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e-Bus Market Feasibility in city of Harare

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e-Bus Feasibility for city of Harare was taken up after the National e-Mobility Policy Roadmap, which consisted of various policy measures to achieve stated EV targets by 2030 along with their timelines, resource requirements and key stakeholders responsible for implementation had been developed. The e-Bus feasibility study provides detailed assessment for first e-Bus deployment in the capital city Harare for Intracity commute. It assesses the possible routes, fleet size, deployment scenarios, business models, finance requirement and their impacts. Based on the analysis, most suitable case for first e-Bus deployment in the city has been indicated.

During the study, the key stakeholders consulted were from four priority sectors; Transport, Energy, Climate, and Finance. They ranged from the government ministries, government authorities, non-governmental organisations, private sector, academic and research institutions, and development partners.

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Abbreviations

AC	Air conditioned
BAU	Business as usual
BEB	Battery electric bus
BESS	Battery energy storage system
BSS	Battery storage system
BTB	Business to be
CAFE	Corporate Average Fuel Efficiency
CAPEX	Capital expenditure
CBD	Central business district
CBM	Coal-bed methane
CBU	Completely built unit
CCC	Copenhagen climate centre
CCS	Combined Charging System
CKD	Complete knocked-down kit
CMED	Central mechanical equipment department
CNG	Compressed Natural Gas
COE	Centre of Excellence
CPO	Charge Points Operators
CVR	Central Vehicle Registry
DC	Direct current
DDF	District Development Fund
DISCOM	Distribution company
EPR	Extended Producers Responsibility
ESAP	Economic Structural Adjustment Program
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GCC	Gross cost contract
GCF	Green Climate Fund
GHG	Green House Gas
HT	High tension
ICE	Internal combustion engine
ICT	Information and communication technologies
IPP	Independent power producers
KAIST	Korea Advanced Institute of Science and Technology
KPI	Key Performance indicators
KW	Kilo Watt
LEDS	Low emission development strategy

LIB	Lithium Ion Battery
MFA	Mobility for Africa
MW	Mega Watt
NDC	Nationally Determined Contributions
NDS	National Development Strategy
NEP	National Energy Policy
NMT	Non-Motorised Transport
NOI	Net operating income
NREP	National Renewable Energy Plan
OEM	Original Equipment Manufacturer
OLEV	On-Line Electric Vehicle
OPEX	Operational Expenditure
PPP	Public Private Partnership
PT	Public Transport
PTA	Public transport Authority
PV	Photo Voltaic
RDC	Rural District Councils
RE	Renewable Energy
RES	Renewable Energy Sources
RMT	Road Motor Transportation
SLA	Service Level Agreements
SOC	State of Charge
SUV	Sport Utility Vehicle
TCO	Total cost of ownership
TOD	Time-of-day
TOU	Time-of-use
V2G	Vehicle to Grid
WTT	Well to Tank
ZERA	Zimbabwe Energy Regulatory Authority
ZESA	Zimbabwe Electricity Supply Authority
ZETDC	Zimbabwe Electricity Transmission and Distribution Company
ZPC	Zimbabwe Power Company
ZUPCO	Zimbabwe United Passenger Company

1. Introduction

As per IEA Global Energy Review 2021 Globally, carbon dioxide emissions via coal energy generation plants are on course to surge by 1.5 billion tones. To address this, Countries around the world have to move rapidly to start cutting emissions addressing climate change. One of the leading sectors contributing to carbon emissions is transport sector. To address emission issues pertaining to transport sector, many country governments have taken initiative to convert conventional (ICE) vehicles to electric vehicles. Electric vehicles are energy efficient over ICEs and get around 85% useful energy conversion (in comparison to ICEs around 15% useful energy).

Zimbabwe is producing 22% of its total GHG emissions from Transport sector. The Government of Zimbabwe has recognised the importance of decarbonisation of transport sector; and electrification of passenger transport sector is first step towards it. EV Policy Roadmap for Zimbabwe has been developed and includes different passenger vehicle segments including, two wheelers, three wheelers, four wheelers, intercity buses and intracity buses (including kombis). The prioritisation analysis undertaken by MFA and pManifold Consortium in consultation with national and local stakeholders identified intracity buses as highest priority for electrification – given country's ambition to improve public transport and its electrification.

The capital city Harare extends a potential market for e-buses in Zimbabwe. The city serves as the country's political, economic and cultural centre, and has a population of more than 1.6 million[1] (2021) spread over an area of about 960 sq. km.

1.1 Objectives of Project

The challenge of climate change requires Zimbabwe to access and develop technologies relevant for implementing appropriate mitigation and adaptation projects and actions. There are a number of challenges for road transport in Zimbabwe due to (i) the high rate of motorization, with the vehicle fleet doubling every 10 years, (ii) the level of reconditioned cars imported from industrialized countries, and (iii) the contribution of GHG emissions from transport, mainly from direct combustion of fossil fuels and $CO_{2.}$ Nearly 97 per cent of transportation GHG emissions come through direct combustion of fossil fuels, with the remainder being carbon dioxide (CO_2) from hydrofluorocarbons emitted from vehicle air conditioners and refrigerated transport.

Transport is seen by the Government of Zimbabwe as an enabler for other sectors. Urban sprawl, particularly in Harare and Bulawayo, has resulted in increased commute distances for citizens. The Climate Response Strategy (2015) described how the major challenges for the road transport sector include the rate of motorization and the quality of fuel. The traffic is increasing rapidly with the vehicle fleet doubling every 10 years. Under its Physical and Social Infrastructure pillar, Zimbabwe is committed to introducing a transport policy framework that encourages the use of low carbon transport, such as electric vehicles, and the integration of climate resilience into transport planning and infrastructural development.

UNEP Copenhagen Climate Centre (UNEP CCC) is implementing a request received from Zimbabwean Government to Climate Technology Centre and Network (CTCN) to:

1 https://worldpopulationreview.com/countries/cities/zimbabwe

1. Develop a cohesive electro-mobility policy, planning and market framework to transform Zimbabwe's transport sector, aligned to its Low Emissions Development Strategy (LEDS, 2019) that commits to consideration of policy amendments to guide private sector investment into the economically viable abatement potentials.

2. Assess the market readiness, enabling measures and instruments to aid the deployment of electric vehicles in Zimbabwe, aligned to its LEDS commitment to conduct economic cost/benefit analyses of mitigation measures.

3. Deliver an action plan and business case for electric vehicles and associated charging infrastructure deployment; and

4. Work with the Government of Zimbabwe to build the capacity of stakeholders, to facilitate the delivery of a comprehensive electro-mobility roadmap and charging infrastructure.

The project (Phase-1) included EV Policy framework and road-map development for e-mobility implementation in Zimbabwe. As a part of prioritization analysis of the vehicles for e-Mobility, e-Intracity buses has been assigned top priority by Zimbabwe stakeholders.

The objective of this part of the project (Phase-2) is to prepare a "Market feasibility study for intracity e- Buses deployment in Harare". The anticipated outcome from implementation of this phase is a feasibility study for intracity e-Buses including strategic policy measures for implementation, bus routes for electrification with required infrastructure for charging, business models for implementation, and a concept note for funding. This will contribute to developing a modern, sustainable, efficient mode of public transport in the city of Harare.

1.2 Scope of Project

Government of Zimbabwe is putting efforts in making public transport clean and improve the quality of service. In order to achieve this, ZUPCO is focusing on phasing-out the old, inefficient vehicles as well as the unauthorized small buses from the system. Three factors; 1) huge ownership of private pre-owned vehicles; 2) demand for public transportation for the captive users who travel long distances and cannot afford to travel by their own vehicle or own a vehicle and; 3) high fuel prices provide a great opportunity for improving efficiency of existing public transportation and introducing clean public transportation through e-Buses.

As per the prioritization analysis in Phase 1, intracity bus transportation was prioritized and the capital city of Harare was chosen for first e-Bus deployment in discussion with Ministry of Transport, ZUPCO (National Public transport Authority for urban transport). 12 M Non-AC (60–63-seater) standard high floor buses are being looked upon for first deployment of e-Buses for intracity transport.

This study focuses on analysing e-Bus feasibility in city of Harare. One depot and potential routes are analysed and recommended for e-Bus deployment for up to 50 e-Buses. The study also includes the e-Bus technology comparison and selection, charging infrastructure guidelines, financial requirements, potential impacts and policy measures for adoption of e-Buses.

The first deployment (pilot) usually leads to set example, build skills, learnings and experiences from the new intervention. Similarly, first e-Bus deployment will help envisaging the applicability and scalability of e-Bus deployment nationwide. It will also help to understand the potential of local ecosystem development for e-Buses as well as other e-vehicle segments.

1.3 Global Learnings on Challenges with e-Buses Deployment

e-Buses are complex from operations perspective than their conventional counter parts like diesel buses or CNG buses. Conventional buses can be refuelled in few minutes and can easily complete their schedule without additional refilling. However, e-Buses often have short range due to lower energy density of batteries. The batteries of e-Buses are heavier, and they impact the bus efficiency expressed in electric units (kWh) consumed per kilometre. To put it in perspective, a diesel bus can go approximately 4 km in one litre (~0.85 kg) of diesel. However, for 4 km range, an e-Bus with efficiency of 1 kWh/km, needs an onboard battery storage of 40 kg weight. Also, e-Buses can take substantial time to recharge the battery. Time lost during charging can lower daily vehicle utilization of e-Buses.

Financially, e-Buses can deliver economic performance (BNEF, 2020) as compared to that of ICE buses. Lower operational cost due to cheaper fuel combined with lower maintenance, reduces the operational cost of buses. However, e-Buses are costlier. High upfront cost of e-Buses increases capital requirement as well as financing cost. Thus, to deliver net benefits as compared to conventional buses, lower operational cost should offset high acquisition cost. Thus, it becomes important to fully appraise technical concepts involved in e-Bus operation before embarking on planning task.

1.3.1 Technical Concepts: e-Bus, Battery and Chargers

Before starting the feasibility study, it is useful to understand different components of e-Bus ecosystem and their characteristics. Bus, battery and charger are three major components of an e-Bus system, which are elaborated below.

1.3.1.1 e-Buses

Electric buses are driven by an electric motor and energy stored on-board. Globally e-Buses are available in different sizes such as 7m-mini, 9m-midi, 12m-standard and 18m to 24m articulated buses[2]. An Important attribute of an e-Bus is its efficiency. An electric motor and other allied on-board equipment including air conditioners, lighting, etc. consume energy. The efficiency of e-Bus is measured by number of electric units (kWh) consumed per km distance covered. Another important attribute of e-Bus is its weight, which along with weight of battery impacts bus efficiency.

1.3.1.2 e-Bus Battery

Battery is an assembly of cathode and anode dipped in acidic solution, which can generate electric current. Numerous forms of assemblies are possible (series and parallel). Battery capacity is measured in kWh. Weight of a battery depends on the size of battery in kWh and the battery technology used. For each kWh increase in battery capacity, weight of battery increases. Most common batteries used in electric buses are nickel based batteries and lithium based batteries. Among all battery technologies, Li-ion batteries are most preferred, due to their long life, and high storage capacity per kWh. Following are the concepts related to battery of EV.

- **Battery power (Watt)** - Multiplying the voltage by the current provides power.
- **Amount of energy stored (kWh)** - Multiplying battery power with time for which battery can keep dispensing the power gives storage capacity of battery expressed in watt-hr. 1kWh battery can run an appliance of 1000 watts for one hr.
- **Specific energy/ energy density (kWh/kg or kWh/m3)** - Is the amount of energy that can be stored per unit weight or per unit volume.

2 Zero-Emission Technology Inventory, 2021 by CALSTART. https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

- **Charge rate (1/hr)** - It is measure of speed with which battery can charge or discharge. It is inverses of time taken in hours to charge or discharge. If a battery takes 5 hours to discharge, its C Rate is 1/5.
- **State of charge (%)** - State of charge (SOC) is charge in % available in battery. Min SOC is often referred as least SOC to be always maintained for long battery life.

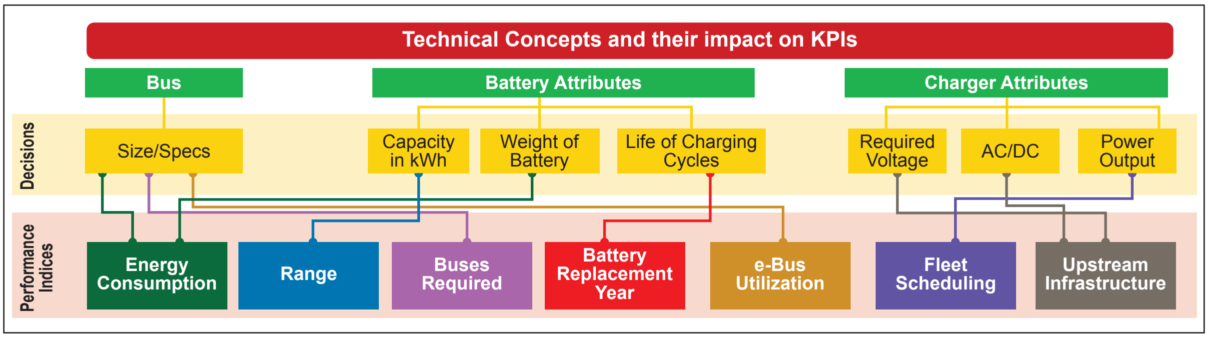
1.3.1.3 e-Bus Charger

Charger is a unit used to refuel/recharge battery and is commonly known as Electric Vehicle Supply Equipment (EVSE). Its power, i.e., ability to deliver energy (kW) in one hour is called charger power, expressed in kW. A 100kW charger (with 1 charge rate rate) can fully charge a 100kWh battery in 1hr. Chargers are available in varying powers. A low power charger is generally preferred for long charging time and vice versa.

Charging time = $\frac{Battery\ Capacity\ (kWh)}{Charger\ Power\ (kW)}$

Charger power should be appropriate so as to cause minimal impact on e-Bus availability for operation.

Figure 1.1 Dependence of key performance indicators (KPIs) on Attributes of e-Bus



It is imperative to choose right combination of above-mentioned e-Bus system elements, to minimize the 'Total Cost of Ownership (TCO)' of deployment of the e-Bus fleet. The choice of these elements also affects the overall e-Bus operations and performance. The key performance indicators of bus operations are; energy consumption, range, number of buses required, battery replacement, e-Bus utilization, fleet scheduling and upstream infrastructure.

Interconnection of the e-Bus elements is shown in Figure 1.1. The right choices, planning and pre-implementation assessments of the given elements, their impacts with respect to the KPIs can help successful deployment of e-Buses.

1.3.2 Key Barriers to e-Bus Adoption

From several pilots, experiments and early adoptions worldwide, it is experienced that transition to e-buses, has brought up some pain points, practical difficulties and barriers. Industries and governments tend to struggle to maintain, sustain and scale-up e-Bus deployments. Such key pain points and barriers identified from various international case studies are organized into the three general categories; technological, financial, and institutional and others. Table 1.1 presents barriers[3] and provides guidance for decision making and required planning efforts for e-Bus adoption.

3 WRI, 2020 https://wrirosscities.org/sites/default/files/barriers-to-adopting-electric-buses.pdf

Table 1.1 Key Barriers to e-Bus adoption

General Barriers			
	Technological	**Financial**	**Institutional**
Vehicle and Batteries	• Lack of information on the advantages and disadvantages of e-Buses • Range and power limitations of e-Buses • Design flaws in e-Buses • Disjointed or limited e-Bus marketplace	• High up-front capital costs of e-Buses • Higher TCO of e-Bus than planned • Lack of financing options	• Difficulties for manufacturers in engaging with cities • Lack of a plan to remove current bus stock
Agencies and Operators	• Procurement: o Lack of information on how operators to start o Lack of information on e-Bus (size, specs); battery (size, chemistry, specs); etc. • Set-up and commission: o Lack of understanding on set-up and commission and the requirements to upgrade infrastructure • Operation: o Unplanned SOC depletion o High range deviation than stated specs o Trip loss/delays o Low e-Bus utilization	• Rigid financial management and business models • Scaling investment past initial pilot programs	• No enabling policies supporting adoption of e-Buses • Negative public perception • Coordinating maintenance duties • Weak governmental coordination • Informal transit
Grid and Charging Infrastructure	• Limitations of the charging ports and stations • Grid instability • Lack of standards and regulations on charging infrastructure	• Large capital expenses for grid infrastructure • Difficult to determine grid infrastructure responsibilities	• Lack of space and land to install infrastructure • Limited planning for long- term implications

1.4 Methodology

Considering the experiences, learnings from global practices on e-Bus deployments; this pre-feasibility study has adopted an inclusive approach for planning first e-Bus deployment in city of Harare. A six-step approach (refer Figure 1.2) is adopted to undertake the pre-feasibility assessment which is inclusive of desk research, stakeholder engagement and expert consultations.

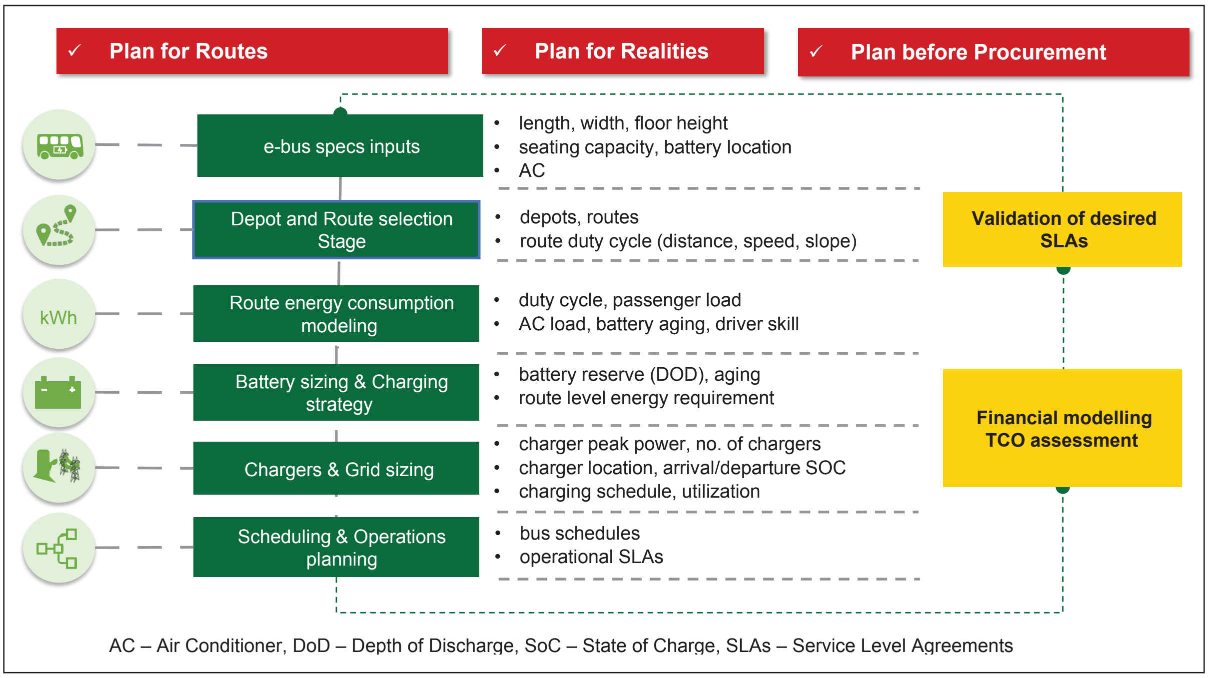
a) **e-Bus specs and input:** Brief global and regional EVs market overview is undertaken to check availability of e-Bus models in market. A suitable e-Bus size is defined based on consultation with local transport authority in city of Harare.

b) **Depot and route selection stage: Depots has been selected based on their capacity to handle e-Buses considering space requirements of charging infrastructure. Also, most feasible routes for electrification has been selected from stakeholder consultation based on passenger demand, existing operation.**

c) **Route energy consumption modelling:** Detailed technical analysis is conducted which includes, energy consumption modelling for selected routes under different scenarios like AC on/off; passenger overloading; route conditions; traffic conditions and others[4]

4 using pManifold's EVFleetPlanner© tool

Figure 1.2 Systematic Planning for e-Buses Technology Selection and Fleet Scheduling



d) **Battery sizing and charging strategy:** Required battery sizing (in kWh) for meeting energy need (accounting for SOC and ageing) was estimated . After which, appropriate charging strategy was selected for bus fleet operations(including different scenario for overnight and opportunity charging). Different battery sizes and charging options are assessed together to identify suitable battery and charging option for e-Bus deployment

e) **Scheduling & operations planning: Overall fleet scheduling has been performed which was followed by e**stimating required charging infrastructure for selected e-Bus (fleet) including selection of charging technology, number of chargers, associated grid infrastructure etc.

f) **Scenario selection stage:** All e-Bus scenarios have been evaluated based on TCO and technical attributes of e-Bus System i.e., bus, battery and chargers and charging strategy.

Further as a part of the technical feasibility assessment, (chapter 7,8 and 9), policies for e-Bus adoption and scale-up have been recommended. The implementation guidelines and mechanisms for both e-Bus and charging infrastructure have been included. Financial requirements, suggested business models for e-Bus implementation are also included as part of this feasibility assessment.

2. Country Landscape

2.1 Country Profile

2.1.1 Geographic Profile

Zimbabwe is a landlocked country with an area of 390,757 km²; laying to the south of the equator. It is part of the African continent bordering Zambia to the north-west, Mozambique to the north-east, South Africa and Botswana to the south. The landscape of Zimbabwe has mostly high plateau with higher central plateau (high veld) and mountains in east. The overall topography varies from flat and rolling ranges, to farmland and mountains, all marked by granite outcroppings.

Points of geographical interest include the Victoria Falls and manmade Lake Kariba on the Zambezi River[5], the mountainous Eastern Highlands along the Mozambique border, and the historically important ruins of Great Zimbabwe, the capital of the ancient civilization of Zimbabwe, located near Masvingo, and several game parks.

Zimbabwe lies on the central plateau where the climate is moderate in all seasons with warm days and cool nights. In Harare, the average low temperature in winter is 7.22°C at night in winters (May-August), though frost occurs occasionally. The average daily temperature in summer is 23.89°C, with temperatures seldom surpassing 32.22°C[6]. River Zambezi, the mountain ranges, ores and metals are key natural resources in the country. The minerals namely coal, chromium ore, asbestos, gold, nickel, copper, iron ore, vanadium, lithium, tin, platinum group metals are found in Zimbabwe.

Figure 2.1 Geographical location of Zimbabwe and city of Harare

5 https://www.countryreports.org/country/Zimbabwe/geography.htm. Zambezi forms a natural riverine boundary with Zambia; in full flood (February-April) the massive Victoria Falls on the river forms the world's largest curtain of falling water; Lake Kariba on the Zambia-Zimbabwe border forms the world's largest reservoir by volume (180 cu km; 43 cu mi)

6 https://www.countryreports.org/country/Zimbabwe/geography.htm

2.1.2 Socio-economical Profile

Zimbabwe is a lower middle-income country with 39.8 billion USD economy (2,622 USD per capita)[7]. As per Global Competitiveness Report 2019[8], Zimbabwe stood at 127th place among 140 countries with score of 44.24. The total population of Zimbabwe is at 15.25 million[9] with 38.4% of people residing in urban areas[10]. Remaining majority of population lives in rural areas.

The country has had several transitions in past twenty (20) plus years including prolonged periods of economic recession, political challenges and more regular climate-induced humanitarian crises. However, since past decade the country is in the nascent stages of development[11].

In recent years the government has taken steps to accelerate progress on human development and economic development with the ushering in of a new vision, premised on reforms to transform Zimbabwe into a prosperous and empowered upper middle-income society by 2030[12].

The Zimbabwe Vision 2030 plan focuses on power, transport, water and sanitation, information and communication technology, housing for infrastructure development; education and health for social development; and fiscal space for development, arrears clearance and debt restructuring, aid coordination, anti-money, laundering, financial intermediation, stability & inclusion, currency reforms for inclusive growth of Zimbabwe.

2.1.3 Transport sector

According to the African Development Bank Zimbabwe Infrastructure Report (2019), the transport sector in Zimbabwe comprises five modes namely, road, rail, aviation, inland water and pipeline transport. The Ministry of Transport and Infrastructure Development (MoT) is responsible for i) formulation of national transport and infrastructure policies, ii) ensuring that the Transport Sector complies with national and international standards, iii) the supervision and administration of relevant national and international regulations including treaties and protocols of all aspects of the Transport and Infrastructure Sectors.

There are other authorities responsible for the administration of the road network namely Department of Roads (DoR), Urban Municipalities, Rural District Councils (RDCs) and the District Development Fund (DDF). The road network is maintained through a funding framework that includes, fuel levies, overloading and abnormal fees, heavy vehicle surcharge, transit fees, vehicle licensing fees and transport services.

In the late 1990s, the road transport sector was deregulated as part of economic reform program to increase private sector participation[13] (Zimbabwe infrastructure Report, 2019). As part of this deregulation, the public transport sector was also deregulated which led to the termination of the Zimbabwe United Passenger Company's (ZUPCO) monopoly on urban transportation. It resulted in to introduction of other players and the public transport go dominated by kombis[14] (15–39-seater). Due to the relative lower fare, availability, accessibility and convenience, it became the popular choice for people for long distance daily commute. Other than kombis, large 9–12-meter buses with 40 to 60 passenger seating capacity buses are also operational in Zimbabwe, majority for intercity travel where the commute distance is greater than 25 kms.

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7 https://www.heritage.org/index/country/zimbabwe
8 Report by World economic forum
9 https://www.worldometers.info/world-population/zimbabwe-population/
10 National Development Strategy 1 (NDS1) 2020, GOZ
11 Zimbabwe's Human Development Index score in 2019 stood at 0.571— ranking at 150 out of 189 countries. Gender Inequality Index score of Zimbabwe was 0.527, ranked at 129 out of 162 countries in 2019.
12 Zimbabwe's VISION 2030, "Towards a Prosperous & Empowered Upper Middle-Income Society by 2030", GOZ.
13 Zimbabwe's Infrastructure Report 2019, GOZ,
14 Kombis are 6–7-meter mini buses with 15–25-seater passenger carrying capacity.

2.1.4 Energy Profile

Energy in Zimbabwe sourced from wood fuel (61%), petroleum (18%), electricity (13%), and coal (8%). The Energy sector falls under the Ministry of Energy and Power Development and is regulated through the Energy Regulatory Authority Act [Chapter 13;23] of 2011 and other ancillary instruments which gave way for the operationalization of Zimbabwe Energy Regulatory Authority (ZERA).

Zimbabwe relies on coal and Hydro power plants for electricity generation. Some of the solar and wind energy potential is also utilized for electricity generation. Petroleum is used in industries (milling, agricultural applications)[15], transportation while wood fuel and kerosene are used in most rural hoses for cooking, lighting and other necessary day to day applications.

In electricity segment, grid is well developed and having built capacity , efforts after 1980 are on to improve supplies in urban areas and extend supplies to rural business and government administrative areas[16]. This has enabled electricity access to 80% Urban and 21% Rural population.

2.1.4.1 Electricity generation and demand

Most of Zimbabwe's electricity is produced at the Kariba Dam Hydroelectric Power Station (about 750 MW), at Hwange Thermal Power Station which has an installed capacity of 920 MW, and at three minor coal fired stations. Apart from the Kariba Dam Hydroelectric Power Station, there is still quite a lot of hydropower potential especially along the Zambezi River. Solar Power has enormous potential both in small and large scale but is not adopted widely yet. While wind and biogas energy are other possibilities being explored in the country as an alternate renewable source of energy[17].

The country has an installed capacity of about 2,300 MW, with Zimbabwe Power Company (ZPC), a generation subsidiary of ZESA, owning around 95% of this. The source of generation are coal, hydro, solar, and bagasse. More than 50% of electricity is generated from hydropower power while the remainder is from thermal power plants. The power generation capacity of Kariba Dam Hydroelectric Power Station is about 750 MW and Hwange Thermal Power Station has an installed capacity of 920 MW.

Current demand peaks at around 1,800 MW in the peaks winter months, with a slightly lower peak during the rest of the year at around 1,500 MW. During the night from 10 pm to 5 am, demand drops to below 900 MW[18]. Against this background, the actual power generation capacity is about 1,400MW against a peak demand of about 1,700MW.

Zimbabwe's power deficit is close to 1,000 MW during peak demand periods and the national electricity utility company complements its suppressed generation with imports of up to 400 MW from its neighbours. It imports about fifty Mega Watts (50 MW) from HCB, Mozambique, and around three hundred Mega Watts (300 MW) from Eskom, South Africa whenever finances allow. This resulting in periodic load shedding when demand surges. Zimbabwe is also exporting around eighty Mega Watts (80 MW) of power to NamPower, Namibia based on a commercial agreement between Zimbabwe Power Company and NamPower.

A number of independent power producers are present in Zimbabwe, who are currently generating mainly for own consumption. The existence of a conducive policy and legal framework has enabled investment in the renewable energy sector. The government has also implemented sector specific incentives to promote private investment in renewable power generation such as:

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15 Zimbabwe Energy Profile. http://www.reegle.info/countries/zimbabwe-energy-profile/ZW
16 Country Energy Information Zimbabwe. http://www.energyrecipes.org/reports/genericData/Africa/061129%20RECIPES%20 country%20info% 20Zimbabwe.pdf
17 Energy in Zimbabwe: http://en.wikipedia.org/wiki/Energy_in_Zimbabwe
18 SADC e-Mobility Outlook: A Zimbabwean Case Study by, Remeredzai Kuhudzai, 2020

- Duty exemption on solar PV products and Lithium-ion batteries SI 147/2010) and (SI13/2020
- National project status for RE projects
- Corporate income tax holiday for the first 5 years for power generation projects and thereafter 15% (Finance Act GN 158A of 2018).
- Net Metering is being implemented (SI 86/2018).
- IDBZ Project Preparation and Development Fund (PPDF) to bring projects to bankability
- Prescribed asset status to renewable energy projects
- Reduced Licensing Fees and Requirements for D9evelopers of RE Projects

Significant independent power producers (IPPs) are now operational, and some are feeding into the national grid. Amendments have been proposed to the net metering regulations such as increasing the maximum cap to 1 MW from 100 kW, compensation factor to be reduced from 0.9 to 0.8; that is, for every kWh that the participant exports to the grid, the participant shall receive a credit of 0.8kWh in the billing period, and no participant shall claim monetary compensation from the distribution licensee for energy in kWh exported to the grid[19].

2.1.4.2 Electricity Transmission, Distribution

In Zimbabwe, most transmission lines are high-voltage three-phase alternating current (AC). Electricity is transmitted at high voltages (420, 330,220 kV or below) to reduce the energy loss which occurs in long-distance transmission. Power is usually transmitted through overhead power lines. Underground transmission is sometimes used in urban areas or environmentally sensitive locations. A sophisticated control system is installed at National Control Centre to ensure that the power generation very closely matches the demand. If the demand for power exceeds supply, the imbalance can cause generation plant(s) and transmission equipment to automatically disconnect or shut down to prevent damage. In the worst case, this may lead to a cascading series of shutdowns and a major regional blackout.

Zimbabwe's Electric transmission networks are interconnected into regional wide networks which reduce the risk of such a failure by providing multiple redundant, alternative routes for power to flow should such shutdowns occur. ZETDC determines the maximum reliable capacity of each line (ordinarily less than its physical or thermal limit) to ensure that spare capacity is available in the event of a failure in another part of the network.

Transmission-level voltages are usually considered to be 132 kV and above. Lower voltages, such as 33 kV and 11 kV, are usually considered sub transmission voltages, but are occasionally used on long lines with light loads. Voltages less than 33 kV are usually used for distribution. Since overhead transmission wires depend on air for insulation, the design of these lines requires minimum clearances to be observed to maintain safety. Adverse weather conditions, such as high winds and low temperatures, can lead to power outages.

Electric power distribution is the final stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers. Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage ranging between 11 kV and 33 kV with the use of transformers. Primary distribution lines carry this medium voltage power to distribution transformers located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage used by lighting, industrial equipment and household appliances. Often several customers are supplied from one transformer through secondary distribution lines.

19 Zimbabwe Energy Regulatory Authority presentation "Solving Key Issues in the Energy Sector" International Renewable Energy Conference and Expo 2020

Commercial and residential customers are connected to the secondary distribution lines through service drops. Customers demanding a much larger amount of power may be connected directly to the primary distribution level or the sub transmission level. Urban distribution is mainly underground, sometimes in common utility ducts. Rural distribution is mostly above ground with utility poles, and suburban distribution is a mix.

2.1.5 Key Plans and Policies

Followings are the key Policies in Zimbabwe through which the country is putting efforts to achieve GHG goals, clean mobility, new generation and new technology mobility and supporting electric vehicle implementation

- Intended National Determined Contributions (NDC)
- National Development Strategy (NDS)-2020
- Zimbabwe Long-Term Low GHG Emission Development Strategy targets 2020-2050 (LEDS)
- National Climate Change Response Strategy
- Climate Change Policy- 2016
- National Transport Master plan-2018
- National Energy Policy-2012
- National RE Policy-2019

EV Roadmap has been prepared which can become a guiding plan towards clean energy and mobility practices.

3. City Profile and Existing Bus Transport in Harare

3.1 Harare City profile

Harare is capital of Zimbabwe and lies in the north-east of Zimbabwe and situated at the watershed plateau of two major rivers; Zambezi on the north and Limpopo on the south[20]. The area has prime agricultural soils offering Harare opportunities for agricultural activities in addition to the dominant manufacturing sector contributing to 40% of the country's economy. It was positioned at the core of the political and economic processes of the colonial establishment and witnessed an unprecedented growth in construction as a result.[21]

Harare was formerly known as Salisbury (1953-63), which was declared a municipality in 1897. It was the capital of the Federation constituted by Nyasaland (Malawi), Northern Rhodesia (Zambia) and Southern Rhodesia (Zimbabwe). At the time of Zimbabwe's independence in 1980, Harare's population was 616,000.

Figure 3.1 Map of city of Harare[22]

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20 Government of Zimbabwe (2011).

21 International Bank for Reconstruction and Development (IBRD) (1958)

22 Mapz.com

Its current population is estimated to be 1.4 million while the entire metropolitan area raises this figure to 2.1 million.[23] The lifting of institutional apartheid controls that restricted movement prior to independence is responsible for the city's population doubling in this time.[24]

As the capital, Harare is where most of the country's economic processes are concentrated. Estimates suggest that one in three Zimbabweans live in Harare, with the city's economy contributing 40% of the national gross domestic product.[25] However Harare's formal and informal economies have not been integrated and socio-spatial disparities remain deeply entrenched.[26] The city acts as a major hub for the country's road, rail and air transport networks, and is positioned strategically for trade and tourism. After independence in 1980, Harare inherited a robust manufacturing sector that was anchored by mining and agricultural activities. However, starting in 1982, the country experienced recurrent episodes of disruptive weather patterns alongside ill-conceived macro-socioeconomic policy decisions by the post-colonial government. Whilst Harare benefitted from significant infrastructure investments compared to other cities during the colonial and post-colonial periods, since 2000 there has been a decline in both physical and social amenities. In addition to limited or absence of infrastructure and services in some areas, authorities have also failed to maintain existing infrastructure.

The country's debilitating macroeconomic situation has also affected city's infrastructure, facilities, transport system, road network and so-on. The set-back in industry have increased the country's dependency on imports. Rising number of imported (Japan, Asia, US) pre-owned vehicles on-road is creating alarming situation in Zimbabwe and so in city of Harare. Vehicles arrive in the country daily in great quantities and the majority of them are destined for Harare.

According to the Central Vehicle Registry (CVR 2012), the number of vehicles in the country increased by approximately 6% from 522,682 in 1999 to 973188 by 2009. As per CVR 2021 recent numbers, there are total in 1,393,779 of vehicles in the country. Albeit the un-availability of figures by city, it is estimated that about 70% of these vehicles are in Harare. It is evident that there is a clear mismatch between increases in the number of vehicles plying the streets of Harare and provision of road space resulting in severe congestion. The city experiences high levels of congestion which can be protracted for several hours.

3.2 City Transport in Harare

Under a World Bank supported Economic Structural Adjustment Program (ESAP), the urban public transport industry in Zimbabwe was deregulated in 1993. The deregulation caused a significant increase in the number of privately operated public transport vehicles (mostly mini buses known as kombis) and a substantial increase in capacity, an expansion of the urban transport network as new services was introduced by local authorities that were not served by public transport prior to deregulation, and a considerable reduction in average waiting times for passengers. There were, however, a number of adverse effects, including rapid growth in the number of small public transport vehicles that had an adverse effect on the environment.[27]

The Zimbabwe United Passenger Company (ZUPCO), a franchise under the Ministry of Local Government was launched in 2019 as the Government's attempt to solve the transport crisis in the wake of increased fuel prices. It began as a franchise for buses. The project began with 200 buses and now the project to date has about 900 buses throughout the country. After pandemic, the franchise now regulates kombis as well.

23 Government of Zimbabwe (2012)
24 Munzwa and Wellington (2010); and Potts (2011)
25 Government of Zimbabwe (2012).
26 Chikowore (1993)
27 https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/11.%20Zimbabwe%20Report_Chapter%209.pdf

3.3 Existing Bus Transportation in city of Harare

Public transport system within the city includes both public and private sector operations. City of Harare has some more than ~8,000 intracity public transport vehicles which include kombis, mini-buses (majorly known as kombis) and standard buses. About 40% kombis (including mini-buses) in the city are not complying and following permits and rules. Fleet operators usually follow mix model of running some buses/kombis under ZUPCO and others in private to hedge their revenue and compliance risks.

Under ZUPCO Franchise there are 1384 vehicles including franchised kombis, mini-buses and standard buses have following split (Refer Table 3.1).

Table 3.1 Existing Public transport vehicles in Harare (2021)

SNo.	Vehicle	Total Vehicles	Vehicles under ZUPCO Franchise	Common Models running	Seating Capacity	Standing capacity/ Overloaded[28]	Length (m)
1	Kombi	771	759	Toyota Hiace, Nissan Caravan	12 - 24 (15-seater most common)	-	4.42 - 5.26
2	Mini-bus (referred as Kombi)		6	Nissan Civilian, Toyota Coaster, Indian Tata, IVECO (UK)	25 - 39	10 - 15	6.2 - 7.7
3	Standard bus	613	613	FAW, Golden Dragon, VW, Yutong/ Zhongtong, AVM/DAF (local model)	40 - 60 (some models-75)	25 - 30	11.48 - 12.45

Among the 613 standard buses 32 are owned by ZUPCO, 469 are private and sub-contracted by ZUPCO and remaining 112 buses are leased from CMED. The standard buses (12 m) are mainly the Golden Dragon from Belarus, VW from South Africa (imported by Government/CMED/ZUPCO) and Yutong/Zhongtong from China and locally assembled AVM/DAF buses as well as some imported from UK and Europe by private operators. Kombis are mainly Toyota Hiaces and Nissan Caravan, imported from Japan and UK as second-hand panel minibus vans which are then put in some locally assembled seats.

3.3.1 ZUPCO Bus Ownership and Operating Models

ZUPCO also has its own residual fleet in operation. Their own fleet currently comprises of 50 buses. These are 61 to 63-seater FAW buses (12m non-AC) and some buses are allowed a particular standing capacity. These buses are more than 12 years old. ZUPCO operates these buses for intracity commute at the moment with average 150 to 250 km daily travel[29].

In this operation model the ownership of buses is fully with ZUPCO and is run by ZUPCO's own staff; both for daily operations and Maintenance. ZUPCO manages the route and provides with a conductor who collects the cash and cashes it in everyday to the ZUPCO depot. ZUPCO also owns other supporting infrastructure i.e., bus shelters, stops, terminals, depots that are required to run the buses.

3.3.1.1 ZUPCO Sub-contracting Model

To run a vehicle under ZUPCO franchise, an operator needs to provide a road worthy vehicle which at first inspected by the Vehicle Examination Department (VED) and further inspected by the Central

28 illegal after Covid 19
29 ZUPCO, 2022

Mechanical Equipment Department (CMED). After inspection, vehicle insurance and passenger insurance are required. The documents of insurance and inspection are to be submitted to ZUPCO along with the vehicle for enrolment after which a route is assigned to the operator.

ZUPCO manages the routes and provides with a conductor who collects revenue every day to the ZUPCO depot. The number of routes given to a particular individual is dependent on the number of vehicles they enrol under ZUPCO; however, operators usually ask to be assigned to the more lucrative routes for all their vehicles so as to insure easier management of the private fleet. The table below gives the hiring fees paid by ZUPCO to operators. This amount does not change with the distance travelled.

Table 3.2 Hiring fees paid by ZUPCO to Operators[30]

Hiring Fees paid by ZUPCO for	Zimbabwean dollar (ZWL) per day
Bus	$ 18,000
Kombi	$ 6,700

3.3.1.2 ZUPCO Lease Model

In the lease model, Central Mechanical Equipment Department (CMED) under Ministry of Transport currently purchase buses and lease them to ZUPCO. These buses are being purchased from Belarus, China and south Africa.

The buses are fully funded by the Government of Zimbabwe and owned by CMED. CMED then handover the buses to ZUPCO for daily bus operations where ZUPCO provides the staff for operations of the buses. The operational staff includes the drivers and the conductors. Regular maintenance, overhauling and all other maintenance activities are undertaken by CMED. For such maintenance a monthly invoice is generated to ZUPCO which has to paid with a fixed service fee. The recent procurement of ICE buses have been done through the same process and settings.

3.3.2 ZUPCO Depots and Terminals

At present there are four depots owned and operated by ZUPCO namely, Willowvale, Belvedere, Hood Road and Chitungwiza; having well equipped workshop and skilled manpower.

i) **Willowvale depot** is mainly for buses having nearly 500 bus parking capacity. It is mostly used for parking and has the equipped workshop for repair and maintenance of buses with skilled staff. (~500), mostly for parking, closer to suburbs, have biggest central workshop

ii) **Belvedere depot** is placed behind ZUPCO Head office in CBD and is primarily used for buses. It has parking capacity for ~500 buses. The area of CBD is highly occupied due to the radial arrangement of routes. This depot is currently crowded, and the daily operations of buses are causing traffic bottlenecks, restrictions on turning movements.

   a) Mainly for buses (~500 buses capacity).
   b) It also gets kombis (<50), behind ZUPCO head office

iii) **Hood Road depot** is situated near the CBD towards south west and is mainly used for parking kombis. It has capacity to park 500 kombis. The depot is comparatively smaller than that of Belvedere and Willowvale depots and is suitable more for the mini and midi bus parking.

30 Consultations with Kombi operators (January,2022)

iv) **Chitungwiza (Makoni Area) depot:** The Chitungwiza depot is situated at the south of city of Harare and is located nearly 25 km far from CBD. This is an important depot as Chitungwiza is sub-urb of city of Harare and has the only big depot to serve the buses making trip from Centre to Chitungwiza.

Map 1 ZUPCO Depots

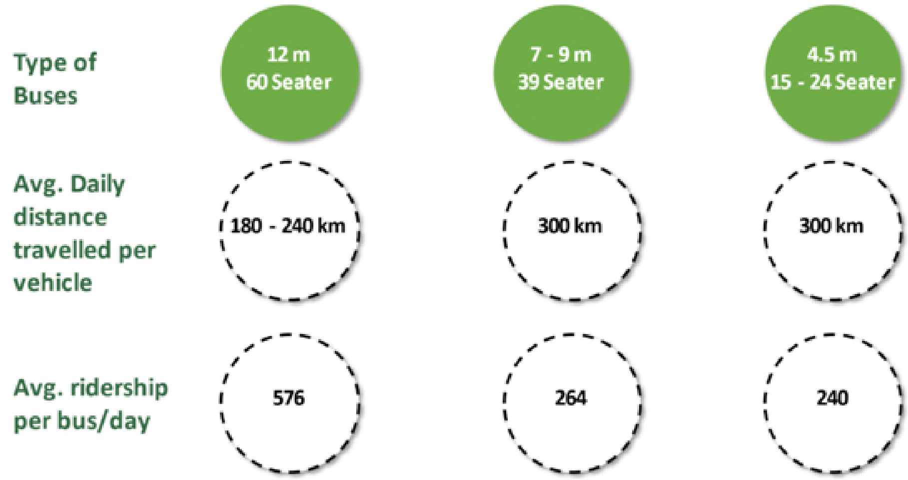
Based on consultation with operators following major terminals were identified. There are 7 terminals in the CBD namely Mbare (A & B), Market Square, Charge office, Fourth Street, Copacabana, Ruzende Parkade, Copacabana, Machipisa, these are the endpoints and start points of routes and have limited parking space available mostly for day time parking for boarding-alighting and the layover period, where bus awaiting to start the next trip (forward or return).

Among these terminals Mbare is the centrally located biggest terminal in the city, having all intercity routes starting and majority of intracity routes (intracity and sub-urban) starting from the same point. It has two parts; Mbare A for buses and Mbare B for kombis

3.3.3 ZUPCO Fleet Schedule and Operations and Routes

Bus service in city of Harare operates for 18 hours a day; starting its first operation from 4:00 am in the morning till 10:00 pm in the night. 6 am to 10 am in the morning and 3 pm to 6 pm in the evening are peak hours of the day; and rest till 10:00 pm are non-peak hours. Buses ply with an interval of 20 minutes in Peak hours and 30 minutes in non-peak hours. Kombis ply up to 20 km routes while buses ply up to 30 km routes. Buses do mainly 3-4 round trips per day while kombis do at least 6 round trips per day. Round trips is one journey combining one trip from the sub-urb to the CBD/Mbare termini and then return trip. The 60-seater 12 m buses perform 180-240 km per day with an average ridership of 576 passengers per bus per day. 40-seater 7 m to 9 m buses perform 300 km distance each daily with average ridership of 264

Figure 3.2 Current ZUPCO bus operations in city of Harare



passengers per bus per day. Rest mini buses/kombis with 15-24 seating capacity perform average 300 km distance each with average ridership of 240 passengers per bus per day. The Figure 3.2 below shows the current bus operations of ZUPCO buses.

Private operators provide vehicle plus its maintenance while ZUPCO provides fuel, conductor and overhead/management of routes (executive management, depot managers, route monitoring staff, office staff, fuel dispensers, bus dispatchers etc.). Currently the normal route fares are 45ZWL for standard buses and 60ZWL for kombis and mini-bus.

However, recently ZUPCO has enrolled the services of national railways of Zimbabwe which are scheduled for 5 am in the morning and 6 pm in the evening, run from the suburbs to the city centre. The demand from suburbs along the line are catered by the standard buses by taking passengers from the rail way wagon to the CBD with a tariff of about 50 cents USD equivalent which is inclusive of the train and the shuttle to the suburb. There are only 3 routes for this train service,

1) Ruwa-Mabvuku route
2) Tynwald Dzivarasekwa route
3) City centre- Rugare-Kambuzuma- Mufakose route

There is a mix of operators running on these routes, some are ZUPCO owned, and others are the private operators under ZUPCO. The buses are usually parked at the depot after end of the operations. Re-fuelling, daily and periodic maintenance activities are carried out in the ZUPCO workshops.

3.3.4 ZUPCO Bus Transport Routes

There are about 121 urban city routes under ZUPCO for both kombis and buses[31]. Based on preliminary stakeholder discussions, major fleet routes are mapped and compiled in Table given below.

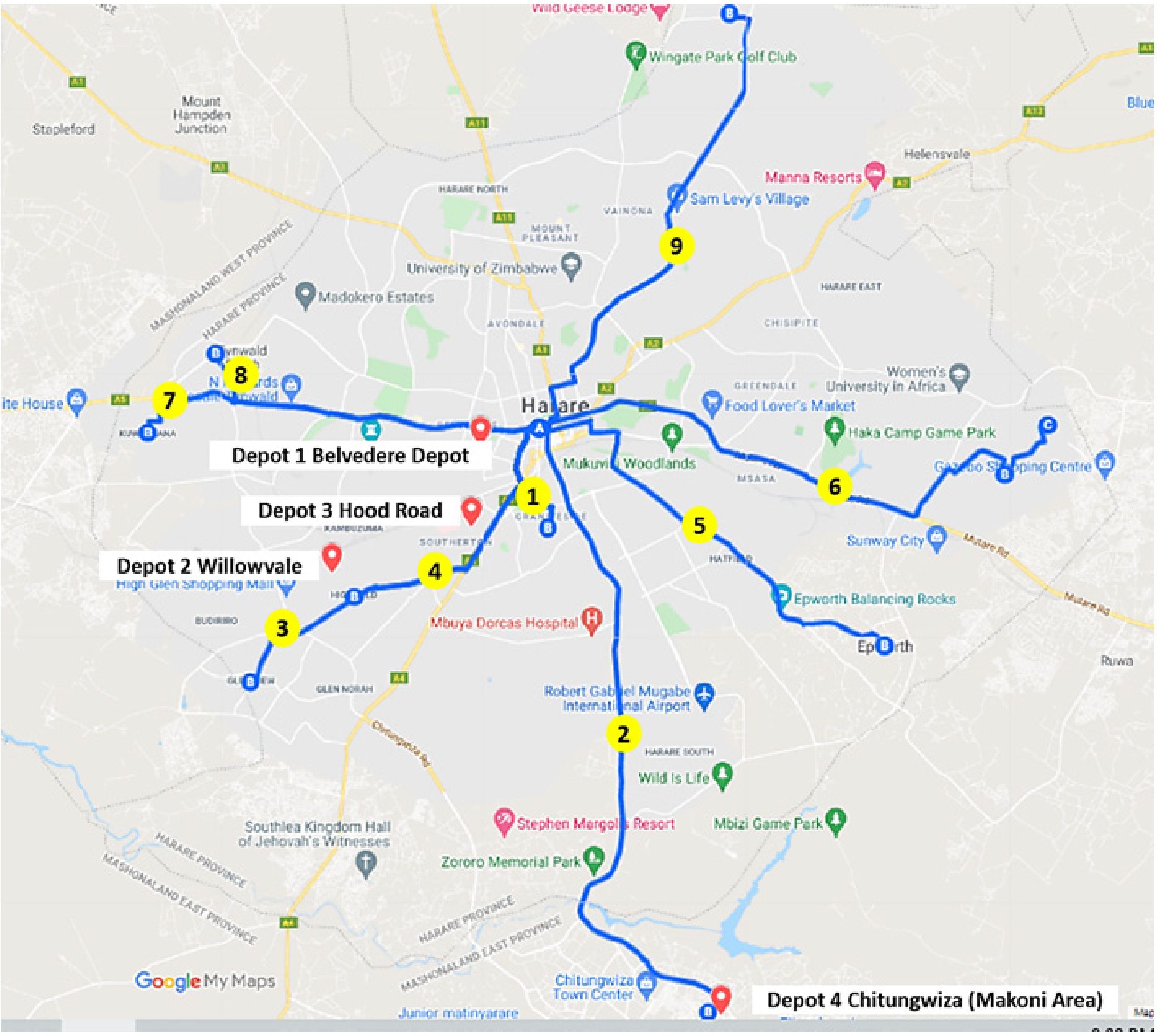
31 http://www.zupco.co.zw/harare_urban.html

Table 3.3 Public Transportation Major routes

Major route from Central Business district (CBD)	Intra-city Suburbs	Inter-city/ rural / Satellite towns	Bus terminus (CBD rank)
	Permits issued by local authorities under Ministry of Local Government now under ZUPCO	Permit issued by Road Motor Transportation (RMT) (permits suspended for buses)	
Seke Road	Chitungwiza, Waterfalls, Sunningdale, St Martins/Accadia, Braeside, Logan Park	Seke Rural, Hwedza	Charge Office
Remembrance Drive	Mbare, Ardbennie, Prospect		Market Square / Copacabana
Simon Mazorodze A4 (Masvingo Road)	Highfield, Glen Norah, Hopley, Stoneridge, Ushewokunze, Parktown, Houghton Park, Southerton, Glen View,	Beatrice, Chivhu	Market Square / Mbare
Lytton/Coventry Roads	Kambuzuma, Mufakose, Marimba, Budiriro		Market Square / Mbare
Bulawayo Road A5 West	Kuwadzana, White House, Warren Park, Norton, Dzivarasekwa, Belvedere, Westlea, Madokero, White House Glenary,	Chegutu, Kadoma	Copacabana / Mbare
Lomagundi Road A1 (Chinhoyi Road)	Marlborough, New Marlborough, Emerald Hill, Avondale	Mt Hampden, Stapleford, Gwebi, Banket, Chinhoyi	Copacabana / Mbare
Golden Stairs Road A1 / A11	Mt Pleasant, Belgravia	Bindura, Mt Darwin, Glendale, Christon Bank, Mazowe, Concession	Ruzende Parkade / Market Square / Mbare (Inter City only)
Borrowdale/ Domboshava Road	Helensvale, Borrowdale, Hatcliffe, Vainona	Domboshava, Musana, Bindura	Fourth Street / Mbare
Enterprise Road A2	Chisipite, Highlands, Grange, Helensvale	Chishawasha, Juru, Murehwa, Mutoko, Mutawatawa,	Fourth Street / Mbare
Mutare Road A5 East	Msasa, Eastlea, Hillside, Rhodesville, Mabvuku, Tafara, Ventersburg, Zimre Park, Ruwa, Mabvazuva, Eastview	Goromonzi, Melfort, Bromley, Marondera, Macheke, Headlands, Headlands, Rusape	Fourth Street / Mbare
Chiremba Road	Epworth, New Sarum, Hatfield, Msasa Park, Cranborne		Fourth Street / Mbare

1) Mbare, 2) Chitungwiza / Makoni, 3) Glen View, 4) Highfield, 5) Epworth, 6) Mabuvuku-Tafara, 7) Kuwadzana 1-7, 8) Dzivarasekwa, 9) Hatcliffe

Figure 3.3 Major Routes (trunk routes) and Depots[32]



32 The fleet size and routes for electrification are identified, shortlisted and finalised based on further stakeholder consultation and inputs from Steering committee.

4. e-Bus Depot and Routes Selection

Urban bus transportation is operated on several routes. With existing practice of running ICE buses on the routes is far different than running an electric bus on same route, as their energy requirement for every route change based on unique route characteristics. An e-Bus is dependent on its battery and battery is subject to behave differently with respect to the route specific terrains, lengths, travel time, driving behaviour and overall route energy requirement. This translates ultimately to the charging requirements i.e., charging time, charging infrastructure requirements change making each route a different case to run e-Buses.

Considering e-Bus deployment as a new ecosystem altogether except the purpose to serve passenger demand; it is necessary to wisely select the depot and potential routes for electrification. To support above mentioned purpose, following chapter describes background, criteria for selection and selected depot and routes.

4.1 Depot Selection

Among four depots of ZUPCO namely Belvedere, Hood Road, Willowvale, Chitungwiza; Willowvale Depot is identified suitable for first deployment of e-Buses in city of Harare. Willowvale depot is situated along Willowvale road; between the sub-urbs and the city centre providing good connectivity.

As per consultation with ZUPCO, it was identified that, most of the travel demand during start of operations of buses is from sub-urbs to CBD (Market Square). The Depot has ample parking capacity with well-equipped workshop. It is also a dedicated depot for bus operations. The Belvedere depot also has a well-equipped workshop while currently is acquired by CMED for O&M for all fleet under their jurisdictions.

Current bus operations from the centrally located depots namely Belvedere and Hood Road depot are making bus operations difficult and responsible for the congestion in city Centre. Hence operating e-Buses from Willowvale depot will make an ideal case for first deployment of electric buses. Based on its capacity and potential, Willowvale depot can provide service to i) high demand areas ii) decongesting CBD in busy hours and occupying iii) utilize the of the space, infrastructure and optimum use of available facilities in the depot.

The Willowvale depot has an area of 73,125 sq.m. with parking capacity of nearly 500 buses with concretized surface and well-equipped workshop. Its capacity of repair and maintenance is to serve 26 buses in parallel. The depot has total of 5,670 sq.m. area covered under roof comprising of different sections for workshop, staff rooms, store rooms, trimmer shop, welding bay, couch repair bay etc.

The depot has 20 standard pits provided with drainage system. Underground storage system is used for fuel/oil storage. A current staff of 787 is available on site including for R&M, Administration, Drivers, Conductors, service workers and others. There are typically 16 hrs operation of Willowvale depot while some departments like fuelling, control room are operational for 24 hrs.

Figure 4.1 Depot Location existing condition

4.2 Route Selection

4.2.1 Route selection criteria

To ensure an implementable concept for validation this study focuses on BEB implementation considering on existing routes. The road network serving existing city bus transportation services have mostly paved and of acceptable quality of road surfaces.

The routes are selected in multiple consultations with ZUPCO; the public transport authority in Harare. Key operational, technical and commercial parameters are used for route selection and are described as follows:

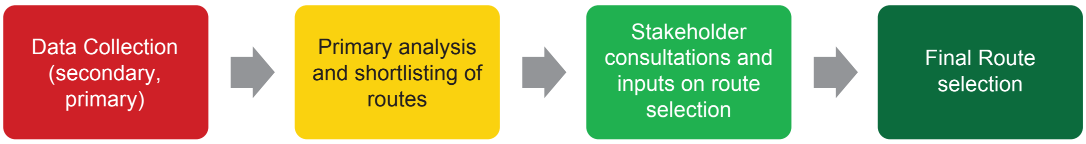
Table 4.1 Parameters for route selection

Parameter	Description
Passenger demand	• Passenger demand is important aspect to understand financial and commercial viability and bankability of the service. Passenger demand is used by public transport Authorities (PTAs) to design bus service (number of buses, trips, bus size, headways etc.) on given routes. It also useful to analyse patterns of passenger travel behaviour based on gender, occupation, Origin-destination, travel time, accessibility, affordability and others. Based on scope and need for study, the depth of passenger demand survey varies • For this feasibility study, 'Boarding-alighting' survey was conducted where the number of passengers boarding, on-board and alighting at each stop were counted. This helped calculating average ridership and to select bus and fleet sizing
Route length and condition	• Route length is necessary to understand as it directly impacts the energy/fuel consumption. City of Harare has radial road network (with radius of ~25 km) where every major (Arterial) road starts and ends at the city centre (CBD). Current bus routes range from 5 km to 25 km in and around periphery of the city of Harare. • Existing conditions of the bus routes range from average to good. Good condition or routes with paved surfaces helps smooth operations of buses

Parameter	Description
Distance to depot / charging station	• Distance from depot impacts the daily travel distance for a bus More distance increases the dead mileage i.e., distance travelled by bus without passengers (non-billable). More dead mileage leads to more consumption of fuel, time and hence the extra cost. Short/no distance would make an ideal case for setting-up charging infrastructure and eliminating chances of delays, losses, extra energy requirement and saving 'extra' cost as well
Distance and capacity of feeders on envisaged charging stations/depots	• The distance and capacity of feeders (grid) to respective charging stations is important to assess any power infrastructure issues that would affect the operational and technical aspects of the e-Bus operations
Maximum gradient and elevation profile of route	• The grade is elevation profile of a route. The difference between two gradient points impacts energy requirement to ply buses on the route. Gradient upward would require high energy and vice-versa for downward gradient • Choice of e-Bus is an important decision which depends on power requirement for a route. With higher motor power the cost of bus will increase • An average gradient of 5% is considered acceptable (normal conditions) to operate e-Buses
Operational characteristics	• Operational characteristics include, time of operation, route specific travel time, schedule, headways, layovers, operations and maintenance of buses • For electric buses, the operational characteristics may require change as full charging of e-Buses requires 1 – 4 hours for fast charging or 3-6 hours for slow charging • Based on route energy, battery size, passenger demand and charging, the e-Bus operations may need modifications and optimisation in required number of fleets, their headways and charging schedules
Number of stops per route	• Bus stops allow passenger boarding and alighting and ensure accessibility to the users. While it also increases the travel time • A distance of 500 m – 750 m is considered as ideal distance between two stops from point of view of users, bus service, accessibility. While planning the service, the number of stops should be considered wisely with focus on catering travel demand and optimising energy consumption

4.2.2 Route selection methodology

Figure 4.2 Route selection methodology



All existing public transport routes in city of Harare were identified. Broader operational, institutional and regulatory and financial data was collected from key stakeholders[33] (refer Chapter 3.3.4). ZUPCO has played a major role in providing inputs and validating the understanding about city bus transportation in Harare.

Broad mapping (refer chapter 3.3.4) of existing city bus routes was prepared based on consultations with ZUPCO. Through preliminary analysis major public transport corridors and possible electrification corridors were identified and validated from key stakeholders (ZUPCO, city government of Harare).

ZUPCO also provided guidance and recommended most suitable corridor and possible routes thereafter. A list of routes and requested operational, technical, financial parameters was provided for further assessment.

33 Consultations with ZUPCO, city government of Harare, local bus operators and experts were conducted during December 2021 to January 2022. There are no current studies available on public transport in city of Harare and information is gathered based on consultations.

4.2.3 Shortlisted Route profile

Existing intracity transport routes cater to the demand are within the city as well as some peripheral settlements and towns. In this case the routes lengths go as high as 25 kilometres. Based on common understanding (with ZUPCO) the routes with less than 20 kms were agreed to be prioritised among 121 Public transport routes in Harare.

As the depot centric approach was chosen, Willowvale depot is prioritised for electrification. Also, Willowvale Depot has Twenty-Two operational routes among which below Five routes are shortlisted in consultation with ZUPCO due to: 1) High passenger demand and ridership, 2) Proximity to Depot, 3) Lucrative routes, 4) Good feeder roads, 5) Short routes

The routes are shortlisted based on parameters described in Chapter 4.2.1; and are namely 1) Glen Norah 2) Glen View 1 3) Machipisa 5) Budiriro 1 and 5) Budiriro current. Route 4 and 5 (Table 4.2) overall show similar characteristics and are in same direction (west) from city centre hence have set to alternate priority. All other routes given in the table are set prioritized based on their characteristics and in consultation with ZUPCO.

Table 4.2 Route profiling for shortlisted routes for electrification[34]

Parameter`	R1	R2	R3	R4	R5
	Glen Norah A	Glenview 1	Machipisa	Budiriro 1	Budiriro Current
Round trip length (km)	**29**	**30**	**18**	**36**	**37**
No. of existing buses	**12**	**11**	**10**	**11**	**11**
Demand for more buses	**Estimated higher than existing (~25 on each route)**				
No. of round Trips/day	7	7	7	7	7
Route ridership (Pax/day)	10,752	9,856	8,960	9,856	9,856
Daily operational distance travelled (kms/day/bus)	~203	~210	~150	~250	~250
Dead mileage (kms/day/bus)	8	9	6	10	10
Total distance (kms/day/bus)	~220	~220	~160	~260	~260
Number of stops one way	6	5	3	4	4
Operational hours	7 hours peak: Morning peak 4 hrs. and evening peak 3 hrs.				
	Total 18 hours				
Start time	4:00 AM				
End time	10:00 PM				
Headway	Off-peak – 20 Min				
	Peak – 15 Min				

The routes start from Willowvale depot to the start points/terminal to end point/terminal at Market Square terminal at CBD. The Market Square terminal has ~10,000 Sq.m. with parking capacity of ~120 buses[35].

34 The Shortlisted routes are suggested by ZUPCO based on preference, revenue generation capacity, proximity to depot, potential to run first e-Bus pilot; and are subject to change if any changes in current understanding, suggestions, recommendations, preferences of local public transport authority/decision making authority.

35 Considering 60% capacity of terminal to park the buses and other space required for movement of buses.

5. Technical Assessment for e-Bus feasibility

This chapter presents the route level characteristics and energy demand assessment of selected five (5) routes for e-Bus deployment. After route and depot selection the route level information was collected for analysing energy consumption requirements of each route. The data was collected through on-site surveys.

Two types of surveys were conducted on selected five routes, namely;

1) Enroute duty cycle data collection through mobile application
2) Boarding alighting survey to capture passenger ridership data

Both the surveys conducted during peak time (Morning). Duty cycle survey has captured travel information of bus on specific route i.e., time, location, speed, distance travelled (after regular intervals of 1-4 second); while boarding alighting survey captured the peak our passenger demand and the number of stops enroute. Other characteristic of the bus service and inputs were captured through the consultations with ZUPCO.

5.1 Key considerations for technical assessment

The duty cycle data was captured through and out was received in MS-Excel files. Through preliminary assessment following characteristics of routes were identified (Table 5.1). Average, minimum, maximum speeds; total time of travel (completion of one trip); total distance travelled; route gradient are the key characteristics (outputs) derived from preliminary assessment; useful for route level energy modelling.

5.1.1 Existing ICE Bus Operations

Table 5.1 Common operational parameters for existing 12 m standard ICE buses in Harare[36]

Parameter	Unit	R1	R2	R3	R4	R5
		Glen Norah A	Glenview 1	Machipisa	Budiriro 1	Budiriro Current
Existing number of buses	#	11	10	12	11	11
Average speed[37]	kmph	12.87	25.66	15.44	12.35	15.09
Average route gradient	%	-0.3%	0.0%	0.2%	0.4%	0.4%
Average passenger occupancy	Pax/trip	43	58	21	55	60
	Pax/round trip	85	115	80	110	119
Average distance	km	14.55	14.87	9.19	17.79	18.33
One way trip duration: forward	Hrs	00:56	00:31	00:56	01:00	00:50
One way trip duration: return	Hrs	00:50	00:38	00:35	00:51	00:50
Round trip duration	Hrs	01:47	01:09	01:32	01:51	01:40
Working days	#	300	300	300	300	300
Total round trips per day	#	7	7	7	7	7
Total distance travelled per day	km/day	204	208	129	249	257
Total distance travelled per year	km/year	74,353	75,975	46,956	90,917	93,666

36 The operational parameters are obtained through consultations with ZUPCO (January – March 2022)

37 Average speed, Average route gradient, Average Distance, one way Trip Duration: Forward, one way Trip Duration: Return, Round trip Duration are modelled out-puts (Duty cycle analysis and sci-lab simulation)

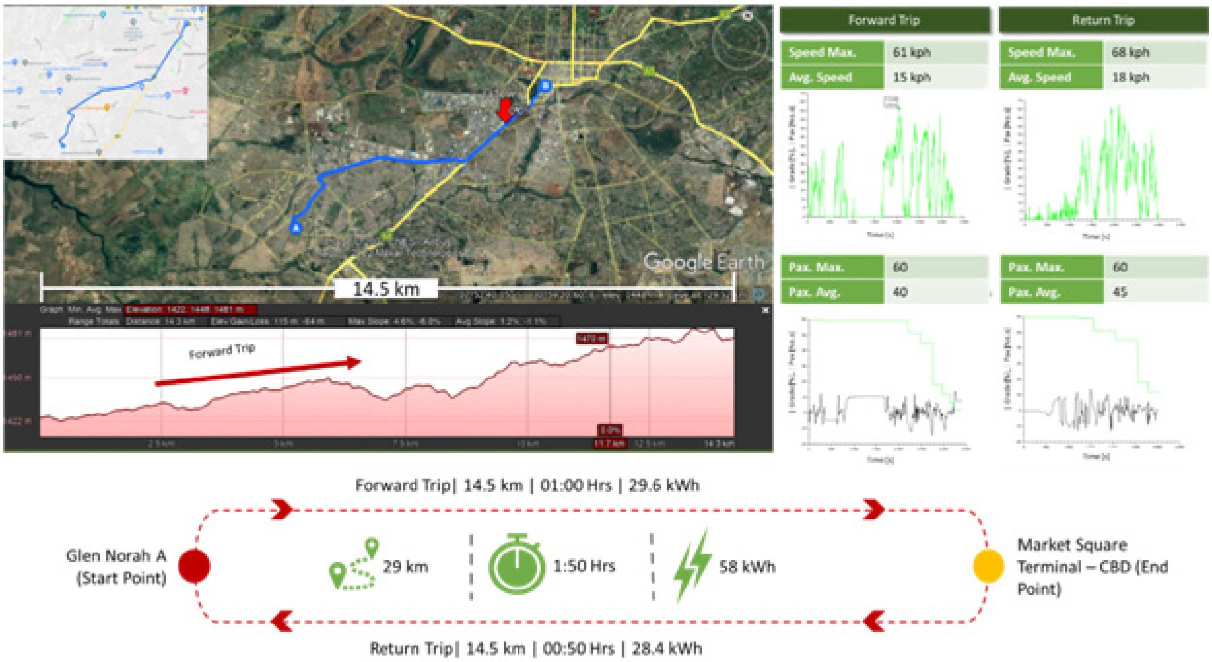
5.2 Routes energy assessment

Route energy assessment is an outcome of processing duty cycle data collected using ICE bus and applying for an e-Bus through virtual modelling[38]. This gives the likely energy consumption by e-Bus operations on same routes where ICE buses are currently plying. Each route has different characteristics in terms of terrain, length, traffic condition, road surface conditions hence the energy consumption and performance of buses vary route to route. This is further reflected in Route level profiling and energy consumption assessment.

5.2.1 Route profile and energy consumption

Following illustrations present the forward, return and round-trip profiling for each of the five routes. It includes, 1) Route profile: Length, terrain; 2) Passenger Loading – maximum and average passenger loading against grade; 3) Speed Profile: maximum and average speed (kph) against time (s); 4) Round trip energy consumption (kWh) with split between forward and return trips (also time and distance).

Figure 5.1 R1 Glen Norah A route profile



38 In this case the virtual model used for simulation is developed in Sci-lab. Sci-Lab: Sci-Lab is a free and open-source software for engineers & scientists, with a long history (first release in 1994) and a growing community (100 000 downloads every month worldwide). https://www.scilab.org/about/scilab-open-source-software

Figure 5.2 R2 Glen View 1 route profile

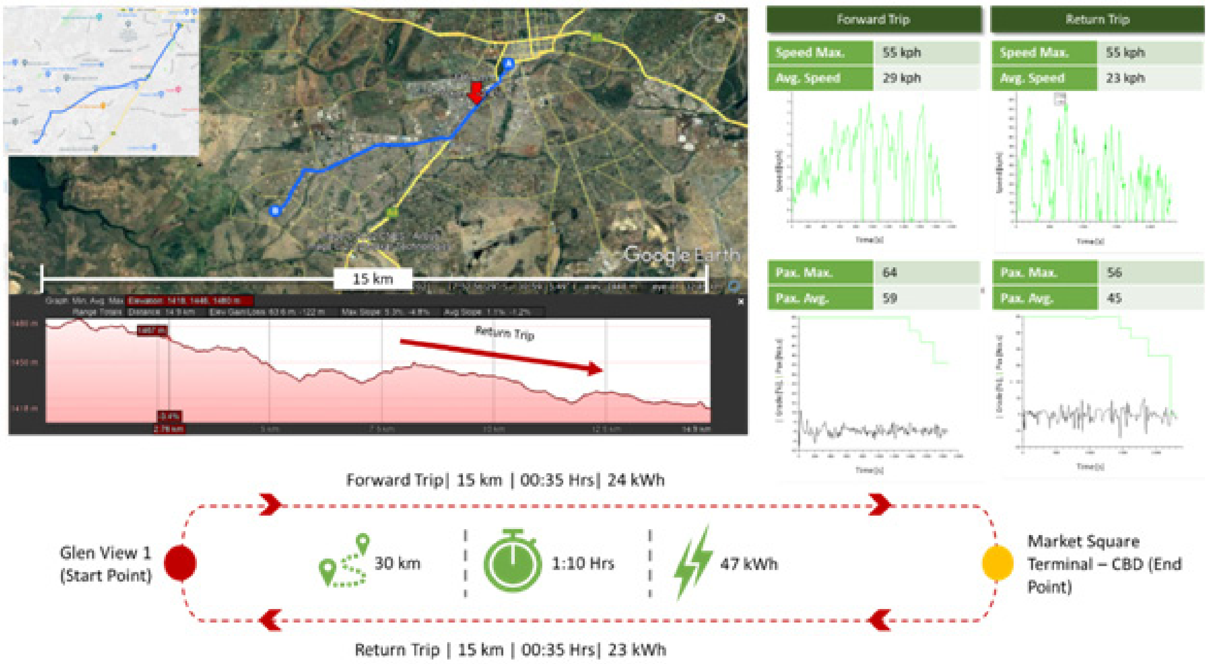


Figure 5.3 R3 Machipisa route profile

Figure 5.4 R4 Budiriro 1 route profile

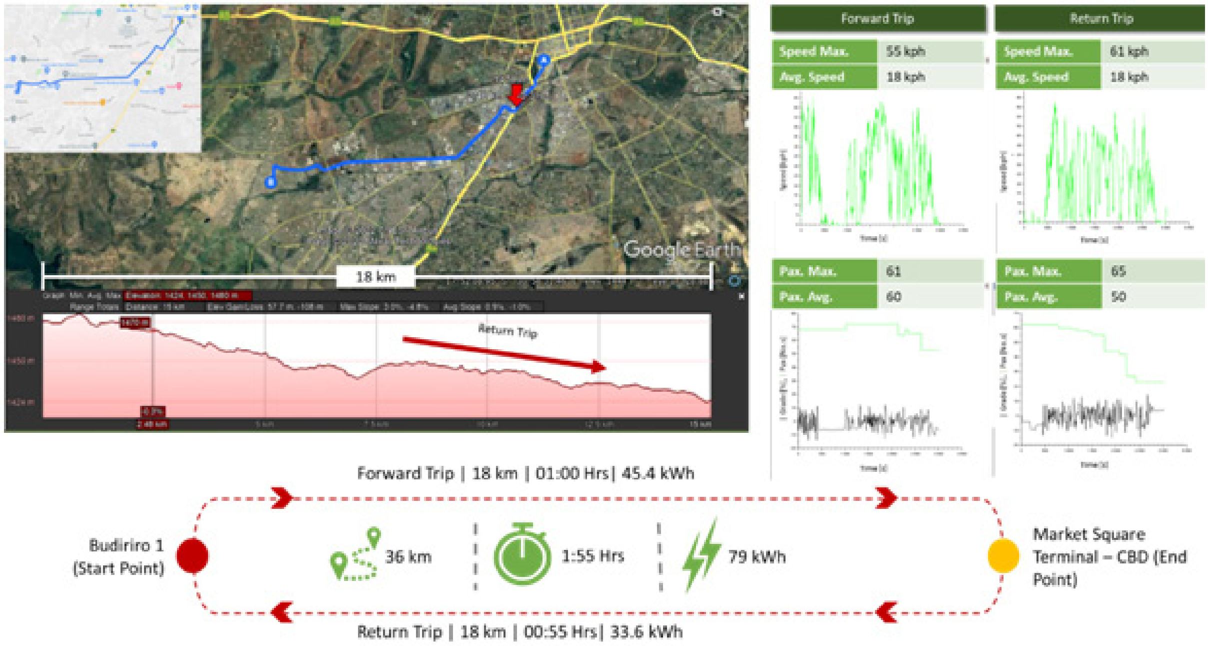
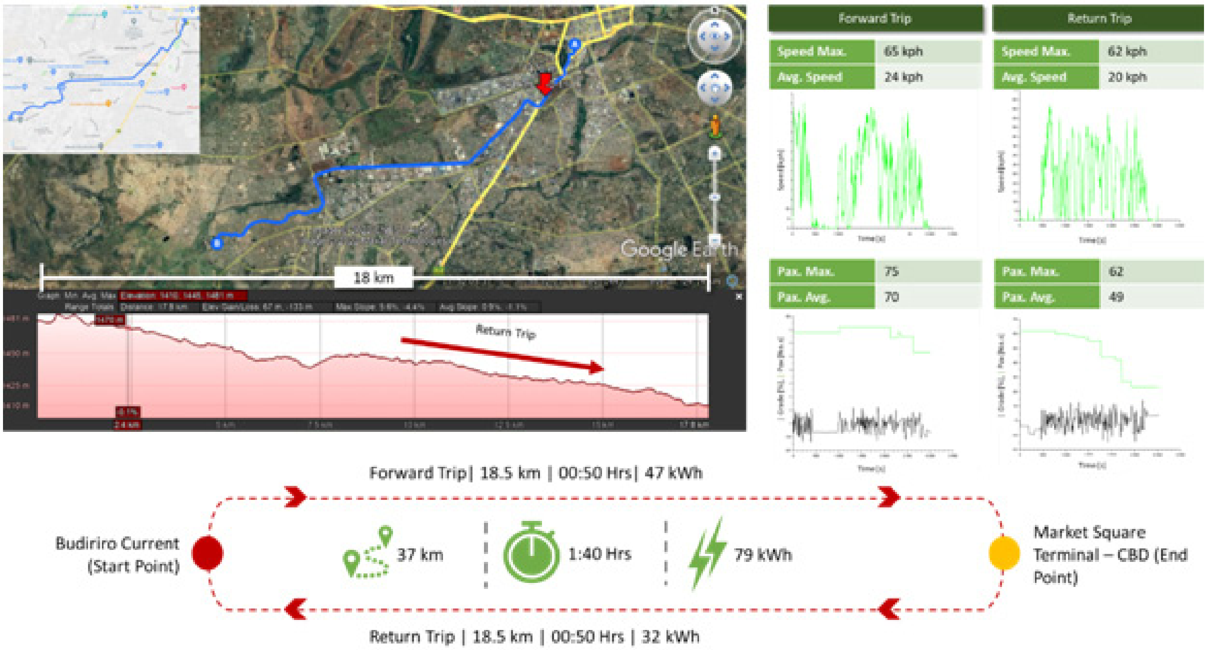


Figure 5.5 R5 Budiriro Current route profile



R4 Budiriro 1 and R5 Budiriro current are the longest among all five routes. Passenger loading on both this route is also the highest with over 50 passengers per trip (over 100 passengers per round trip). The speed profile of these routes show frequent accelerations and decelerations of vehicles during peak hours which showcase poor driving, road or traffic conditions; or combinations of these. The terrain, driving and passenger loading conditions are leading high energy consumption.

Glen Norah A is the third highest energy consuming route with 58 kWh round trip energy requirement. The length of this route is nearly equal to that of R2 Glen View 1 i.e., 14.5 km and 15 km respectively. While the difference between energy consumption is significant. R1 Glen Norah A consumes 23.4% high energy than that of R2 Glen View 1 (Round trip energy - 47 kWh).

Passenger loading on R2 Glen View 1 is higher as compared to R1 Glen Norah A but the energy consumption lower. Which showcase the difference in speed profile and driving conditions on both these routes in peak hour. R2 Glen View 1 has a smooth speed profile with moderate accelerations and decelerations showcasing better driving, road or traffic conditions; or combinations of these. The driving conditions significantly affect the energy consumption.

R3 Machipisa is the shortest among all five routes with 9 km length. The passenger loading is also lowest with average of 18-23 passengers per trip (40-42 passengers per round trip). While the speed profile of this route shows frequent accelerations and decelerations of vehicles during peak hours which showcase poor driving, road or traffic conditions; or combinations of these. It also increases the travel time during peak hours. The terrain, driving and passenger loading conditions are leading high energy consumption.

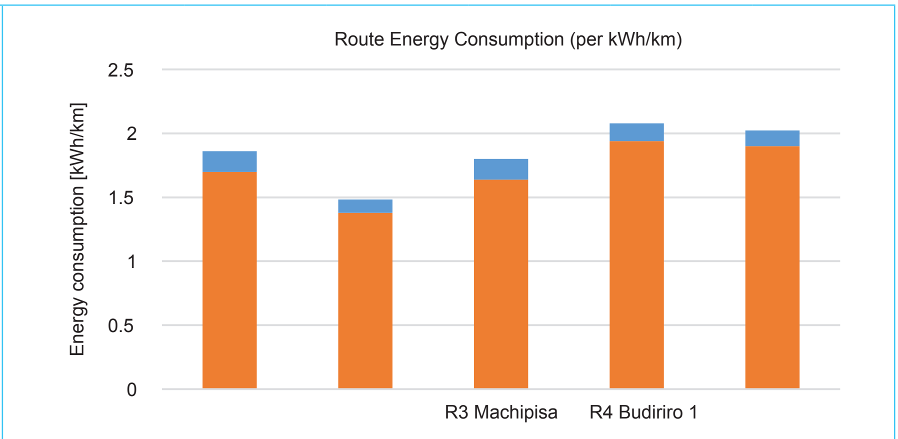
5.2.2 Energy consumption analysis

R4 Budiriro 1 and R5 Budiriro current are highest length, travel time and are highest energy consuming routes among five routes. The energy requirement per kilometre is as high has 2.22 kWh/km and 2.16 kWh/km respectively for R4 Budiriro 1 and R5 Budiriro current. R1 Glen Norah A is third highest in energy consumption and travel time required to complete one round trip. The energy consumption per kilometre is 1.99 kWh/km. The per kilometre energy consumption for R2 Glen View 1 is 1.59 kWh/km which is lowest among all five routes. R3 Machipisa is the shortest route while having high per kilometre energy consumption of 1.92 kWh/km.

Table 5.2 Route energy consumption: key outcomes

R1: Budiriro1 &
R5: Budiriro Current
are highest energy consuming route Among 5 routes analysed

R2: Glen Norah A,
R4: Machipisa
Are moderate and
R2: Glen View 1 is lowest energy consuming route.



Energy consumption [kWh/km]	1.99	1.59	1.92	2.22	2.16

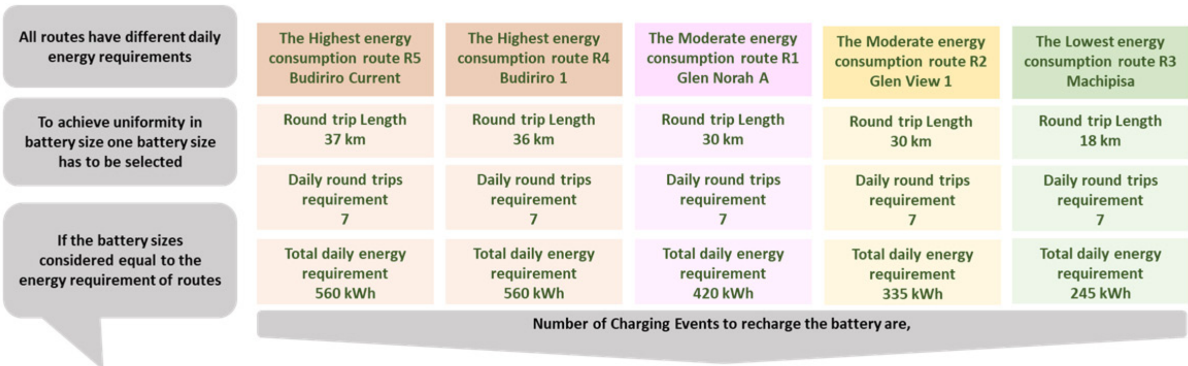
Key Outcomes	Units	R1	R2	R3	R4	R5
		Glen Norah A	**Glenview 1**	**Machipisa**	**Budiriro 1**	**Budiriro Current**
Total Energy consumption	**kWh**	58	47	35	79	79
Existing number of buses	**Nos.**	11	10	12	11	11
Average speed	**kmph**	16.34	25.86	12.73	19.24	21.85
Average passenger occupancy	**Pax/trip**	43	58	21	55	60
	Pax/round trip	85	115	41	110	119
Passenger occupancy (peak)	**%**	66%	90%	32%	86%	93%
Round trip distance	**km**	30	30	18	36	37
Round trip duration	**hrs**	01:50	01:10	01:30	01:50	01:40

Per kilometre energy consumption is used to identify the daily route energy demand to provide e-Bus service. The choice of battery size, selection of charging strategy and charger type is further decided based on energy requirement.

5.3 e-Bus Battery and Charging Strategy selection

Selecting battery size and appropriate charging strategy for e-Bus deployment is the next step after route level energy consumption assessment. The high energy consuming routes mentioned in above chapter (5.2) lead to higher daily energy requirement. Sizing of batteries for e-Buses on high energy consuming route in this case may give and oversized battery as a result while other lower energy consuming routes may not require huge battery to serve required daily operations. Batteries are rechargeable and can serve required daily energy demand through opportunity charging. On one hand high-capacity battery sizes are capable to give more rage and battery life to that of lower capacity batteries. While on the other hand High-capacity batteries are expensive, add into the investment requirement, reduce passenger occupancy and increases the weight of the vehicle; ~ 10 kg/kWh of capacity. In case of electric buses, the weight is one of the factors which impact energy consumption of the battery and involved operational costs. Hence it is essential to size the battery judicially. This section analyses minimum battery size that is required to fulfil the operational requirements to serve end users.

Figure 5.6 Battery selection framework and selection of closest battery sizes



	Budiriro current	Budiriro 1	Glen Norah A	Glen View 1	Machipisa
245 kWh Battery	2.31	2.31	1.73	1.38	1.00
335 kWh Battery	1.68	1.68	1.25	1.00	0.72
420 kWh Battery	1.34	1.34	1.00	0.80	0.58
560 kWh Battery	1.00	1.00	0.75	0.60	0.43

- **R2 Glen View 1 depicts moderate number of charging events with and average battery size of 335 kWh**
- **R3 Machipisa depicts lowest number of charging events and the lowest energy requirement of 245 kWh**

- **240 kWh and 324 kWh battery capacity are closest sizes available in market.**
- **Both battery sizes are further assessed on highest energy consuming route to understand the charging requirement**

R3 Machipisa and R2 Glen View 1 are lowest energy consuming routes. If the battery size considered equal to total daily energy requirement of each of these routes; then then the number of charging events required to cater daily route energy demand is calculated in the table above. In this case; 245 kWh and 335 kWh are the daily energy requirements of R3 Machipisa and R2 Glen View 1 respectively. 240 kWh[39] and 324 kWh[40] battery sizes are closest sizes available in market and used commonly for city e-Bus operations. Some global examples of different e-Buses and their battery sizes deployed globally are given in the table below Table 5.3.

39 Tata Motors e-Bus
40 BYD e-Bus

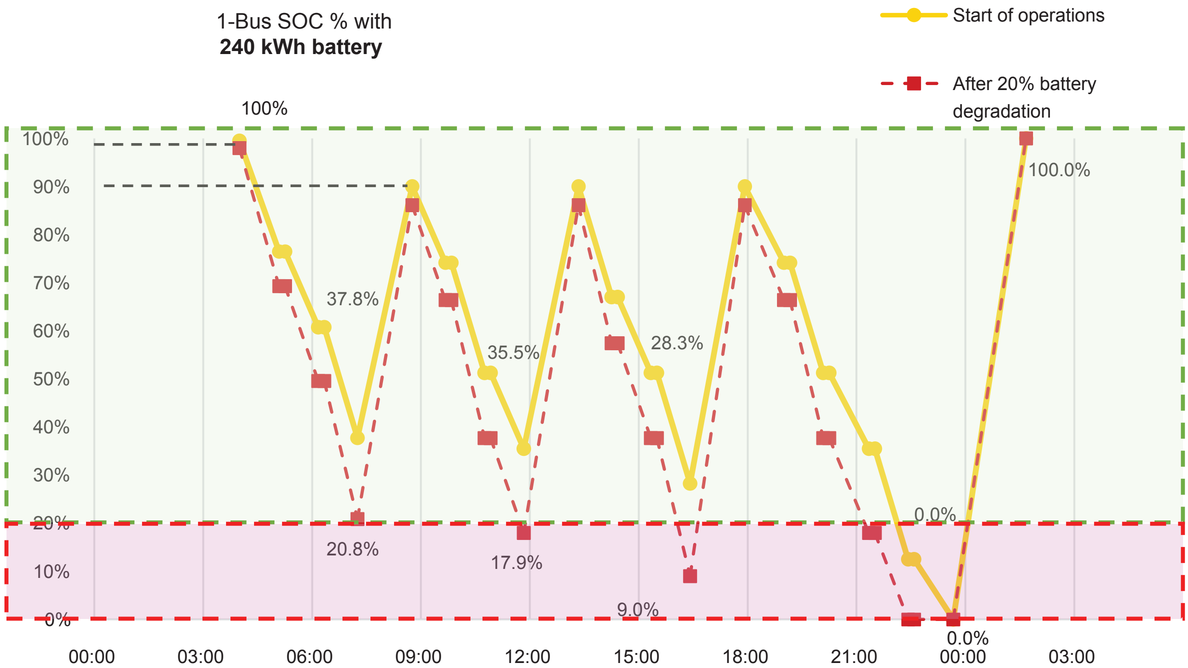
Table 5.3 Global example of e-Buses and their battery sizes

Country	City	e-Bus OEM	e-Bus Size	Seating capacity (Total/Only seating)	Battery Size (kWh)
India[41]	Kolkata	Tata Motors	9 m	45/30	125
			12 m	60/50	188
China[42]	Shenzhen	BYD (C8, K8)	10 m	C8: 24-44 K8: 87/40-44	253-331
Chile[43]	Santiago	BYD	9 m 12 m	45/30 81/50	157 277
		YOUTONG	12 m	87	324
		FOTON	9 m 12 m	47 90	129 385
		ZHONGTONG	12 m	74	315
Finland[44]	Helenski	BYD	9 m	45/30	157
		Poterra	12 m	60/50	280
		Youtong	14 m	87	324

5.3.1 Applicability of selected battery sizes

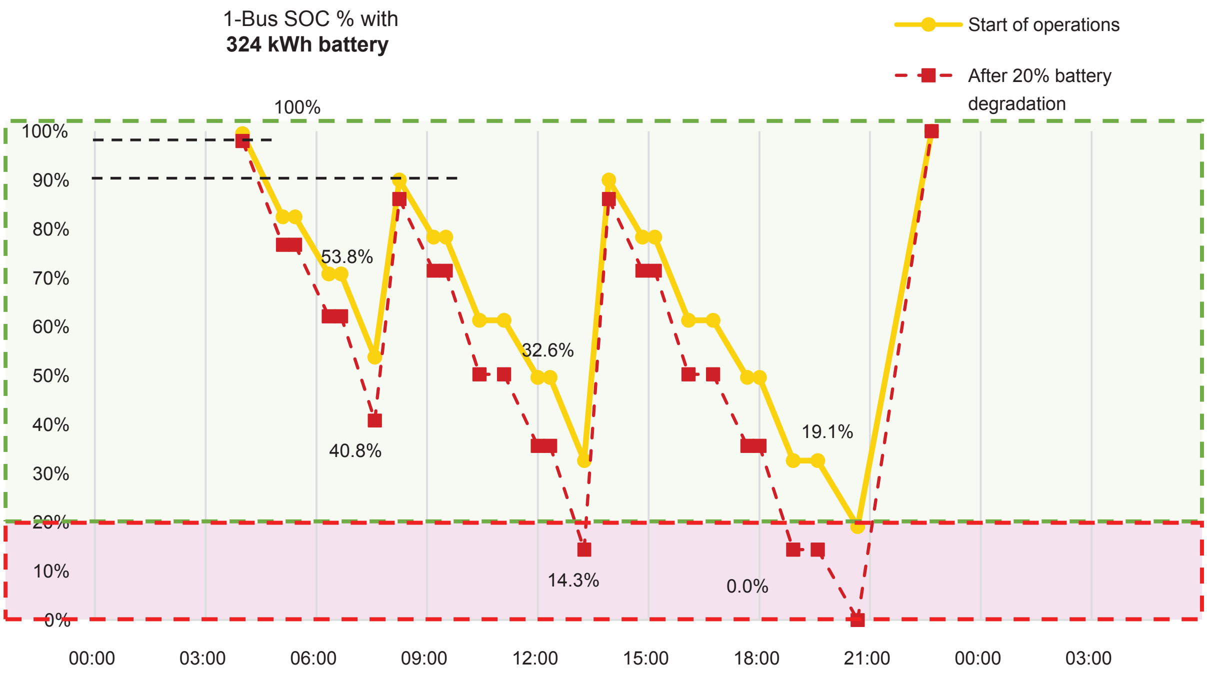
The selected battery sizes i.e., 240 kWh and 324 kWh are further assessed to check if they can suffice the energy demand for all vehicles. Following Figure 5.7 and Figure 5.8 illustrate the battery charging, dis-charging and re-charging requirements for both battery sizes.

Figure 5.7 1-Bus SOC % with 240 kWh battery



41 https://iea.blob.core.windows.net/assets/db408b53-276c-47d6-8b05-52e53b1208e1/e-bus-case-study-TERI-Kolkata.pdf
42 China: BYD C8 model is an all-sit bus type with customized seat capacity between 24 and 44. BYD K8 seat number of 87/30-39 means, 30-39 seats, with total passenger capacity (including standing passengers) of 87. https://iea.blob.core.windows.net/assets/db408b53-276c-47d6-8b05-52e53b1208e1/e-bus-case-study-Shenzhen.pdf
43 https://iea.blob.core.windows.net/assets/db408b53-276c-47d6-8b05-52e53b1208e1/e-bus-case-study-Santiago-From-pilots-to-scale-Zebra-paper.pdf
44 https://iea.blob.core.windows.net/assets/db408b53-276c-47d6-8b05-52e53b1208e1/e-bus-case-study-Helsinki.pdf

Figure 5.8 1-Bus SOC % with 324 kWh battery



State of Charge (SoC) showcases behaviour of the battery. SoC means the available charge in the battery after very charge and discharge. To ensure smooth operations of buses; it is imperative to maintain 20% SoC after use (discharge). After consuming 80% of battery energy, bus performance would be constrained due to unavailability of enough charge to power the motor. Refer annexure 11.4 for common disruptions in e-Bus operation. To avoid any disruptions due to lack of planning for accounted possibilities of battery behaviour it is essential to assess battery and its charging requirement.

This is checked using two selected battery sizes on the highest energy consuming route R5 Budiriro current. If battery size is sufficient to serve demand for highest energy consuming route, it can suffice for all other lower energy consuming routes (as explained in Figure 5.6)

To maintain minimum SOC of 20% before every charging event, the charging of e-Bus would need optimisation with 3-4 times or more opportunity charging to cater route energy demand of 560 kWh per day for both battery sizes. Where battery with 240 kWh would need more than four re-charging events and battery with 324 kWh would need more than three re-charging events. Above analysis summarises that 240 kWh is the minimum battery size that would be required to cater the daily highest energy demand (for R5 Budiriro current).

5.3.2 e-Bus Charging Strategy selection

Selected battery sizes further need to be analysed for their suitability with different charging options. In city of Harare, the e-Buses are to operate from Willowvale depot which is located at 3-5 km distance from starting point of each route which would incur dead mileage likely to consume some additional energy. This will largely depend on which charging strategy is used. Hence it is important to plan for different possibilities of charging and evaluate them for selection of best suitable charging strategy for e-Bus deployment. This chapter presents possible charging options and evaluates their suitability considering two different battery sizes, battery SoC requirements, route level energy requirements, passenger demand, operational characteristics of service (routes and bus).

5.3.2.1 Charger and Charging strategy

Globally there are several applications of e-Bus charging infrastructure adopted, and they vary prom case-to case basis. Some Global examples are stated in the table Figure 5.9 & Table 5.4 of this chapter and elaborated with global best practices in Table 8.1 of Chapter 8.1.

Conductive i.e., Plug-in charging is found suitable for the first e-Bus deployment. As first experience; operating e-Buses with Plug-in type charger would help building confidence in operations of e-Buses; understand differences between ICE and e-Bus refuelling and hands-on experience of operating charging infrastructure.

5.3.2.1 Charging Technology

Based on the global experiences, most preferred charging technology is Plug-In charging due to simplicity, market availability, high safety, moderate cost and more successful operations with respect to electric bus charging. The same Plug-in charging is recommended for first deployment of e-Bus charging. This will include the set-up of Electric vehicle supply equipment (EVSE), grid infrastructure, step-down infrastructure located at suitable locations for e-Bus charging.

Figure 5.9 Charging Technology and Types

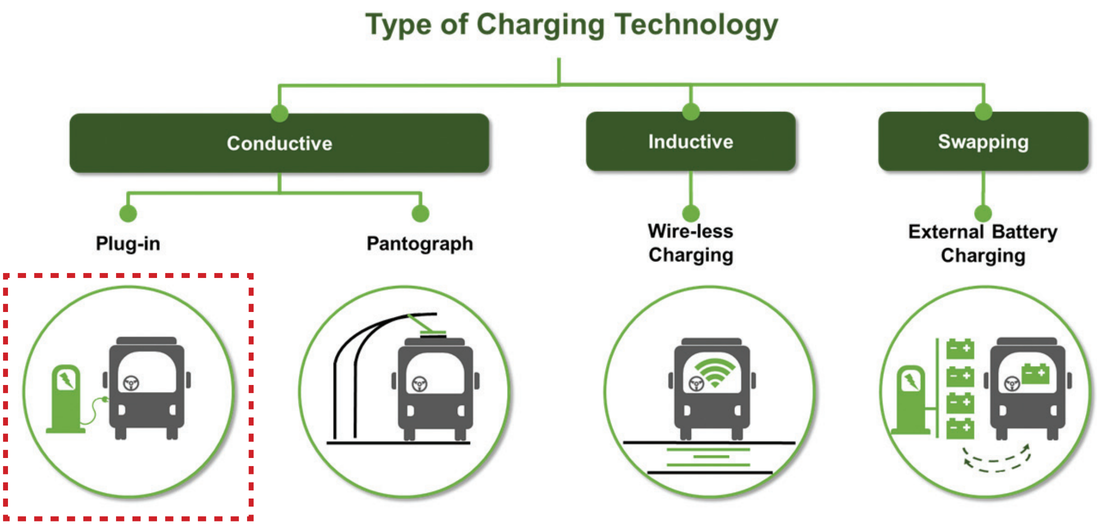


Table 5.4 Charging Technology and Types, pros and Cons

Charging Technology		Pros	Cons
Conductive	Plug-in Pantograph	• Provide multiple charging levels • Provide high efficiency • Coordinated V2G facility • Reduce the grid loss maintain voltage level • prevent grid power overloading • Active power support.	• Complex infrastructure • Restriction to the electricity grid • Fast charging cause voltage instability in the distribution system • Need a standard connector/charging level • Grid power overloading will cause due to uncoordinated charging • V2G operation reduces the lifetime of the battery.
Inductive	Wireless charging	• EV recharge it safely and conveniently • No need for any standard connector • No need for any standard Socket • Recharge when the vehicle is in motion	• Power transfer is generally weak • The range of 20 to 100 cm for efficient power transmission • The transmitter and the EV should be real-time and communication latency.

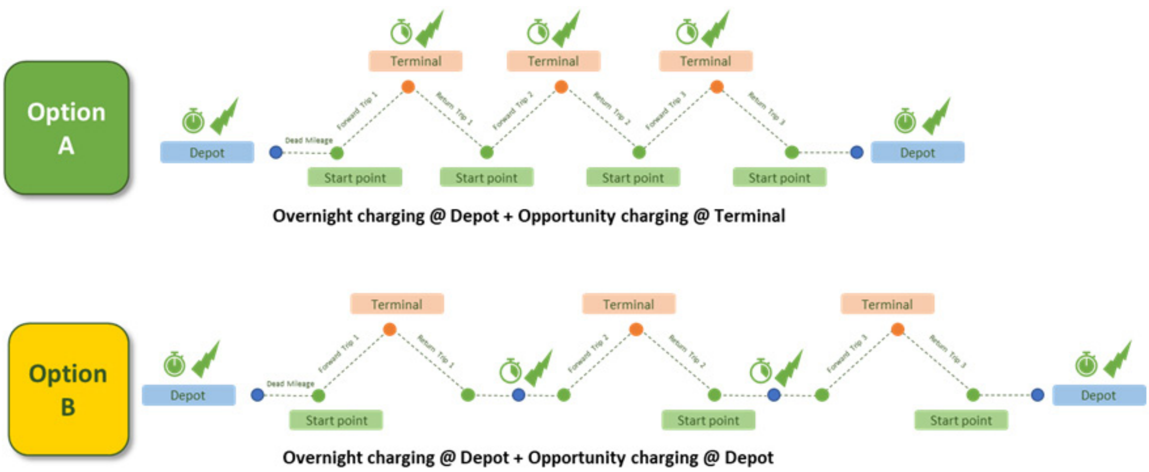
Charging Technology		Pros	Cons
Swapping	External Battery Charging	• Quick battery replaces (Fully charged) • Extend the battery life by slow charging • Help utilities in balancing the demand and load by using the V2G facilities • Easy to integrate with the locally generated Renewable Energy Sources (RES).	• Costlier than ICE vehicle because of the monthly rent to Battery storage system (BSS) • The huge investment required for both equipment and batteries • Need a large stock of expensive batteries • Many areas needed to accommodate the batteries • Different EVs have different battery standards

5.3.2.3 Charging strategy: Overnight charging + Opportunity charging

Overnight depot charging plus opportunity charging is recommended for operation of e-Buses based on the shortlisted battery sizes. Based on existing i.e., Business as Usual (BAU)) scenario the Willowvale depot is located at 3-5 km distance from the start locations of every route which adds in to the daily distance travelled up to 10 km dead mileage per bus per day, given one-time overnight bus charging. After performing 2-3 round trips (more or less depending upon route energy requirement, batter and its recharging needs), e-Bus will require top-up charging to cater the need for rest operations. Hence, for overnight plus opportunity charging two options (Figure 5.10) for charging strategy are identified in consultation with ZUPCO.

- **Option A**: Overnight charging @ Depot + Opportunity charging @ Terminal

Figure 5.10 e-Bus Charging options identified for e-Bus deployment



- **Option B**: Overnight charging @ Depot + Opportunity charging @ Depot

5.3.2.4 e-Bus Feasibility Assessment Scenarios

Table 5.5 e-Bus Feasibility Assessment Scenarios

Scenarios	Scenario 1		Scenario 2	
	Scenario 1 A	Scenario 1 B	Scenario 2 A	Scenario 2 B
Battery size	240 kWh	240 kWh	324 kWh	324 kWh
Charging strategy	Overnight Charging + Opportunity Charging			
Overnight Charging	@ Willowvale Depot	@ Willowvale Depot	@ Willowvale Depot	@ Willowvale Depot
Opportunity Charging	@ Market Square Terminal (CBD)	@ Willowvale Depot	@ Market Square Terminal (CBD)	@ Willowvale Depot

Considering two different battery sizes and the charging options identifies; Scenarios evaluated for e-Bus feasibility are as follows:

For each of the five routes scenarios given in above table are modelled and their outcomes are reported below. Each scenario was first applied to Highest energy consuming route R5 Budiriro current to understand maximum requirement for e-Buses to ply on the route. The outcomes are captured in following categories and parameters:

1) Fleet: Number of buses
2) Battery: Battery size, battery life (battery cycles consumed per day)
3) Chargers: Number of chargers (slow and/or fast), type, size and location of chargers, Number of buses shared per charger, charger utilisation
4) Operations: Trips (one way and total round trip), passenger demand served, headway, dead mileage, total daily distance travelled), fleet utilisation

Following illustrations give out-put of application of above-mentioned scenarios in Table 5.5; on a highest energy consuming route

Scenario 1: 240 kWh battery: 1 Vehicle SOC assessment and optimisation for highest energy route R5 Budiriro current

Figure 5.11 1-Bus SOC%: S1-A: Highest energy consuming route | R5 Budiriro Current

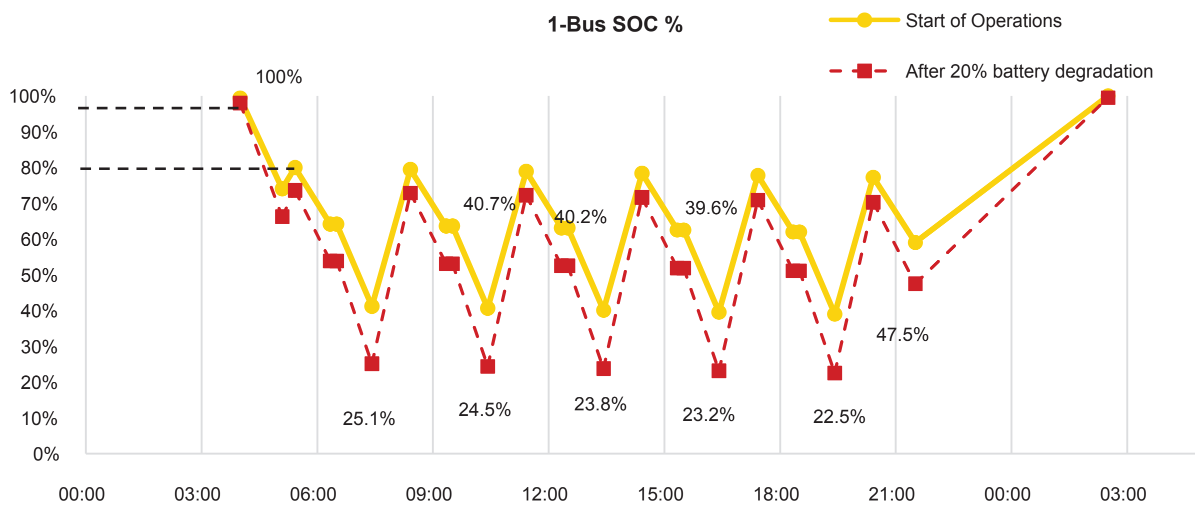


Table 5.6 S1-A: R5 Budiriro current Route level operation, e-Bus, Battery charging requirements

Total trips	Headway	Charging		
12	10	Type	Opportunity Charging	Overnight Charging
		Number of events	6	1
		Time	20 to 60 Min	5 Hrs.
		Location	Terminal Charging	Depot Charging

Components	Unit	Bus	Charger	Battery
Number of Units	Nos.	18 Buses	7 (6+1) Fast Chargers (160 kW) @ Terminal 18 Slow Chargers (30 kW) @ Willowvale depot	240 kWh – Li-ion battery
Utilization	%	56% Utilisation	67 % Utilisation of fast & 21 % Utilisation of slow chargers	-
Life	Years	15	10	3.8

S1-A: Overnight charging @ Depot + Opportunity charging @ Terminal

Figure 5.12 1-Bus SOC%: S1-B: Highest energy consuming route | R5 Budiriro Current

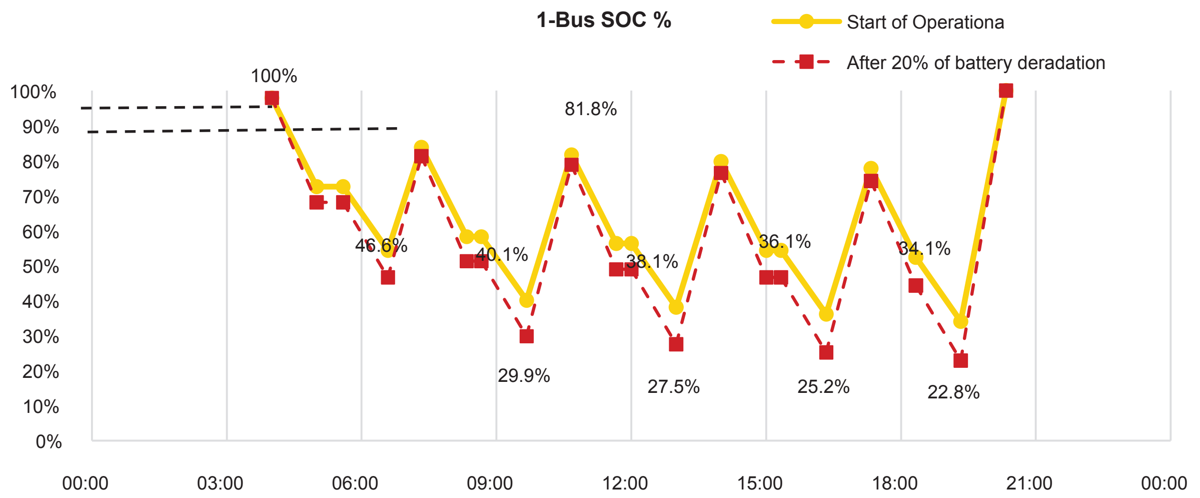


Table 5.7 S1-B: R5 Budiriro current Route level operation, e-Bus, Battery charging requirements

Total trips	Headway	Charging		
10	10	Type	Opportunity Charging	Overnight Charging
		Number of events	4	1
		Time	40 to 60 Min	2 Hrs.
		Location	Depot Charging	Depot Charging

Components	Unit	Bus	Charger	Battery
Number of Units	Nos.	20 Buses	8 (7+1) Fast Chargers (120 kW) @ Willowvale depot	240 kWh – Li-ion battery
Utilization	%	56% Utilisation	69% utilisation	-
Life	Years	15	10	4.16

Scenario 2: 324 kWh battery: 1 Vehicle SOC assessment and optimisation for highest energy route R5 Budiriro current

Figure 5.13 1-Bus SOC%: S2-A: Highest energy consuming route | R5 Budiriro Current

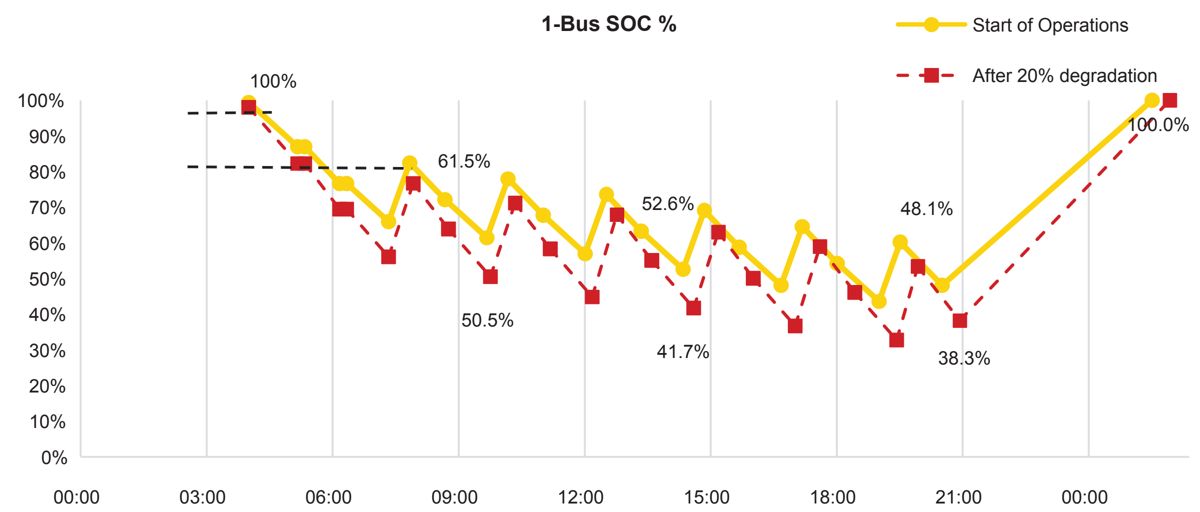


Table 5.8 S2-A: R5 Budiriro current Route level operation, e-Bus, Battery charging requirements

Total trips	Headway	Charging		
14	10	Type	Opportunity Charging	**Overnight Charging**
		Number of events	**6**	**1**
		Time	**30 Min**	**5 Hrs.**
		Location	**Terminal Charging**	**Depot Charging**

Components	Unit	Bus	Charger	Battery
Number of Units	Nos.	17 Buses	5 (4+1) Chargers (160 kW) @ Terminal 17 Chargers (30 kW) @ Willowvale depot	324 kWh – Li-ion battery
Utilization	%	56% Utilisation	59% utilisation of fast & 21 % Utilisation of slow chargers	-
Life	Years	15	10	5.18

S1-B: Overnight charging @ Depot + Opportunity charging @ Terminal

Figure 5.14 1-Bus SOC%: S2-B: Highest energy consuming route | R5 Budiriro Current

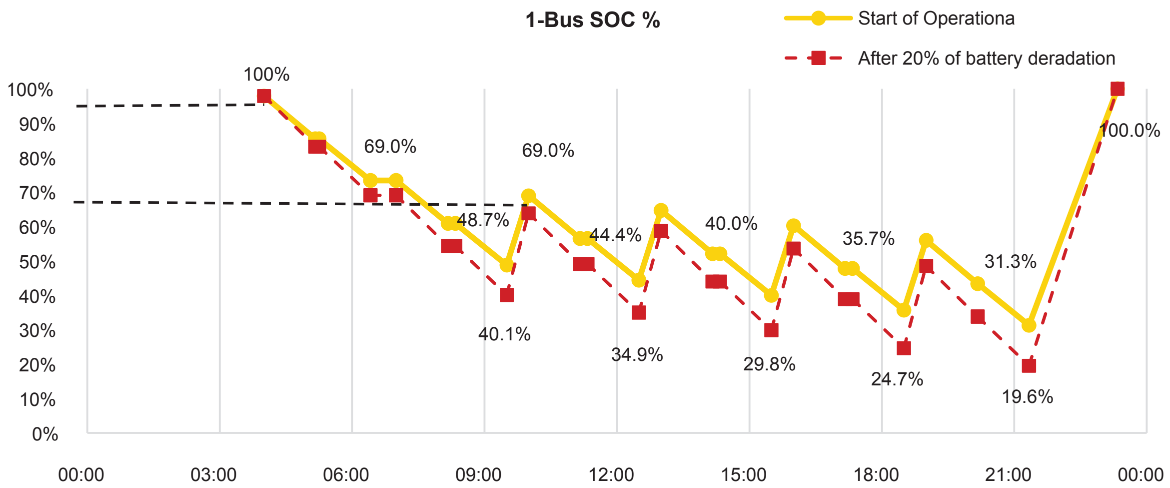


Table 5.9 S2-B: R5 Budiriro current Route level operation, e-Bus, Battery charging requirements

Total trips	Headway	Charging		
14	10	Type	Opportunity Charging	**Overnight Charging**
		Number of events	**4**	**1**
		Time	**35 Min**	**2 Hrs.**
		Location	**Depot Charging**	**Depot Charging**

Components	Unit	Bus	Charger	Battery
Number of Units	Nos.	17 Buses	7 (6+1) Chargers (120 kW) @ Willowvale depot	324 kWh – Li-ion battery
Utilization	%	56% Utilisation	71 % utilisation	
Life	Years	15	10	4.9

The similar route level analysis is carried-out for all other 4 routes namely R1 Glen Norah A, R2 Glen View 1, R3 Machipisa, R4 Budiriro 1. The tables bellow summarise the route level requirement of fleet, chargers, battery life and e-Bus operations for different scenarios; for all 5 routes.

Table 5.10 Summary of Route level assessment: Fleet, charger sizing and operational requirements – scenario 1: A & B

Summary of Route level assessment Fleet, charger sizing and operational requirements – scenario 1 (A&B)		BAU- ICE Buses					Scenario 1 : 240 kWh Battery									
							A: Overnight charging @ Depot + Opportunity charging @ Terminal					B: All charging @ Depot (Overnight + Opportunity)				
		Glen Norah A	Glen View 1	Machipisa	Budiriro 1	Budiriro current	Glen Norah A	Glen View 1	Machipisa	Budiriro 1	Budiriro current	Glen Norah A	Glen View 1	Machipisa	Budiriro 1	Budiriro current
Bus	**Nos.**															
Fleet	Nos.	**11**	**10**	**12**	**11**	**11**	**16**	**12**	**15**	**17**	**18**	**20**	**15**	**18**	**20**	**20**
Passenger Loading	Pax/bus/trip	64	64	64	64	64	50	50	50	50	50	50	50	50	50	50
(*design capacity of bus is considered)	Pax/bus/round trip	128	128	128	128	128	100	100	100	100	100	100	100	100	100	100
Operations																
Total Ridership (Designed)	Pax/Route/day	9,856	8,960	10,752	9,856	9,856	9,600	9,600	10,500	10,200	10,800	9,856	8,960	10,752	9,856	9,856
Round trips	Nos.	7	7	7	7	7	6	8	7	6	6	6	8	8	6	6
Route Distance		29	30	18	36	37	29	30	18	36	37	29	30	18	36	37
1 Bus daily operating kms	km/bus/day	204	208	129	249	257	175	238	129	214	220	175	238	147	214	220
Dead Mileage	km/bus/day	10	10	10	10	10	10	10	10	10	10	40	40	30	40	40
Dead mileage ratio	% Of total operational kms	5%	5%	8%	4%	4%	6%	4%	8%	5%	5%	23%	17%	20%	19%	18%
Total daily distance travelled kms	km/bus/day	214	218	139	259	267	185	248	139	224	230	215	278	177	254	260
Headway	Hrs	00:15	00:15	00:15	00:15	00:15	00:10	00:10	00:10	00:10	00:10	00:10	00:10	00:10	00:10	00:10
Total running time per bus	Hrs/bus/Trip	1.83	1.17	1.58	1.92	1.67	1.83	1.17	1.58	1.92	1.67	1.83	1.17	1.58	1.92	1.67
Total running time per bus	Hrs/bus/day	12.83	8.17	11.08	13.42	11.67	11.00	9.33	11.08	11.50	10.00	11.00	9.33	12.67	11.50	10.00
Total operational hours	Hrs	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Fleet utilisation (peak)	%	71%	45%	62%	75%	65%	61%	52%	62%	64%	56%	61%	52%	70%	64%	56%
Battery																
Battery size	kWh						240	240	240	240	240	240	240	240	240	240
Battery life cycles consumed per day							1.76	1.91	1.25	2.37	2.38	1.68	1.42	1.20	2.05	2.19
Battery life							5	5	5	4	4	5	6	8	4	4
Charger																
Number of fast chargers	#						5	5	5	5	6	7	7	6	7	7
Charger type											120 kW (DC Fast)					120 kW (DC Fast)
Location of chargers											Market Square Terminal					Willowvale Depot
Number of buses shared per charger	Bus/Chargers						3	2	3	3	3	3	2	3	3	3
Charger utilisation							56%	50%	33%	66%	67%	57%	54%	44%	68%	68%
Number of slow chargers							17	13	16	18	19					
Charger type											30 kW (DC Slow)					
Number of buses shared per charger											Willowvale Depot					
Charger utilisation							21%	21%	21%	21%	21%					

Table 5.11 Summary of Route level assessment: Fleet, charger sizing and operational requirements – scenario 2: A & B

Summary of Route level assessment Fleet, charger sizing and operational requirements – scenario 2 (A&B)		BAU- ICE Buses					Scenario 2 : 324 kWh Battery									
							A: Overnight charging @ Depot + Opportunity charging @ Terminal					B: All charging @ Depot (Overnight + Opportunity)				
		Glen Norah A	Glen View 1	Machipisa	Budiriro 1	Budiriro current	Glen Norah A	Glen View 1	Machipisa	Budiriro 1	Budiriro current	Glen Norah A	Glen View 1	Machipisa	Budiriro 1	Budiriro current
Bus	**Nos.**															
Fleet	Nos.	**11**	**10**	**12**	**11**	**11**	**14**	**12**	**14**	**17**	**17**	**18**	**12**	**14**	**17**	**17**
Passenger loading	Pax/bus/trip	64	64	64	64	64	50	50	50	50	50	50	50	50	50	50
(*design capacity of bus is considered)	Pax/bus/round trip	128	128	128	128	128	100	100	100	100	100	100	100	100	100	100
Operations																
Total ridership (designed)	Pax/Route/day	9,856	8,960	10,752	9,856	9,856	9,800	9,600	11,200	10,200	10,200	10,800	9,600	11,200	10,200	10,200
Round trips	Nos.	7	7	7	7	7	7	8	8	6	6	6	8	8	6	6
Route distance		29	30	18	36	37	29	30	18	36	37	29	30	18	36	37
1 Bus daily operating kms	km/Bus/day	204	208	129	249	257	204	238	147	214	220	175	238	147	214	220
Dead mileage	km/Bus/day	10	10	10	10	10	10	10	10	10	10	60	70	30	50	50
Dead mileage ratio	% Of total operational kms	5%	5%	8%	4%	4%	5%	4%	7%	5%	5%	34%	29%	20%	23%	23%
Total daily distance travelled kms	km/Bus/day	214	218	139	259	267 -	214	248	157	224	230	235	308	177	264	270
Headway	Hrs	00:15	00:15	00:15	00:15	00:15	00:10	00:10	00:10	00:10	00:10	00:10	00:10	00:10	00:10	00:10
Total running time per bus	Hrs/Bus/Trip	1.83	1.17	1.58	1.92	1.67	1.83	1.17	1.58	1.92	1.67	1.83	1.17	1.58	1.92	1.67
Total running time per bus	Hrs/Bus/day	12.83	8.17	11.08	13.42	11.67	12.83	9.33	12.67	11.50	10.00	11.00	9.33	12.67	11.50	10.00
Total operational hours	Hrs	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Fleet utilisation (peak)	%	71%	45%	62%	75%	65%	56%	56%	56%	56%	56%	56%	56%	56%	56%	56%
Battery																
Battery size	kWh						324	324	324	324	324	324	324	324	324	324
Battery life cycles consumed per day							1.51	1.41	1.07	1.76	1.76	1.45	1.41	1.18	1.87	1.87
Battery life							6	6	9	5	5	6	6	8	5	5
Charger																
Number of fast chargers	#						5	5	6	6	6	7	7	6	7	7
Charger type											160 kW (DC Fast)					160 kW (DC Fast)
Location of chargers											Market Square Terminal					Willowvale Depot
Number of buses shared per charger	bus/chargers						3	2	2	3	3	3	2	2	2	2
Charger Utilisation							58%	50%	29%	59%	59%	71.9%	87.5%	62.2%	71.9%	71.9%
Number of slow chargers							15	13	15	18	18					
Charger type											30 kW (DC Slow)					
Number of buses shared per charger											Willowvale Depot					
Charger utilisation							21%	21%	21%	21%	21%					

5.4 Comparison of e-Bus Deployment scenarios

Table 5.12 Comparative Matrix of Two different battery sizes and their impact of e-Bus operations

Parameters	Scenario 01: 240 kWh Battery	
	Battery Size	Charging Option B
	240 kWh	324 kWh
Fleet Size	• More Fleet required	• Similar but relatively lower fleet size
Range	• Less • Lesser battery capacity, lesser the range	• More • More battery capacity hence more range (35% more)
Bus operations	• Less range and a greater number of Charging events required	• More range and less Charging events • More availability of fleet for operations
Vehicle weight	• Less	• More • 35 % more weight
Battery volume	• Less	• More • 35% more volume
Battery age	• Less	• More • 35% more
Charging time requirement	• Less Charging Time	• More Charging time • 40% more

Table 5.13 Comparative Matrix of Two different Charging options and their impact on operations and different parameters through-out lifecycle

Charger	Opportunity Charging: @ Terminal + Overnight Charging: @ Willowvale Depot	Opportunity Charging + Overnight Charging @ Willowvale Depot
Number of chargers required	• More	• Less
Charger utilisation	• Less	• More
Charging flexibility	• More	• Less
Pilot Learnings and scale-up potential	• More scale-up potential due to flexibility and different charging options available on both ends	• Less- scale-up potential, as a limited number of chargers are available
Risk of breakdowns	• Less As battery charged overnight at slow rate. Slow charging helps reducing energy discharge	• More Faster the charging faster will be the energy discharge
Battery Life	• More as slow charging helps improving battery life	• Less as fast chargers affects battery life
Staff required for charging operations	• More As chargers to be deployed at two different locations	• Less As chargers to be deployed at single location

Based on the technical comparison of two different Battery sizes and charging options, the lowest battery size of 240 kWh and charging option A is selected looking at benefits over the respective other option in terms of smooth e-Bus operations, risks, battery life, infrastructure utilisation, flexibility and scale-up potential of the e-Bus deployment. Scenario 1 A is hence recommended for first e-Bus deployment based on technical assessment.

To re-confirm the selection of scenarios; all four options i.e., Scenario 1A, Scenario 1B, Scenario 2A & Scenario 2B are further assessed in chapter 9.

6. e-Bus & Charging Business Models

Adoption of e-Buses is expected to help lower the carbon footprint and save money on fuel and emissions. Enhancing electric public transportation is becoming an important focus globally. As the benefits of electric buses have been recognized globally, some cities have taken steps to incorporate them into their fleets.

6.1 Actors in the e-Bus Ecosystem

Among the important actors, the electric bus ecosystem is dominated by the following players; Government authorities- charged with the responsibility of providing public transportation services (often referred to as “authority”), bus manufacturers (with/without battery), battery manufacturers, electric utility, private operators and, financial institutions.

High capital costs of e-Buses necessitate adjustments to standard business models and require focusing exclusively on subsidies aimed at lowering the capital costs to make them comparable to conventional buses. A business model should strive for operational and financial sustainability through technological advancements, effective grid management, and efficiency enhancements.

6.2 Global Practices for e-Bus Business Models

The business models widely used around the world have been summed up in Table 6.1. It includes the cities where these were implemented, type of models, their characteristics and pros and cons.

Table 6.1 Global practices for e-Bus Business Models

Activities/ Parameters	Integrated Public Transport Authority (PTA) Model	Gross Cost Contract	Hybrid Mode of Contract	SPV
implemented City	Sao Paulo	Medellin, Columbia	Shenzhen Model, China	Hangzhou Model, China
e-Bus Investment	Transport Operator	Metroplus (Govt budget support/public company)	Government	Joint Venture (Central Govt+ Local Govt+ BYD+ Energy supplier/China Southern Power Grid)
e-Bus Ownership	Transport Operator	Metroplus	Private Operator	Joint Venture
e-Bus Operation	Transport Operator	Metroplus	Private Operator	Joint Venture
e-Bus Maintenance	Transport Operator	OEM/AMC Provider + Local Govt.	Private Operator	BYD/AMC Provider
Chargers O&M	Transport Operator	OEM/AMC Provider	OEM/AMC Provider	BYD + Energy supplier
Ticketing	Transport Operator	Local Govt. (Tarjeta bip)/ City Level Trust	Government	Joint Venture
Characteristics	1. Maximum PTA control 2. Availability of PTA funds to own and operate the service 3. Existing experience in bus operations 4. Capacity to cater for all risks	1. Operator is paid to operate public transport services over the life of a contract anywhere directed by the municipality 2. Limited Govt. funds available 3. Govt. has minimal experience in bus operations and maintenance 4. Govt. is willing to share responsibility	1. Less cost-intensive 2. Risk is shared among all the involved partners 3. Individual experience is leveraged in each sector	1. More specialized services (operator, OEM, and energy supply) 2. Existing experience of bus operations 3. Energy supplier well capable of battery and charging provisions
Pros	1. PTA has the complete ability to adjust or restructure routes, schedules, and fares 2. Viability gap funding, if available, is easier to obtain	1. Harness actors' experience 2. Less upfront investment by Govt. 3. Minimizes authority's staffing requirements 4. Increase in operational efficiency of the system	1. Improves task efficiency related to operating and maintaining e-Buses and the infrastructure 2. Better inventory management and skill concentration	1. Small but significant engagement of govt. 2. Removes destructive competition and allows complementary approach 3. Improves task efficiency related to operating and maintaining e-Buses and the infrastructure 4. Better inventory management and skill concentration
Cons	1. Due to high capital investment, attracting sufficient private players may be difficult 2. Significant influence on PTAs budget 3. May result in low overall efficiency due to govt.'s lack of expertise or prior experience with electric mobility and management	1. Non-compliance with the SLA, may result in penalties	1. Management and coordination of participants may be difficult for the state	1. Requires diligent and competent municipal authority to supervise 2. Energy provider might face low utilization during the initial phases, when volumes are low

6.3 Potential Business Models for e-Bus operations

For each of the four proposed business models, six areas of activity have been identified. These are; e-Buses investment (stakeholder in charge of providing funds or support for purchase); e-Buses ownership (stakeholder in charge of owning the e-Buses); e-Buses operations (stakeholder in charge of operating the buses on the routes and providing necessary manpower); e-Buses maintenance (stakeholder in charge of maintaining the bus fleets); O & M of chargers (stakeholder in charge of operating and maintaining the chargers); and ticketing (stakeholder in charge of collecting ticket fares).

Table 6.2 Potential Business Models for e-Bus deployment.

Potential Business Models	e-Buses investment	e-Buses ownership	e-Buses operations	e-Buses maintenance	Chargers' O&M	Ticketing
Model-1 (Conventional)	Donor agency + GoZ support	ZUPCO	ZUPCO	ZUPCO	ZUPCO	ZUPCO
Model-2 (GCC)	e-Bus OEM + GoZ support	e-Bus OEM	ZUPCO	e-Bus OEM	e-Bus OEM	ZUPCO
Model-3 (Hybrid)	Donor agency + GoZ support	Leasing co./ CMED (lease to ZUPCO)	ZUPCO	e-Bus OEM (contract from Leasing co.)	Charger OEM (contract from Leasing co.)	ZUPCO (use this to pay to Leasing co.)

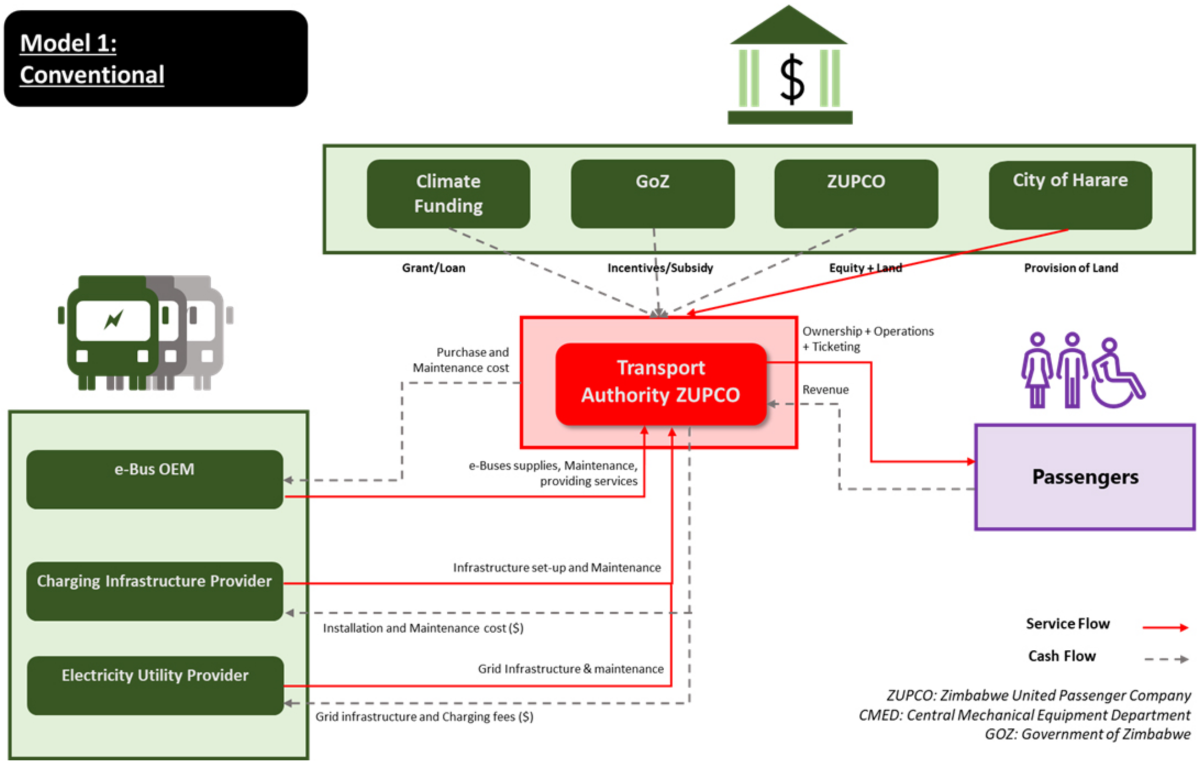
6.3.1 Model 1: Government Driven Model

This model is predicated on the premise that, due to the high capital investment required, attracting sufficient private players will be difficult. As a result, the government agency responsible for bus operations will assume complete responsibility, including procurement through outright purchase, provision and maintenance of facilities, and revenue collection.

Funds from the donor agency as well as the Government of Zimbabwe would be utilized to procure the e-Buses and the ownership would be transferred to ZUPCO. ZUPCO, as a stakeholder, would be in charge of operating the buses on selected routes, providing manpower, maintaining the buses, O&M of chargers, and ticketing.

The benefits of this arrangement include the government's complete ability to adjust or restructure routes and schedules, as well as fares. In this instance, viability gap funding, if needed, will be easier to get. However, this model will have a significant influence on the government's budget and may result in low overall efficiency due to the government's lack of expertise or prior experience with electric mobility and management.

Figure 6.1 Service and Cash flows for Business model 1: Conventional Government Driven Business Model



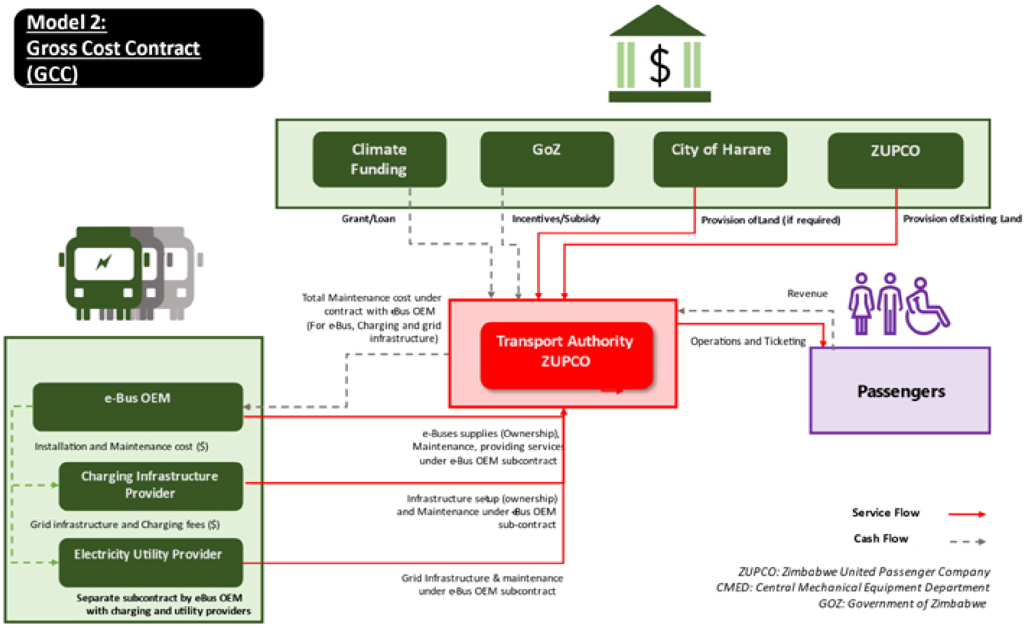
6.3.2 Model 2: Gross Cost Contract

In this arrangement, the government may partner with a private company to implement e-Bus programme through a public-private partnership. This strengthens each partner's functions by leveraging each other's experience. In this arrangement, private operator acquires and owns buses equipped with batteries, charging systems, and operates and maintains the buses. The city government and transport authority provides land, infrastructure, and other supporting services. The authority arranges for revenue collection either in-house or through an outside firm.

The e-Bus OEM enter into a contract with the government through a bidding process. The bidding parameter is a fixed cost for operations and maintenance (O & M), and it is based on a scheduled kilometre. In this model in Zimbabwe, the OEM would purchase and own the e-Buses while GoZ would provide financial support in the form of subsidies to the OEM. Even though the buses would be operated by the OEM, support staff and ticketing staff would be provided by ZUPCO, who would be trained by the OEM to leverage the expertise of the OEM in maintaining the fleet and the chargers. However, ZUPCO would arrange for ticketing as shown in Figure 6.2.

This strategy envisions the authority investing less upfront in bus fleets and charging infrastructure. The operational efficiency of the system tends to improve as a result of each stakeholder's increased focus on their competence. The partnership agreement defines each partner's position and obligations. Non-compliance with the service level agreement (SLA) could result in penalties.

Figure 6.2 Service and cashflows for Business model 2: GCC Business Model

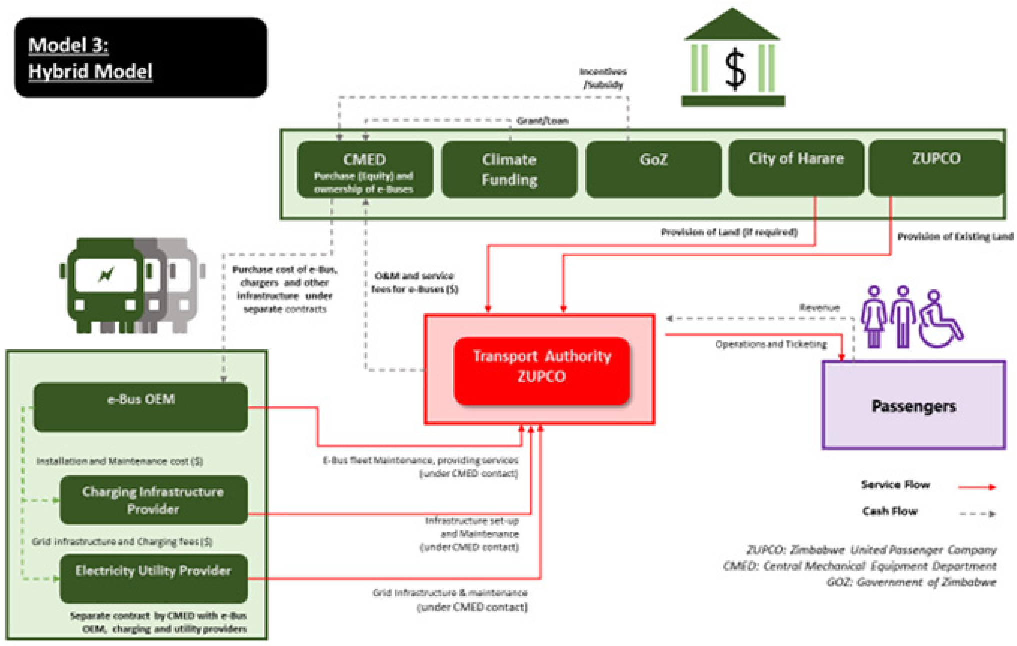


6.3.3 Model 3: Hybrid Mode of Contract

In this arrangement in Zimbabwe, a financing institution or a leasing company will provide funds to the government's subsidiary CMED to support the purchase of e-Bus fleet and retains its ownership.

However, ZUPCO is given the charge of operating the buses on the route and providing manpower (through lease) since CMED has no experience or staff familiar with routes. To leverage the experience and knowledge in maintaining the fleet and the chargers, CMED (the leaser) makes contract with the e-Bus OEM, charger OEM, and electricity provider. ZUPCO (the transport authority) arranges for revenue collection, which is used to make lease payments to the CMED (leasing company).

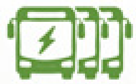
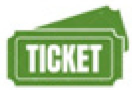
Figure 6.3 Service and cash flows for Business model 3 - Hybrid Model A: CMED Lease



6.4 Recommended Business Model for e-Bus deployment

Currently ZUPCO is using three models for bus operations as described in chapter 3 (section 3.3). Considering current practices, preferences, requirements for e-Bus operations, investment needs and suitability in the context of city of Harare, hybrid business model has been identified as the suitable model for adoption.

Table 6.3 Potential Business Models for e-Bus deployment

						
	e-Buses investment	**e-Buses ownership**	**e-Buses operations**	**e-Buses maintenance**	**Chargers' O&M**	**Ticketing**
Model-3 (Hybrid)	Donor agency + GoZ support	Leasing co./ CMED (lease to ZUPCO)	ZUPCO	e-Bus OEM (contract from Leasing co.)	Charger OEM (contract from Leasing co.)	ZUPCO (use this to pay to Leasing co.)

7. Enabling Policy Measures for e-Bus Adoption

The EV Roadmap for Zimbabwe has been prepared. As part of the process, transport electrification potential and feasibility was systematically analysed as part of vehicle prioritization exercise. Intracity bus segment was prioritized based on the stakeholders consultation on prioritization. The Policy Roadmap contains demand and supply side policies to drive electrification for all EV segments including e-Buses. This chapter highlights the specific policies for e-Bus segment directly drawn from EV Policy Roadmap for Zimbabwe.

7.1 Target

It is targeted to electrify 15% e-Buses fleet by 2030 which can be achieved through yearly sales target of 70% by 2030[45]. This targets corresponds to 16,149 e-Intracity buses in Zimbabwe. Nearly 4,050 captive chargers would be required for the targeted fleet.

The first deployment of 50 e-Buses will set an example for replicating it in other cities for intracity passenger commute. The incentives needs to be given by the government only for advanced battery chemistries including Lithium-ion based batteries. Lead acid batteries needs to be discouraged.

7.2 Demand side Measures

Demand side measures boost the demand for e-Bus for different use cases by subsidising and incentivising e-Buses, and if required, by mandating adoption of e-Buses. The demand side measures include both fiscal and non-fiscal measures to create demand for e-Buses.

7.2.1 Financial Incentives for e-Bus Purchase

7.2.1.1 Lower the Purchase Cost of e-Buses

The following policy measures are proposed to lower the purchase cost of e-Buses.

Policy	Policy Description
Subsidizing e-Buses	• Encourage e-Bus fleet owners/operators through right amount of governmental capital subsidy on new e-Buses that meet quality and safety standards. The capital subsidy should be linked to battery size and vehicle performance, and should be capped at two levels; 1) Maximum subsidy per EV, and 2) Maximum number of EVs that would be subsidised. This will provide certainty to the government budget planning. Battery subsidy can be close to current battery pack price (200 USD/kWh)[46]. Maximum subsidy per EV can be defined by average battery size for most common use case. EV subsidy can be gradually phased-out over years as EV reaches ICE price parity. • It is proposed to provide effective subsidy of 40% as percentage of landing price of new e-Buses for 2022-25; 25% for 2026-30; and 15% for 2031-35 periods. • Pre-owned EVs can be exempted from capital subsidy (but can be given VAT deduction and registration benefits). Above proposed capital subsidy is similar to exempting custom duty for 2-Wheeler, 3-Wheeler and 4Wheelers (personal and taxi). Intracity and intercity bus segments will need more than custom duty exemption to meet proposed subsidies. The additional requirement could be met through VAT deductions over and above custom duty deductions. The proposed subsidy should also be extended for completely knocked down (CKD) kits. Assembly of EVs needs to be encouraged for EV segments as it generates employment. (Refer the policy measure 'Exemption of import duties on e-Bus sub-systems and raw materials' in the Policy Roadmap report.)

45 70% Sales target = 70% e-Buses in yearly purchase/adoption of buses

46 Subsidy is subject to change with change in the National Policy Roadmap for Zimbabwe

Policy	Policy Description

Reduction of taxation on e-Buses[47]	• Reduce VAT on new and pre-owned e-Buses, and the VAT can be gradually resumed post price parity of EVs with ICEs and market development[48].
	  ○ For new / pre-owned e-Buses (CBUs – completely built units) VAT can be reduced from current 14.5% to 4.5% for 2022-2030 period and thereafter (from 2031) restored to the same level as for ICE buses.
	  ○ For new / pre-owned e-Buses (CKDs – complete knocked down kits) VAT can be reduced from current 14.5% to 0% for 2022-2030 period and thereafter (from 2031) restored to the same level as for ICE buses.
	• This should be reviewed every 5 years.

Exemption of vehicle registration charges on e-Buses	• Exempt registration fees on new and pre-owned e-Buses for 2022-30 period to support initial market development and stimulate adoption. It can be resumed to the same as for ICEVs from 2030 onwards, or after number of EVs are at par with ICEs. The exemption in repeat taxes should be reviewed in 2025 (or after five years) based on level of EV adoption.
Exemption of repeat taxes on e-Buses	• Exempt the repeat taxes including registration renewal and licensing on new and pre-owned e-Buses for 2022-30 period to support initial market development. It can be resumed to the same level as for the ICE buses from 2030 onwards. The exemption in repeat taxes should be reviewed in 2025 (or after five years) based on level of e-Bus adoption.
Support for retrofitting e-Buses	• Extend same benefits to ICEV retrofitted EVs as provided to pre-owned EVs from 2030.

7.2.1.2 Ease and Lower the Cost of Financing EVs

Policy	Policy Description
Provision to encourage banks to finance e-Bus both for individual (B2C) and fleet (B2B) ownership	• Develop mechanisms to allow easy and attractive financing for e-Bus (both for individual and fleet purchase) at differential reduced interest rates from banks (national banks, private banks, and NBFCs). This should include financing individuals, public transport fleet and commercial fleet operators. • Direct banks to include e-Bus financing into their priority sector lending portfolio
Accelerated depreciation and/or appropriate tax holidays for e-Buses	• Allow accelerated depreciation and/or tax holidays on investment in new e-Buses

7.2.1.3 Lower Usage Cost of EVs

Policy	Policy Description
Lower cost of charging e-Buses	• Local electricity distribution company (DISCOM) can provide support through; 1) Setting-up e-Bus charging infrastructure, 2) Integrated and attractive financing mechanism for EVSE OEMs.

7.2.2 Non-Fiscal Incentives for EVs

7.2.2.1 Convenience and Ease in Registration and other Processes, and Parking

Policy	Policy Description
Ease of process of registration, permits, transfers and ownership of e-Buses	• Establish single window clearance system for vehicle registration, licensing, permits, transfers (aligned with new and clear vehicle classification system) for both Individual and fleet ownership of e-Buses
Provision of dedicated parking and charging stations for e-Buses	• Plan and provide separate charging stations with dedicated space for e-Bus parking and charging, servicing, storage, maintenance and monitoring.

47 Reducing VAT only over custom duty exemption can be preferred to incentivise local production over imports. Some vehicle segments like Intercity e-Buses will need higher incentives over and above VAT exemption and capital subsidy or alternative custom duty for suitable market attractiveness in initial years

48 VAT concession/exemption is subject to change with change in the National Policy Roadmap for Zimbabwe

7.2.3 Building and City Development Codes

7.2.3.1 Easy access to EV Charging in New Buildings and Urban Spaces

Policy	Policy Description
Revision and redrafting of building code and city development code to incorporate e-Bus charging infrastructure	• Revise ‘building code’ and ‘city development code’ for mandatory installation of e-Bus charging infrastructure. Prepare guidelines on mandate for setting up e-Bus charging infrastructure (stations) with minimum space, layout allocation and respective adjustment in consecutive land-uses, activities and structures.

7.2.4 Dis-incentivizing ICE Buses

7.2.4.1 Discourage use of ICE Buses

Policy	Policy Description
Increase of VAT on ICEVs	• Increase VAT on ICEVs. VAT increase on ICE buses from current 14.5 % to 19.5% during 2022-30 (across vehicle segments)[49]
Increase of taxes on petrol and diesel	• Increase taxes on fossil fuels to discourage ICE buses • Following increase in fuel taxes proposed[50]: ○ Custom duty increase by 1% every year until 2030 ○ Carbon tax increase by 5% every year until 2030.
Mandatory periodic pollution test	• Develop robust pollution measurement and control system with annual mandatory pollution test (linked to vehicle age and emissions)

7.2.5 Consumer Awareness

7.2.5.1 E-Bus Mass Awareness Program

Policy	Policy Description
Awareness campaigns andtTraining programs for public transport users	• Design and conduct repeat public awareness programs on e-Bus benefits and available support from the government and local ecosystem, targeting fleet owners and public transport users. • Leverage existing automotive dealer network to provision e-Bus experience centre and promote e-Buses. First deployment of e-Bus could incorporate this measure to increase reach and popularity of e-Buses for different e-Bus fleet applications.

7.3 Supply-Side Measures

Supply side measures are responsible to boost the e-Bus manufacturing, supply of e-Buses, chargers and other required sub-systems, and create strong local supply chain for e-Buses. The supply side measures include fiscal, non-fiscal and regulatory measures as follows.

49 VAT increase/changes for ICEVs is subject to change with change in the National Policy Roadmap for Zimbabwe
50 Fuel tax increase/change is subject to change with change in the National Policy Roadmap for Zimbabwe

7.3.1 Emission Standards

7.3.1.1 Stricter Vehicle Emission Standards

Policy	Policy Description

Stricter vehicle emission standards and enforcement (for all type of vehicles including new /pre-owned vehicles, imported/locally-built vehicles etc.)	• Adopt and strongly enforce stricter vehicle emission standards for all ICE buses in the country, including for:
	  ○ Imported/local buses (New): Need to comply with new Euro VI standards
	  ○ Imported/ local buses (pre-owned): Need to comply with Euro IV standards at minimum.
	• Imported/local buses (running-on-road):
	  ○ 1) If age > 10 years: annual pollution certification should be mandatory to comply with their respective Euro II/ Euro III/ Euro IV standards (according to the requirements when built)
	  ○ 2) If age > 15 years: Scrappage incentive given or higher annual pollution cess levied.

7.3.1.2 Stricter Fuel Standards

Policy	Policy Description
Stricter fuel standards for petrol, diesel and gas	• Adopt and strongly enforce stricter fossil fuel standards (for petrol, diesel, and gas) complying with defined vehicle emission standards (E.g.: Euro VI fuel standards for Euro VI vehicle standards)

7.3.2 EVs and Charging Infrastructure Standards and Guidelines

7.3.2.1 EVs Vehicle Classification

Policy	Policy Description
Vehicle classification system revision to differentiate e-Buses	• Revise existing vehicle classification system (separate for passenger and freight transport, and distinguishing between commercial and private use) so that different types of ICE and e-Buses fit properly in the categorization. Classification of e-Buses should be based on battery energy capacity (kWh) and traction motor size (kW) instead of engine capacity (cc) used for for ICE buses

7.3.2.2 EV Quality and Safety standards

Policy	Policy Description
Formulation of e-Bus quality and safety standards for safe import and local production	• Formulate standards and guidelines for both new and pre-owned e-Buses to be eligible for the government incentives. International standards from UNECE, ICE and others can be appropriately adopted to govern high quality imports (through pre-shipment inspection certification) and local production. • Adopt relevant global safety standards for different types of e-Buses (new, pre-owned and retrofits), advanced battery technologies, charging technologies, e-Bus and chargers' inter-connections and their inter-operability, chargers and grid inter-connection and communication, security against theft and end consumer communications including vehicle to load/home/grid standards.

7.3.2.3 National Standards for EV Charging

Policy	Policy Description
Clear definition of national standards for e-Buses charging	• Adopt and strongly enforce clear e-Bus charging standards for both AC and DC chargers across vehicle segments and location (captive and public charging) • Captive charging and public charging: DC charging given high mix of Europe and Japan imports (30/50/100 kW). The numbers, types, mix and tariffs of chargers can be left open for market forces to decide • Battery swapping and charging: Allow innovations and deployments

7.3.3 EV Mandate for Local OEMs

7.3.3.1 Minimum Share of EVs in Production/Sales Portfolio

Policy	Policy Description
Definition of minimum percentage of overall production/sales of e-Buses	• Develop e-Bus mandate for local automotive OEMs to assemble/manufacture EVs (as minimum % of total vehicle production/sales) and link appropriate incentives • One mechanism can be implementing CAFE (Corporate Average Fuel Efficiency) and regulate average g/km CO2 across local OEM production portfolio

7.3.4 Financial Incentives for OEMs

7.3.4.1 Lower EV Production Cost

Policy	Policy Description
Fiscal incentives on e-Bus production setup	• Encourage local assembly and manufacturing of e-Buses, sub-system and components through attractive fiscal incentives to the industry in form of land/ electricity/ capital subsidy/ interest subsidy/ tax subsidy etc. This to also include mining industry for raw materials use in e-Buses
Exemption of import duties on e-Bus sub-systems and raw materials	• Reduce import duties on EVs raw materials (like cells), sub-systems (EV batteries, on-board and off-board chargers, motors etc.), and CKD kits. Review every 5 years and continue till local ecosystem is developed.

7.3.4.2 Increased localization

Policy	Policy Description
Localisation targets for e-Bus adoption	• Set gradual increasing localisation targets for different e-Bus segments to encourage more and more local assembly and production. Manufacturers can be incentivised to increase localisation to avail different fiscal incentives from the government.

7.3.5 Financial Incentives for Public and Fleet Charging Infrastructure

7.3.5.1 Lower Capital cost to Setup Public Charging Stations

Policy	Policy Description

Capital subsidy for all types of public charging stations (AC/DC, fixed/ swap battery)	• Encourage private, public and utility companies to set-up e-Bus captive/public charging stations and services and extend capital subsidy. Following subsidy is proposed on public chargers (intra-city and inter-city):
	  ○ Slow chargers: 50% 2022-2025 period; 25% I 2026-2030 period; No subsidy thereafter.
	  ○ Fast chargers: 75% 2022-2025 period; 25% 2026-2030 period; No subsidy thereafter.
	• Battery Swapping stations (rural and urban): battery and charger subsidy can be combined and extended to battery swapping stations (if applicable)
	• Renewable integration: with e-Bus charging, this should be additionally incentivised through available renewable fiscal incentives (and also exempting wheeling charges)
	• Alternative to capital subsidy: Another option instead of giving capital subsidy for e-Bus chargers can be to exempt them from custom duty and/or VAT. This will be similar to custom duty exemption to solar equipment/ appliances import into the country

Low-cost land allotment on long lease for public charging	• Allocate the government land on low cost long lease for establishment of captive charging infrastructure. Support ease of land identification and leasing procedures for the same.
Incentives to DISCOMS to own and setup e-Bus charging stations	• Power distribution companies should be allowed to capitalise cost of setting up and running captive and public charging stations for e-Buses

7.3.5.2 *Lower Operations Cost to run Public Charging Stations*

Policy	Policy Description
Reduction of electricity cost through separate e-Bus tariff for public charging	• Build separate e-Bus focused lower cost electricity tariff system for public charging stations as well as commercial EV fleet stations. The tariff system should reflect time-of-day (TOD) or time-of-use (TOU) tariff to differentially charge peak and off-peak charging times • There can be exemption on demand charges (fixed component of electricity tariff) for e-Bus business for first 5 years for e-Bus charging stations

7.3.6 EV Mandates for Government Agencies

7.3.6.1 *EV Mandates for Government Agencies*

Policy	Policy Description
Mandate for government. agencies and offices to adopt e-Buses	• Mandate different government departments and agencies to go for e-Bus procurement and/ or leasing for their employees' commuting needs. This can be started small and gradually increased to 100% in the next 3-5 years. This can drive first demand for e-Buses and also make it highly visible. • This can be started with vehicles in the pool and Public Service Commission buses which are used to commute the government officers and the staff

7.3.6.2 *Government Driven EVs Aggregation and Bulk Procurement*

Policy	Policy Description
Aggregation of e-Bus demand and stimulating local supply	• Authorize appropriate government agency to aggregate e-Bus demand (from the government departments, fleet operators, corporate, others) and do bulk procurement of e-Buses. Local supplies could be encouraged and increased through additional price discounts.

7.3.7 Grid Management

7.3.7.1 *Charging Integration for Grid stability*

Policy	Policy Description
Guidelines/ standards for grid and chargers interconnectivity and communications for overall grid stability, safety, and e-Bus operations	• Develop guidelines for grid and chargers interconnectivity for both captive and public chargers and charging stations. It should include easier new connection or existing sanctioned load revision for setting up e-Bus charging

7.3.7.2 *Time-of-Use (TOU) Tariff System*

Policy	Policy Description
TOU tariff system for grid load management	• Introduce TOU tariff system for EVs connection to allow differential tariffs for EV charging based on peak and non-peak power. This should be initiated with public transport e-Buses charging stations.

7.3.7.3 Improving Grid Access in Urban and Rural Areas

7.3.7.2	Policy Description
Expansion of grid and off-grid infrastructure and power quality	• Encourage expansion of grid and ensure gird infrastructure accessibility for reliable e-Bus charging in urban and rural areas with right mix of grid, off-grid and smart-renewable integration. Target 100% connections and 24x7 power for all. ○ Drive government. and private investments in the national grid expansion ○ Encourage decentralised renewable energy (DRE) /solar mini grids (by the government and private players) to integrate e-Buses (including plug-in charging and swap batteries) for urban and rural use cases Revise different electricity tariffs for healthy and faster power sector development.

7.3.8 Disposal, Reuse and Recycle

7.3.8.1 Vehicles Scrappage Guidelines

Action	Policy Description
Definition of national guidelines for vehicle scrappage (focus e-Bus)	• Define guidelines for vehicle scrappage. • Scrap after 20 years of life, if the vehicle does not pass fitness and emission tests. Introduce additional green tax for vehicles greater than 20 years life. Provide additional incentive on e-Bus purchase when ICE bus scrapped • Adopt Extended Producers Responsibility (EPR) by mandating OEMs to set-up collection centres and recycling facilities

7.3.8.2 Retrofit of ICEVs into EVs

Policy	Policy Description
ICE bus retrofit to e-Bus permitted	• Allow retrofit of ICE buses to e-Buses following safety standards.

7.3.8.3 Battery Re-use and Recycle Guidelines

Policy	Policy Description
Outline environmental guidelines for battery re-use and recycle	• Develop guidelines covering collection, storage, transportation, re-use and recycle of used/ waste batteries from EVs. ○ Collect 100 percent Lithium-Ion Batteries (LIBs) from EVs through Extended Producer's Responsibility (EPR) ○ Clearly define battery-value for reuse in the market and create a secondary market

7.3.8.4 Vehicles Scrappage and Battery Recycling Facilities

Policy	Policy Description
Capital subsidy for setting up vehicle scrappage and battery re-use/recycle facilities	• Provide capital subsidy and other support (land, electricity, others) for setting up vehicle scrappage and battery re-use/recycling facilities

7.3.9 R&D, Pilots, and Capacity Building

7.3.9.1 National R&D Centres on EVs

Policy	Policy Description
Establishment of industry-academia e-Bus Centre of Excellence (COE*)*	• Extend R&D grants and facilitate best national academic Institutes to build Centre of Excellence (COE) in collaboration with industry to drive research and development on various aspects of EVs and low carbon transportation and energy. • Encourage industry participation for commercial R&D, patents, start-ups incubation and scalable deployments of EVs. Provide additional fiscal incentives to industry for R&D investments in e-Buses.

7.3.9.2 EV Pilots and Deployment

Policy	Policy Description
Support for e-Bus pilots and experimentation	• Establish a government linked e-Bus Accelerator which can actively coordinate academia and industry research with focus on running pilots, developing different use cases viability and their scale up. • The Accelerator can also facilitate fund raising from various development agencies and coordinate between different government. Departments.

7.3.9.3 EV Training and Capacity Building

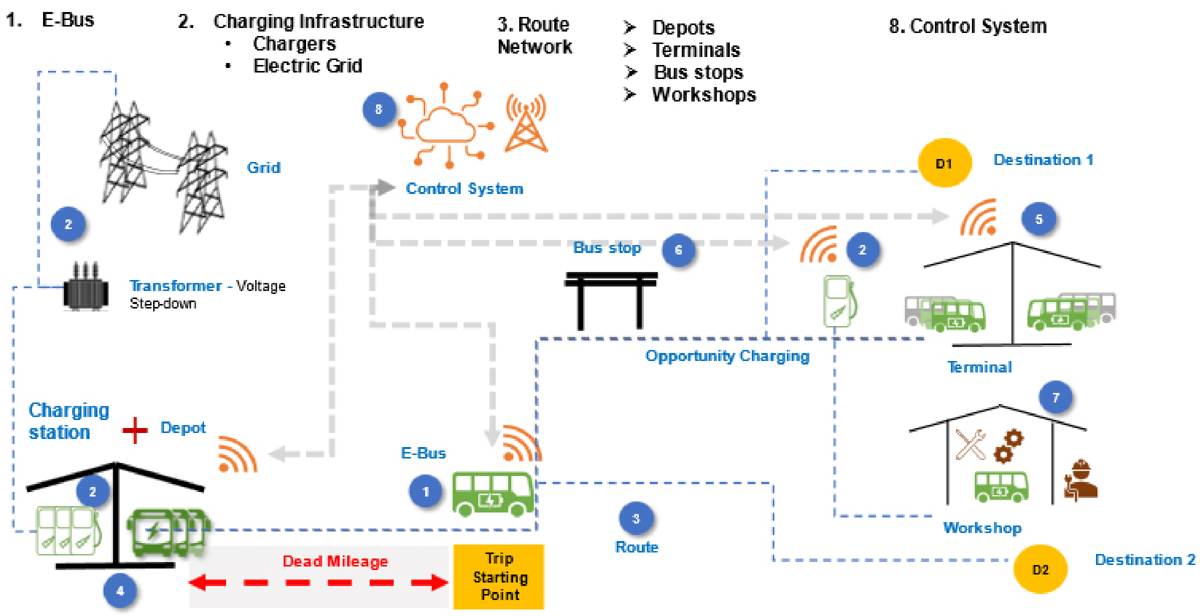
Policy	Policy Description
Setup e-Buses training and capacity building ecosystem	• Encourage technical universities/ institutes to develop degree and vocational courses in e-Buses and the system planning. • Set-up National EV Skills Council to focus on e-Bus skills development and certification across e-Bus value chain, in close association with industry and academia. • Facilitate e-Buses training infrastructure through grant money and set up regional training centres.
Strengthen e-Bus repairs and services across the nati*on*	• Develop guidelines for OEMs and dealers to partner with local institutions and build strong training and certification skill programs to build local expertise on e-Buses assembly, repairs & services, retrofitting, driving, etc.
e-Bus boot-camps for OEMs and supplier*s*	• Conduct e-Bus boot camps for existing/new automotive OEMs and suppliers to assist them to shift to e-Buses production and supplies.

8. City Charging Infrastructure Guideline

For e-Bus operations, it is imperative to establish robust and safe charging infrastructure. Designing and deploying a sound charging infrastructure is therefore crucial for bus service providers for their smooth operations as well as to optimize the investment.

An important factor in planning e-Bus charging infrastructure is the required size and volume of infrastructure required. As compared to light duty vehicles, e-Buses have batteries with different capacities. These include 80, 120, 180, 240, 320, 400 kWh and more, and have high power requirement for charging. For such high-capacity batteries, charging can be only facilitated through a separate set-up. This includes infrastructure to pull power from the grid, chargers (i.e., EVSEs), power back-up, safety and monitoring systems. It makes the charging infrastructure a high cost set-up requiring proper planning.

Figure 8.1 Sample illustration for Charging infrastructure and e-Bus set-up for operations



The chargers and grid infrastructure requires space and facilities for e-Bus plug-in, plug-out and manoeuvring. Cities usually have petrol / diesel stations that could accommodate charging stations with appropriate changes to suit e-Buses and access to grid. The type of chargers, charger rating, charging strategy, efficiency etc. need to be pre-defined and deployed .

Charging infrastructure guidelines given below may help making right choices and fulfilling the different technical, operational and financial requirements for the e-Bus deployment.

8.1 Charging infrastructure for e-Buses: Global best practices

Table 8.1 Detailed summary of e-Bus charging systems and infrastructure best practices[51,52]

DC Plug-in

DC Pantograph

Inductive Charging

Battery Swapping

	Parameters	Justification of the Ideal Value	DC Plug-In	DC Pantograph	Inductive charging	Battery swapping
	Description		This entails DC charging by a plug-in connection.	This category includes DC charging via pantograph with on-board bottom-up or off-board top-down configuration	This category includes all charging technologies which achieve wireless transfer of electricity, either by static or dynamic induction.	This entails cases; where depleted vehicle batteries are swapped with fully charged batteries.
Technical parameters for selection of charging technology	**Input voltage from grid (V)**	**Voltage required for the vehicle charging is prescribed as the same as of grid voltage, so that no additional infrastructure is necessary for charging station installation.**	415 or above	415 or above	415 or above	415 or above
	Output range of chargers available in market (kW)	**Minimum output range is most preferred.**	50 - 150	150 - 650	50 - 250	Data not publicly available
	Output power considered for analysis (kW)	**Minimum output power is most preferred.**	70	300	200	No typical value assumed
	Charging/ Swapping time	**Charging technology which charges faster is more suited to maintaining service headways.**	1.7 - 2 hours	~ 25 minutes	Not reported	2.5 - 10 minutes
	Electricity connection required (HT/LT)		HT	HT	HT	HT
	Ancillary infrastructure required	**Minimum requirement of Ancillary infrastructure is most preferred.**	Distribution Transformer, HT/LT switchgear, liquid cooled cables, protection relay and SCADA	Distribution Transformer, HT/LT switchgear, liquid cooled cables, protection relays and SCADA	Distribution Transformer, HT/LT switchgear, road embedded cables, protection relay and SCADA	Distribution Transformer, HT/LT switchgear, cables, protection relays and SCADA
	Auxiliary energy consumption	**Minimum energy consumption is most preferred.**	Low	Medium	High	High
	Area requirement per EVSE (sq. m)	**Minimum area requirement is most preferred.**	2	2	2	No typical value assumed

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	Parameters	Justification of the Ideal Value	DC Plug-In	DC Pantograph	Inductive charging	Battery swapping
Economic parameters for selection of charging technology	**Capital cost of charging technology (USD)**	**Minimum price of the EVSE is suitable for bus charging.**	20,000 – 28,000	40,000 – 150,000	290,000 or above	420,000 or above
	Cost of ancillary infrastructure (USD)	**The one which entails least ancillary cost would be desirable.**	3,000 – 5,000	7,000 – 16,000	5,000 – 9,500	3,000 – 5,000
	Maintenance cost (%)	**Minimum cost is desirable.**	10% of installation cost for periodic maintenance; 2% of installation cost for regular maintenance			
Other parameters for selection of charging technology	**Ease of drawing electricity from the distribution network**	**Moderately difficult distribution is most preferred.**	Moderately difficult; possible to draw electricity through a DT connected to a HT line	Difficult; must be drawn only from 11/33 kV substation, which is not as accessible as a HT line	Moderately difficult; possible to draw electricity through a DT connected to a HT line	Moderately difficult; possible to draw electricity through a DT connected to a HT line
	Established precedence for charging buses		Yes	Yes	Limited	Limited

Best Practice examples

- **DC Plug-In: Shenzhen, China**
  - China has successfully electrified its e-Bus fleet of over 16,000 buses. e-Bus operators collaborated with charging infrastructure providers to establish charging facilities at depots and the bus routes maintaining a 1:3 charger to-bus ratio.
  - The typical charging time reported in case of overnight charging at the depot is around 2 hours. However, there are also charging stations installed enroute, which are reported to charge the buses in approximately 40 minutes.
- **DC Pantograph: City of Geneva**
  - City of Geneva employs DC pantograph-based technology for charging trolley e-buses (ABB, 2019). The e-Buses are charged at three different output power levels: 600 kW, 400 kW and 45 kW. The 600 kW 'flash' charging stations that provide a quick power boost in a short span of 15-20 seconds are reportedly the fastest in the world. The 400 kW and 45 kW charging stations charge the battery in 5 and 30 minutes respectively.
- **Inductive charging (Wireless): Gumi, South Korea**
  - South Korea started e-Bus operation in 2014, where the fleet is charged via induction (Ahn, 2017).
  - The Korea Advanced Institute of Science and Technology (KAIST) developed the proprietary magnetic resonance technology used for charging e-Bus batteries.
  - Every On-Line Electric Vehicle (OLEV) e-Bus is equipped with a special receiver which can collect electric power wirelessly from the underground power supply while in motion or at the stationary condition.
  - It is reported to operate at an efficiency of 85%.
- **Battery swapping: Jeju Island South Korea**
  - Jeju Island South Korea is a unique market for e-Buses where charging by conductive, inductive and battery swapping technologies has been employed. E-buses with battery swapping technology operate on Jeju Island (Park, 2016).

- The e-Buses used in this project has 51 kWh battery bank which is mounted on the roof of the bus. The battery swapping stations located at the bus-stops have battery charging facilities and robotic systems for swapping.
- At the swapping station, there are two automatic robotic systems to remove the depleted battery from the bus and attach a fully charged battery.
- The swappable batteries used in this project weigh approximately 760 kg and has a special shock absorption design feature (Begins, 2019).

8.2 Criteria for the strategic development of Charging Infrastructure

8.2.1 Charging Demand Assessment

Sr. No.	Components	Description
1	Charger Sizing	Charger sizing needs to be done after knowing the e-Bus operations requirements (energy, battery, bus and charging scheduling). It is required to select the charging technology and estimate required number of charging units (EVSEs/Pantographs/swapping system etc.). This will further be basis to estimate the power load to be proposed.
	Power load estimation	Estimating demand for required peak power is necessary to consider as it is the foremost deciding factor for planning and providing charging infrastructure. The required peak load needs to be calculated including considerations for power losses at generation, transmission and distribution. Estimated peak power should be used to sanction the load to operate e-Bus charging station.

For first deployment of e-Buses, charger sizing can be done based on recommended e-Bus operations. The charger required are;

- **Depot Charging:** Overnight charging at Willowvale Depot; 50 chargers with 30 kW rating and
- **Terminal Charging:** Opportunity charging at terminal; Market Square 16 chargers of 120 kW rating.

Based on existing peak power assessment, e-Bus deployment would add up to the existing power requirements for city of Harare as follows.

- Load for charging station at Willowvale depot (overnight charging) will add 2.4 MW (2363 kW) peak power to the existing peak demand in the city of Harare.
- Load for charging station at Market Square terminal (opportunity charging) will add 3 MW (3024 kW) peak power to the existing peak demand in the city of Harare.

This can be facilitated through special agreements between power generating and distributing agencies, and the e-Bus operator (ZUPCO) including providing un-interrupted reliable power supply. It would be an added benefit if the power is generated from renewable sources such as solar and hydro.

8.2.2 Spatial Planning

Sr. No.	Factor	Description
1.	Charging location and integration with Urban land-use planning	• e-Bus charging infrastructure need to integrate with urban land-use and its related activities. considerations are as follows i. placement of e-Bus charging locations at either ends of routes or at one end as per requirement and planning. ii. Making opportunity charging options available for e-buses and other uses. iii. Using public charging station accessible and usable for buses and others. • Appropriate city and building codes revision for e-Bus charging infrastructure will be important for; i) public charging stations, ii) dedicated/ captive fleet charging, iii) battery swapping, and iv) other charging locations (commercial malls, homes, kerb side parking, public parking, etc.)
3.	Area selection	• Metro cities, capital cities/ regions are experiencing scarcity of land and that impacts the land acquisition cost as well. This may affect land acquisition for EV charging infrastructure • Support from national, regional, local government departments, power utilities, existing fuel (oil) stations needed for extending long-term low-cost leases from their available suitable land pockets. It will help competitive EV charging infrastructure development.
4.	Area requirement	• Suitable sizing of the land should be done accounting for; i) charger (EVSE) setup, ii) EVs parking and charging, iii) EVs queuing, iv) EVs manoeuvring/ circulation for entering and exiting the charging bays, and v) administrative office.
5.	Accessibility to grid	• Typically, the costs for providing grid connection from high voltage line to EV chargers is quite high (depends on distance) and is borne by charging station operator. This can create financial viability issues, especially in early EV market development stage when EVs demand is low. • Suitable size of land needs to be selected accounting for the spatial proximity of land and access to grid. Proximity of grid connection will enable easy access and minimize the grid connection cost to bring electricity to charging station.

Charging Location and integration with urban land-use planning: Location of e-Bus charging is decided based on start and end points of routes. The charging strategy adopted for e-Bus deployment is overnight + opportunity charging. As routes are operated from Willowvale depot, a charging station for overnight charging is needed at Willowvale depot. While the location of opportunity charging can be at Market Square terminal.

As both land for depot and terminal are available with ZUPCO, it can be designed and planned for utilizing existing space optimally for e-Bus parking and charging. Based on technical feasibility, it is recommended that:

- The charging stations are provided at both ends of the routes.
- All three route start at Willowvale depot and end at the Market Square terminal at CBD.
- Willowvale depot should facilitate overnight charging while Market Square terminal to be dedicated for opportunity charging.

Area selection:
Selected areas of Willowvale Depot and Market Square terminal at CBD, both have enough space to accommodate 500 and 120 buses respectively. The land for both depot and terminal is available with ZUPCO, which does not have to invest in land and can reutilise the available public transport infrastructure.

Area requirement: An EVSE with 30kW-160 Kw capacity requires space of ~1 Sq.m. and a 12 m e-Bus would require space of ~40 Sq.m. Based on the fleet size and charging requirement, the details are;

- Depot charging: Total charger space requirement is 25 S.qm.; and
- Terminal charging: Total charger space requirement is 14 S.qm.

Accessibility to grid: As per consultations with ZETDC and ZUPCO, it is understood that, although there are existing issues of load shedding and power cut-offs for domestic use, it would not be a problem for e-Bus operations. The distribution agencies can ensure required load, access to grid and reliability of power. Both, depot and terminal are in proximity to the grid connection. Therefore, it is doable for local power distribution company to provide un-interrupted grid access.

8.2.3 Grid Infrastructure Requirements

Sr. No.	Factor	Description
1.	Accessibility to required load and supporting infrastructure	• e-Bus charging stations because of combined high connected load (coming from multiple chargers) will require high grid voltage access (13.2kV/220V) point and appropriate distribution transformer • It should be ensured that grid has the sufficient capacity to accommodate the heavy load required to charge the buses. Or arrangements should be made to access required power as estimated.
2.	Electricity tariff	• Electricity cost (both fixed demand and variable energy charges) is significant operating cost for charging stations • Appropriate EV specific separate tariff category or concession to existing applicable tariff (both demand and energy charges) can support early market development
3.	Grid interconnection and safety	• At e-Bus charging stations, use of fast chargers (typically DC) lead to high power load on grid. This may cause power factor, load factor, harmonics, voltage deviations, etc. on the power grid, and hence should follow country's grid code and regulations for overall grid safety
4.	Integration with renewable energy (generation and storage)	• e-Bus will have positive impact on operation, environment and economy if they can use renewable sources for charging. The source of renewable generation can be at charging site and/or wheeled from distant plant • The renewable energy integration with local battery energy storage system (BESS) at charging stations can help transition to cleaner EVs, healthier air, improved peak load management and lower cost of electricity.

As described in chapter 8 (section 8.2), e-Bus pilot will require 2.4 to 3.1 MW peak power at the two charging stations. To meet the power demand, a grid voltage of 220 V and 0.015 MA is required at Willowvale depot and while opportunity charging station needs a grid voltage of 220 V and 0.02 MA.

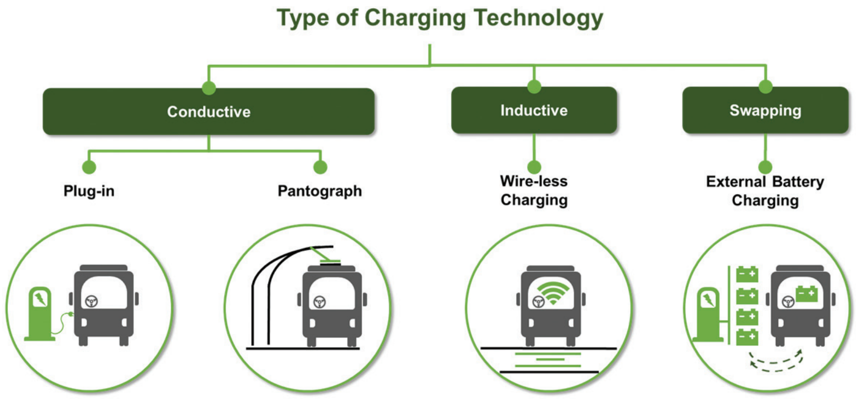
The required grid voltage and current needs to be facilitated by ZETDC appropriately with detailed demand assessment before deployment. Power distributors need to ensure un-interrupted and reliable power supply to the charging stations. The flexibility of augmenting the capacity in future has to be taken in account in case of future expansion of e-Bus deployment.

Current tariffs of electricity are based on the number of units consumed and vary from 0.01 to 0.2 USD/ kWh[53]. The tariffs need to be revised and Time of Use tariff system can be introduced (see section 7.3.7) to allow for differential tariffs for EV charging based on peak and non-peak power. It is also necessary to plan for optimizing grid load requirement. Grid code regulations[54] are published by ZERA, which has to followed while planning grid infrastructure for e-Bus charging station to ensure interconnectivity and grid safety.

Integrating renewable energy will help eliminating Well to Tank emissions (WTT) and it can be facilitated through enabling special contracts for clean energy provision between e-Bus operator / Public Transport Authority (PTA), power distributor and power producer. Innovation and experiments with business models for e-Buses should be encouraged for integration of renewable energy.

53 https://www.zera.co.zw/
54 https://www.zera.co.zw/wp-content/uploads/2019/09/Electricity-Grid-Code-Regulations.pdf, https://rise.esmap.org/data/files/library/zimbabwe/Documents/Energy%20Access/Zimbabwe_Electricity%20distribution%20code%20regulations.pdf

8.2.4 Charging Technology Selection



Sr. No.	Factor	Description
1.	Charging technology used in electricity transfer	• Different charger technologies include; i) conductive charging (fixed chargers/ down pantograph/ up pantograph), ii) inductive or wireless charging, iii) battery swapping - it needs to be mapped to different type of e-Buses (as per technology, battery capacity, battery ratings, service need and others).
2.	Charging types and power output of the charger	• e-Buses will require AC and/or DC chargers of different power rating capabilities (Level 1, Level 2, and Level 3) for charging. This will be based on battery size and type, model of charging, number of planned charging events and required charging time.
3.	Charging strategy	• e-Buses by their operational characteristics (daily distance, time and speed profile, terrain, weather) will have varying energy requirements. This can be supported by different battery–charger systems like; i. Big battery with overnight charging ii. Small battery with mix of overnight charging and enroute opportunity charging iii. Battery Swapping: based on appropriate e-Bus operations planning for battery swapping. • The charging strategy needs to be designed considering specific e-Bus application and cost-performance trade-offs.
4.	Communication and protection protocols	• EV chargers will increasingly use advanced communication protocols with; i. Power distribution grid for better load management and ii. Charge Points Operators (CPOs) for billing, payment and smart management & maintenance services. • E-Bus fleet for their high impact on power grid and continuity of public services will need increasing use of advanced/smart monitoring and control systems at charging stations
5.	Interoperability	• Interoperability in different e-Bus models and makes (across different OEM models) can allow access charging stations operated by different providers through a single application or platform • Interoperability can also help in improving charging station utilization by sharing of e-Bus fleet chargers between; i. Other public transport vehicle segments (e.g., bus depot chargers shared with taxis, and other commercial fleets) ii. Other non-public transport vehicle segments (e.g., sharing intra urban public charging station with private vehicles; sharing inter-provincial bus charging stations with heavy commercial/freight vehicles like trucks).
7.	Charging standards	• There are different charging standards including Combined Charging System (CCS), CHArge de MOve (CHAdeMO) and GB/T, which have been adopted by OEMs and countries. Countries are either allowing all or limiting to one-to-two standards for public chargers. • These standards govern mainly; i) design of connectors (both charging outlet and vehicle inlet), ii) communication between charger and vehicle, and thus influence interoperability • Charging standards for e-Buses need to be developed in co-ordination with national standards for electric vehicle charging

Plug-in charging (conductive) technology is suggested considering the first-time e-Bus deployment in city of Harare. E-Buses with 240 kWh battery capacity are suggested for the first deployment which will require DC charging (LEVEL 3 charging >20 kW) charging at depot and/or terminal both for overnight and opportunity charging. The charger ratings may differ from 50 kW to 120 kW based on the charging strategy and charging schedule. The required charger ratings are specified in section 8.2.

For overnight charging it is suggested to adopt DC slow charger with 30 KW capacity and for opportunity charging, 120 KW DC fast chargers is recommended. The EVSEs has to be aligned/adjusted with the communication protocols of grid and battery and CPOs.

The selected e-Buses need to ensure interoperability with the charging infrastructure to help optimize charger utilization. In case of DC fast chargers, cars and other light duty vehicles cannot use that. e-Bus deployment will build experience on e-Bus charging and open up possibilities to integrate the charging with other vehicle segments. It will take a few years. Until then, it is suggested to provide dedicated charging for e-Buses with no integration with other segments such as taxies, SUVs etc.

OEMs available locally, regionally and globally could be approached for the required EVSEs. This may help get chargers at competitive prices.

8.2.5 Operation planning

Sr. No.	Factor	Description
1.	Route coverage	• Buses typically operate on defined routes and local regions by their franchisee terms and conditions. Charging model selection should ensure appropriate coverage of public transport routes and their local demand dynamics for suitable utilization (currently and in future)
2.	Charging optimisation	• The charging model should optimize and provide flexibility and capacity to cover dead mileage for e-Buses over and above daily billed travel distance from their typical daily operations

The charging infrastructure sizing is undertaken based on integrated analysis of route energy, battery sizing, and scheduling of both fleet and chargers. The analysis also accounts for the dead mileage consideration. There are two charging events where dead mileage occurs. In the first trip-Willowvale depot to route start point and the last trip- route start point to Willowvale depot, due to overnight charging at Willowvale depot. Due to opportunity charging at Market Square terminal (CBD), no dead mileage occurs during the opportunity charging event. The dead mileage is about 5% of total distance travelled by a bus per day (per route). Planning opportunity charging at Market Square terminal would help minimizing the dead mileage and provide flexibility in charging.

8.2.6 Charging Infrastructure Safety

Sr. No.	Factor	Description
1.	Disaster resiliency	• The land topography should be checked for any natural and man-made disasters like floods, earthquake, etc. that could disrupt safe EV charging.
2.	External safety considerations	• The weather conditions and safety of surroundings (living things) from any short circuits and direct contact with electricity should be taken into considerations.

The city of Harare encompasses a hilly terrain with altitude of 1493 m. at city’s central region, 1550 m. at north eastern part and it gradually reduces as moving towards west and south west of the city outskirts radially to 1420 m. The routes chosen for e-Bus deployment currently are not vulnerable to natural disasters. However, the man-made hazards have to be taken into consideration. It may include major accidents, manhandling and vandalism of public infrastructure, riots and others. As the weather is moderate in Zimbabwe, e-Buses are likely to perform well in the city of Harare. Actual operation of e-Buses may provide data on their performance. The first deployment will help gathering the experience which can be applied in the future deployment of e-Buses.

8.2.7 Business Model Selection

Sr. No.	Factor	Description
1.	Cost of charger and charging infrastructure	• Cost of chargers and required supporting associated infrastructure has high implication on overall project cost. This gets further challenged with lower charger utilization in early market development stage if the e-Bus fleet is small. • The number of chargers need to be judicially calculated contingency considered before purchasing chargers and charging infrastructure • Governmental fiscal incentives on EV chargers and associated infrastructure can help business viability for charging infrastructure providers and operators.
2.	Charging infrastructure investment and ownership model	• Potential business models for providing charging infrastructure can explore leveraging current practices such as; i. Sub-contracting through e-Bus OEMs where they may invest and/or operate charging stations ii. Sub-contracting for e-Bus charging i.e., charging as a service as follows; ▪ EVSE OEMs invest and/or operate charging stations, ▪ Energy distribution companies (public and or private) invest and/or operate charging stations iii. Full ownership of infrastructure and sub-contracting operations and maintenance by OEMs
3.	Business synergies with EV charging	• Different businesses (e.g., fuel station operators, power utilities, commercial malls, public parking spaces, EV OEMs, etc.) not directly into e-Bus operations may benefit from supporting EV charging (investing and/or leasing land) and leveraging their primary business
4.	Pricing model	• Depending on the charging infrastructure ownership model and e-Bus types; there can be different pricing models for charging stations. These include; i) pay by electricity use, ii) pay by charging session, iii) pay by battery swap, iv) pay by charging time, v) bundled subscriptions, and others.

ZUPCO has currently franchised the public transport service operations to the third party i.e., private bus fleet owners to run buses for ZUPCO urban bus service.

9. e-Bus Investment, Funding, and Deployment Plan

This section assesses the technical scenarios developed in section 5.5.1.3 on cost parameters. All costs related to purchase of e-Buses, charging infrastructure and their operations are considered to assess lifecycle cost implications of e-Bus deployment.

9.1 TCO analysis

Total cost of ownership (TCO) is studied to understand the lifecycle cost of e-Buses compared to that of current ICE buses running on roads. The TCO helps comparing two different technologies based on common parameters (both operational and financial).

9.1.1 Key Parameters for TCO Assessment

The routes identified through the technical feasibility are further assessed on parameters that impact different costs of owning the buses. TCO analysis was done to assess the financial feasibility of e-Buses in comparison with currently operational ICE buses.

Following tables (Table 9.1 & Table 9.2) represent key operational and cost parameters that impact the cost of operating ICE and e-Buses.

Table 9.1 Key technology and operational (technical) considerations for ICE and Bus

Parameter	Unit	ICE Bus	e-Bus
Route characteristics			
Operational Days per year	No of Days/ Year	300	300
Avg. km Run per day[55]		~ 200	~200
Dead mileage per day (minimum)[56]	km	10	≧10
Vehicle characteristics		**Golden dragon 12 M Non-AC ICE bus**	**BYD 12 M Non-AC e-Bus**
Fuel tank capacity/Battery capacity	Litres or kWh	150	240 or 324
Motor-powered	kW		150 X 2 (300)
Battery technology		N.A.	LI-Ion battery
Range (stated by OEM)	Km/Full tank	600	200 or 280
Vehicle efficiency	Km/Litre; Km/kWh	4 km/l	0.5 to 1 km/kWh*[57] can go up to 2 km/kWh
Refuelling/Charging time	Hrs	5-10 Minutes	Slow Charging: 4-6 Hrs Fast Charging: 1 to 2 Hrs
Bus Life	Years	15	15
Charging infrastructure characteristics			
Charger rating	kW		DC Slow: 30 kW; DC Fast: 120 kW
Number of Vehicles shared per charger	Nos.		
Charger efficiency	%		95%
Grid Losses	%		10%
Charger Life	Years		10

55 The daily kilometres travelled by bus will change per route
56 The dead mileage adds up to the daily travelled distance by a bus
57 The efficiency is OEM claimed and subject to change as per route energy requirement.

The operational days per year for e-Buses are considered equal to the ICE buses. On an average the daily operational distance (billable with passengers) ranges from 140 km to 250 km per day (section 5.3.2.4;Table 5.10 Summary of Route level assessment: Fleet, charger sizing and operational requirements – scenario 1: A & B Table 5.10 anTable 5.11 Summary of Route level assessment: Fleet, charger sizing and operational requirements – scenario 2: A & Bd Table 5.11). As buses operate from Willowvale depot and the route start points are different, there will be dead mileage for every bus. Dead mileage would occur in every trip where a bus needs to travel from Willowvale depot to the route start point, which is minimum 10 km for ICE Buses. In case of e-Buses the dead mileage will depend on the selection of charging strategy, number of charging events and number of non-operational (un-billed) trips accounted on all routes. Every extra mile will add extra cost to the bus operations. This is calculated for each route across all scenarios and has been summarised in sectio 1.3.

Vehicle efficiency and range gives the amount of fuel that would be consumed per route both for ICE buses and e-Buses (electricity consumed per day). The fuel/charging requirement determines the capacity and number of chargers required and effectively impact the cost incurred to purchase and operate the chargers.

Table 9.2 Key cost considerations for ICE and Bus (capex and opex)

Parameter	Unit	ICE Bus	e-Bus 240 kWh	e-Bus 324 kWh
CAPEX				
Vehicle purchase cost (Including all taxes[58])	USD/Vehicle	121,736	247,686	247,686
BatterycCost (Including all taxes[59])	USD/kWh	-	286	286
	USD/Battery	-	68,700	92,745
Total vehicle cost	USD/Vehicle	121,736	3,16,386	340,431
Charger cost[60]	USD/kW		140	140
OPEX				
Fuel/Electricity cost	USD/Litre or USD/kWh	1.34	0.01	0.01
Maintenance	USD/km	0.02	0.01	0.01
Staff, administration & other expenses per km	USD/km	0.032	0.032	0.032
Finance cost in USD (real terms)	%			
Insurance cost as % of Vehicle value	%	8	8	8
Salvage Value	%			
• Vehicle	%	10%	10%	10%
• Battery	%		20%	20%
• Charger	%		3%	3%

In the cost parameters, two types of cost are considered; 1) capital cost, and 2) operational cost. Capital cost includes the vehicle purchase cost including all taxes, battery and charging infrastructure costs. The operational cost includes the fuel, maintenance, staff, insurance and any other recurring costs in vehicle operations.

The costs of battery, chargers and required grid infrastructure accounts for a a sizable chunk of investment in case of cost of e-Buses. Typically, current cost of e-Buses is 2.5 to 2.8 times higher than that of ICE

58 effective tax = 25% Custom Duty + 14.5% VAT + Registration charges = 43%

59 Taxes on battery are considered same as effective tax on vehicle. Though the battery cost is calculated separately for purposed differentiating the effect of subsidy in further calculation; battery is integral part of the vehicle hence same taxes are applied on the battery

60 The charger cost is considered global benchmarks and average rate of e-Bus chargers worldwide. The charger cost may differ for different technology.

buses. The fuel cost of e-Buses (current electricity cost) is 17 times cheaper than the fuel cost of ICE buses. For TCO assessment the capital costs are annualised over a period of fifteen (15) years assuming 15 years as the useful life of e-Buses. Operational costs are calculated on yearly basis. Addition of annualised capital cost and annual operational cost indicates total cost of ownership per year. This is further calculated as TCO per day and TCO per kilometre also. TCO per day indicates the daily e-Bus deployment expenses and TCO per kilometre indicates the economy of deploying e-Buses. Lesser the TCO per km, less the operational expenses of e-Buses.

9.1.2 TCO Assessment for e-Buses

Based on the considerations stated above, total cost of ownership was calculated for the existing ICE bus fleet (referred as BAU) and e-Bus fleet required for all five routes across all scenarios (e-Bus deployment scenario- referred as BTB).

Figure 9.1 TCO Comparison for Scenario 1: A & B (Without Subsidy)

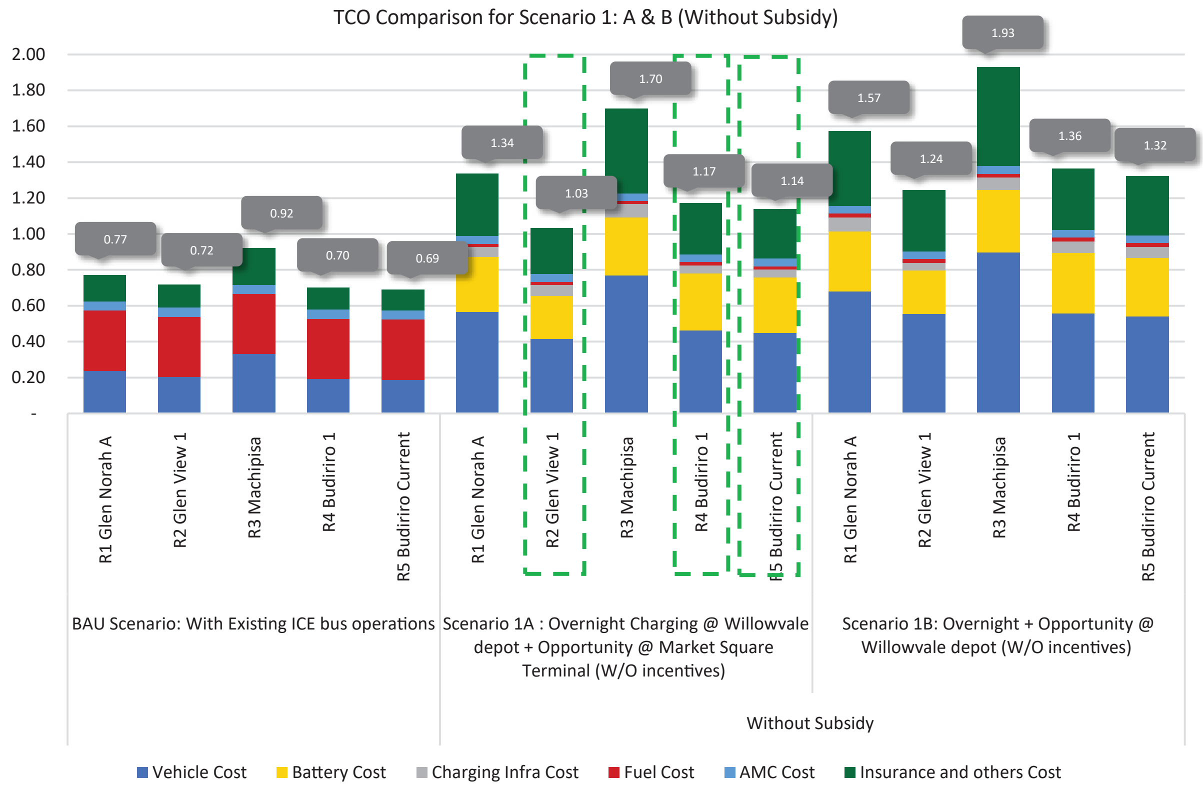
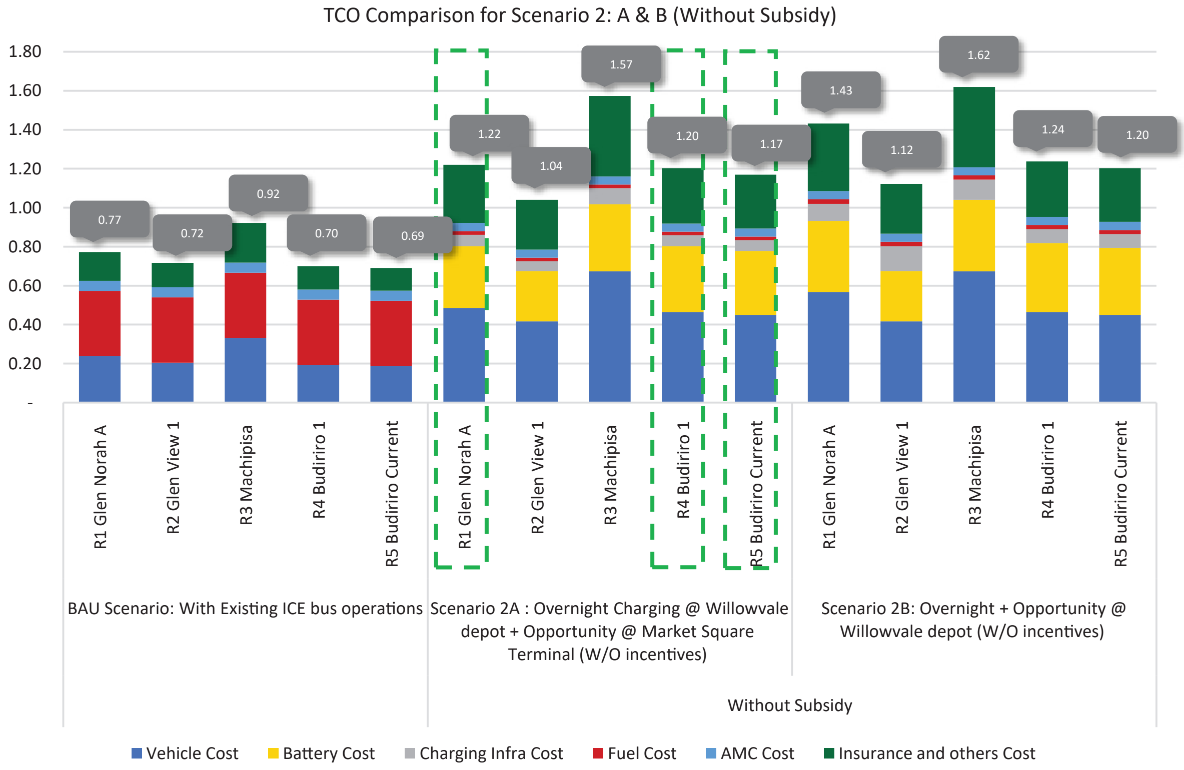


Figure 9.2 TCO Comparison for Scenario 2: A & B (Without Subsidy)



For the first deployment of electric buses a fleet up to 50 e-Buses is desired. Based on Table 5.10 Summary of Route level assessment: Fleet, charger sizing and operational requirements – scenario 1: A & BTable 5.10 andTable 5.11 Summary of Route level assessment: Fleet, charger sizing and operational requirements – scenario 2: A & B1, the number of e-Buses required per route ranged from 12-18 buses. A combination of three routes would make total fleet size nearly to 40-45 buses. Considering a buffer of one bus per ten e-Buses, the total fleet size would range from 44 to 50 buses to achieve desired fleet size. Based on the technical assessment (section 3) and the TCO assessment above, combination of three suitable route was selected as follows.

It was observed that R2 Glen View 1, R4 Budiriro 1 and R5 Budiriro have lesser TCO as compared to R1 Glen Norah A and R3 Machipisa currently. TCO for R2, R4 and R5 is less due to high daily operational kilometres (~200 km/day) while daily operational kilometres of the other two routes R1 and R3 are less (120 and 174km/day).

Above TCO comparison shows that scenario 1A and scenario 2A are potential suitable options for e-Bus deployment. These options are further assessed based on the investment required in the sections that follow. The Table 9.3 summarizes the e-Bus sizing for scenario 1A and scenario 2A which is further used for investment sizing calculations from the same scenarios.

9.2 e-Bus Deployment and Investment Requirements for Shortlisted Scenarios

9.2.1 e-Bus Deployment Requirements for Shortlisted Scenarios

Based on recommendations in section 9.1.2, the e-Bus deployment size is given in Table 9.3. The required e-Bus specifications, viz., daily operational requirement for e-Buses including daily trips, distance; charging requirements including number of chargers required, charger sizing (kW), peak power requirement (load) for recommended charging stations, and daily energy demand are calculated and summarised below.

Table 9.3 Recommended e-Bus scenario: 1A and Scenario 2A

Item		Units	Scenario 1 A		Scenario 2 A	
Number of e-Buses (Fleet size)		#	**47 e-Bus + 3 spare e-Bus (1 bus / 10 buses)**		**46 e-Bus + 4 spare e-Bus (1 bus / 10 buses)**	
			Total 50 Buses		**Total 50 Buses**	
Daily total trips on route by fleet		#	5-7		5-7	
Vehicle specifications	Peak motor power	kW	300 (150*2)		300 (150*2)	
	Battery pack	kWh	240 kWh		324 kWh	
Charging infrastructure	No. of chargers	#	@ Willowvale depot	- 50 (47+ 3 additional) 30 Kw dc slow chargers	@ Willowvale depot	- 49 (46 + 3 additional) 50 Kw dc slow chargers
			@ Market Square Terminal	- 16 (12+3 additional) 120 kW DC fast chargers	@ Market Square Terminal	-14 (11 + 3 additional) 160 kW DC fast chargers
	Peak power/ day	kW/ day	@ Willowvale depot	2363 (~2.4 MW)	@ Willowvale depot	2315 (~2.3 MW)
			@ Market Square Terminal	3024 (~3.1 MW)	@ Market Square Terminal	3528 (~3.5 MW)
	Total energy demand per day	kWh/ day	19147 (~19 MWh)		18743 (~18.7 MWh)	
	Charger specs	kW (AC/ DC)	Plug-in DC Fast chargers 120 kW (2 Gun) Plug-In DC Slow 30 kW		Plug-in DC Fast chargers 160 kW (2 Gun) Plug-In DC Slow 30 kW	

9.2.2 Investment Requirement for Shortlisted e-Bus Scenarios

Fore recommended e-Bus scenario (Table 9.3), the investment requirement is given in Table 9.4. It includes Investment requirements for e-us fleet, chargers, grid infrastructure, battery replacement and other yearly operational requirements for a fleet size of 50 e-Buses.

Table 9.4 Investment sizing for two scenarios 1A and 2A

Parameter		Unit	Scenario 1A	Scenario 2A	
		12 m Non-AC Standard - 240 kWh battery	12 m Non-AC Standard - 324 kWh battery	Remarks/ Assumptions	
Vehicle	Vehicle type	m	12	12	
	AC		Yes	Yes	
	Floor height		High floor	Low floor	
Fleet	10 Fleet size	11 #	12 50 13 (47+3 Extra)	14 50 15 (46+4 Extra)	16 Input variable
Capital Cost (Vehicle + Battery)	One vehicle cost (without battery) including taxes	USD/vehicle	2,47,686	2,47,686	Refer *TCO-Buses* Sheet
	Battery size	kWh	240	324	Based on electric vehicle specifications for desired vehicle type
	Battery cost	USD/kWh	200	200	Industry assumptions- subject to change
	Effective tax rate on battery	%	43%	43%	Refer *TCO-Buses* Sheet
	Battery cost (without subsidy)	USD/vehicle	68,700	92,745	Calculated
	One vehicle cost with battery, including taxes	USD/vehicle	3,16,386	3,40,431	Calculated
	Subsidy from the government	USD	NA	NA	The investment size is considered without subsidy; however, the subsidy is proposed in EV Roadmap is 200 USD/kWh
	One vehicle cost with battery and including subsidy	USD	3,16,386	3,40,431	Calculated
	Total fleet cost with battery (and including subsidy)	USD	**1,58,19,313**	**1,70,21,563**	Calculated

Parameter		Unit	Scenario 1A	Scenario 2A	
		12 m Non-AC Standard - 240 kWh battery	12 m Non-AC Standard - 324 kWh battery	Remarks/ Assumptions	
Charging Capitalization Cost	Fast Charger				As per charging requirements and battery size
	17 No. of chargers required	18 #	19 16	20 14	Operations summary sheet
	Fast charger size	kW	120.0	160.0	As per charging requirements and battery size
	Charger cost	USD/charger	16,800	22,400	Assumption- Around 84 USD/kW-peak
	Grid infra cost	USD/charger	10,800	14,400	Assumption- Around 90 USD/kW-peak
	Installation and commissioning charges	USD/charger	4,140	5,520	Assumption- 15% of overall charging cost
	Total cost per charger		31,740	42,320	
	Slow Charger				
	21 No. of chargers required	22 #	23 50	24 49	Operations summary sheet
	Slow Chargers Size	kW	30.0	30.0	As per charging requirements and battery size
	Charger Cost	USD/charger	4,200	4,200	Assumption- Around 84 USD/kW-peak
	Grid Infra cost	USD/charger	2,700	2,700	Assumption- Around 90 USD/kW-peak
	Installation and commissioning charges	USD/charger	1,035	1,035	Assumption- 15% of overall charging cost
	Overall cost of charger and infrastructure	USD/charger	7,935	7,935	Calculated
	Overall charging capitalization cost	**USD**	9,04,590	9,81,295	Calculated
Land Capitalization Cost	Land required per charging station cum service station cum workshop (assuming idling area)	Ha	Existing depot and terminal Used	Existing Depot and Terminal Used	No additional cost required
	Land cost per hectare (including land acquisition)	USD/Ha	NA	NA	
	Total Land Cost	**USD**	**NA**	**NA**	

Parameter		Unit	Scenario 1A	Scenario 2A	
		12 m Non-AC Standard - 240 kWh battery	12 m Non-AC Standard - 324 kWh battery	Remarks/ Assumptions	
Total CAPEX		USD	**1,67,23,903**	**1,80,02,858**	
Million USD		**16.72**	**18.00**		
Operational Cost	Annual vehicle kms (Operational)	kms/year/ vehicle	68,718	67,271	Refer operations summary sheet
	Total annual kms (Operational)	kms/year	3,435,913	3,363,546	Refer operations summary sheet
	Electricity consumption	kWh/year	6,299,198	6,166,467	
	Annual Electricity Cost/ Fuel Cost	**USD/year**	**62,992**	**61,665**	
	Maintenance cost	USD/km	0.0100	0.0100	
	Manpower cost	USD/km	0.0320	0.0320	
	Annual Maintenance Cost	**USD/year**	**144,308**	**141,269**	
	Annual insurance and other charges	**USD/year**	**990,745**	**990,745**	
Total OPEX		USD/year	**1,198,045**	**1,193,679**	
		Million USD/ year	**1.20**	**1.19**	

9.3 Comparison of Shortlisted Scenarios for Final Selection and Recommendations

Technical assessment suggests scenario 1A for e-Bus deployment, where the battery size is 240 kWh. Scenario 2A with 324 kWh battery size also I provides similar benefits except the high battery cost due to additional 80 kWh. To recommend the best suitable e-Bus deployment case, the above two similar scenarios were evaluated on financial parameters and also to understand how costs impact the TCO/day and TCO/km.

The combination of routes R1 Glen View 1, R4 Budiriro 1 and R5 Budiriro current was therefore selected for further comparison of the scenarios 1A and 2A.

Table 9.5 Comparing Scenario 1A with Scenario 2A

Scenarios	Units	Route selection composition R2 + R4 + R5
Scenario 1 A **Bus** – 12 m non-AC, 50-seater, **240 kWh battery** **Charging Technology:** DC fast charging **Charging strategy:** Overnight charging @ Willowvale Depot + opportunity charging @ Terminal		
Number of buses	Nos.	**47**
TCO/fleet/day	USD/day	10,444
TCO	**USD/km**	**1.2**
Total Investment size	**Mn USD**	**16.72**
Scenario 2 A **Bus** – 12 m non-AC, 50-seater, **324 kWh battery** **Charging Technology:** DC fast charging **Charging strategy:** Overnight charging @ Willowvale Depot + opportunity charging @ Terminal		
Number of buses	Nos.	**46**
TCO/fleet/day	USD/day	10,224
TCO	**USD/km**	**1.25**
Total Investment size	**Mn USD**	**18.00**

Based on Table 9.5, Scenario 1A is better as it gives high 'Fleet TCO' , 'Lowest TCO/km' and a more number of buses for lower TCO' than scenario 2A. Hence it is recommended to select scenario 1A for first e-Bus deployment.

9.4 Environmental Impact Analysis

The environmental impact assessment was done for selected scenario 1A by comparing an ICE bus with an e-Bus, as shown in Table 9.6. ICE buses produce 1.3 kg CO2 per kilometre, while e-Buses produce zero tailpipe emissions. The tailpipe emissions are also referred as tank to wheel emissions, and include other harmful emissions from ICE buses that affect the human health adversely. e-Buses can curtail such emissions fully. There are other emission that are also considered. These are 'well to tank emissions' and refer to emissions produced during extraction of oil/fuel from its source and its transportation to the fuel station. In case of e-Buses the well to tank emissions are currently five times more (per vehicle km) as the source of electricity generation is from coal. With more renewables these emissions can be curtailed which will help reduce well to tank emissions and make e-Buses cleaner mode of transport.

Table 9.6 presents the emission factors to calculate the implied emissions per vehicle-km. It was found that the grid factor significantly influences the GHG impact of e-Buses. For the year 2022, in the business-as-usual scenario (BAU), with a grid dominated by fossil fuel sources with 5% renewable mix, e-Bus causes 28% (of total[61]) less GHG emissions compared to diesel bus. Therefore, only operating e-Buses will not meet the greener target unless source of electricity is coming from cleaner grid (with more share of renewables). Zimbabwe is currently working to bring more renewables to mitigate both tailpipe and lifecycle emissions to meet its GHG mitigation targets.

In Business-to-be scenario (BTB) renewable mix is envisaged to be 26.6% by 2030[62]. This will help further reduce "well to tank emissions" from e-Bus deployment. Although this is one way to reduce emissions, the project need not wait till 2030 for the grid to become clean. Other options such as solar power integration in e-Bus charging are helpful to make energy production cleaner.

61 Emissions are of two types making total GHG emissions caused by a vehicle segment; that is, Well to Wheel (WTW) = Well to Tank (WTT) + Tank to Wheel (TTW).
62 Zimbabwe's Renewable Energy Policy, 2030.

Table 9.6 Implied Emission per Vehicle-km of e-Bus and ICE Bus

Engine Type	Average Distance Travelled	18Operational Days[1]	Fuel Efficiency	Emission factor (EF)	GHG Emission	VKT	Implied Emission/Veh-km
	V-km/ day	days/ year	Litres/ 100 kms or kWh/ 100 kms	kgCO2e/ Litres or kgCO2e/ kWh	kgCO2e/ year	Vkm/ year	kgCO2/ V-km
	A	B	C	D	E = (AxB) x (C/100) x D	F = (AxB)	G = E/F
Diesel	250	329	44	2.48	89,751	68,985	1.30
BAU: Electric with 5% renewable mix	204	329	184	0.53[62]	65,066	68,985	0.94
BTB: Electric with 26.6% renewable mix	204	329	184	0.35[63]	43,763	68,985	0.63

Table 9.7 Emissions, fuel and Economic savings from e-Bus deployment

Benefits over lifetime (15 years)	Unit	1 e-Bus (BAU)		50 e-Buses (BAU)	
		BAU	BTB	BAU	BTB
GHG reduction	Tons CO_2	490	912	24,489	45,623
Economic savings from GHG reduction	USD	48,978	91,247	2,448,885	4,562,331
Fuel saving	Litres	31,108		1,555,398	
Economic savings from fuel saving	USD	41,996		2,099,787	

The proposed e-Bus deployment has potential to reduce ~2 Mn USD from fuel (diesel) savings and ~4.5 Mn USD from GHG emission reduction over 15 years of e-Bus operations[65].

63 Grid emission per unit (kWh) of electricity generation with lower RE penetration (Business as Usual – BAU)
64 Grid emission per unit (kWh) of electricity generation with higher penetration of RE energy (Business to Be – BTB)
65 Savings from CO2 emissions reductions were calculated at USD 1000/ton of reductions.

9.5 Recommended e-Bus deployment size

Routes	Glen view 1, Budiriro 1, Budiriro Current
Depot	Willowvale
Terminal	Market Square
e-Bus and battery Size	12 m non-AC, standard; 240 kWh battery
Fleet size	50 (46 + 4 Extra)
Charging strategy and sizing	• Charging strategy: Overnight charging + opportunity charging • Charger sizing: ○ 50 chargers: 30 kW, Plug in- 1-gun, slow DC Willowvale Depot ○ 16 chargers: 120 kW, Plug in- 2 guns, fast DC Market Square Terminal
Bus operations	18 hours schedule with 10 minutes headway
Total investment size	16.72 Mn USD (without subsidy)
Business model	**Hybrid Business model (3)**: Buses owned by CMED and provided to ZUPCO for operations with single contract with e-Bus OEM for bus, battery, charger installation, and operations

9.6 Financial Analysis

The lack of parity between electric and conventional buses is the major barrier to market penetration unless the government interventions are introduced. As mentioned earlier, the comprehensive e-Mobility Road map pushes for the inclusion of e-Bus operations. Financial analysis (TCO assessment) between e-Bus and ICE Bus provides net operating income (NOI) as negative due to high capital cost of e-Bus. This suggests the need for government intervention for costs reduction to make r e-Bus operations viable. Based on stakeholder discussion, grants, loans, and operational subsidies are identified to achieve parity with ICE buses. Here, detailed analysis has been carried out for intracity routes with different financial and operational requirements.

Coupling price reductions with grant/loan for vehicles, batteries and charging points (for 5 years) by the Government of Zimbabwe (GoZ) is recommended for the first deployment of 50 e-Buses. This results in 16% rate of return for intracity operation for e-Buses. Considering high occupancy and good ridership, support through grant and concessional interest rates would help the e-Bus public transport project viable.

Table 9.8 Financial Analysis for first deployment of 50 e-Bus

Component	Unit	Proposed Business Model	Name of Institution
Business Model			
Vehicle capitalization cost	#	8.3% grant (VAT incentive) and 91.7 % loan @10% interest rate for amortization period of 5 years	
Battery capitalization cost	#	100% grant (subsidy) and 0% loan @10% interest rate for amortization period of 5 years	
Charging infrastructure capitalization cost	#	50% grant (Subsidy), 50% loan @10% interest rate for amortization period of 5 years	
Charging services	#	Operated by e-Bus/Charger OEM under separate contracts under CMED (cost recovered from collected revenue)	
Interest rate subsidy	#	10% interest rate subsidy by Government of Zimbabwe (GoZ)	
Electricity cost	#	No subsidy over industrial tariff by Government of Zimbabwe (GoZ)	

Component	Unit	Proposed Business Model	Name of Institution
Maintenance cost	#	Operated by ZUPCO and e-Bus OEM to Maintain buses through separate contracts from ZUPCO or CMED (cost recovered from collected revenue)	
Annual insurance cost	#	Cost recovered from collected revenue	
Annual registration/ renewal cost	#	Cost recovered from collected revenue	
Battery replacement	#	Cost recovered from collected revenue	
Land capitalization	#	NA	
Project Capitalization Cost			
Vehicle	USD	*1,23,84,313*	
Battery	USD	*34,35,000*	
Charger	USD	*9,04,590*	
Land	USD	*0*	
Total	USD	*1,67,23,903*	
Support and Subsidies			
Grant			GCF + Government of Zimbabwe
Vehicle	USD	*10,27,898*	
Battery	USD	*34,35,000*	
Charger	USD	*4,52,295*	
% Of Project Capitalization Cost	%	*29%*	
Loan			Nationalised / Private Bank
Vehicle	USD	*1,13,56,415*	
Battery	USD	*0*	
Charger	USD	*4,52,295*	
% Of Project Capitalization Cost	%	*71%*	
Operational Subsidy			Government of Zimbabwe
Exemption on Electricity cost per kWh	%	*0%*	
Interest Rate Subsidy	%	*0%*	
Total Operational Subsidy	**USD**	*0*	
Projected Monthly Net Revenue			
Year 1 to 7 average	USD/ Year	*50,10,609*	
Year 8 to Year 15 average	USD/ Year	*61,70,489*	
All years average	USD/ Year	*55,90,549*	
Economic Performance			
MIRR	**%**	***16%***	

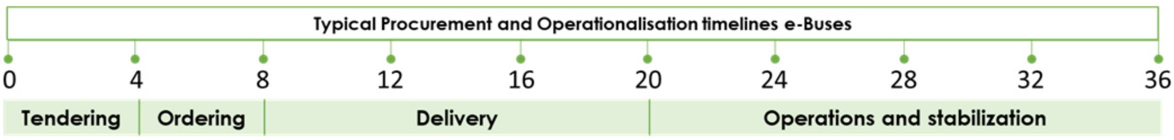
9.7 Deployment Plan

In this chapter, various phases of the e-Buses' deployment are defined, and time estimated to complete the process. Three phases in the project are defined as planning, procurement, and manufacturing phases. The short-term deployment phase continues till the third year from the initial deployment of the e-Bus pilot, wherein the first 50 e-Buses are deployed in the city of Harare. For this, completely built units (e-Buses and chargers etc.) need to be imported[66]. The fourth and fifth year refer to the medium-term deployment phase where an additional 200 e-Buses should be deployed in Harare and other cities. In this phase also, completely built units will need to be imported. Beyond the fifth year, the long-term deployment vision is to scale up the deployment across Zimbabwe with higher fleet sizes. However, this phase is earmarked for the "Made in Zimbabwe" initiative, supporting local manufacturing. Table 9.9 reflects the deployment strategy as explained above.

Table 9.9 e-Buses Deployment Phases

Phases	Short Term	Medium-term	Long term
Time Period	**Year-1 to Year-3**	**Year-4 to Year-5**	**Year-5 and above**
Planning & procurement	First 50 e-Buses deployment in Harare	Scale up phase & higher deployment (additional 200 e-Buses)	Scale up phase & higher deployment
Import/Local manufacture	Import of Complete Built Unit (CBU)	Import of Complete Built Unit (CBU) + local Assembly	Local assembly + manufacturing

Figure 9.3 Typical process of e-Bus procurement and operational timelines



66 Zimbabwe imports vehicles from Japan, United States, Japan and China and other African countries.

10. Conclusion

The proposed project is earmarked to be implemented on three routes in city of Harare namely Glen View 1, Budiriro 1 and Budiriro Current. Other routes within the city could also be operationalized to increase electric bus ridership and make e-Buses visible. Under the proposed project, the daily passenger trips are between 30,000-35,000 in Harare, and these will be served by 50 high-occupancy electric buses. This will generate multiple benefits over the implementation period on the selected corridors where the electric buses will be in service. Exposure to tailpipe emissions that contain air pollutants, will reduce benefitting many street vendors, passengers, walkers, cyclists and others. It will also help reduce the health risk associated with local air pollution.

e-Bused have potential to improve service quality in terms of comfort, convenience and reliable means of public transport. Many local artisans, start-ups, maintenance technicians, transport service operators, and dpare part vendors would be potential beneficiaries of this project. This project has potential to set best regional example of e-Bus deployment and carving clean mobility path. This will not only be the motivation for public transport users to use clean fuel buses but may other people may shift from private transport to the public transport in and around city of Harare.

Although the intent of this project is to introduce e-Bus, it could also set an example for private individuals and other vehicle segment fleet operators for adopting EVs by replacing ICEVs. The network of charging stations in the city and connectivity from CBD to sub-urbs would increase EV visibility and encourage other potential vehicle owners to procure electric powered vehicles instead of fossil fuel-based vehicles. Integration with solar power in the project will add value to country's clean energy mission and make e-Bus deployment much cleaner by cutting down the grid emissions.

Being the first of its kind to be introduced in Harare, electrification of e-Bus would drive Zimbabwe's green development initiatives. This project would be pioneer for e-Bus and broader e-Mobility pilots and further scale-ups in Zimbabwe. This will allow gradual decarbonisation of urban transport systems across the country. The project would be a suitable model for implementing Zimbabwe's National e-Mobility Policy Roadmap and the realization of the transport emission reduction objectives under Zimbabwe's NDCs.

In terms of technology transfer, the project will be an ambitious effort for realization of electric mobility not only in Zimbabwe but across the sub-region. It would help introducing and establishing strong local e-Bus and EV market, supply chain and regional industry connect for Zimbabwe. The electric bus project would further demonstrate Zimbabwe's commitment to modernizing urban transport by shifting from fossil-fuel-based systems to green electric mobility. The project has potential to transform the modal mix of urban transport into more organized and competitive bus services. It is envisaged that by 2030, the total number of electric buses in Zimbabwe could scale-up to more than 4000.

11. Annexure

11.1 Plans and Policies summary

Sr. No.	Policy/Regulations	Measures/mandates/provisions
1	Intended National Determined Contributions (NDC)	• **Reduce** energy related **GHG emissions** per capita by **33%** below the **2030** BAU scenario • **Ethanol** blending • **Energy efficiency** improvement • Increasing **Hydro power** in energy mix • Changing thermal power station technologies • **Coal-bed methane (CBM)** power • **Solar powered off-grids**
2	National Development Strategy (NDS)-2020	• **Local bus production**: 60% in 2025 • **Import bill reduction** on buses: 44% by 2025; • Local bus production employment: 4500+ by 2025 • Reduce road accidents & fatalities by 25% p.a • **Increase power supply**: 3467 MW by 2025 • Access to electricity: 54% by 2025 • Commission SATCC road standards: 10% by 2025 • Increase road network in good condition: 24,500 km by 2025 • Achieve **high quality and efficient public transport** services (rural and urban) • **Target mineral value chains of Nickel, Copper, Iron, Cobalt** • Construction of **additional 280 km of transmission and distribution network** by **2025** • Clear **road maintenance** backlog, **upgrading and expanding** road network and maximize use of **locally available resources** • Strengthening of financial and institutional maintenance of the network • Promotion of RE sources • Enhancing investment in **mining** towards **exploration, beneficiation** and value addition of minerals
3.	**Zimbabwe Long-Term Low GHG Emission Development Strategy targets 2020-2050 (LEDS)**	• Reduction in gasoline and diesel consumption by ICE vehicles • Increase renewable power demand from 2032 onwards to reduce grid GHG intensity • Reduced transmission system losses • Reduced carbon intensity of travel system • **Uptake electric** and hydrogen **vehicles** • Reduce **fossil fuel** component in the energy mix through **blending** displaced diesel consumption (rail + road) by less CO_2 intensive electricity provided from the grid • **Large hydropower** (including Batoka and devil's gorge) • Solar PV utility projects • Municipal biogas power projects • Increasing efficiency of power generation supply • **Shifting** away from **passenger car** use to **modern buses and NMT**

Sr. No.	Policy/Regulations	Measures/mandates/provisions
4.	National Climate Change Response Strategy	• Control and capture short-lived climate pollutants • Promote and incentivize use **of cleaner technologies** • Plan **transport policy framework** for transport with **low carbon** with legal provisions to promote low carbon emission • Promote research and development in the **RE sector** • **Develop and implement incentives** aimed at promoting and reducing **costs of RE** such as RE feed-in tariffs, net metering, subsidies and tax redemptions to make RE technologies affordable • Integrate and **build capacity for climate resilience** into transport planning and infrastructural development • Review, implement, enforce and monitor **emissions** and effluent **standards** for industries • Provide incentives such as **tax relief** and financing for companies that **invest in technologies** that **reduce GHG** emissions from their production processes • Introduce regulations that promote use of NMT to reduce carbon emissions & make provisions for NMT on existing and new road networks • Introduce an **effective mass public transport system** that includes use of big buses and rail
5	Climate Change Policy- 2016	• Promote **research** in the **climate-energy- economic nexus**, including assessment of the impacts of climate variability and change on the **production** of energy from **climate-sensitive sources** (such as hydro-power and solar). • **Develop capacity** among technical staff to adapt infrastructure plans to climate change • Improve road and rail infrastructure • Promote the adoption and utilization of **market-based instruments** to mitigate climate change • Improve road and rail infrastructure for efficient transportation of goods and people • Promote **research**, development, adoption and deployment of robust, gender-sensitive, sustainable **green technologies** • **Remove** all **trade barriers** for adoption of appropriate **clean technologies and practices** • **Promote** and provide **financial** and **economic incentives** for use of **cleaner technologies and practices** (innovation and technology transfer in industry)
6	National Transport Master plan-2018	• Promoting use of NMT • Better environmental standards – efficient fuel policy; reduce Green House Gases; emissions testing • **Improved vehicle technology** – **electric vehicles** • Better utilization of appropriate modes – rail, air or pipelines for large masses/volumes of freight over long distances; mass transit • Containing transport demand – limiting travel distances; NMT • Integrated land use and transport planning – densification, integrating land use planning with transport and environmental planning
7	National Energy Policy-2012	• Minimum **ethanol/petrol blend** target of 20% by 2015, and a 5% **biodiesel blend** by 2020 • Promote and increase usage of RE through investments (rural and urban) • Incentivize RE through subsidies and tax concessions and others • Ensure that petroleum products meet international specifications/standards
8	National RE Policy-2019	• Install RE capacity of: - 1,100 MW by 2025 or 16.5% of the total generation from RE sources, whichever is higher; and - 2,100 MW by 2030 or 26.5% of total generation from RE sources, whichever is higher

The following documents were studied to understand the transportation landscape of Zimbabwe

Zimbabwe National Transport Master Plan (ZNTMP 2018)	To prioritise proposals, programmes, and projects with high impact, • projects requiring relatively little resources, • exploring and encouraging private sector participation, • promoting projects supporting mining, industry, agriculture, and tourism sectors • prioritising projects reducing the cost of goods export and services • supporting domestic manufacturing	Provision for road transport sector • Improvement in roads connecting Major urban centres, (dualization and rehabilitation) and provision of missing links (new lines) • Dedicated Mass transit corridors • Links to support tourism development • Bridge widening, improvement, and replacement The plan highlights other proposals related to the Air, Aviation, Rail sector other than Road transport sector and gives Investment requirements for each of the identified project. One of the short-term goals in the master plan include introducing Electric Vehicles for their economic efficiency, low noise pollution and clean technology.	
Vision 2030	To transform Zimbabwe into an upper middle-income economy, raise employment levels upwards, and to progressively reduce the poverty rate to levels consistent with the upper middle-income economies, among other factors	Transport Vision 2030 • Dualization & Ring-Roads: o Dualization of trunk roads o Construction of ring-roads around urban centres • Urban Mass Transit System: o Re-introduction of efficient Mass transit systems for decongestion o Introduction of competent traffic management systems • Rail: Investment in o Light rail transport systems in the major urban centres of Harare and Bulawayo o World class rail infrastructure • Ports and Entry: o Upgrading of ports of entry o Establishment of inland dry ports to decongest border posts and ease the flow of traffic • Airports Infrastructure: Upgrading of airports infrastructure and improve connectivity. (Small aerodromes in Mutare, Masvingo and Buffalo Range in Chiredzi)	Power Vision 2030 • Raising installed generation capacity, new power stations • Achieve 95% Urban and 75% Rural Electrification • Investment in Electricity sector from PPP, Joint ventures and IPPs • Rural electrification with end-use infrastructure development • Hwange Thermal Power Station, addition of Units 7 and 8 • Batoka Gorge Hydro-Electric Scheme, which involves construction of the dam, power station, and the power evacuation and transmission infrastructure

National Energy Policy (2012)	The NEP identifies the key challenges in the exploitation, distribution and utilisation of different energy resources, and provides broad policy objectives and strategies to address those challenges	To explore feasibility of measures for pollution control to use environment friendly fossil fuels o Unleaded gasoline o Blend petrol o Low-sulphur diesel o Importation fuel-efficient vehicle • Actions to be taken by government o to promote energy efficient vehicles and awareness for the same o Integrate and harmonise implementation of national policies related to the transport sector o Promoted development and use of alternative fuels (biodiesel and ethanol blending	Government will continue with its programme of encouraging Independent Power Producers (IPPs) • Facilitate grid extension and energy efficiency in supply side • Improve investment opportunities on supply side • Financing and subsidising electrification projects • Determining the appropriate mix between grid and off-grid technologies • Sensitive but firm strategies to deal with non-payment, energy theft, and vandalism of infrastructure so as to minimise losses • Unbundle the state oil company, NOCZIM, into a trading company, Petro trade, and an infrastructure company, NOIC
National Renewable Energy Policy (2019-2030)	NREP focusses on establishing market-oriented measures and regulatory instruments for the renewable energy sector in Zimbabwe. Primarily, the renewable energy sector in Zimbabwe consists of solar, hydro, wind, geothermal and biomass		The goal is to increase access to clean and affordable energy through addition of installed RE capacity of o 1,100 MW (excluding large hydro projects) by the year 2025 or 16.5% of the total generation from RE sources, whichever is higher; and 2,100 MW by the year 2030 or 26.5% of total generation from RE sources, whichever is higher
Zimbabwe Long-term Low Greenhouse Gas Emission Development Strategy (20202050)	To guide the country's development pathways in the wake of climate change	Mitigation measures for Transport sector in Zimbabwe • Local biofuel production • Fuel economy policy • Electric- and hydrogen fuelled vehicles • Public transport (modal shift)	Mitigation Measures for Power sector • Large hydropower (including Batoka and Devil's Gorge) • Solar PV utility projects • Municipal biogas power projects • Increase in power demand met from renewables from 2032 onwards to reduce grid GHG intensity • Reduced transmission system losses, increasing efficiency of power generation supply
Zimbabwe Climate Policy (2016)	To guide climate change management in the country, enhance the national adaptive captive, scale up mitigation actions, facilitate domestication of global policies and ensure compliance to the global mechanisms	• Improve road and rail infrastructure for efficient transportation of people and goods • Promote cleaner fossil fuel technologies and access to clean and affordable energy • Enhance monitoring reporting and verification systems based on appropriate methodologies to account for GHG emissions in the energy sector	Promote renewable energy and adoption of energy efficient technologies and practices • Promote research, development, adoption, and deployment of robust, gender-sensitive, sustainable green technologies

Intended Nationally Determined Contribution (INDC) – 2015	In view of the high energy sector GHG (in comparison to other sectors), the mitigation component of Zimbabwe's INDC is therefore focusing on the energy sector.	Transportation Projects Identified under energy sector • Refurbishment and Electrification of the rail system • Solar powered off-grids • Reviewing the Transport system	The Mitigation Contribution for Zimbabwe is given as 33%* below the projected business as Usual energy emissions per capita by 2030 • Ethanol blending • Solar water heaters • Energy efficiency improvement • Increasing hydro in our energy mix • Changing thermal power station technologies • Coal-bed methane (CBM) power Others • Integrated Waste Management • REDD+ implementation
Zimbabwe Motor Industry Policy 20172030	To take the local motor industry to the next level by promoting local assembly and exports of motor vehicles into the region and the rest of the world, in line with the Zimbabwe Agenda for Sustainable Socioeconomic Transformation (ZIMASSET) as well as increasing capacity utilisation of car assemblers from the current levels of less than 10% to 100% of installed capacity	Government support – stimulate local demand, export incentives to OEMs, tariff adjustment • Control on second-hand imports Surtax imposition, Conformity to standards and Pre-shipment Inspection, • Categorisation and regulation of the motor industry • Development of the motor industry • Value chain and cluster • Addressing the issue of variety	
Zimbabwe's National Climate Change Response Strategy (2013	To create a climate change resilient nation. Mission is to ensure sustainable development and a climate proofed economy through engaging all stakeholders recognizing the vulnerable nature of Zimbabwe's natural resources and society	Introduce a transport policy framework that encourages use of transport with low carbon emissions. • Integrate climate resilience into transport planning and infrastructural development	Introduce policies and regulatory frameworks for renewable energy, energy conservation and energy efficiency • Strengthen energy planning, research, and development • Promote low carbon energy provision and use

SADC Industrialisation Strategy and Roadmap (2015-2063)	SADC Strategy for Economic Transformation aims at Leveraging the Region's Diverse Resources for Sustainable Economic and Social Development through Beneficiation and Value Addition	The expansion, upgrading and interconnection of the regional transport systems (road, rail, air and ports) would greatly enhance trade flows and the mobility of factors of production • Priority to the efficiency of the present transport corridors to enhance trade and enable alternative transport links Efficiency of interfacing between the multi-modal transport components • Investment to improve the quality of the regional transport network across all modes while • Promoting alternative renewable energy sources for the transport sector.	Investment in energy provision both for domestic use and export to regional partners through the Southern African Power Pool • Reliability, efficiency, and cost effectiveness of energy supply • Involvement of IPPs to ease the burden on the government investment spending. • Alternate energy sources to be exploited focusing on renewables Adoption of energy efficient technologies to reduce the cost of production and minimise greenhouse gas emissions • Fast-track the current and proposed hydro-power projects
Zimbabwe Infrastructure Report 2019	Detailed assessment of the current status of the infrastructure and services in transport, electric power, information and communication technologies (ICT) • Sets achievable objectives and action plan for Zimbabwe's infrastructure by2030	Capital requirement: ~ USD 28.56 billion (most required for Road transport sub sector - ~ USD 27.92) Activities to be carried out for road sector • Institutional reforms • Road network rehabilitation • Periodic Maintenance	Capital requirement: • ~ USD 42 million for required distribution projects • ~ USD 468 million for the required transmission projects • ~ USD 629 million required to connect new projects (Batoka Hydro and Hwange Expansion) • Rehabilitation and Expansion of Generation Capacity • Rehabilitation and Expansion of the Transmission and Distribution Grid • Institutional Capacity Building Programmes • Energy efficient usage and commercial performance of power utilities

11.2 Survey forms

11.2.1 Boarding Alighting Survey form

Table 11.1 Passenger demand survey: Boarding-Alighting (on site and Bus on-board)

Route Name:		BUDIRIRO 1&2						
Code:		R1						
Route Start and End Points		Name of Location/Land Mark		Latitude			Longitude	
	Start	Budiriro1 bus top		-17.900523			30.925192	
	End	Market Square		-17.836918			31.04209	
Time of survey		Trip Start time (hr:min)			Trip End Time (hr:min)			
		06:28			07:38			
Stops		Geographic co-ordinates		Dwelling time (seconds Minutes)	Number of passengers (Nos.)			
Number	Name, Landmark	Latitude	Longitude		Boarding	Alighting	On-board	
Stop 1	WILLOWVALE DEPOT	-17.875436	30.965871					
Stop 2	BUDIRIRO 1 BUSTOP	-17.892574	30.934097	10mins	61		61	
Stop 3	BUSTOP 1 CHITOWA RD	-17.892368	30.942064	30s	6		67	
Stop 4	BUSTOP 2 2 ND RD	-17.891343	30.946941	10s	5	1	72	
Stop 5	BUSTOP 03 87TH DR	-17.889817	30.951205	10s		1	71	
Stop 6	BUSTOP 4 17TH RD	-17.857051	30.958998	15s		2	70	
Stop 7	CSC	-17.874467	30.986945	10s		1	68	
Stop 8	VARICHEM	-17.87427	30.996059	30s		7	67	
Stop 9	ZUVA Southerton	-17.873847	31.005822	30s		2	60	
Stop 10	POST OFFICE	-17.861898	31.019748	30s		2	58	
Stop 11	MANCHESTER	-17.857507	31.024805	30s		4	54	
Stop 12	ZBC	-17.85025	31.030445	30s		2	52	
Stop 13	FLY OVER	-17.845469	31.039052	1mins		5	47	
Stop 14	MARKET SQAURE	-17.836917	31.04209			47	0	
Stop 15								
Stop 16								
Stop 17								
Stop 18								
Stop 19								
Stop20								
Stop 21								
Stop 22								

11.3 Electricity tariff in Zimbabwe

Table 11.2 Electricity tariffs in Zimbabwe[67]

Energy Consumption [kWh]	Tariff [ZWL/kWh]	Tariff [USD/kWh]
0-50	2.38	0.03
50-100	4.77	0.06
101-200	8.36	0.10
201-300	11.93	0.14
301-400	13.71	0.16
401<	14.31	0.17

11.4 Disruptions in e-Bus Operations

Table 11.3 Typical disruptions in the e-Bus operations

Disruptions	Mitigation Measure
During the rainy season, there may be flash floods or water logging	Provision of storm water drainage in the depots and upliftment of the drainage system with a proper gradient of 1:150 (concrete roads) along the routes.
Battery Ageing	Charging at slow rates of 0.18 to 0.5C for a long duration, so that per day, 1-1.5 charging cycles are consumed. It would ensure a longer duration of battery life. If fast charging is required, the charging time should be kept to a minimum and the SoC should be kept between 20 and 90 percent at all times.
Changes in passenger loading	Operations with variable frequency for off-peak and peak hours
Power Outage	Micro grids, generator availability, or alternative power sources such as solar power in depots and terminals. The use of solar power would also reduce the dependency on non-renewable electricity generation.
Bus/Charger breakdown/ Extremely high passenger demand for certain days (for instance, festival/some major program)	Spare buses/chargers can be used.
Route blockage due to unavoidable situations such as accidents	Buses can be re-routed for the specific time period while retaining the passengers. ITS infrastructure can be utilized to get information about accidents instantly.
Non-availability of depot staff for parking and charging / non-availability of drivers	Capacity building programmes should be held for all the depot staff. future technology of automated charging can be developed as an option. Additional drivers, with proper knowledge, can be kept on standby or can be taken on contract for such periods.
Regular maintenance	It can happen either at the depot or during the layover between trips.

67 https://www.zera.co.zw/, April 2022