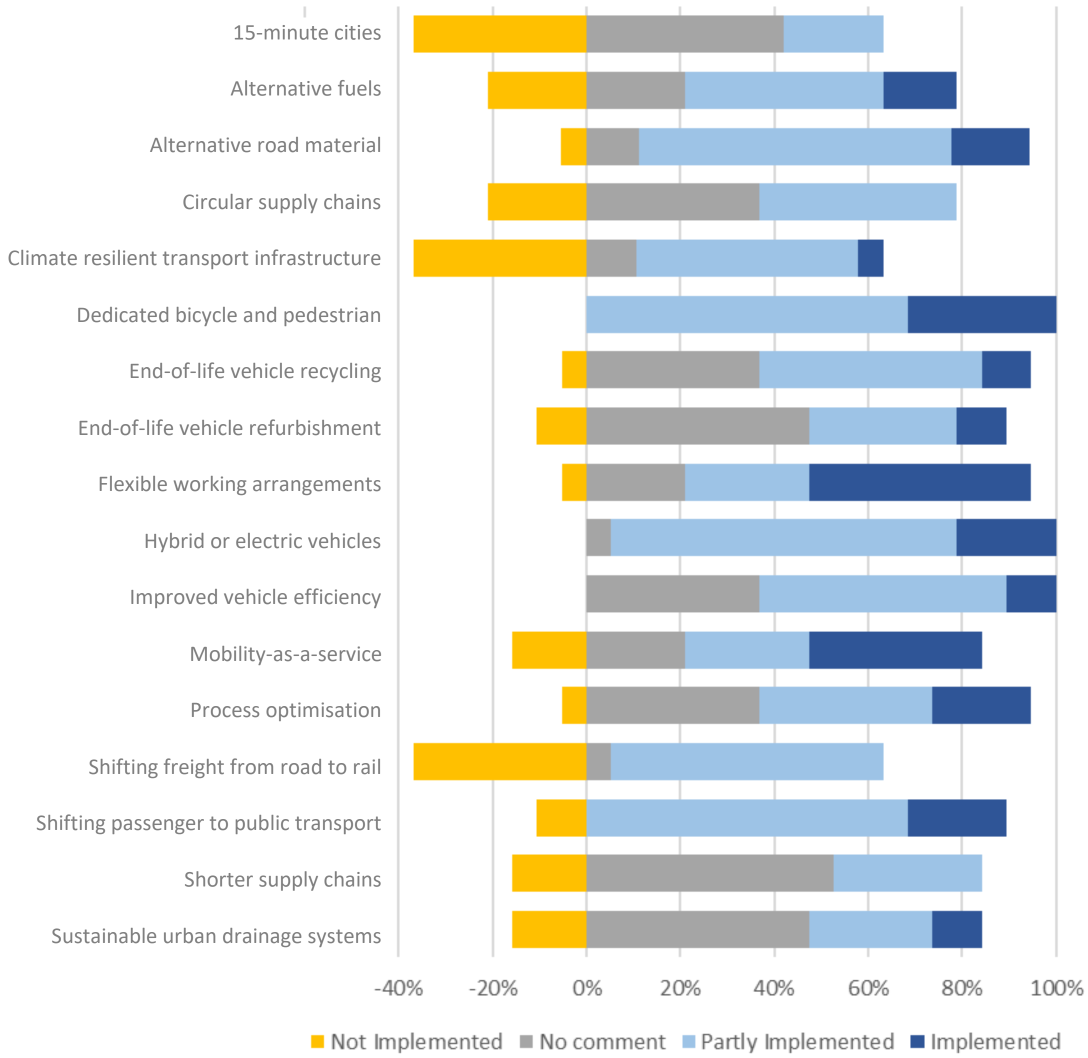

Figure 10. Level of implementation of circular mobility interventions in South Africa

The three *least implemented* circular interventions were found to be shifting freight from road to rail; 15-minute cities; and climate resilient transport infrastructure.

Climate resilient transport infrastructure was noted by stakeholders as having a high level of readiness to implement (Figure 9), but currently a low level of implementation, which may make this a CEI for fast-tracking in terms of implementation in South Africa.

The 15-minute city concept is considered unfeasible by many stakeholders, for many South African cities given the lack of integration between urban and transport planning, urban sprawl, dormitory townships on the outskirts of cities, and high land costs in central business districts that inhibit low-income residents. However, it does provide an opportunity to rethink the future development of South African cities.

Shorter supply chains, and Sustainable Urban Drainage Systems (SuDS) are noted as having low levels of implementation in South Africa. SuDS as a sustainable approach to stormwater control management, conserves nature, while improving the health of the society through treatment of water, with enhanced management of flooding effects as compared to conventional stormwater control which prioritises only flooding effects control. Armitage *et al.*, (2013) emphasizes that SuDS has been widely adopted internationally as a sustainable approach for stormwater drainage management. However, the approach has only been used on a small scale in South Africa. However, SuDS are growing in popularity in residential areas and estates (Armitage *et al.*, 2013).). Examples include the eThekwini Green Roofs Pilot Project in Durban's CBD; intensive green roof in Department of Environmental Affairs and Development planning in Cape Town; swales combined with bioretention areas in Hawaan Estate, Umhlanga; bioretention area situated between housing units in the Evergreen Retirement Village in Cape Town; roadside swale found in Cotswold Downs Golf Estate, and large roadside detention pond in Hillcrest, Kwazulu-Natal.

Stakeholders were asked which CEIs, if implemented in the South African mobility sector, could lead to inclusive growth and decent jobs. The most prominent responses included:

- *End-of-life vehicle remanufacturing, refurbishment, and recycling:* Extending vehicle lifespans through remanufacturing and refurbishment within the South African automotive sector (synergy with existing vehicle manufacturers and OEMs). Creating jobs in remanufacturing, and in the recycling of end-of-life vehicles that cannot be repaired for reuse.
- *Vehicle battery recycling and second-life applications:* Grow local recycling and beneficiation of vehicle batteries, including EV batteries.
- *Shifting freight from road to rail* could provide new employment opportunities in rail logistics, scheduling, and station management, counteracting concerns about job losses in the trucking industry.
- *Shifting passenger transport to public transit:* Expanding the public transit system, which requires skilled labour for operations and maintenance.
- *Mobility-as-a-Service (MaaS)* (e.g., ride-sharing, e-scooters, and other micro-mobility solutions): Implementing MaaS would provide employment opportunities in digital platforms, logistics, maintenance, and customer service roles.
- Expansion of local *EV manufacturing and assembly*.
- Development and roll-out of *public charging infrastructure*, to support uptake of EVs.
- *Alternative fuel production (e.g., biofuels):* Developing local biofuel production can create new industries and employment opportunities in rural areas.
- *Urban and rural infrastructure development:* Building climate-resilient and sustainable urban transport networks can stimulate local job creation.

A concern raised by stakeholders was the potential for *geographic disparities* in the distribution of job opportunities. While urban centres are likely to benefit from EV infrastructure and new mobility solutions, rural areas may be left behind unless there is deliberate planning to ensure equitable access to job opportunities. Inclusive growth will therefore require targeted initiatives to promote infrastructure development and job creation in underserved regions.

4.4 Challenges and Obstacles to Implementation

During the engagements with stakeholders, there were however several challenges and obstacles noted regarding the uptake and implementation of circular interventions in the South African mobility sector. The suggested actions to overcome these obstacles and enable the implementation of CEIs in the South African mobility sector are discussed below.

Policy and regulatory support: The lack of a specific national circular economy policy was noted. Current policies (within and between line departments) are fragmented, and there is no dedicated circular economy legislation to drive sector-wide adoption. It was noted that there is a need for better coordination between economic, industrial, transport and environmental policies to ensure a holistic approach to circular economy implementation. Specific sector policy needs included the need to develop standards and regulations that support the use of alternative materials in road construction and sustainable road designs. Policies promoting vehicle remanufacturing, refurbishment and recycling. Supportive policies to prioritize climate-resilient infrastructure development. Policies that mandate the use of low-emission technologies and sustainable design practices. Stringent emission standards and regulations need to be enforced to drive the adoption of cleaner technologies. By implementing stricter emissions standards for Internal Combustion Engine (ICE) vehicles, the sector can incentivize a shift towards electric vehicles (EVs) and alternative fuel vehicles. These regulations would not only create pressure for industry compliance but also encourage investment in low-emission transport solutions. The 2018 Green Transport Strategy was considered to be outdated and does not reflect recent technological advancements and global shifts towards net-zero transport systems.

Infrastructure investment and development, including technological innovation: These included investing in the expansion and upgrade of rail networks and infrastructure to support road-to-rail logistics. Building a nationwide network of EV charging stations and hydrogen refuelling stations. Including setting requirements for local content in EV manufacturing and component supply to ensure that job creation benefits local communities. Significant capital investment for building resilient roads; upgrading stormwater drainage systems and implementing sustainable urban drainage systems (SuDS) to adapt to increased rainfall and flooding risks. Expanding and modernising the public transit network, including buses and rail. Developing the local end-of-life vehicle and battery recycling infrastructure and capability.

Stakeholder collaboration and public-private partnerships: Infrastructure development will require significant funding. Greater public-private sector collaboration, and potential public-private partnerships are seen as a means of bridging this funding gap and accelerating infrastructure development. This includes involving construction companies, logistics operators, environmental agencies and community groups to align efforts, share resources and support inclusive project development and widespread access to employment opportunities. In addition to promoting investments, public-private sector collaboration is seen as a way of sharing best practices.

Closely linked with increased sector investment, is the need for *financial incentives for green technologies:* These include subsidies and tax benefits to reduce the high cost of adoption of EVs and fuel-efficient vehicles. Tax benefits or grants to encourage investment in end-of-life vehicle remanufacturing and refurbishment. Incentives to establish local vehicle and battery recycling facilities.

Incentives for local EV production, and subsidies to encourage public transit expansion.

Skills development and workforce readiness: The need for skills development, upskilling and reskilling to implement CEIs is recognised. This includes creating training programs to equip workers with a different set of skills for new jobs in circular mobility industries, including vehicle remanufacturing or recycling, EV production, advanced manufacturing, new mobility solutions, infrastructure development, and public transit operations. It was felt that there is a need for a comprehensive sector skills development strategy to reskill workers and ensure that they are equipped for future jobs in the mobility sector.

Research and innovation: Investment in research and development (R&D) to advance new technologies, including green infrastructure solutions, and new design standards and guidance for incorporating climate resilience into road infrastructure; alternative fuel technologies. To bring R&D results from the lab into society and establish early markets, technology demonstration is essential. The need to test and pilot alternative road materials. This requires close coordination between government, industry players, and research institutions to align goals and accelerate implementation.

There is also an acknowledgement that adopting and scaling circular mobility interventions will require *data and technology integration*, including the adoption of digital platforms for logistics optimisation.

Regarding specific sector activities, extensive discussions were held around the *shift of freight and passengers from road to rail*. Inefficiencies in the South African rail sector have caused a significant shift of goods transport from rail to road, which is unsustainable in the long term. Road-to-rail initiatives were highlighted as being of critical importance for reducing logistics costs, mitigating environmental pollution (including emissions), and achieving sustainability in South Africa's transport sector. The integration of road and rail logistics is seen as not only a key intervention for decarbonizing the transport sector but also vital for improving the overall efficiency and competitiveness of the automotive supply chain. Rail transport is generally more cost-effective for bulk goods over long distances, therefore transitioning to rail would decrease logistics costs, enhancing the competitiveness of South African goods in both domestic and international markets. This would be particularly beneficial for the automotive industry, where high logistics costs can undermine profitability. By decreasing the number of heavy trucks on the roads, road-to-rail integration would also reduce wear and tear on road infrastructure, thereby lowering road maintenance costs for the government and extending the lifespan of critical road networks. To realise this critical intervention of road-to-rail integration, there is a clear need for investment in rail infrastructure, where funding remains a significant constraint.

Logistical challenges, such as the lack of coordination between different transport modes, and the absence of efficient rail-to-road intermodal facilities, were also highlighted as challenges that impede full implementation of rail-to-road strategies.

The automotive industry and other key sectors have been slow to adopt rail as a primary mode of transport due to uncertainties about service reliability and infrastructure readiness. Therefore, closer collaborative efforts are needed between government and industry stakeholders to align goals and coordinate investments, such as ongoing efforts to optimise critical routes like the Durban-to-Gauteng corridor, where alleviating congestion is a top priority.

Large-scale investments are needed to upgrade rail infrastructure, increase capacity, and address inefficiencies at key transport nodes. This includes expanding rail networks, modernizing facilities, and building intermodal terminals. Building intermodal hubs that seamlessly connect road and rail networks is crucial for making rail a viable option for businesses. These facilities would enable easy transfer of goods between transport modes, reducing delays and logistics costs.

4.5 Conclusion

A coordinated approach between industry stakeholders and government departments is needed to align policies, investments, and timelines. Although there are ongoing collaborations with entities such as Transnet and the dtic, more needs to be done to accelerate implementation where roles and responsibilities of each stakeholder are clearly defined.

There is currently no comprehensive policy framework to support the shift from road to rail. Regulatory and infrastructure changes are needed to make rail transport more attractive to businesses, such as modifying rail wagons and infrastructure to accommodate new vehicle models and larger shipments. The introduction of policies that encourage the use of rail for freight transport will greatly assist in fast-tracking implementation. This could include tax incentives for companies that shift to rail, subsidies for rail investments, and regulatory reforms to streamline logistics operations. By addressing the gaps in existing policies and introducing targeted support measures, the government can create an enabling environment that promotes investment, job creation, and sustainable growth in the mobility industry.

The transition to a circular economy in the South African mobility sector has the potential to drive inclusive growth and job creation, but success will depend on strategic planning, investment in skills development, and targeted policy support. By addressing these challenges, South Africa can build a more resilient and sustainable mobility sector that benefits all citizens.

5 Quantifying the impacts of a circular development path

The transition to a more circular mobility sector and the adoption of circular interventions, will result in disruption, whether intended or unintended. Shifting commuters from single-occupancy vehicles (whether ICE or EVs) to public transport, will result in reduced demand for light passenger vehicles, which will disrupt local automotive manufacturing, but will create new opportunities in public transport systems and local manufacturing of larger passenger vehicles. Shifting freight from road to rail, will disrupt long-haul trucking, but will create trucking opportunities for last-mile solutions, and new opportunities in rail systems, including local manufacturing of rolling stock. With more than 60% of locally manufactured passenger vehicles destined for export markets (Lamprecht, 2023), international commitments to shift to NEVs will disrupt the local automotive industry (See Section 2.5.4) but can create new opportunities in local remanufacturing and refurbishment.

Modelling provides us with an opportunity to better understand the intended and unintended consequences of these disruptions. This allows the public and private sectors to better manage these shocks, and to respond appropriately to ensure maximum social, economic and environmental benefits for South Africa.

CEIs represent proposed changes to a complex socio-economic system, with a view on improving multiple parameters. Ideally, interventions need to be selected and prioritised based on their potential systemic impacts – and, to this end, some measure of quantification is required. Impacts can be quantified from several different perspectives and frameworks – these should take a holistic view on the system and should evaluate the relative performance of an initiative in terms of multiple parameters.

To quantify and compare systemic impacts, different modelling techniques can be employed, including Systems Dynamics (SD) modelling, macroeconomic modelling, cost-benefit analysis, and more. Each of these approaches provides insights at a different level of abstraction. A clear modelling question should guide the selection of approaches. Further, to make informed data-driven decisions, good quality data needs to be available. In the mobility sector, the opportunity exists to enhance both the reach and quality of nationally available information (CSIR, 2024; Department of Transport, 2005).

This section illustrates two of the techniques that can be applied to quantify the impact of different CEIs in the mobility sector. In the long run, it is foreseen that a portfolio of modelling approaches could be employed across different CEIs.

The purpose of this chapter is to illustrate how two modelling approaches can support decision-making with respect to CEIs:

- Systems Dynamics Modelling (Refer to Appendix 2)
- Macroeconomic analysis (Refer to Appendix 3)

Systems Dynamics Modelling (SDM) provides a means of understanding and analysing the dynamic behaviour of the system (in this case: a sector), and exploring how an intervention in one part of the system affects another part thereof, as well as how a system is expected to evolve over time (Sterman, 2002). It is often used to evaluate policy options; as such it mostly (but not exclusively) supports tactical decision-making. For example, the expected impact of a shift of freight from road to rail on parameters such as emissions and traffic safety can be analysed and compared.

Macroeconomic modelling provides a means of quantifying the disruption (either positive or negative) of a specific intervention to the economy in terms of environmental, social and economic impacts (i.e., it assesses the impact against multiple parameters). The analysis quantifies potential benefits and pitfalls of the intervention under consideration and, as such, can guide the realization of benefits and the development of interventions to ensure a just transition towards circular mobility. As such, it supports strategic decision-making. For example, the impact of a transition from ICE vehicles to NEVs on selected macroeconomic indicators (e.g., GDP, job creation, etc.) can be assessed. Where multiple interventions are considered, the results can be used to compare and evaluate their impacts at a macro level (e.g., DEA, 2014).

By way of illustration, the models described in this chapter outline the potential impact of decisions at the meso- and macro-levels. For each model, the intent with the model and overview of results are described here, while the model and modelling approach are outlined in the relevant Appendices.

The preliminary results provided here serve as example only. More comprehensive and detailed modelling is required to support South Africa's transition to a more circular economy. Modelling that will provide greater insights into the economic and social benefits of disrupting the current linear development path for South Africa's mobility sector.

5.1 Systems dynamics modelling

5.1.1 Model overview

Systems Dynamics Modelling (SDM) is an effective analytical method employed to comprehend the dynamics of intricate systems over time. The process entails creating simulation models that accurately represent the interconnections, feedback mechanisms, and temporal delays within a system. SDM is highly efficient for analyzing systems in which the dynamic behavior arises from the interplay of numerous components, such as in the fields of economics, environmental management, and urban planning.

In this modelling approach, a system is modelled in terms of its subsystems and the assumed relationships between them. The model is developed to allow different scenarios to be tested, and the performance of scenarios are compared relative to predefined performance parameters. The strength of this approach is in comparing the relative impact of scenarios on overall performance, even though the assumptions made could imply that the absolute value of performance parameters are not exactly reflecting reality. For example, the impact of more passengers using public transport on the environment could be compared with the environmental impact of shifting freight from road to rail. The relative reduction in CO_2 emissions could guide prioritisation, even though these emissions figures may or may not be exact, depending on the accuracy of information that is available. In essence, SD models allow decision-makers to obtain an indication of the impact of different interventions *relative* to each other.

SD modelling uses stocks, flows, feedback loops, and time delays to depict the structure of a system. Stocks refer to accumulations of resources, flows describe rates of change, and feedback loops can be either reinforcing or balancing. SD models simulate the interactions between elements to forecast the long-term effects of policies, identify sources of influence, and examine the prospective outcomes of different options.

Within the realm of transportation systems, the utilization of SDM is particularly valuable for analyzing the impact of alterations in infrastructure, policy, and behavior on factors such as congestion, pollution, and urban development. It offers a comprehensive perspective, enabling policymakers to consider the wider effects of their choices and to evaluate various scenarios prior to implementation. In summary, SDM is a powerful instrument for comprehending intricate, ever-changing systems and for facilitating well-informed decision-making in diverse domains.

For this analysis, a few CEIs were identified that have the potential to create positive impact. The model was developed to assess the relative impact of these interventions. The impact of the following circular economy interventions (CEIs) was tested:

1. Dedicated bicycle and pedestrian facilities
2. Shifting freight from road to rail
3. Shifting passenger to public transport
4. Hybrid or electric vehicles
5. Flexible working arrangements

The energy usage of the different interventions was compared to assess the relative improvement brought about by each.

5.1.2 Results

In comparing the relative impacts of the various interventions, the following can be deduced:

The results show that certain CEIs have significant positive impact on the transport system, with the potential to improve overall mobility in South Africa. Shifting from road to rail; adoption of NEVs; and flexible working arrangements resulted in the most improvement on the transport system.

Improvements in rail infrastructure can result in an increase in rail utilization, albeit with a significant delay of approximately 10 years. This delay implies that, although investments in rail infrastructure are advantageous, they necessitate a long-term commitment and perseverance before tangible results are observed.

The adoption of EVs and more flexible working conditions decrease energy consumption associated with commuting. The energy consumption of internal combustion engine (ICE) vehicles is nearly ten times that of EVs, thereby underscoring the substantial environmental advantages of transitioning to electric mobility. Both flexible working conditions and NEVs were shown to decrease energy usage.

The analysis also indicates that the mere act of increasing petroleum prices is insufficient to encourage individuals to shift to public transportation. The necessity of a comprehensive approach to transport planning is underscored by the fact that a combination of enhancements across multiple variables is required to influence modal split. The shifting of passengers to public transport will have a positive impact on the transport system, however this will only be achieved once sustainability in the transport system improves. Sustainability in the transport system being measured by safety, affordability, accessibility, efficiency, resilience and minimization of carbon, other emissions and environmental impact (UN, 2016).

Dedicated bicycle and pedestrian lanes however were shown to have very little to no impact in the transport system. The data suggests that an investment in Non-Motorized Transport (NMT) infrastructure does not lead to a substantial increase in use. This implies that the decision to utilize NMT may be more influenced by the perceived safety and comfort of the individual than by the mere availability of infrastructure – factors that were not considered in the current model.

In general, the results emphasize the necessity of multifaceted strategies to accomplish sustainable transport objectives within the intricacy of urban transport systems. Although infrastructure investments are essential, the future of urban mobility is also influenced by factors such as safety, long-term planning, and behavioural adjustments. These are equally important.

5.2 Macroeconomic analysis

5.2.1 Model overview

This modelling approach takes a macro perspective on the economy and evaluates the repercussions of proposed macro-level interventions on key economic parameters. As such, it guides decision-making in terms of investment in initiatives at a national level. It expresses impact in terms of economic, social and environmental parameters, and considers macroeconomic activity as a basis for analysis.

By way of illustration, the macroeconomic model was used to investigate and quantify the '*Transport and Storage*' (TaS) sector's contribution to South Africa's economy, employment, and GHG emissions through the completion of a Macro-Economic Impact Assessment (MEIA). This sector best represents freight transport and logistics-related activities in the economy and will experience repercussions (either positive or negative) when transport and logistics-related CEIs are implemented. By expressing impacts in terms of economic, social and environmental parameters, multiple perspectives are assessed. This creates the opportunity to weigh the benefit of positive impacts (e.g., environmental) of a CEI against negative impacts (e.g., employment losses), and provides targets for CEI intervention design to minimize unintended consequences.

The analysis highlights the significance of the TaS sector to the South African economy. The adoption of CEIs will result in disruption and as such, it is important that further macroeconomic modelling be undertaken to fully quantify the impacts (both positive and negative) of these circular interventions.

The analysis was completed by using an analytical model developed by Conningarth Economists (Conningarth Economists, 2024) that allows the user to quantify the macro-economic and socio-economic impacts of sector-specific projects within South Africa. The model utilizes an input-output table known as the Social Accounting Matrix (SAM), which is in line with the National Accounts published by the South African Reserve Bank and captures the flow of financial and economic activity within different sectors.

5.2.2 Results

The MEIA, as outlined in detail in Appendix 3, highlights the socio-economic contributions of South Africa's TaS sector, under the assumption that the sector's turnover equalled R1.117 billion in 2023 (see Appendix 3 for the calculation). Most noteworthy is the sector's total GDP contribution (i.e., direct, indirect and induced impact) of R1.129 billion, and its employment generation for about 3.5 million people, of which 73% are semi- or un-skilled. The sector further contributed about R380,000 million to state revenue, which equates to government funding for just over 84,000 educators, 17,000 hospital beds, 2900 doctors, 18,800 low-cost houses, and 3,696,000 beneficiaries, for example. From an environmental perspective, if was found that the sector's service delivery resulted in the emission of about 102 Mt CO_2 GHGs in 2023.

Since the TaS sector is heavily reliant on the *Petroleum* and the *Manufacturing of Transport Equipment* (MoTE) sectors, CEIs such as reframing urban design around the 15-minute city concept, with greater use of non-motorized transport (NMT); shifting freight from road to rail; shifting passengers from ICE to EVs; alternative fuels; mobility-as-a-service, etc. will disrupt these traditional sectors. On the flip side, adoption of CEIs provides extensive new opportunities for the South African economy which are yet to be fully modelled in terms of their macroeconomic impact. An understanding of the disruptive impact of CEIs will assist decision-makers and solution developers ensure a just transition to a circular economy, i.e., a more circular development path that decouples mobility from resource consumption; creates more liveable cities; and ultimately a more effective and efficient mobility sector.

5.3 Conclusion

The SDM (meso-level) and MEIA (marco-level) approaches presented in this section demonstrate the value of modelling in understanding the positive and negatives impacts of adopting CEIs.

The SDM modelled five CEIs, to illustrate how these interventions could impact specific elements within the mobility sector against the status quo. The MEIA has provided insights into the importance of this sector to the South African economy. More detailed macroeconomic modelling, designed in collaboration with decision-makers, will be required to fully understand the positive and negative impacts of disrupting this highly linear, resource intensive sector, through the adoption of circular interventions.

6 Conclusions

South Africa's resource-intensive mobility sector provides a strong case for transitioning to a circular economy, offering opportunities to enhance efficiency, sustainability, and resilience. This may include a shift in standard practice and embracing more efficient travel patterns to enhance mobility for South African households and businesses. This report identifies 17 CEIs based on current international trends in mobility, with the potential to drive circularity in South Africa. Through (i) optimising resources, (ii) extending lifecycles of vehicles and infrastructure, (iii) prioritising the regeneration of natural systems, the sector can increase its sustainability, resilience and contribution to overall economic growth.

The transition to a more circular mobility sector has the potential to drive inclusive growth and job creation, but will depend on strategic planning, investment in skills and infrastructure, and targeted policy support. By addressing these challenges, South Africa can build a more resilient and sustainable sector that benefits all citizens. Success will require a co-ordinated approach between the public and private sectors.

While South Africa does not yet have a dedicated circular economy strategy, several national policies already incorporate circular economy principles for mobility. The Green Transport Strategy serves as a framework that guides sustainable transport development and aligns with several of the CEIs proposed in this report, such as incorporating multiple modes of transport for efficient freight and passenger travel, prioritising dedicated NMT infrastructure and climate action within the sector. Despite limited implementation, existing policies provide a foundation for transitioning away from a linear economy that is driven by resource consumption and disposal.

There was consensus amongst stakeholders that the adoption of circular practices would be beneficial for the South African mobility sector. Stakeholders agreed that all identified CEIs have some *level of readiness* for implementation in South Africa. As expected, given their current level of adoption in South Africa, flexible working arrangements; and mobility-as-a-service (MaaS), were scored by respondents as having the highest levels of readiness to implement.

In terms of *actual implementation*, respondents noted that all identified CEIs had some level of implementation, but not all at a scale for impact. According to respondents the three *most implemented* CEIs in South Africa are: flexible working arrangements; mobility-as-a-service (MaaS); and dedicated bicycle and pedestrian facilities. Climate resilient transport infrastructure, and sustainable urban drainage systems (SuDS) were noted by stakeholders as having a high level of readiness to implement, but currently a low level of implementation, which may make these CEIs suitable for fast-tracking in terms of implementation in South Africa.

Challenges highlighted by stakeholders include the need for tailored regulatory support to implement specific interventions, such as the need to develop standards and regulations that support the use of alternative materials in road construction and sustainable road designs. Infrastructure investment and development, including technological innovation was also noted as a critical need to implement some CEIs such as the expansion and upgrade of rail networks and EV charging infrastructure which can also benefit local communities through skills development and job creation. Infrastructure investments and implementation of key CEIs will also rely on effective stakeholder collaboration and strategic public-private partnerships to align efforts, share resources and support inclusive project development and widespread access to employment opportunities. The need for financial incentives for green technologies was also highlighted as an important vehicle to fast-track the adoption of CEIs.

The success of urban mobility systems is strongly influenced by user perceptions, long-term planning, and behavioural adjustments, which therefore must be considered in the transition to a more circular mobility system. However, opportunities exist through skills development programs to upskill and reskill the workforce within the mobility sector. The need for a comprehensive sector skills development strategy was identified to equip workers for future jobs in the mobility sector. Investment in strategic research and development will also assist in advancing innovative technologies.

Decision support tools were applied to illustrate their use in assessing the impacts of adopting CEIs. The transition to a more circular economy will result in disruption, whether implemented locally, or by other countries. The macroeconomic assessment highlighted the importance of this sector to the South African economy, and the careful consideration and design of interventions that is needed to ensure a just transition to a circular economy. Accurate and reliable transport and logistics information is required to enable useful and usable data-driven decision models – a gap that needs to be addressed to support a circular economy transition. Initial findings from the Systems Dynamic Modelling confirm that CEIs can drive long-term sustainability but require coordinated policy efforts, infrastructure investments, and stakeholder collaboration. The delayed impact of rail and public transport improvements highlights the importance of early and consistent action, while EV adoption and flexible working arrangements provide immediate energy savings.

To achieve a resilient and sustainable mobility sector, South Africa must adopt a holistic, long-term approach – balancing infrastructure investment, behavioural shifts, and regulatory support to ensure system-wide transformation.


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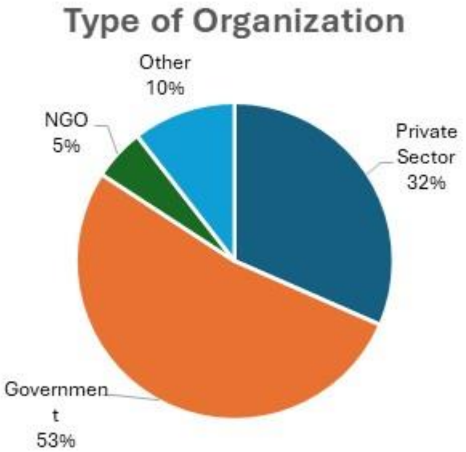
Appendix 1

Questionnaire Results



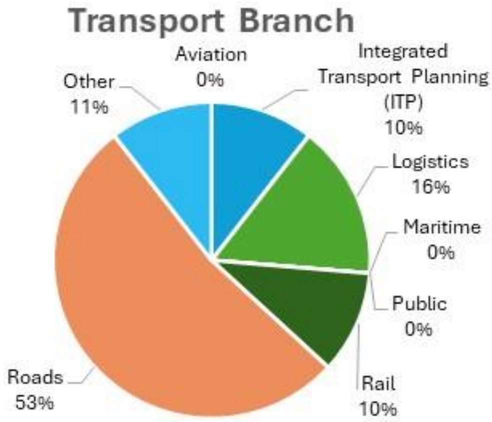
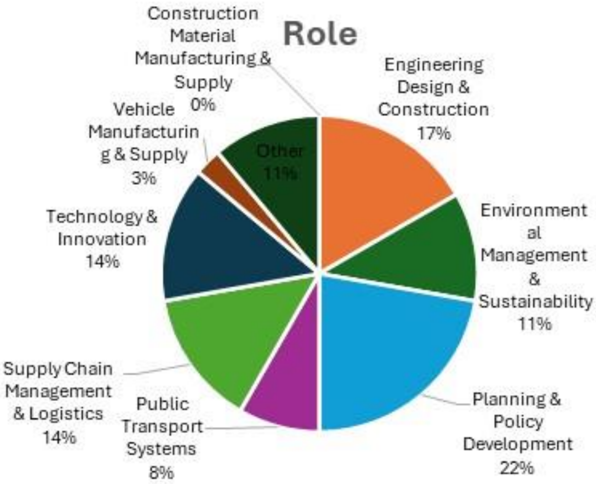


Figure 1A. Type of organization and transport branch which stakeholders engaged are from



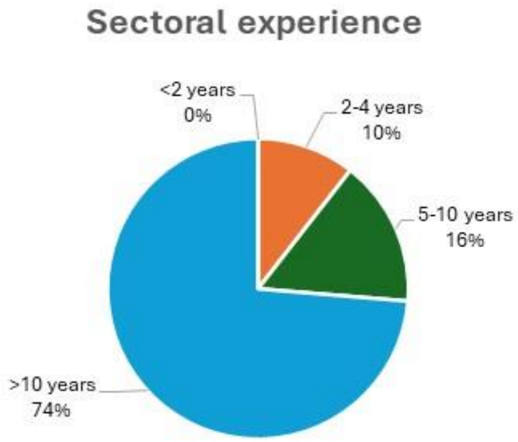


Figure 1B. Role and sectoral experience of the stakeholders engaged

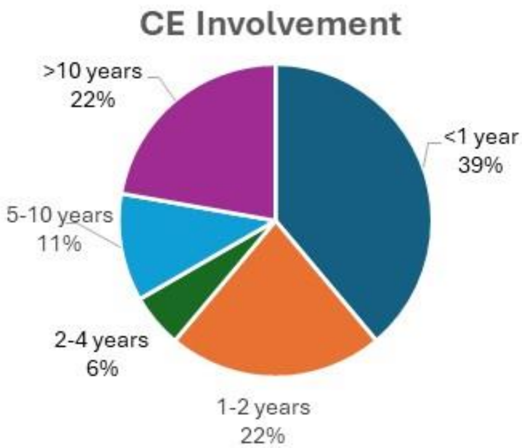


Figure 1C. Circular economy knowledge and involvement experience

Appendix 2
Systems Dynamics Modelling

1. Introduction

Systems Dynamics (SD) modelling is an effective analytical method employed to comprehend the dynamics of intricate systems over a period. The process entails creating simulation models that accurately represent the interconnections, feedback mechanisms, and temporal delays within a system. It is highly efficient for analysing systems in which the dynamic behaviour arises from the interplay of numerous components, such as in the fields of economics, environmental management, and urban planning.

SD modelling uses stocks, flows, feedback loops, and time delays to depict the structure of a system. Stocks refer to accumulations of resources, flows describe rates of change, and feedback loops can be either reinforcing or balancing. SD models simulate the interactions between elements to forecast the long-term effects of policies, identify sources of influence, and examine the prospective outcomes of different options. SD modelling is a powerful instrument for comprehending intricate, ever-changing systems and for facilitating well-informed decision-making in diverse domains.

2. An SD Model of Circular Economy Interventions (CEIs)

A systems dynamics model of circular economy interventions (CEIs) in the transport system was developed, based on the fundamental principles and structure of the transport system. The model is primarily aimed at describing the complex links and interactions between the key components of the transport system, such as nodes, networks, demand, and flows. The elements function as the fundamental components of the model, offering a structure for simulating and analysing the dynamic behaviour of the transport system.

By utilising the fundamental elements of the transport system as the foundation of the model, it becomes feasible to precisely depict the intricate interconnections, time lags, and nonlinearities that define the dynamics of real-life transportation. For example, the model has the capability to replicate the impact of demand fluctuations on the movement of people or commodities; the response of networks to different levels of congestion; and the influence of infrastructure investments on the overall performance of the system over a period.

Moreover, this fundamental methodology enables the model to be flexible and applicable to various scales and settings, whether it is examining a regional urban transportation system or a countrywide freight network. By basing the systems dynamics model on the fundamental components of the transport system, it guarantees that the simulations are both accurate and applicable, offering significant insights for the purposes of planning, policy-making, and optimising transport operations. The model seeks to capture the transport system and how it will be affected by different circular economy interventions.

The methodology adopted in the modelling is the eight-step systems dynamics (SD) modelling process, including system conceptualisation, model formulation, and decision-making, with elements of group model building as shown in Figure 2A.

Figure 2A: Eight-step systems dynamics (SD) modelling process (Pillay *et al.*, 2019)

3. Project Inception

The project inception step included identifying the modelling problem and the focusing question. This helped identify the key stakeholders and the technical team that would be required. The focusing question in this case was investigating how different CEIs will affect the transport system. It is important to note that the model should not be employed to substantiate a prejudiced or preconceived result regarding the behaviour of emergent systems. The primary focus should be on constructing a mathematically rigorous model that accurately describes the system. As properly described in Pillay *et al.* (2019)

> *"The model would not be predictive but descriptive, and the results would not be accurate to the last decimal point; however, value would be obtained through understanding the factors that affected the patterns of behaviour of the graphical trends, so that leverage points could be identified to effect change and impact the system positively. Although validated empirical data should be used to calibrate the model, experience and tacit knowledge could also be used, so the need for subject matter experts in the working group would be critical. The model should not be used to prove a biased or preconceived outcome with respect to emergent system behaviour, since the emphasis should be on a mathematically sound model that represents the system as closely as possible."*

3.1. Concept to Context

The team was assisted in contextualizing the project requirements by establishing a suitable modelling timeframe, which provided insight into determining the necessary data resolution. Different data proprietors were identified for further liaising or as workgroup members, contingent upon the resolution of the data. The systems dynamicist subsequently developed a diagrammatic framework, referred to as a causal loop diagram (CLD), by utilizing the operational and theoretical data associated with the system problem that was being modelled. The CLD contextualized the upstream and downstream variables within the system, even though it did not provide quantitative directional linkages. In the absence of data for quantitative mathematical equations, proxy solutions were implemented. The development of a CLD was successful in offering stakeholders a straightforward framework for elucidating the context of the system and providing them with a "bird's-eye" view of the system problem being modelled. The time frame considered in this case is 12 years and the variables mentioned here are shown in Figure 2B.

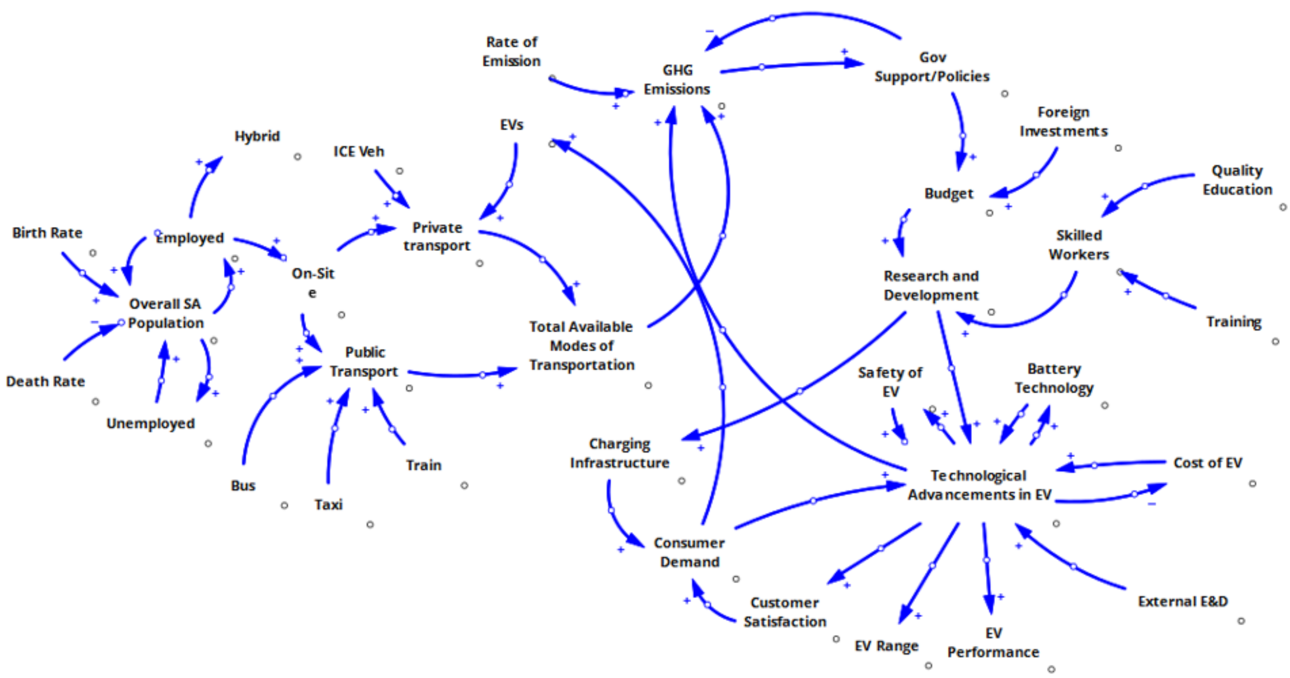


Figure 2B: Causal Loop Diagram of CEIs in the transport system

3.2. Boundary Setting

Boundary setting was essential for preventing the project scope from being exceeded and ensuring that the complexity of the model was balanced with the appropriate level of comprehension. In order to generate CLDs, a collaboration and ideation team was identified, which was associated with group model building exercises. The sessions were facilitated by the systems dynamicist, who guided the discussion toward topics related to specific circular interventions such as electric vehicles (EVs) and environmental factors, while avoiding emotionally charged arguments. The CLDs were revised as part of a dynamic process that was iterative throughout the project's lifespan. Additionally, stakeholder discussions were instrumental in the finalisation of the assumptions required for subsequent work and the identification of variables that could be excluded, as a result of the customer-defined project scope. Depending on the stakeholders' visual and interpretive learning approaches, the SAM and the CLDs offered a more profound comprehension of the system problem.

This step entailed the identification of exogenous (not influenced by the state/feedback loops of the model) and endogenous variables (dependent on the system state) that would be incorporated into the model. The historic behaviour of these variables was also determined to enable the mathematical formulation of future trends based on previous data. Figure 2B shows the CLD of CEIs for the transport system.

The CLD above acts as a mind map for the entire transport system considering different CEIs that could be applied and how that affects key functions within the transport system. The causal loop aims to interrelate every variable within the system investigating how certain variables influence each other within the system and how all defined variables contribute to the functioning of the transport system.

3.3. Systems Analyses

Before beginning the structural design of the systems dynamics model, a substantial amount of time was devoted to the identification and contextualisation of the problem, as well as the analysis of data and systems. Statistical methods and programmable algorithms (i.e. Excel, VBA and Python) were employed to ascertain the patterns or relationships between variables in the analyses.

Based on the physical/structural constraints of real systems elements, perpetual linear growth trends were disregarded. This allowed the systems dynamicist to determine whether any integration errors or incorrect structural linkages were made, which could have led to significant variances in the results when the modelling software was employed. Based on availability, the data used in the model is from StatsSA and was therefore modelled at a national level to appropriately depict all of the variables in the model. There are challenges obtaining data at a city level even though the CEIs are implemented at a city level. This indicates a gap in data that will need to be addressed for future studies.

3.4. Model Development and Design

The variables and elements discussed in the SAM and CLD were causally and mathematically linked in the model structure, which was developed using iSee Stella Software. The stock-flow-feedback structures were developed using the "Principle of Accumulation," as illustrated below, and rate equations were formulated to establish initial variable parameters. Typically, the "converter" employs mathematical formulas to transform input data into output data. The term "flow" denotes the rate at which the stock will fluctuate at any given moment. The "cloud" denotes equities that are situated beyond the model's boundary (Figure 2C).

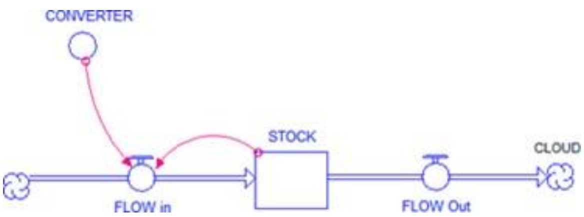


Figure 2C: Stock-flow-feedback structure

Equation (1) was used in the model structure (see Causal Loop Diagrams for relationships modelled), which determines that the Stock at time *t* is found from the Stock at a previous point in time, ($t - dt$), by adding the net quantity that accumulated as the result of the inflow and outflow during the period *dt*.

$$Stock\ (t) = Stock(t - dt) + (In\,f\,low\ Rate - Out\,f\,low\ rate) \times dt \qquad (1)$$

Feedback loops control the behaviour of a system over time. Reinforcing loops cause exponential growth or decline, while balancing loops cause goal-seeking behaviour, and they have a quantity that will grow rapidly for a while and then slow down, as it converges in on its goal. Various balancing feedback loops were built into the simulator (see Causal Loop Diagrams for relationships modelled). The iSee Stella software used in developing the SD model also allowed for an engagement platform to be built for interaction with the model and run scenarios.

The CLD of the system was then modelled in terms of stock and flow diagrams in Stella. Different relationships between the variables (both quantitative and qualitative) were modelled. Some relationships were represented in terms of graphs that show how the variable has been behaving in the past and some relationships were modelled in terms of mathematical equations. The system map is shown in Figure 2D.

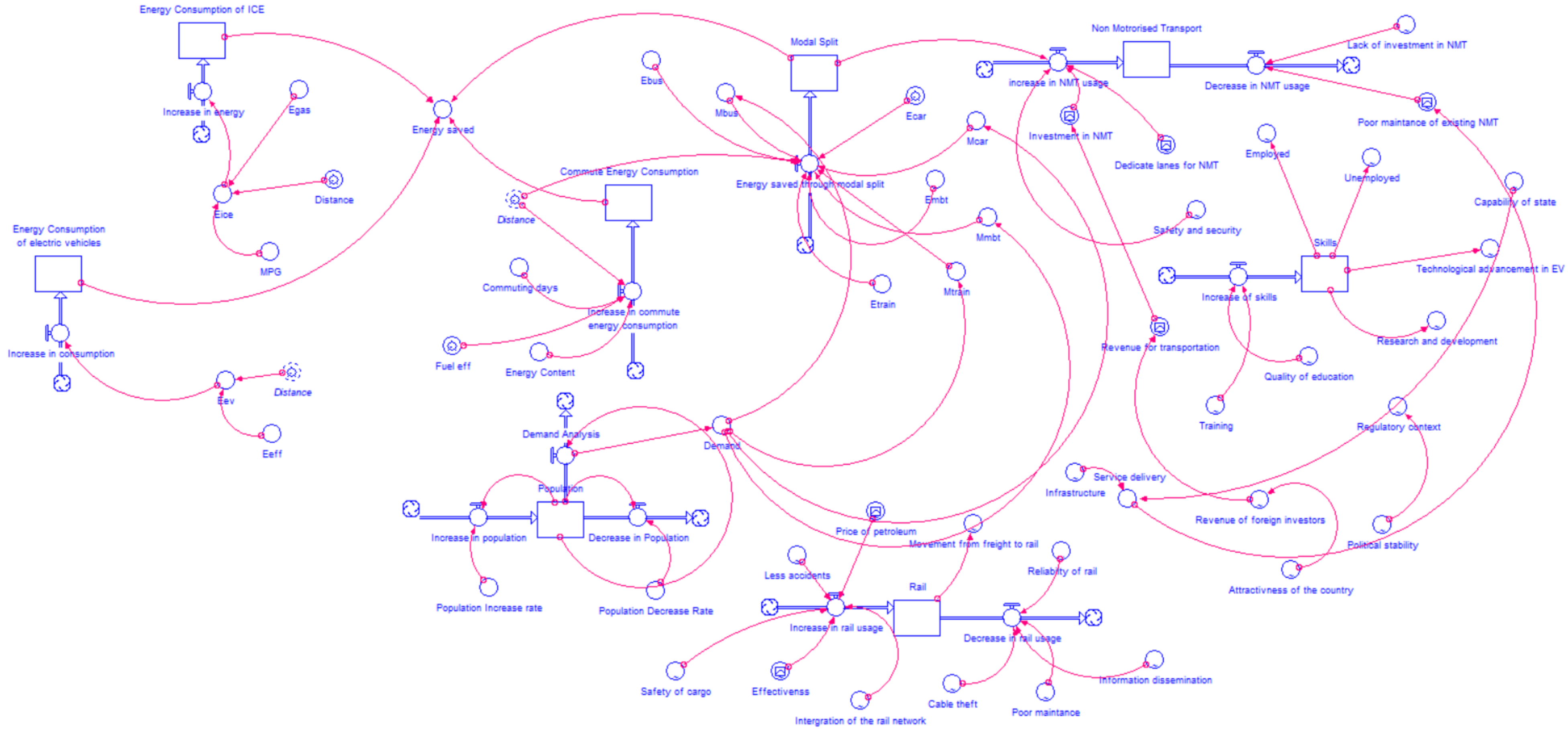


Figure 2D: System map

4. Baseline Analysis

Engagement with stakeholders highlighted the potential of the following CEIs, which would benefit from being tested for adoption in South Africa:

i. Dedicated bicycle and pedestrian facilities
ii. Shifting freight from road to rail
iii. Shifting passengers to public transport
iv. Hybrid or electric vehicles
v. Flexible working arrangements

These are described as follows:

i. Dedicated Bicycle and Pedestrian Facilities: The creation and improvement of infrastructure that is specifically designed for cyclists and pedestrians, including bike lanes, pedestrian paths, and secure crossings. The objective of this intervention is to enhance urban mobility, reduce traffic congestion, and promote active transportation.

ii. Transitioning Freight from Road to Rail: Promoting the transportation of commodities via railways as opposed to roads. The objective of this method is to improve the efficacy of freight transport systems, reduce road congestion, and reduce GHG emissions.

iii. Transitioning Passengers to Public Transportation: Encouraging the use of public conveyance in preference to private vehicles. This could entail the enhancement of public transport services, the expansion of routes, and the implementation of policies such as congestion pricing or incentives for public transport use. The objective is to enhance air quality, reduce the number of vehicles on the road, and reduce emissions.

iv. Electric or Hybrid Vehicles: Promoting the use of electric or hybrid vehicles (EVs) as an alternative to conventional internal combustion engine vehicles. This intervention is dedicated to the reduction of emissions, the reduction of fossil fuel dependence, and the facilitation of a transition to more sustainable urban transportation systems.

v. Flexible Working Arrangements: Enacting policies that permit staggered schedules, remote work, or flexible working hours. This intervention endeavours to mitigate traffic congestion, enhance work-life balance for employees, and mitigate the environmental impact of commuting by decreasing the number of commuters during peak hours.

These interventions are designed to promote efficiency within the transport system, sustainable urban mobility, and improve the overall quality of life of all citizens in urban areas.

4.1. Policy Insights and Validation

The process of validation will be continuous and will entail the contact of stakeholders to review the model scenarios and adjust the model in accordance with new information and experience. This phase encompassed empirical data validity, operational validity, and conceptual validity. The operational validation and conceptual model validation were conducted to ensure that the model's scope and level of detail were sufficiently representative of the transport system problem and could have addressed the focusing question. This was done by stress testing the model to identify where the model falters and to properly identify the boundaries in which the model question proves true. Empirical data validity entailed comparing the simulation results to the measured data and guaranteeing a close fit. Where research or actual data was unavailable, the validation process also entailed extensive engagements with stakeholders who have experience in specific areas.

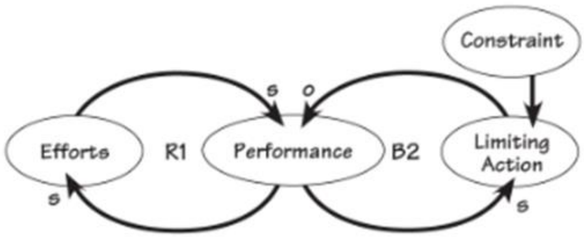
4.2. Results, Discussions and Recommendations

The identified CEIs were modelled using the CLD shown in Figure 2D and the results for each intervention are discussed below.

4.2.1. *CEI: Adoption of Non-Motorized Transport (NMT)*

The building and enhancement of infrastructure especially meant for walkers and cyclists, including bike lanes, pedestrian walkways and safe crossings. This initiative seeks to improve urban mobility, ease traffic congestion, and encourage active transportation.

This kind of intervention shown to have the '*limit to success*' archetype. Within systems thinking, the "Limits to Success" archetype explains a situation whereby initial success within a system finally results in its own limiting factors, so creating a barrier to further growth or even causing decline; basically, "too much of a good thing" can become problematic over time as shown below. Limiting factor in this case can be safety and security of passengers within the transport system.



'Limits to Success' graphic (Braun, 2002)

The stock of non-motorized transport increases in the CLD because of the "Increase in NMT usage" flow influenced by the variable "Investment in NMT". The "Decrease in NMT usage" flow is the one emptying the "Non-motorized transport" stock. Lack of investment in NMT and inadequate maintenance of current NMT influence the fluctuation in NMT use. Relating to the whole system modelled, the subsystem represented below is typical of the NMT system.

Starting at 20.3%, the non-motorized stock represents the percentage of the NMT consumption based on the national household travel survey. One can raise this by investing in NMT and creating dedicated NMT lanes. Regarding NMT, the investment is 'Lack of investment' and 'inadequate upkeep of the current infrastructure' lowers the stock.

The present transport investment in the interphase layer, based on the 2023 budget statement, is R351.1B and was adjusted to values between 2% and 5% in STELLA. The ranges for changes were selected since those represented the percentages of changes in the transport system over time according to StatsSA.

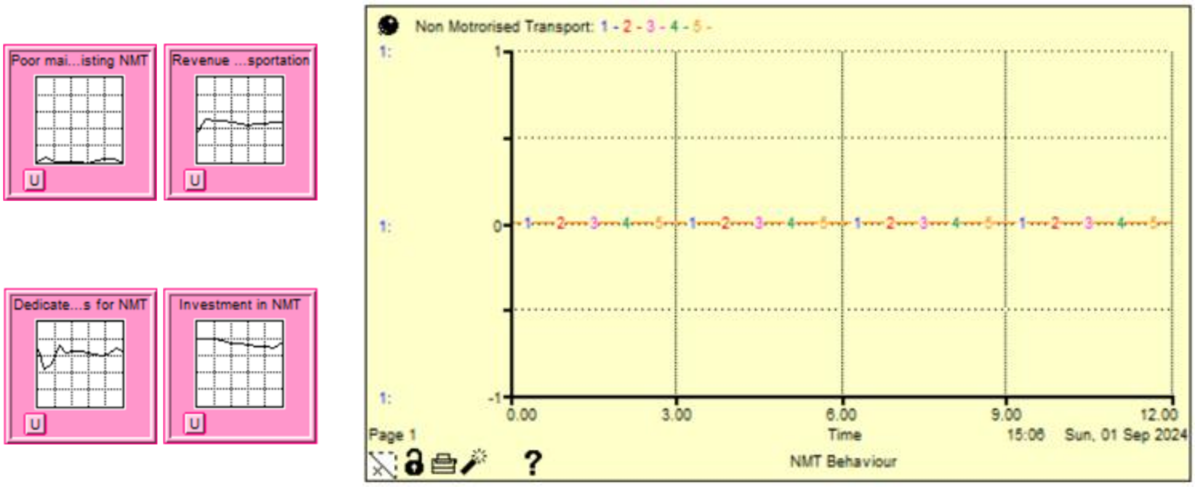


Figure 2E: NMT Behaviour results

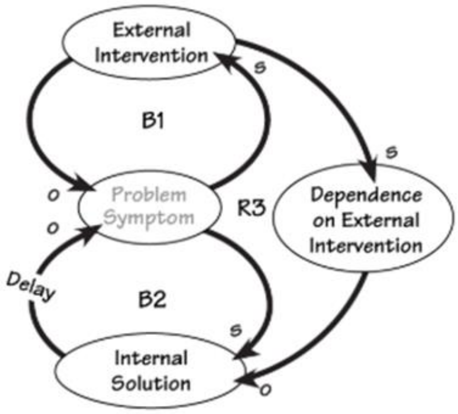
Graph 1 (in Figure 2E) exhibits the baseline in the model's interphase layer. The baseline reflects business-as-usual. Should the variable not change, this is how passengers will make use of NMT. Although the NMT architecture shows improvement in Graph 2, this indicates that system behaviour is the same as before. Dedicated NMT infrastructure makes no improvements in NMT usage. Indicating that the NMT consumption is not changed by a dedicated NMT infrastructure. Graphs 3-5 reveal that increasing the investment in NMT facilities does not help to increase the NMT consumption. The National Household Travel Survey revealed that South African passengers claimed not to use NMT as a means of transportation because of safety and security. The non-change in utilization despite the efforts could be due to the fact that NMT's usage is more related with the passengers' feeling of safety in transportation than with the infrastructure. Still, the safety of the passengers in NMT is not regarded as the scope of the model.

The results of the model provide insightful analysis of the dynamics of metropolitan transportation networks and the effectiveness of different kinds of interventions.

Notwithstanding the expenditure, the data points to no appreciable rise in the utilization of Non-Motorized Transport (NMT) infrastructure. This suggests that factors not taken into account in the present model, the choice to apply NMT could be more impacted by the perceived safety and comfort of the individual than by the sheer availability of infrastructure. The results of the National Household Travel Survey help to justify this.

4.2.2. CEI: *Transitioning freight from road to rail*

It was found that the behaviour of this sub-model matched the '*shifting burden*' archetype. The burden of transporting goods and people was shifted from the rail infrastructure to the road infrastructure. In systems thinking, the "*shifting the burden*" archetype describes when an individual tries to solve a problem by focusing on quick, symptomatic fixes instead of addressing the underlying root cause. This makes individuals more dependent on these temporary fixes, which makes the problem worse in the long run. In other words, the responsibility for solving the problem is shifted from finding the root cause to managing the symptoms, which can lead to an addiction-like cycle where the temporary fix is needed to keep things looking normal, as shown below. When the rail infrastructure in South Africa started to deteriorate, movement of goods and people were shifted to the road infrastructure. Much like the archetype described above.



"Shifting burden/Addition" graphic (Braun, 2002)

In the diagram of causal loops the flow of "increase in rail usage" increases the "rail" stock. The following factors influence the flow of "Increase in rail usage": "less accidents," related to rail accidents; "effectiveness," of rail; "safety of cargo"; "integration of the rail network"; "price of petroleum." The "Decrease in rail usage" flow, influenced by "Reliability of rail," "Information dissemination," "Poor maintenance," "Cable theft," drains the "rail" stock. The rail stock itself influences "Movement from goods to rail."

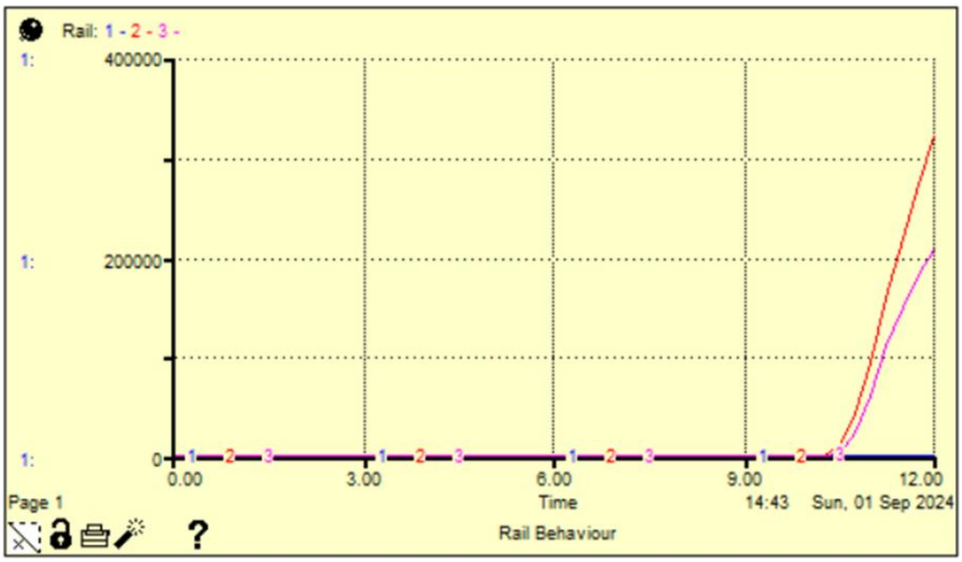


Figure 2F: Rail behaviour results

Based on the 2023 budget speech, the present transport investment is R351.1B, with 2.3% allocated to replace and upgrade SANRAL infrastructure. This was adjusted to values between 2% and 5% in STELLA. The ranges for changes were selected since those were the percentages of changes in the transportation system over time according to StatsSA.

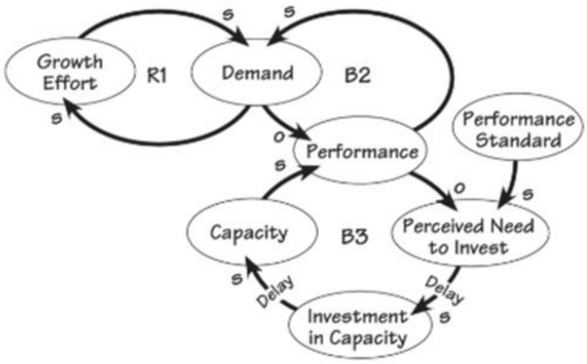
Graph 1 (in Figure 2F) in the interphase layer shows the baseline, which indicates business-as-usual on how rail use will vary over a 12-year period should nothing be done. Starting at 12,9%, the present consumption by South African passengers comes from the rail stock. Graph 2 illustrates that although there is a delay of ten years before noticing gains, enhancing the variables that raise the efficacy of rail would improve the usage of rail. Variables raising the rail's effectiveness were raised by between 2% and 5% to determine whether the CEI would be beneficial. The ranges for changes were selected since those represented the percentages of changes in the transportation system. These factors raise capacity; they also lower congestion; they improve energy efficiency; they guarantee dependability; they ensure infrastructure fit for long distances. These gains accumulated over the course of twelve years.

Graph 3 indicates that rail network improvement will follow from improvements in variables that raise the efficacy and quality infrastructure. The factors of improving the quality of train variables introduced are those of cleanliness, safety, greater dependability and accessibility and connection with other modes. Those were raised by percentages ranging from 2% to 5% with ten years before noticeable changes.

Although the circular economy will benefit generally from changes in rail, gains will only appear ten years after implementation. It indicates that raising the quality of the rail as well as the efficiency of the rail network would be most wise. The results of the investments will be delayed despite cumulative impacts; this should not deter investment and ongoing efforts. The model shows that, while with a considerable delay of around 10 years, changes in rail infrastructure can lead to an increase in train usage. This delay suggests that, even if rail infrastructure expenditures have benefits, they need long-term dedication and endurance before noticeable outcomes show.

4.2.3. CEI: Shifting passengers to public transport

The archetype of '*Growth and Underinvestment*' defined this subsystem. Basically, the organization fails to invest sufficiently to meet increasing demand, which then becomes a justification for further underinvestment, so undermining future growth as shown below. The "*Growth and Underinvestment*" archetype is a system dynamics concept that describes a situation where a sector experiences growth in demand but due to a lack of proactive investment in capacity, its performance suffers, leading to a self-perpetuating cycle of underinvestment and limited growth potential. With rapidly increasing population there has been little investment in public transport infrastructure compared to the rate at which the population is increasing.



'Growth and Underinvestment,' graphic (Braun, 2002)

This CEI was shown with modal shift, which displayed the percentage of people who choose public transit over their personal vehicles. Based on the National Household Travel Survey, the modal shift stock began at 35%, the percentage of persons using public transport. This was adjusted to values between 2% and 5% in STELLA. The ranges for changes were selected since those represented the percentages of change in the transportation system. The study shows that raising petrol prices by itself is not enough to shift people to public transport. The fact that a combination of improvements across several variables is needed to affect modal split emphasizes the need for a thorough approach to transportation planning.

4.2.4. CEIs: Adopting Electric or Hybrid Vehicles

Successful mode of this sub system was achieved using technical calculations.

Formula for Energy Saved

1. Calculating the Energy Consumption of ICE Vehicles:

EICE = MPG × Egas

where:
EICE = Energy consumed by the ICE vehicle (in MJ or kWh)
D = Distance travelled (in miles or kilometres)
MPG = Miles per gallon (fuel efficiency of the ICE vehicle)
Egas = Energy content of gasoline (in MJ/gallon or kWh/gallon). Typically, gasoline has an energy content of about 33.7 kWh/gallon or 121 MJ/gallon.

2. Calculating the Energy Consumption of EVs:

EEV = DX Eeff

where:
EEV Energy consumed by the EV (in kWh)
D = Distance travelled (in miles or kilometres)
Eeff = Energy efficiency of the EV (in kWh/mile or kWh/km). A typical value might be around 0.3 kWh/mile.

3. Calculating the Energy Saved:

Esaved = EICE - EEV

Below are the references and sources for the information used in the calculations above:
Energy Content of Gasoline:
The U.S. Department of Energy provides information on the energy content of fuels. According to their data, the energy content of gasoline is approximately 33.7 kWh per gallon (121 MJ/gallon). Source: *U.S. Department of Energy - Energy Content of Fuels*
Average Fuel Efficiency of ICE Vehicles:
The average fuel efficiency of internal combustion engine (ICE) vehicles can vary widely, but a typical value used for general calculations is around 25 miles per gallon. Source: *U.S. Environmental Protection Agency - Fuel Economy*
Energy Efficiency of Electric Vehicles:
The energy efficiency of electric vehicles is generally measured in kWh per mile or kWh per kilometer. A typical value for modern EVs is about 0.3 kWh per mile. Source: *U.S. Department of Energy - Fuel Economy of Electric Vehicles*

Assumptions: Data unavailability for South African sources led to USA sources being used for several numbers in the computations. These sources offer the fundamental information needed to do the energy savings analysis between ICE cars and EVs.

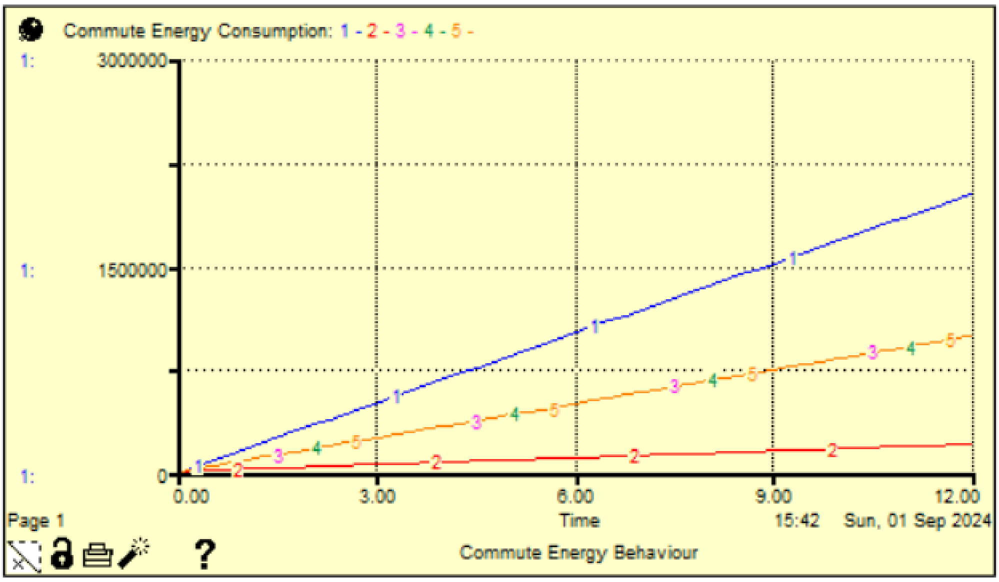


Figure 2G: Commute energy behaviour results

Turning to electric vehicles (EVs) drastically lowers travel energy consumption (Figure 2G). The model indicates that ICE vehicles consume approximately ten times the energy consumed by EVs. The results highlight the possibilities of EVs in lowering the energy consumption related with commuting. The model underlines the significant environmental benefits of switching to electric transportation.

CEIs: Adopting flexible working arrangements

Working from home and flexible working conditions have a positive '*Shifting of burden*' archetype, since lack of commute for work, shifts the behaviour and travel patterns and places less strain on the transport system, since workers do not have to travel to work and can work from home. So, commuting is not considered.

Technical calculations were also used in order to successfully mode this sub system.

Technical calculations:

1. Energy Consumption for Commute (E_commute):

Ecommute DX FXCXT

Where:
D = Round-trip distance of the commute (in km or miles).
F = Fuel efficiency of the vehicle (in liters/km or gallons/mile).
C = Energy content of the fuel (in MJ/liter or MJ/gallon).
T = Number of commuting days per year.

2. Energy Savings from Working from Home (E_savings):

Esavings = Ecommute × N

Where:
N = Number of days worked from home
Below are the references and sources for the information used in the calculations above:
Energy Content of Fuels: The Engineering Toolbox
Fuel Efficiency and Vehicle Emissions: [U.S. Department of Energy - Fuel Economy]
Remote Work and Environmental Impact: Kitou, E., & Horvath, A. (2008). Energy-related emissions from telework. Environmental Science & Technology, 42(16), 5734-5740.

USA sources were used for some values in the calculations because of data unavailability for South African sources. Applying these formulas and references, customizes the calculations to specific scenarios, adjusting the variables to reflect different commuting distances, fuel efficiencies, and working-from-home schedules

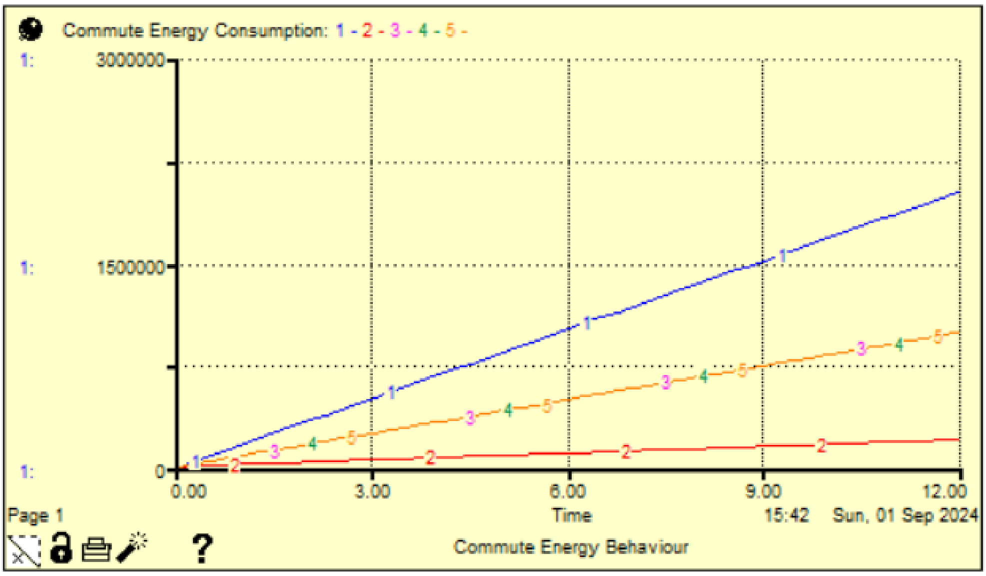


Figure 2H: Commute energy consumption

Graph 1 (in Figure 2H) is the baseline and shows how the commute energy increases in a linear way over the 12-year period. This is business-as-usual if no changes are done to the system. In Graph 2-3, after a decrease of the travel distance, number of commuting days and an increase of fuel efficiency, a decrease in the commute energy is noted. This suggests that flexible working conditions can significantly reduce commute energy. The results highlight that more flexible working conditions lower the energy consumption related to commuting. The model underlines the significant environmental benefits of having flexible working conditions.

5. Conclusion

Appendix 2 shows the process followed in modelling identified CEIs in the South African transport sector. The model results show that interventions like shifting freight from road to rail; shifting passengers to public transport; hybrid or electric vehicles, and flexible working arrangements make the most impact in terms of improving efficiency of mobility in the country including energy consumption within the mobility sector. Investing in rail infrastructure and operational efficiency will lead to increased rail usage, but improvements will only be realised in the medium- to long-term, with a 10-year delay before tangible benefits emerge. This underscores the need for long-term commitment and strategic planning to enhance rail transport's effectiveness and sustainability. Interventions like dedicated bicycle and pedestrian facilities will make an impact only once implemented in a sustainable transport system that address commuter concerns such as safety and reliability. The analysis also indicates that changing a single variable, such as increasing petrol prices, is insufficient to encourage individuals to use public transportation. The necessity of a comprehensive approach to transport planning is underscored by the fact that a combination of enhancements across multiple variables is required to influence modal split.

The analysis of various interventions in urban mobility highlights the complexities of transport systems and their dynamic responses to investments. The enhancement of non-motorized transport (NMT) infrastructure, such as bike lanes and pedestrian walkways, was initially expected to improve urban mobility and promote active transportation. However, the system's behaviour aligned with the '*Limits to Success*' archetype (Braun, 2002), demonstrating that despite infrastructure improvements, NMT usage remained largely unchanged. The findings suggest that perceived safety and security concerns, rather than infrastructure availability alone, play a more significant role in influencing NMT adoption.

Similarly, efforts to shift freight and passenger transport from road to rail exhibited characteristics of the '*Shifting the Burden*' archetype (Braun, 2002). The results indicated that while rail improvements could yield significant benefits, these gains would only materialize after approximately ten years. This underscores the need for long-term investment and strategic planning rather than relying on short-term fixes to address transportation challenges.

The study also examined modal shifts towards public transport, revealing patterns consistent with the '*Growth and Underinvestment*' archetype (Braun, 2002). Without sufficient investment in public transit systems, demand remains unmet, perpetuating a cycle of underfunding and underperformance. Addressing this issue requires proactive investment to enhance capacity, reliability, and accessibility.

Transitioning to electric vehicles (EVs) and promoting flexible work arrangements showed significant potential for reducing transport-related energy consumption. The calculations indicated that EVs consume nearly ten times less energy than internal combustion engine (ICE) vehicles, making them a viable strategy for improving energy efficiency in urban mobility. Additionally, flexible working arrangements reduced the strain on transport networks, aligning with the '*Shifting the Burden*' archetype by redistributing demand rather than expanding infrastructure.

In conclusion, the SD model demonstrates that while infrastructure investments are crucial, their effectiveness is influenced by broader system dynamics, including behavioural factors, long-term commitment, and complementary policies. Sustainable transport planning requires a multifaceted approach that integrates infrastructure development, safety improvements, behavioural incentives, and policy reforms to create a truly transformative urban mobility system.

Appendix 3
MEIA modelling

1. Introduction

This section investigates the *Transport and Storage* (TaS) sector's contribution to South Africa's economy, employment and greenhouse gas (GHG) emissions through the completion of a Macro Economic Impact Assessment (MEIA). The TaS sector is selected as focal point, since it best represents economic outcomes associated with transport and logistics.

The purpose of the analysis is to ***quantify the TaS sector's socio-economic and environmental contributions to the South African economy***. The analysis is completed using an analytical model developed by Conningarth Economists that allows the user to quantify the macro-economic and socio-economic impacts of projects within South Africa. The model utilizes an input-output table known as the Social Accounting Matrix (SAM), which is in line with the National Accounts published by the South African Reserve Bank and captures the flow of financial and economic activity within different sectors.

2. Standard socio-economic structure of Transport & Storage sector

This section lists the standard input data for the TaS sector, as suggested by the MEIA model, which provides an indication of its socio-economic structure. Based on the employment split for the TaS sector shown in Figure 3A, almost a fifth of the sector's employees (i.e., 19%) are unskilled, while more than a quarter (i.e., 29%) are specialized.

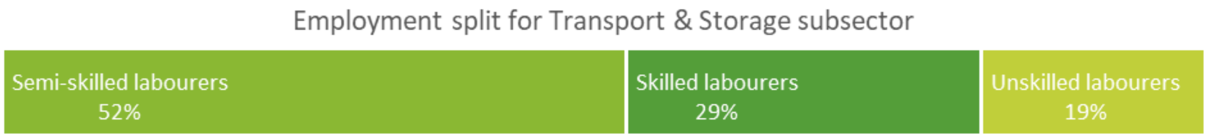


Figure 3A. Standard employment split for the TaS sector

Approximately 86% of the TaS sector's turnover is derived from domestic applications, with the remaining percentage attributed to exports. The TaS sector's total turnover can also be split according to economic entities, as shown in Figure 3B.

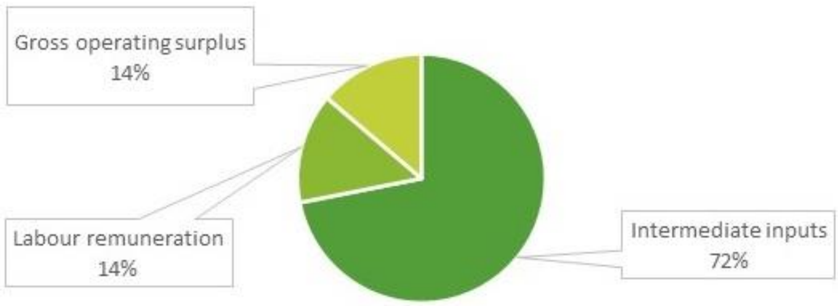


Figure 3B. Split of turnover between various economic entities

As shown in Figure 3B, about 72% and 14% of the TaS sector's total turnover is spent on intermediate inputs (i.e., operating expenditure) and salaries and wages (labour remuneration), respectively. The remaining portion (14%) consists of the sector's net profit, interest on loans and depreciation. Labour remuneration is further broken down between skilled (31%), semi-skilled (58%) and unskilled labour (11%).

The percentage contributions of the top 20 intermediate inputs to the TaS sector are given in Figure 3C. As expected, *petroleum* is the sector's most significant operating expense and accounts for almost 29% of the total, followed by the *Manufacturing of transport equipment* (MoTE) with 11.4%.

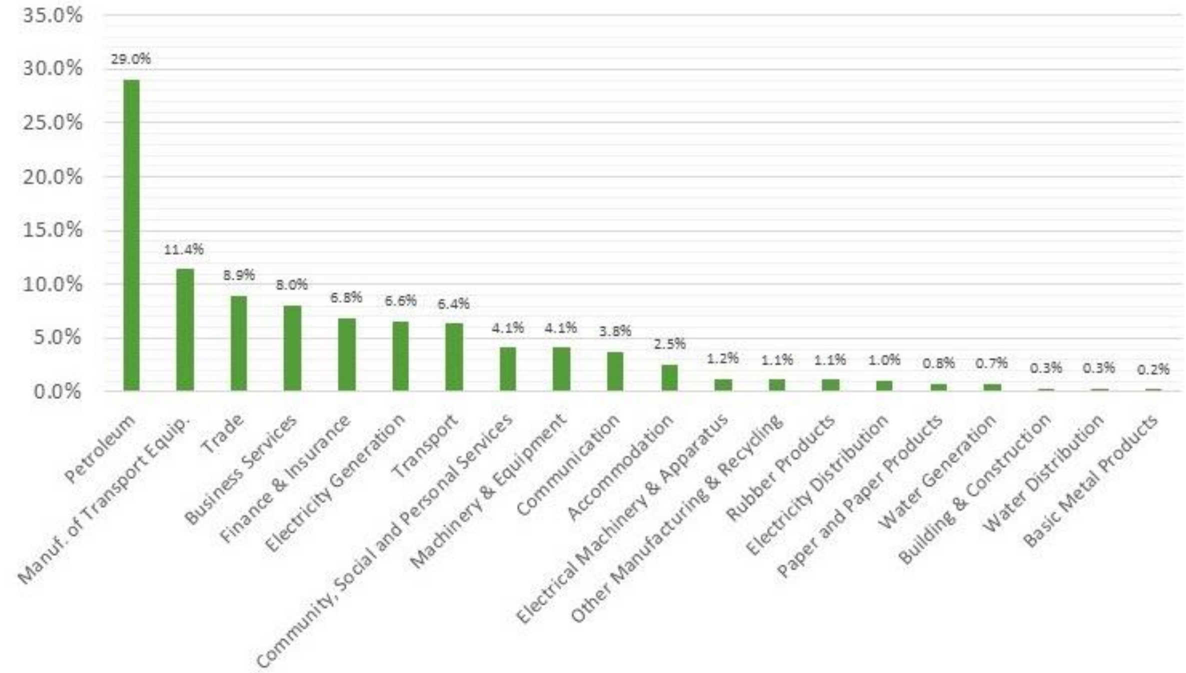


Figure 3C. Top 20 intermediate inputs of the TaS sector

3. Transport and Storage sector turnover for 2023

The *gross value added* by the *Transport, Storage and Communication* sector was R494,962 million in 2023 (current price), as stated in the South African Reserve Bank (2024, pp. S-116)'s Quarterly Bulletin for June 2024. Based on the data inherent to the MEIA model, the *Transport and Storage* components account for 63% of this sector, such that their combined gross value added, also referred to as their Gross Domestic Product (GDP), was R313,985 million in 2023. Note that the required data is not available to identify the GDP contribution of the Transport component only.

Assuming a Production-GDP multiplier of 3.56, the turnover of the TaS sector in 2023 is calculated and assumed to be R1,117,056 million. This value refers to the revenue generated by all the transport and storage-related services delivered in the year under consideration. In essence, the Production-GDP multiplier represents the relationship between the sector's turnover and GDP contribution, and was calculated using the equation below (assuming an operating expenditure contribution of 71.9%):

$$GDP - Production\ Multiplier = \frac{1}{100\% - Operating\ Expenditure's\ \%\ Contribution}$$

4. Macro-economic impact of the sector in 2023

A sector's impact on the economy refers to its contribution to overall economic activity in terms of a number of key macroeconomic parameters. This section discusses the national macro-economic impact of the TaS sector in 2023 when calculated using the MEIA model and assuming a total turnover of R1,117,056 million. Figure 3D provides a summary of the main results. It shows the impact of the sector on employment and on key economic indicators.

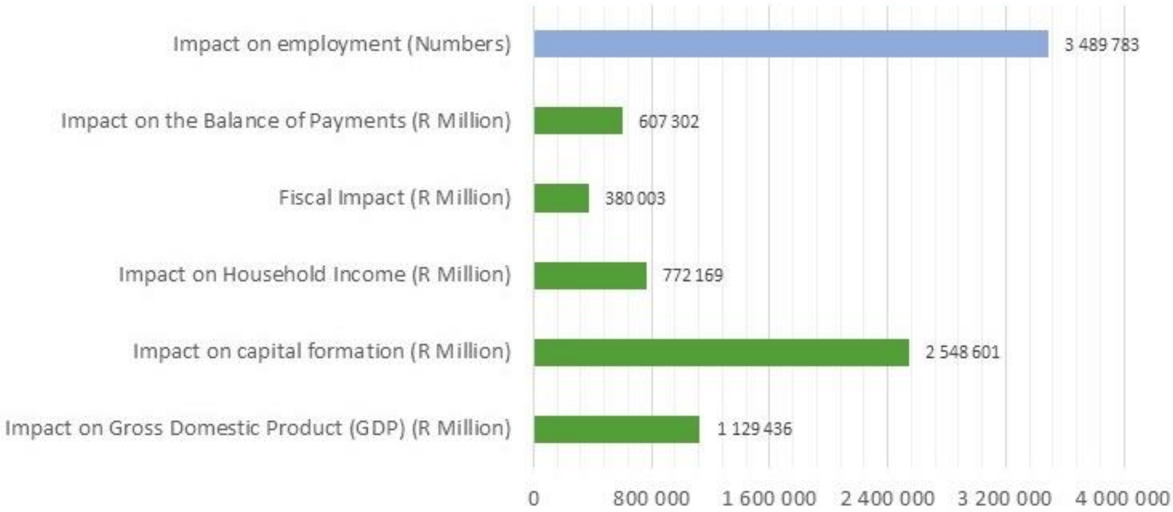


Figure 3D. Macro-economic impact of the TaS sector on the economy in 2023

4.1 Impact on GDP

Figure 3E shows the economy-wide sectoral impact and their linkage effect (i.e., direct, indirect and induced impact) on GDP as a result of the sector.

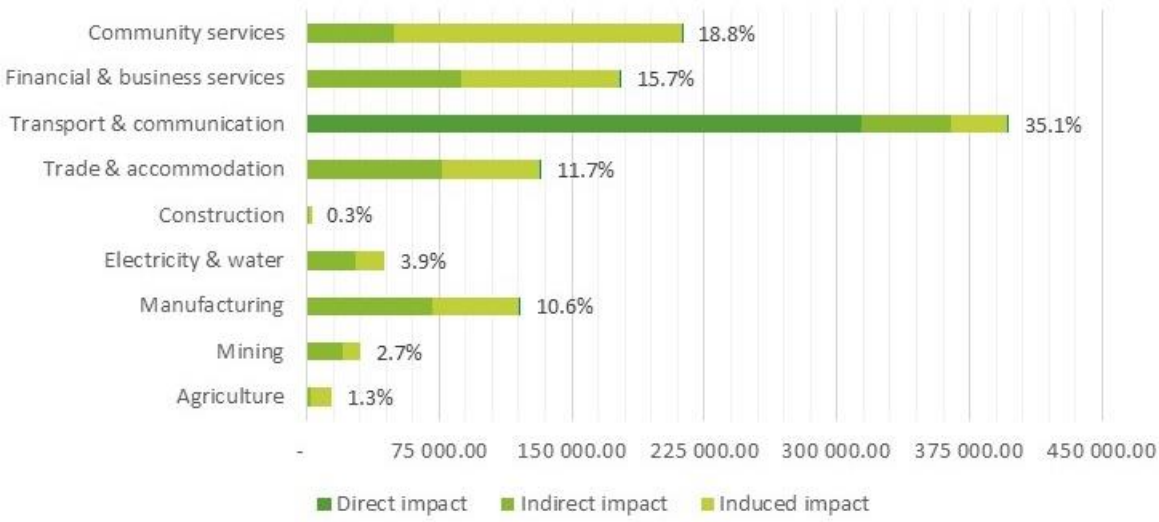


Figure 3E. Sectoral impact of the TaS sector on GDP in 2023

Direct impact refers to the impact on GDP resulting from businesses directly involved in the TaS sector, while *indirect impact* results from businesses and industries providing support. Induced impact occurs as a result of the use of employee remuneration to purchase goods and services.

It is evident from Figure 3E that services rendered in the TaS sector (direct impact) leads to economic activity within the rest of the economy (indirect and induced impact). As expected, the contribution of the TaS sector to GDP is the largest at 35.1%, followed by community services at 18.8%.

4.2 Impact on employment

The TaS sector supports employment for almost 3.5 million people. Figure 3F shows the breakdown of the number of employment opportunities and the linkage effect per sector.

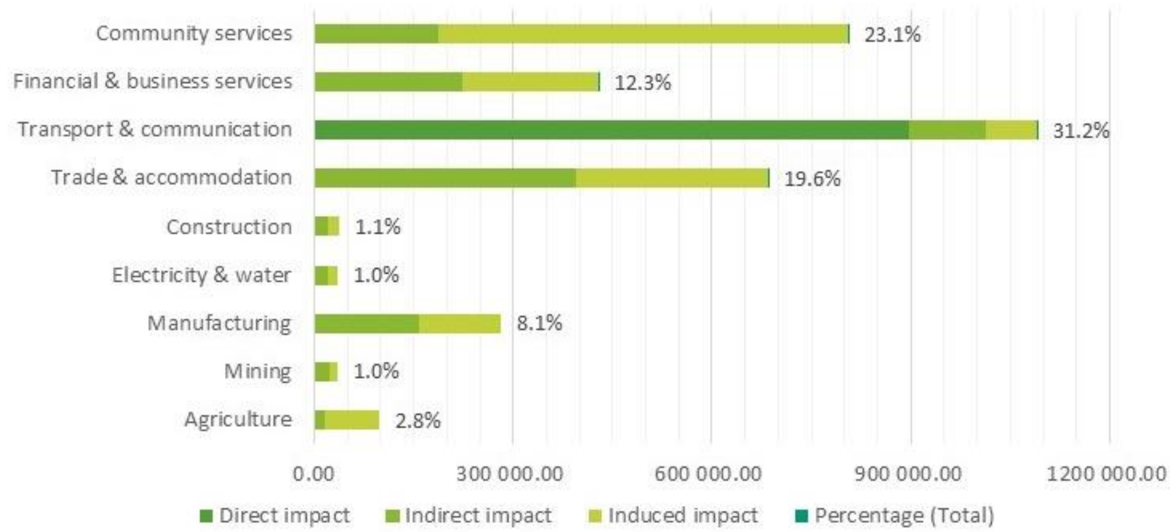


Figure 3F. Sectoral employment impact of the TaS sector in 2023

As seen in Figure 3F, 19.6% and 12.3% of the employment opportunities fall within the Trade and accommodation sector and the Financial business services sector, respectively, as a result of both indirect and induced impacts from the TaS sector. Furthermore, only 26% of the overall employment opportunities occur due to the TaS sector's direct impact, as seen in Figure 3G.

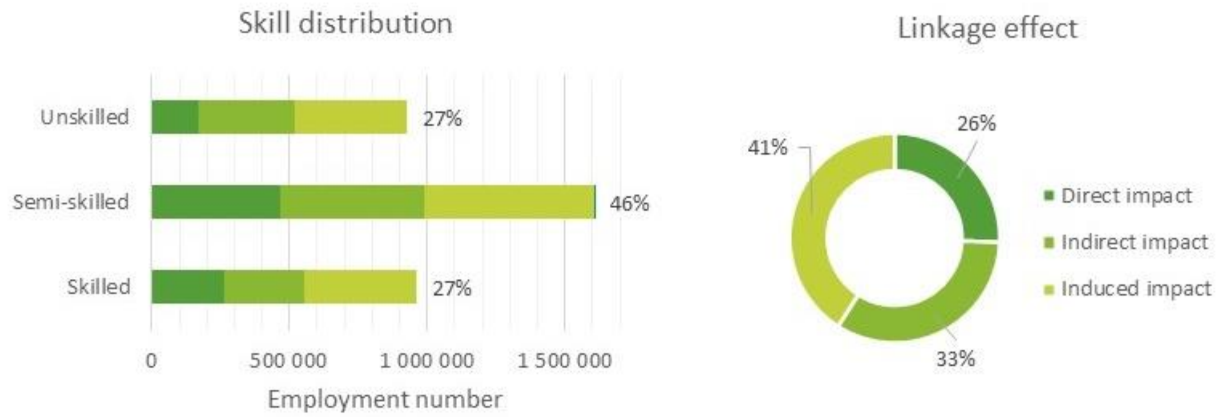


Figure 3G. Employment and Linkage effect of the TaS sector for 2023

4.3 Impact on Balance of Payments

A country's balance of payments summarizes its economic activity with the rest of the world. The TaS sector contributed R607,302 million as a result of import substitutions and exports worth R958,675 million and R158,381 million, respectively, along with imports worth R509,754 million.

4.4 Impact on Household Income and State Revenue

The TaS sector increased the country's household income with R772,169 million in 2023, of which 17% went to low-income households, 34% to medium-income households and 49% to high-income households. Furthermore, the sector contributed R380,003 million to the state's revenue (fiscus), all of which went to the National Government.

4.5 Impact on social indicators

The contribution of the TaS sector to state revenue allows for government expenditure on various social services. As shown in Figure 3H, it is expected that the contribution of the TaS sector could, for example, allow the government to fund just over 84,000 educators, 17,000 hospital beds, 2,900 doctors, in our education and healthcare sectors, amongst other things.

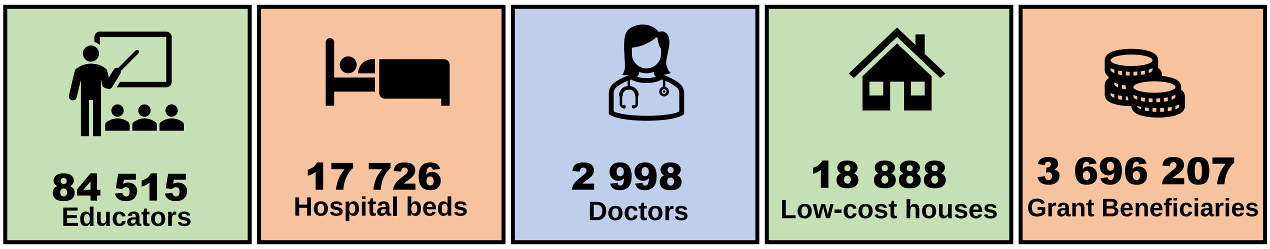


Figure 3H. Social contribution of government revenue derived from the TaS sector

4.6 Impact on emissions

In 2023, the operations of the TaS sector resulted in the emission of about 102 Mt CO_2e GHG, of which 56% (i.e., 56.8 Mt CO_2e) were due to its direct impact. Figure 3I provides a breakdown of the total emissions.

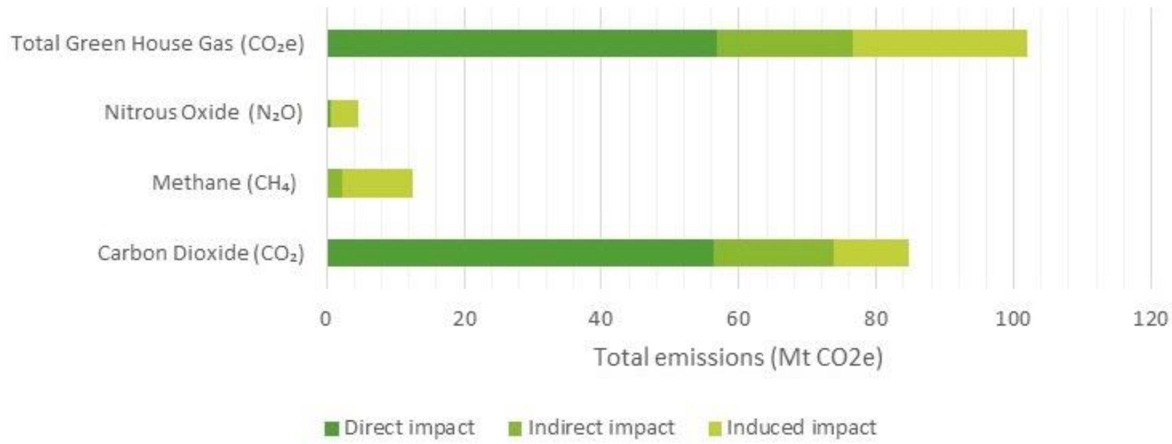


Figure 3I. Impact of the TaS sector on greenhouse gas emissions in 2023

6. **Conclusion**

The MEIA outlined here highlights the socio-economic contributions of South Africa's TaS sector, under the assumption that the sector's turnover equalled R1.117 billion in 2023. The sector was selected since it would most be affected by interventions aimed at influencing transport and logistics. Most noteworthy is the TaS sector's total GDP contribution (i.e., including direct, indirect and induced impact) of R1.129 billion, and its employment generation for about 3.5 million people of which 73% thereof are semi- or un-skilled. The sector further contributed about R380,000 million to state revenue, that equates to government funding for e.g., just over 84,000 educators, 17,000 hospital beds, 2,900 doctors, 18,800 low-cost houses, and 3,696,000 grant beneficiaries. From an environmental perspective, if was found that the sector's service delivery resulted in the emission of about 102 Mt CO_2e GHG emission in 2023.