IMPLICATIONS FOR TRANSITIONING TO AN ALTERNATIVE FUEL BUS FLEET: A COST AND CLIMATE IMPACT PERSPECTIVE

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ABSTRACT

Since the inception of the Paris Agreement in 2015, commitments to a more sustainable long-term climate change outcome have taken traction in both the public and private sector. This can be seen in changes in international norms and standards, local policy and legislation, adoption of green technologies and utilisation of sustainable sourcing and materials.

In the transport sector, these changes have taken the form of efficiency improvements in existing technologies including internal combustion engine vehicles, the introduction of electric and hydrogen powered vehicles, policies incentivising the ownership of electric vehicles, access to financing through climate funds and many others. For public entities responsible for ensuring viable public transport, the question of transitioning to alternative fuels is now a pertinent one.

This paper examines the anticipated cost and climate impact associated with the transition to an alternative fuel bus fleet in the South African context. This is done through estimating the total cost of ownership of various bus types and demonstrating the impact on cashflows and budgeting for given scenarios. Moreover, it estimates the reduction in tailpipe emissions associated with diversifying the bus fleet mix, particularly in the context of improved emission of internal combustion engine vehicles. Lastly, it considers the economic context of South Africa, and the balance of committing to decarbonisation strategies, while addressing infrastructure and other needs.

1. INTRODUCTION

1.1 Introduction

Sustainability has become embedded in our decision-making process when considering the formulation of policies, deployment of infrastructure and operations, and directing investment. In the South African context, this is reflected in various policy documents including the National Development Plan (Department of the Presidency, 2012), Green Transport Strategy for SA (Department of Transport, 2022), Green Paper on the Advancement of New Energy Vehicles in South Africa (DTIC, 2021), Sustainable Development Goals: Country Report 2023 (Statistics South Africa, 2023), IRP (National Department of Energy, 2019), Green Taxonomy (Department of National Treasury, 2022), among others. The National Land Transport Strategic Framework (2023-2028) acknowledges the environmental impact of transportation and planning authorities have implemented several interventions to mitigate these impacts. These include supporting green technology, particularly efficient vehicle technologies, promoting the adoption of electric vehicles (EVs), and encouraging the use of cleaner propulsion fuels like Hydrogen, Compressed Natural Gas, and Euro VI fuel standards (Department of Transport, 2023).

Green initiatives are also supported through a number of green funding opportunities such as Green Fund (South African Government, n.d.), Green Finance Platform (Green Finance Platform, 2024), Green Cape (GreenCape, 2024), green bonds provided by Africa Development Bank (AfDB) (DBSA, 2021) and in alignment with the Development Bank of South Africa (DBSA) Green Bond Framework. In addition to these funds are other financing institutions including private sector participation and banks like Investec, development finance institutions (DFIs) such as the Industrial Development Corporation of South Africa Ltd (IDC), together with National Treasury and the South African Reserve Bank (Meattle et al., 2023). Private capital, DFIs and industry play a crucial role in supporting the government by providing the necessary financing for implementing the outlined policy actions in the Electric Vehicles White Paper (DTIC, 2023) and guided by the DBSA Green Bond Framework (DBSA, 2021).

However, the South African development landscape and competing priorities are typical of a developing nation – should South Africa (SA) prioritise investment in education, healthcare, energy, housing, or transport? Should it follow international trends in investing in the deployment of EVs and associated infrastructure when the country experiences the worst rolling blackouts (i.e., loadshedding) yet (BizNews, 2024). Should the transport authorities responsible for ensuring a functional public transport system consider investing in the deployment of an electric bus fleet? While this paper doesn’t seek to answer all these questions, it will provide the reader with a better understanding of the developmental context of SA particularly in relation to global trends relating to transport and climate change, EV deployment and the energy crisis. Moreover, it will estimate the cost, and budget implication of deploying a battery electric bus (BEB) fleet, and the potential emission savings related thereto for various scenarios.

1.2 Aim of Paper

This paper aims to present the cost and climate impact of transitioning from a diesel to a BEB fleet, in the South African context. It discusses the current global- and local context of EV policy and deployment. Furthermore, it estimates the cost impact by calculating the total cost of ownership (TCO) of a typical bus fleet in SA, given a particular bus fleet mix and certain operational constraints i.e., annual kilometres (km) travelled.

In addition, this paper estimates the total cost of deployment of a BEB fleet over an 18-year period, and its associated atmospheric emissions. This is contained to the South African context where careful consideration is necessary in achieving an appropriate balance between climate change mitigation and competing developmental priorities. Various considerations are presented for transport authorities when planning for future development.

1.3 Problem Statement

Transport authorities are faced with a developmental dilemma of investing in infrastructure and public transport operations, in a rapidly changing environment. These authorities need to plan for future contexts, while balancing the needs of the present. To support effective decision making, policy makers and public transport authorities need to consider the TCO, total cost impact (in terms of cumulative cashflow on budgets), and emissions reduction measures of its public transport operations, in the context of global trends, competing domestic priorities and budget constraints.

2. SHAPING THE CONTEXT

2.1 Introduction

Since 1990, South Africa has experienced a significant rise in temperatures, doubling the global average increase. The country's National Adaptation Plan indicates a troubling trend of more frequent extreme weather events, including heat waves, slightly longer dry spells, and intensified rainfall (USAID, 2023). Such shifts underscore the urgency of addressing climate change, and pose a challenge to reshaping global development strategies to balance immediate needs with long-term sustainability.

The National Development Plan 2030 outlines SAs struggle with poverty, unemployment, and inequality (Department of the Presidency, 2012). A key strategy for overcoming these challenges is "decoupling" the economy from environmental damage. This implies breaking the link between economic activity, environmental degradation, and reliance on fossil fuels by shifting away from carbon-intensive economic practices towards environmentally sustainable alternatives. This transition is particularly challenging given SAs rich biodiversity (Convention on Biological Diversity, n.d.; Poulsen, 2020), juxtaposed with an unemployment rate of 31.9% (StatsSA, 2023). This, for instance, stands in stark contrast to India's average unemployment rate of 8.2% between 2018 and 2023 (Trading Economics, 2024).

The urgency of climate change demands innovative solutions. Many countries around the world face similar challenges and are adapting their approaches to combat this global crisis. Successful strategies often include implementing strong climate policies, encouraging the adoption and manufacturing of EVs, increasing EV use, and demonstrably reducing emissions. These efforts reflect a growing recognition that development and climate action must be aligned to ensure a sustainable future for all. This literature review explores how various countries are tackling these challenges by examining:

- Policy implementation.
- Incentives for EV adoption and manufacturing.
- Adaptation and uptake of EVs.

2.2 Global Context

Cities and metropolitan areas around the world are undergoing rapid urbanisation and this growth in urban population places an urgent need for efficient and well-developed mobility options, including comprehensive public transport networks, especially in developing and emerging countries (Jain & Draexler, 2021). Economic growth in recent decades, increased demand for private cars and falling costs have led to a significant increase in private car ownership and use, especially in developing countries, which contributes to air pollution, road traffic accidents, and has caused several urban problems such as urban sprawl and sustainable mobility challenges (Jain & Draexler, 2023). And so, there is a need to strike a balance between urbanisation, mobility, and sustainability. Early efforts to combat climate change focused on reducing greenhouse gas (GHG) emissions from developed countries. Following the Paris Agreement's implementation, over 180 countries pledged to make a significant contribution towards keeping the global temperature below 2°C and to take measures against further warming (Oreggioni et al., 2021).

Climate concerns in developed countries in the past decades has led to a focus on climate change mitigation policies being enforced in the developed world. In December 2019, the European Commission adopted the European Green Deal. The goal is for the EU to become a climate-neutral economy by 2050, working towards a zero-emissions goal. As of September 2020, the European Commission pledged to reduce net GHG emissions by at least 55% by 2030 compared to 1990, putting Europe on the path towards climate neutrality by 2050 (European Commission, 2021).

To ensure that Europe achieves its climate goal, it will implement a comprehensive infrastructure plan that incorporates alternative fuels and facilitates the transition to near-zero emission vehicles by 2050. The Sustainable and Smart Mobility Strategy shaped by the European Commission (2020), provides a framework for transforming the EU's transport system. Despite the transport sector's current reliance on fossil fuels, the strategy focuses on promoting zero- and low-emission vehicles and renewable fuels. Successful use of these fuels requires the development of a comprehensive and geographically balanced network of charging and refuelling infrastructure (European Commission, 2021). This strategy also recognises the importance of addressing regional differences so that EU regions are not left behind in the transition to sustainable transport. In particular, the uptake of low-emission vehicles in the passenger car market depends on the availability of convenient charging and refuelling infrastructure across the EU. The EU has created a regulatory environment with policies and strategies which encourage all its citizens to actively participate in climate change and emissions reduction.

Similarly, the Asian Pacific Economic Cooperation (APEC) Putrajaya Vision 2040 aims to pursue strong, balanced, secure, sustainable and inclusive growth by promoting economic policies that address environmental challenges such as climate change. The Vision's approach involves promoting economic policies, cooperation, and growth that support worldwide efforts to tackle environmental challenges, including climate change, natural disasters and extreme weather events (APEC, 2020). China for instance, is promoting the development of its EV industry through policies and measures that are advantageous to both car manufacturers and consumers. Additionally, entrepreneurs are urged to participate and enhance charging and other services. Not only are these policy initiatives applicable to domestically produced EVs, but some imported EV models, such as Tesla (Ge, 2023).

Since 2009 onwards, the Chinese government has released 39 policies, and more than half of these policies fall into the category of promotional measures, indicating a strong governmental focus on fostering the environment for EV development (Asia Pacific Economic Corporation, 2017). China introduced purchase grants, tax benefits, preferential vehicle registration policies, driving and parking privilege, government financial support for charging infrastructure, beneficial treatment for charging station, and incentives for using EV buses and like the European countries, has policies supporting these measures.

In Japan, however, EV regulation is not a universal policy, as multiple government agencies are involved in the development and supervision of automobile regulations. Emission standards; maintenance programs, vehicle inspections, and safety; industrial and energy policies are all driven by different ministries (i.e., Ministry of the Environment, Ministry of Land, Infrastructure, Transport and Tourism, Ministry of Economy, Trade and Industry).

Japan not only has policies enabling climate change and the use of EVs, but they have also been pioneering battery fuel cell manufacturing and EV production. There are numerous financial incentives that the Japanese government offers to encourage the uptake of EVs. EV purchases are currently subject to a subsidy between ¥650,000 (approximately ZAR83 655[1]), and ¥850,000 (approximately ZAR109 395[1]) depending on various factors such as distance travelled per charge, electricity consumption (similar to gasoline mileage), and availability of external power sources, power capabilities and other factors. Furthermore, from fiscal financial year 2024 onwards, the government will include evaluation items such as the number of charging points installed at each manufacturer's dealership and their ability to respond to repairs and maintenance (Shimbun, 2023). The country is home to several EV manufacturers (e.g., Honda, Nissan, Suzuki, Toyota, Yamaha among others) which are subsidised (Schroeder, 2013), and have been actively participating in the EV market since the 1970s.

One of the largest emitters of emissions the United States (US) (WRI, 2023), is actively working towards various climate mitigation objectives, with the overarching US strategy incorporating measures to address both short-term and 2050 climate objectives namely:

- A 50-52% reduction below 2005 levels, encompassing all business sectors and carbon emissions as set out in the 2030 National Determined Contributions (NDCs) (United States Department of State and the United States Executive Office of the President, 2021).
- Achieving 100% carbon pollution-free electricity by 2035(United States Department of State and the United States Executive Office of the President, 2021).
- Attaining net-zero emissions by no later than 2050 (United States of America, 2021)

The transport sector is the single largest source of greenhouse gas pollution in the US, accounting for 29% of US emissions (World Resources Institute, 2023). A major factor influencing the uptake of EVs in the US was the federal EV tax credit, originally established as part of the American Reinvestment Recovery Act of 2009 (World Resources Institute, 2023). In the US, there is a one-time state (federal) tax credit available to consumers when filing their income taxes, for the year in which they purchased an EV. The incentives range from $2,500 (approx. ZAR47 623[2]) to $7,500 (approx. ZAR142 871[2]) depending on the battery capacity of the EV (Kohn et al., 2022).

Besides the federal incentive, several other policies and programs have been introduced by states, utilities, and local governments to encourage EV adoption. The measures encompass rebates and state tax credits, access to High occupancy vehicles (HOV) lanes, investment in EV charging infrastructure, compliance with manufacturer sales requirements, and a decrease in oil-based fuel consumption. Taxes on these policy implementations have led to large differences in EV adoption between states, with California leading the way with a 17.1% EV market share in 2022, while states like North Dakota, with less than 1% market share, are trailing behind (as of 2021) (World Resources Institute, 2023). The US economy and its priorities are different from those of developing countries.

In developing countries like Ethiopia, India, and Haiti, the adoption of EVs is influenced by a more complex set of factors compared to industrialised areas like Europe and North America. While reducing GHG emissions remains a concern, the primary focus in these

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[1] Based on exchange rate as at 22 January 2023, 05:54 UTC

[2] Based on exchange rate as at 22 January 2023, 06:09 UTC

developing regions is often on socio-economic development, particularly in addressing underserved populations and eradicating extreme poverty (Dioha et al., 2022). Developing country policymakers are focused on the development of infrastructure and access to modern energy for basic services, leading to policies such as subsidies for fossil fuels and electricity tariffs. For EVs to gain commercial traction in developing countries, they must demonstrate the ability to address not only climate change mitigation, but also other critical challenges facing these regions (ibid).

The challenges in introducing EVs in developing countries include infrastructure, accessibility and affordability, and a technology and skills gap (Zamanov, 2023). One such barrier to the adoption of EVs in developing countries is the insufficient charging infrastructure. Building a comprehensive network of charging stations demands significant investments and careful planning, capacity for which many developing nations currently lack (Dioha et al., 2022; Gokasar et al., 2023; Zamanov, 2023). The lack of charging equipment makes it difficult for EV owners to find convenient charging points. Furthermore, the absence of dependable electricity hinders the widespread adoption of EVs in certain areas, and potentially more so in nations where fossil fuels are utilised for energy production (Zamanov, 2023). Apart from the infrastructure challenges, the purchase price of EVs remains high relative to their fossil fuel powered counterparts.

The high initial costs associated with EVs act as a deterrent to their adoption in developing countries. Prices of EVs, particularly the batteries, remain elevated compared to ICE vehicles, creating an affordability gap for a significant portion of the population (Kim & Hartmann, 2021). Limited availability of affordable EV models in these nations, coupled with manufacturers prioritising developed markets, further hinders widespread adoption (ESMAP & The World Bank, 2023; The World Bank, 2022). Additionally, the production and maintenance of EVs may encounter technical obstacles due to the lack of advanced technology and expertise in certain regions. Securing a qualified workforce for the maintenance and repair of EVs through capacity building and technology transfer initiatives is crucial for the sustainable integration of EVs in developing countries (Zamanov, 2023). Driven by the anticipated surge in EVs, researchers are actively studying various aspects of EVs, including energy consumption, Carbon Dioxide (C02) emissions, and TCO (Suttakul et al., 2022). Cities around the world are looking for ways to reduce air pollution, and electric buses are emerging as a potential solution (Rubnitz & Moon-Miklaucic, 2018).

However, the transition to electric buses isn't without its challenges. The biggest hurdle is the upfront cost. Electric buses typically have a higher purchase price compared to diesel models (Fernandes, 2022).This can be a significant barrier for public transportation agencies with limited budgets (Bligh, 2023). Additionally, electric bus batteries, while improving in lifespan, eventually need replacement, adding to the operating costs (Lander et al., 2021). The key to understanding the financial viability of electric buses lies in considering the TCO. This takes into account the purchase price, maintenance, fuel/electricity costs, and potential resale value over the entire lifespan of the bus (Woody et al., 2024). In many cases, electric buses can achieve a lower TCO compared to diesel buses when considering the long-term operational savings. Although this is not always the case (NDC Support Facility et al., 2019).

The TCO highlights the potential for significant long-term operational cost savings associated with e-buses, such as lower fuel costs and reduced maintenance needs. In the long term, operational cost savings can outweigh the higher upfront costs compared to diesel buses. In the case of Santiago, BEBs have the lowest TCO relative to diesel and

CNG for instance, with the TCO for diesel buses being 9% higher than for BEBs (NDC Support Facility et al., 2019). Triatmojo et al. (2023) found that for Trans Jakarta's electric bus adoption, high annual utilisation is necessary to achieve a TCO per kilometre competitive with conventional options. Increasing annual mileage from 71,000 km to 80,000 km significantly reduces the TCO gap, from 20% to 11%. In China, the BEBs that receive government subsidies have a TCO of 2.21 ¥/km, which is about 35% less than the TCO of 3.40 ¥/km on a diesel bus (Chen,Yang et al., 2021). This is similar Montevideo, where a subsidy for bus concessionaires allow diesel fleets to be at least 20% less than its electric counterpart (NDC Support Facility et al., 2019). It is therefore critical to understand context.

As governments invest in urban public transportation to reshape city dynamics, understanding the cost implications of transitioning to alternative fuel vehicle fleets is important. More importantly, the economics of decarbonisation (World Bank, 2015) are just not yet in favour of an all-electric solution as many manufacturers and customers still require subsidies, rebates or incentives to ensure financial feasibility (Chen, Yang et al., 2021). While governments in the developed context may be able to continue supporting these schemes, it is unlikely that this will realise in the developing context because of other competing priorities. However, many governments are offering financial incentives to encourage the adoption of electric buses and incentives can help public transport agencies bridge the gap between the higher upfront cost of electric buses and the lower long-term operational costs (Triatmojo, Safrudin, Posada, Kusumaningkatma et al., 2023).

Ultimately, the decision to transition to an electric bus fleet requires careful consideration. The encouraging aspect is that electric buses offer long-term cost benefits. They have fewer moving parts and require less maintenance than diesel buses (Minjares et al., 2020). Plus, the cost of electricity can be lower than diesel per kilometre (Kim & Hartmann, 2021) leading to significant operational savings over time. There is also the potential for infrastructure investment to be offset by these long-term savings. Installing charging stations and potentially upgrading the grid might be necessary, but the cost can be recouped by bus operators over the operating life of the bus, through lower operating expenses (Sclar et al., 2019).

2.3 Local Context

South Africa, like many other countries, has committed to reducing its GHG emissions through its signature of the Paris Climate Agreement (Martin, 2016), development of its National Determination Contribution document (South African Government, 2021) and, more specifically in the transport sector, the drafting of numerous policy documents as mentioned in the Introduction. Coupled with this, the SA government has begun opening the energy sector in SA to enable increased participation by the private sector in electricity generation, but to allow the private sector to procure energy from independent power producers (IPPs). This has been necessitated by on-going rolling backouts (since 2008), a significant increase in the price of electricity (Moolman, 2017), and de-risking energy security in SA. A major step toward enabling this has been unbundling (i.e., legally separating the generation, transmission, and distribution businesses within) the national utility, Eskom (Steenkamp & Weaver, 2022).

The challenges associated with Eskom, and the rolling blackouts have significantly impacted the country's ability to grow (Steenkamp & Weaver, 2022). This is reflected by poor economic growth experienced since the onset of rolling blackouts, with the average economic growth for the period 2008-2022 being 1.31% (never exceeding 3.2% with the exception of 2021 following a 6% contraction in 2020 as a result of the COVID-19 pandemic) (World Bank, 2024). This poor economic performance is further compounded by SAs inefficient ports (BDO South Africa, 2023), failing railway system (Tusini et al., 2021), poorly maintained road infrastructure (Businesstech, 2022) and the government's inability to resolve these challenges timeously (Gumede, 2022). These challenges are unsurprising given SAs history; however, progress is being made elsewhere in the transport sector, albeit slowly.

A crucial step forward by the SA government is the Green Transport Strategy for South Africa, as it acknowledges the pertinent need to reduce emissions within the transport sector and illustrates these through its key objectives. One of the objectives is that of supporting the transport sector in its transition towards climate resilient transport operations and infrastructure. While acknowledging the Department of Transport's (DoT's) responsibility in facilitating integrated public transport and balancing socio-economic needs, it also aims to mitigate the transport sector's contribution to climate change (Department of Transport, 2022). These two objectives alone set the direction and tone for implementing-agents to pursue.

Moreover, to encourage the adoption of EVs, the DOT has set out specific actions required – including the facilitation of incentives – for EV manufacturing and use of local materials in manufacturing crucial components, and investment in research and development of battery and other technologies among others. Furthermore, it acknowledges the need for collaboration between the DoT and the Department of Trade and Industry and support by National Treasury (Department of Transport, 2022). However, both the government and private sector are necessary if a transition to sustainable transport is to be realised.

The private sector has played a pivotal role in driving the transition to alternative fuel vehicles. This has happened through increased efficiencies in electricity generation technology and battery technology over the last 2 decades in particular, the deployment of EV charging infrastructure for public use (Bharadwaj, 2023; DTIC, 2023) and access to financing (Department of Transport, 2022; DTIC, 2023). This is reflected in the decreasing cost of electricity (per kWh) (on a levelized cost of electricity basis), increase in battery capacity and efficiency, increased driving ranges and decrease in charging times, and various funds that have created facilities for financing green technologies (Department of National Treasury, 2021, 2022; Meattle et al., 2023). Similarly, there has been an increase appetite in the adoption of BEB from public transport operators with entities such as the City of Cape Town issuing a Request for Information for the procurement of BEB in 2023 (EasyTenders, 2023). Golden Arrow Bus Service (a company providing road based public transport for 162 years) based in Cape Town has made significant progress in trialling electric buses in SA and has committed to transitioning its 1100 diesel bus fleet to an all-electric fleet over the next 18-years (Van Zyl, 2023).

Metros in SA have made commitments to reducing its climate impact (City of Ekurhuleni, 2023; City of Polokwane, n.d.; City of Tshwane, 2020; eThekwini Municipality, 2023; Ferreira & Simpson, 2022), including its impact through the provision of public transport services (Krynauw, 2015; Swart & Sasman, 2023). Addressing the issue of emissions in the public transport space relies on the spatial and development planning imperatives of the state, and emissions across the entire value-chain. If we assume development is realised in a way that facilitates efficient transport (e.g., mixed-use, transit-oriented development etc.), and that a conscious effort is made to reduce emissions across the value-chain, then addressing emissions through public transport operations are necessary.

It is also well documented that increasing the modal share of public transport relative to private vehicles reduces the emissions associated with transportation. This is an important step to be supported by education, in reducing the emissions associated with transportation. Additionally, employing demand side management interventions may reduce emissions, or moving to energy efficient transport. Part of energy efficiency improvements is upgrading to zero-emissions buses, that are, in the case of electric buses, charged by renewable energy (RE) sources (DTIC, 2023). Increasing generation has seen progress through the unbundling of Eskom and diversification of the energy mix in SA through an increase deployment of RE sources, as mentioned above (Steenkamp & Weaver, 2022).

Apart from the policy shift mentioned earlier, the uptake of EV in SA has been slow relative to global trends (Malinga, 2022) with EVs, hybrids and plug-in hybrids totalling 0.88% of SAs total new-vehicle sales for 2022 (Bubear, 2023). This is unsurprising as EVs constitute a significant upfront cost (relative to its diesel counterpart), primarily due to production and battery production costs, ad valorem tax, and import duties for instance (ibid). Moreover, the high cost of financing, on-going rolling blackouts, increasing price of electricity and range anxiety continue to play a role in deterring consumers from purchasing EVs. While the latter factors are less likely to inhibit the procurement of BEB for public transport, other factors come into play.

The energy requirement at depots to support the overnight charging of a 50 BEB fleet will potentially result in an increase in transformer capacity, in addition to acquiring of switchgear, and charging equipment. For metros that are operating with fleets above 100 buses, substantial infrastructure interventions are required. The depot design will also be a function of numerous operational factors (a charging strategy will likely need to be developed), while public transport operators may require the procurement of a larger depot, notwithstanding the issue of security of property. If the operators are to procure RE, then wheeling agreements will need to be put in place. Alternatively, operators can generate their own RE although this is unlikely given the space required to generate sufficient electricity to charge a BEB fleet (DTIC, 2023). For municipal bus services (including Bus Rapid Transit), this will all likely be funded through public funds, with cost reflective tariffs and full cost recovery being highly unlikely (ibid).

In terms of emissions, according to the WRI (2023), in 2019 SAs total CO2e emissions was 555.4Mt, of which the transport sector accounted for 58.5Mt (a little over 10.5% of total emissions in SA). The transport sector in SA accounts for 0.12% of global GHG emissions, with the combined global transport sector accounting for 8266.93 Mt of CO2e in 2019 (of the total 36948.98 CO2e emitted, i.e. 22%). The energy sector in SA is by far the greatest contributor of emission in SA and accounts for more than half of the total GHG emissions, followed by the transport sector. It is therefore imperative that both sectors implement emissions reductions measures, as charging EVs through electricity produced through coal-fired power, does very little to mitigate emissions (DTIC, 2023).

Despite the slow progress of implementing interventions to reduce its carbon footprint, South Africa has managed to develop the Green Transport Strategy, Electric Vehicle White Paper, South African Climate Finance Landscape which are positive steps towards realising the transition to climate-resilient transport and supports the use of EVs within the country. The strategies outline specific measures, incentives and cooperation between the state and private sector to promote sustainable transport. Transport authorities, bus operators and manufacturers are crucial in the transition to zero-emissions public transport and align with South African metro commitments to reduce climate impact.

Notwithstanding this, the challenges of high initial costs, financial nuisances during the adoption process, and slow adoption are still present, necessitating ongoing efforts towards a sustainable transition.

3. SCENARIO DEVELOPMENT AND ANALYSIS

This chapter discusses the approach, scenario development and assumptions, and analysis results. Additional information related to these can be found in Appendix A.

3.1 Approach

The approach followed is simple. Three scenarios were developed and the TCO, cumulative cost implication, and emissions impact of different bus fleet mixes analysed based on these scenarios. The TCO estimation methodology employed in this paper is typical for analysis of this nature and has been utilised in various studies including: Kim & Hartmann (2021), Onat & Khan (2022), and Suttakul et al. (2022), among others.

3.2 Model Development

An excel-based model was developed to estimate the TCO, cost and emissions impact of various scenarios. The model is a cashflow model, with provision for estimating tailpipe emissions. The modelling process is illustrated in Figure 1. The model is built on assumptions in order to simulate various scenarios, and as with any analysis of this nature the results need to be viewed in this context. More importantly, the results need to be viewed with cognisance of the limitations. The model is considered appropriate for making inferences regarding the cost and exhaust emissions for bus fleets in the South African context.

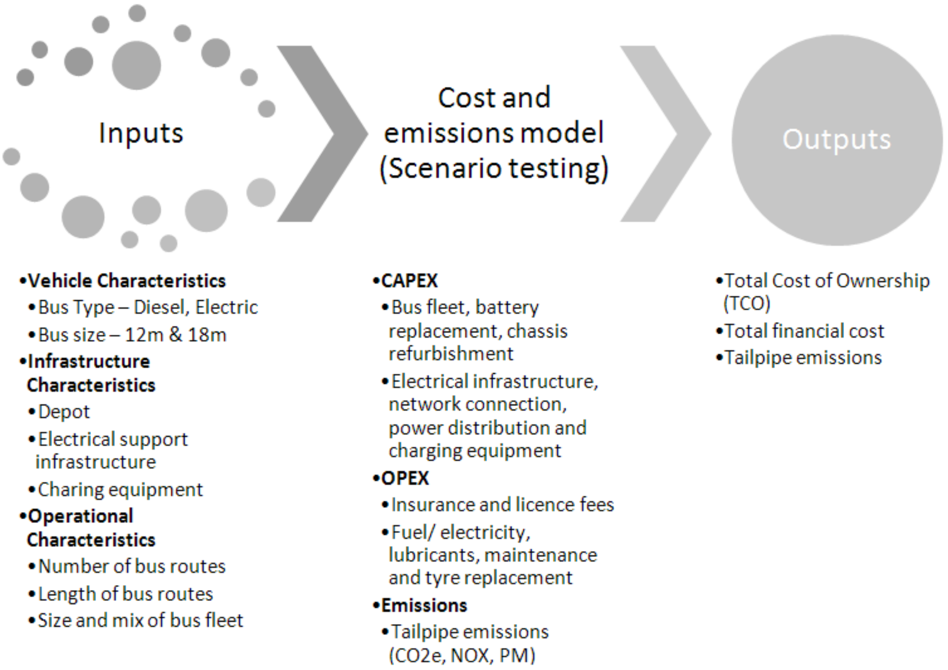

Figure 1: Modelling Approach

The inputs considered can be broadly categorised as those pertaining to vehicle characteristics, infrastructure characteristics and operational characteristics. For the estimation of cost and emissions, various calculations based on these inputs and assumptions are conducted. Costs considered are those pertaining to capital expenditure, for both bus fleet and associated infrastructure; and emissions considered are tailpipe emissions only.

As alluded to above, assumptions were made to simulate scenarios. These assumptions are tabulated in Table 1. These assumptions are presented under four categories namely: economic (economic parameters), financial (related to vehicle financing), operational (related to bus fleet), and infrastructure (related to depot, and charging equipment). See Tables 5, 6 and 7, in Appendix A for model inputs.

Table 1: Modelling assumptions

Category	Sub-category	Assumption
Economic	Base year	2023
	Monetary values	Nominal (excludes any inflationary changes over the analysis period.) Cashflows not discounted to present values
	Analysis period	19 years
	Residual value	20% of bus purchase price
	Other	Prices exclusive of VAT and shipping
Financial	Financing/ loan	For vehicle purchases only (excl. infrastructure & charging equipment) (no upfront payment/ deposit assumed)
		7-year repayment period Interest fixed at current prime lending rate (11.75%[3]) No deferment
Operational	Total fleet size	Fixed fleet size of 200 buses for estimating TCO and cumulative cost implication
	Fleet mix	Nominal 12m or nominal18m bus variant only
	Operational distance	Fixed distance travelled: 50 400 km per annum (pa)
	Operational period	18 years
	Other	EURO VI buses for replacement (scenario 0 and 1) One-off full fleet replacement – no staging. Battery replacement in year 10 of bus operations Major refurbishment of buses in year 10 of bus operations
Infrastructure	Electrical	Electrical infrastructure requirements a function of existing electrical capacity, bus fleet mix, and charging strategy
	Charging equipment	Charging at 2x depots only, no staging area charging requirements assumed
	Refuelling equipment	No upgrades, only maintenance
	Depots	No infrastructural upgrades for scenario 0, upgrades assumed for scenario 1 and 2 inline with the above
	Other	No electricity or diesel supply constraints

In this analysis, the TCO is the total cost of owning (capital expenditure i.e., CAPEX) and operating a bus fleet over the life of the bus (operating expenditure i.e., OPEX) (including dead milage), which includes the necessary electric infrastructure and charging

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[3] South Africa's prime lending rate as at 24 January 2024 (since 26 May 2023)

equipment. This is a reasonable assertion as, both the public and private sector would require the necessary infrastructure and charging equipment should they operate on electric only, or mixed bus fleet which includes electric buses. It is however acknowledged that the total cost of ownership may exclude operations, given different business models, or contracting arrangements between authorities and operators for instance, as one may own the vehicle but not bear the financial burden of operations.

Moreover, the TCO is assuming 1-year for the upgrade of necessary infrastructure and charging equipment (acknowledging that Scenario 0 has no upgrading requirement), in addition to an operational period of 18-years. The TCO, for all scenarios, is therefore calculated over a 19-year period. The TCO is therefore presented as a cost per km.

TCO = [(CAPEXfleet + CAPEXelectric) + (OPEXfleet + OPEXelectric)] / km travelled

The financial cost is the total cost of owning and operating a bus fleet over the life of the bus, and the necessary electric infrastructure and charging equipment, but not expressed in terms of km travelled.. For the purpose of this paper, the financial cost can be presented as cashflows over the analysis period.

FinCost = (CAPEXfleet + CAPEXelectric) + (OPEXfleet + OPEXelectric)

The total emissions are calculated as the total CO2e, Nitrogen Oxide (NOx) and particulate matter (PM) as a function of the operational kms of the bus fleet. These are generally measured in g/kWh, but have been converted to emissions per operational km i.e., g/km.

Em = km travelled x g/km

Emission impact modelling is simplified in that it estimates the emission on a per km basis irrespective of geography and climate. Moreover, it considers tailpipe emissions only.

3.3 Limitations

It is important to understand the limitations as the results need to be viewed with cognisance thereof. The primary limitations of the study are as follows:

- Future uncertainty is unaccounted for as all cost inputs are considered in nominal terms and are constant throughout the analysis period. For instance, no inflationary changes to inputs are assumed.
- Staggered procurement and deployment of bus fleet is not done. Ideally capital investments of this nature are time sensitive, and the phasing of procurement important to the overall cost implication of the entity funding the investment. However, full fleet replacement is assumed to take place at once.
- Tailpipe emissions are estimated only. The emissions associated with the full lifecycle of the bus was not considered. This is acknowledged as a significant limitation to the argument for proceeding with the deployment of BEBs on the basis of a reduction in emissions.

3.4 Scenario Development

The buses considered in this analysis are BEBs and diesel buses. Whilst diesel-electric hybrid buses exist, these are not considered in the analysis given their unavailability to the

South African market. Moreover, and in the South African context, BEBs are not yet manufactured at scale for procurement. For this analysis unless stated otherwise, diesel buses procured are assumed to be EURO VI standard. Furthermore, for each scenario an existing diesel fleet requires full replacement. To consider the cost and climate impact three scenarios were developed namely: a base scenario i.e., diesel only bus fleet, and an alternative scenario which considers a mix bus fleet (i.e., both BEBs and diesel buses), and a third scenario which considers a full BEB fleet. A summary of the three scenarios is presented in Table 2.

The first scenario (Scenario 0) considers a context where the public purse is constrained and cannot afford the premium (in terms of purchase price of buses) associated with early uptake of BEBs in the South African context. This scenario requires no additional infrastructure, and the procurement of diesel buses only.

The second scenario (Scenario 1) is based on current supply side market penetration constraints, for instance, minimum order quantity associated with the procurement of BEBs locally. Moreover, the supply side constraint for particular bus configurations (like 18m BEBs). This, coupled with the affordability, and balancing upfront expenditure for infrastructure, considers a minority of BEBs as part of the bus fleet mix.

The final scenario (Scenario 2) assumes no budgetary constraint, and no supply side constraints. This scenario is based on complete replacement of diesel buses and assumes BEBs only, with the necessary electric infrastructure and charging equipment to support the BEB fleet.

Table 2: Scenario summary

Bus Type	Scenario 0 (Full diesel)	Scenario 1 (Mixed fleet)	Scenario 2 (Full electric)
Total number of buses	200	200	200
Total number of diesel buses, and bus length	80 x 12m 120 x 18m	120 x 18m	N/A
Total number of BEBs, and bus length	N/A	80 x 12m	80 x 12m 120 x 18m
Availability	Numerous local suppliers, with technology readily available.	Currently BEBs available for import, with commitment for local production contingent on demand. 18m BEB available in the near future only	
Annual km travelled	50 400 km (12m and 18m)		
Cost of diesel (at the coast as at 04 April 2024)	R22,17/l	R22,17/l	N/A
Cost of electricity (incl. kVA charges)	N/A	R1.64/ kWh	R1.64/ kWh

3.5 Total Cost of Ownership

The TCO, as defined above, is presented in Figure 2. It is evident that there is a marginal difference between the TCO of Scenario 0 and Scenario 1 of less than 2%. In other words, a mixed fleet relative to a full diesel fleet provides for marginal savings only, in terms of its TCO. However, the difference between Scenario 0 and Scenario 3, is far greater at approximately 14% in terms of the TCO. This means that a full BEB fleet is less expensive on a TCO basis than that a full diesel fleet, given the assumptions. These results are similar to those of other studies as mentioned in Chapter 2.

Figure 3 and Figure 4 illustrate the costs related to the bus fleet itself. From these two graphs the difference in operating costs, between a full diesel bus fleet, a mixed bus fleet and full BEB fleets become clearer. Moreover, the greatest savings are in the bus operating costs themselves – fuel (i.e., electricity and/ or diesel), lubricants and tyre replacement.

The TCO of the three scenarios illustrate that, based on the assumptions, a full BEB fleet is less expensive relative to a full diesel fleet and mixed fleet. The magnitude of difference is between 14% and 41% (see Figure 2 and Figure 4), when considering the cost inclusive of all infrastructure, and excluding all capex respectively. Moreover, the results suggest that the greater the proportion of BEBs in the fleet, the lower the operational cost one could expect (relative to a full diesel fleet). It is however important to be reminded that context (and assumptions) is crucial in viewing these results, as a decrease in the operational kms per annum for instance would reduce the BEBs operational cost advantage, or similarly an increase in the cost of electricity, or a decrease in the cost of diesel for instance.

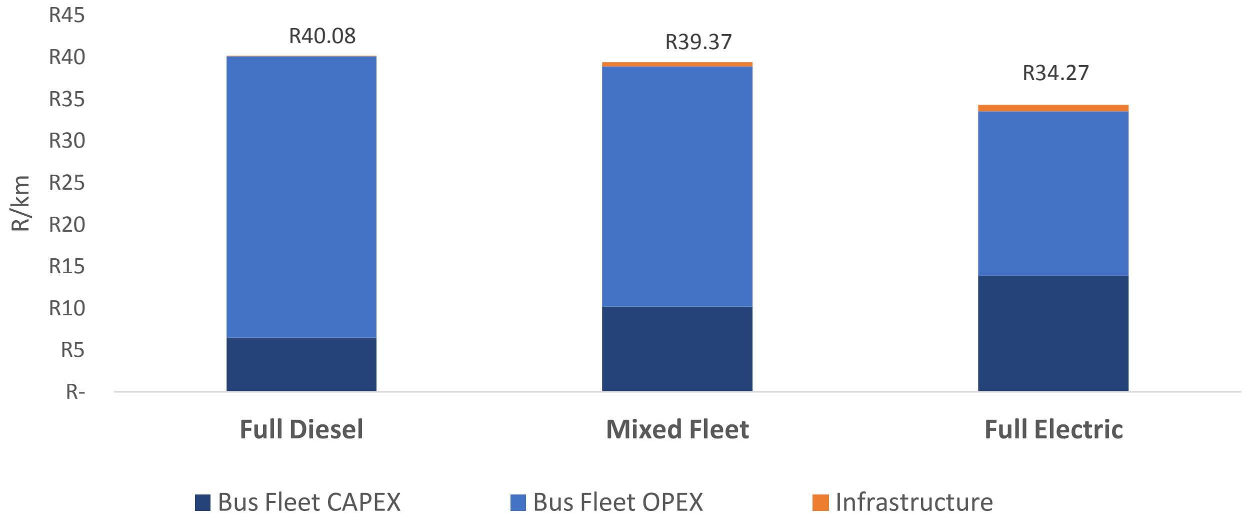

Figure 2: TCO (R/ km travelled)

When ignoring the impact of electric infrastructure in the TCO, the difference in cost grows relative to the full diesel scenario. The mixed fleet scenario indicates a decrease of approximately 3%, whereas the full BEB fleet scenario indicates a decrease of approximately 16% when considering the capital and operational cost associated with the bus fleet only. See Figure 3.

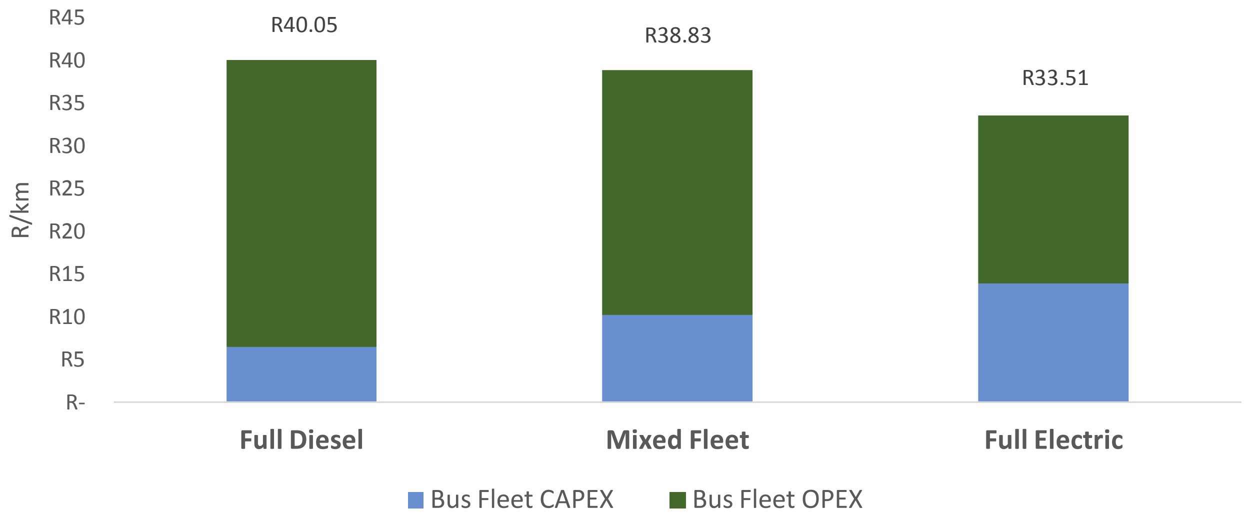

Figure 3: Total cost of owning and operating the bus fleet (excl. infrastructure) (R/km travelled)

When considering the OPEX only, the full BEB fleet has a significantly lower total cost of bus operations at approximately 41% less than a full diesel fleet on a cost per km travelled basis. A mixed fleet has a lower bus operational cost relative to a full diesel fleet of approximately 14%. This, over the 18-year operational period. See Figure 4.

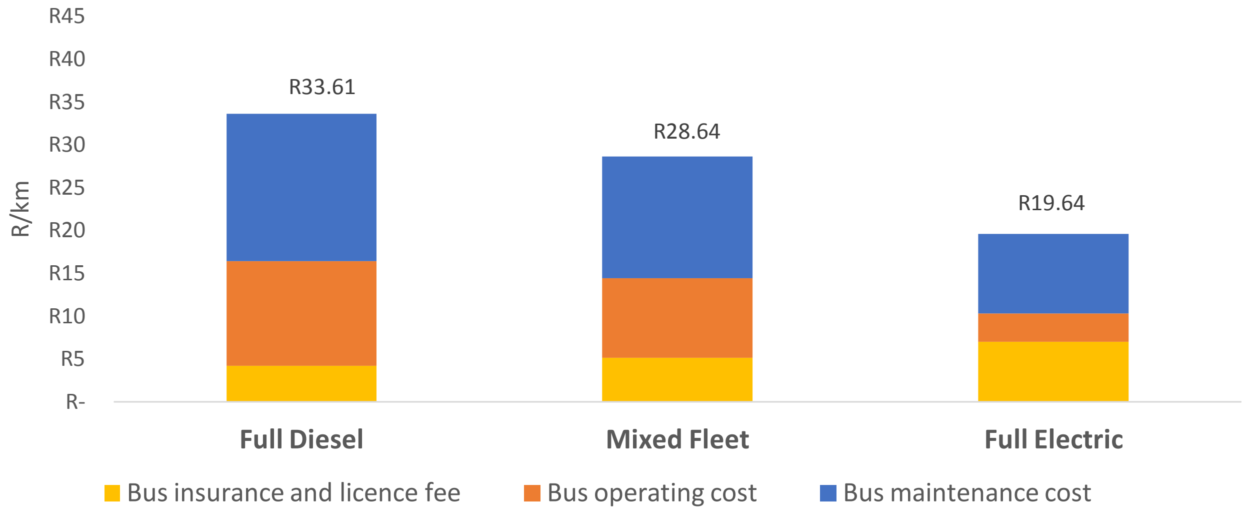

Figure 4: Total cost of operating the bus fleet (excl. infrastructure) (R/km travelled)

3.6 Financial Cost

When comparing the TCO of different scenarios it is important to remain cognisant of the impact of the investment on cashflow, particularly in the case of state-owned public transport services where revenue recovery isn't necessarily the main priority, and budget deficits can be excepted. While the TCO may be favourable over the life of the asset (or analysis period) the cash impact in the short to medium term may deter the investor (or funder) as they balance priorities.

To avoid the significant initial capital outlay related to vehicle purchases, a loan facility is assumed for all scenarios. Figure 5 illustrates the total cumulative cost of each scenario. It is evident that before year 15 (of the analysis period) the total cumulative cost of the full diesel bus fleet is less than that of the others scenarios. However, from year 15 onwards, both the mixed fleet scenario and the full BEB fleet are less expensive. This is as expected as the TCO is lower for Scenario 1 and Scenario 2 relative to Scenario 0.

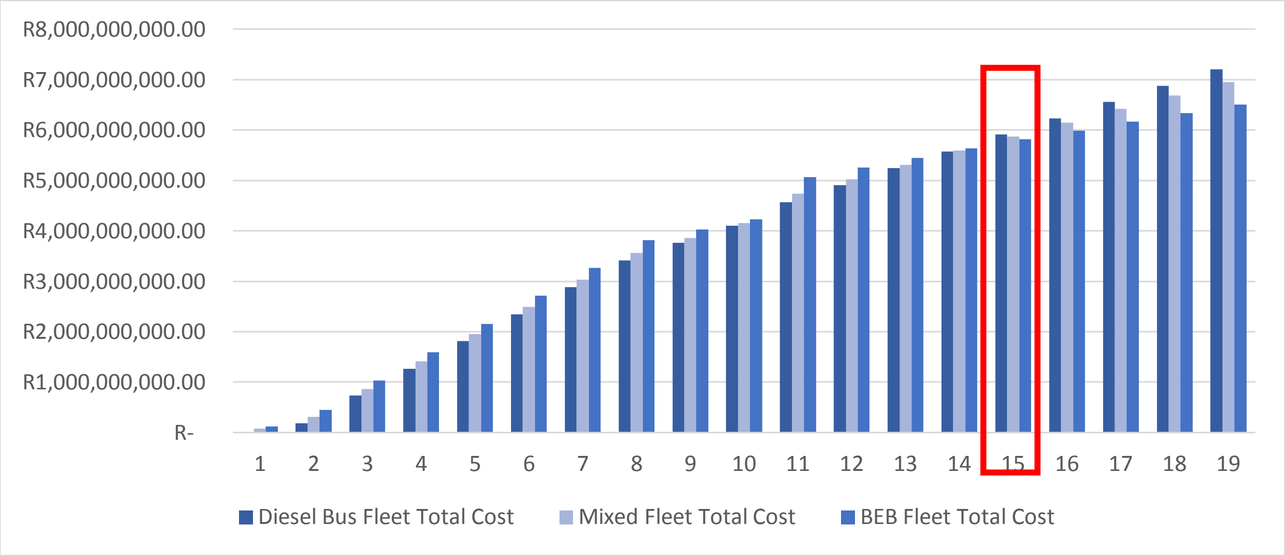

Figure 5: Total Cumulative Cost

The late breakeven point is important to consider as the asset has almost reached the end of its life. Risk associated with a breakeven point late in the life of asset, particularly in relatively new technology, is important as the benefits (e.g., profits) associated with being in a net-positive position sooner rather than later is what is generally prioritised in the private sector. Moreover, the question of opportunity cost becomes increasingly relevant, particularly in the context of rapidly evolving technology. A further consideration, given the late breakeven point, is asset replacement, as the entity may not be in a financial position to finance the replacement of the asset, given the late point of profitability. However, in the context of public transport where profitability is unlikely, managing the entities deficit will be crucial.

In line with the literature, and results present herein, the difference in terms of capital expenditure is significant as electric infrastructure, and charging infrastructure is required which is not necessary in the case if one replaces an existing diesel fleet. Also, the cost difference between diesel buses and BEBs remains significant, further increasing the capital outlay. However, the operating cost of a BEB fleet is significantly less than that of a diesel equivalent. The CAPEX cost difference is, in time, offset by the OPEX cost difference, ultimately resulting in the full BEB fleet being less expensive by approximately 9.7% over the analysis period. See Table 3 below.

Table 3: Cost impact

Scenario	Scenario 0	Scenario 1	Scenario 2
	Diesel only	Mixed fleet	Full electric
% Difference in CAPEX		-41,5%	-118,1%
% Difference in OPEX pa		14.4%	40.8%
Energy Source cost	Diesel only	Diesel & Electricity	Electricity only
Weighted average ZAR per km cost	R 33.63	R 28.75	R 19.68
Average km travelled per annum	50 400		
% Difference in total cost over 19 years		3.5%	9.7%

3.7 Emissions Impact

The investment decision may require other social needs to be met (e.g., local procurement requirements, enterprise or supplier development targets etc.), or in this case take account of the emissions given the push toward zero-emission. It is important to note that this analysis does not account for all emissions associated with the deployment of a BEB fleet (i.e., cradle-to-grave emissions), and this limitation is acknowledged given the resource intense nature of components like the battery. However, the tailpipe emission has been accounted for. The estimated emissions for Scenario 0 and Scenario 1 are presented in Table 4.

In the context of transport contribution to the total C02 equivalent (CO2e) emissions emitted in SA, the reduction in emissions based on this analysis appears marginal. The total CO2e emissions for the full diesel fleet scenario is 0.0084Mt per annum. This is approximately 0.014% of the total transport contribution to CO2e in SA. If we assume the replacement of 12m and 18m diesel buses with BEBs, based on the planning of major cities in SA (namely, Cape Town, Ekurhleni, eThekwini, Johannesburg, and Tshwane) and assuming the same parameters and limitations, the reduction in CO2e would be 0.128Mt per annum i.e., approximately 0.22% of total transport contribution to CO2e emission in South Africa.

Over the 18-year operational period, approximately 0.151Mt of C02e is avoided, which if adopted across major cities in SA will have a cumulatively reduction of approximately 2.3Mt of CO2e, which remains marginal. However, this may not necessarily be the case when considering emissions associated with the full life cycle of the asset. And, as alluded to earlier, the ideal first step to reducing emissions is modal shift from private vehicles to public transport.

Table 4: Tailpipe emissions per annum (tonnes)

Indicators	Scenario 0 (Full Diesel Fleet – 200 diesel buses)	Scenario 1 (Mixed Fleet – 120 diesel buses)	Scenario 2 (Full Electric Fleet – 200 BEBs)	*Major cities in South Africa
CO2e	8 406	5 044	0	128 244
PM	0,302	0,181	0	46 131
NOx	11,088	6,652	0	16 914

*Result based on fleet size from C40 & Logit (2024, p. 157)

4. CONCLUSION

This paper set out to estimate and present the cost and climate impact of transitioning from a diesel to a battery electric bus fleet, in the South African context. First the global and local context with respect to EV considerations was discussed. Following this, three scenarios were developed with the same operational considerations, but with different bus fleets in line with a typical municipal bus fleet in South Africa. This information was input into an excel based model used to calculate the TCO, cumulative cost impact and tailpipe emissions for each scenario presented.

The results indicate, based on the assumptions and analysis presented, that operating a full diesel fleet has a higher ownership and operating cost relative to operating a full BEB fleet over a 19-year analysis period. A BEB fleet has a TCO approximately 14% lower than an equivalent diesel fleet. These results are similar to other TCO studies reviewed, while taking cognisance of those particular contexts. Furthermore, a potential hinderance to the adoption of BEB is one of cashflow, as the initial capital outlay for the deployment of a BEB fleet is greater than that of a diesel fleet given the infrastructure requirements; and the total CAPEX is approximately 118% greater of a full BEB fleet over a 19-year analysis period. Additionally, the BEB fleet reaches a breakeven point (relative to a full diesel fleet) in year 15, i.e., 4-years away from the buses end-of-life posing risks to potential funders and raising the question of opportunity cost.

With respect to tailpipe emissions, operating a full BEB relative to a full diesel fleet avoids approximately 0.151Mt of C02e over an 18-year operating period, a marginal difference, which if adopted in major cities in South Africa will have a cumulatively reduction of approximately 2.3Mt of CO2e. Although, it should be emphasised that this excludes the full-life cycle emissions, which will likely result in a net negative impact with respect to the CO2e emission contribution. Furthermore, the marginal reduction in emissions coupled with the lack of information around the full life cycle cost of BEBs, is a significant impediment to the argument *for* the transition to BEBs on the basis of emissions reduction.

While global trends indicate an appetite for, and an increase adoption of EVs, it is important that South Africa acknowledges its current economic and socio-economic context. The balance of competing priorities in the South African context while trying to honour commitments to climate change, places significant pressure on government capacity and an already constrained public purse. It is the mandate of the state to deliver and provide a functional transport system that is affordable. The question of whether to follow the global trend of adoption of EVs is one worth considering, however the timing thereof is crucial as the cost impact could be significantly different should one defer the early adoption of this technology. Perhaps a more pertinent question, is which other interventions would yield better outcomes for South Africa, both in terms of economic impact and greenhouse gas emission reduction? For example, would the adoption of EURO VI diesel buses, in the short term at least, improve the broader transport emissions contribution by ensuring improved availability of cleaner diesel while allowing BEB technology to mature through the development of the private vehicle market.

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6. REFERENCES

APEC. 2020. *Asia-Pacific Economic Corporation Putrajaya Vision 2040.*

BDO South Africa. 2023. *The economic toll of port and rail inefficiencies*. Available at: https://www.bdo.co.za/en-za/home/featured-insights/the-economic-toll-of-port-and-rail-inefficiencies

Bharadwaj, R. 2023. *The Rise of Electric Vehicles in South Africa*. Bolt Earth. Available at: https://bolt.earth/blog/south-africa-ev-market

BizNews, E. 2024. Eskom warns to expect an even darker 2024 after South Africa's worst year of load-shedding in 2023. *BizNews.Com*. Available at: https://www.biznews.com/energy/2024/01/08/eskom-warns-darker-2024-after-worst-year-2023

Bligh, J. 2023. *Transitioning to EV fleets: Key to resilience & cost savingsV Fleets*. EV Magazine. Available at: https://evmagazine.com/fleet-and-commercial/transitioning-to-ev-fleets-key-to-resilience-cost-savings

Bubear, R. 2023. *Here's How Many EVs and Hybrids Were Sold in SA in Q1 2023*. Cars.Co.Za. Available at: https://www.cars.co.za/motoring-news/heres-how-many-evs-and-hybrids-were-sold-in-sa-in-q1-2023/162775/

Businesstech. 2022. *South Africa's roads are collapsing*. Available at: https://businesstech.co.za/news/government/652421/south-africas-roads-are-collapsing/

C40 Cities, & Logit. 2024. *Accelerating a market transition in South Africa – Insights into the bus industry and emerging electric bus models.pdf*. C40 Studies.

Chen, Yang, Zhou, Weimin, Berlin, Annika, Deng, Huijing, Tian, Danhui, Wang, Jin-1498055, Zhang, Xiuli, Jenn, Alan, Wang, Yunshi, Liu, Yu, Li, Jingyun, Wei, Fulei, Wang, Qian-000536199, Bian, Yong, & Li, Chunmei. 2021. *Electrification of Public Transport: A Case Study of the Shenzhen Bus Group* (1 1). Available at: https://documents1.worldbank.org/curated/en/708531625052490238/pdf/Electrification-of-Public-Transport-A-Case-Study-of-the-Shenzhen-Bus-Group.pdf

City of Ekurhuleni. 2023. *Review of Integrated Development Plan 2022/23-2026/27*. Available at: https://www.ekurhuleni.gov.za/wp-content/uploads/2023/04/2022-23-to-2026-27-Reviewed-Draft-IDP-Council.pdf

City of Polokwane. (n.d.). *Integrated Development Plan 2022/23*.

City of Tshwane. 2020. *City of Tshwane Integrated Development Plan: Revision for 2020/21 and Service Delivery and Budget Implementation (SDBIP) Scorecard*. City of Tshwane.

Convention on Biological Diversity. (n.d.). *South Africa – Main Details*. Country Profiles; Secretariat of the Convention on Biological Diversity. Available at: https://www.cbd.int/countries/profile/?country=za Accessed 21 January 2024.

DBSA. 2021. *DBSA Green Bond Framework*. Available at: https://www.dbsa.org/sites/default/files/media/documents/2021-03/DBSA%20Green%20Bond%20Framework%20-%2022%20January%202021.pdf

Department of National Treasury. 2021. *Financing a Sustainable Economy*.

Department of National Treasury. 2022. *SA Green Finance Taxonomy – 1st Edition.pdf*. Available at: https://www.treasury.gov.za/comm_media/press/2022/SA%20Green%20Finance%20Taxonomy%20-%201st%20Edition.pdf

Department of the Presidency. 2012. *Our future – Make it work: National Development Plan 2030*.

Department of Transport. 2022. *Green Transport Strategy for South Africa (2018-2050)*. Available at: https://www.brundtland.co.za/wp-content/uploads/2022/11/Green_Transport_Strategy_2018_2050_onlineversion.pdf

Department of Transport. 2023. *National Land Transport Strategic Framework (2023-2028).* Department of Transport South Africa. Available at: https://www.gov.za/sites/default/files/gcis_document/201702/40621gon132s.pdf

DieselNet. 2021. *Emission Standards: Europe: Heavy-Duty Truck and Bus Engines*. Available at: https://dieselnet.com/standards/eu/hd.php#stds

Dioha, MO, Lukuyu, J, Virgüez, E & Caldeira, K. 2022. Guiding the deployment of electric vehicles in the developing world. *Environmental Research Letters*, 17(7):071001. Available at: https://doi.org/10.1088/1748-9326/ac765b

DTIC. 2021. *Auto Green Paper on the Advancement of New Energy Vehicles in South Africa*. Available at: https://www.gov.za/sites/default/files/gcis_document/202105/44606gen308.pdf

DTIC. 2023. *Electric Vehicle White Paper*. Available at: https://www.thedtic.gov.za/wp-content/uploads/EV-White-Paper.pdf

EasyTenders. 2023. *Tender: RFI017/2022/23*. This Request for Information (Rfi) Is to Provide Information Regarding Battery Electric Buses (Beb) and t... | EasyTenders. Available at: https://easytenders.co.za/tenders/bid-numberrfi017-2022-23bid-descript-rfi017-2022-23-99761

ESMAP & The World Bank. 2023. *Electric Mobility & Power Systems: Impacts and Mitigation Strategies in Developing Countries*. Available at: https://documents1.worldbank.org/curated/en/099050123125542493/pdf/P1746590c032c506708d4905fad210b582c.pdf

eThekwini Municipality. 2023. *Draft eThekwini Municipality: Integrated Development Plan: 5 Year Plan: 2023/24 to 2027/28*. eThekwini Municipality.

European Commission. 2020. Sustainable and Smart Mobility Strategy (European Commission) [Strategy Report]. European Commission. Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12438-Sustainable-and-Smart-Mobility-Strategy_en

European Commission. 2021. *Regulation of the European Parliament and of the Council on Deployment of Alternative Fuels Infrastructure, and Repealing Directive*.

Fernandes, A. 2022. What are the Challenges of Transitioning to Electric Buses? [Automotive]. *StratioAutomotive*. Available at: https://stratioautomotive.com/challenges-transitioning-electric-buses/

Ferreira, A & Simpson, K. 2022. *Five-year Integrated Development Plan July 2022-June 2007*. City of Cape Town.

Ge, A. 2023. *Electric vehicle regulation and law in China | CMS Expert Guides*. Available at: https://cms.law/en/int/expert-guides/cms-expert-guide-to-electric-vehicles/china

Gokasar, I, Deveci, M, Isik, M, Daim, T, Zaidan, AA & Smarandache, F. 2023. Evaluation of the alternatives of introducing electric vehicles in developing countries using Type-2 neutrosophic numbers based RAFSI model. *Technological Forecasting and Social Change*, 192, 122589. Available at: https://doi.org/10.1016/j.techfore.2023.122589

Green Finance Platform. 2024. *South Africa. Green Finance Platform*. Available at: https://www.greenfinanceplatform.org/country/south-africa

GreenCape. 2024. *Green Finance*. Available at: https://greencape.co.za/sector/green-finance/

Gumede, W. 2022. *SA's entire infrastructure is on the verge of total collapse*. Available at: https://www.wits.ac.za/news/latest-news/opinion/2022/2022-07/sas-entire-infrastructure-is-on-the-verge-of-total-collapse.html

Jain, A & Draexler, S. 2021. *Background paper Comparative analysis of bus technologies for fleet renewal*.

Kim, H & Hartmann, N. 2021. *Total Cost of Ownership Analysis of Battery Electric Buses for Public Transport System in a Small to Midsize City*. Available at: https://www.mdpi.com/1996-1073/14/14/4384

Kohn, E, Huang, C & Kong, N. 2022. *Electric Vehicle Incentives in 15 Leading Electric Vehicle Markets* (p. 31). University of California.

Krynauw, M. 2015. *Presentation to SA Road Federation AGM 27 October 2015*.

Lander, L, Kallitsis, E, Hales, A, Edge, JS, Korre, A & Offer, G. 2021. Cost and carbon footprint reduction of electric vehicle lithium-ion batteries through efficient thermal management. *Applied Energy*, 289:116737. Available at: https://doi.org/10.1016/j.apenergy.2021.116737

Malinga, S. 2022. *SA trails behind global market with 1.5K electric vehicles*. ITWeb. Available at: https://www.itweb.co.za/article/sa-trails-behind-global-market-with-15k-electric-vehicles/wbrpOMg2zza7DLZn

Martin. 2016. List of Parties that signed the Paris Agreement on 22 April. *United Nations Sustainable Development*. Available at: https://www.un.org/sustainabledevelopment/blog/2016/04/parisagreementsingatures/

Meattle, C, Solomon, C, Radmore, J, Johansson, L, Gwebu, L & Fernandes, P. 2023. *The South African Climate Finance Landscape 2023: A technical report prepared for the Presidential Climate Commission*. Available at: https://www.climatepolicyinitiative.org/wp-content/uploads/2023/11/The-South-African-Climate-Finance-Landscape-2023.pdf

Minjares, R, Dallmann, T, Masebinu, S & Posada, F. 2020. Part I: Greening The Future Fleet. *International Council on Clean Transportation*.

Moolman, S. 2017. 350% increase in a decade: How expensive is electricity in South Africa compared to other countries? *PowerOptimal*. Available at: http://www.poweroptimal.com/350-increase-decade-expensive-electricity-south-africa-compared-countries/

National Department of Energy. 2019. *Integrated Resource Plan (IRP2019)*.

NDC Support Facility, Steer, & The World Bank. 2019. *Green Your Bus Ride: Clean Buses in Latin America*. Available at: https://documents1.worldbank.org/curated/en/410331548180859451/pdf/133929-WP-PUBLIC-P164403-Summary-Report-Green-Your-Bus-Ride.pdf

Onat, N & Khan, MJA. 2022. *Total Cost of Ownership Framework for Procurement of buses used in Public Transportation*.

Oreggioni, GD, Monforti Ferraio, F, Crippa, M, Muntean, M, Schaaf, E, Guizzardi, D, Solazzo, E, Duerr, M, Perry, M & Vignati, E. 2021. Climate change in a changing world: Socio-economic and technological transitions, regulatory frameworks and trends on global greenhouse gas emissions from EDGAR v.5.0. *Global Environmental Change*, 70:102350. Available at: https://doi.org/10.1016/j.gloenvcha.2021.102350

Poulsen, Z. 2020. *Introducing South Africa's biodiversity hotspots. BotSoc*. Available at: https://botanicalsociety.org.za/a-megadiverse-country-introducing-south-africas-biodiversity-hotspots/

Rubnitz, T & Moon-Miklaucic, C. 2018. How 3 Cities Are Navigating the Transition to Electric Buses. *TheCityFix*. Available at: https://thecityfix.com/blog/on-the-road-to-electric-how-3-cities-navigate-the-transition-to-clean-bus-fleets-christopher-moon-miklaucic-talia-rubnitz/

Schroeder, M. 2013. *Comparative Innovation Policy Analysis-Electric Vehicle Development in Japan and Germany*. Waseda University, Graduate School of Asia-Pacific Studies.

Sclar, R, Gorguinpour, C, Castellanos, S & Li, X. 2019. *Barriers to Adopting Electric Buses*.

Shimbun, TY. 2023. *Japan EV Subsidy Program to Evaluate Measures by Manufacturers; Charging Point Numbers, Response to Issues to Impact Subsidies*. Available at: https://japannews.yomiuri.co.jp/politics/politics-government/20231124-151544/

South African Government. (n.d.). *Green Fund*. Available at: https://www.gov.za/about-government/government-programmes/green-fund. Accessed 31 January 2024.

South African Government. 2021. *South Africa's First Nationally Determined Contribution under the Paris Agreement*. Available at: https://www.dffe.gov.za/sites/default/files/reports/draftnationalydeterminedcontributions_2021updated.pdf

Statistics South Africa, K. 2023. *Sustainable Development Goals: Country Report 2023* [Country report]. Statistics South Africa.

Statssa. 2023. *Statistics South Africa on Quarterly Labour Force Survey quarter three 2023. South African Government*. Available at: https://www.gov.za/news/media-statements/statistics-south-africa-quarterly-labour-force-survey-quarter-three-2023-14

Steenkamp, M & Weaver, Z. 2022. *The economic impacts of rolling blackouts on South African: Shaping the context*. Afro Development Planning Pty Ltd.

Suttakul, P, Wongsapai, W, Fongsamootr, T, Mona, Y & Poolsawat, K. 2022. Total cost of ownership of internal combustion engine and electric vehicles: A real-world comparison for the case of Thailand. *Energy Reports*, 8:545-553. Available at: https://doi.org/10.1016/j.egyr.2022.05.213

Swart, M & Sasman, N. 2023. *Comprehensive Integrated Transport Plan 2023-2028*. City of Cape Town.

The World Bank. 2022. *Electric Vehicles: An Economic and Environmental Win for Developing Countries*. World Bank. Available at: https://www.worldbank.org/en/news/feature/2022/11/17/electric-vehicles-an-economic-and-environmental-win-for-developing-countries

Trading Economics. 2024. *India Unemployment Rate*. Available at: https://tradingeconomics.com/india/unemployment-rate

Triatmojo, A, Safrudin, A, Posada, F, Kusumaningkatma, M, Minjares, R & Triatmojo, A. 2023. Evaluation of factors that affect total cost of ownership in support of Transjakarta's electric bus adoption plans. *International Council on Clean Transportation*, 2023(12).

Tusini, N, Tshabalala-Kingston, P, Zatu, Z & Mahuma, G. 2021. *Opinion: SA's rail system is broken. This is how it happened, and how to fix it*. Business. Available at: https://www.news24.com/fin24/opinion/opinion-sas-rail-system-is-broken-this-is-how-it-happened-and-how-to-fix-it-20211126

United States Department of State and the United States Executive Office of the President. 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050* [Report].

USAID. 2023. *2023 USAID South Africa Climate Change Country Profile*. Available at: https://www.usaid.gov/sites/default/files/2023-11/2023-USAID-South-Africa-Climate-Change-Profile.pdf

Van Zyl. 2023. *Golden Arrow to introduce 60 electric buses per year starting 2024*. Available at: https://www.capetownetc.com/news/golden-arrow-to-introduce-60-electric-buses-per-year-starting-2024/

Woody, M, Adderly, SA, Bohra, R & Keoleian, GA. 2024. Electric and gasoline vehicle total cost of ownership across US cities. *Journal of Industrial Ecology*, 28(2):194-215. Available at: https://doi.org/10.1111/jiec.13463

World Bank. 2015. *Decarbonizing Development: Planning Ahead for a Future with Zero Emissions*. World Bank. Available at: https://doi.org/10.1596/21887

World Bank. 2024. *GDP growth (annual %) – South Africa*. World Bank Open Data. Available at: https://data.worldbank.org

WRI. 2023. *World's Top Emitters Interactive Chart I World Resources Institute*. Available at: https://www.wri.org/insights/interactive-chart-shows-changes-worlds-top-10-emitters

Zamanov, N. 2023. *Electric Cars in Developing Countries: Exploring the Challenges and Opportunities*. Available at: https://cyberswitching.com/electric-cars-in-developing-countries/

7. APPENDIX A

Table 5: Electric infrastructure and charging equipment total cost (model inputs)

Power supply provided	Scenario 1 (5 MVA)	Scenario 2 (7 MVA)
Number of BEBs in fleet	80	200
Total OPEX (pa)	R 1,060 000	R 1,180 000
Total CAPEX	R 79,000,000	R 119, 551,610

Source (Authors estimates based on engagements with industry experts)

Table 6: Bus CAPEX (model inputs)

Bus Type	Length	Purchase price	Mid-life refurbishment	Battery replacement
Euro VI - Diesel	12m	R4,950,000	R500 000	N/A
	18m	R6,700,000		
BEB	12m	R9,000,000		R2,000,000
	18m	R12,200,000		R2,800,000

Source (Authors estimates based on engagements with industry experts)

Table 7: Bus OPEX and emissions (model inputs)*

Bus Type	Length	Fuel (R/km)	Lubricants (% of fuel cost)	Maintenance (R/km)	Insurance (pa)	License fees (pa)	Tyres (per tyre)	Tailpipe Emissions
Euro VI Diesel	12m	R 9.42	0.5%	R 16.20	4.9%	R24,702	R6,500	CO2e 834 NOx 1.1 PM 0.03
	18m	R 12.94		R 17.80		R57,000		
BEB	12m	R 2.11	0.2%	R 8.80		R24,702		0
	18m	R 2.95		R 9.70		R57,000		

*Excludes cost associated with overheads and driver remuneration

Sources (Authors estimates based on engagements with industry experts, DieselNet (2021))