DECARBONISING PASSENGER TRANSPORT: BRT OPTIONS, INFRASTRUCTURE, AND COLLABORATIVE PRIORITIES

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ABSTRACT

As the impacts of climate change become more visible, the call for solid action on reduction of greenhouse gas emissions has become stronger. Transportation has a key role in the South African decarbonisation context. In this study we explored the role of electrified bus rapid transit systems (BRT) in decarbonisation programming. By focusing on urban passenger transport, we evaluated the suitability of two BRT electrification options of decarbonising BRT using meta-analysis and road mapping. Additionally, by adopting a multi-disciplinary ecosystem view in the analysis, the constraints to implementation and potential role of collaboration were evaluated. Findings show that a hybrid configuration that combines battery electric and fuel cell electric vehicles should considered in deep decarbonisation to fulfil national and private sector stakeholder requirements. In the solution design phase, a multi-disciplinary ecosystem improves understanding of stakeholder requirements. Further, collaboration of key stakeholders lowers execution risk by improved risk allocation. The findings and conclusions of this study contribute to improving the application of fact driven policy and the development of robust transport decarbonisation programmes. However, further studies incorporating lifecycle cost-benefit analyses are required for higher fidelity decarbonisation programme designs.

1. INTRODUCTION

Transportation is one of the biggest drivers of fossil fuel usage that has resulted in anthropogenic greenhouse gas emissions rising to unprecedented levels (Singh et al., 2015). The rise of greenhouse gases has been shown to be related to climate change which has been characterised by rising temperatures (Kellogg, 2019). As a response to climate change, the global community has begun efforts to decarbonise their economies and the decarbonisation of the energy and transportation sectors is expected to play a significant role in the decarbonisation process (Gössling & Scott, 2018; Zawieska & Pieriegud, 2018; Victoria et al., 2019).

South Africa is one of the countries with the highest carbon intensities in the world (Goh et al., 2018). This trend has been driven by the dependence of the country on coal for power generation and fuel produced by coal to liquid processes (Jin & Kim, 2018). In 2015, direct transportation carbon dioxide emissions contributed 12.6% to South Africa's gross carbon dioxide emissions (Department of Environmental Affairs, 2020). Due to the impact of the transportation sector on emissions, it is imperative that the transportation sector plays a key role in decarbonising the economy.

South Africa’s efforts in reducing the emissions contribution of transportation are outlined specifically in the Green Transport strategy (GTS) Department of Transport (2018) and more broadly in South Africa’s Low emission development strategy (SA LEDS) 2050 (Department of Environmental Affairs, 2018). Together, the GTS and SA LEDS articulate commitment to reduce transport emissions by 5% by 2030 to achieve the nationally determined contributions (NDCs) (Department of Transport, 2018). The specific means of attaining this reduction include a combination of measures including infrastructure improvements, vehicle efficiency standards, fuel switching to reduce emission factors and strengthening roadworthiness systems (Department of Environmental Affairs, 2018, Department of Transport, 2018). While the strategies identify areas of action, they are not prescriptive in the pathway to be used so while transport electrification is mentioned, there is no prescription of the means of vehicle electrification. Hence, further research is required to facilitate the selection of specific decarbonisation pathways for the strategic areas in the national strategy.

This paper presents a discourse on the decarbonisation of public transport in line with the strategy to promote a modal shift towards more efficient and easier to decarbonise modes as outlined in the GTS (Department of Transport, 2018). It aims to close the existing gap in public transportation decarbonisation by selecting potential technology options and evaluating their suitability taking into consideration other non-technical factors that affect implementability. In the study we focus on Bus rapid transit (BRT) systems and pursue the answers three questions which include i) what are the national requirements for deploying BRT for decarbonisation? ii) which electrified BRT options best fulfil the requirements for the South African context? and iii) what are the constraints and enablers in implementing the options? We depart from the narrow focus on the disciplinary specific benefits to selection and implementation of transport decarbonisation solutions. Instead, we adopt a broader multi-disciplinary approach that considers how the actor interactions and expectations solution ecosystems. Further, it explores how to gain wider solution acceptance that would aid the realisation of the anticipated benefits. The findings and conclusions of this study contribute to improving the application of fact driven policy and the development of robust transport decarbonisation programmes.

2. THEORETICAL FRAMEWORK

Academic research often articulates decarbonisation as a purely technological or behavioural transformation exercise, and this often results in oversimplification of programmes resulting in subpar performance (Mulholland et al., 2017). Taking time to understand the needs of key players in the implementation context, through a participatory ecosystems approach, can help avoid adoption of inferior solutions (Godínez-Zamora et al., 2020). Understanding stakeholder expectations and priorities avoids project acceptance failures like the Gauteng freeway project (Malahleha, 2011; Pienaar, 2012, Parrock, 2015). Sections 2.1-2.3 articulate the South African context for decarbonisation, decarbonisation rationale and a justification of the focus on decarbonisation of bus rapid transit systems (BRT) in South Africa.

2.1 The Context for the Decarbonisation of the South African Transport Sector

South Africa relies on four main modes of transport: air, maritime, road and rail (Department of Transport, 2018). However, the domestic transport market consists mainly of road and rail transport which account for the bulk of passenger and freight transport. considering the fuel requirements, road transport has a greater share of activity, compared to rail and air, accounting for 88% fuel demand in the domestic context (Stone et al., 2018). According to Statistics South Africa (2019), both freight and passenger rail traffic continues to decline while road transport consistently grows. In terms of emissions, the transportation sector emitted 10.8% of national GHG emissions in 2010 (Devarajan et al., 2009) and that had risen to 13% by 2017 (Merven et al., 2019). Of the total, road transport has the biggest share of emissions accounting for 90% of the greenhouse gas emissions from land-based transport as shown in Figure 1 (Department of Environmental Affairs, 2016). Hence, when considering transport decarbonisation, road transport sector offers a significant opportunity.

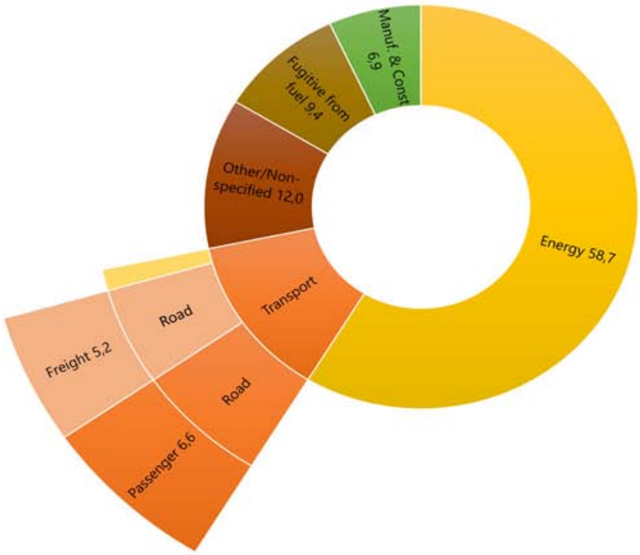

Figure 1: Breakdown of 2017 South Africa GHG emissions by sector (Source: DoEA, 2020)

The distribution in emissions between freight and passenger road transport are almost evenly split at 44% and 56% of road transport emissions (Venter & Mohammed, 2013). This is consistent with the South African fleet configurations where registered higher emitting passenger vehicles were almost two and half times as many as freight vehicles at the time of reporting (Stone et al., 2018). Further, in the passenger transport segment, the majority of South Africans use higher emitting private vehicles compared to lower emitting mass transport options like buses or trains (Stats SA, 2019). While there has been growth in the road transport sector, the composition of fleet in terms of passenger and freight vehicles has not significantly changed when considering changes like dieselisation of the fleet (Merven et al., 2019).

2.2 Decarbonisation Rationale

The emissions attributable to passenger transport are equal to the sum of modal emissions associated with travel activity. This can be expressed mathematically, by the Equation (1).

$$\text{Passenger transport emissions} = M_T \times \sum (I_{ij} \times x_{ij} \times E_{ij}) \quad (1)$$

Where:

M_T total passenger miles per period, I_{ij} is the modal intensity for mode i using fuel j, x_{ij} is the modal share of mode i using fuel j and E_{ij} is the emission factor of mode i using fuel j.

From Equation (1) it can be seen that emissions will increase with increased passenger activity and average modal emissions. To decarbonise the options should be based on reducing the passenger mileage, fuel consumption, selecting less intense modes and less emission intense fuels. Modal intensity incorporates the efficiency of different technology options and can thus be used to assess impact of changes in technology within modes and fuel categories. Analysis of the effectiveness of interventions can thus be evaluated using Equation (1) for example where urban design is used and has an impact on passenger mileage and influences vehicle efficiency (Zawieska & Pieriegud, 2018).

Using similar logic, several strategies for transport decarbonisation are being applied including integrated smart city design (Zawieska & Pieriegud, 2018), deployment of vehicle efficiency and roadworthiness standards (Vanderschuren & Jobanputra, 2005), alternative fuel programmes (Hallquist et al., 2013; Suleman et al., 2015), battery electric vehicles (BEVs) (Kontou & Miles, 2015) and fuel cell electric vehicles (FCEVs) (Lajunen & Lipman, 2016). None of the solutions satisfy the requirements for every context, hence, each nation needs to consider its context and select solutions that will yield meaningful results in its decarbonisation programmes (Tvinnereim & Mehling, 2018).

2.3 Why Focus on Bus Rapid Transit System Decarbonisation

Bus rapid transit systems (BRT) are bus-based systems that make use of high-capacity buses and prioritised roadways to enhance road commuting systems (Ni, 2018). They can be standalone or can be connected to a feeder mode such as a park and ride station (Currie, 2006). According to Dittmar and Ohland (2004), BRT is an integrated approach as it involves some spatial planning approaches to optimise flow and capacity of development corridors. The integrated approach is particularly important where park and ride configurations are used due to the high space requirement (Dittmar & Ohland, 2004). On their own, conventional BRT systems contribute to decarbonisation by aggregating passengers and using higher efficiency vehicles, thus in Equation (1) decarbonisation achieved by reducing congestion which contributes to low fuel efficiencies (Sebastiani et al., 2016). Further decarbonisation can be achieved by electrifying with low carbon renewable electricity sources such as wind and solar. The interfaces of BRT with other transport modes and the number of parameters that can be manipulated inn Equation (1) to achieve decarbonisation make BRT systems a robust platform for understanding the dynamics of decarbonisation programmes in the transport sector.

3. BRT ELECTRIFICATION OPTIONS FOR DECARBONISATION

Two pathways were identified for achieving deep decarbonisation of BRT systems through electrification. The first pathway is the use of low carbon electricity to charge batteries on board the buses and create conventional battery electric buses and these are discussed in 3.1. The second uses low carbon electricity to produce hydrogen and the hydrogen is used in on-board fuel cells and the features of this option are discussed in 3.2. The use of either has advantages and disadvantages.

3.1 Battery Electrified BRT (BEV BRT)

Battery electric vehicles work by being driven by an electric drivetrain using electrical energy stored in a battery and generally refer to all electric battery powered vehicles (Grebe & Fischer, 2018) as opposed to hybrid powered PHEVs (Fiori et al., 2017). BEVs come in three configurations based on the battery and charging mechanism; flash, opportunity and overnight charged BEVs (Sebastiani et al., 2016). Using current technology, the charging time comes at a cost to the range that the battery storage can provide to the vehicle (Mohamed et al., 2017).

Several issues hinder adoption of BEVs including prohibitive cost of purchase (Safari, 2018), short range, lengthy charging times (Rezvani et al., 2015) and generally suffer from a poor market image. As a result, they tend to need added support to stimulate acceptance in the market (Lévay et al., 2017). These challenges may be significantly constraining for vehicles that have commercial application as turnaround times between trips has an impact on the fleet size and revenue generation potential. However, they are advantageous with respect to the cost of ownership which tends to be lower than conventional transit vehicles (Wu et al., 2015). Developments in technology are ongoing and transit optimised BEVs are nearing full commercialisation in several countries (Zhou et al., 2016).

3.2 Fuel Cell Electrified BRT (FCEV BRT)

Fuel cell electric vehicles are closely related to BEVs with the energy storage and deployment mechanisms being the main difference (Lajunen & Lipman, 2016). While BEVs store energy in batteries that can be charged on or offboard, FCEVs use hydrogen as the energy carrier and the conversion of power to gas tends to be done off-board (Cai et al., 2019). Due to storage of energy as hydrogen, there is use of a fuel cell stack to produce the electrical energy for providing propulsion and powering on-board systems. FCEVs tend to have an operational advantage of longer range and shorter charge times (Lajunen & Lipman, 2016). Challenges with hydrogen include higher fuel pricing and low volumetric density which may complicate onboard storage. However, developments on the production and storage frontiers are making FCEVs competitive with BEVs (Bessarabov et al., 2016). Additionally, for South Africa, growth of a hydrogen economy would open doors for creation of new economic activity that can enhance the value added by the minerals industry particularly the platinum industry thus spreading the benefits (Pillay & Ntuli, 2016; Bessarabov et al., 2017).

4. STAKEHOLDER REQUIREMENTS AND IMPLEMENTATION CONSTRAINTS

4.1 Decarbonisation Policy

South Africa’s decarbonisation policy is embodied by the Green Transport strategy (GTS) (Department of Transport, 2018) and more broadly in South Africa’s Low emission development strategy (SA LEDS) 2050 (Department of Environmental Affairs, 2018). Together, the GTS and SA LEDS articulate the strategic activities to reduce transport emissions by 5% by 2030 to achieve the nationally determined contributions (NDCs) (Department of Transport, 2018). The measures include smart urban design, intelligent e-mobility, infrastructure improvements, vehicle efficiency standards, fuel switching to reduce emission factors and strengthening roadworthiness systems (Department of Environmental Affairs, 2018; Department of Transport, 2018). These policies are supported by specific sectoral instruments e.g., Land transport act, Public transport act, environmental management act and the carbon tax act. In addition, decarbonisation activities that create opportunities for local manufacturing are also documented in Department of Trade and Industry’s (DTI) Industry policy action plans (IPAP) (2014, Department of Trade and Industry, 2017).

4.2 Other Stakeholder Requirements

The degree to which a programme meets stakeholder needs determines its success (de Oliveira & Rabechini Jr, 2019). There are several stakeholders in the transport decarbonisation process, and they have may interests that are not be aligned (Clapp et al., 2010; Biber et al., 2016). To cater for the needs of stakeholders in decarbonisation we used the guidelines of the PMI project management Body of knowledge (PMBOK) to identify and analyse stakeholder needs (de Oliveira & Rabechini Jr, 2019). The summary of stakeholders and their needs is summarised in Table 1.

Table 1: Summary of key stakeholders and their needs in the transport decarbonisation

	Stakeholder/Interest group	Description	Interests/Requirements
1	*Citizens & Business community*	South African citizens	• Affordable, accessible, safe, reliable transport (Walters, 2013)
2	*Government of South Africa*	Central government	• Achievement of development objectives (National Planning Commission, 2013) • Service delivery
3	*Implementing government departments*	Department of Transport (DoT), Department of environmental affairs (DEA),	• Reliable, affordable, accessible, safe, and sustainable transport sector (Walters, 2013) • Achievement of GHG reduction targets in NDCs (Department of Transport, 2018) • Improved air quality (Department of Environmental Affairs, 2018)
4	*Supporting government departments and SOEs*	Treasury, South African Revenue Service (SARS), Department of Energy (DOE), Department of Trade and Industry, Eskom	• Efficient transport to enable the economy (Department of Transport, 2018) • Optimised fiscal collection and expenditure (Devarajan et al., 2009) • Optimised infrastructure configuration and utilisation • Local industry stimulation (Department of Trade and Industry, 2017)
	Regulators	NERSA, DEA, SANS/SABS/SATAS	• Protection of consumers/Environment • Compliance with relevant systems and standards
6	*Local governments*	Metro/Local/District Municipalities	• Service delivery and smooth, sustainable operations (Jance, 2018)
7	*Industry Associations*	SAPIA, SAPRA, NAAMSA, AIEC, SABOA.	• Effective collaboration for transformation of sectors for effective climate change adaptation
8	*Development Agencies*	Industrial Development Corporation (IDC), Technology Innovation Agency (TIA), Development Bank of Southern Africa (DBSA)	• Capacity and infrastructure development (Department of Trade and Industry, 2017)
9	*Multilateral development agencies/Institutions*	GIZ, African Development Bank (AfDB), World Bank, Southern African Development Community (SADC), African Union (AU)	• Development finance for capacity development (Wright and Fjellstrom, 2003, Dane et al., 2019)
10	*Unions*	National Union of Metalworkers of South Africa (NUMSA), South African Transport and Allied Workers Union (SATAWU) and Congress of South African Trade Unions (COSATU)	• Protection of employee interests: jobs, conditions of service.

5. IMPLEMENTATION CONSIDERATIONS FOR SUCCESSFUL DECARBONISATION

For decarbonisation to be successful, they need to satisfy the needs of all key stakeholders and overcome implementation constraints (Oke et al., 2017; de Oliveira & Rabechini Jr, 2019). Sections 3 and 4 presented an exploration of the options for decarbonising BRT and the key stakeholders and their interests, respectively. In sections 5.1 and 5.2, taking into consideration the stakeholder requirements, we present the recommended solution configuration and potential impacts, implementation constraints. Finally, in 5.3 we propose the collaborative areas that should be focused to produce a BRT decarbonisation programme that meets the requirements of key stakeholders.

5.1 Recommended BRT Electrification Option Configuration and Potential Impact

BEVs and FCEVs are the most readily deployable and mature technologies that can be used to achieve this. However, when considering the wider implications of deploying either of the technologies, BEVs may be advantages for trip distances less than 160km while FCEVs are better for longer trips (Thomas, 2009). Considerations for the implementation context suggest a hybrid BEV and FCEV fleet may be the best way to decarbonise BRT through electrification. Since BRT usage aligns with GTS strategy of promoting public transport usage in urban centres, it is likely to have negative impacts that will create resistance from some stakeholders when it is scaled to national scale. A summary of the likely impacts of BRT decarbonisation when deployed at national scale include:

- Negative shift in demand for petroleum-based fuels, as j in Equation (1) changes from fossil to renewable energy, with negative impacts along petroleum value chains that could affect up to 100000 workers (Dane et al., 2019). The associated workers unions can be expected to fight this unless alternative solutions that help the workers are presented.
- Petroleum infrastructure will become stranded e.g., refineries, service stations, transportation, and storage infrastructure (Dane et al., 2019). Owners of these assets can be expected to be a source of resistance to decarbonisation programmes.
- Increased usage of public transport is likely to weaken private vehicle demand which will affect the vibrant automotive sector which may also lead to job losses and small business closures (Pitot, 2011; Department of Trade and Industry, 2017).
- Small businesses that were serving the fuel retail, private motor vehicle and MBTs industries my lose markets due to decreased uptake (Dane et al., 2019).

5.2 Implementation Constraints

Decarbonisation through implementation of BEV and FCEV BRT will shift the energy sourcing from fossil fuels to cleaner and more renewable sources and this will create shifts in infrastructure necessitating an investment in a new configuration of infrastructure in urban areas.

I. *BRT system design*:
   - Improve access through feeder networks (Adewumi and Allopi, 2013, Walters, 2013), security, and safety (Onatu, 2011; White, 2016; Mthimukhulu, 2017) in BRT networks.

- Improve ticketing systems to make BRT systems interoperable between corridors e.g., Tshwane, Ekurhuleni, Rea Vaya systems and Gautrain systems (Onatu, 2011).
- Resolution of contracting challenges with BRT service providers and partners from conventional bus systems and MBT arrangements, including payments management (Du Toit, 2009; Williams, 2017).

II. *Urban transport infrastructure delivery:*

- Whilst system design constraints in (i) mostly deal with acceptance of BRT as an option and smooth operation, urban infrastructure constraints involve overcoming legacy spatial designs that do not facilitate efficient operation of BRT (Onatu, 2011; Jance, 2018; Ni, 2018). Overcoming this constraint, creates a base platform for efficient low carbon BRT system (Parmar & Kasundra, 2019).

III. *Energy infrastructure*:

- Expansion of low carbon affordable sources of energy e.g., solar and wind will be critical for the success of BRT (Department of Environmental Affairs, 2018).
- Investment in renewable low carbon hydrogen production and distribution systems.
- Development and standardisation of design, operation, and safety codes for BRT network infrastructure (Angelina et al., 2017).

IV. *Electrification technology localisation*:

- Technology ecosystems for transportation fuel cells and flash charging technologies that is required in electrifying BRT, though mature in other markets, need to be localised to reduce risk and drive operational and maintenance costs down (Kontou & Miles, 2015; Li et al., 2016; Sebastiani et al., 2016).

5.3 Potential Areas of Collaboration to Minimise Execution Risks

In Sections 5.1 and 5.2, potential pitfalls that could hinder the acceptance and successful implementation of BRT electrification emerged. Several of the challenges affect more than one stakeholder group, hence a collaborative approach to resolving negative impacts and implementation constraints is proposed in Table 2 as five collaboration areas and respective priorities for collaborative clusters.

6. CONCLUSION

Road transport is a significant contributor to carbon dioxide emissions in South Africa and is thus a crucial part of the national climate change response. Due to rapid urbanisation, public transport in urban centres has also become a key element of the transport decarbonisation dialogue. The complexities of urban public transport mean that there is no single solution for all cities, hence, cities need to evaluate the decarbonisation options that fulfil their requirements. However, the common element of decarbonisation programmes is their multi-stakeholder nature which makes decarbonisation complex and thus risky. In this study we focused on exploring options for using electrified BRT as a tool for decarbonisation in urban cities and examined the needs of key stakeholders and how to improve chances of successfully decarbonising with BRT. A unique feature of this study was the deviation of the practice of academic studies that tend to focus on attaining discipline specific goals and ignore the other salient aspects affecting implementability of potential solutions. The recommendations from such studies then fail to find broad acceptance when tabled for implementation. The first key lesson from our study is that due to the spatial features of South African urban centres, both BEV and FCEV BRTs should be considered in to craft a hybrid solution in using BRT to decarbonise urban transport. Secondly, adopting an ecosystem view allows the inclusion of key stakeholders that would be excluded if traditional approaches to stakeholder identification are used. Thirdly, the multi-disciplinary nature of ecosystems approaches can enhance visibility of stakeholder shared interests thus improving the chances of acceptance of decarbonisation recommendations that emerge from academic research. Finally, adopting multi-disciplinary perspectives in facilitating collaboration can enhance cooperation between stakeholders that might appear to not have shared interests. One of the key limitations of our study was the lack of quantified lifecycle costs for the different programme designs. However, the scope for such a multi-city exercise would require a separate study and is thus is recommended as separate future feasibility research.

Table 2: Collaboration priorities in BRT decarbonisation programmes

Item	Collaboration area	Collaboration Priorities
1.	BRT expansion	• Development of safe, reliable, and affordable services (McCaul, 2009, Onatu, 2011) • Collaboration of Municipalities, department of transport, infrastructure developers and service providers to supply reliable and affordable services (Department of Transport, 2018)
2.	Infrastructure adaptation	• Provision of low cost, low carbon power Infrastructure development through collaboration of IPPs, NERSA, Eskom, Equipment, and part manufacturers. (Department of Environmental Affairs, 2018) • Development of charging infrastructure codes and standards for local BRT systems through collaboration of Eskom, Municipalities, Council for Scientific and Industrial Research (CSIR) and academic institutions.
3.	Human capital adaptation management:	• Collaboration between companies, training institutions, unions in developing and providing transitional retraining to equip employees with relevant skills for emerging industries.
4.	Technology ecosystem strengthening	• Collaboration between DTI, IDC, TIA, CSIR, Manufacturers in the expansion of local ecosystems to supply components for hydrogen production, batteries, fuel cells, vehicle spares etc. (Department of Trade and Industry, 2017) • Collaboration between freight and passenger industry vehicle providers to lower the technology costs for FCEVs
5.	General transition management	• Collaboration between Treasury, Multilateral institutions, Unions etc in smoothing of cost and benefit allocation in the transition process so that vulnerable members do not bear most of the costs e.g., small businesses and individuals (Department of Environmental Affairs, 2018)

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