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Re-Imaging Low Carbon Mobility Transitions In South Africa: A Case Of Public Transport

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Abstract

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This manuscript reimagines South Africa's public transport system, using the multi-level perspective (MLP) transition-theoretical lenses of analysis developed by Geels et al., (2016). Rapid urbanisation, the climate change crisis and emergency, rapid motorisation and rising pollution levels, failing and ageing infrastructure, spatial inequality and fragmentation, and uneven low-carbon transitions across transport modes and industrial sectors constitute key levers of change that frame the unfolding low-carbon public transport transitions in South Africa. Using the multi-level perspective transition lenses and selected key informant interviews, along with case studies from the Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga, and KwaZulu-Natal provinces, the manuscript unravels the conflicting rationalities and realities associated with advancing just public transport transitions in South Africa. The manuscript proposes that a reimagined low-carbon urban transport and mobility transition is not enough and is incomplete without a complementary and proportionate development of at-scale rural mobility transitions.
Keywords: Low carbon mobility transitions (LCMT; Multi-Level Perspective (MLP), Just public transport transitions (JPTT); Urban and Rural Mobility (URM); Rapid urbanisation (RU); Spatial transformation (ST).

1. Introduction

In South Africa, transport is the third largest contributor to national greenhouse gas emissions, accounting for about 11–12% of total CO_2 emissions, with over 90% from road transport (Oladunni, & Olanrewaju, 2022; Ndhlovu, Mhlanga, & Duri, 2025). Public and shared transport is the backbone of mobility for most South Africans: 24.3% of workers use minibus taxis; only 3.6% use buses, reflecting network and coverage gaps; 6.3 million households use public transport weekly for work; 74.5% spend R300+ per month (Stats South Africa, 2023). A low-carbon future in South Africa is usually referred to as a decarbonised future (National Development Plan, 2030). Minimising emissions is not a challenge for the transport sector alone but an economy-wide approach towards adopting and using low-carbon power sources throughout the economy and society. The Green Transport Strategy (2017) in South Africa is targeted at reducing GHG emissions from the transport sector by 50–80% by 2050 relative to 1990 levels (Giliomee, & Booysen, 2023; Amen, 2021; Amen et al., 2024;). It also includes mode shift targets and an interim target for vehicle efficiency by 2030 (Government of South Africa, 2017; 2018a,b; Giliomee, & Booysen, 2023). Suggested pathways toward embedding deep decarbonisation in South Africa include the following: Bold measures aimed at fossil fuel substitution by renewables, preserving valuable forest and agricultural carbon sinks; critical mass update and use of energy efficient technologies and materials in the economy and society (including a shift from ICE to EVs etc. (Olojede, 2021; Giliomee, & Booysen, 2023). Ultimately, the combined effect of such a transformation and change is the achievement of a net zero carbon economy and vision for South Africa by 2050 (Government of South Africa, 2017, 2018a, 2018b). Overall, the problem of low-carbon transitions is complex, multidimensional, and contextual (refer to **Figure 1**).

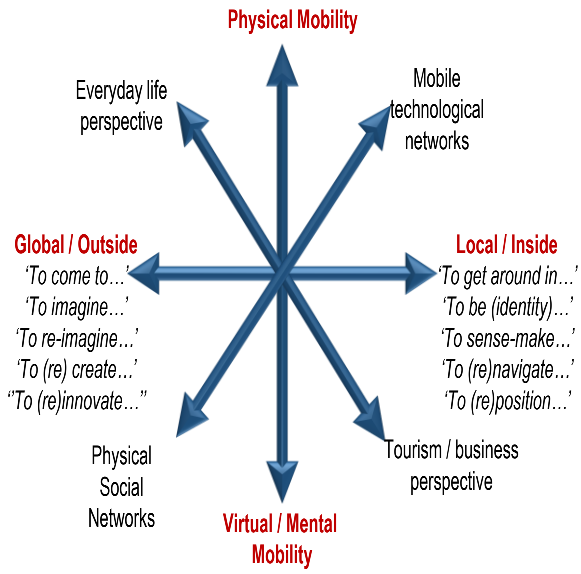

Figure 1. The challenge of low-carbon mobility transitions 'web' in a changing world.

As indicated in **Figure 1**, the challenge of the low-carbon mobility transitions 'web' in a changing world is finding permanent and lasting solutions to offset public transport disruptions. These disruptions can be caused by shifts in geopolitics, climate change, health crises, and emerging vulnerabilities in public transport in a rapidly socio-economically transforming, technologically advancing, and digitally driven world. The challenge is manyfold: 1. To continue to provide low-carbon mobility solutions that respond to the virtual and mental mobility possibilities (now and in the future), 2. How to enhance physical mobility in support of globalisation and improving everyday personal experiences for commuters and residents/citizens alike, and 3. How to achieve all of the above mentioned without compromising the capacity and ability of the existing and planned public transport systems to innovate and re-invent itself for relevance, impact and continuity. **Figure 2** presents a schematic illustration of the adapted deep public transport low-carbon mobility transitions discourses that require navigation in seeking to re-imagine low-carbon transitions in South Africa. The low-carbon public transport should cover all dimensions, including: inclusive public transport transition (i.e. processes, impact and coverage), pace and speed of implementation as well as geographic coverage and time horizon linked to achieving full deep, integrated and comprehensive public transport transition.

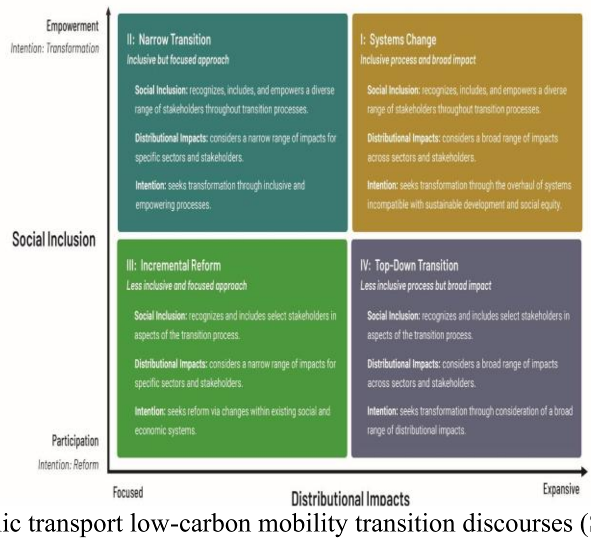

Figure 2. Adapted deep public transport low-carbon mobility transition discourses (Sources: Adapted from Ward, 2025).

1.1 Problem Statement and Research Gap

The study adopts the multi-level perspective (MLP) transition theoretical lenses of analysis (Geels, 2016) in re-imaging low carbon public transport transitions for South Africa. Re-imagination of the public transport sector sits at the intersection of multiple crises and opportunities for public transport and spatial transformation trajectories, including: 1. Rapid urbanisation, 2. Climate change crisis and emergency, 3. rapid motorization, 4. Growing pollution emission levels, 5. Failing and ageing infrastructure, 6. Spatial inequality and fragmentation, 7. Uneven low-carbon transitions by transport modes and industrial sectors. **Figure 3** presents the Theoretical Foundations for Low Carbon Transport Transition Pathways, as developed by Geels, which is used as a departure and framing point for re-imagining multiple scenarios for low-carbon public transport transitions in South Africa. There is limited and inconclusive research and policy work on low-carbon transitions in South Africa, thereby providing both motivation and justification to focus on contributing to and expanding the body of knowledge and evidence on low-carbon transport transitions in South Africa.

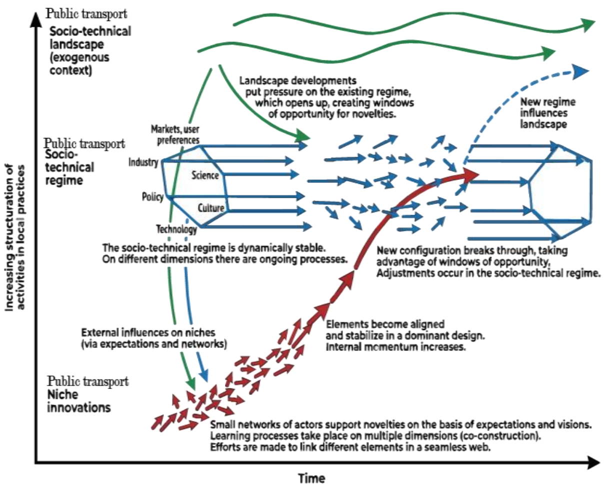

Figure 3. Theoretical Foundations for a Low Carbon Transport Transitions Pathways (Source, Adopted after Geels, 2002).

1.2 Aim, Objectives and Research Question

The aim of the manuscript is to reimagine South Africa's public transport system in terms of a low-carbon economy. The objectives of the paper are the following:

- Outline the current state of South Africa's public transport system in cities, towns and communities.
- Explore the public transport low-carbon transitions lived experiences in South Africa, making use of case studies from Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal provinces.
- Proposing a reimagined low-carbon public transport transitions typologies applicable to different-sized urban settlements in South Africa.

1.3 Significance and Structure of the Manuscript

The manuscript is important as it seeks to provoke and sustain low-carbon public transport transitions debates in South Africa with implications for similar discourses in developing countries. Galvanising policy and practical actions towards solutions that contribute towards low-carbon cities, economies and communities is critical for sustainable development and links perfectly with the interlinked SDGs, namely: SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation and Infrastructure, SDG 11: Sustainable Cities and Communities, and 13: Climate Action. Valorising, optimising, and implementing the correct mix and scaled low-carbon technologies, strategies and actions are important in the shared pursuit of achieving low-carbon economies in the World. Low-carbon transport transitions receive limited research and policy attention, with grey literature available, although a critical mass of literature remains an area for further development.

The manuscript is organised into *five (5) sections*. *Section one (1)* provides the setting and background for the study, including the problem statement, research gap, research aim, objectives, and guiding framing questions. *Section two (2)* presents the materials and methods used by the study. The study design, setting, sampling methods and approach, participants and subjects, procedures and protocols, as well as data analysis and methods employed are presented. *Section three (3)* presents the study results using thematic analysis and the Respondents' Agreement Index (RAI) statistical technique for analysis and inference. *Section four (4)* presents a discussion of the study results. The findings and outcomes are interpreted in the context of existing and prior studies. *Section five (5)* presents a summary of key findings, discusses the study's limitations, and highlights areas for future research and development.

2. Materials and Methods

2.1 Study Design and Setting

The study employed an exploratory sequential research design and mixed-methods approach – incorporating both qualitative and quantitative research paradigms as well as primary and secondary data collection for expanded understanding of the study phenomenon (Arent, Wise & Gelman, 2011: 584-593). Qualitative methods in the form of 20 purposively sampled key informant interviews (KII) participants and the use of a checklist guided observation surveys, provided deep, contextual insights into the lived experiences (LE) and viewpoints of low carbon public transport transitions in Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal provinces (Malterud, Siersma & Guassora, 2016: 50-55).

To broaden the sample's diversity and mitigate bias, snowball sampling was employed as a supplementary technique (Ting et al. 2025:3). A randomly distributed sample and questionnaire administration of 166 Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal provinces households was conducted to capture residents' lived experiences and views in respect of public transport in South Africa (Malterud, Siersma & Guassora, 2016:7). In 2024 South Africa's provincial populations, and their share of the total, were: Eastern Cape: 7,176,230 (11.4%); Free State: 3,044,050 (4.8%); Gauteng: 15,931,824 (25.3%); KwaZulu-Natal: 12,312,712 (19.5%); Limpopo: 6,402,594 (10.2%);

Mpumalanga: 5,057,662 (8.%); Northern Cape: 1,372,943 (2.2%); North West: 4,155,303 (6.6%) and Western Cape: 7,562,588 (12.%) (StatsSA, 2024). The questionnaire distribution was modelled around the adjusted population shares of the province as follows: Limpopo (11,8%=20), Gauteng (29,28%=49), Eastern Cape (13,19%=22), Western Cape (13,88%=23), Mpumalanga (9,26%=15)and KwaZulu-Natal (22,56%=37) provinces. Data gathered was analysed thematically, descriptive statistics & the Respondents' Agreement Index(RAI) using the Statistical Packages for Social Sciences (SPSS) version 28.0 and Microsoft Excel tools

2.2 Study Area

South Africa's transition toward low-carbon public transport is uneven and spatially differentiated, with provincial dynamics shaping distinct pathways. A growing body of academic and policy literature emphasises that "province-specific solutions" are essential because "challenges and contexts vary between provinces" in achieving emissions reductions in the transport sector. Against this backdrop, Limpopo, Mpumalanga, KwaZulu-Natal, Western Cape, and Eastern Cape can be understood as differentiated low-carbon public transport transition case studies, each reflecting unique socio-economic, spatial and infrastructural realities.

Limpopo Province, located in the far northern part of South Africa. Limpopo Province is situated in the northernmost part of South Africa and is geographically positioned at approximately 22° South latitude and 29° East longitude. It offers a distinctive geographical setting that makes it a valuable case study for understanding transport systems and low-carbon mobility transitions in predominantly rural regions. The province shares international borders with Zimbabwe, Botswana, and Mozambique. It is strategically positioned as a strategic gateway for regional trade and cross-border movement. Domestically, it borders Mpumalanga, Gauteng, and North West provinces, linking it to South Africa's primary economic core while remaining largely peripheral in terms of infrastructure development. The spatial structure of Limpopo is predominantly low-density and rural, with settlements widely dispersed across vast distances. Major urban nodes such as Polokwane (the provincial capital), Thohoyandou, Tzaneen, and Mokopane serve as regional service centres, but much of the population resides in villages and former homeland areas. In terms of transport geography, Limpopo is structured around a limited number of primary transport corridors. The N1 national corridor, which runs from Gauteng through Polokwane to Zimbabwe, is the most significant arterial route, facilitating both passenger mobility and freight movement. Other important corridors include the R81, R71, and R37, connecting agricultural and mining areas to regional markets. Rail infrastructure exists but is largely oriented toward freight transport, particularly minerals, and has limited relevance for daily commuter mobility due to declining passenger rail services. The province's geographical context contributes to a strong reliance on road-based transport systems, especially minibus taxis, which dominate both urban and rural mobility. The other case study area, Mpumalanga Province is located in the eastern part of South Africa and can be geographically situated at approximately 25° South latitude and 30° East longitude. The province's terrain, while scenic, creates logistical complexities that reinforce dependence on road-based transport systems, particularly in areas where rail infrastructure is either limited or oriented toward freight rather than passenger mobility. Mpumalanga's location along South Africa's eastern boundary, where it borders Mozambique and Eswatini, enhances its role as a regional transport corridor. The province forms a key component of the Maputo Development Corridor, which links the industrial heartland of Gauteng to the Port of Maputo. From a low-carbon perspective, Mpumalanga exemplifies a transition space where environmental imperatives intersect with economic dependency on carbon-intensive industries. Meanwhile, the Eastern Cape Province of South Africa is located along the south-eastern coastline of the country and can be geographically positioned at approximately 32° South latitude and 26° East longitude. The Eastern Cape Province provides an important case study for understanding low-cost public transport transitions in South Africa, particularly in contexts characterised by rural dispersion, economic constraints, and limited infrastructure investment. Unlike highly urbanised provinces such as the Western Cape or Gauteng, the Eastern Cape reflects a transition pathway shaped less by advanced technological systems and more by affordability, accessibility, and incremental improvements to existing mobility systems. At the same time, the other case study area, the KwaZulu-Natal (KZN) is located on the eastern seaboard of South Africa, occupying a strategic position along the Indian Ocean coastline. The province lies approximately between 28° to 31° South latitude and 29° to 32° East longitude. KwaZulu-Natal's geographical location also underpins its role as a major transport and logistics hub. The province hosts the Port of Durban, the busiest container port in sub-Saharan Africa, which serves as a key node in global and regional trade networks. Inland transport corridors, particularly the N3 corridor, connect Durban to Gauteng, facilitating the movement of goods and passengers between the coast and the country's primary economic centre. This corridor is one of the most heavily trafficked routes in South Africa and is central to national logistics and supply chains. On the other hand, the Western Cape Province is located on the south-western tip of South Africa, occupying a strategic position along both the Atlantic and Indian Ocean coastlines. It lies approximately between 31° and 35° South latitude and 18° and 25° East longitude, placing it within a Mediterranean climatic zone, which is unique within the southern African context. This location strongly influences the province's environmental conditions, settlement patterns, and transport systems. The province's coastal plains—particularly around Cape Town and the Cape Flats—are relatively flat and densely populated, forming the core of urban and economic activity. In contrast, inland regions such as the Karoo are sparsely populated and characterised by semi-arid conditions, leading to lower transport demand and more limited infrastructure. This contrast between dense urban areas and remote rural hinterlands creates a dual transport geography, where advanced, integrated transport systems coexist with more basic, low-access networks. Meanwhile, Gauteng Province, is the smallest yet most economically significant province in South Africa, is located in the north-central part of the country. It lies approximately between 25° and 27° South latitude and 27° and 29° East longitude, placing it on the interior plateau known as the Highveld. Despite its relatively small geographic size, Gauteng is the most densely populated and urbanised province, making it a unique spatial unit within the national landscape. The province's settlement geography is highly urbanised and concentrated, with more than 90% of the population living in urban areas.

Gauteng is structured around a polycentric urban system, where Johannesburg serves as the financial and commercial core, Pretoria as the administrative capital, and Ekurhuleni as an industrial and logistics centre. These cities are interconnected through dense transport networks, forming a continuous urban agglomeration that drives national economic activity.

Figure 4 presents the study map location of select province case Studies in South Africa: Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal.

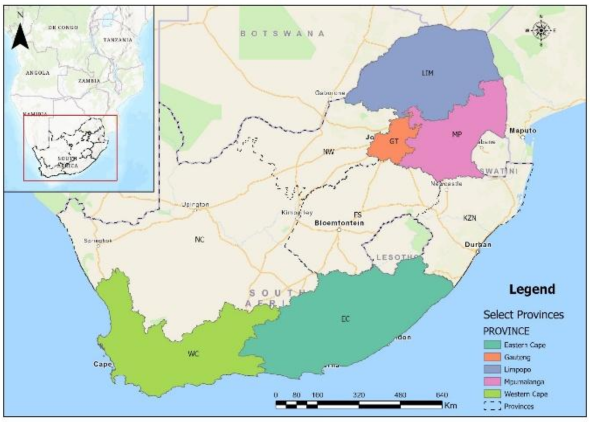

Figure 4. Study map location of select province case Studies in South Africa (Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal).

2.3 Participants or Subjects

A randomly distributed sample and questionnaire administration of 166 Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal provinces households was conducted to capture residents' lived experiences and views in respect of public transport in South Africa (Malterud, Siersma & Guassora, 2016:7). In 2024 South Africa's provincial populations, and their share of the total, were: Eastern Cape: 7,176,230 (11.4%); Free State: 3,044,050 (4.8%); Gauteng: 15,931,824 (25.3%); KwaZulu-Natal: 12,312,712 (19.5%); Limpopo: 6,402,594 (10.2%); Mpumalanga: 5,057,662 (8.%); Northern Cape: 1,372,943 (2.2%); North West: 4,155,303 (6.6%) and Western Cape: 7,562,588 (12.%) (StatsSA, 2024). The questionnaire distribution was modelled around the adjusted population shares of the province as follows: Limpopo (11,8%=20), Gauteng (29,28%=49), Eastern Cape (13,19%=22), Western Cape (13,88%=23), Mpumalanga (9,26%=15)and KwaZulu-Natal (22,56%=37) provinces. The 20 purposively sampled key informant interviews (KII) participants were drawn from the Department of Transport (both national and provincial (7=35%); Research and Academia (CSIR (2=10%) and Universities (3=15%), Municipalities (7=35%) and NGO/Transport Advocacy Group (1 = 5%). The distribution of key informants was representative of the array of key stakeholders and institutions that interact and impact the low-carbon public transition space and conversations. Data gathered were analysed thematically, and descriptive statistics and the Respondents' Agreement Index (RAI) were calculated using the Statistical Package for the Social Sciences (SPSS) version 28.0 and Microsoft Excel.

To validate and strengthen the findings, secondary databases were accessed and analysed for trends and patterns in the public transport landscape and changes in South Africa. The following databases were accessed and analysed:

- National Household Travel Survey (NHTS), 2003, NHTS, 2013, NHTS, 2020.
- Stats South Africa, 2011 & 2016 and 2022.
- Integrated Transport Plan (ITP), Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal Municipalities (2003–2026).
- Passenger Rail Agency of South Africa (PRASA) annual reports.
- South African National Roads Agency Limited (SANRAL) annual reports.
- National Land Transport Strategic Framework 2006–2011.
- Public Transport Strategy, 2007.

2.4 Materials and Equipment

The manuscript is organised into *five (5) sections*. *Section one (1)* provides the setting and background for the study, including the problem statement, research gap, research aim, objectives, and guiding framing questions. This study investigated the Relative Importance Index (RII) in ranking low-carbon transition solutions (LCTS) and pathways for public transport in South Africa. Quantitative methodologies were adopted in this study. Twenty (20) key informant interviews and one hundred and sixty-six (166) random general questionnaire surveys throughout South Africa were sampled randomly. Primary data were collected using a closed-ended 5-point Likert-scale questionnaire. RII was used to rank the different LCTS, transformation levers, and action areas. The themes investigated in the low-carbon transition were implementation solutions, transformation levers, and action areas. The five-point scale ranged from 1 (strongly disagree) to 5 (strongly agree) and was computed to the Respondents' Importance Index (RII) for each factor.

2.5 Procedures and Protocols

The studies that informed this publication were approved by the Ethics Committee of the University of Venda (Ethical Clearance Approval No FSEA/22/URP/15/1707, November 2022 and FSEA/23/URP/01, November 2023. Informed consent was obtained for the anonymized research participants' information published in this manuscript.

2.6 Data Analysis

Data were analysed thematically using the Respondents' Agreement Index (RAI), and inferences were drawn using Statistical Packages for Social Sciences (SPSS) version 28.0 and Microsoft Excel. The Relative Agreement index was calculated based on the information provided in the questionnaires. The Respondents Agreement Index (RII) calculation was significant to this study because its result indicated the ranked degree of relevance. To calculate the relative index, the following formula was applied.

RII=∑Wx X /AxN

Where:

W = the weight given to each response, X = the frequency of each response, A = the highest weight (5 in this case), N = the total number of respondents.

According to Akadiri (2011), five important levels derived from RI values are the following: high (H) ($0.8 \leq RI \leq 1$), high medium (H–M) ($0.6 \leq RI \leq 0.8$), medium (M) ($0.4 \leq RI \leq 0.6$), medium-low (M-L) ($0.2 \leq RI \leq 0.4$) and low (L) ($0 \leq RI \leq 0.2$).

Low Public Transport Transitions Implementation Solutions and Low Carbon Transitions: Transformation Levers and Action Areas were evaluated for Cronbach's Alpha Reliability. Prior to the analysis, the Cronbach's Alpha Test was conducted to assess the scale's internal consistency for rating the various solutions, transformation levers, and action areas. A score of 0.70 or higher indicates that the rating scale is internally consistent (Ayarkwa, Opoku, Antwi-Afari, & Li, 2022). The criteria of Cronbach's alpha for establishing internal consistency reliability are: excellent ($\alpha>0.9$), good ($0.7<\alpha<0.9$), acceptable ($0.6< \alpha<0.7$), poor ($0.5< \alpha<0.6$), and unacceptable ($\alpha<0.5$). The result of this test was 0.878, indicating the reliability of the Likert scale used to rate the low-carbon public transport solutions, transformation levers, and action areas.

3. Results

3.1 Presentation of Key Findings

3.1.1 Low Carbon Transitions: Transformation Implementation Solutions

The Respondent Agreement Index (RAI) is a statistical tool used to rank factors by their importance or impact. Research commonly uses it to prioritise items based on respondents' ratings. **Table 1** presents the low public transport transitions implementation solutions as analysed from the RAI.

Table 1: Low Public Transport Transitions Implementation Solutions.

S/N	Solution Typology	Density Levels (H, L)	Levels of Automation (P, F)	Implementation Timeframes (ST, MT, LT)	(5)—Strongly Agree—(1) Strongly disagree (N = 166)					SWV	RAI(MS)	MD (RAI)	RAI Rank	Rank
					5	4	3	2	1					
1	Shared Shuttles and Mobility Services [1]	H	P	ST	112	14	29	4	7	718	4.33	**0.87**	**H**	**1**
2	Moving and Reshaping the Automobile Based Mobility Market[2]	L	P	ST-MT	92	24	19	20	11	664	4.00	**0.8**	**H**	**2**
3	Smart, Connected and Integrated Public Transport Corridors[3]	H	F	MT– LT	57	18	26	13	52	513	3.09	**0.62**	**H-M**	**3**
4	Critical Mass and Uptake of Plentiful Pods and Autonomous Mobility[4]	Low	Full	Long Term	26	16	23	53	48	417	2.51	**0.50**	**M**	**4**
	Average RAI(MS) (composite score)										3.48		-	-

Key: H = High, L = Low; P= Partial, F=Full

[1] This refers to and covers the following: Compact and densified city centre; Transit-oriented development; Walking, bike-sharing, and scooters (motorcycles) for short journeys and trips; Ride-sharing minibuses for longer journeys
Carpooling policies and share systems, e.g., Uber, Tuktuks, etc.

[2] This refers to and covers the following: Cars rule, walking and cycling decline; Customised mobility packages offer prepaid travel allowance for use on road and rail; Integrated smart ticketing systems, etc.

[3] This refers to and covers the following: Switch easily between intelligent, automated, bus, taxi and rail services; Guided by all-knowing personalised travel applications etc.

[4] This refers to and covers the following: Fleet of autonomous pods replace public transport and privately owned cars; Passengers can opt to share for cheaper fares etc.

The highest RAI was 4.33 while the lowest was 2.51. Deviations around the mean of the highest and lowest RAI were 1.82. All deviations around the mean (i.e., RAI) were positive, indicating that sampled study respondents considered them leading factors in the implementation of solutions for low-carbon public transport transitions. These implementation solutions were: Shared Shuttles and Mobility Services (SSMS) (0.87). KII number 10 indicated that in, Limpopo, thedispersed settlement structure and limited formal transport systems mean that shared mobility - particularly informal minibus taxis and walking - dominates everyday travel. The KII further indicated that emerging research on the "green economy in the transport sector" in Limpopo suggests that sustainable mobility transitions in such contexts depend less on electrification and more on improving infrastructure, accessibility, and integrated rural transport systems (Odiyo, Bikam, Chakwizira, 2022). Moving and Reshaping the Automobile-Based Mobility Market (MRAMM) (0.8) was also a key prioritised solution. KII number 12 explained that the current transport patterns in Mpumalanga province (which are symptomatic of general patterns throughout South Africa, albeit with local and contextual nuances) are highly carbon-intensive, with road freight accounting for approximately 87% large share of movements emphasising the emissions intensity of existing systems. This corroborates various academic and policy studies that confirm that shifting freight "from road to rail" is one of the most effective mechanisms for reducing greenhouse gas emissions in the transport sector generally and in South Africa's transport sector in particular (Aritua, Havenga, Simpson, Swarts, Neethling, & de Bod, 2025; Churchman, Dekker, & Anable, 2026). Smart, Connected and Integrated Public Transport Corridors (SCIPTC) (0.62) were also viewed as an important solution action area. A KII respondent No 6 from the Western Cape Province was proud to share how the province had invested in integrated public transport (IPT), via the MyCiTi BRT system, which was described as benchmark for low-carbon infrastructure design in South Africa. Indeed, life-cycle assessments of BRT stations in South Africa have identified MyCiTi infrastructure as highly efficient in terms of "carbon footprint and embodied energy intensity," demonstrating the potential of design innovation to support decarbonization in the public transport sector (Louw, & Netswera, 2024). The Critical Mass and Uptake of Plentiful Pods and Autonomous Mobility (0.50) was the lowest ranked and of medium importance, highlighting the future need to focus on those aspects in embedding a long-term sustainable low-carbon transition public transport transitions strategy and plan. Calls and granular research analysis in respect of possible issues, impacts and application remits of AVs beyond the driverless car and implications for low carbon public transport tranistions especially in developing countries still require further investigation (Jones, Sadowski, Dowling, Worrall, Tomitsch & Nebot, 2023)These findings have implications and resonate with the need to develop a clear low carbon public transport transitions implementation roadmap with disaggregated transport corridors, neighbourhoods, and at all transport spatial scales with targets covering public transport indicator framework and complete dashboard monitoring system to improve public transport service levels (LOS), commuter experience and public health.

3.1.2 Low Carbon Transitions: Transformation Levers and Action Areas

Table 2 presents the low carbon transitions: transformation levers and action areas.

Table 2: Low Carbon Transitions: Transformation Levers and Action Areas.

S/N	Low Carbon Transitions: Transformation Levers and Action Areas	(5)—Strongly Agree—(1) Strongly disagree (N = 166)					SWV	RAI(MS)	MD (RAI)	RAI Rank	Rank
		5	4	3	2	1					
1	Low Carbon Public Transport Transformation (LCPTT)	124	18	24	0	0	764	4.60	**0.92**	**H**	**1**
2	Low Carbon Public Transport Reconfiguration (LCPTR)	84	47	21	4	10	689	4.15	**0.83**	**H**	**2**
3	Low Carbon Public Transport Technological Substitution (LCPTTS)	59	45	12	20	30	581	3,50	**0.7**	**H-M**	**3**
4	Low Carbon Public Transport De-alignment and Re-alignment (LCPTDR)	21	16	33	63	33	427	2.57	**0.51**	**M**	**4**
	Average RAI(MS) (composite score)							**3.71**			

Key SWV (summation of weight value); RAI (respondents' agreement index); MD

As highlighted in Table 2, the highest RAI was 4.60, while the lowest was 2.57. Deviations around the mean of the highest and lowest RAI were 2,03. All deviations around the mean (i.e., RAI) were positive, indicating that sampled study respondents considered them leading factors in low-carbon public transport transitions. These variables were: Low Carbon Public Transport Transformation (LCPTT) (0.92), spatial fragmentation (0.92), Low Carbon Public Transport Reconfiguration (LCPTR) (0.83), Low Carbon Public Transport Technological Substitution (LCPTTS) (0.7), and Low Carbon Public Transport De-alignment and re-alignment (0.51). These findings have implications and resonate with the need to develop an integrated low-carbon public transport indicator framework and dashboard monitoring system to improve public transport service levels (LOS) and commuter experience.

3.2 Interpretation of Key Findings

The findings have implications for public transport low-carbon transitions in South Africa and developing countries. Opportunity exists for low-carbon public transport transitions as the legal and policy framework is in place (Odiyo, Bikam, & Chakwizira, 2022). The biggest challenge for the accelerated uptake of low-carbon public transport has been implementation capacity mismatches and gaps between plans and projects linked to: skills gap; funding gap; structures and governance gaps; data and information currency gaps (Jones, Sadowski, Dowling, Worrall, Tomitsch & Nebot, 2023; Louw, & Netswera, 2024; Aritua, Havenga, Simpson, Swarts, Neethling, & de Bod, 2025). The implementation of catalytic and transformative projects such as rapid rail links, trams or light rail, rail buses, Bus Rapid Transit, Speed Rail, ToD, integrated transport and spatial planning, and shifting freight from road to rail is critical (Ndhlovu, Mhlanga, D., & Duri, 2025). It is also critical to realise that some of these solutions are not entirely new imagination but reimagination in different contexts. Trams were once in use in Pretoria and Johannesburg, until they were discontinued in the late1960s early 1970s owing to viability considerations (Wood, 2024).

4. Discussion

4.1 Summary of Key Findings

4.1.1 Complexity, Scale and Impact in Low Carbon Public Transport Transitions (LCPTT) Exist

A complexity scale and intensity framework for local low-carbon (or "carbon-efficient") public transport transitions in South Africa can be structured to capture (a) how difficult transitions are to implement (complexity) and (b) how strong and rapid the interventions are (intensity). In South Africa, the relationship between complexity and intensity underscores the importance of strategic sequencing. Short-term actions should prioritise low-complexity, relatively low-cost interventions that can deliver immediate benefits and build institutional capacity. Over the medium term, cities can pursue more integrated, higher-intensity strategies, including expanding BRT systems and gradually introducing low-emission vehicles. In the long term, achieving a fully decarbonised and inclusive public transport system will require sustained commitment to high-complexity, high-intensity transformations, supported by national policy alignment, innovative financing mechanisms, and strong stakeholder engagement. Indeed, this observation and implications were summarised by KII#14, who indicated that "Not all South Africa is the same urban and rural landscape. We have different hierarchies of urban and rural settlements and continuums in between. In essence, rural areas, small rural towns exist alongside world-class urban metropolitan agglomerations. Appropriate urban public transport low-carbon transitions must be fit for purpose and scaled to the size of the respective town. Solutions have to be differentiated to accommodate big metropolitan cities such as Johannesburg, Pretoria, Cape Town and Durban, as well as secondary cities such as Polokwane, Bloemfontein, Port Elizabeth, and rapidly growing and expanding former homeland towns such as Thohoyandou, Giyani, Mthatha, etc.

4.1.2 Differentiation, Transformation, Impact and Context Matter

Low-carbon public transport transitions in South Africa cannot be understood through a single, uniform pathway; rather, differentiation, impact, and context are central to shaping how such transitions unfold across the country. These three dimensions highlight the uneven, place-specific, and multi-layered nature of change, reflecting the diversity of South African cities, institutions, and mobility systems. Differentiation is fundamental because South Africa's urban and transport landscape is highly heterogeneous. Metropolitan areas such as Johannesburg, Cape Town, and eThekwini operate within relatively stronger institutional and financial frameworks, enabling them to pursue more advanced interventions, including Bus Rapid Transit (BRT) systems, integrated public transport networks, and pilot projects for electric buses. In contrast, secondary cities and smaller municipalities often face significant capacity constraints, limited budgets, and weaker governance systems, which restrict their ability to move beyond basic service provision. As a result, low-carbon transitions cannot be designed as one-size-fits-all solutions; they must account for variations in institutional capacity, infrastructure readiness, and the structure of transport services. Indeed, this observation and implications were summarised by KII# 3, who indicated that "A lot of people in the big cities have lost faith in public transport, let alone public transport technologies being used and peddled as hook lines for a switch in travel movement, patterns and distribution. Generally, the average South African prefers to drive rather than walk, to use private vehicles and shared transport such as Uber, Bolt, etc., rather than jump into a public bus, be it BRT, Vaya or any other mode, except minibus taxis, which are faster. In addition, the built environment, architecture, and public transportation modes are not conducive to walking or biking. While there are iconic NMT infrastructure mainly developed during the 2010 World Cup build-up to the soccer jamboree, there has not been a sustained and high-impact transformative implementation of a pedestrian-friendly and low-carbon suite of interventions to make a significant and transformative impact that supports a transition towards low-carbon public transport in the country, which is quite unfortunate.

4.1.3 The Unique History and Context of Public Transport Development and Architecture in South Africa

Context is perhaps the most critical dimension shaping low-carbon public transport transitions in South Africa. The country's transport system is deeply embedded in a unique historical and socio-spatial context, marked by apartheid-era planning that segregated residential areas from economic centres, resulting in long and costly commuting patterns. This legacy continues to influence travel demand, modal choices, and the viability of different transport interventions. Any effort to decarbonise public transport must therefore engage with these structural realities, recognising that technological solutions alone are insufficient. Context also includes the broader political and economic environment, which affects policy implementation, stakeholder alignment, and resource allocation. For instance, the prominence of the informal transport sector reflects both a market response to gaps in formal provision and a livelihood system for thousands of operators and workers. Transition strategies that ignore this context risk resistance and failure, whereas those that incorporate the principles of a "just transition" can foster greater inclusivity and legitimacy.

4.1.4 Flexibility, Re-engineering and Repurposing in Low Carbon Public Transport Transitions (LCPTT) is Important

Flexibility, reengineering, and repurposing are emerging as essential pillars in advancing low-carbon public transport transitions in South Africa, particularly in a context defined by institutional fragmentation, infrastructural constraints, and socio-economic inequality. These concepts reflect a pragmatic and adaptive approach to transition—one that recognises that South Africa cannot simply replace existing systems wholesale, but must instead adapt, transform, and optimise what already exists while progressively introducing low-carbon innovations. Instead of committing exclusively to full electrification of bus fleets, cities may adopt a mix of technologies - such as hybrid buses, cleaner fuels, and incremental electrification—depending on financial feasibility and energy supply stability. In a resource-constrained environment like South Africa, where building entirely new infrastructure can be prohibitively expensive, repurposing provides a cost-effective alternative. For instance, existing bus depots can be adapted to support electric vehicle charging infrastructure, while underutilised rail corridors can be revitalised to shift passengers from road to rail, thereby reducing emissions. Similarly, existing vehicles within the minibus taxi fleet could be gradually retrofitted or replaced with lower-emission alternatives, rather than being abruptly phased out.

4.1.5 The Low Carbon Public Transport Transitions (LCPTT) Value System and Transport Dividend Ecosystems Must Be Optimised

A value system optimised for low-carbon public transport transitions in South Africa must be grounded in a careful alignment of environmental imperatives, socio-economic priorities, and institutional realities. However, sustainability in South Africa cannot be narrowly defined by carbon reduction alone. It must also encompass the long-term viability of transport systems, including their financial sustainability, operational reliability, and compatibility with broader urban and energy systems. A value system optimised for low-carbon public transport transitions in South Africa balances environmental ambition with social justice, economic efficiency, and institutional feasibility. By prioritising sustainability, equity, efficiency, resilience, integration, and innovation, such a value framework provides a guiding foundation for navigating the complex and context-specific challenges of transition. It ensures that efforts to decarbonise public transport contribute not only to climate goals but also to the broader objectives of inclusive development and improved quality of life for all South Africans. Indeed, this observation and implications were summarised by KII# 18, who indicated that " The transport policy and legislative framework and related environmental instruments are relatively fine. While these may generally require a bit of tinkering and refinement here and there, in essence, they are good enough for any required low-carbon transition in public transport. Where we really struggle is on the implementation side – this is because of budgetary constraints, skills mismatches, and lopsided priorities, affected by local and city governance politicking, gimmicks, and agendas. These usually have the overall net effect of slowing down momentum and delaying the implementation of high-impact, low-carbon public transport projects, programmes and activities."

4.2 Implications of the Findings

The combined study findings have implications and expression in four interrelated and interdependent step-wise low-carbon transition scenarios. These re-imagined scenarios apply to different types of regions and urban areas in South Africa, but are not mutually exclusive. Figure 5 – 8 presents the four main images of low-carbon public transport transitions applicable to South Africa.

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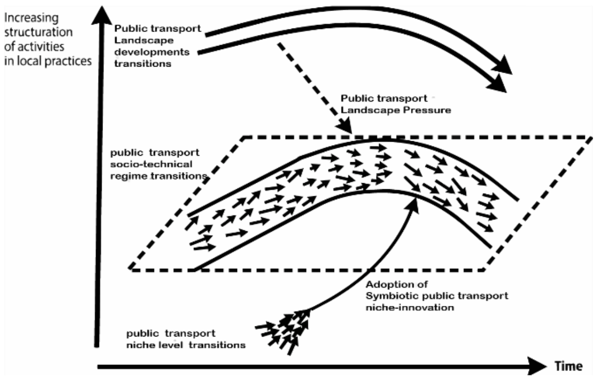

Figure 5. Low Carbon Public Transport Transformation (LCPTT) (Source, Adopted after Geels, 2002; 2016).

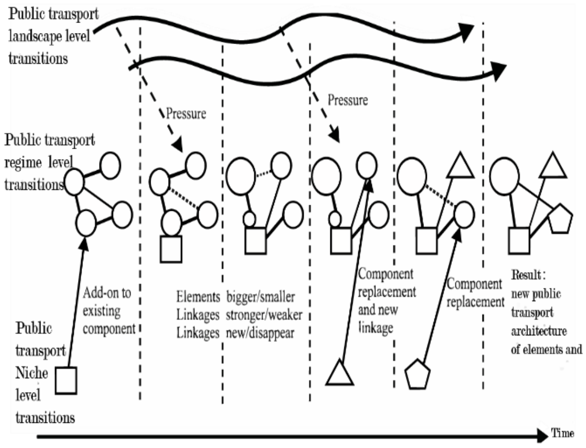

Figure 6. Low Carbon Public Transport Reconfiguration (LCPTR) (Source, Adopted after Geels, 2002; 2016).

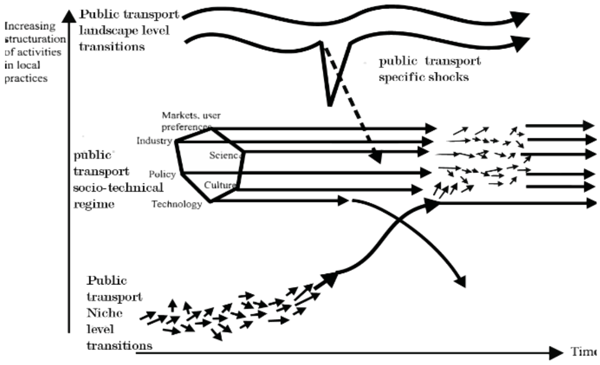

Figure 7. Low Carbon Public Transport Technological Substitution (LCPTTS) (Source, Adopted after Geels, 2002; 2016).

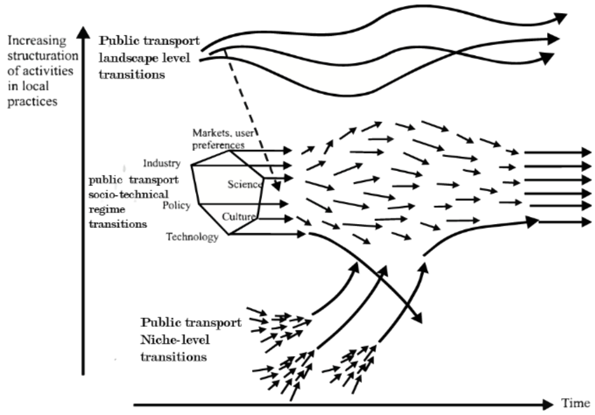

Figure 8. Low Carbon Public Transport De-alignment and Re-alignment (LCPTDR) (Source, Adopted after Geels, 2002; 2016).

4.2.1 Limitations of the Study

The study used a cross-sectional design. A longitudinal study approach can yield much deeper and sharper insights, as it is carried out over a longer period, e.g., 5, 10, 15, or 20 years. The 20 key insights are important for shedding light on and highlighting the headline issues confronting the low-carbon mobility transition debate. However, a larger sample size of key enough interviews could have yielded greater insights and higher levels of validity for generalising the results than the current sample. 7 out of the 9 provinces were used as case studies. While this was representative, it would not be the same if all 9 provinces in the country had been sampled and the results subsequently analysed.

4.2.2 Recommendations for Future Research

These can take the form of futures and foresight studies, modelling and simulation studies, technology transfer and implementation studies, as well as skills and capacity building and readiness studies covering the following topics or themes:

- Low-carbon mobility transitions in South Africa: The Rail Sector
- Low-carbon mobility transitions in South Africa: The Marine Sector
- Low-carbon mobility transitions in South Africa: The Aviation Sector

- Low-carbon mobility transitions in Southern Africa: Country Comparative Studies
- Low-carbon mobility transitions in Africa: Country and Regional Blocs Comparative Studies
- Low Carbon mobility transitions in the World: Global North, Global South, Global East & Global West Comparative Studies
- Low carbon mobility transitions and the Fourth Industrial Revolution in South Africa, Southern Africa and Africa

5. Conclusions

This manuscript has reimagined South Africa's public transport system's low-carbon transition, drawing on the Multi-Level Perspective (MLP) theoretical lens. The reimagination of public transport's low-carbon transition is occurring in the context of rapid urbanisation, shifts in geopolitics, the climate change crisis and emergency, rapid motorisation, rising pollution levels, failing and ageing infrastructure, and spatial inequality and fragmentation. Differentiated and uneven low-carbon transitions across transport modes and industrial sectors constitute agents, drivers, and enablers of change that frame the unfolding imaginaries of low-carbon public transport transitions in South Africa. The case studies from Limpopo, Gauteng, Eastern Cape, Western Cape, Mpumalanga and KwaZulu-Natal provinces have assisted in unravelling the conflicting rationalities and realities associated with advancing just public transport low-carbon transitions in South Africa. Reimagining low-carbon urban transport and mobility transitions in South Africa is not enough and is incomplete without a complementary and proportionate development of at-scale rural mobility transitions.

The low carbon public transport transitions landscape pathways and impact in South Africa is influenced by the following four interrelated drivers and factors of change and transformation: complexity and scale; differentiation and transformation; history and public transport infrastructure architecture; flexibility, re-engineering and repurposing; and value system and transport dividend ecosystems. The application and context customization of Geels (2016) multi-level perspective (MLP) transitions and pathways theory to low carbon public transport in general and South Africa in particular expands and extends the theoretical and practical application of the theory (Geels et al., 2016). This is now being expanded beyond the original application fields of interdisciplinary studies of innovation studies, evolutionary economics and sociology of technology to multi-disciplinary fields of architecture and the built environment including transportation planning and engineering, construction management and urban planning (Geels, 2019; Geels & Locatelli, 2024). Additionally, the manuscript presents evidence based research regarding navigating tensions between rapid and just low carbon transitions making use of South Africa as a case study thereby enriching and contributing towards practical ways in implementing the just and low carbon public transport transitions in developing countries (Newell, Geels, & Sovacool, 2022). The manuscript main contribution is proposing that a reimagined low carbon urban transport and mobility transitions is not enough and complete without a complementary and proportionate development of at scale rural mobility transitions. Striking a balance between different forms of low carbon public transport transitions hierarchy images and scenarios in South Africa requires an understanding of the history and context of public transport development and pathways in South Africa.

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Conflicts of Interest

"The author(s) report no conflicts of interest."

Data Availability Statement

All data generated or analysed during this study are included in this published article and its supplementary files.
The anonymized interview transcripts are available from the corresponding author upon reasonable request.

Institutional Review Board Statement

The study was approved by the Ethics Committee of the University of Venda (Ethical Clearance Approval No FSEA/22/URP/15/1707 November 2022 and FSEA/25/URP/01 November, 2026).

CRediT Author Statement

Conceptualisation: J.C.; Methodology: J.C. Writing – original draft: J.C.; Writing – review & editing: J.C.; Visualisation: J.C.; Supervision: J.C. All authors have read and approved the final version of the manuscript.

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