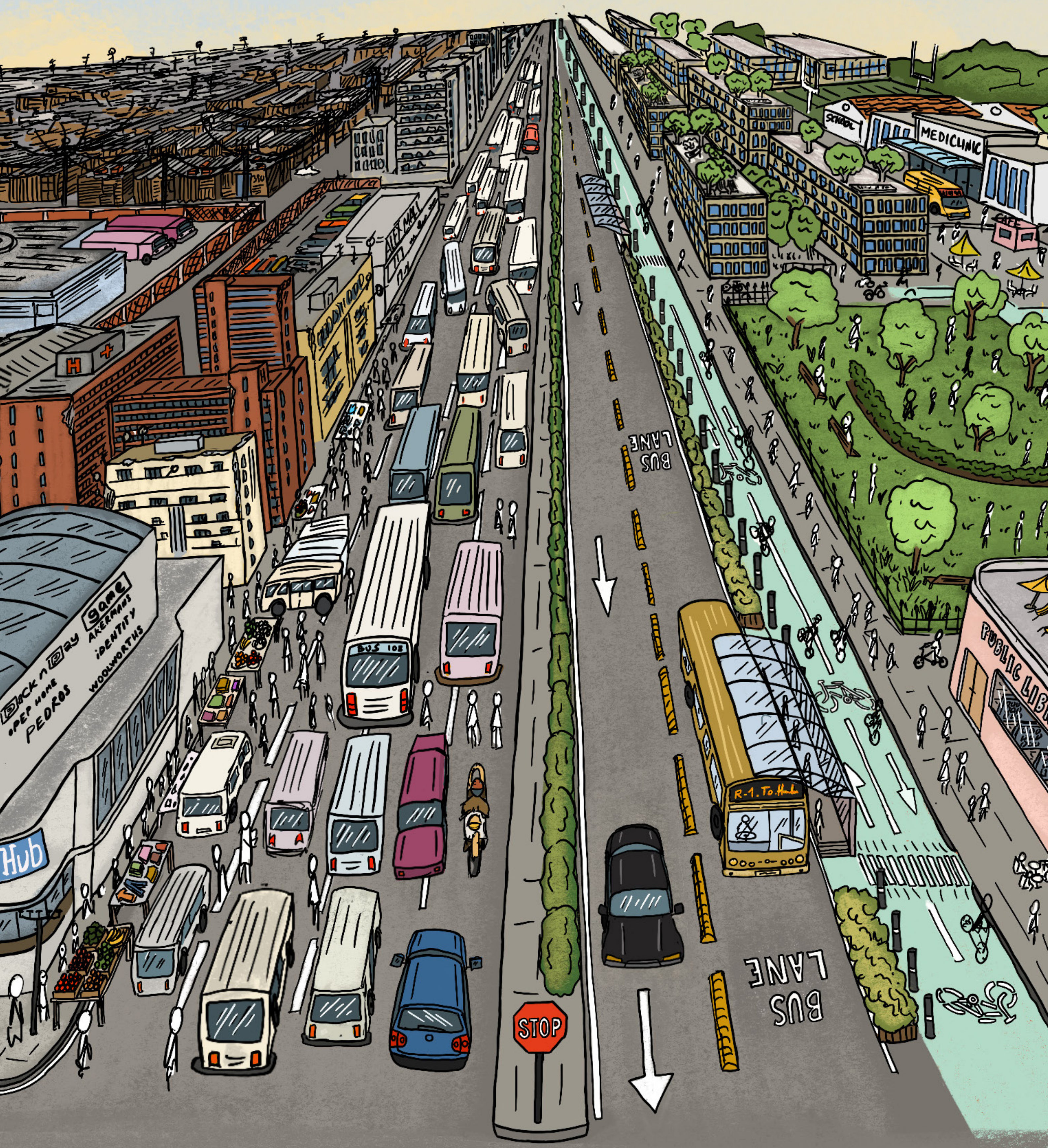
LEARNING BY DOING TRANSPORT MODELLING

Development of transport storylines for the transition from current modus operandi to a good life

TANYA LANE-VISSER & MARIANNE VANDERSCHUREN



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The Learning by Doing Project

TRANSPORT MODELLING

Development of transport storylines for the transition from current modus operandi to a good life

Tanya Lane-Visser & Marianne Vanderschuren

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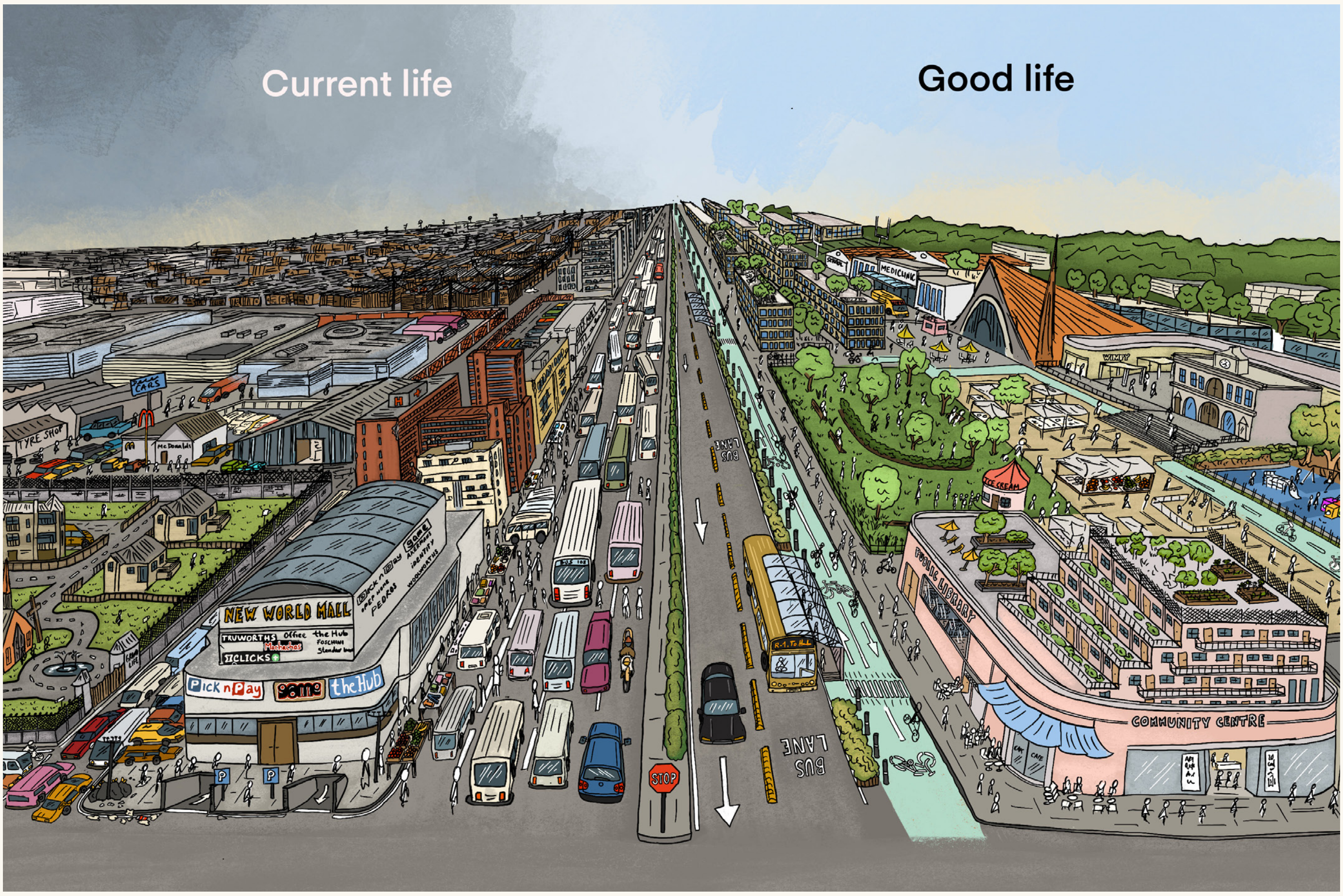
ABSTRACT

The Learning by Doing project investigates mitigation strategies in many contexts, from various perspectives and in a multitude of countries. The purpose of this study is to explore transition pathways between the present and 2050 for the South African transport sector. Specific attention is paid to the contribution of the sector towards reaching the country's greenhouse gas emissions targets, while a 'good life' is created for its citizens.
A scenario planning model was custom built for this analysis and validated against existing models. Part of the work also included designing and executing a survey with respondents representing the South African population, to collect inputs for the model.
The scenario modelling results indicate that no single 'silver bullet' type of solution exists and that combinations of land-use, as well as transport energy management measures (representing avoid, shift, and improve measures) will be required to reduce emissions sufficiently.
Two main conclusions are drawn. The first is that striving for shorter trips as opposed to fewer trips yields the same quantum of emissions savings, but it provides a lot more scope for achieving additional objectives simultaneously. The second conclusion is that it is possible to decarbonise transport to the required extent without giving up on the ideals of the 'good life' (as set out in the Learning by Doing project). There is synergy between these activities that, when harvested appropriately, can lead to the satisfaction of multiple objectives at the same time.



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1 Introduction

The Learning by Doing (LbD) project, an IKI funded project involving teams from Mexico, The Dominican Republic, Lebanon, and South Africa, seeks to expand mitigation-adaptation synergies, nature based and nature inspired solutions, and foster innovation and build coalitions around them in different regional contexts. These contexts are explored by outlining visions and transitions for 2°-1.5°C futures that can materialise by 2050, and illustrating the socio-economic, cultural, and natural features of such societies. The visions are equipped with country and region-specific portfolios of projects and activities, and outline skills, practices, and knowledge to support and advance them.

The South African Learning by Doing team, in collaboration with a select group of stakeholders, have developed an overall narrative of a good life, and just transitions towards it in South Africa. The narrative can be viewed in Attachment A. Transportation is an integral part of the economy and is the third largest greenhouse gas (GHG) emitting sector in the country, contributing more than 10% of the country's gross emissions. This equated to approximately 55 million tonnes of carbon dioxide (CO_2) in 2020 (Venter, 2023). Reducing emissions from transport will go a long way to support achieving the National Determined Contribution (NDC) targets set by the government. The current targets are to reduce GHG emissions compared to 2015 levels by 42% by 2025 and by between 91% and 93% by 2050 (UNFCCC, 2020; Climate Chance, 2018). South Africa's Low Emission Development Strategy 2050 (UNFCCC, 2020) indicates the goal of achieving net zero emissions by 2050.

Transportation is inextricably linked to quality of life, affecting people's mobility and access to opportunities, goods and services, the environment they live in, daily commuting times and conditions, personal safety, security, disposable income levels, and to some extent the affordability of food and goods. While transport systems often reinforce suboptimal urban shapes and disparities, it can also be used as an instigator for positive change in urban structure and liveability.

In this transport modelling study, the South African narrative of a good life is combined with transport scenario planning to explore transport development pathways towards a better future. The humanitarian and societal need and desire for positive and just change lays the foundation for the modelling work, differentiating this study from other transport emissions projections. In this research, a fundamental change to the urban fabric is envisioned and its impacts quantified. Both quantitative and qualitative aspects are considered in the development of four scenarios aimed at leveraging changes to the transportation sector to support the country's ideals of reaching net zero emissions by 2050, whilst improving quality of life for its citizens at the same time.

The research methodology followed is described in section 2 of this report, after which the good life survey is discussed in section 3. Section 4 elaborates on the development and modelling of the four scenarios, the results of which are presented in section 5. The policy implications of this research are discussed in section 6 and the report is concluded in section 8.

2 Methodology

Information gathering and establishment of the scope of work formed the initial part of the study. Both quantitative and qualitative factors were explored and debated in several virtual workshop sessions with members of LbD South Africa. This led to the development of four scenarios to be modelled. In the first scenario, the 'do nothing' scenario, there are no fundamental changes to the transport system, nor to the external drivers of transport demand. To calculate this scenario, transport demand in 2019 was determined.

2019 was selected as base year, due to good data availability, combined with the fact that it resembles normal operating conditions prior to the Covid-19 pandemic. The travel and transport restrictions associated with the pandemic were

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temporary and have been excluded from further analysis. Expected projections of external driving forces behind transport volumes were applied to the base year volumes to establish the baseline Business as Usual (**BAU**) transport growth from 2019 to 2050.

The connection between the good life narrative and the transportation sector lies in the desire to live differently in the good life to what people are accustomed to today. In passenger transport terms, this relates to the travel times and modes that citizens would prefer to use for their daily travel needs. Changes to the structure of the economy in terms of import versus local production volumes, combined with changes to the locations of certain economic activities lead to changes in the freight transport network in support of the good life. In order to determine what access priorities and changes to economic activities apply to the vision of the good life, an online survey was developed that was sent out to the public beyond the project team, asking pertinent questions to inform the modelling. The survey, thus, represents a wider view of what the good life might entail and how that differs from the status quo, and reduces scope for subjective influence from the project team. The survey outputs were converted into changes to the spatial structure of settlements and economic activities in the country that correspond to the ideals of the narrative. Scenario 2 (**Good Life Ideals**) is the scenario where these spatial changes are modelled.

The project has two potentially conflicting objectives: to determine pathways for South Africa to reach its NDC goals without impeding the ability to live the life described in the good life narrative. Although the spatial planning interventions in Scenario 2 made headway in terms of reducing emissions from the transport sector (10%), this is not enough to reach the unofficial government target of reducing transport sector emissions by nearly 50% to a total of 25 Mt CO_2e by 2050 (confirmed by expert opinion). Additional changes to the transport system will be required. Scenario 3 (**Good Life Ideals and NDC Target Emissions**) represents the transport sector changes required to meet both the good life ideals of Scenario 2 and the transport sector's emissions reduction target.

As shown in Figure 1, there is still a strong preference for private cars amongst survey respondents. This is in contrast with the good life narrative. Aspirations of current public transport users to own a private car remain high and vehicle ownership per capita is expected to increase over time (Mtembu, 2020). A move towards formal public transport away from minibus taxis (MBTs) and cycling is noted, with walking featuring strongly. Some 21% of survey respondents indicated that non-motorised transport (NMT) should make up more than 70% of all trips in a good life environment. A shift towards greater use of NMT will support the ideals for improved wellbeing in the good life, as these modes involve physical activity, yielding the associated health benefits of a more active lifestyle. Additionally, NMT is the least expensive mode of travel, which supports the lower dependence on employment to be able to make a living, as described in the narrative. The spatial changes brought about in Scenario 2 also affords greater scope for NMT, as travel distances between housing and services is lower. Scenario 3 assumes that all trips that can be undertaken by NMT or public transport (PT) within the travel time budgets indicated in the survey are shifted.

The effect of these changes is noteworthy – an additional saving of 32% of emissions on top of the spatial planning savings is achieved. This brings emissions near the 25 MtCO_2e target, but the scenario can only lower emissions to a minimum of 26.5 MtCO_2e by 2052, after which the growth in population en economic activity is expected to increase total transport demand to such an extent that total emissions start to rise beyond this level. The NDC has a timeframe attached to its target – 2050. Further changes to the transport sector are, thus, needed to lower emissions below the target value and to do so by 2050. These changes constitute Scenario 4 (**Good Life Ideals and NDC Target Emissions by 2050**).

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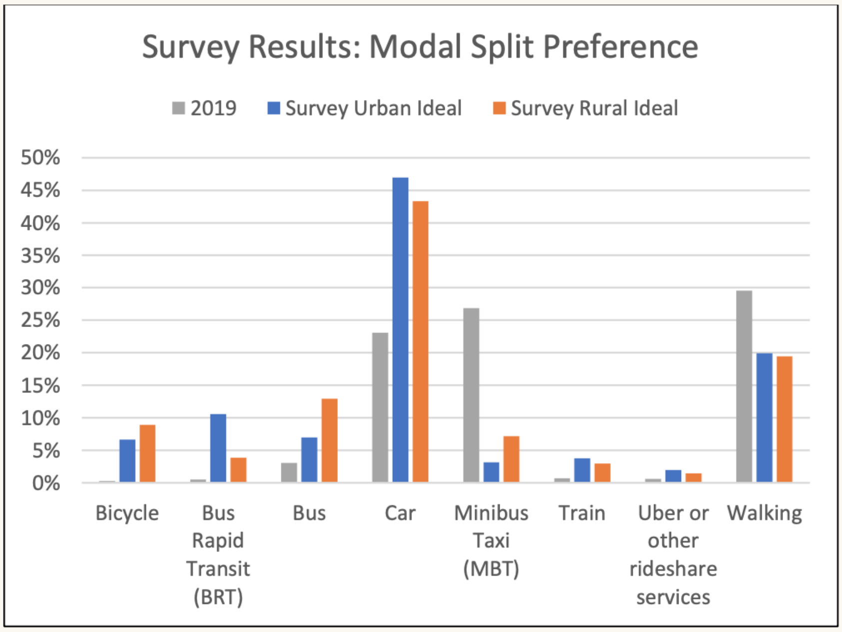

Figure 1 The modal split preference as indicated in the survey.

The uptake of electric vehicles (EVs) as an alternative to internal combustion engines (ICE) has increased tremendously in the last five years (Figure 2) and is expected to more than double by 2030 (IEA, 2023). Scenario 4 explores the impact that the introduction of EVs has on total emissions over time and its contribution to reaching the NDC emissions total volume and time goals.

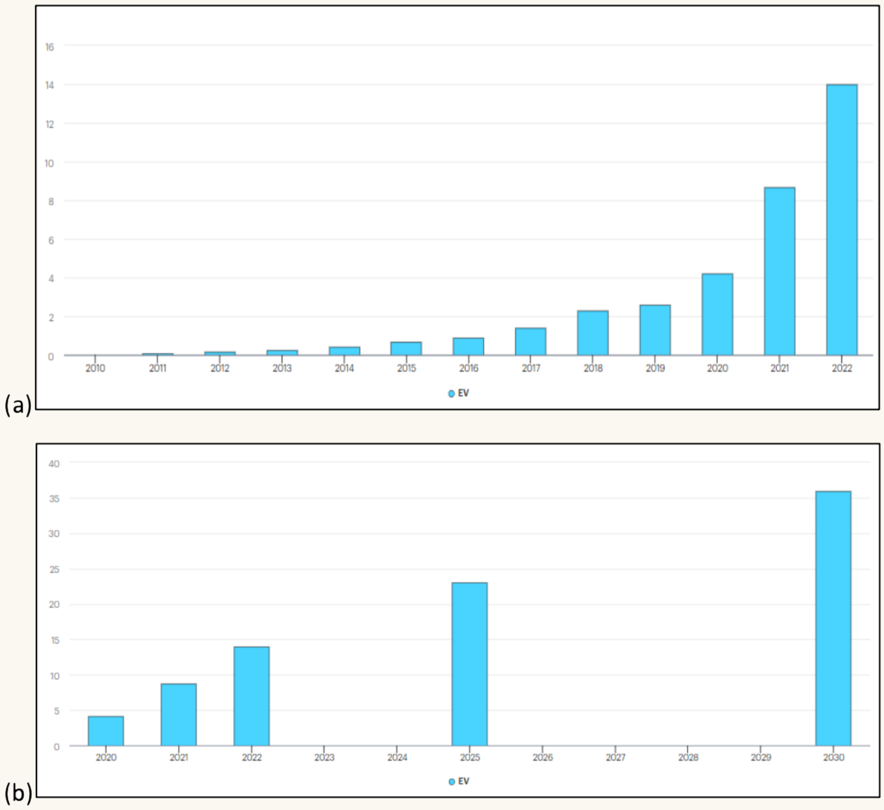

Figure 2 Global EV car sales share (a) historic, (b) projected (IEA, 2023).

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Figure 3 summarises the research methodology used in this project as a flow diagram. The progression between scenarios, as well as the checks to determine whether the scenario objectives were met are indicated by the blue processes and decisions. The purple blocks indicate where the survey outputs are used as inputs to the modelling. Literature based data are represented in orange and the three energy demand mitigation interventions (one avoidance measure, one shifting measure, and one improvement measure) that differentiate the scenarios are indicated in the white blocks. The result of all these processes and scenarios lead to the various transport transition pathways (indicated in green) which form the final output of the modelling.

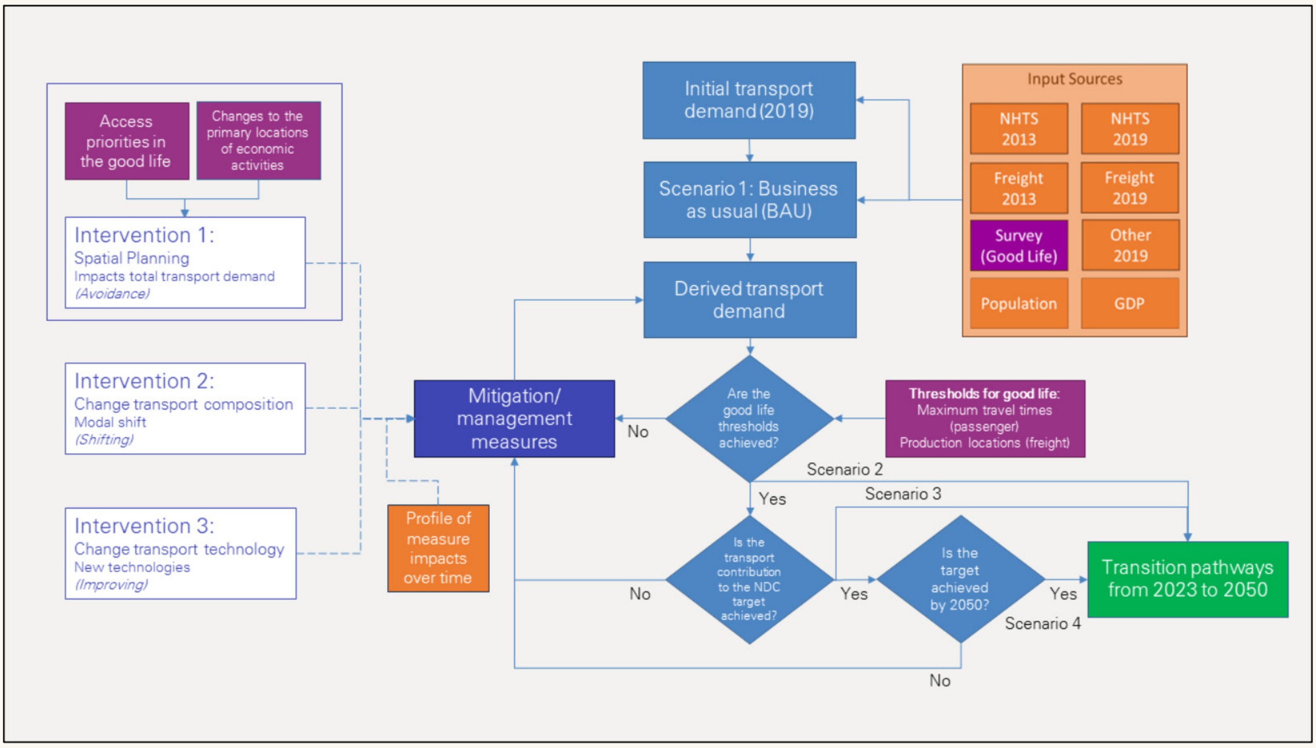

Figure 3 Graphic depiction of the research methodology

3 The Good Life Survey

The survey forms an instrumental part of this project, providing parameters and insights not available at the start of the work. Respondents were given a brief definition of what is meant by the good life, without being to suggestive or prescriptive. Francisco de la Mora, a graphic artist, and member of the international LbD project team, created an image contrasting the urban life today with what the narrative and workshops envision for the good life, in collaboration with the authors. This image (shown on the cover of the report) is presented at the start of the survey to help orient respondents. Ethics clearance to conduct the survey was obtained from the University of Cape Town Ethics Committee prior to deployment.

The survey was created on Google Forms and consists of 11 questions:

- Question 1: Consent,
- Question 2: Urban travel time and mode preferences to access various services,
- Question 3: Rural travel time and mode preferences to access various services,
- Question 4: Maximum housing density and height restriction preferences,

- Question 5: Sourcing of food (local, regional, national, and international) preferences,
- Question 6: Sourcing of goods (local, regional, national, and international) preferences,
- Question 7: Expectation of how food and goods consumption volumes will change over time,
- Question 8: Share of trips to be undertaken by NMT,
- Question 9: Average household spend on transportation in relation to household income,
- Question 10: Percentage reduction in transport related air pollution to aim for,
- Question 11: Demographics of the respondent.

The full survey is included in Attachment B. The questionnaire was sent out from 17 to 31 July to three different respondent pools: (1) all the members of the South African Institution for Civil Engineering (SAICE), (2) staff of the Western Cape Government, and (3) colleagues, the LbD scrum participants and the general public (links to the surveys were posted on LinkedIn and other social media). A total of 201 responses were captured during this period. Some 31% of respondents were female and 69% male. The majority of respondents (54%) are between 36 and 64 years old, with 34% being between 18 and 34 years old, and 11% 65 years or older. It is recognised that this is not an entirely representative sample of South African society, but it does cast the net beyond climate scientists and transport engineers only.

The survey results that directly informed the modelling exercise are described throughout this document (Questions 2, 3, 5, 6, 7, and 8). There were, however, a couple of questions where the distribution of answers was either inconclusive, or not directly relevant to the modelling in the end. For the sake of completeness, these results are presented in the rest of this section.

3.1 Survey results

Although 77% of respondents agreed that there should be an urban height restriction (with 80% indicating between 2 and 4 stories for residential buildings and 82% saying 10 stories or less for commercial buildings), they were divided on the matter of the preferred housing density (Figure 4). Only 17% would find apartment buildings with more than 4 stories acceptable in a good life environment, whilst a significant 32% felt that nothing smaller than a 500 m² would suffice, indicating a desire for space and land. The survey responses give no indication that only one form of housing is preferred over another, and it is expected that a mixture of different types of housing will be acceptable in the future.

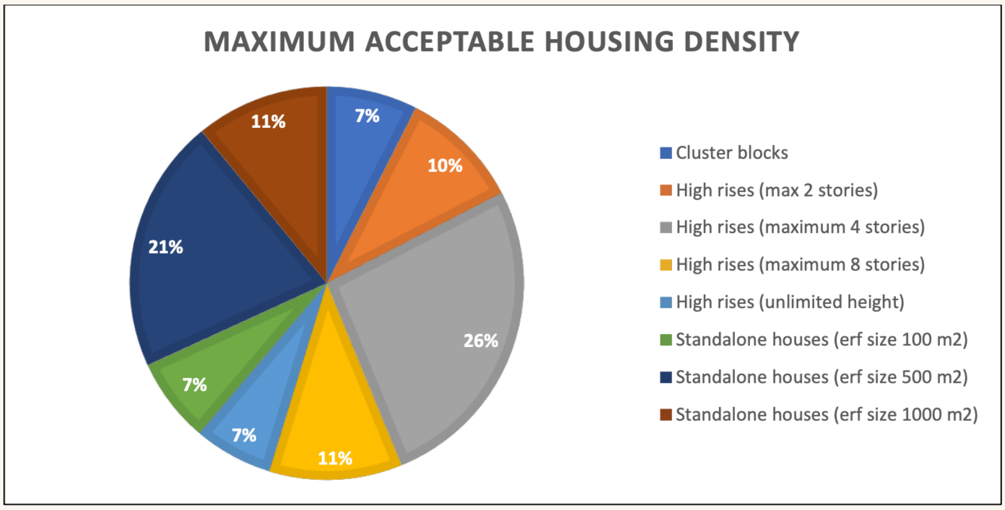

Figure 4 Survey results: Question 4 – Maximum housing density

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On the question of household expenditure on transport, 76% of respondents feel that at least half of households should spend less than 20% of their household income on transport. Presently, about half of South African households (49.9%) spend less than or equal to R1 799 per month, whilst 20.6% spends more than R500 a month on public transport (NHTS, 2020). Any interventions that could reduce that financial burden of transport will, thus, be welcomed in a good life environment.

In total, 94% of respondents indicated that 75% or less of the current air pollution emissions should be eliminated in the hypothetical good life (Figure 5). Interestingly, only 7% expected all air pollution from transport to be gone. This potentially indicates people's understanding that transitioning away from current technologies and modus operandi is not a straightforward, nor an easily achievable objective. There is definitely some consensus that efforts towards reducing air pollution should be made in earnest.

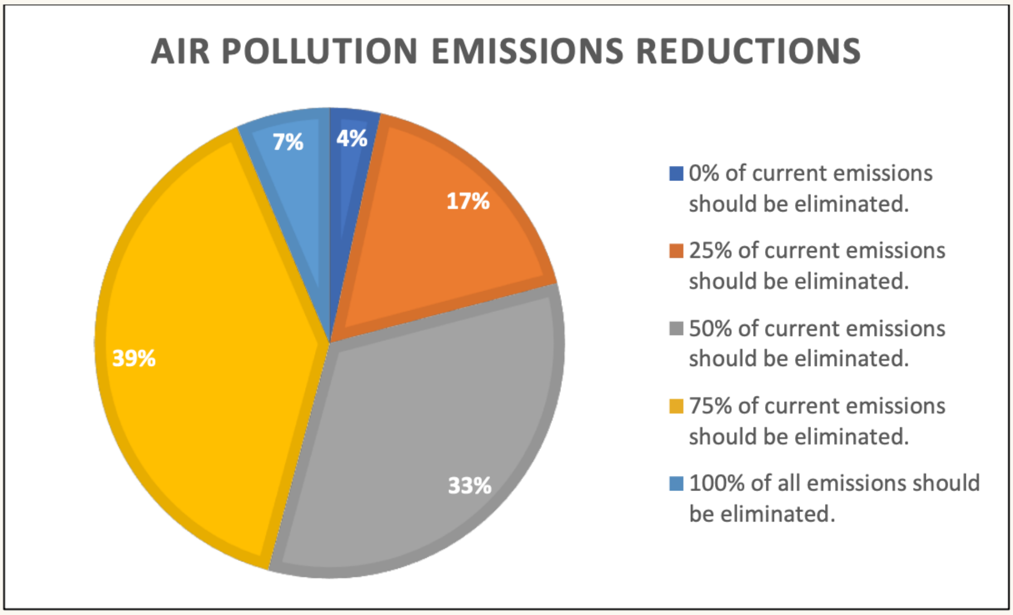

Figure 5 Survey results: Question 5 – Emissions reduction target

3.2 Survey feedback and future recommendations

The feedback obtained on the survey was generally positive, with the respondents reaching out to the authors indicating their belief that this is a pertinent topic and important work. A few requests to share the research outputs were also received. On the contrary, there were a couple of questions where some respondents felt it was unclear and some respondents would have liked clearer definitions of some of the terms (such as how to exactly distinguish between urban or rural). On the whole, there were no detrimental problems rendering results not useful and the surveys were successfully deployed. It is recommended to perhaps issue the surveys again in the future in the hope of collecting more (diverse) responses. The updated data can easily be input into the transport models and the impacts of changes to the input parameters determined. The feedback receive from this survey run can be used to improve clarity where this was flagged.

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4 Scenario Development and Modelling

4.1 Initial transport demand (2019)

4.1.1 Passenger transport

The input data for passenger transport volumes in 2019 was obtained from the National Household Travel Survey (NHTS) 2020. This survey is published as a joint venture between Statistics South Africa and the National Department of Transport. Data for the survey was collected from 65 000 dwellings across the country between

January and March 2020. Whilst this is technically 2020 data, it is believed to be representative of the travel behaviour in the year from March 2019 to March 2020.

The NHTS (2020) contains data on the average number of trips per person per day for various purposes. The 11 summary purposes used in this study are:

- To access nature and leisure.
- To access land (for agriculture).
- To access food shopping.
- To access shopping for other goods.
- To access administrative services.
- To access employment.
- To access education.
- To access healthcare.
- To access friends, families, and social gatherings.
- Long distance travel.
- To access religious institutions.

These values are upscaled to represent the number of trips for the entire population over a year. Knowing the total number of trips is only half of the information required, though. The average distance per trip is required in order to calculate the total passenger kilometres travelled in a year.

Unfortunately, the NHTS does not contain any information on average trip distances, nor does any other public database. The average travel time per trip purpose (in minutes) from the NHTS was used, in conjunction with average travel speeds per trip purpose, to determine the average distances travelled per trip purpose (in km). To determine average travel speed per trip purpose, values for the average travel speed per mode (in km/h) was combined with the modal split per trip purpose (calculated from the NHTS data) to produce a weighted average travel speed per trip purpose. Long distance travel trips are formed by proportionally combining business trips (>20 km) and overnight trips in the NHTS.

With the total passenger kilometres known, the total emissions from transport can be determined. This is a function of the modal split per trip purpose, the trip passenger kilometres per trip purpose, and the emissions factors per mode per passenger kilometre. The product of these three components equates to the total emissions produced from passenger transport activities. Data on the emissions factors published by Ritchie (2023) was used (Figure 6).

4.1.2 Freight transport

For freight transport, data on the total tons and ton kilometres of freight transported in the country in 2019 was obtained from the GAIN Group Freight Demand ModelTM. The ton kilometres are disaggregated into 81 commodities (the full list is included in Appendix C) and for each commodity a split between road and rail transport is applied. The result is a

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total ton kilometre (tkm) value for road freight and for rail freight in 2019. Similar data for both passenger and freight transport volumes in 2013 was also collected for potential use in determining historic transport trends.

Road transport volumes are disaggregated into different vehicle classes, according to the categorisation in Stone et al. (2018). The authors of this paper provided additional data and information to use in the LbD project. Their work contains the transport share and average load factors per vehicle class for South African freight, as well as energy intensity values per vehicle type (in MJ/km). When applying these factors to the 2019 freight volumes, the total energy demand from freight transport for the year is calculated in megajoules (MJ). A conversion factor from MJ to grams of carbon dioxide (CO_2) of 76 g/MJ diesel and 71 g/MJ gasoline was used. This corresponds to factors found in the literature (https://www.volker-quaschning.de/datserv/CO2- spez/index_e.php). All trucks in South Africa in 2019 were diesel driven. Only a portion of light delivery vehicles are petrol driven, but these vehicles fall in the grey area between passenger and freight transport.

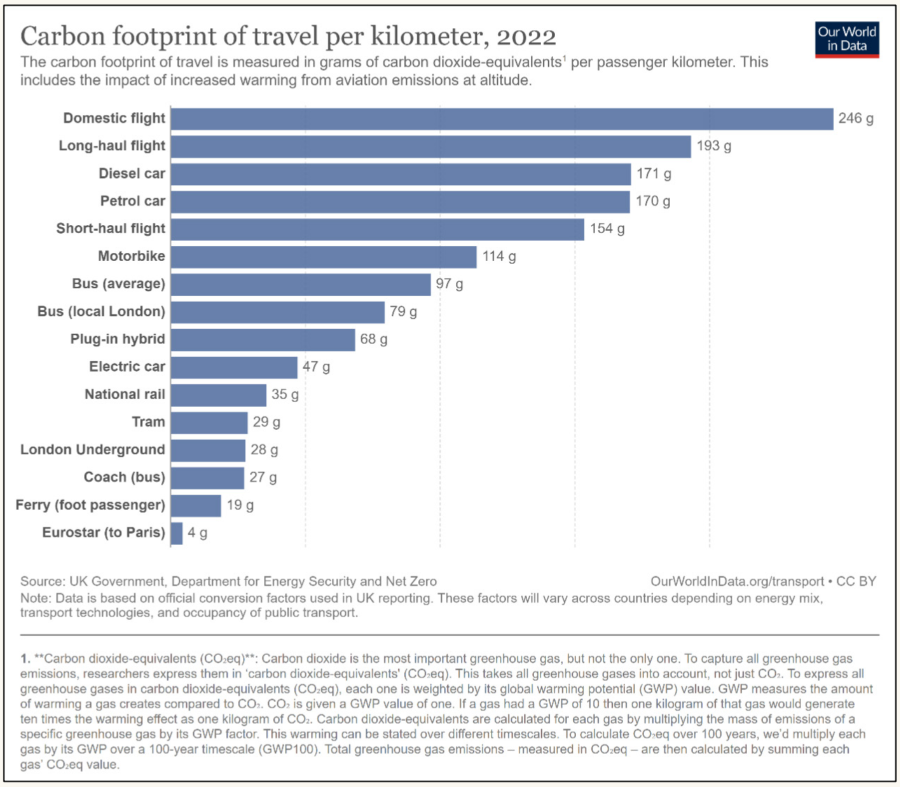

Figure 6 Emissions factors for various passenger transport modes (Ritchie, 2023)

A rail energy intensity of 0.065 MJ/tkm used in Lane & Vanderschuren (2011) was applied to total rail transport volumes. The Department of Transport's Railway Master Plan 2022-2023 state that only 10% of long-distance rail lines in the country are electrified. It is assumed that this linearly changes to a 100% electrified freight rail network by 2040. South Africa's electricity grid has an emissions factor of 1.06 kg CO_2e/kWh (ESKOM, 2021). There is a target to lift the share of renewable energy in the power generation mix from 11% currently to 41% by 2030 (Kemp, 2023). Following this timeline, to an ultimate total renewable share of 10% by 2050, the energy intensity of electricity used is reduced over time in a near linear fashion. It is assumed that there are no GHG emissions associated with the generation of electricity from renewable sources.

4.1.3 Total transport emissions and validation

Passenger transport emissions (31 143 Gg CO_2e) plus freight transport emissions (14 865 Gg CO_2e) amount to a total of 46 007 Gg CO_2e. This is within 0.5% of the total transport emissions (46 207 Gg CO_2e) reported from the transport

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sector (excluding domestic water-borne navigation) for 2020 in the National GHG Inventory Report (DFFE, 2022), validating the model inputs and structure. As an additional validation, the same methodology to calculate the transport demand for 2019 was applied to the 2013 data collected and compared to the Energy Systems Research Group (ESRG) at the University of Cape Town's national energy model transport values, which they have calibrated based on 2013 data. Both validations are within approximately 5% of the ESRG totals, encouraging confidence in the results.

4.2 Scenario 1: Business as usual (BAU)

The main assumption in the BAU scenario is that there are no meaningful changes to the transportation system, the technology used or urban design. Current travel demand patterns are expected to continue and evolve in line with historic trends and future projections of the drivers of transport demand.

4.2.1 Passenger transport

Projected growth of passenger transport volumes is based on different combinations of gross domestic product (GDP) forecasts for South Africa, the country's Gini index and population growth outlook for each trip purpose (Table 1). GDP data was obtained from https://data.oecd.org/gdp/real-gdp-long-term-forecast.htm, values to determine the Gini coefficient from https://data.worldbank.org/indicator/NY.GNP.PCAP.CD?locations=ZA and the population growth estimates from https://statisticstimes.com/demographics/country/south-africa- population.php.

Table 1 Projection basis for BAU pkm

Trip purpose	BAU growth projection basis
Access to nature and leisure	Gini
Access to land	Population
Access to food shopping	90% population; 10% GDP; online shopping trend
Access to other shopping	40% population; 60% Gini; online shopping trend
Access to administrative services	Population; digitisation of services trend
Access to employment	GDP; reduction of 5-day work week
Access to education	50% population
Access to healthcare	90% population; 10% Gini
Access to friends, family and social gatherings	Population
Access to religious institution	Population
Long distance travel - business	GDP; reduction of 5-day work week
Long distance travel - overnight	Gini

The prevalence of online shopping is predicted to grow from 58% (currently) to 71% in 10 years' time (Wunderman Thompson, 2023). It is assumed that growth will slow to a linear increase of around 1.8% per annum thereafter. The effect of this will be a reduction in shopping trips inversely proportional to this trend. The increase in digitisation of administrative services is expected to follow an s-curve up (based on a literature review and expert opinion) to the point where 90% of all administrative services can be accessed online, having an inversely proportional impact on trips to access administrative services.

Several countries have started to experiment with reducing the number of working hours per week. Working from home is another trend that has recently emerged, and which has been engrained as a new way of life for many people post the pandemic. It is assumed that over time, the number of trips for employment will decrease by 40% to represent work trips for 3 days of the week only. It is, however, important to note that in transport, when people save time on commuter trips during the week, they are more willing to travel greater distances over the weekend. Freeing up time, due to reduced employment requirements is not expected to result in lower transport volumes, but rather shifts trips between purposes.

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The trips 'saved' are redistributed in equal fashion between trips to access nature and leisure, land for agriculture, other shopping, friends, family and social gatherings, religious institutions, and long-distance travel.

4.2.2 Freight transport

In a similar fashion to determining the passenger transport growth profiles, a projection basis was assigned to each freight commodity. The commodities were first classified as being either food or goods, matching the survey and NHTS categorisations. A percentage split between the influence of GDP and population growth on each commodity was applied based on previous work and expert consensus to determine the tkm values over time. These classifications and assignments can be seen in Appendix C.

4.2.3 CO_2 emissions

To calculate the total emissions for this scenario, it is first necessary to determine the trajectories of power mix for propulsion. In passenger transport, it is assumed that all buses have diesel engines, all minibus taxis and motorcycles only use petrol and that regular vehicles start with a mix of diesel (39.49%), petrol (60.48%) and electric (0.03%) propulsion systems. Historic trends of petrol and diesel fuel shares in South Africa are assumed to continue and the proportion of electric vehicles remain constant. By 2050, diesel vehicles constitute 14.9% of the vehicle parc and petrol vehicles 85.1%.

Commuter rail is assumed to be 100% electrified, and long-distance rail maintain a constant split of 10% electrified and 90% diesel powered. Aircraft efficiency is expected to improve over time in a linear manner to reach a final efficiency improvement of 90% by 2060.

Freight energy efficiencies per vehicle type are assumed to be constant in this scenario, with only the change in tkm affecting the total emissions values.

4.3 Scenario 2: Good life ideals

The South African narrative clearly describes communities that are closer, tranquil, with more freedom and less living from payday to payday, being trapped in the daily grind. There is also a reduced need to consume and waste, and an appreciation for the land and what it can offer. Communal areas, activities and labour replace the individualistic tendencies that abound today.

The 15-minute city is a new urban planning concept aimed at rethinking urban areas to make them more sustainable, healthy, and just (Schauenberg, 2023). The idea is that cities are designed in such a way that most daily necessities are within a 15-minute walk of bicycle trip from where residents live. International experiments to test the theory are underway in 16 cities at present, notably Paris and Barcelona. Conceptually speaking, the 15-minute city is a very good fit for the good life described in the narrative. It is based on this premise, that conforming to the principles of a 15-minute city will support efforts to reach the good life, that scenario 2 is designed.

4.3.1 Passenger transport

The survey results for questions 1 and 2, pertaining to average access times for various services, find the ideal average access time urban settings equal to 20 minutes and in rural areas equal to 29 minutes. Figure 7 displays the survey results in comparison to current access times. Overall, people want to be closer to daily necessities in urban environments and are willing to travel further distances for social reasons or to land used for agriculture. It is not surprising that average access in rural areas is higher than in urban areas, as the low densities in rural settings necessitate this.

The survey travel time preferences per purpose are assumed to be the actual average times in the year 2050 in this scenario. Urban and rural travel preferences are applied in the ratio of 65% urban and 35% rural as per the NHTS 2020. These travel times are converted to the corresponding trip distances, based on the modal split per trip purpose and the average travel speed per mode. These values remain unchanged from the **BAU** scenario. Average trip distances are assumed to reduce exponentially between 2019 and 2050 and unique exponential profile matching the 2050 values

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exactly was determined for each trip purpose. The total passenger kilometres and emissions for this scenario is then calculated in the same manner as in the **BAU** scenario but based on the updated trip distances.

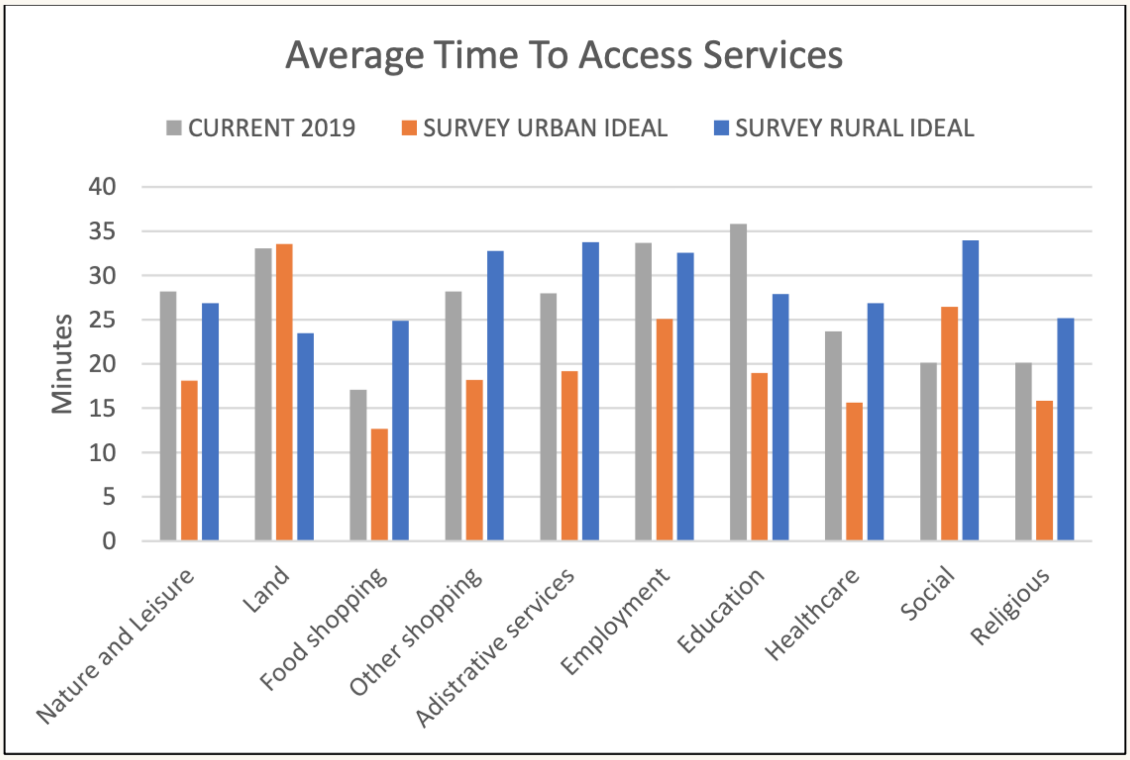

Figure 7 Average access time preferences indicated in the survey.

4.3.2 Freight transport

Survey questions 5, 6 and 7 pertain to this scenario. Survey respondents were asked to specify the ideal split between the origins of food and goods consumed in a good life environment. The four types of origins are:

- Local – being from the same district,
- Regional – being from the same province,
- National – being from the rest of South Africa,
- International – being imported.

The responses to questions 5 and 6 are shown in Figure 8 and Figure 9, respectively.

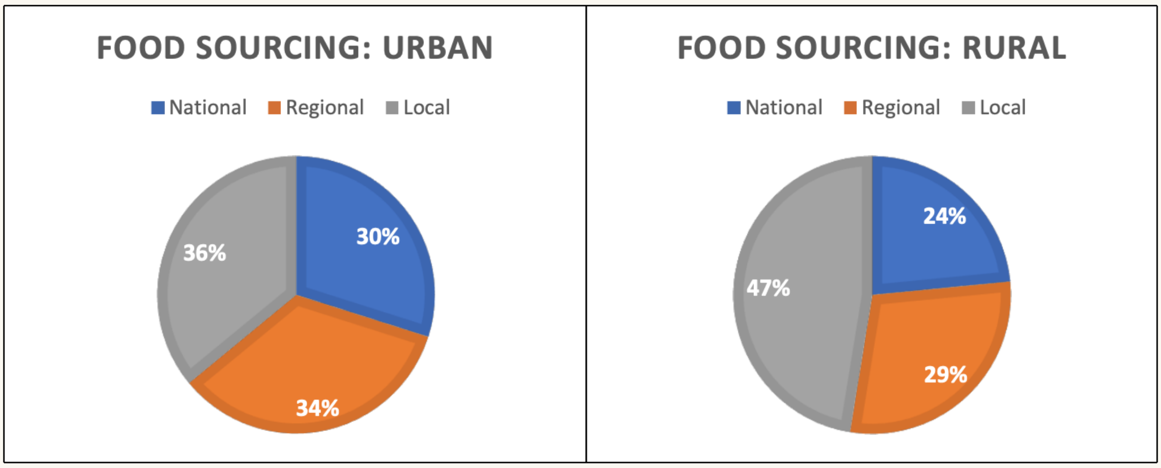

Figure 8 Food sourcing preferences indicated in the survey.

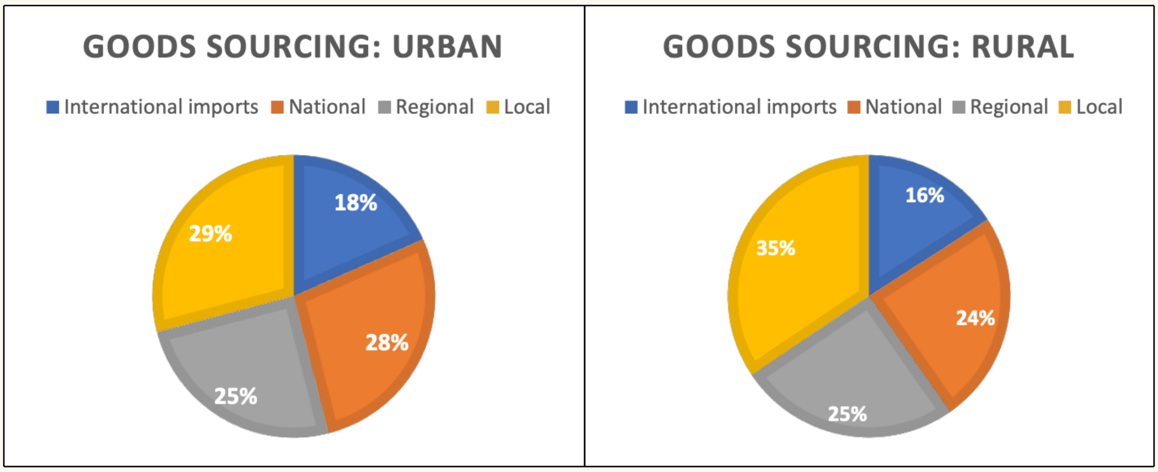

Figure 9 Goods sourcing preferences indicated in the survey.

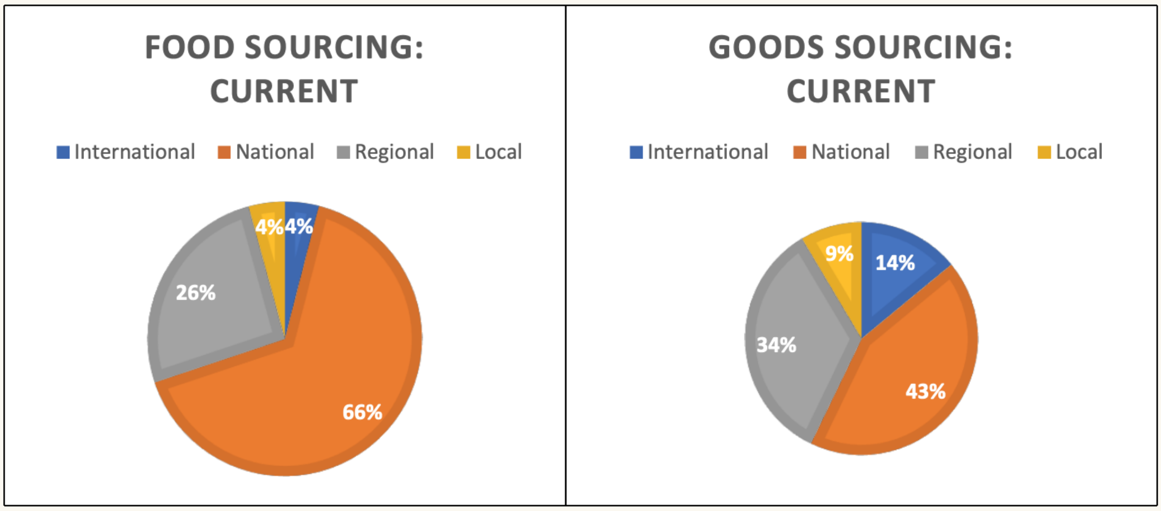

Figure 10 Current food and good sourcing distributions.

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Figure 10 indicates that both the foods and goods markets are dominated by imports at present. The survey results, on the other hand, show a clear preference for shifting production to local markets and closer to the point of consumption. The narrative of the good life speaks about changes to consumerism and production patterns as well. Food production is specifically mentioned to occur in a more decentralised manner, moving away from industrialised meat production and the heavy land requirements of industrialised agriculture. Distributed manufacturing of goods with a reduced reliance on global supply chains are part of this vision as well.

This formed the basis of the spatial changes to the production economy modelled in Scenario 2. Not all commodities are amenable to relocation. Minerals and the mining activities that accompany it can, for example, only occur where the minerals are found geographically. Similarly, based on geography and weather patterns, all agricultural endeavours cannot be successfully pursued anywhere. The commodities were further categorised based on whether they were amenable to relocation of production, or not. The short list of viable commodities is shown in Table 2. It is assumed that for these commodities, the sourcing preferences indicated in the survey results will apply in the **Good life ideals** scenario. This impacts the average travel distances for these commodities. It is further assumed that the savings are achieved following a slight exponential curve, with impacts starting from 2029 and the full saving reached by 2050.

Table 2 List of commodities identified to be potentially amenable for relocation of production activities.

Commodities potentially amenable to relocation	
Maize	Slaughtered animal meat
Sunflower Seed	Soya bean products
Vegetables	Animal feed
Potatoes	Beverages
Grapes	Tobacco Products
Subtropical Fruit	Textile Products
Citrus	Wood timber and products
Deciduous Fruit	Wood chips
Milk (bulk)	Printing and Publishing
Eggs (poultry)	Bricks
Processed Foods	

On the question of the expected change in consumption volumes over time (question 7), there is no consensus on what will happen with goods consumption and the majority (49%) of respondents felt that food consumption levels will remain the same. These values were, thus, excluded from further analysis.

4.4 Scenario 3: Good life ideals and NDC target emissions

Two objectives exist in this scenario – the transport sector must conform to the spatial changes required as part and parcel of moving towards the good life and the South African ambition to the reduce transport sector carbon emissions to 25 Gg CO_2e is strived for. The spatial changes in the **Good life ideals** scenario are not sufficient to achieve both of these objectives. Going back to the 15-minute city ideals of being able to walk or cycle for most daily trips, a modal shift towards more non-motorised transport (NMT) use and more public transport (PT) use constitutes the intervention in this scenario.

The preferred average travel times indicated in the survey are again used to represent the ideal values in 2050. Using the known average walking (4.8 km/h), cycling (25 km/h) and public transport travel speeds per mode, the maximum travel distance per trip purpose for each of these three modes is determined. The full NHTS dataset was used to determine

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what percentile of trips per purpose fall within these distance thresholds. It is assumed that this is the maximum percentage of trips able to shift from motorised propulsion or private transport to NMT or PT by 2050. An exponential shift in the number of trips per mode is assumed, starting in 2019 and reaching 100% of projected savings in 2050. It is, furthermore, assumed that all trip types excluding shopping and healthcare trips are amenable to shift. Walking or cycling with heavy, bulky, or fragile items purchased can be cumbersome and it assumed that only up to 80% of food shopping and 50% of goods shopping trips can shift towards NMT or PT. When travelling to access healthcare services, it is not ideal to need to physically exert yourself if you are unwell. However, some healthcare trips are for regular check-ups or prescription renewals, and it is assumed that 20% of these trips are able to shift modes.

When additional trips are allocated to PT, it is allocated according to the modal split of the trip purpose in question for all forms of buses, rail, and minibus taxis. The list of modes per trip purpose as captured in the NHTS data is presented in Table 3.

Although NMT delivery services such as bicycle deliveries do exist, the volumes of freight that can be dispatched by NMT and PT are extremely low compared to the volume of freight transportable in a truck. Improvements to freight tkm are eliminated in this scenario.

Table 3 List of passenger transport modes included in the analysis.

List of modes included in the model for passenger transport	
Train (Metrorail)	Car/bakkie passenger
Long distance train	Lift club
Bus	Car/bakkie driver
BRT/IRT Bus	Truck/tractor/trailor passenger
Gautrain Bus	Truck/lorry/tractor driver
Long distance bus	Company vehicle
Metered taxi	Scooter/motorcycle
App based taxi (Uber)	Tuk-tuk
Special transit for disabilities	Bicycle
Minibus taxi commuter	Animal transport
Minibus taxi long distance	Boat/ship
School bus	Aircraft
Sedan taxi	Rapid rail (Gautrain)
Bakkie taxi	Walking (all the way)
Other	

4.5 Scenario 4: Good life ideals and NDC target emissions by 2050

The target objectives in this scenario are even stricter than in Scenario 3. Here Scenario 3 objectives need to be met, but by a 2050 deadline. Changing the propulsion of transport activities to a more efficient and lower emitting option, namely electric vehicles (EVs), is the intervention modelled in this scenario.

4.5.1 Passenger transport

In the passenger transport calculations, it is assumed that the modal split and spatial planning parameters remain constant in this scenario. The only change comes about in terms of the technology mix used in each mode and the associated changes in efficiency, as well as emissions. For electrified rail, the improvement in emissions as the South

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African grid moves over to renewables (90% by 2050) comes into play. There is a linear transition away from diesel rail towards fully electric rail by 2040 assumed. The transition from diesel buses to electric buses is modelled based on the statement by Golden Arrow Bus Services in Cape Town that they will shift over 60 buses per year in order to transition their entire fleet in 18 years. This tempo is adopted for all buses in this scenario.

International Energy Agency (IEA) data from the Global EV Data Explorer (https://tinyurl.com/2mn47sxh) including historic and projected stock share data for electric vehicles in South Africa and Europe are used to forecast the growth in EV share of the car parc for this scenario. EV adoption rates in South Africa are assumed to lag the European rates by 11 years. Additionally, it is assumed that all EV market share gains are at the expense of petrol vehicles, given the expected decline in diesel market share shown in the current projections.

4.5.2 Freight transport

It is assumed that freight trucks will transition at the same pace as the EV market share for passenger cars. This trend implies that 42.5% of vehicles are electric by 2050.

5 Results

5.1 CO_2 emissions and the environment

The transport emissions pathways for each scenario are shown in Figure 11. The BAU scenario starts off with emissions increasing for the first decade, after which the total emissions remain relatively constant, despite ever increasing GDP and population values. This implies that there is already an increase in transport efficiency planned in current transport development trends.

Scenario 2 is shown to improve upon Scenario 1, although the savings become more pronounced towards the end of the period. This makes sense, as changes to urban form and the spatial structure of the economy will start of slowly, picking up speed as the cumulative impacts of projects are realised. Unfortunately, the NDC target remains well out of reach. There are limitations to the spatial and structural changes that are possible.

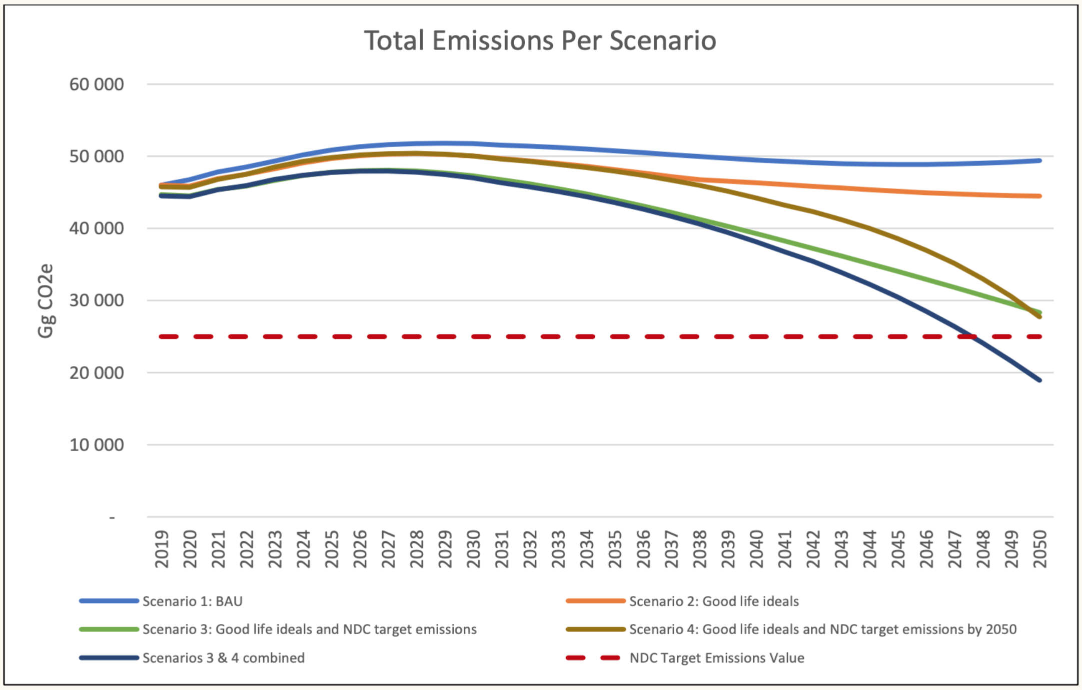

Figure 11 Transport transition pathways from 2023 to 2050

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Scenario 3, where the gains from the spatial changes in Scenario 2 are coupled with the maximum benefit of moving towards NMT and PT performs really well. The target value is not met by 2050, however, and so even greater efforts to reduce overall transport emissions are required.

Looking at the effectiveness of various NMT options in isolation (Figure 12), it can be seen that walking on its own does not move the needle very far (5% additional savings achieved in 2050). Doing both walking and cycling extends the reach of the mode shift intervention to more trips and can lead to 21% additional savings to those in Scenario 2. Moving more towards public transport, even though motorised transport is still required, makes the biggest impact (26% additional savings in emissions). This can be ascribed to the large area that can be covered by public transport services whilst still adhering to the maximum travel times indicated in the surveys.

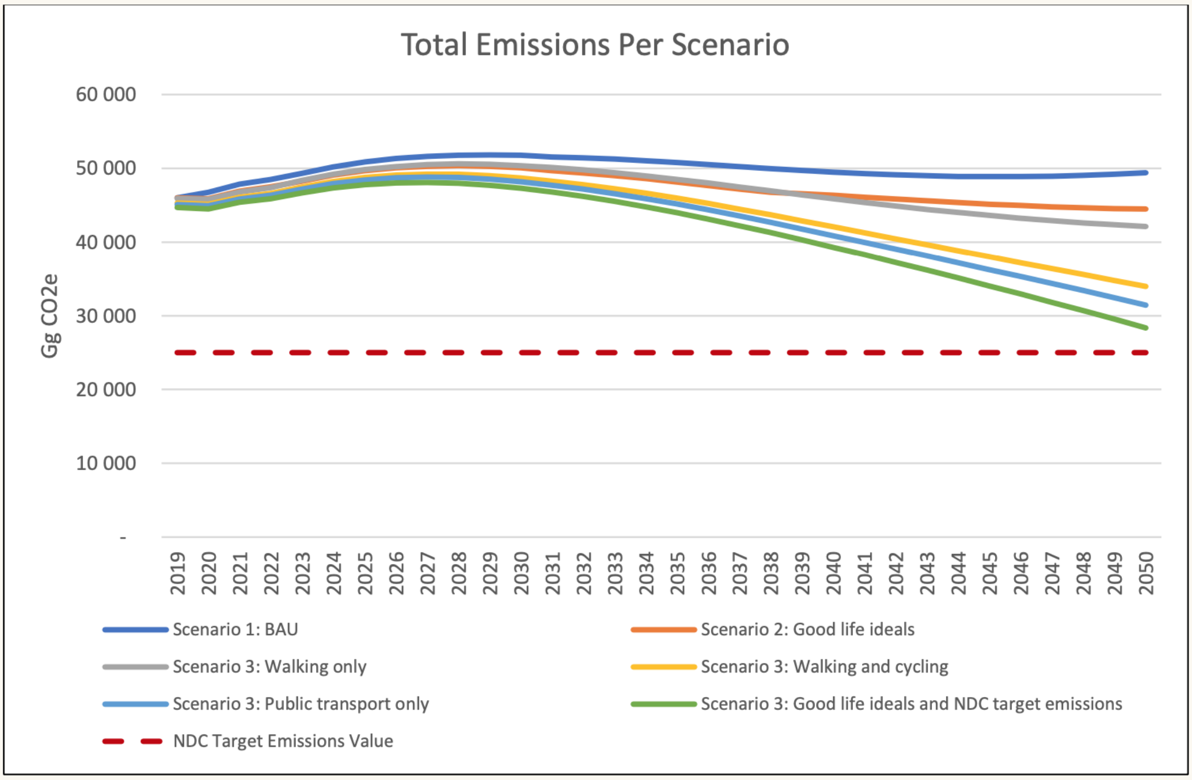

Figure 12 In-depth look at scenario 3 alternatives.

Combining both NMT mode shifts with the shift towards PT (Scenario 3) is the most impactful, however. Even though the catchment area for trips to shift is the same as in the public transport only variant, the benefit of NMT over PT for the area where both modes overlap renders this the preferred combination. It is assumed that trips will be assigned in order of priority where walking is ranked first, cycling second and public transport third. Put differently, residents are assumed to prefer walking, when possible, over fiddling with a bicycle for short distances. Public transportation trips are only chosen when the distance to travel is too far to reach the destination in a reasonable amount of time or exertion on a bicycle.

Looking at Figure 11 again, the introduction of and switch to electric vehicles in Scenario 4 does not improve much upon the spatial changes of Scenario 2 for about two thirds of the period. Then the impacts start to become meaningful and within a little more than 10 years the savings achieved match and surpasses those of Scenario 3. The sudden increase in effectiveness can likely be ascribed to the combined impact of the improvements of the electricity grid emissions and its transition towards renewables and the exponential adoption rate for EVs starting to gain momentum round about the same time. As

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with Scenario 3, the spatial changes required for the good life, combined with electric vehicles alone, will not be enough to reach the NDC target by 2050. It can, however, reach the target by 2053. It is only when the avoid, shift, and improve measures are all combined and implemented that the NDC target can be successfully reached before 2050 (by 2048).

Comparing the levels of waste associated with each scenario, the more efficient use of urban space in scenario makes it very attractive. Pushing towards greater use of NMT and PT does not introduce new waste to the system and is intended to make better use of the existing PT systems (reducing waste). The introduction of EVs, however, goes hand in hand with the problem of discarding batteries that have exceeded their useful lifetimes. A new stream of waste is, thus, created in scenario 4.

5.2 Health and safety

There are different fatality rates associated with different road transport modes. When fatality rates are applied to the total transport volumes per mode, the relative performance of each scenario in terms of safety can be compared (Table 4). It is interesting to note that the PT only variant of Scenario 3 performs much worse in terms of safety than any of the others. This is due to fact that fatality rates for buses are more than 10 times higher than the other modes. The rate used for buses is, however, a composite rate including both urban and long-distance bus trips and should be used with caution. Accidents on long distance trips tend to occur at higher speeds and if a bus is involved, many passengers are involved. Both of these factors increase the risk of high fatality rates for long distance bus trips. Assuming high fatality rates for public transport bus trips, shifting more urban trips towards buses is expected lead to more accidents with high fatality rates. In the variant where NMT and PT is combined, the volume of the total reduction in trips is enough to offset the negative bus fatality rates. Scenario 4 is excluded from the safety analysis, as there is no material difference between the fatality rates of EVs and ICE vehicles.

Table 4 Summary of road transport fatalities per scenario

Scenario	Fatalities in 2050
Scenario 1: BAU	4 388
Scenario 2: Good life ideals	3 742
Scenario 3: Walking only	2 992
Scenario 3: Walking and cycling	1 458
Scenario 3: Public transport only	3 003
Scenario 3: NMT and public transport	969

Each of the three mitigation scenarios will have positive health impacts, as they all reduce the total travel volumes by at least the amount shown in Scenario 2. Fewer trips equal lower levels of congestion (associated with high anxiety and stress levels and general unhappiness), lower levels of air pollution and, consequently, positive impacts on respiratory and heart health. Shorter trips and fewer commutes can also have positive mental health impacts, freeing up idle (wasted) time to potentially spend on activities that bring joy to life. Scenario 3 has the additional mental and physical health benefits of moderate levels of activity required to complete a portion of trips. Scenario 4, in turn, has the advantage that EVs produce no tailpipe emissions, leading to great improvements in terms of air quality (on top of the improvements due to reduced travel volumes). It can, thus, be expected that the combination of Scenarios 3 and 4 (which implicitly include scenario 2) will create an environment with the most beneficial health impacts.

5.3 Economics

Public transport pricing is generally related to the distance travelled or time spent in the system. If the number of trips required, or the average duration of trips are reduced, a saving in the expenditure on public transport can be expected.

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This will be the case in scenario 2. Walking, in turn, is free, and cycling requires a once-off purchase of a bicycle unless the bicycles are provided by the authorities. A shift towards greater use of NMT will also have a positive effect on the proportion of household income that needs to be spent on transport. Additionally, if more users make use of the public transport systems provided, it enables the PT systems to run as efficiently as possible, ultimately creating the potential to reduce public transport fares, or at least restrict it to the bare minimum rate. It is unclear whether a shift towards EVs will reduce public transport costs. Initially there will be substantial capital expenses and the cost recovery of this might not make this scenario the economic best performing one.

Of course, changing the spatial structure of cities and economic activities will also have costs attached, however it is expected that the transition can be more organic, being less capital intensive for one entity that has to foot the bill, as the costs will be shared by many. The transport operators in Scenario 2 will not have to make great investments in infrastructure or vehicle stock. Economically speaking, reorganising urban spaces, and pushing towards more NMT, are the preferred interventions.

6 Policy Implications

The most interesting policy implication of this study is that it demonstrates that fact that it **is** possible to decarbonise the transport system significantly, without compromising the quality of life of citizens, or being at the expense of the economy. The total quantum of economic activity (represented by the total ton of goods transported) is not specifically reduced in any of the scenarios, yet there are substantial emissions savings to be achieved from changing where economic activity takes place. In terms of passengers, all services and the total number of trips remain the same in all scenarios. The gains, thus, do not come from withdrawing opportunities from the population, but rather from changing the way that people go about performing all the tasks they do now. Additionally, the stated preferences of the survey population are adhered to in all scenarios, and emissions reductions are still observed, indicating that the ideal of providing people with the access they want is not incompatible with the ideal of lower the environmental footprint of the transport system.

Furthermore, the study shows that the concept of the 15-minute city can support both of these objectives, simultaneously. This opens up a new avenue for policy development around spatial planning for both urban and economic activities. The 15-minute city scenario (Scenario 2 combined with walking and cycling modal shifts) leads to a 15 438 Gg CO_2e reduction, which equals 31% of the **BAU** scenario emissions. This entails urban densification (within certain boundaries), without infringing upon people's mobility, access to opportunities or average travel times. The golden rule that emerges is to strive for shorter trips, not fewer trips.

The findings in this report are in line with the Avoid-Shift-Improve philosophy for transport energy demand management. Policies on transport emissions reductions can be prioritised accordingly. The first priority is the need to avoid what can be avoided. Doing this without unintended socio-economic consequences can be problematic, but the spatial planning redesign interventions described in this study provide viable solutions to this problem. Having eliminated all unnecessary travel, the next priority if to shift what can be shifted, to less polluting modes. Here the benefits from improved spatial planning are evident – more trips can shift to NMT and PT and still be completed within acceptable trip durations, because the urban landscape and economic production is more compact. A modal shift towards NMT and PT is 9% more effective when the spatial planning changes have already been put in place, compared to shifting from the **BAU** scenario alone. Once all avoid and shift interventions have been exhausted, the policy focus should move to improve interventions. This essentially means that the private car transport that cannot be removed is at least done in the most sustainable manner. This includes pollution reduction through EV promotion. Overall, avoid interventions reduce emissions by 10%. Adding shift interventions reduces overall emissions by an additional 33% and implementing the improve measures contributes to another 5% emissions saving.

A policy directive that flows forth from this assessment is that all trips that can be completed by NMT or PT, within the stated acceptable time frames, should be restricted to these modes as far as possible. Another policy directive that is revealed in this study is the need to encourage activities to move online as much as possible. Reducing the need to travel for services when the same utility can be achieved virtually is shown to be a great way of avoiding unnecessary travel.

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7 Transport related additions to the narrative

Some transport specific elements that can be included in updated versions of the South African narrative can be identified. The most fundamental concept of the urban design will be that everything that is essential is close by. People will walk and cycle more. For longer distance trips (typically to access agricultural land, employment opportunities, visit friends and family, or attend social gatherings) public transport services will be used. Where individual motorised travel is still required, the use of EVs and not ICE vehicles is promoted.

There will also be fewer trips needed because lots of activities have moved online. This relates to trips to access administrative services and shopping (both food and other goods) in particular, although not exclusively. There is a high priority for human interaction in the good life. Trips of a more social nature will remain a necessity, but the mundane and routine tasks can be assumed to have moved online.

Table 5 provides a list of the commodities that can potentially shift towards more local production in the good life.

Table 5 List of commodities that are deemed amenable to spatial change initiatives.

Commodities potentially amenable to relocation	
Maize	Slaughtered animal meat
Sunflower Seed	Soya bean products
Vegetables	Animal feed
Potatoes	Beverages
Grapes	Tobacco Products
Subtropical Fruit	Textile Products
Citrus	Wood timber and products
Deciduous Fruit	Wood chips
Milk (bulk)	Printing and Publishing
Eggs (poultry)	Bricks
Processed Foods	

As a final note, although density is vital in the good life urban environment, there are limits to what this means. Typically, buildings would not be more than four stories high.

8 Conclusions

This study used a combination of forecasting and back casting to develop a set of scenarios to inform on the potential of different transport emissions transition pathways. The results provide the insights that no single ideal solution exists that can achieve the good life ambitions along with the stated sectoral NDC target. However, when avoid, shift, and improve interventions are combined, all emission and 'good life' objectives can be met. There are synergies unlocked when interventions are combined, yielding the whole greater than the sum of the parts.

The survey undertaken as part of this work proved to be instrumental. Its outputs are used as direct inputs to the formulation of Scenarios 2 and 3, whilst it also shaped the thinking on the topic. The inclusion of the survey demonstrates that it is valuable to gain insights from the greater public, especially when working on future planning studies.

Analysing the results of the study lead to the emergence of what seems to be a golden rule: strive for shorter trips, not fewer trips. Applying this principle to policy formulation will afford the opportunity to preserve people's freedom, whilst

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improving upon transport environmental impact performance metrics.

All-in-all, the ideals of the good life and the implied changes to urban form and the location of economic activities are shown to be a good way of reducing emissions, waste, negative health impacts, road fatalities and household expenditure on transport. Additionally, it enables all the other benefits of the good life for the other sectors of the economy to co-exist. Although effective in achieving the stated objective of reducing emissions, it still needs to be accompanied by complementary interventions or other, specific, stated objectives.

Whilst urban densification comes out as a clear ideal for future development, the question of what this urban structure looks like and whether it can work in practice remains. It is understood that there are limitations to the height that buildings can and should reach, and that there needs to be equitable space for all services. What does this do to the urban footprint, how many new buildings will be required (and at what cost) and what density is sufficient? There is scope to expand this body of work in the future. One way to advance the topic will be to find answers to these questions. Moreover, the scope of the survey can be expanded, and it can be re-issued to enlarge the answer sample set. The model can then be updated to reflect the new information, rendering it even more representative of the colloquial expectation of what a 'good future' entails.

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