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Market feasibility study of e-Bus deployment in Accra and Kumasi

UNIVERSITY OF GHANA

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Abbreviations

AC	Air Conditioner
AFDB	African Development Bank
AGM	Absorbent Glass Mat
BTB	Business-to-be
BAU	Business-as-usual
BESS	Battery energy storage system
BEV	Battery electric vehicle
BRT	Bus Rapid Transit
CBD	Central Business District
CBU	Complete Built Unit
CCS	Combined Charging System
CEPS	Customs, Excise and Preventive Service
CES	City Express Service
CNG	Compressed Natural Gas
COE	Centre of Excellence
CPESD	Coordinated Programme of Economic and Social Development Policies
CPO	Charge points operators
CVC	Customs Valuation Code
DC	Direct Current
DOD	Depth of Discharge
DVLA	Drivers and Vehicles Licensing Authority
EF	Emission Factor
EURO	European
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GAMA	Greater Accra Metropolitan Area
GAMP	Greater Accra Master Plan
GAPTE	Greater Accra Passenger Transport Executive
GCC	Gross Cost Contract
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GGGI	Global Green Growth Institute
GHG	Green House Gas
GHS	Ghanaian Cedis
GKA	Greater Kumasi Area
GPRTU	Ghana Private Road Transport Union
GPS	Global Positioning System
GRIDCo	Ghana Grid Company
GSA	Ghana Standards Authority

GUTP	Ghana Urban Transport Project
GWh	Gigawatt hours
HBW	Home-Based-Work
HT	High Tension
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
INDC	Intended Nationally Determined Contribution
IRR	Internal rate of Return
ISO	International Organization for Standardization
ISTC	Intercity State Transport Company
ITS	Intelligent Transport System
KPI	Key Performance Indicator
KW	Kilo Watt
MLGRD	Ministry of Local Government and Rural Development
MMTL	Metro Mass Transit Limited
MOT	Ministry of Transport
NDC	National Determined Contribution
NH	National Highway
NIP	National Infrastructure Plan
NOI	Net operating income
NRSA	National Road Safety Authority
NVTI	National Vocational Training Institute
OD	Origin Destination
OEM	Original Equipment Manufacturer
OLEV	On-Line Electric Vehicle
OPEX	Operational Expenditure
PM	Particulate Matter
PPP	Public-private Partnership
PT	Public Transport
PTO	Public Transport Operator
QBS	Quality Bus Services
SLA	Service level Agreement
SOC	State of Charge
SPV	Special Purpose Vehicle
SSNIT	Social Security and National Insurance Trust
TCO	Total Cost of Ownership
TESDA	Technical Education and Skills Development Authority
UG	University of Ghana
UN	United Nation
UNEP	United Nations Environment Programme
USD	United States Dollar
V2G	Vehicle to Grid
VAT	Value Added tax
VKT	Vehicle kilometre Travelled
WTT	Well to tank
ZEV	Zero emission Vehicle

1. Executive Summary

Introduction

Transport is a significant emitter of greenhouse gas (GHG) emissions and air pollutants in most cities in Ghana. Road transport alone contributes 45.4% to total fuel combustion emissions and accounts for 13% of the overall national GHG emissions in 2016, showing a rising trend of 42% in the last ten years. Of the total road transport GHG emissions of 6,051.4 metric tonnes in 2016, buses account for 21%. Also, buses account for 17% of the total PM2.5 emissions in the country.

Transition to electric mobility presents an opportunity to re-draw the city's emission and mobility pattern. City buses have a lifespan between 12-23 years, and therefore, today's technological decisions will determine air quality and emission trajectories for decades to come. Although urban buses typically have lower CO_2 emissions per passenger transported than private cars, they also account for about 1/4 of black carbon emissions from road transport. Hence, the project aims to promote climate resilience and green development by reducing GHG emissions from public transportation. Electrification of a bus is earmarked to be implemented on two major road corridors in Accra and the Accra-Kumasi.

Planning for e-Buses

Based on stakeholder consultation, two intracity routes, i.e., a) Adenta-Tudu and b) Tema-Tudu and one intercity route, i.e., Accra-Kumasi, have been selected for e-Bus deployment based on ridership, scheduled trips/day, daily run, etc. to be rolled out in two phases. The first phase will focus on intracity e-bus operations in Accra. Later, the intercity e-bus operations may be considered. Similarly, a depot at the start and end location has been selected for e-Bus parking and charging purpose. However, these new genres of the vehicle are quite different from conventional. They have a limited range, need substantial recharging time and are costlier to acquire but are affordable to operate. Therefore, this project aims to devise a technical assessment and prepare infrastructure and operational plans for e-Buses, as shown below.

Item		Units	Adenta-Tudu-Adenta	Tema-Tudu-Tema	Accra-Kumasi-Accra
Energy Consumption per day (3 round trips/e-Bus)		kWh	309	456	890
Daily Bus Utilization		km/bus/day	108	108	496
Number of e-Buses (Fleet Size)		#	50 operational e-Buses + 5 reserved e-Buses = 55 e-Buses	25 operational e-Buses + 3 reserved e-Buses = 28 e-Buses	17
e-Bus Parking/Charging Requirement at Depot		#	**Adenta Depot**: 31 **Tudu Depot**: 19	**Tema Depot**: 25 **Tudu Depot**: 0	**Accra Depot:** 6 **Joffel Depot:** 4 **Kumasi Depot:** 7
Vehicle Specifications	Peak Motor Power	kW	500	500	500
	Battery Pack	kWh	324	324	422

Item		Units	Adenta-Tudu-Adenta	Tema-Tudu-Tema	Accra-Kumasi-Accra
Charging Infrastructure	No. of Chargers	#	**Adenta Depot**: 17 **Tudu Depot**: 15	**Tema Depot**: 7 **Tudu Depot**: 0	**Accra Depot:** 3 **Joffel Depot:** 2 **Kumasi Depot:** 4
	Peak Power/ day	Mega Watt/ day	**Adenta Depot**: ~ 6.42 **Tudu Depot:** ~ 5.67	**Tema Depot**: ~2.646	**Accra Depot:** ~4.2 **Joffel Depot:** ~2.8 **Kumasi Depot:** ~5.6
	Charger Specs	kW (AC/ DC)	240 kW DC Fast Charger (2 Gun)	240 kW DC Fast Charger (2 Gun)	240 kW DC Fast Charger (2 Gun)
	Energy Demand	kWh/day	309 kWh/bus/day x 50 buses = 15,450 kWh/ day	456 kWh/bus/ day x 25 buses = 11,400 kWh/day	890 kWh/bus/day x 17 buses = 15,130 kWh/ day

Impact Assessment

The introduction of 100 high-occupancy buses will improve clean, reliable and safe public transport to nearly 24,000 passengers daily in Accra and 2,000 commuting between Accra and Kumasi. Each bus adopted provides around 466 tons of GHG emission savings, translating to approximately 46 thousand USD GHG Social costs avoided through its 15-year service life. Additional savings may be realized if its source power comes from green sources either by directly purchasing from the RE power plant or through onsite RE installations. The health benefits from the adoption of battery-electric buses relative to euro 4 Diesel Buses are higher than the social benefits of the avoided GHG gases. In proportion to 100 e-Buses, this will result in 46,684 Tonnes $kgCO_2$ of GHG saving and 4.6 Million USD of economic saving.

2. Introduction

Concerns about energy security, greenhouse gas (GHG) emissions and rising air pollution are certainly building an argument for sustainable transport. The introduction of EVs has been touted as a gamechanger in the country's ambition to reduce the transport sector's dependency on fossil fuels and mitigate GHG emissions.

Ghana is a lower-middle-income country and one of Africa's fastest-growing economies, with transport playing an important catalyst and strategic role in the economy. Ghana's 4th GHG Inventory (2019) shows a significant growth in the energy sector, contributing 36% of emissions in 2016, with transport accounting for 48%. The government's efforts are being undertaken to introduce full electric vehicles (EVs). For instance, the Minister for Finance and Economic Planning has promised incentives for imported EVs. Such targeted interventions can potentially lower the capital cost, which is very crucial to the uptake of EVs in Ghana. Similarly, increased efficiency, improved operational economics, falling component costs, and generous government subsidies are propelling higher adoption.

Ghana's ambitious strategy to tackle climate change has been well articulated in its recent medium-term development policy frameworks, such as the "**Coordinated Programme of Economic and Social Development Policies** (CPESD) 2017-2024" and the "**National Climate Change Policy**" and its related action plans and strategies. These initiatives, including plans for the mass movement of urban dwellers on **high occupancy buses**, affordable and convenient public transport, and cleaner transportation, aim to improve the efficiency and sustainability of road transport infrastructure and services and mitigate climate change climate variability. This is captured in the renewed transport policy interest to "*develop a cohesive e-mobility policy, planning and market framework to transform Ghana's transport sector into a modern, sustainable, effective, forward-looking and results-driven sector*".1 The "*National Electric Mobility Policy and Market Readiness Framework for Ghana" study, undertaken by the University of Ghana (UG) in partnership with UNEP-DTU, also highlights that* **buses can become a high-priority vehicle segment for electrification.**

Also, it is certain that in the upcoming years of the current decade (the 2020s), there will be a substantial deployment of e-Buses in the fleets of transit agencies. Hence, a long-term planning approach is necessary for the successful deployment of e-Bus, which includes operational complexities, technical feasibility, financing, business model, etc.

1 This commitment includes a number of policy goals, including: (4.2.3) Provide transport infrastructure and services without jeopardizing society's, environment's, health, or climate integrity; (4.2.4) Create an enabling environment for public and private sector participation in transport infrastructure development and service provision; (4.2.5) Adopt and promulgate a transport planning framework based on effective use of policy, long term plans, medium term programmes; (4.2.6) Develop an institutional framework that separates policy, regulation, asset management, and service provision by transport sector and (4.2.10) Apply new and appropriate technology and innovations to transport infrastructure and service delivery

2.1 Objectives of the Project

The overall objective is to promote a technology shift from fossil-fuel-based vehicles to e-Buses. Thus, the **"Market feasibility study for e-Bus deployment in Accra and Kumasi**" project envisions an intracity e-Bus scaled-up in Accra complemented by an intercity e-Bus commute between Accra and Kumasi. Specifically, the project focuses on:

- Intercity e-Bus pre-feasibility analysis between Accra and Kumasi
- Intracity e-Bus pre-feasibility analysis for Accra

2.2 Project Scope

The development of the market feasibility study for e-Buses in Accra and Kumasi includes institutional and legal frameworks and cost-benefit analyses. They also include other interventions that will propose the most suitable policies and incentives, infrastructure requirements and other suitable measures indicated for the transformational shift to low carbon road transport in Ghana.

2.3 Global Learnings on e-Buses Deployment Challenges

From an operations standpoint, e-Buses are more complex than their conventional counterparts, such as diesel buses or CNG buses. Conventional buses can be refuelled in a few minutes and easily complete their schedule without additional refilling. However, the range of an e-Bus is frequently limited. The batteries of e-Buses are heavier, and they negatively affect the efficiency of the bus expressed in electric units (kWh) consumed per kilometre. To put it in perspective, a diesel bus can go approximately four km on one litre (~0.85 kg) of diesel. However, for a four km range, an e-Bus with an efficiency of two kWh/km needs onboard battery storage of 80 kg. Also, e-Buses can take a substantial amount of time to recharge the battery. Time lost during charging can lower the daily vehicle utilization of e-Bus.

Financially, e-Buses can deliver more economical performance (BNEF, 2020). Lower operational costs due to cheaper electricity, combined with lower maintenance, reduce the operational cost of buses. However, e-Buses are costlier, and high bus costs often increase upfront capital requirements and increase financing costs. Thus, to deliver net benefits compared to conventional buses, lower operational costs should offset high acquisition costs. It, therefore, becomes important to fully appraise the technical concepts involved in e-Bus operation before embarking on a planning task.

2.3.1 Technical Concept

The three components of the e-Bus system are the bus, battery, and charger.

E-Buses are driven by an electric motor. A bus, battery, and charger are three components of the e-Bus system and energy is stored on-board. Like other buses, e-Buses can come in different standard sizes. An important attribute of a bus is its efficiency. An electric motor and other onboard equipment, including air conditioners, lighting, etc., consume electricity. The efficiency of a bus is measured by the number of electric units (kWh) consumed per km covered. Another important attribute of the bus is its weight, which, along with the weight of the battery, impacts the efficiency of the bus.

Battery capacity is expressed in kWh. For each kWh increased, battery weight also increases. A battery is an assembly of cathode and anode dipped in an acidic solution that can generate electric current. Numerous forms of assemblies are possible. The following are the most common battery chemistries: lead-acid tech, nickel base, lithium-based Batteries, etc. Among all battery chemistries, Li-ion batteries are most preferred due to their long life and high storage capacity per kWh. The concepts related to an EV's battery are as follows.

- **Battery Power (Watt):** Multiplying the voltage by the current provides power.
- **Amount of energy stored (kWh):** Multiplying battery power with the time for which the battery can keep dispensing power gives the storage capacity of the battery expressed in watt-hr. A one kWh battery can run an appliance of 1000 watts for one hour.
- **Specific energy or energy density (kWh/kg or kWh/m^3):** It is the amount of energy that can be stored per unit weight or per unit volume.
- **Charge Rate (1/hr):** This is a measurement of how quickly a battery can charge or discharge. It is the inverse of the 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 (%):** It is the level of charge of an electric battery relative to its capacity. The units of SoC are percentage points (0% = empty; 100% = full).

Charger is a unit used to refuel or recharge a battery. Its power, i.e., its ability to deliver energy (kW) in one hour, is called charger power, expressed in kW. A 100kW charger can fully charge a 100kWh battery in one hour. Chargers are available with varying powers. A low-power charger is generally preferred for a longer charging time and vice versa.

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

Charger power should be appropriate to cause a minimal effect on the availability of e-Buses for operations.

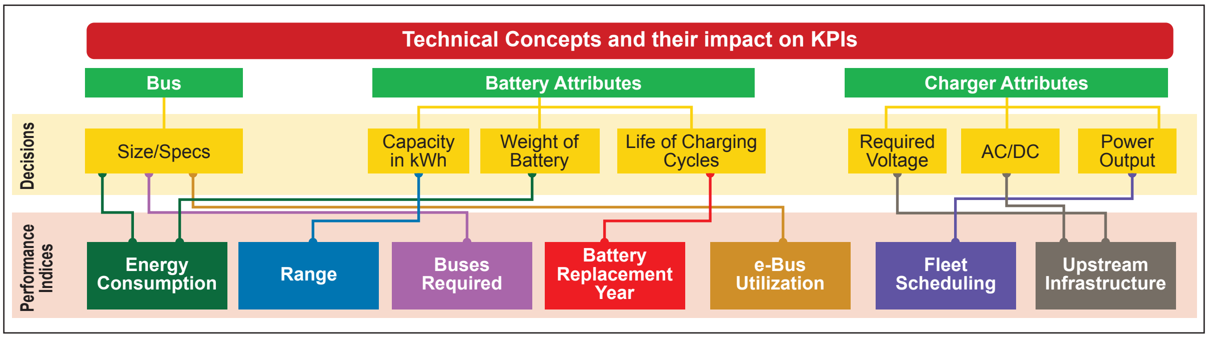


Figure 1 Dependence of KPIs on Attributes of e-Bus

It is important to choose the right attributes for these e-Bus system elements to minimize the total cost involved. These attributes can affect various key performance indicators of bus operation, like energy consumption, range, bus requirements, battery replacement, e-Bus utilization, etc. Figure 1 demonstrates the impact of key attributes of e-Bus elements on KPIs.

2.3.2 Key Barriers to e-Bus Adoption

The transition to e-Buses, however, has been subject to growing pains as industries and governments alike struggle to nurture the nascent e-Bus marketplace into maturity. Key barriers identified from various international case studies are organized into three general categories (technological, financial, and institutional) and represent issues that transcend different elements within the e-Bus trade space. This helps to provide a first-of-its-kind map of hazards to help guide high-level planning efforts safely along the road to e-Bus adoption. These key barriers are listed in Table 1.

Table 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:
	  ○ Lack of information for operators
	  ○ Lack of information on e-Bus (size, specs); battery (size, chemistry, specs); etc.
	• Set-up and commission:
	  ○ Lack of understanding on set-up and commission and the requirements to upgrade infrastructure
	• Operation:
	  ○ Unplanned SOC depletion
	  ○ High range deviation than stated specs
	  ○ Trip loss/delays
	  ○ Low e-Bus utilization
		• Rigid financial management and business models
		• Scaling investment in 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

2.4 Methodology

Considering the approaches used in various literature, a mixed-method approach has been used for the purpose of this study. Routes and depots have been selected based on stakeholder consultation and selection criteria used in feasibility studies. Energy consumption modelling has been performed for selected routes, and scenarios have been formulated to assess the technical feasibility of e-Bus. The detailed methodology for systematic planning for e-Buses technology selection and fleet scheduling is illustrated in Figure 2:

- **e-Bus specs input**: Conduct a brief global EV market assessment to identify **suitable e-Bus models** for use to replace existing ICEVs.
- **Depot and Route Selection Stage:** Depots have been selected based on their capacity to handle e-Buses, considering the space requirements of the charging infrastructure. Also, the most feasible routes for electrification have been selected through stakeholder consultation based on passenger demand and existing operations.
- **Route energy consumption modelling**: Conduct detailed technical analysis on energy consumption modelling for selected routes under different scenarios like AC on/off, passenger overloading, etc., has been performed (using pManifold's EVFleetPlanner© tool).

- **Battery sizing and Charging Strategy**: Estimate the required battery sizing to meet energy needs while accounting for SOC and ageing. After that, select an appropriate charging strategy for bus fleet operations, including different scenarios for overnight and opportunity charging.
- **Scheduling & Operations planning:** This is a measurement of how quickly a battery can charge or discharge. It is the inverse of the time taken in hours to charge or discharge. If a battery takes 5 hours to discharge, its C rate is 1/5.
- **Fleet Scheduling:** Overall fleet scheduling has been performed, which results in estimating the required charging infrastructure for select e-Bus (fleet), including the selection of charging technology, number of chargers, associated grid infrastructure, etc.
- **Scenario Selection Stage:** All e-Bus scenarios have been evaluated based on TCO and technical attributes of the e-Bus system, i.e., the bus, battery, and chargers, along with the charging strategy, which has to be finalized.

Further, e-Bus adoption and scale-up implementation recommend the proper charging infrastructure guidelines and mechanisms for both e-Bus and charging infrastructure.

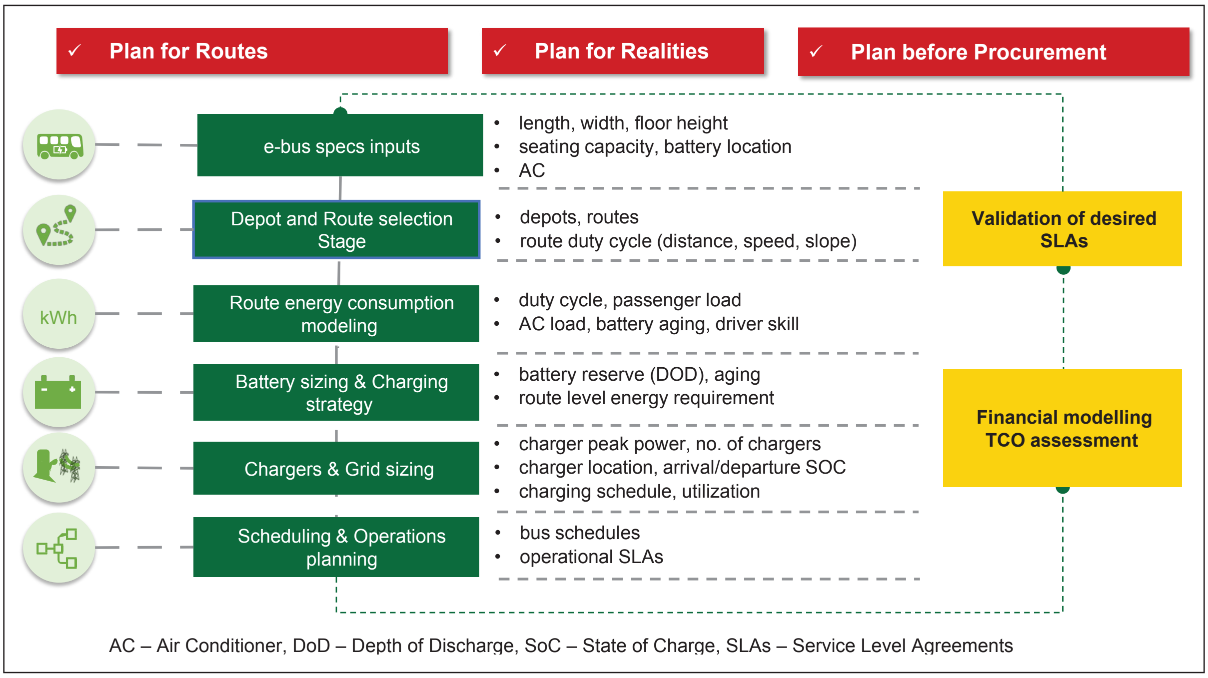


Figure 2 Systematic Planning for e-Buses Technology Selection and Fleet Scheduling

3. Country Landscape

3.1 Country Overview

3.1.1 Geographical & Socio-economical Profile

Ghana, a country with a landmass of about 238,535 sq. km, is bounded by Burkina Faso in the north, Ivory Coast in the west, Togo in the east and both the Gulf of Guinea and the Atlantic Ocean in the south. Currently, 31 million people live in the country (GSS, 2022), making it the second most populous in West Africa after Nigeria.

Accra has been Ghana's national capital since 1877 when the British colonial government moved its administrative functions to this hitherto "small fish village," which began in the late 16th century (Stanley, 1874; cited in Acquah, 1972). Accra and its contiguously built area, commonly referred to as the Greater Accra Metropolitan Area (GAMA), are the hubs for business, technology, and education, raking in a quarter of the country's GDP and attracting over 80% of all foreign direct investment in Ghana (ARUP, 2016). GAMA covers about 1,500 sq. km of urban space. At its core is the Accra Metropolis (AMA, > two million inhabitants (Ghana Statistical Service, 2019)) and 12 other metropolises and municipalities, including the shipping and industrial metropolis of Tema, to the east and to the west, the Awutu Senya East municipality, whose administrative capital, Kasoa, is functionally linked to the AMA regarding work and shop-related trips (Agyemang, 2017; Yeboah, 2000). Accra's population growth in 2010 stood at 3.5%. Presently, this city is home to over five million inhabitants (Ghana Statistical Service, 2019).

Kumasi, Ghana's second-largest city, is located in the transitional forest zone of Ghana and covers about 250 sq. km of geographic space. Kumasi's strategic location makes it a major destination for migrants from all over the country and beyond (Cobbinah & Amoako, 2012). Kumasi City, with more than two million inhabitants (Ghana Statistical Service, 2019) and its seven contiguously built municipalities and districts, collectively known as Greater Kumasi Area (GKA), currently accommodate over three million inhabitants, according to an estimate by the Ghana Statistical Service (2019).

In terms of the economy, Ghana is one of Africa's fastest-growing economies, with a GDP of about USD 175.2 billion. This is despite the decelerating economic performance over the past five years, due in part to the COVID-19 pandemic and its associated shocks, as well as abrupt declines in the country's commodity exports. According to the World Bank (2022), Ghana's economy is projected to recover gradually over the medium term, thanks to commodity price growth and strong domestic demand. Annual growth is expected to average 5.1% between 2021 and 2023. Following a 1.7% decline in 2020, real per capita GDP was projected to return to pre-COVID-19 levels in 2021.

3.1.2 Transport Sector Profile

Most of the trips in Ghana—an estimated market share of over 90% and 95% of passenger and cargo traffic, respectively—are conducted by road (GoG, 2017). Despite this reality, public investments in infrastructure generally, and the road sector, in particular, seem not to have responded adequately to the growing need to use road infrastructure. Road infrastructure financing in Ghana is obtained primarily from the Consolidated Fund, the Road Fund, and other internally generated funds. Also, financial support from donors plays a critical role in the sector, even though such support appears to have dwindled significantly in recent years. As a result, road infrastructure is beset by poor maintenance and unimproved surfaces. For instance, most road networks in cities are unpaved (30.6%), while a paltry 19.4% are paved. The rest of the statistics on the nature of urban roads in Ghana are captured in Table 2.

Table 2 Urban Road network by surface type by Length (km) as at 2015[2]

Surface Type	Total length (Km)	Percentage (%)
Rigid	3	0.01%
Asphaltic Concrete	956	3%
Surface Treated	5,044	16%
Gravel	5,225	17%
Earth	4,231	13.7%
Total paved	6,004	19.4%
Total unpaved	9,457	30.6%
Total	**30,923**	**100%**

In terms of service provision, public transport in GAMA and Kumasi is dominated by private sector-led paratransit operations (also known as trotros) and shared taxi services. Depending on carrying capacities, trotros may be labelled as micro (10 - 15 passengers), mini (16 - 25 passengers), and midi (26 - 44 passengers), respectively. The popular vehicle makes and models often used for trotro operations are the Mercedes-Benz 207, the Mercedez-Benz Sprinter, the Nissan Urvan, the Toyota Hiace, and the Ford Transit. These popular vehicle types may be found at the major public terminals all over major cities in Ghana, as shown in Figure 3.

(i) Tema Station, Accra Central

(ii) Achimota Terminal, Achimota

(iii) Kaneshie Market Station, Kaneshie

(iv) Circle/Odawna Terminal, Kwame Nkrumah Circle

Figure 3 Popular Trotro vehicle types operating at selected terminals

2 Compiled from GoG 2017

Trotro operators have unionized into powerful owner and operator unions, with the Ghana Private Road Transport Union (GPRTU) being the largest. The unions offer services along defined routes, usually between terminals or "lorry parks". In the Greater Accra area, there are believed to be about 6,000 people engaged in the operation of recognized routes. These services have many positive points, including universal provision, stability, self-financing, and relative affordability to the people. Nonetheless, as reported by the World Bank study, these operations also suffer from a number of quality problems, including:

i) Operation of a 'fill and go' system, which can cause long delays for off-peak users and difficulty boarding along the route

ii) Large numbers of vehicles parked at terminals during off-peak hours cause congestion, inefficiency, and long driving hours

iii) Lack of incentives for vehicle owners to upgrade their vehicles or properly train their drivers.

3.1.3 Emission Profile; Relevant Policy, Plan & Targets from Transport

Economic growth in Ghana is largely driven by its growing agricultural exports, industrial development, and service sector. This growth has had a major impact on the transport sector and the mobility needs of the citizens. Road or Surface transport is the primary means of passenger and goods transportation in Ghana. This fact is reflected by the growth of motor vehicle registrations in the country, as shown in Figure 4.

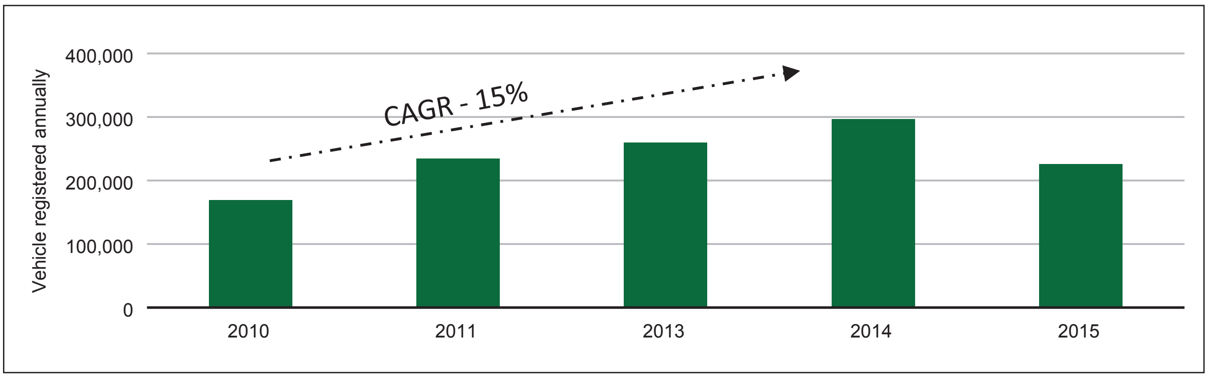


Figure 4 Trends in motor vehicle registrations in Ghana (2010-2015)[3]

The total number of registered vehicles population in Ghana in 2015 stood at approximately 1,952,564. Out of which The Greater Accra Region has the highest number of registered vehicles of about 1,164,942, followed by Kumasi with just 269,689. The remaining regions recorded about 517,933 registered vehicles, resulting in a steady growth in the vehicle/population ratio from about 50 vehicles per 1,000 population in 2010 to about 70 vehicles per 1,000 population in 2015, as shown in Figure 5.

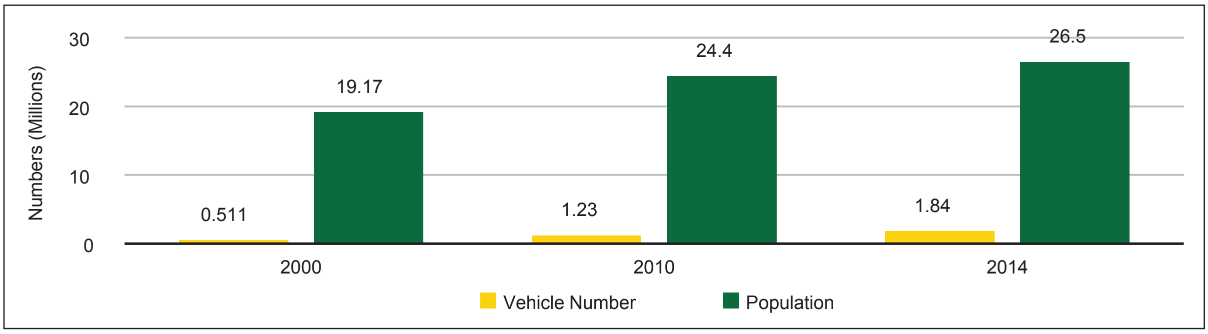


Figure 5 Comparison b/n Population and On-road Vehicles[4]

3 Ministry of Transport, 2016
4 Ministry of Transport, 2016

Closely tied to the rising vehicle stock is the substantial growth in the energy sector, which contributed 35.6% of the emissions in 2016. Transport is the predominant source of greenhouse gases (GHG) in the energy sector, accounting for 47.7% of emissions. Vehicle emissions contributed to more than 7.2 $MtCO_{2e}$ emissions in 2016, representing 17% of overall emissions. Ghana's 3rd national communication reports a significant upward trajectory of emissions over the past two decades. The main drivers for the increase in transport emissions are continued growth in the number of used vehicles and over-reliance on low-capacity passenger vehicles with poor servicing and maintenance, along with the use of sub-standard fuels.

Ghana, in its nationally determined contribution (NDC), committed to a 15% reduction in GHG emissions by 2030 from the business-as-usual scenario (BAU). This is expected to reduce total national GHG from the projected 74 $MtCO_{2e}$ to 63 $MtCO_{2e}$. However, with technology and financial support that can scale up mitigation actions such as renewable energy, reducing importation of high fuel consumption vehicles and promoting sustainable mass transportation, the emissions can be brought down to 41 $MtCO_{2e}$ and below emissions, in 2016, as shown in Figure 6.

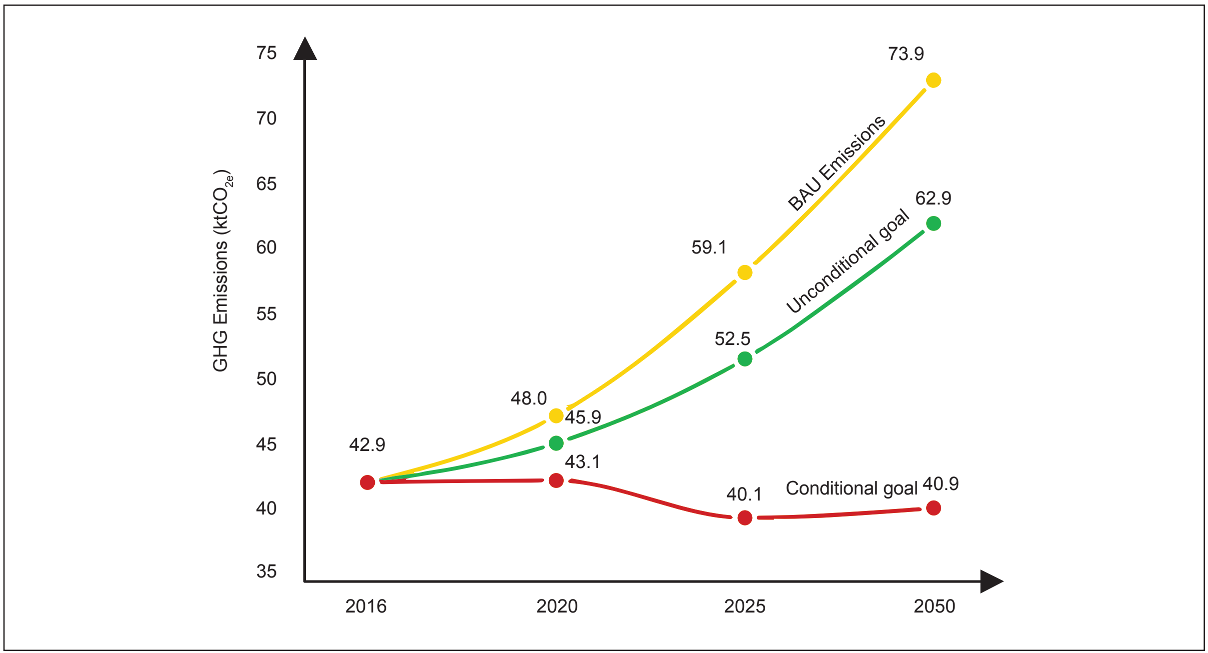


Figure 6 GHG Emissions projection from 2016 to 2030

Going forward, Ghana's vision for the transport sector aims to provide an "integrated, efficient, cost-effective, and sustainable transportation system responsive to the needs of society, supporting growth and poverty reduction and capable of establishing and maintaining Ghana as a transportation hub of West Africa" (GoG, 2020, p. 38). Thus, under the National Infrastructure Plan (NIP), the government wants to upgrade the current underperforming transport infrastructure to a "typical high and upper-middle-income country" (GoG, 2017, p. 57). To this end, specific Modal Master Plans have been proposed to improve urban transport infrastructure under the NIP initiative for GAMA and Kumasi. The Greater Accra Master Plan (GAMP), for instance, was prepared with the technical support of the Korean Government through KOICA to address GAMA's urban transport needs and improvements from 2015 to 2035. Table 3 presents a snapshot of the ongoing project in Accra.

Table 3 Infrastructure projects under the Greater Accra Master Plan[5]

Improvement Item	Short-term	Mid-term I	Mid-term II	Total
BRT (length)	Adenta-CBD, Amasaman-CBD	Motorway Kasoa-CBD	Amasaman-Ringroad Achimota-Labadi	6 routes
	49.9 km (24.9 km)	61.4 km	56.7 km	168.3 km (24.9 km)
Arterial Bus (length/bus)	Line 2-1, 2-2 Line 3-1, 3-2	Line 1, 2-3 Line 4-1, 4-2	Line 4-3, C-1, C-2 Line C-3	12 lines
	71.5 km / 158 (85)	122.6 km / 177	98.3 km / 146	292.4 / 478 (85)
Hub Terminal	(Amasaman, Ofankor) Adenta, Madina, 37 Lorry	Kasoa, Sowutuom Community 1, Sakaman	Ashaiman, Circle, Kaneshie, 37 Lorry (Achimota)	13 hub terminals (3)
Transfer Facility	5 facilities	3 facilities	3 facilities	11 transfer facilities

Additionally, it has been widely recognised that electrification of the transport sector is one of the several technological trajectories that can address some of the environmental issues associated with the growth in vehicles and travel, oil demands, and climate change impacts. Ghana made commitments in the fight against climate change through its Intended Nationally Determined Contribution (INDC) in 2015. Specific targets concerning the urban transport sector include: increasing the number of trips by public transportation by 10% in the 4 major cities; sustainable mass transportation modes (rail and bus transit systems); reducing travel time by at least 8 minutes per trip by public transport, and decreasing traffic congestion levels. The first target was accomplished, through the Ghana Urban Transport Project (GUTP), with the establishment of high QBS as part of the BRT initiative on the Amasaman, Adenta, and Kasoa corridors-Ayalolo services, although they are bedevilled by poor ridership and unsustainable financial challenges. It is estimated that the development of a full BRT has the potential to reduce emissions by 1.63MtCO_2 by the year 2040 when combined with other climate change mitigation measures (GoG, 2015b). The electrification of the QBS and the deployment of e-Buses in Accra can accelerate the achievement of this target as well as the NDC target (-15% relative to BAU). Coupled with this, the QBS, when developed into a full BRT system, can potentially minimize traffic congestion in Accra, thereby contributing to the New Urban Agenda on improving transport and mobility infrastructure systems and consequently enhancing efficiency, connectivity, accessibility, health, and quality of life of urban dwellers (UN-Habitat, 2015).

The utilization of electric mobility in Ghana is still in the infant stages of development. The government is considering the introduction of tax exoneration for electric vehicles as part of plans to promote a technology shift from fossil fuel-based vehicles and, by so doing, enable the transition to low-emission transportation. In this regard, the government is on the move to secure high-occupancy e-Buses for urban transport through the Green Climate Fund (GCF) and other development partners. These actions have occasioned inter-sectoral collaboration and industry partnerships, including a pilot installation of electric vehicle (EV) charging systems (e.g., at A&C Mall in East Legon and Stanbic Heights, Airport City).

3.1.4 Energy Profile (Grid Mix/Grid Coverage/Policies)

As the progress of electrification for the public transportation sector is accelerated, it becomes more important to integrate renewable energy sources for electricity generation and energy storage.

As of 2020, the grid in Ghana has nearly 36.28% generation capacity from renewable sources (with hydro), as shown in Figure 7. Total electricity generation almost doubled from 10,166 GWh in 2010 to 20,170

5 GoG, 2017

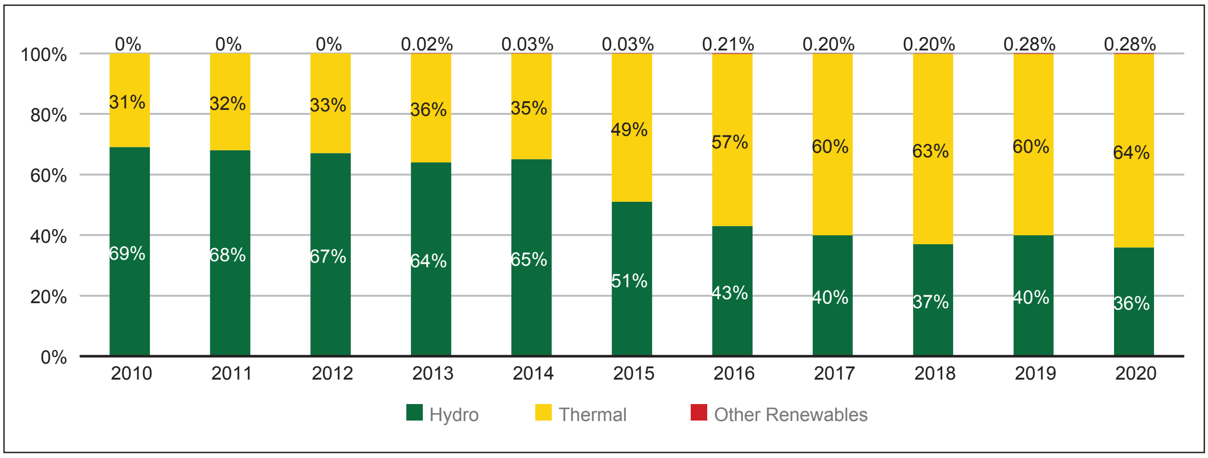


Figure 7 Trends and mix of electricity generation in Ghana

GWh in 2020, representing an annual average growth rate of 7.1%. The renewables share is also growing fast, thereby reducing the carbon footprint of the energy used by e-Bus for charging. Even for emitting sources like thermal (coal), more stringent elaborate emission cutting measures are feasible in a fixed power generation setup compared to a mobile IC engine aboard a vehicle.

3.2 City Profile and Existing Bus Transport in Accra & Kumasi

3.2.1 City of Accra and Kumasi

Accra, the national capital since 1957, and its contiguously built area, commonly referred to as the Greater Accra Metropolitan Area (GAMA), is the most urbanized. In what began in the late 16th century as a "small fish village" (Stanley, 1874; cited in Acquah, 1972), GAMA presently is the hub for business, technology, and education, ranking in a quarter of the country's GDP and attracting over 80% of all foreign direct investment in Ghana (ARUP, 2016). GAMA covers about 1,500 sq. km of urban space. It is composed of the Accra Metropolis (AMA, >2 million inhabitants (Ghana Statistical Service, 2019)) at its core and 12 other metropolises and municipalities. Whereas, Accra seems to have reached saturation point as it has shown consistent declines in the annual growth of its urban population from 6.1% in 1960 to 3.5% in 2010 (Ghana Statistical Service, 2013). This may be due in part to the continuous fragmentation and carving out of some municipalities and district assemblies from the Accra metropolis. Thus, Accra no longer enjoys its primacy status, as Kumasi, the nation's second-largest city, is fast urbanizing, as shown in Figure 8.

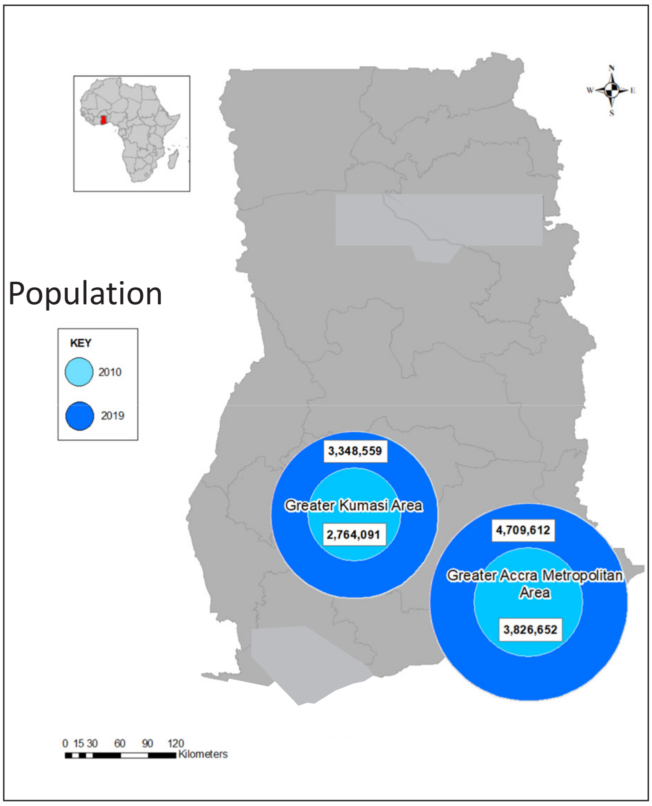


Figure 8 Urbanization trends in Accra and Kumasi[6]

6 National Electric Mobility Policy and Market Readiness Framework for Ghana, Ongoing (2022)

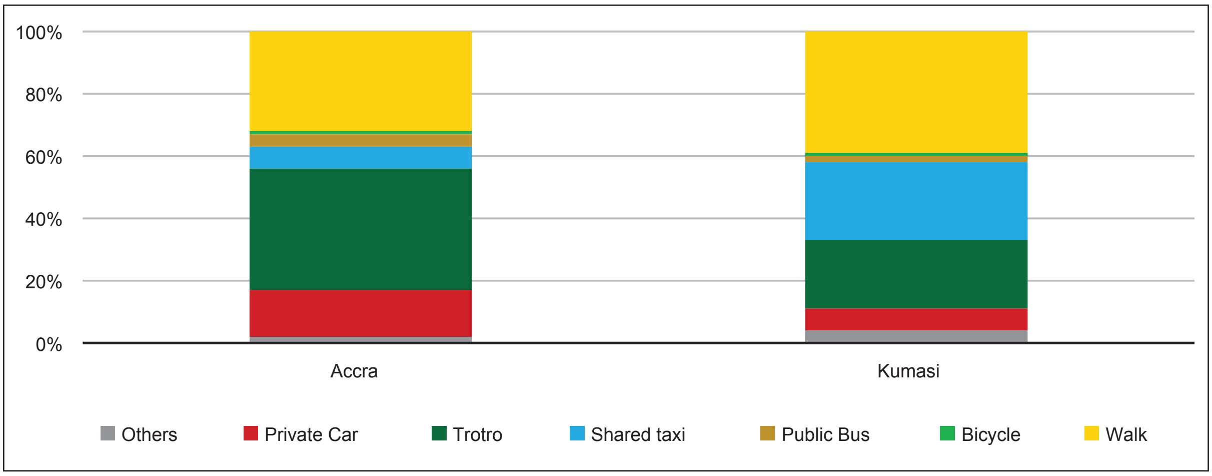


Figure 9 Mode share work trips

Source: National transport survey, 2007

Figure 9 shows that most urban residents in Accra and Kumasi are forced to use walking as a mode of transport due to a mix of limited infrastructure provision and a limited supply of motorized transport services. For instance, in Accra, around 65% of residents walk for different purposes. A large section of the population also depends on public transport modes, so more than 85% of the population in Accra either uses public transport or walks to their destinations.

3.2.2 Bus Landscape

3.2.2.1 Intracity Bus Landscape (Accra)

The government had experimented with formal bus operations since the pre-independence era when in 1927, the Accra Town Council introduced passenger-only buses. However, the state operation of buses has achieved limited results. Hart (2013) argues that the steady decline of the municipal bus system started around the mid-1960s due to high operational costs and stiff competition from the trotro operators. The 1970s and 1980s witnessed a further decline. For instance, the Omnibus Services Authority (OSA), established in 1969, and the City Express Service (CES), formed in 1981 to provide bus services, attracted fewer passengers (CES carried fewer than 10% of commuters in 1992). The state then gave up on running formal bus services, and the private-sector bus operators filled in the void. Presently, Metro Mass Transit Limited (MMTL) and Aayalolo Quality Bus Services (QBS) are the two leading intracity formal bus operating companies in Accra. In Kumasi, the MMTL and the 'Adehyee' Transport Services (which is the equivalent of Accra's Aayalolo) run formal buses to serve commuters.

The Metro Mass Transit (MMT) Limited was formed in March 2003 as a quasi-private bus company jointly owned by the government (through the Ministries of Transport and Local Government and Rural Development) and some private entities which held 55% equity. In November 2016, a high-quality bus service (Type B), popularly known as "Aayalolo," was introduced on the Tudu-Amasaman corridor in Accra. This is the brainchild of the 2008 Ghana Urban Transport Project, supported by the Ghana government, the World Bank, the French Development Agency (Agence Française de Development, AFD) and the Global Environment Facility (GEF).

Structure

The MMT Limited is governed by a board of directors. However, the day-to-day activities of the company are run by the management headed by the managing director. The company reports to the governing board, which has representation from the Ministry of Transport and other relevant institutions. The Aayalolo is also governed by a 17-member board whose membership is derived from all 12 local administrative assemblies in Accra and the Senya Awutu East in the Central Region of Ghana. A Chief Executive Officer, who is in charge of the Greater Accra Passenger Transport Executive (GAPTE), supervises the day-to-day activities of the company. The MLGRD plays a supervisory role using the LI 1961.

Fleet size and Network

The MMT operates a variety of makes and models of buses for its various service types. This is presented in Table 4.

Table 4 Current operational fleet characteristics of the MMT Limited (Accra and Kumasi)[7]

Bus Type (length)	Quantity of buses	Quantity of buses (Operational as of June 2018)	Total Passenger Capacity (Seating; Standing)
HUANGHAI COACHES	2	1	83 (43;40)
HUANGHAI CITY 1	116	77	150 (39;111)
HUANGHAI CITY 2	84	60	-
ANKAI/DRAGON	3	3	-
VDL NEOPLAN CITY 1	48	10	99 (33;66)
VDL NEOPLAN CITY 2	144	54	88(47;41)
VDL NEOPLAN COMM1	28	8	62(62;0)
VDL NEOPLAN COMM2	132	54	63 (63;0)
VDL JONCHEERE COMM 1	178	71	62(62;0)
VDL JONCHEERE CITY 1	149	62	88 (45;43)
TATA MARCOPOLO	45	16	70 (60;10)
ASHOK LEYLAND	87	23	77 (57; 10)
TATA COMMUTER 1	11	3	69 (59; 10)
DAEWOO COMM 1	-	-	49 (49;0)
DAEWOO COMM 2	-	-	62 (62;0)
TOTAL	**1027**	**442**	

A total of 275 Scania Marcopolo Viale BRT buses have been imported for the exclusive use of the QBS in Accra. Presently, most buses are parked at the main depot at the Achimota terminal, as seen in Figure 10.

7 MMTL website https://metromasstransit.com.gh/bus-route-operation-types/ Accessed on 11/09/2021 & Personal Communication

Figure 10 SCANIA buses at Achimota bus terminal

Operations

The two formal bus companies operate on busy routes originating from the city centre and heading in different directions from the city. These routes include the Guggisberg Avenue, the Tudu-Kasoa, along the Winneba/Graphic Road, and the Tudu-Amasaman route, along the Nsawam Road, just to name a few.

Figure 11 High-capacity routes and facilities along which the MMT and QBS buses operate in Accra

It is noteworthy that the MMTL has a relatively more extensive system of routes and stops in Accra. As seen in Table 5, prior to 2020, MMTL buses were seen on almost all the important routes in Accra.

Table 5 Operational visibility of MMTL and QBS in Accra[8]

Major Routes in Accra	Pre-Covid era (2016-2020)		Post-2020	
	MMTL	QBS	MMTL	QBS
Tudu-Amasaman	12	60	1	30
Accra (Tudu)-Tema	24	-	4	-
CBD-Ministries Circulation	2	-	-	-
Guggisberg Avenue	-	-	-	-
Liberation Road (through to Adenta)	24	3	2	10
Adenta to Circle	4	-	-	-
Nima-Kanda Highway	-	-	-	-
Ring Road	-	-	-	-
Winneba-Graphic Road (through to Kasoa)	8	8	2	15
Tudu to Ashaiman	15	5	1	10
Tudu to Teshie-Nungua	6	-	1	4
Total	**95**	**76**	**11**	**69**

About 50% of MMTL's operations along these busy routes involve high-frequency bus services, on average every 10-minute interval, leading into or out of the central business district of Accra. The service does not extend beyond a radius of more than 40 km from the cities. The MMTL also operates intercity bus services over long distances of about 140 km in one direction and an interurban/rural-urban service that connects most transportation-deprived rural areas to larger towns. However, the COVID-19 pandemic and operational challenges seem to have negatively impacted the company's active business.

The Aayalolo began a pilot high-quality bus service (Type B) on the 20.65 km Tudu-Amasaman route, along the Accra-Nsawam Road, with 28 buses. By October 17th 2017, the company had increased its fleet size to 58 buses, indicating that the service was enjoying massive patronage by commuters. Subsequently, the Tudu-Adenta and Tudu-Kasoa corridors were earmarked for an extension of the service. Unfortunately, since June 2019, ridership has dipped significantly, to the extent that the Aayalolo has been running limited morning (5:30-8:30 am) and evening (2:30-7:00 pm) services. Similar to the MMTL, the QBS is reeling under the effects of COVID-19 and prevailing operational challenges.

The main depot serving MMTL buses is located at Kaneshie, specifically along the Nii Teiko Din Street in Accra (see Figure 6, labelled as "Kaneshie depot"). The 10-acre facility currently holds close to 250 buses, most of which are broken-down vehicles. Other facilities available include a bus maintenance workshop, a warehouse, a bus parking depot, a fuel depot, a bus washing bay and several administrative offices.

8 Personal communication, 2021

The Government of Ghana has commissioned an ultramodern bus loading terminal and/or depot at Tudu, to serve the operational needs of both MMTL and Aayalolo buses. In Figure 10, the location of this facility is labelled as “Tudu depot”. This facility has a commercial block with 14 offices, a restaurant, and a banking hall. Furthermore, it has a parking space for seventy-eight (78) buses and a drop-off space for thirty-two (32) passengers. Figure 12 shows the frontage of the ultra-modern terminal/depot facility at Tudu.

Figure 12 An ultra-modern bus terminal/depot at Tudu

Figure 13 Adenta BRT Terminal

Another bus terminal/depot, which the government also owns, has been put up at Adenta in Accra. In Figure 13, the location of this facility is labelled as “Adenta depot”. The facility comprises a bus terminal building, 18 offices, a restaurant, a bank, a supermarket building, a 10-seater washroom, a passenger park-and-ride, and bus parking, covering an area of about six acres.

In terms of fare structure, the MMTL charges relatively low fares. The fares are normally graduated for its intra-city bus operations. This means that even though a flat fare may be attached to the routes, passengers only pay the equivalent of the travel distance. The flat fares per route are as follows: Tudu-Amasaman (GHS[9] 3.00), Tudu-Tema (GHS 5.00), and Tudu-Adenta (GHS 5.00). The rest are Adenta-Circle (GHS 4.00), Tudu-Kasoa (GHS 4.00), Tudu-Ashaiman (GHS 4.50) and Tudu-Teshie/Nungua (GHS 5.00). The Aayalolo, on the other hand, uses a zonal fare charge system. There are four zones in which charges are made. Along the Tudu-Amasaman corridor, the zones include Amasaman-Ofankor (Zone 1), Ofankor-Achimota (Zone 2), Achimota-Circle (Zone 3) and Circle-Tudu (Zone 4). These zones are illustrated in Figure 12. Since 1st April 2018, the fare is GHS 1.30 to travel within a zone and GHS 1.80 to travel within two zones. A commuter pays GHS 2.20 and GHS 2.50, respectively, for travel within 3 and 4 zones.

3.2.2.2 Intercity Bus Landscape

The main publicly-owned bus company that plies the Accra-Kumasi route is the Intercity State Transport Company (ISTC). The MMTL has a minimal presence on this route. However, private bus companies, including VIP, VVIP, and OA, compete for passengers on this route.

The roots and origin of intercity STC (ISTC) began in 1909 as a Government Transport Department to cater to the central government’s needs. Over the years, the company has gone through changes as it was taken over by private company VANEF after it had acquired majority shares. Since October 2003, it has been known as Intercity STC Coaches Limited. Presently, Intercity STC is owned by Social Security and National Insurance Trust (SSNIT), which has a majority share of 80% after taking over from VANEF and GoG, which owns the minority share of 20%.

9 1 GHS = 0.16 USD (24/11/2021)

Institutional structure

ISTC Limited is governed by a board of directors. However, the company's day-to-day activities are run by management, headed by the managing director, with three deputy managing directors in charge of finance and administration, operations, and technical services.

Operational landscape and routes

ISTC operates inter-city transport services, package/parcel/courier services, engineering consultancy services, and bus hiring services using their high-capacity buses to all 16 regions of Ghana.

Fare structure

The ISTC charges a flat rate of GHS 45 per passenger for all trips between Accra and Kumasi. This appears to be cheaper than privately-owned bus services that also serve the route.

Fleet landscape

The ISTC operates a variety of makes and models of buses and luxury coaches for the various service types. This is presented in Table 6. Figure 14 shows the Scania Marcopolo Viaggio bus and a Toyota Hiace mini-bus, which serve the Accra-Kumasi route.

Table 6 Operational fleet characteristics of the ISTC Limited in 2021[10]

Bus Type (length)	Quantity of buses	Passenger Capacity (Seating)	Air-Conditioned
GrandBird	40	49	YES
Scania Marcopolo Paradiso	40	44	YES
Scania Marcopolo Viaggio	10	52	YES
Toyota Hiace	12	14	YES
AMPS mini buses	10	14	YES
MPlaza	10	-	YES
Nordic	7	-	YES

Figure 14 Sample considering the Accra-Kumasi route

10 Personal communication

Key Depots and Terminals for the Accra-Kumasi Intercity Service

The main Accra ISTC depot is located at its head office at No. 1 Ajuma Crescent, opposite the Awudome Cemetery, Kaneshie. In Figure 11, the location is labelled as "ISTC Main Depot, Circle". The 10.43-acre plot of land can hold 120 buses. In addition, the facility has a guesthouse, a training school, a mosque, and a space for park and ride. Also, the depot has a canteen/restaurant, a station for the Ghana National Fire Service, a DVLA inspection site, a fuel station, a clinic, a passenger lounge, and an engineering workshop which can hold close to 50 buses.

Buses departing for the journey to Kumasi usually take off from the 0.8-acre "ISTC Terminal, Odawna". This terminal can hold eight buses at a time. It can boast of a passenger lounge, a washroom, and an Office Depot. From here, the buses may pick up passengers waiting at the "BRT/ISTC Terminal, Achimota". This facility has a bus holding capacity of two buses, a washroom, and a passenger lounge. ISTC drivers and passengers take a mandatory short rest at the Linda Dor Highway Rest Stop for the Accra-Kumasi-bound journey. In Kumasi, the ISTC has four main terminals/depots. Their geographic locations and available facilities are illustrated in Table 7.

Table 7 ISTC facilities in Kumasi[11]

Location	Land size (acres)	Bus holding capacity	Facilities
Oforikrom	22.37	100 buses	Valuation office, Warehouse, Engineering workshop, Fuel station, Training school
Asafo	1	6	Washroom, Passenger lounge, Cal banking hall
Adum	1.69	5	Restaurant, Passenger lounge, Petty trader stores
Kumasi Goil (Labour)	-	5	Fuel station, Washroom

The driving crew and passengers returning to Accra from Kumasi stop at the Joffel Catering Services for a short break, and passengers may alight at the "BRT/ISTC Terminal, Amasaman" or the "BRT/ISTC Terminal/Depot, Achimota" in Accra.

11 Personal Communication, 2021

4. e-Bus Routes and Depot Selection

The consultant must examine many criteria while determining the best route and depot for the e-Bus pilot. As a baseline, we used the current bus route network, which is substantially paved and in acceptable condition.

The route selection for the roll-out of e-Buses must also include commercial, technical, and operational considerations, including the location of charging stations and the operationalization of e-Bus charging.

The following are major commercial and technical route selection considerations:

- **Passenger Demand**: The demand for e-Buses is critical to their financial, commercial, and bankability. Passenger demand determines the number of buses and public transport operators (PTOs) deployed along a route. The number of buses on a route indicates the probable cost savings for bulk e-Bus purchases. The demand also incorporates gender differences, demographics, and the availability of public transportation.

- **Length**: Route length is a factor in route selection for several reasons, including:
    - As in Accra, the city is low-lying, and the buses operate on the busy routes originating from the city centre and heading in different directions with a relatively more extensive system of routes and stops. About 50% of MMTL's operations along these busy routes involve high-frequency bus services, on average every 10-minute interval, leading into or out of the central business district of Accra. The service does not extend beyond a radius of more than 40km from the cities. The MMTL also runs the Inter City bus services generally over long distances, about 140 km in one direction.
    - However, while considering the intercity route from Accra to Kumasi, since Kumasi is a hilly terrain, there comes the need to assess the technicalities in terms of charging and energy requirements.
    - Charging flexibility: Shorter routes provide for more charging flexibility, especially when one end of the journey has a damaged charger or a blackout.
    - Safety: If an e-Bus malfunctions and cannot continue the trip, the closer the route is to the city, the more likely it is to get another bus to serve the stranded passengers.
    - Greater operational flexibility is crucial in the roll-out of new technologies, and shorter distances equate to safer, more dependable operations.
    - In the lack of data, the route length is utilized instead of the total distance run on each route. The route length is utilized to comprehend conventional lengths, not only for present operations but also for future bus routes.

However, the depot's selection is based on the ownership, the capacity, and the functionality to cater to the selected routes with the least minimum dead kilometres and accessibility to the grid. Since Accra is a low-lying area, the occurrence of flash floods is a major concern, thus, making it an important factor of consideration during depot selection.

4.1 Route Selection

4.1.1 Consideration

The following criteria represent the consultant's primary considerations for determining the ideal route/(s) and were determined through data collection and stakeholder interactions.

- The demand on the existing routes.
- The distance between the start and end points of a route is a critical factor in determining the charging intervals of the e-Buses and the charging technology solution that will be used.
- Road condition is a critical factor in route selection since it affects both maintenance needs (i.e., increased vibrations caused by mountainous roads that might damage cabling) and the engine power demand specification requirements for e-Buses.
- The route's grade and elevation profile govern the e-Buses' engine power demand specification requirements. Suppliers provide common e-Bus specs that are well-suited to relatively level terrain. If routes selected demand engine power for steeper gradients, bespoke e-Bus requirements would be required, increasing the cost of e-Buses. An elevation profile that would make it impossible for a bus to restart acceleration in the middle of a steep gradient slope would be excluded from the final route selection.

4.1.2 Methodology

The route selection methodology is summarized in Figure 15.

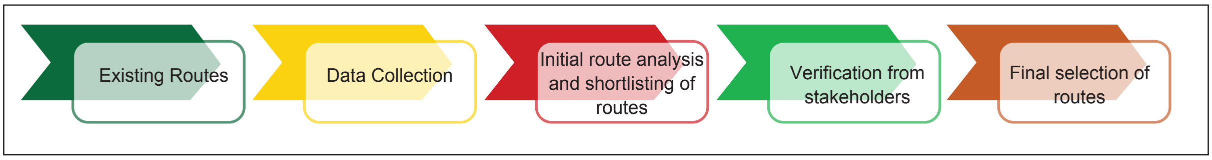


Figure 15 Route Selection Methodology

4.1.2.1 Existing Routes: Intracity

Line	Routes	Length
Line 1	Kasoa~CBD	27.4km
Line 2-1	Amasaman~CBD	21.2km
Line 2-2	Ofankor~CBD	14.6km
Line 2-3	Ofankor~Circle	23.1km
Line 3-1	Adenta~CBD	19.6km
Line 3-2	Madina~CBD	16.8km
Line 4-1	Tema~Sakaman	39.0km
Line 4-2	Tema~CBD	33.1km
Line 4-3	Ashaiman~Circle	31.5km
Line C-1	Ringroad-Circulation	19.8km
Line C-2	Achimota~Labadi	27.3km
Line C-3	Sakaman~Ringroad	19.7km

Figure 16 Existing Intracity Routes

As shown in Figure 16, the city of Accra has 12 important intracity routes. Currently, because of the pandemic, the conditions of the buses have deteriorated because of non-functionality during lockdowns. However, the demand is higher as life returns to normalcy, as the supply is not. Thus, to revive the services, the consultant wants to upgrade the existing technology by deploying e-Buses on the two most important routes, i.e., Tudu-Adenta (18 km) and Tudu-Tema (36 km). The data collection regarding passenger demand shows that these two routes are heavily loaded.

4.1.2.1.1 Selected Routes: Intracity

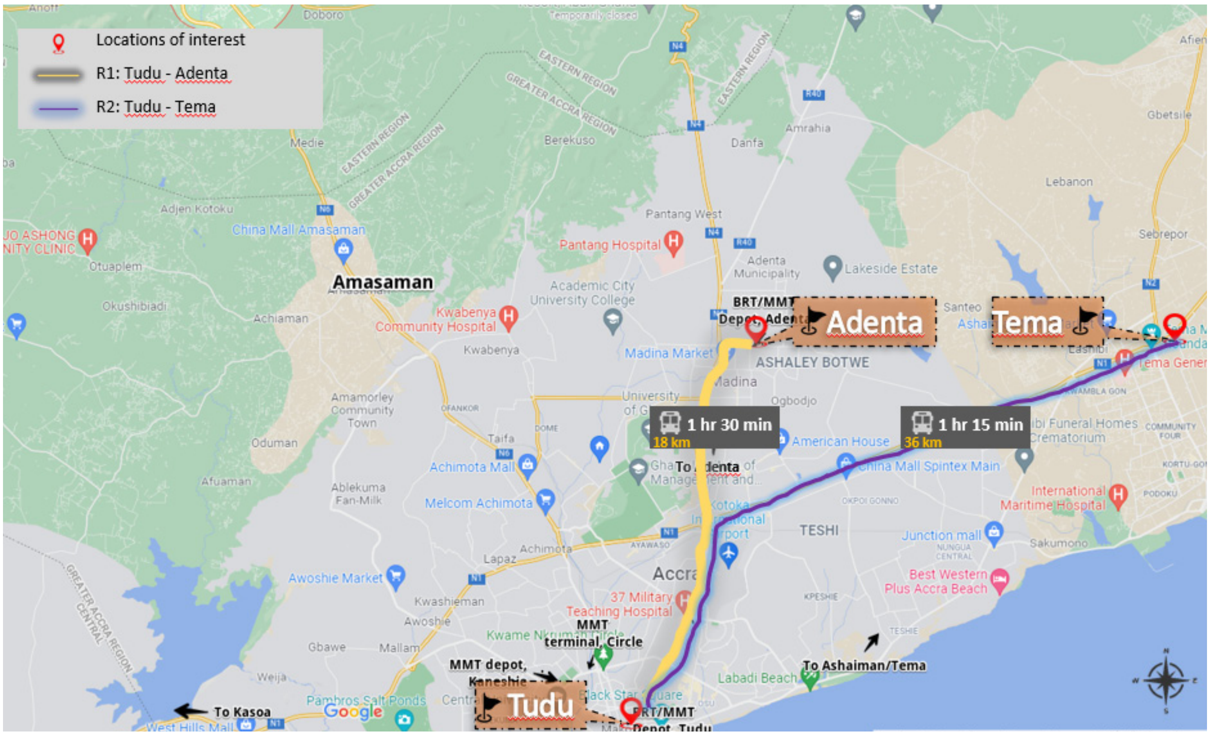


Figure 17 Selected Intracity Routes for electrification

Figure 17 shows the two selected routes based on the below characteristics:

1) High daily run, i.e., > 180 km/bus/day
2) High ridership (4,000-6,000 pphpd[12]), which would provide the operator with high revenues while also serving as a benchmark in terms of operational efficiency for scaling up operations on the remaining routes

4.1.2.1.2 Selected Route Profile: Intracity

Even though the Tudu-Adenta route is exactly half (18 km) of the Tudu-Tema route (36 km), the time taken is nearly equivalent because of the speed profiles of the routes. With Tudu-Adenta being a busier route than the Tudu-Tema route, it takes almost the same amount of time to traverse from one end to the other, and it can be visualized in Figure 18.

The altitude varies from 30m to 120m (calculated from the mean sea level) on both routes. The Tudu-Adenta route has higher grades involved in the onward journey as it moves away from the coast. In contrast, the Tudu-Tema route is like a small crest mid-way as it moves away from the coast, runs parallel, and then again returns towards the coastline in the onward journey, which can be visualized in Figure 19.

12 PPHPD: Passenger peak hour per direction

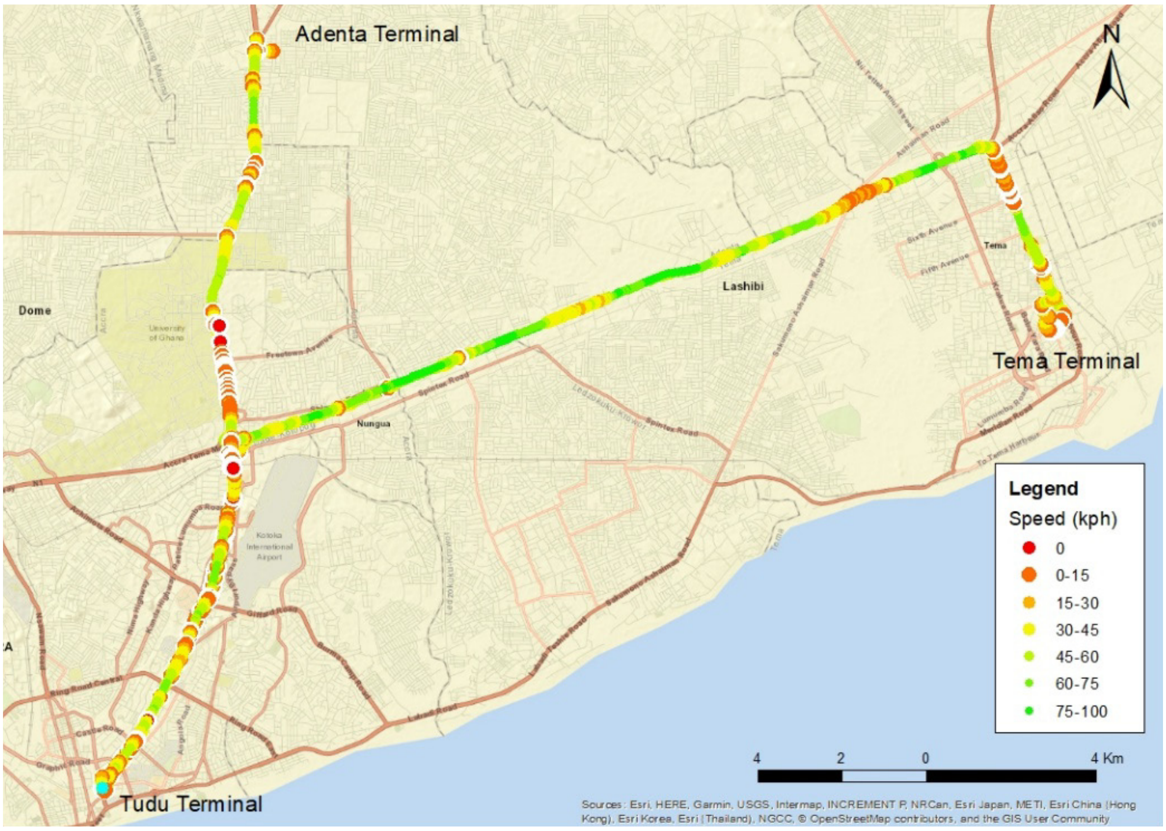


Figure 18 Speed Profiles of the Selected Routes

Figure 19 Altitude Profiles of the Selected Routes

4.1.2.2 Existing Routes: Intercity

For assessing the feasibility of an intercity route, the route from Accra to Kumasi was proposed by the client for electrification. The route starts from Accra's CBD to Abrepo Junction at Kumasi and has two mid-way stops at 95 km from Accra, i.e., Linda Dor Rest Stop, Bunso Junction, and one around 15 km from Bunso Junction, namely, Joffel Catering Services Rest stop, Anyinam. These rest stops are used as refreshment facilities by the passengers while plying on a longer route, as shown in Figure 20.

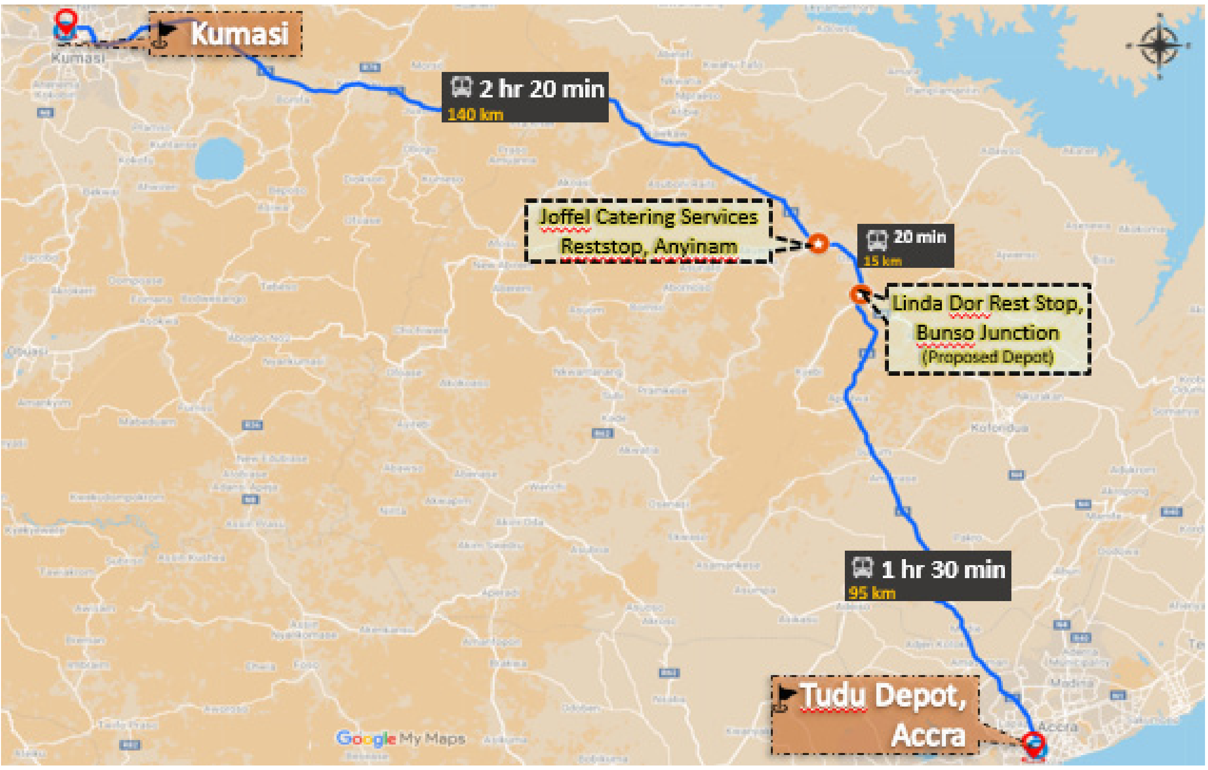


Figure 20 Selected Intercity Route for electrification

The intercity route is an NH, so the speeds on the route are majorly around 60-75 kmph, except in the city centres. However, Kumasi lies on hilly terrain, and Accra, being a coastal city, the route is more gradient-intensive onward. Hence, it is critical to consider the route's gradient when planning for a better and uninterrupted service to the passengers. The speed[13] and the altitude profiles of the route can be visualized in Figure 21 and Figure 22, respectively.

13 The diesel bus's top speed is measured at 120 kmph. As of now, no e-Bus comes in this range. Therefore, energy consumption calculations are applied to the top speed of a representative e-Bus model and battery with a top speed of 70 kmph. Henceforth, energy consumption with a speed limit is lower than without a speed limit, which is the existing preference of the driver. Hence, this will be further studied to know the best model for e-Bus in Ghana.

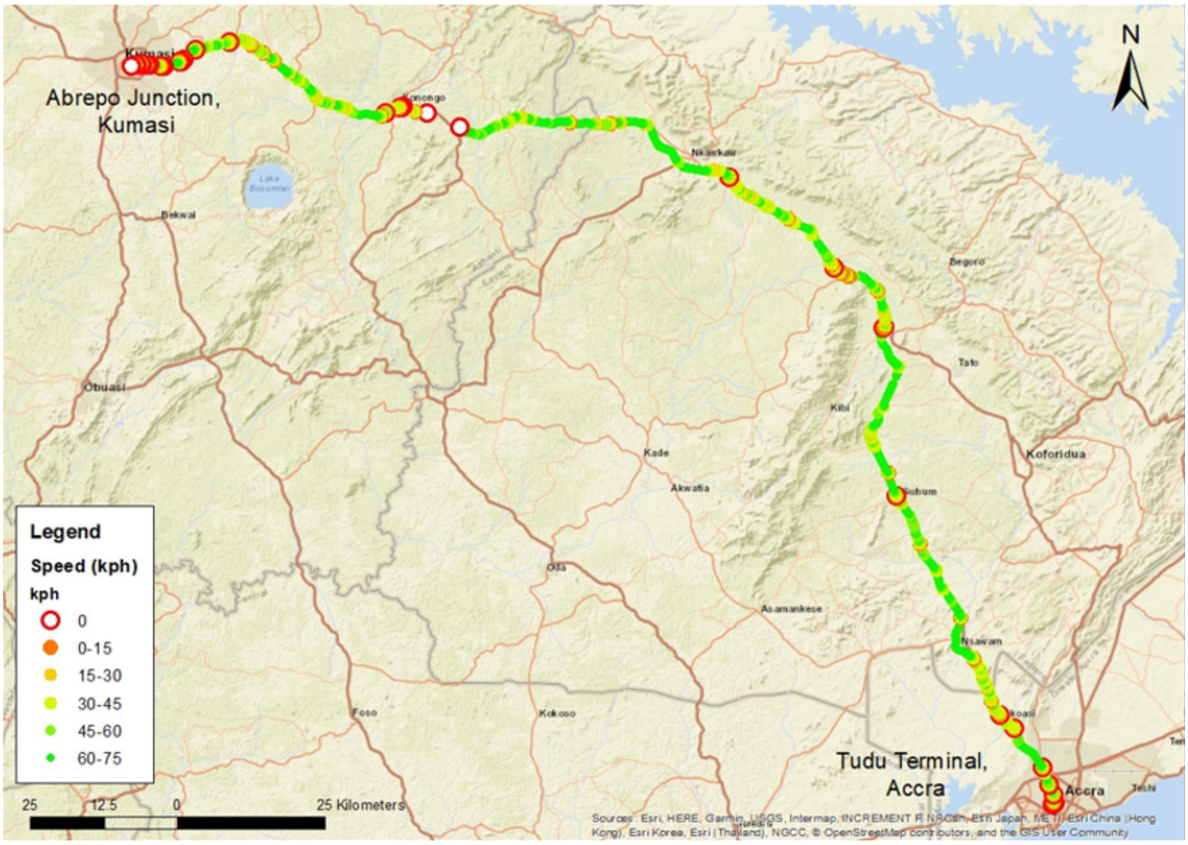


Figure 21 Speed Profile of the Accra-Kumasi-Accra Route

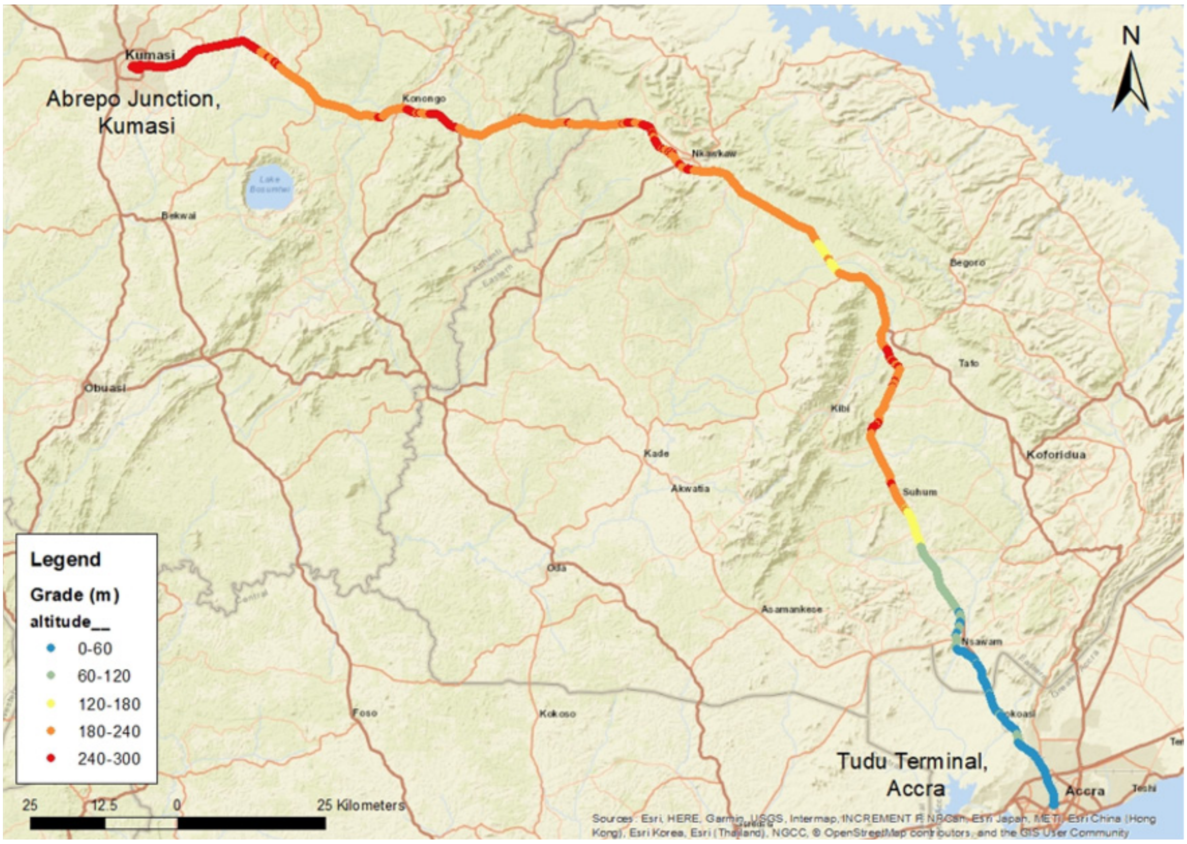


Figure 22 Altitude Profile of the Accra-Kumasi-Accra Route

4.2 Depot Selection

4.2.1 Consideration

The following criteria represent the consultant's primary considerations for determining the ideal depot/(s) and were determined through data collection and stakeholder interactions.

- The depot should be owned by MMTL.
- There should be enough capacity to cater to the buses.
- Fewer dead kilometres to the Origin-Destination (OD) terminal.
- The depot should be able to accommodate the maintenance facility for the e-Buses along with the charging infrastructure.
- The availability of a nearby grid is a must.
- Since Accra is a low-lying area, depots with flooding issues need to be discarded.

4.2.2 Methodology

The depot selection methodology is summarized in Figure 23.

Figure 23 Depot Selection Methodology

4.2.2.1 Depots for the Selected Routes: Intracity

The existing depots for the Tudu-Adenta route are located at the Tudu Terminal, Circle and at Kinbu for the Tudu-Tema route. However, since both the depots are about one kilometre apart, Tudu is proposed as a common depot for both routes.

During the primary surveys, it has been observed that during the morning peak, people move from the sub-urban areas towards the CBD (Tudu) for their HBW (Home-Based-Work) trips and return from the CBD in the evening peak. Thus, the sub-urban ends of both routes are proposed as depots for overnight parking and charging, as shown in Figure 24. The depot profiles are summarized in Table 8.

4.2.2.2 Depots for the Selected Routes: Intercity

The intercity route originates from the MMTL Loading Terminal, Circle at Accra and ends at the MMTL main depot, Abrepo Junction at Kumasi, with a rest stop mid-way at Linda Dor Rest Stop, Bunso Junction. The rest stop for the return journey is the Joffel Catering Services Rest stop at Anyinam. However, in Accra, the existing depot is about 3.64 km from the loading terminal, i.e., the Tudu Depot, as shown in Figure 25.

The ICE buses make empty trips from the Tudu Depot to the Loading Terminal. Dead kilometres should be avoided since battery energy consumption is an important consideration. Thus, Kaneshie was initially considered as the depot for the Loading Terminal Circle but was discarded because, even though MMTL owns it with a holding capacity of 120 buses, it faces a severe flash flooding issue, as confirmed by the consultants and stakeholders. The water pools during peak times, generally once a year for the last five years, at the height of two feet off the ground, which can cause severe damage to the charging infrastructure as well as the e-Buses. However, the Tudu depot, being central to all the operations, is proposed as the main depot as well as the OD terminal.

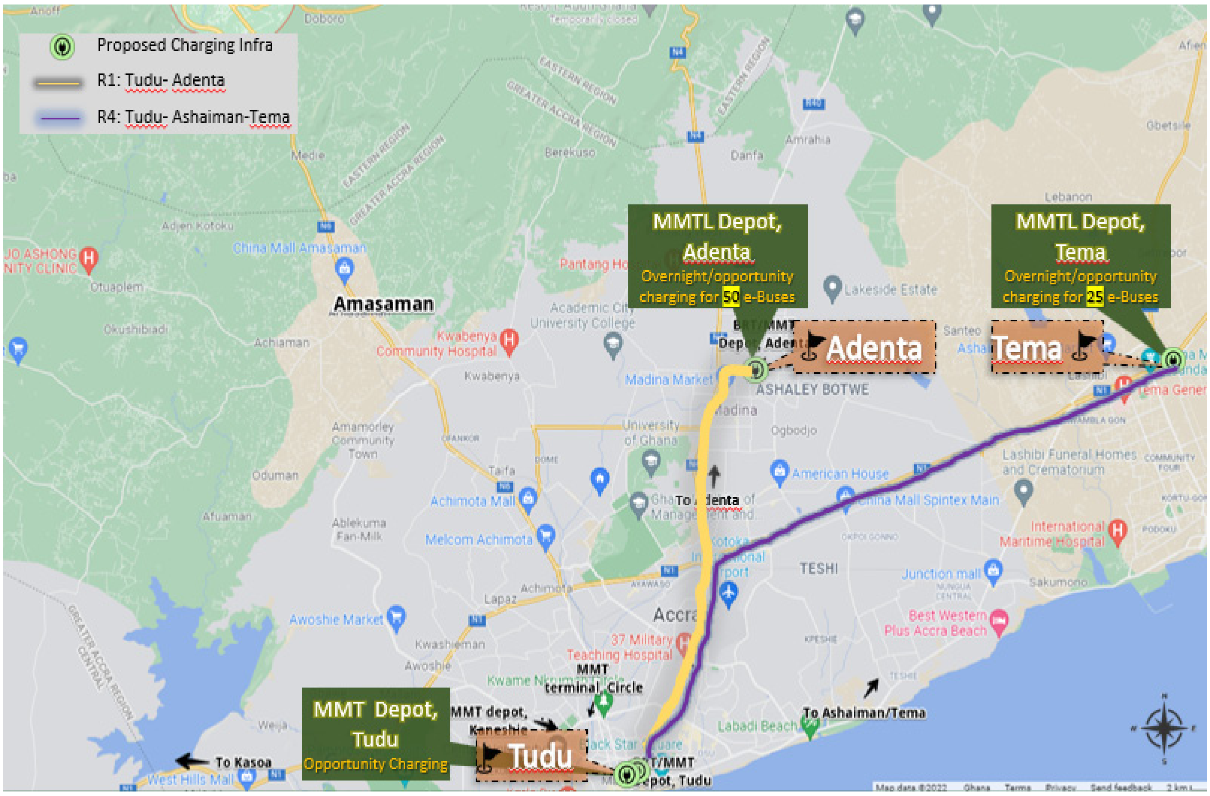


Figure 24 Depots for the Intracity Route

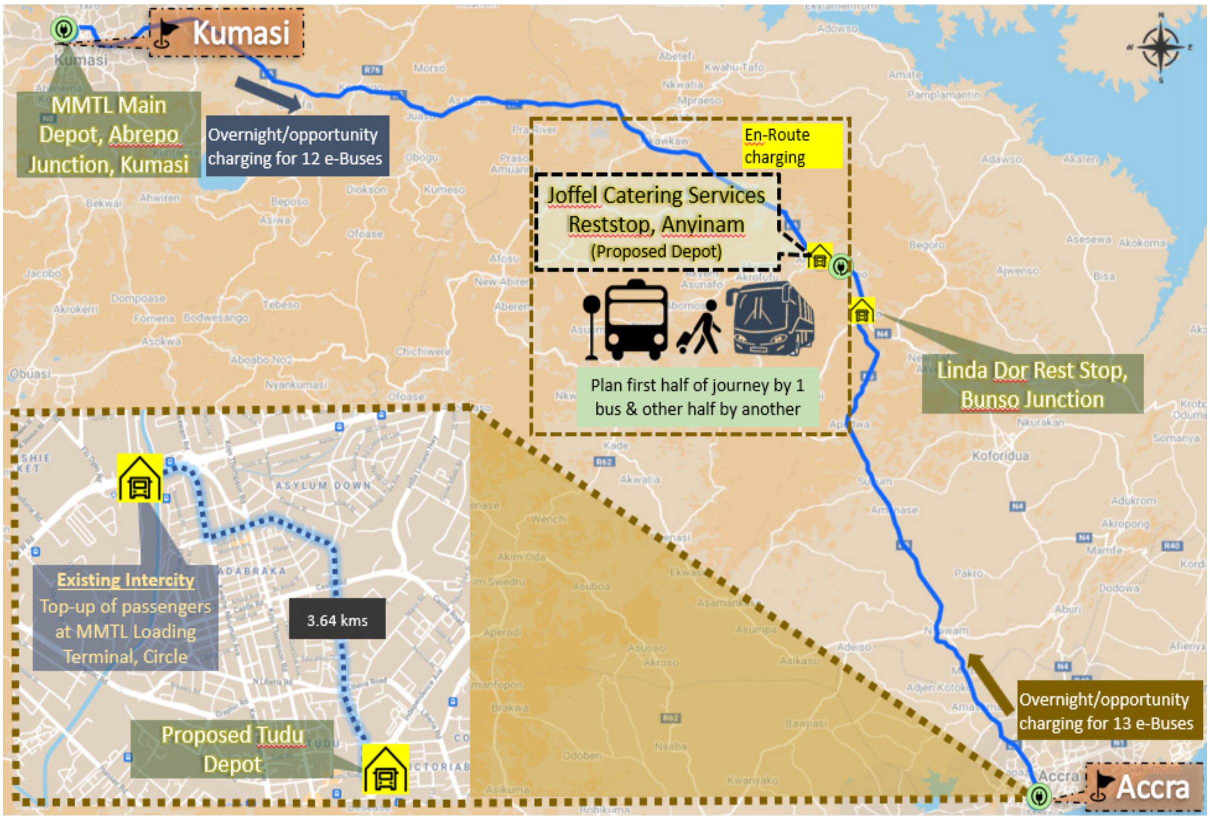


Figure 25 Depots for the Intercity Route

Table 8 Selected Depot Profiles for the Intracity Route

Depot	Ownership	Parking Spaces	Proposed Parking and Charging
Tudu Depot	MMTL	NA	CBD, to be used for opportunity charging/ top-up station
Adenta Depot	MMTL	50	Overnight/opportunity charging
Tema Depot	MMTL	25	Overnight/opportunity charging

The intercity route is longer and more grade-intensive; hence, a trip by a single e-Bus cannot be managed. So, the intermediate rest stop is proposed as a depot to cater to non-stop quality services for the passengers. As explained in the subsequent chapter, the technical analysis reveals that the mid-point of the journey is not the mid-point of energy consumption. Hence, considering Linda Dor as the intermediate depot or terminal does not serve the purpose. Thus, the Joffel Catering Services Rest stop at Anyinam is proposed as the intermediate depot, which is about 110 km from the Tudu Depot.

The depot profiles are summarized in Table 9.

Table 9 Selected Depot Profiles for the Intercity Route

Depot	Ownership	Parking Spaces	Proposed Parking and Charging
Tudu Depot, Accra	MMTL	25	Overnight/opportunity charging
Abrepo Junction, Kumasi	MMTL	50	Overnight/opportunity charging
Joffel Catering Services Rest stop, Anyinam	Private	10	En-route depot charging.

The profile of the selected routes, along with the proposed depots and the operational plan, has been summed up in Table 10.

Selected route and depot have been taken further for technical assessment for e-Bus feasibility.

Table 10 Profile of the selected routes along with the proposed depots and the operational plan

Attributes	Tudu-Adenta	Tudu-Tema	Accra-Kumasi
Type of Route	Intracity	Intracity	Intercity
Total Distance (km)	18	36	250
Total Time taken (hh:mm)	01:30	01:15	05:30
Existing Depot	MMTL Main Terminal, Circle; MMTL Depot Adenta	Kinbu; Tema	Kaneshie Depot, Tudu; Abrepo Junction, Kumasi
Proposed Depot	MMTL Depot, Tudu; MMTL Depot Adenta	MMTL Depot, Tudu; MMTL Depot, Tema	MMTL Depot, Tudu; Joffel Catering Reststop (midway) Abrepo Junction, Kumasi

5. Technical Assessment for e-Bus feasibility

Researchers have approached e-Bus planning from several dimensions. The broader aim is to ascertain the Total Cost of Ownership (TCO)[14] of an e-Bus vis-à-vis a conventional bus. This chapter presents a feasibility analysis of operating e-Buses on the finalized routes.

After routes and depots are identified for e-Bus operation, as discussed in Chapter 4: e-Bus Routes and Depot Selection , the use of energy modelling to realistically determine the e-Bus efficiency based on local conditions and duty cycles was undertaken. For this, vehicle models were developed in Scilab and XCOS for buses representing respective segments to simulate the duty cycles[15] and estimate real-world energy consumption under different conditions (AC, passenger profile, etc.).

The following outputs are confirmed from energy modelling using real-world duty cycles, which are used as input for battery sizing, fleet charging scheduling, and TCO (as shown in Figure 26).

1. Energy consumption and battery sizing[16]	2. Charging frequency and time required for charging
3. Motor Size and Cost	4. Other energy demands, like air conditioning, etc.
5. Charger Size & Cost	6. Total Energy & Power Demand

Lastly, multiple scenarios are generated for meeting e-Bus operational requirements using results from energy modelling, charging scheduling, e-Bus fleet schedules, etc. The detailed methodology is explained in Figure 26.

14 The term "Total Cost of Ownership" (TCO) was coined by Ellram in 1995 to understand the actual cost of buying a good from a supplier29; it is a combination of different costs.

15 The duty cycles were created from real-life measured data from the ICE bus. The GPS data acquired during these runs was used to create respective duty-cycles comprising of bus speed vs. time and road gradient vs distance.

16 Based on the battery energy consumption estimated through simulations, the bus's real-world range has been estimated.

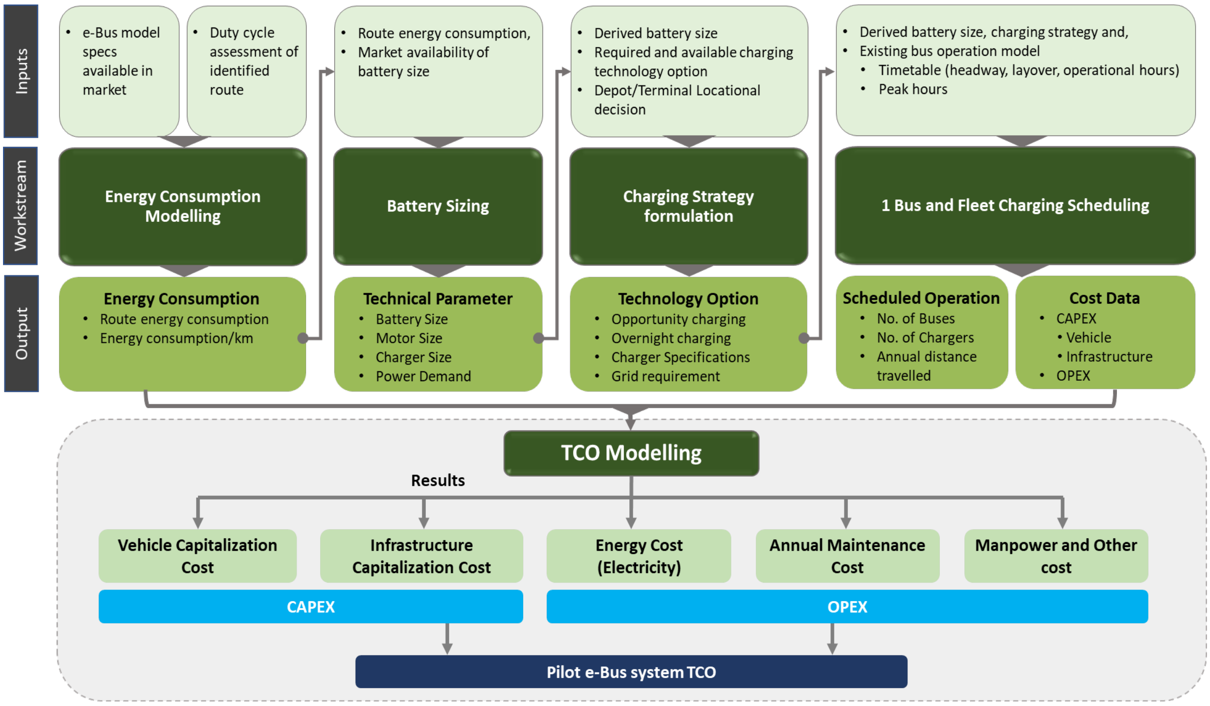


Figure 26 Detailed Methodology for Techno-Commercial feasibility of e-Buses

Route Energy consumption modelling:

The performance of e-Buses depends on terrain, environmental conditions, driving patterns, and other factors, as shown in Table 11. It is important to understand their impact on energy consumption and the mileage of e-Buses. The duty cycle has an important impact on the performance of all buses. For example, heavy traffic forces buses to stop and go very often. As a large quantity of energy is required to overcome inertia, this type of duty cycle (low speed, many stops) causes the fuel consumption of diesel buses to increase significantly. On the other hand, e-Buses are equipped with a kinetic energy recovery system that regenerates energy from braking. The efficiency of such systems can result in extending the range of batteries. Therefore, e-Buses are much less affected by a similar duty cycle.

Table 11 Considerations for Energy Modeling

Acceleration-deceleration	Peak current is drawn from the battery and fuel requirements
Gradient requirements	Energy requirements to climb the grade and downward gradient will determine the possible regeneration
Passenger loading	Energy distribution over the route
Operating schedules	Trips, time, interval, layover, headways etc.

Battery Sizing:

The design of the required battery capacity to cover average daily operations is critical and needs to take into account the following factors:

- Average energy and electricity consumption of e-Bus, including AC
- Maximum daily distance driven

- **Depth of discharge (DoD) and useful capacity:** A battery's depth of discharge (DoD) indicates the percentage of the battery that has been discharged relative to its overall capacity. In most battery technologies, such as lead-acid and AGM batteries, there is a correlation between the depth of discharge and the cycle life[17] of the battery. From industry experience, a DoD of 85% has been provided for deriving battery size.
- **Reserve ratio:** Buses cannot be driven until their batteries are empty, as buses might get stranded. Also, batteries might get a reduced life span if used until 0% state of charge (SOC). The precision of the SOC indicator is not very high, with many suppliers only ensuring a 10% precision level, which might be less if batteries are low. A 20% reserve ratio is considered a minimum, as below 20%, the bus performance is severely constrained to protect the battery from overheating.[18]
- **Ageing factor:** The useful battery capacity gradually drops over charge-discharge cycles accumulated over the period of usage, which has been considered (80% acceptable residual capacity) while sizing the battery and/or scheduling the charging.

Charging strategy and infrastructure planning:

Chargers are important elements of the e-Bus system. Therefore, it is imperative to establish an adequate, robust, and safe charging infrastructure. Details of charging Infrastructure guidelines is given in Chapter 8: City Charging Infrastructure Guideline. It could be further optimized based on the operational requirements and energy consumption modelling for the selected e-Bus route.

Fleet scheduling:

The e-Bus schedule plan will operate with some changes to the existing diesel bus service plans. This will be done by trying to achieve the same service headway by service tier and by route (i.e., minutes between successive arrivals, expressed in terms of frequency or trips per hour) and the span of service (i.e., operating hours by route tier and by route). The e-Bus service scheme differs from the diesel scheme in terms of the fleet size requirement as e-Buses face range limitations and requires charging times. Therefore, Fleet scheduling is an important part of e-Bus planning, and it involves a process of chaining scheduled trips (timetable trips) to cover all of them by the least number of chains (buses). Often chains so formed are called line blocks or bus schedules.

The electric fleet size requirement is, therefore, based on:

i) total number of vehicles that must be deployed, while considering range limitations, to serve the maximum passenger load per day, and
ii) set of spare vehicles for contingency (in case of higher-than-expected demand, in-field breakdowns, or other unforeseen circumstances that may either remove a bus from the operation or require additional buses to be deployed).

Given that e-Buses are range-constrained, an EV scheme requires more vehicles. This may lead to overcrowding at the depots and would also require changing the depot assignments of some routes.

5.1 e-Bus Type and Fleet Size for First Deployment

Based on consultation with the local experts' team and interactions with different government stakeholders (Metro Mass Transit Limited (MMTL) and Ministry of Transport), stakeholders agreed to procure 100 e-Buses. Out of these, 75 e-Buses are allocated for intracity operations, and 25 e-Buses are for intercity operations, as represented in Figure 27.

17 Cyclic life is the number of charge and discharge cycles a battery can sustain in its useful life and depends on how much of the battery's capacity is normally used.
18 Most Chinese operators apply a reserve ratio of 20-30%, i.e., drivers must re-charge buses if the SOC falls below these values;

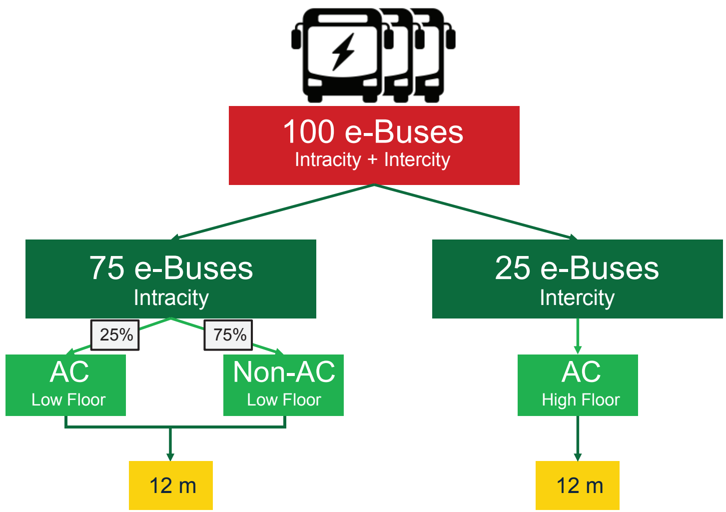


Figure 27 Fleet size for the first deployment

- **Intracity e-Buses:** Based on stakeholder consultation, 75 low-floor e-Buses have been selected for Intracity operation. The major reasons are as follows:
  - Passengers are already experiencing low-floor buses in their existing diesel bus operations
  - Ensure passenger comfort

  AC Buses: Out of these 75 e-Buses, 25% of the buses are agreed to be non-AC buses which are to be used for express service, i.e., those that stop at major bus stops only.

  Non-AC Buses: Out of these 75 e-Buses, 75% of the buses are agreed to be non-AC buses which are to be used for non-express service, i.e., those that stop at every bus stop.

- **Intercity e-Buses:** Based on stakeholder consultation, 25 high-floor air-conditioner (AC) e-Buses have been selected for intercity operation. The major reason is as follows:
  - Passengers are already experiencing high-floor buses in their existing diesel bus operations
  - Lighter in weight
  - Allows better luggage packaging and comfort for intercity-long-distance travel
  - Allows better battery packaging than low-floor e-Buses
  - Allows better operational efficiency and after-sale support.

5.2 Intracity Operation

5.2.1 Route Energy Consumption Modelling

This section presents the duty cycle profile and energy consumption assessment of the finalized routes for e-Bus deployment. Duty cycle and passenger loading data for the Adenta-Tudu-Adenta Route were collected in existing ICE buses during peak hours in December, whereas it was collected on Tro-Tro buses in March for the Tema-Tudu-Tema Route. During the inspection, it was discovered that the Tudu-Tema bus operations had been temporarily halted due to an ongoing challenge, and no MMTL buses are currently operating on this route. The MMTL Director informed us that the buses do not have GPS, so we cannot obtain secondary data from previous trips. Due to these circumstances, the duty cycle data on Tro-Tros were collected.

The observed duty cycle had the highest speed of 120km/hr, but since the e-Buses come in a range of a maximum of 75km/hr, thus, the duty cycles were adjusted accordingly. The processed duty cycles were then provided as inputs together with the reference e-Bus model specifications to assess the route energy consumption in each direction.

Route energy for a duty cycle (which represents the route speed cycle, passenger loading profile, and a particular road gradient profile) has been calculated for which the reference bus model used is the BYD K9[19] 12 m e-Bus with a 324 kWh battery capacity.

5.2.1.1 Adenta-Tudu-Adenta e-Bus route

The route was assessed in each direction, i.e., from 1) Tudu to Adenta and 2) Adenta to Tudu. Table 12 represents the route characteristics-

Table 12 Route Characteristics of Onward and Return Journey

Parameters		Tudu to Adenta	Adenta to Tudu
Max speed	kmph	71	72.3
Average speed	kmph	11	13.5
Start Stops/km	#	0.611	0.44
Distance	km	18	18
Duration	hh:mm	01:30	01:30
Max Grade	%	-8.0% to 6%	
Average Grade	%	-1.85% to 1.44%	
Max Passengers	#	35	36
Average Passengers	#	30	33

The data was collected during the AM peak (between 8:00-9:30) and the PM peak (between 15:00-17:30) periods. The duty cycle profile for the route in each direction is presented in Figure 28.

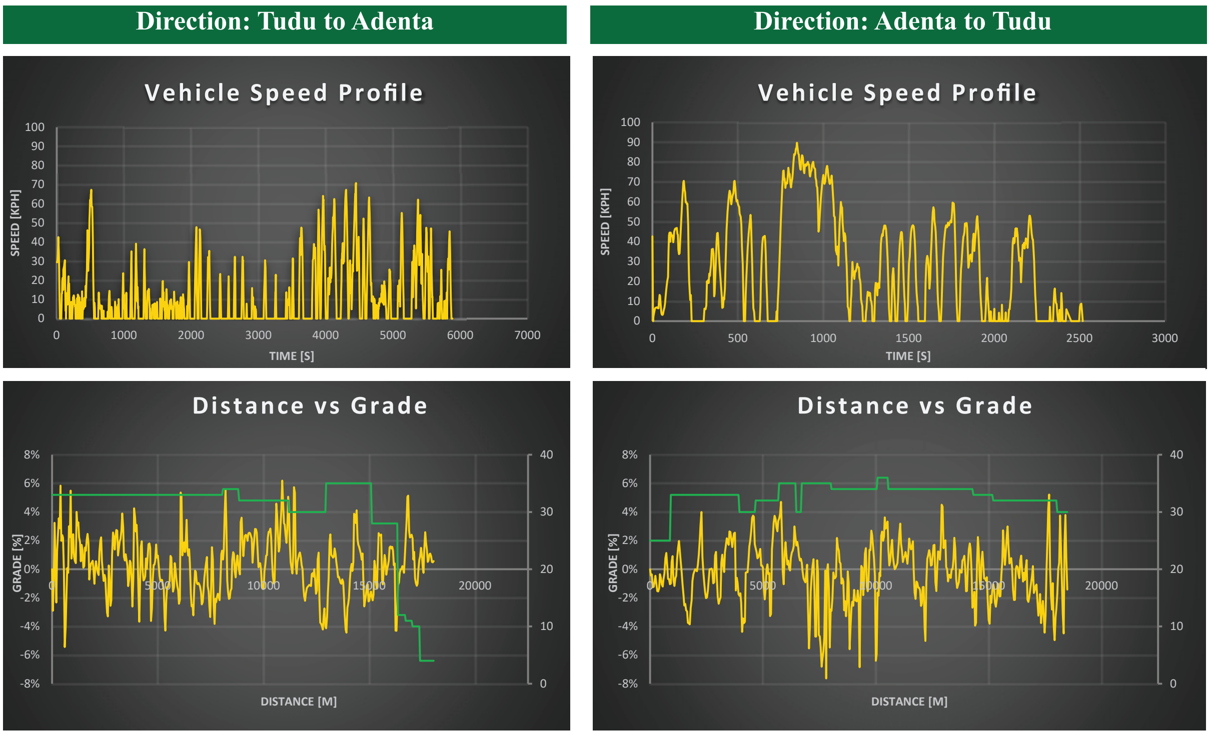


Figure 28 Duty cycle profile of Onward and Return Journey

19 e-Bus Model: BYD K9 12 m AC

Total Energy required for 1 round trip with AC: 103 kWh (46.01 kWh + 57 kWh) is shown in Figure 29.

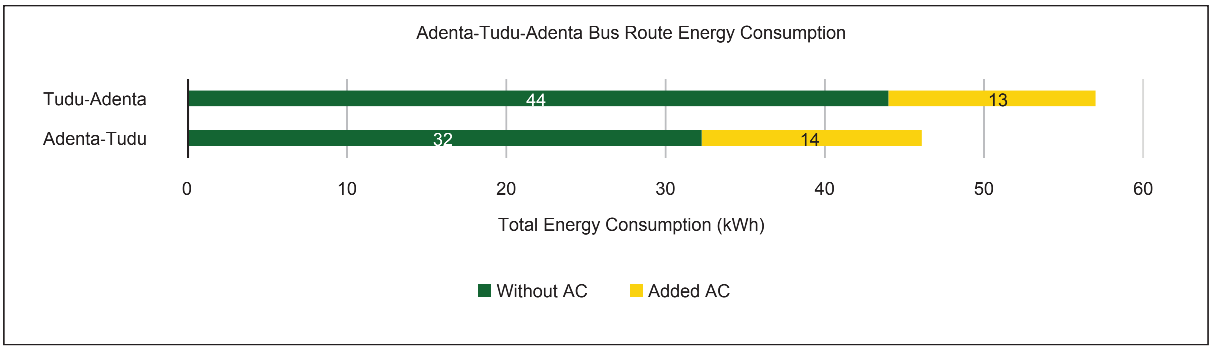


Figure 29 Route energy consumption

Energy Consumption per km (kWh/km)	Tudu to Adenta	Adenta to Tudu
Without AC	2.44	1.79
With AC	3.16 (30% ↑)	2.56 (43% ↑)

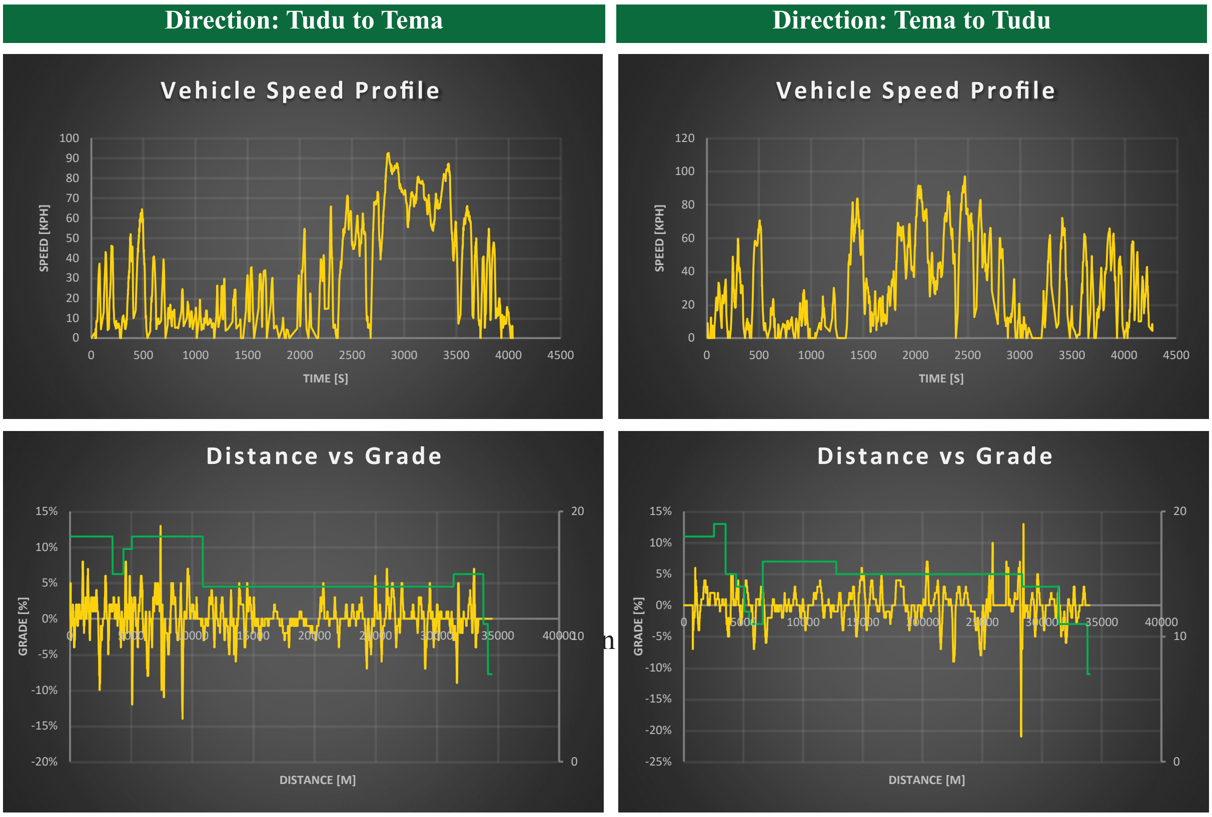
5.2.1.2 Tema-Tudu-Tema e-Bus route

The route was assessed in each direction, i.e., from 1) Tudu to Tema and 2) Tema to Tudu. Table 13 represents the route characteristics.

The duty cycle profile for the route in each direction is presented in Figure 30.

Table 13 Route Characteristics of Onward and Return Journey

Parameters		Tudu to Tema	Tema to Tudu
Max speed	kmph	92	97
Average speed	kmph	40	36.4
Start Stops/km	#	0.444	0.444
Distance	km	36	36
Duration	hh:mm	01:15	01:15
Max Grade	%	-21% to 13%	
Average Grade	%	-4.96% to 7.57%	
Max Passengers	#	18	19
Average Passengers	#	15	14



Total Energy required for 1 round trip with AC: 152 kWh (72 kWh + 80 kWh) is shown in Figure 31.

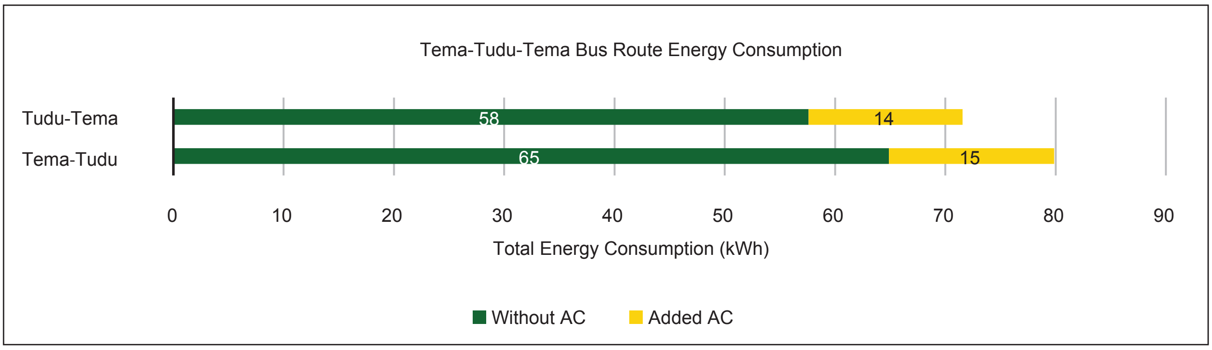


Figure 31 Route energy consumption

Energy Consumption per km (kWh/km)	Tudu to Tema	Tema to Tudu
Without AC	1.69	1.91
With AC	2.11 (24% ↑)	2.35 (23% ↑)

The modelled total energy consumption for the Adenta-Tudu-Adenta bus route 1 round trip journey with AC is estimated to be about 103 kWh. The same for Tema-Tudu-Tema routes is 152 kWh. The detailed summary is presented in Table 14. It can be observed that there is a significant difference in the energy consumption of the routes because Tudu is a lower-lying area along the coast, as compared to Tema and Adenta lies at the highest point of all three. Whenever the e-bus travels on the onward journey, i.e., Adenta-Tudu and Tema-Tudu, the grades are downwards and hence, along with the help of gravitational force, the motor power used is less. Hence, energy consumption is low and vice-versa.

Table 14 Modelled route energy consumption

Routes	Onward Direction		Return Direction		Total 1 round trip route energy consumption (kWh)
	Length (km)	With AC (kWh)	Length (km)	With AC (kWh)	
Adenta-Tudu-Adenta	18	46.01	18	57	103
Tema-Tudu-Tema	36	72	36	80	152

5.2.2 Battery Sizing and Design

5.2.2.1 SOC assessment

5.2.2.1.1 Adenta-Tudu-Adenta Bus route

The energy consumed for 1 round trip in the Adenta-Tudu-Adenta route is assessed with the battery design considerations of DOD, reserve ratio and ageing factor for market available battery packs. The minimum required energy for 1 round trip is estimated to be 103 kWh, considering 85% DoD and 20% capacity fade due to ageing. The SOC assessment has been done for two available models with battery packs of 250 kWh (Tata Ultra) and 324[20] kWh (BYD K9), as shown in Figure 32.

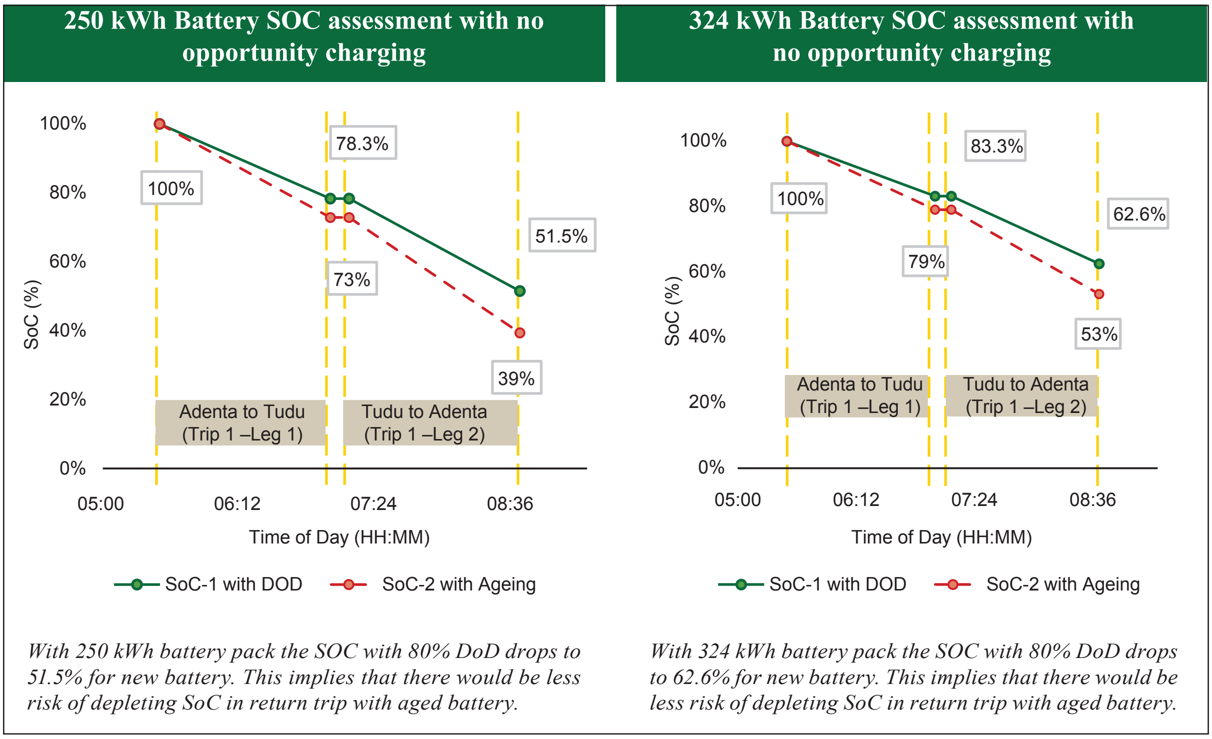


Figure 32 Battery SOC assessment for Adenta-Tudu-Adenta e-Bus route

20 Model with 250 kWh battery (Tata 12 m) has also been analyzed and found inadequate

5.2.2.1.2 Tema-Tudu-Tema Bus route

Similarly, SOC assessment has been done for Tema-Tudu-Tema route as shown in Figure 33.

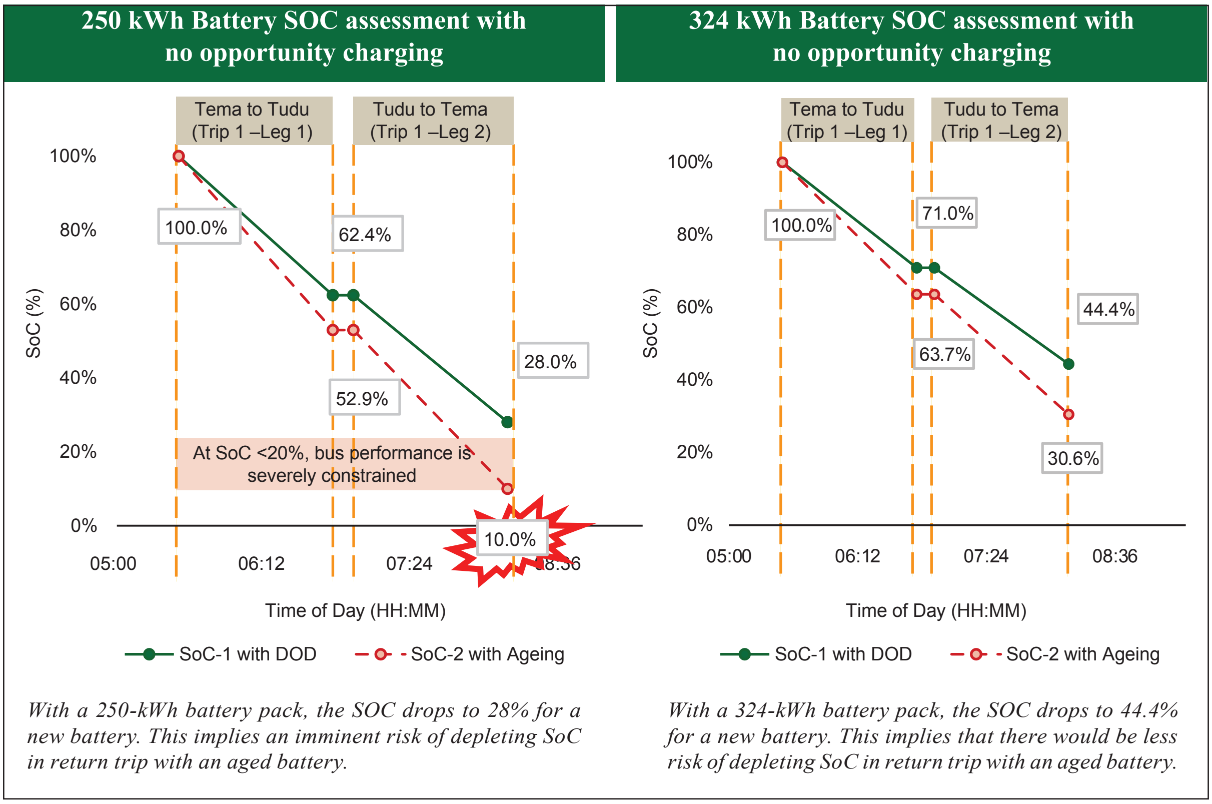


Figure 33 Battery SOC assessment for Tema-Tudu-Tema e-Bus route

The 422 kWh battery packs are further assessed to check with the operational requirement, charging strategy and fleet scheduling for e-Buses.

Derived Battery Sizing:

Considering SOC assessment for both routes, a 250 kWh battery pack results in SOC exhaustion after 1 round trip in the Tudu-Tema route. Hence, to go forward with this battery pack, opportunity charging for a longer duration will be required between the round trip, so it is not recommended. The **324 kWh** battery packs are further assessed to check with the operational requirement, charging strategy and fleet scheduling for e-Buses.

5.2.3 Operational Model and Service Requirements

Based on the operational service requirements, such as the daily number of operational hours and daily kilometres travelled, headways are adopted for the feasibility assessment of e-Bus. The operational requirements are based on the existing ICE bus system operations on the selected route, as shown in Table 15.

Table 15 e-Bus operational characteristics (based on existing ICE bus operations)

Parameter	Unit	Adenta-Tudu-Adenta Bus route	Tema-Tudu-Tema Bus route
Daily round trips/bus	No.	3	3
Daily run for 3 round trips/bus	km	108 (1 round trip: 18 + 18 = 36 km)	216 (1 round trip: 36 + 36 = 72 km)
Daily number of operational hours	hour	16 (5:30 am – 9:30 pm)	16 (5:30 am – 9:30 pm)
Average one-way travel time/ trip/bus	hour	~1:30	~1:15
Headway for fleet	min	Peak hour: 5 min Off-Peak hour: 10 min	Peak hour: 10 min Off-Peak hour: 15 min

5.2.4 Charging Strategy and Infrastructure Planning

Based on guiding considerations presented in Chapter 2 (Introduction), Section 2.4 (Methodology), the charging schedule and strategy are assessed for one e-Bus daily operation. Optimized charging technology has been selected for the Adenta-Tudu-Adenta and Tema-Tudu-Tema e-Bus routes based on the operational requirement and energy consumption.

5.2.4.1 Nomenclature

In Figure 34-Figure 37, the orange colour represents the onward journeys, whereas the return journeys are marked in blue. The Grey colour indicates the layover time. The green patterns indicate the opportunity charging, the dark green pattern represents overnight charging, while the idle time is indicated in the light blue colour. The reference lines drawn vertically indicate the SoC in percentage for each of the stages. The same colour coding has been depicted for the rest of the scenarios.

5.2.4.2 Adenta-Tudu-Adenta e-Bus route

Alternative scenarios are developed for e-Bus operation on the Adenta-Tudu-Adenta route with 324 kWh of reference battery. Two scenarios are modelled for this route. The first scenario considers overnight and opportunity charging at Adenta depot only, as shown in Figure 34. The second scenario considers overnight charging at Adenta depot and opportunity charging at Tudu depot, as shown in Figure 35. The schedule for both scenarios is taken with a peak hour headway of 5 minutes and off-Peak hour headway of 10 minutes.

5.2.4.2.1 Scenario 1: Charging at Adenta Depot only

- DC Fast Charging (0.5 C-rate) at Adenta Depot after completing each round trip
- Battery of 324 kWh will last for ~7.5 years (Battery life cycle consumed/day: 1.1)

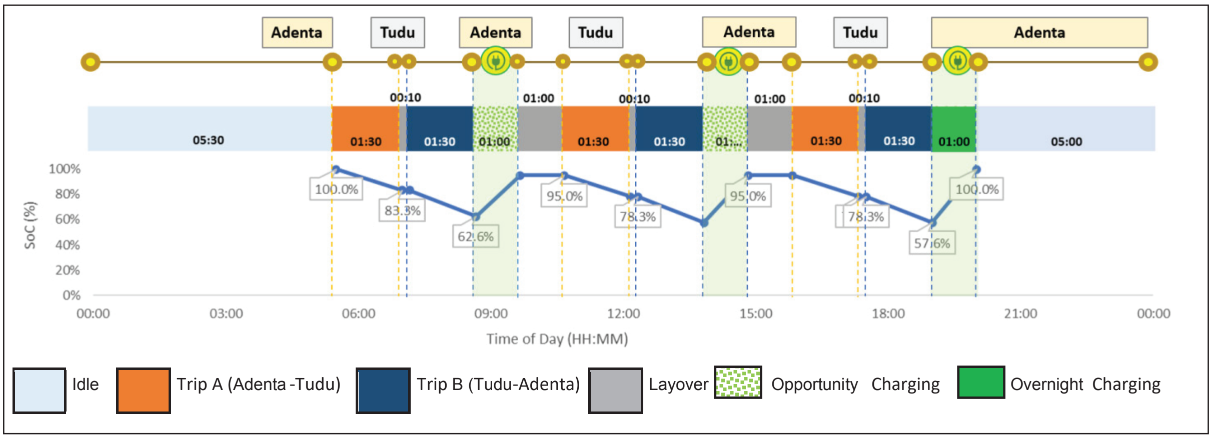


Figure 34 1-e-Bus Schedule with 324 kWh Battery for Scenario 1

5.2.4.2.2 Scenario 2: Opportunity Charging at Tudu Depot and Overnight Charging at Adenta Depot

- Opportunity charging (0.5 C-rate) required at Tudu Depot after completing 1st round trip and 1st leg of 2nd round trip.
- Overnight charging (0.5 C-rate) is required at Adenta Depot after completing 3 round trips.
- A battery of 324 kWh will last for ~7.5 years (Battery life cycle consumed/day: 1.1)

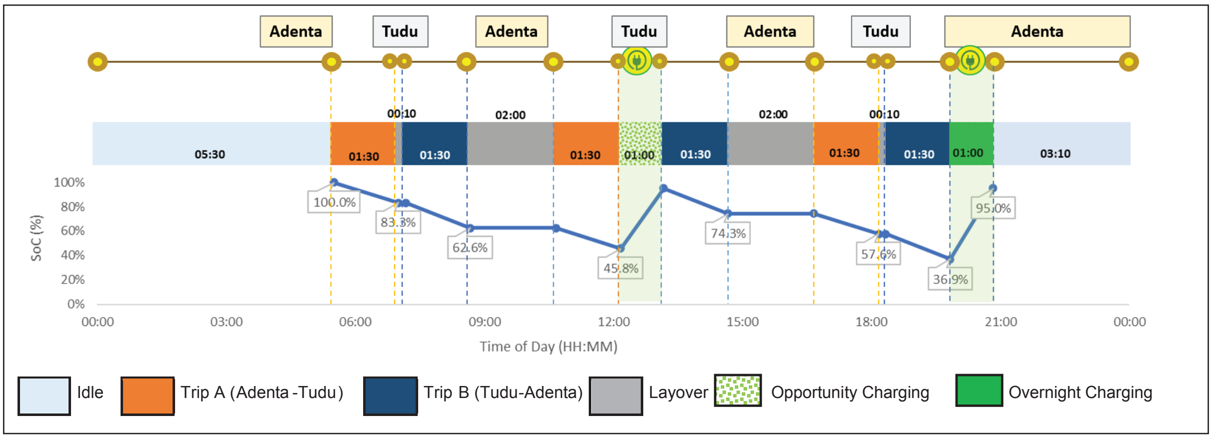


Figure 35 1-e-Bus Schedule with 324 kWh Battery for Scenario 2

5.2.4.3 Tema-Tudu-Tema e-Bus route

Alternative scenarios are developed for e-Bus operation on the Tema-Tudu-Tema route with 324 kWh of reference battery. One scenario, where we have modelled overnight and opportunity charging at Tema depot only as shown in Figure 34. In another scenario, we have modelled overnight charging at Tema depot and opportunity charging at Tudu depot, as shown in Figure 36. The schedule for both scenarios is taken with a peak hour headway of 10 minutes and off-Peak hour headway of 15 minutes.

5.2.4.3.1 Scenario 1: Charging at Tema Depot only

- DC Fast Charging (0.5 C-rate) at Tema Depot after completing each round trip
- Battery of 324 kWh will last for ~7.5 years (Battery life cycle consumed/day: 1.1)

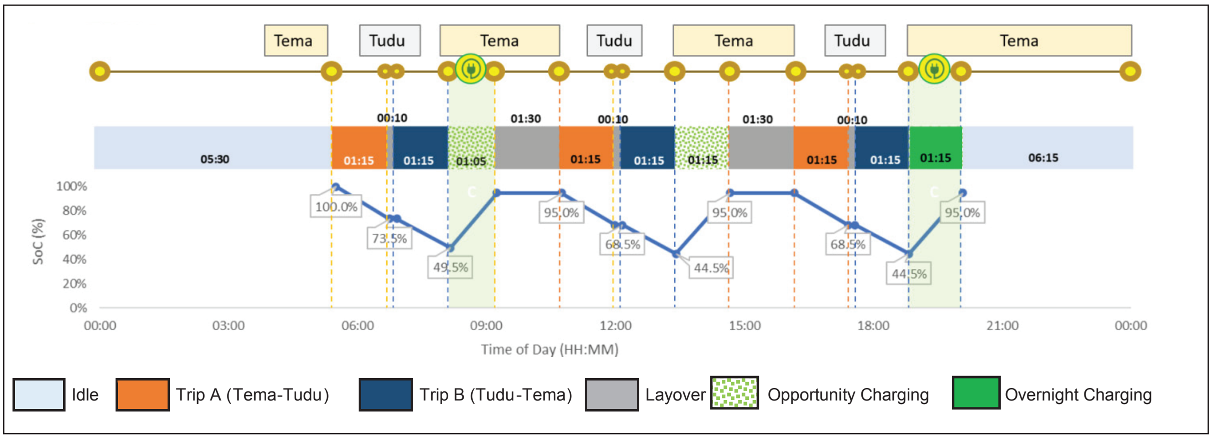


Figure 36 1-e-Bus Schedule with 324 kWh Battery for Scenario 1

5.2.4.3.2 Scenario 2: Opportunity Charging at Tudu Depot and Overnight Charging at Tema Depot

- Opportunity charging (0.5 C-rate) required at Tudu Depot after completing 1st round trip and 1st leg of 2nd round trip.
- Overnight charging (0.5 C-rate) is required at Tema Depot after completing 3 round trips.
- A battery of 324 kWh will last for ~7.5 years (Battery life cycle consumed/day: 1.1)

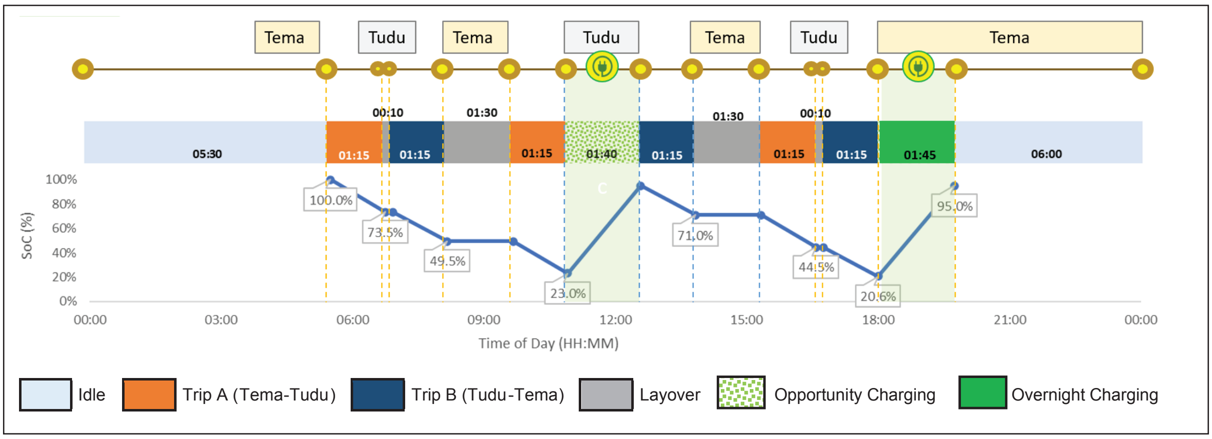


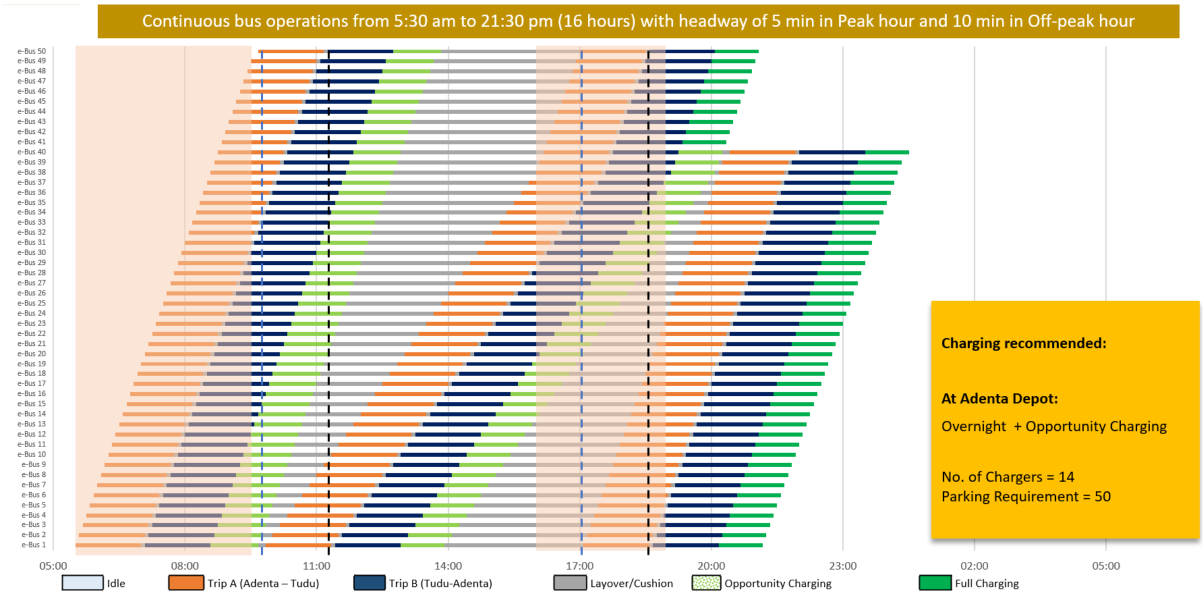
Figure 37 1-e-Bus Schedule with 324 kWh Battery for Scenario 2

5.2.5 Fleet Scheduling

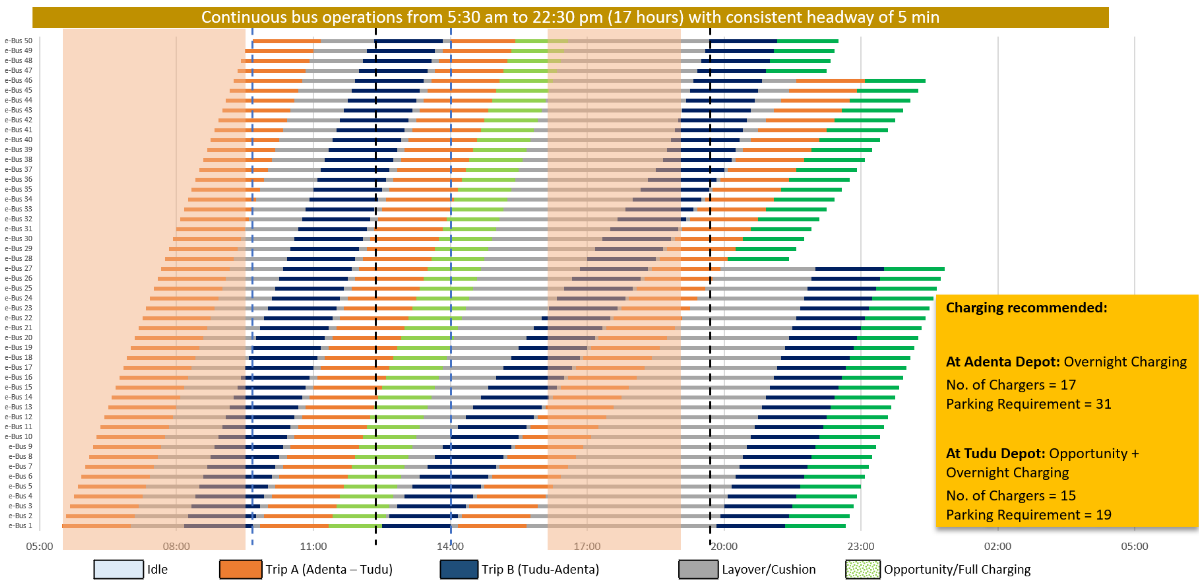
Based on these factors, the fleet size and schedule for e-Bus are estimated and are presented below. The planning of the electric vehicle schedule is done by the initializing schedule for one e-Bus. The schedule is then modelled with the operational requirements of headway and layover charging timings to estimate the required fleet size

5.2.5.1 *Adenta-Tudu-Adenta e-Bus route*

5.2.5.1.1 Scenario 1: Charging at Adenta Depot only



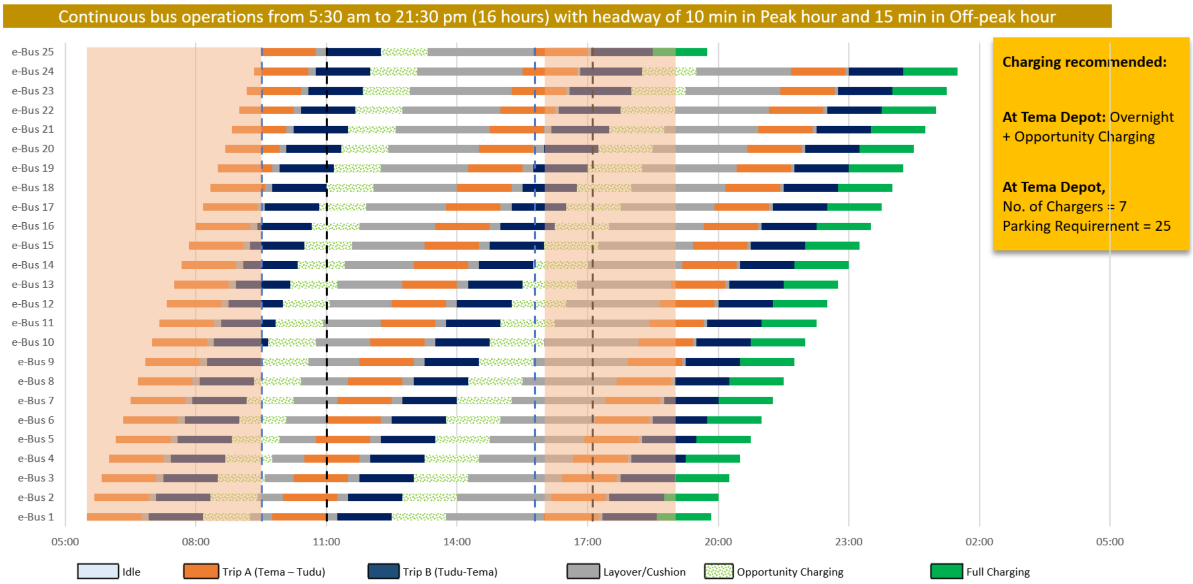
5.2.5.1.2 Scenario 2: Opportunity Charging at Tudu Depot and Overnight Charging at Adenta Depot



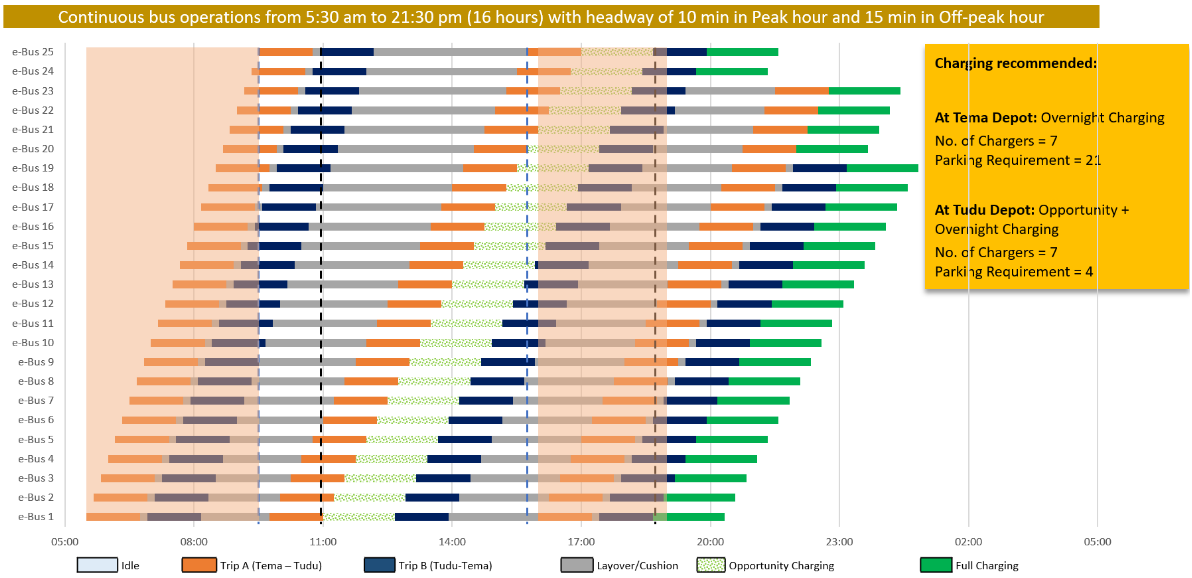
The same nomenclature mentioned in section 5.2.4.1 of the report is used in the images above. In addition to that, the orange vertical rectangular bars represent the morning and evening peak hours in the onward (Adenta-Tudu) and return (Tudu-Adenta) journeys, respectively, and the dotted lines represent that the buses represent are repeating the trips after a given time according to the headways.

5.2.5.2 Tema-Tudu-Tema e-Bus route

5.2.5.2.1 Scenario 1: Charging at Tema Depot only



5.2.5.2.2 Scenario 2: Opportunity Charging at Tudu Depot and Overnight Charging at Tema Depot



The same nomenclature mentioned in section 5.2.4.1 of the report is used in the images above. In addition to that, the orange vertical rectangular bars represent the morning and evening peak hours in the onward (Teema-Tudu) and return (Tudu-Tema) journeys, respectively, and the dotted lines represent that the buses are repeating the trips after a given time according to the headways.

5.2.6 Recommendation

5.2.6.1 Adenta-Tudu-Adenta e-Bus route

Item		Units	Scenario – 1	Scenario - 2
Headway		min	**Peak hour**: 5 min **Off-peak hour**: 10 min	**Peak hour**: 5 min **Off-peak hour**: 10 min
Energy Consumption per day (3 round trips/e-Bus)		kWh	309	
Daily Bus Utilization		km/bus/day	108	
Number of e-Buses (Fleet Size)		#	50 operational e-Buses + 5 reserved e-Buses = 55 e-Buses	
e-Bus Parking/Charging Requirement at Depot		#	**Adenta Depot**: 50 **Tudu Depot**: 0	**Adenta Depot**: 31 **Tudu Depot**: 19
Vehicle Specifications	Peak Motor Power	kW	500	
	Battery Pack	kWh	324	
Charging Infrastruc-ture	No. of Chargers	#	**Adenta Depot**: 14 **Tudu Depot**: 0	**Adenta Depot**: 17 **Tudu Depot**: 15
	Peak Power/day	Mega Watt/day	**Adenta Depot**: ~5.29 **Tudu Depot**: 0	**Adenta Depot**: ~ 6.42 **Tudu Depot:** ~ 5.67
	Charger Specs	kW (AC/DC)	240 kW DC Fast Charger (2 Gun)	
	Energy Demand	kWh/day	309 kWh/bus/day x 50 buses = 15,450 kWh/day	309 kWh/bus/day x 50 buses = 15,450 kWh/day

*Recommended sanctioned load at the site is calculated considering the No of chargers (excluding spare) * peak charger rating*1.05 (losses)*1.5 (sanctioned load). Energy demand at the site is the summation of energy at every site (total energy charged for one route) *1.05+ route 2+ r3+….).*

5.2.6.1.1 Pros and Cons of alternative scenarios

This section provides a comparative analysis of the scenarios, discussing each scenario's pros and cons based on the number of parameters listed and described in Table 16.

Table 16 Pros and Cons of Alternative scenarios

Considerations	Scenario 01: Charging at Adenta Depot only	Scenario 02: Opportunity Charging at Tudu Depot and Overnight Charging at Adenta Depot
Risk in terms of battery	• Managed in both scenarios- ample cushion taken for the duration of each activity • Opportunity charge after every 1 trip. Make sure battery SoC never drops below- 30%, even with an aged battery	
Cost	• **Less** (14 chargers required for 50 buses)	• **More** (32 chargers required for 50 buses)
Bus and Charging Utilization Rate[21]	• 40 buses have 57% uti-lization, 10 buses have 37.5% utilization. • Charger Utilization = 15%	• 27 buses have 57% utilization, 19 buses have 47% utilization, 4 buses have 37% utilization • Charger Utilization = 11.3% (Adenta), 8% (Tudu)

21 Bus utilization = Bus on road time/ Total operations time & Charger utilization = Time for which charger is engaged/ 24 hours

Considerations	Scenario 01: Charging at Adenta Depot only	Scenario 02: Opportunity Charging at Tudu Depot and Overnight Charging at Adenta Depot
Demand-based operational Requirement	• Demand-based operational requirement is getting fulfilled in the morning peak but not completely in the evening peak, but the layover between the trips is more	• Fulfil demand-based operational requirements efficiently, i.e., catering to morning peak hour from Adenta to Tudu and evening peak hour from Tudu to Adenta
Pilot Learnings and Scale-up potential	• Less- scale-up potential, as a limited number of chargers are available	• More- scale-up potential, as an adequate number of chargers available on both ends of the route
Staff required for Charging operations	• Potentially less	• Potentially more

Based on the Pros & Cons analysis of the alternative scenario coupled with consultation and interactions with local experts' team and different government stakeholders (MMTL and MoT), Scenario – 2 has been finalized.

5.2.6.2 Tema-Tudu-Tema e-Bus route

Item		Units	Scenario – 1	Scenario - 2
Headway		min	**Peak hour**: 10 min **Off-peak hour**: 15 min	**Peak hour**: 10 min **Off-peak hour**: 15 min
Energy Consumption per day (3 round trips/e-Bus)		kWh	456	
Daily Bus Utilization		km/bus/day	108	
Number of e-Buses (Fleet Size)		#	25 operational e-Buses + 3 reserved e-Buses = 28 e-Buses	
e-Bus Parking/Charging Requirement at Depot		#	**Tema Depot**: 25 **Tudu Depot**: 0	**Tema Depot**: 21 **Tudu Depot**: 4
Vehicle Specifications	Peak Motor Power	kW	500	
	Battery Pack	kWh	324	
Charging Infrastructure	No. of Chargers	#	**Tema Depot**: 7 **Tudu Depot**: 0	**Tema Depot**: 7 **Tudu Depot**: 7
	Peak Power/day	Mega Watt/day	~2.646	~ 2.646 MW@both depot
	Charger Specs	kW (AC/DC)	240 kW DC Fast Charger (2 Gun)	
	Energy Demand	kWh/day	456 kWh/bus/day x 25 buses = 11,400 kWh/day	456 kWh/bus/day x 25 buses = 11,400 kWh/day

*Recommended sanctioned load at site is calculated considering the No of chargers (excluding spare) * peak charger rating*1.05 (losses)*1.5 (sanctioned load). Energy demand at the site is the summation of energy at every site (total energy charged for 1 route) *1.05+ route 2+ r3+….).*

5.2.6.2.1 Pros and Cons of alternative scenarios

This section provides a comparative analysis of the scenarios, discussing each scenario's pros and cons based on the number of parameters listed and described in Table 17.

Table 17 Pros and Cons of Alternative scenarios

Considerations	Scenario 01: Charging at Adenta Depot only	Scenario 02: Opportunity Charging at Tudu Depot and Overnight Charging at Adenta Depot
Risk in terms of battery	• Managed in both scenarios- ample cushion taken for duration of each activity • Opportunity charge after every 1 trip. Make sure battery SoC never drops below- 30%, even with an aged battery	
Cost	• **Less** (7 chargers required for 25 buses)	• **More** (14 chargers required for 25 buses)
Bus and Charging Utilization Rate	• 24 buses have 46% utilization, 1 bus has 31% utilization. • Charger Utilization = 15%	• 19 buses have 46% utilization, 4 buses have 39% utilization, 2 buses have 31% utilization • Charger Utilization = 18% (Tema), 4% (Tema)
Demand-based operational Requirement	• Demand-based operational requirement is getting fulfilled, but the layover between the trips is less	• Demand-based operational requirement is getting fulfilled, but the layover between the trips is more, i.e., peak hour trips are not fulfilling the demands
Pilot Learnings and Scale-up potential	• Less- scale-up potential, as a limited number of chargers are available	• More- scale-up potential, as an adequate number of chargers available on both ends of the route
Staff required for Charging operations	• Potentially less	• Potentially more

5.3 Intercity Operation

5.3.1 Route Energy Consumption Model

This section presents the duty cycle profile and energy consumption assessment of the Accra-Kumasi Route for e-Bus deployment. The duty cycle and passenger loading data were collected in the existing ICE buses at peak and non-peak hours (morning, afternoon and evening) for December. It undertook a round trip from Accra to Kumasi and returned to Accra from Kumasi within a 24-hour time frame. The processed duty cycles were then provided as inputs together with reference e-Bus model specifications to assess the route energy consumption in each direction.

The route was assessed in each direction, i.e., from 1) Accra to Kumasi and 2) Kumasi to Accra. Table 18 presents the Accra-Kumasi route characteristics.

Table 18 Observed Route Characteristics of Onward and Return Journey (for the month of January 2022)

Parameters		Accra to Kumasi	Kumasi to Accra
Max speed	kmph	123	123
Average speed	kmph	44	46
Start Stops/km	#	0.116	0.155
Distance	km	238	238
Duration	hh:mm	05:30	05:30
Max Grade	%	-11% to 13%	
Average Grade	%	-9.2% to 9.4%	
Max Passengers	#	58	50
Average Passengers	#	31	34

The duty cycle profile for the route in each direction is presented in Figure 38.

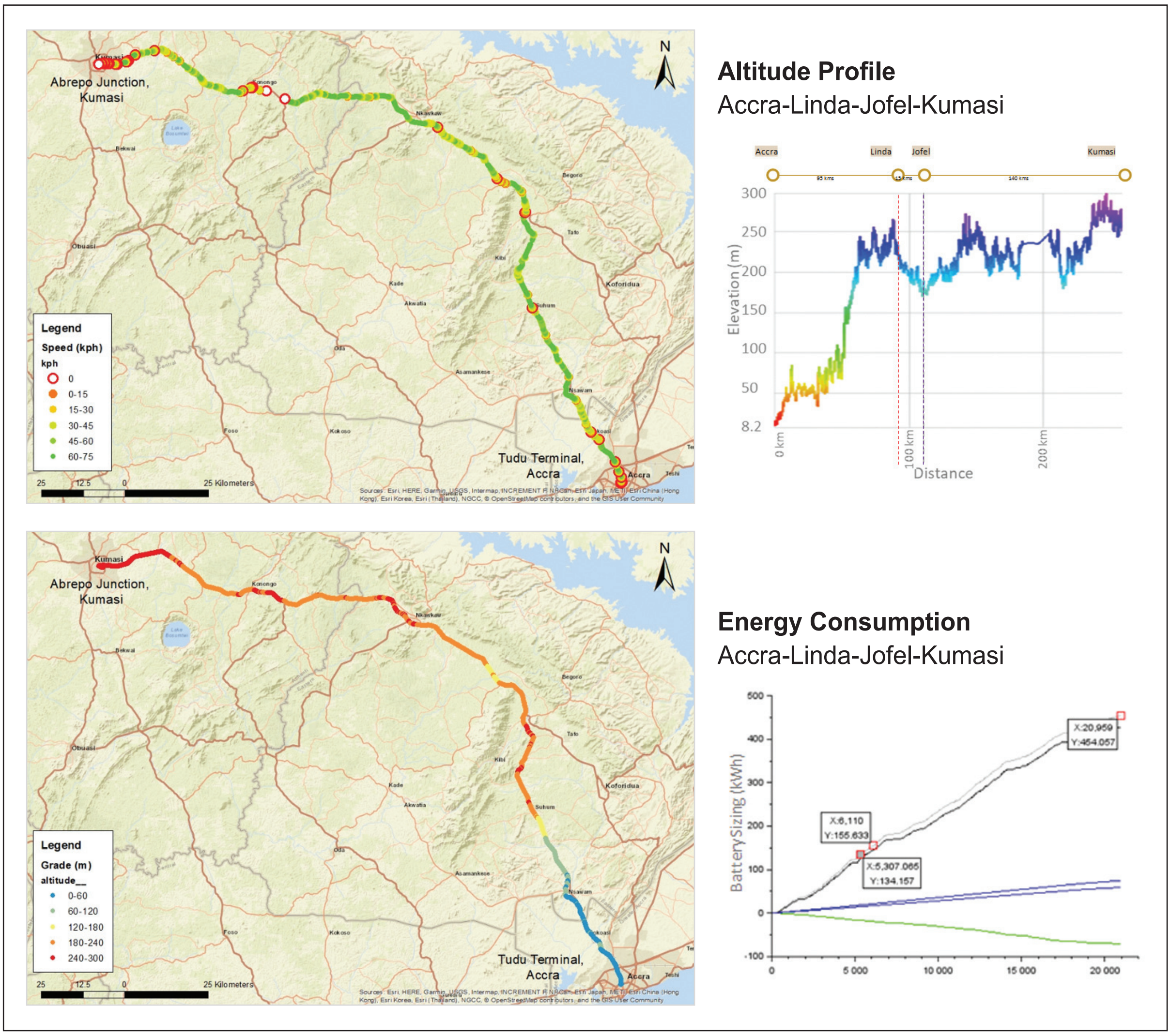
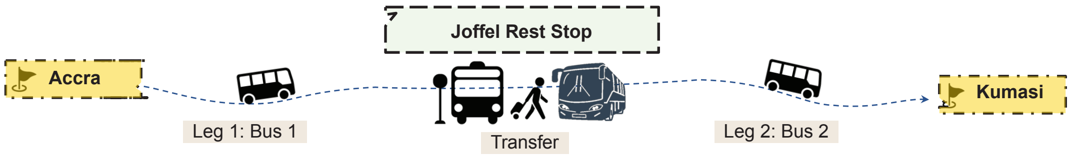


Figure 38 Duty Cycle Profile of Onward and Return Journey

Figure 38 reveals that the mid-point of the journey is not the mid-point of energy consumption. Hence, considering Linda Dor as the intermediate depot or terminal does not serve the purpose. Thus, Joffel Catering Services Reststop at Anyinam is proposed as the intermediate depot, which is about 110 km from the Tudu Depot.



The total energy consumption for the Accra-Kumasi bus route 1 round trip journey with AC is estimated to be about 890 kWh (454+436). The detailed summary is presented in Table 19.

Table 19 Accra-Kumasi e-Bus Route Energy Consumption

Routes	Accra to Kumasi		Kumasi to Accra		Total 1 round trip route energy consumption (kWh)
	Length (km)	With AC (kWh)	Length (km)	With AC (kWh)	
Accra-Kumasi	258	454	258	436	890

Similarly, energy consumption for Accra-Joffel-Kumasi is represented in Figure 39 .

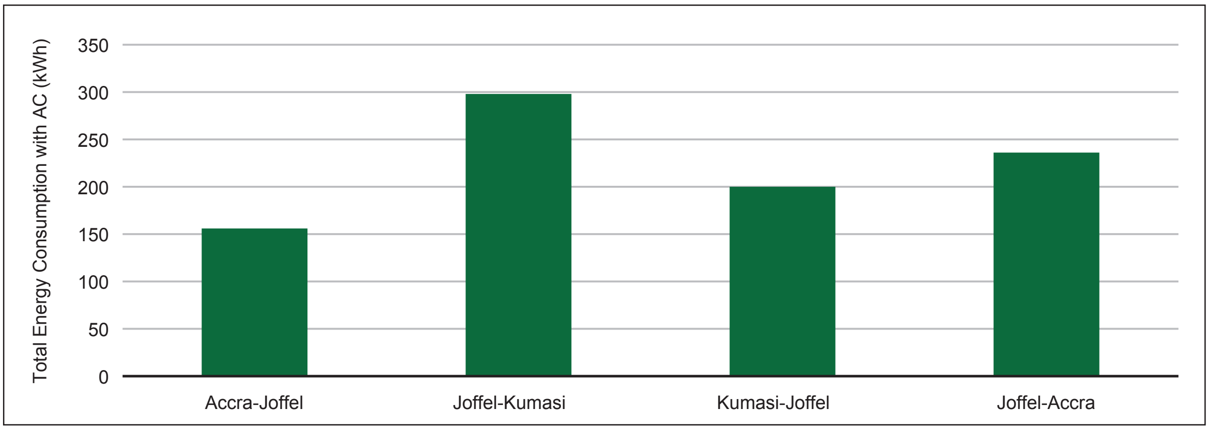


Figure 39 Accra-Joffel-Kumasi e-Bus Route Energy Consumption

5.3.2 Battery Sizing and Design

The energy consumed for 1 round trip in the Accra-Kumasi route is assessed with the battery design considerations of DOD, reserve ratio and ageing factor for market available battery packs. The minimum required energy for 1 round trip is estimated to be 1,228 kWh, considering 85% DoD and 20% capacity fade due to ageing. Currently, no e-Bus models are available in the market that can support 1 round trip of the Accra-Kumasi route without opportunity charging en-route. Therefore, 422 kWh (Yutong U12), the highest battery pack model, is further assessed to check the operational requirement, charging strategy, and fleet scheduling for e-Buses. However, even with en-route opportunity charging at Joffel, the second leg of the journey, i.e., from Joffel to Kumasi, witnesses energy going below 20%. This is due to the hilly terrain, which is not advised in any case.

Moreover, such a scenario also increases the journey time by 18% (~1 hour) because of the opportunity charging involved. This would become a significant trade-off for the passengers compared with the ICE buses. Thus, the only viable option is to have an already charged bus at the Joffel Depot ready for the second leg of the journey as soon as a bus completes the first leg and vice versa. This can prevent the increase in the journey time while providing integrated services to the passengers at their convenience.

5.3.3 Operational Model and Service Requirements

Based on the operational service requirements, such as the daily number of operational hours and daily kilometres travelled, headways are adopted for the feasibility assessment of e-Bus. The operational requirements are based on the existing ICE bus system operations on the selected route, as shown in Figure 40.

Parameter	Unit	Accra-Joffel-Kumasi Bus route	Kumasi-Joffel-Accra Bus route
Daily one-way trips/bus	No.	2	2
Daily run for two one-way trips/bus	km	238	238
Daily number of operational hours	hour	18 (4:00 am – 10:00 pm)	18 (4:00 am – 10:00 pm)
Average one-way travel time/ trip/bus	hour	5 hour 30 minutes	5 hour 30 minutes
Depot waiting Time	hour	1-2	1-2
Headway for fleet	min	**Peak hour**: 1 hour **Off-Peak hour**: 1 hour 30 min	**Peak hour**: 1 hour **Off-Peak hour**: 1 hour 30 min

Figure 40 e-Bus operational characteristics (based on existing ICE bus operations)

5.3.4 Charging Strategy Formulation

Figure 41 provides 1 e-Bus schedule for intercity routes based on the operational requirement and energy consumption.

Figure 41 One e-Bus schedule for the intercity route

Table 20 provides the charging requirements at Accra and Kumasi depots.

Table 20 Energy Requirement

	Unit	Accra Depot	Joffel Depot	Kumasi Depot
No of chargers	#	3	2	4
Peak charger rating	kW	240 kW DC Fast Charger	240 kW DC Fast Charger	240 kW DC Fast Charger
Recommended sanctioned load	kW/day	~1.13 Mega Watt	~0.756 Mega Watt	~1.512 Mega Watt
Energy demand	kWh/bus/day	2,616	1,744	3,052

*Recommended sanctioned load at the site is calculated considering the No of chargers (excluding spare) * peak charger rating*1.05 (losses)*1.5 (sanctioned load). Energy demand at the site is the summation of energy at every site (total energy charged for 1 route) *1.05+ route 2+ r3+....).*

5.3.5 Fleet Scheduling

Figure 42 shows the schedule for the intercity bus services from Kumasi to Accra and return to Kumasi. Each bus makes one round trip in 22 hours, including en-route charging, full charging and idle time. The first bus starts at 4:00 am both from Kumasi and Accra simultaneously. So, e-Bus 1 starts from Kumasi and e-Bus 10 from Accra. Then, as the buses reach Joffel, a fully charged bus is required to be ready at Joffel to carry the passengers to Accra and Kumasi, respectively. Hence, e-Bus 2 and e-Bus 16 undertake their respective journeys. The rest of the schedule can be interpreted in the same way.

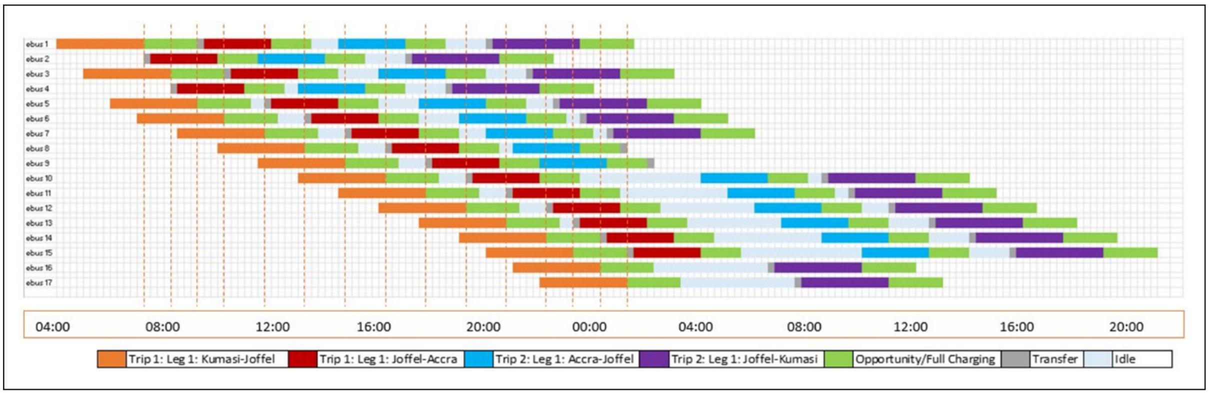


Figure 42 Intercity Fleet Schedule (Accra-Kumasi-Accra)

5.3.6 Recommendation

Item		Units	Description (For recommended Scenario)
Energy Consumption per day (1 round trip)/bus		kWh	890 kWh
Number of e-Buses (Fleet Size)		#	17
Daily Total Trips on route by Fleet		#	17
Vehicle Specifications	Peak Motor Power	kW	500
	Battery Pack	kWh	422
Charging Infrastructure	No. of Chargers	#	**Accra Depot:** 3 **Joffel Depot:** 2 **Kumasi Depot:** 4
	No. of Parking	#	**Accra Depot:** 6 **Joffel Depot:** 4 **Kumasi Depot:** 7

5.4 Disruptions in the e-Bus operations

e-Bus operations depend upon both internal and external systems. While the internal system refers to the bus, the battery, and the related components, the external system refers to the support infrastructure, i.e., the route network, the depots and terminals, the charging infrastructure, the bus stops, and the manpower required for the operations. However, not only mechanical systems but also external factors such as season, traffic, accidents, and so on can cause major disruptions. Table 21 shows some of the few disruptions that could happen, along with their possible mitigation measures.

Table 21 Disruptions in the e-Bus operations

Disruptions	Mitigation Measure
During the rainy season, there may be flash floods or water logging.	Provision of stormwater 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 0.5C/1C 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% at all times.
Changes in passenger loading	Operations with variable frequency for off-peak and peak hours
Power Outage	Microgrids, 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, festivals/some major programs)	Spare buses/chargers can be used.
Route blockage due to unavoidable situ-ations such as accidents	Buses can be re-routed for a specific 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.

6. e-Bus & Charging Business Models

6.1 Business Models

The switch to e-Buses is expected to help lower the carbon footprint while also saving money on fuel. Enhancing electric public transportation appears to be a pressing necessity in every community. The benefits of e-Buses have been recognized globally, and some cities have taken steps to incorporate them into their fleets. For example, the mayor of London has committed to not adding any new diesel buses to the city's fleet beyond 2018[22].

6.1.1 Actors in the e-Bus Ecosystem

Among the actors mentioned previously, the e-Bus ecosystem is dominated by the following players:

- Government authorities are charged with the responsibility of providing public transportation services (often referred to as "authority").
- Bus Manufacturers (with/without battery)
- Battery Manufacturers
- Electric Utility provider
- Private Operators and
- Financial Institutions

High capital costs of e-Buses necessitate adjustments to standard business models rather than 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 22. It summarizes the cities of implementation, the activities involved, the suitability of the model, and its benefits.

22 End of the road for London's 'dirty' diesel buses - BBC News

Table 22 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 PTAs funds to own and operate the service 3. Existing experience in bus operations 4. Capacity to cater for all risks	1. The 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 a complementary approach 3. Improves task efficiency related to operating and maintaining e-Buses and the infrastructure 4. Better inventory management and skill concentration

Activities/ Parameters	Integrated Public Transport Authority (PTA) Model	Gross Cost Contract	Hybrid Mode of Contract	SPV
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 penalities	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 Existing Business Model

Ghana's existing model considered the parameters such as bus operation, ticketing, fare collection, and depot management, initially looked upon by the bus operators, namely, TRO-TROs and MMT. With the inclusion of GAPTE, certain other factors were proposed and risk-sharing.

Before the formation of GAPTE, the bus operators (TRO-TROs and MMT) were in charge of bus operations, ticketing, fare collection, and depot management. However, after the formation of GAPTE, the existing bus operators were replaced by Pilot Type B Bus companies (Aayalolo). The Pilot Type B Bus companies do bus operations and depot management. Other activities were identified, such as system information, marketing, bus stop maintenance (management or enforcement), depot ownership, and contract monitoring. All the new activities, thus, are under GAPTE, along with ticketing and fare collection, as shown in Figure 43. For ICE bus procurement, the Government of Ghana procures the buses and leases them to operators on a lease, and the operator procures the buses through private partnership.

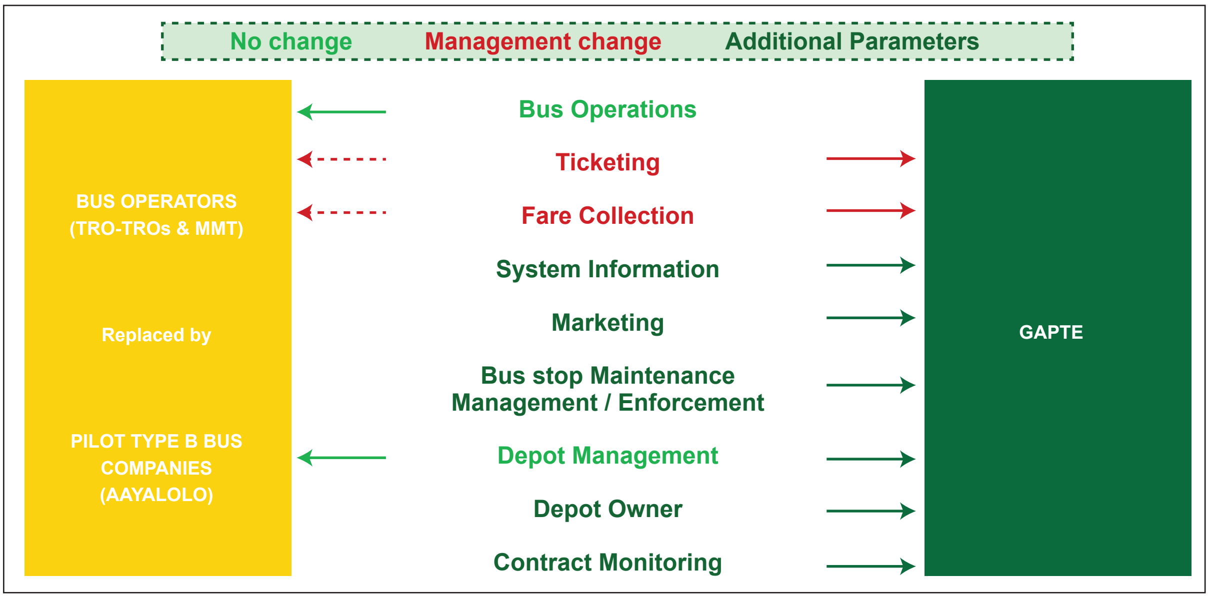


Figure 43 Existing Model before and after the formation of GAPTE

The business model that is in the service delivery agreement with GAPTE has two types of systems, namely, the Control Centre Management and the Contractor System. The contractor system is operational across fares, station services, and vehicle operators. Table 23 provides an accurate understanding of the system.

However, it is unclear how the risk ecosystem and the whole management system would work together even with this system. Further, the charging infrastructure-related details have not been addressed. So, to select the best business model for Ghana, it is essential to map out certain key parameters such as the financial flows, expertise of various stakeholders, and control systems for both the service, the infrastructure, and the grid charging system. Based on the above context, four options have been finalized based on discussion with the stakeholders involved, like, MMTL, MOT, etc.

Table 23 Business Model Activity Mapping

Authority	GAPTE	Out-sourced	Out-sourced	Negotiations
Activity	Control Center Management	Fare System Contractor	Station Services Contractor	Vehicle Operator Contractor
Sub-Activity	• Fare collection & Monitoring • System Information • Contract Monitoring • Enforcement	• Ticketing system & Equipment • Fare Collection • Ticket Sales	• Access Control • System Information • Station Management • Cleaning • Security	• Bus Operation • Depot Management

6.4 Potential Business Models for e-Bus operations

For each of the four proposed business models, six areas of activity have been identified. Those 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); chargers O & M (stakeholder in charge of operating and maintaining the chargers); and ticketing (stakeholder in charge of collecting ticket fares).

The model studied from global practices (7.2 Global Practices for e-Bus Business Models) applied to Ghana will give below kind of operations as summarized in Table 24.

Table 24 Potential Business models for e-Bus Operations

	e-Buses investment	e-Buses ownership	e-Buses operations	e-Buses maintenance	Chargers' O&M	Ticketing
Model-1 (Conventional)	Donor agency + GoG	MMTL	MMTL	MMTL	MMTL	MMTL
Model-2 (GCC)	e-Bus OEM + GoG	e-Bus OEM	MMTL	e-Bus OEM	e-Bus OEM	MMTL
Model-3 (Hybrid)	Financing/ Leasing co. + GoG	Financing/ Leasing co.	MMTL	e-Bus OEM (contract from Leasing co.)	e-Bus OEM (contract from Leasing co.)	MMTL (make Lease payment)
Model-4 (SPV)	Donor agency + SPV	SPV	SPV	OEM (SPV upskilling)	OEM (SPV upskilling)	SPV

6.4.1 Model 1: Integrated Public Transport Authority Model

This model is predicated on the premise that attracting sufficient private players will be difficult due to the high capital investment required. As a result, the government agency responsible for bus operations will assume complete responsibility, including procurement (via leasing[23] or outright purchase), provision and maintenance of facilities, and revenue collection.

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

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

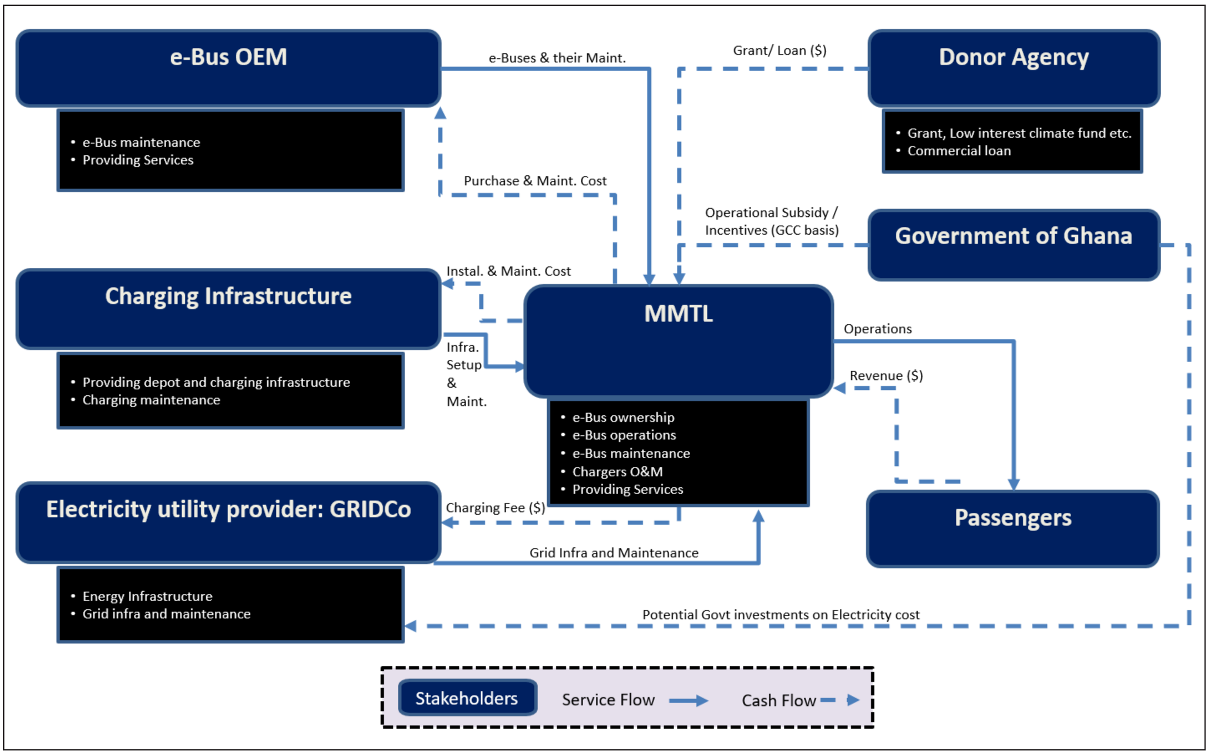


Figure 44 Service and Cash flows for Integrated Public Transport Authority Model

6.4.2 Model 2: Gross Cost Contract

In this arrangement, the government may partner with a private company to implement an e-Bus through a public-private partnership. This strengthens each individual's function by leveraging the experience of the other players. In this arrangement, the private operator acquires (through lease or outright purchase) buses equipped with batteries and charging systems and operates and maintains the buses. At the same time, the authority provides land, infrastructure, and other supporting services. The authority arranges for revenue collection either in-house or through an outside firm.

23 Bus leasing minimizes the capex required for buses. Moreover, the lessor is responsible for upkeep during the lease time.

After winning the bid, the e-Bus OEM enters into a contract with the government. It would purchase and own the e-Buses itself, while GoG would provide financial support through subsidies to the OEM. Even though the buses would be operated by the OEM, support staff would be provided by MMTL, who the OEM would train to leverage the expertise of the OEM in maintaining the fleet and the chargers. However, MMTL would arrange for ticketing, as shown in Figure 45.

This strategy envisions the authority investing less upfront in bus fleets and charging infrastructure. The system's operational efficiency tends to improve as a result of each stakeholder's increased and focused competence. The partnership agreement precisely defines each partner's position and obligations. Non-compliance with the SLA, on the other hand, may result in penalties. The bidding parameter is a fixed cost for operations and maintenance (O & M) that is based on a scheduled kilometre.

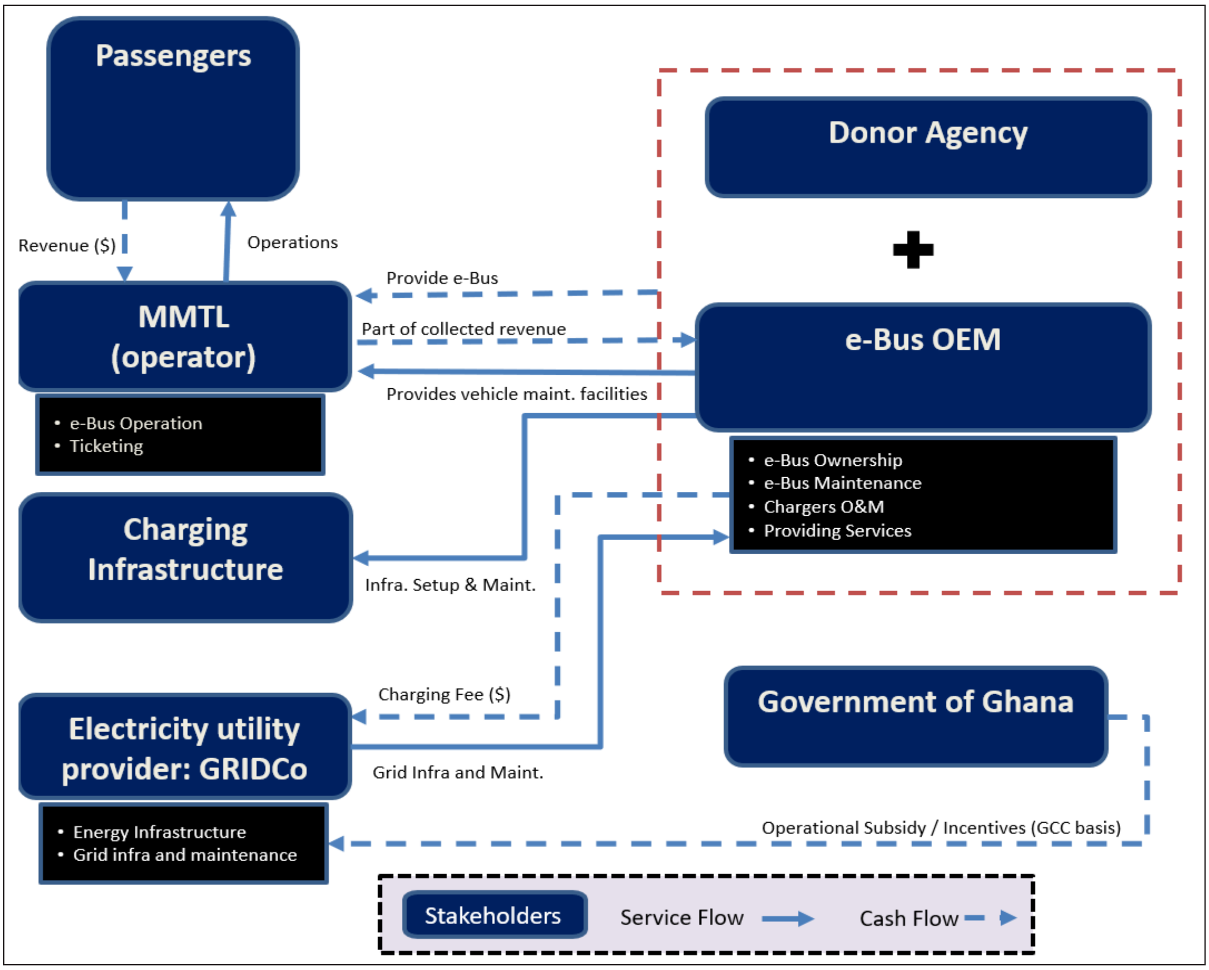


Figure 45 Service and Cash flows for GCC Business Model

6.4.3 Model 3: Hybrid Mode of Contract

In this arrangement, the financing agency or the leasing company provides funds along with the government's subsidiary support to purchase the fleet and retains its ownership. However, the government authority is given the charge of operating the buses on the route and providing manpower because of the non-availability and non-familiarity of the staff and routes with the former. To leverage the best experience and knowledge about maintaining the fleet and the chargers, the leaser takes the e-Bus OEM into action through the contract. However, the government authority arranges for revenue collection, which is used to make lease payments to the leasing company.

The financing agency or the leasing company would purchase the buses with support from GoG as subsidies and retain ownership. The operations would be done by MMTL, including the provision of supporting staff. The fleet maintenance and Chargers' O & M would be acquired as a service with a contract from the OEM from whom the fleet was acquired. Since MMTL is doing operations on the route, they would collect the revenue and pay the leasing company either a fixed system management fee or a scheduled fee as per ridership and km run.

Apart from leveraging all the benefits similar to the GCC mode, this strategy has a lower level of monitoring involved, except for the service quality. The operator keeps the fare box earnings, pays a system management fee, and receives a fixed O & M charge. It is a combination of a system management fee and an authorization grant. The operator with the best or highest fee or grant wins.

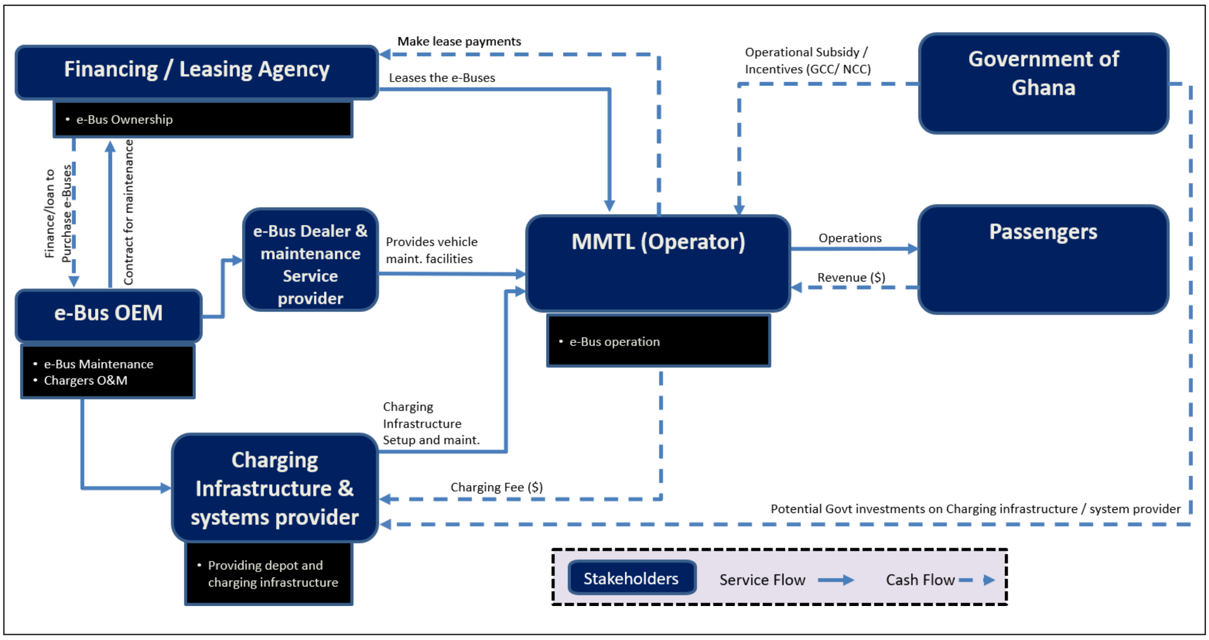


Figure 46 Service and Cash flows for Hybrid Business Model

6.4.4 Model 4: SPV

Under this arrangement, an SPV will be formed by the government and the operator (MMTL). The donor agency would provide funds in the form of grants or subordinated loans through the accredited agency to the SPV. The funds from the government, along with the grants or loans, are used to procure the buses by the SPV. The SPV would own the fleet and operate it and provide support staff. The SPV, along with the OEM (leverage technical know-how), maintains the fleet and the chargers' O & M. The revenue collection arrangement is done by the SPV either by itself or through another party.

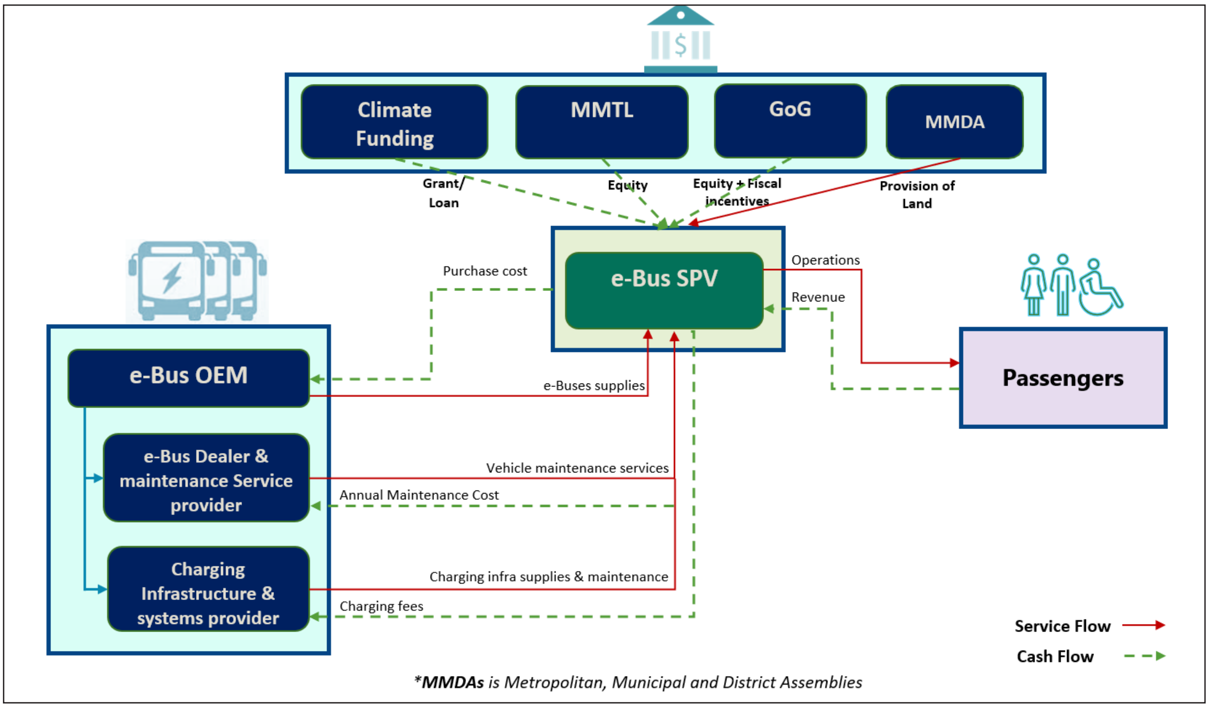
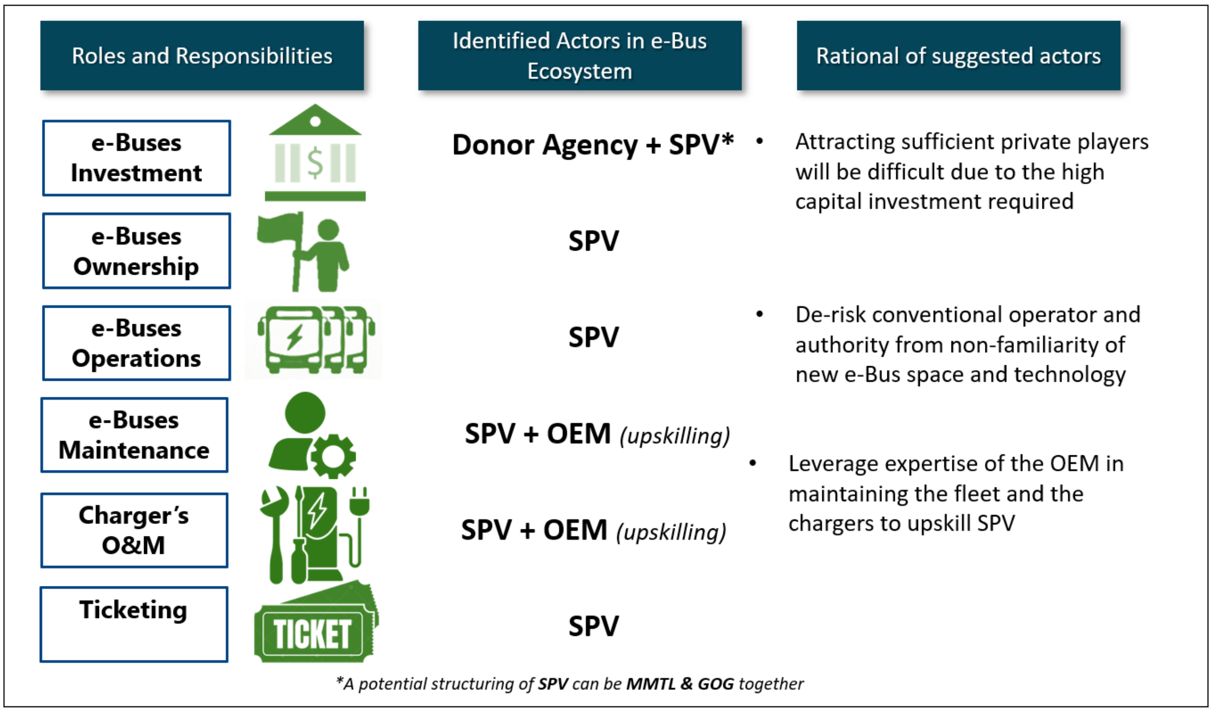


Figure 47 Service and Cash flows for SPV Business Model

	e-Buses investment	e-Buses ownership	e-Buses operations	e-Buses maintenance	Chargers' O&M	Ticketing
Model-4 (SPV)	Donor agency + SPV	SPV	SPV	OEM (SPV upskilling)	OEM (SPV upskilling)	SPV



Model 4 has been finalized after consultations with the MoT and the MMTL.

6.5 Investment Funding Model

The potential sources of funds for infrastructure, including e-Bus, chargers, grids, etc., would be financed through different agencies. Firstly, donor agencies like GEF, GCF, the World Bank, GGGI, etc., would provide grants or sub-ordinated loans through accredited agencies. Secondly, public or private banks like EcoBank would extend investment in the form of commercial loans. Thirdly, the government of Ghana would provide subsidies in the form of capital or interest and reduce or exempt taxation on EV imports. Lastly, the operator in the form of project equity, be it public or private. However, the city government would support licensing, city regulations, etc.

Under the provisions of the 4th model, MMTL as the operator would hold equity and the rest by GoG. Participation of the GoG would be in terms of accessing international grants and extending duty/tax waivers and subsidies. The funds would be acquired 80% through grants and loans (from GCF, AFDB, POSCO, etc.) and 20% by GoG.

The scope of the SPV mentioned above is only for the first 100 e-Buses in the cities of Accra and Kumasi.

7. Enabling Policy Measures for e-Bus Adoption

Having analysed the Country Landscape, which included policies, regulation, demand, and supply-related factors as elaborated in Chapter 3: Country Landscape, barriers have been identified. These are categorized under three groups (market development, industry development and operation).

- **Market development** – looked into the demand-side barriers for e-Bus adoption amongst the MMTL, private operators running buses in Ghana
- **Industry development** – looked into the supply-side barriers for local production of the e-Bus, batteries, chargers and other sub-systems and services by OEMs and suppliers
- **Operations** – looked into the supply-side barriers for setup and operations of charging and energy infrastructure by charging providers and power utility operators

The policy option recommendations are identified against respective barriers through global best practices and further customized for Ghana. Since there is one-to-many mapping of policy options to barriers (i.e., one policy option helping resolve multiple barriers), the policy options are categorized into three groups as follows:

Table 25 Barriers to e-Bus adoption in Ghana

	Primary Barrier for e-Bus adoption	Contributing Barriers
MARKET DEVELOPMENT GAP ANALYSIS	Limited financial attractiveness concerns	Lack of financial viability
		Higher investment cost
		Limited access to financing services
		Limited government resources to extensively support e-Bus adoption
		Unclear support and local thrust to local manufacturing vs imports to harmonize tariffs and import duties with local tax incentives geared at reducing supply chain costs
	Limited performance and quality concerns	Limited range and operational boundaries
		Long charging time
	Technology Inertia issues	Lack of technical support
		High-reliability issues
		Lack of familiarity on the technology
		Negative technology reputation due to previous experience
		The advantage of ICEs in refuelling vs recharging discourages further EV uptake
		The lack of charging stations and sufficient accompanying docking facilities create apprehensions from the market side to acquire more vehicles as it affects service reliability

	Primary Barrier for e-Bus adoption	Contributing Barriers
INDUSTRY DEVELOPMENT GAP ANALYSIS	Higher production cost	Lack of mass demand preventing the adoption of mass production processes and methods
		Weak local supply chain
		High power cost
	Strong competition from imported units	Bigger production volume of imported units thus lower cost
		Better access to technology, components, and materials by competitors
		The lower operating cost of competitors
	High financial liquidity requirement	High inventory cost due to weak local supply chain and intermittent demand
		Slow and high uncertainty on vehicle purchase loan approvals
		Lack of accessible financing resale market for e-Bus vs ICE-Bus
	Limited design flexibility and access to technology	Difficulty in forging technology partnership due to limited demand and lack of international reputation
		Limited access to certain processes due to limited projected production volume
OPERATION GAP ANALYSIS	Lack of third-party charging service providers	Varying battery/ charging technical requirements
		High charging infrastructure investment cost
		Lack of sustainable strategy/ business model for charging infrastructure
	Poor technical support services	Limited local demand to stock on replacement parts and components
		High cost of parts and components due to low volume orders
		Limited human resource/ technical capacity to maintain and service the units

- Target setting for e-Bus
- Demand-side options for stimulating e-Bus adoption
- Supply-side options to stimulate local e-Bus production and growth

The recommendations are suggested for the short-term (till 2025) and medium-term (2026-2030), and long-term (after 2030).

The 'market development' barriers are mapped to demand-side policy options, while 'industry development' and 'operations' barriers are mapped to supply-side policy options. The identified policy elements are summarized in Table 26 and further detailed in the subsequent section.

Table 26 Identified Policy Measures for Ghana

Policy Measures	Policy Sub-Measures
Targets	Target setting – e-Bus, public charging infrastructure and local e-Bus production
Demand-side	Fiscal incentives on purchase and use for e-Bus operators
	Non-fiscal incentives for e-Bus operators
	A fleet mandate for e-Bus operators
	Disincentives on ICE Bus
	Stricter Vehicle and Fuel Emission Standards
	Stakeholders' Awareness of Government and Operators
Supply-side	Zero Emission Vehicle (ZEV) Mandate for OEMs
	e-Bus and Charging Infrastructure Standards and Guidelines
	Financial Incentives for manufacturing of e-Bus, parts, and components
	e-Bus Demand aggregation by Government agencies
	Disposal, reuse and recycle
	Research & Development (R&D), Pilots and Capacity Building

7.1 Target setting

The target setting is an important and strategic activity to achieve the desired e-mobility growth. For e-Bus, the overall strategy is to set the following targets: 1) For e-Bus penetration, 2) For public charging infrastructure and 3) For local e-Bus production, as detailed further. These are;

Table 27 National and Regional level target for e-Mobility growth

Description	National-level	For the region of Accra	
		Intracity level	Intercity level
Target setting for e-Bus penetration in yearly sales	Systematically deploy e-Bus for Urban transportation aiming to achieve at least 16% of the total vehicle fleet mix by 2030	Commence pilot operations with 70 e-Buses by 2023 and work towards upscaling to 1,000 high-capacity e-Buses by 2030	Commence pilot operations with 30 e-Buses by 2023 and work towards upscaling to 300 e-Bus by 2030
Target setting for public charging infrastructure (AC and DC)	Collaborate with the Private Sector to setup at least one charging Hub in each of the 256 local government administrations/ District Assemblies aiming for 2,000 charging points by 2030	Not applicable	New Guidelines to require all new rest stops along intercity road corridors to have Charging points by 2025 and existing rest stops by 2030
Target setting for local e-Bus production	Collaborate with the Private Sector to setup e-Bus production/assembly by 2040	Collaborate with OEMs to begin component manufacturing for e-Bus by 2030	Collaborate with OEMs to begin component manufacturing for e-Bus by 2030

7.2 Demand-side Measures

The recommended demand-side policy options that address the key barrier to e-Bus demand are summarized as follows.

- reduce the overall upfront cost and TCO differential between e-Bus and ICE Bus using fiscal and non-fiscal incentives on purchase and use for e-Bus operators
- create regulatory nudges for operators to transition their fleets to electric
- discourage ICE Bus usage through the introduction of mechanisms like increased excise taxes on ICE and green tax on fuels (petrol and diesel)
- reduce the technology risk borne by operators through an innovative business model
- set stricter vehicle emission and fuel standards to reduce the carbon emissions and particulate matters
- raise awareness and capacity building of stakeholders (national and local government, operators) on e-Bus

Detail description for each of identified measures is elaborated below:

a) Fiscal incentives for Purchase and use of e-Bus Operators:

Monetary incentives can be provided in different ways, such as direct tax exemptions, subsidies for new purchases, or new taxes. Though monetary measures are impactful, it is necessary to ensure the effective management of sound fiscal policy. The Ministry of Finance, being the lead agency for fiscal policy and efficient public financial management, should collaborate with banks and other financial institutions to introduce an affordable financing scheme for individuals and companies for the purchase of EVs in the country. The Ghana Customs, Excise and Preventive Service (CEPS) Management Law (PNDCL 330 of 1993), the CET Act of 2015 (Act 905) and the Customs (Amendment) Act 2020 (Act 1014) should be reviewed to make provisions for the introduction of exemptions for e-Bus. The review is expected to be completed by 2024 with a long-term perspective on zero-rate e-Bus. Other supportive measures such as exemption from the payment of road-user fees, vehicle income tax and operators permit should be considered.

These sub-measures are:

- Allocation of Capital subsidy on purchase of e-Bus
- Reduction of taxation on e-Bus
- Exemption of annual vehicle registration charges on e-Bus
- Reduction of electricity tariff

For e.g., if the above sub-measures are applied to e-Bus in Ghana, an upfront vehicle cost is reduced from ~2.5X, which helps achieve parity with ICE Bus.

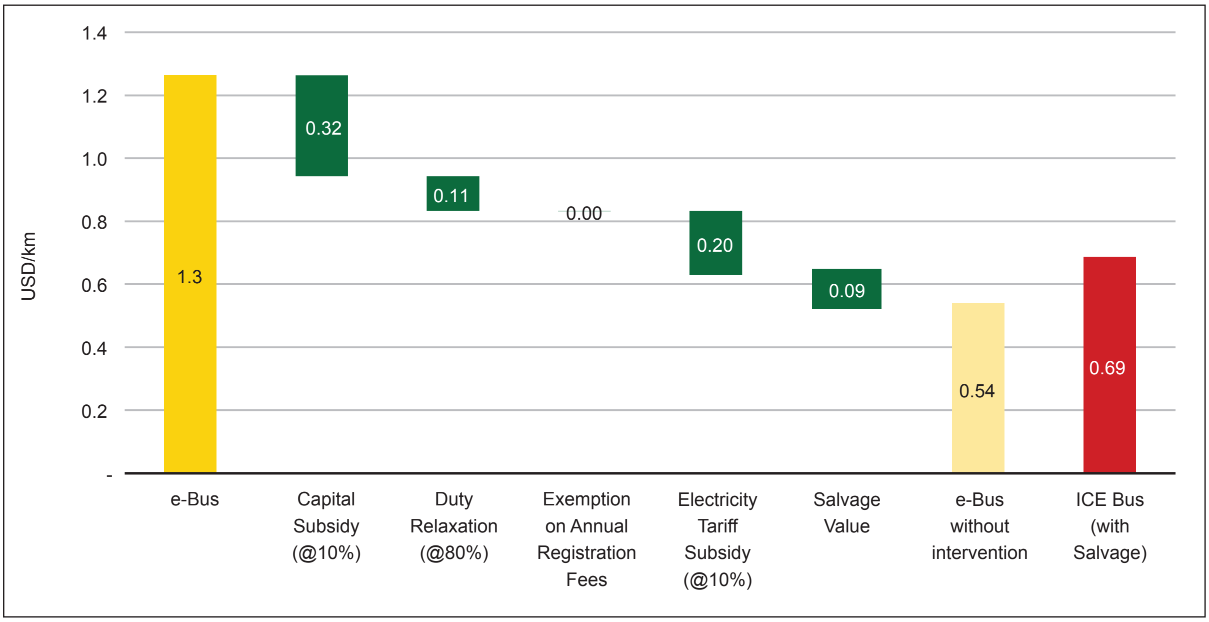


Figure 48 Impact of sub-measures on e-Bus which helps to achieve parity with ICE bus

b) Non-fiscal incentives for e-Bus Operators:

There is a need to provide non-fiscal incentives like introducing preferential franchising conditions for e-Bus services, which could provide additional motivations for the PT operators to go electric. The preferential benefits can be provided in the following ways:

- Faster processing approvals of franchisees (i.e., priority registration and renewal)
- Smaller fleet size requirements
- Preference to bidders for new franchises (i.e., developmental routes) based on the proportion of e-Bus planned to operate on the route
- Longer age limit (subject to road worthiness)

Regulation should support Preferential benefits options like priority registration and expediting the process for franchisees to operate, availing training programs for employees under Technical Education and Skills Development Authority (TESDA) training programs for technicians.

c) Fleet Mandate for Fleet Operators

While no restrictions on conventional units have been introduced locally, initiatives should be directed at mandated electric adoption in the bus fleet. These include the planned green routes, which intend to lock certain routes to e-Bus only, % mix of e-Bus in ICE Bus. An important recommendation is to mandate a gradual increase and minimum per cent target of bus operators' fleet stock to be e-Bus. This can be effected from 2025 onwards and aligned with set national EV targets. Table 27 shows the suggested short, medium, and long-term plans for this mandate.

Table 28 Short-Medium- & Long-term plan for Fleet Mandate

Short-Term (till 2023)	Medium-term (2023-30)	Long-Term (After 2030)
• Roll-out government-private sector-led e-Bus pilot program in highly urbanized cities	• Introduce bus green routes in some highly urbanized cities through net or gross cost contracting • Continue with a government-private sector-led e-Bus pilot program in other localities	• Implement franchise (or age-based limit) expiry-based transition to electrified buses in highly urbanized cities and eventually in all areas. All retired buses in 2040 are to be replaced by electrified systems.

d) Disincentives on ICE buses:

This measure is to discourage the use of ICE Buses in the country. In collaboration with the Ministry of Finance and the Ghana Revenue Authority, the Ministry of Transport should review regulations to propose new taxes on ICE Bus to discourage their import by 2030. These could be

- Introduce excise tax on ICE Bus
- Introduce green taxes on petroleum products to discourage consumption. This would eventually drive the demand for alternative forms of energy

e) Stricter Vehicle and Fuel Emission Standards:

The vehicle emission standards help curb the GHG and other harmful emissions (like CO, NOx, etc.). One of the most widely used vehicle emissions standards is the European or "EURO" standards, commonly named EURO II, EURO III, etc., based on acceptable emission limits. Globally, many countries have moved to successively stringent vehicle emission standards to achieve social and economic benefits over time. In collaboration with the Ghana Standards Authority, the National Petroleum Authority and the Environmental Protection Agency, the Ministry of Transport is developing regulations to impose stricter standards on emissions and fuel for ICE vehicles. For example, stricter emission standards could be imposed for intra-city ICE buses. Currently, the Ministry of Transport is collaborating with relevant agencies to enforce strict adherence to the 50ppm (EURO 4 fuel standards) limit, which may even be lower by 2030.

f) Stakeholders Awareness for Government and Operates:

Some EVs in Ghana are imported by some early adopters and a few corporate organisations. However, public awareness is still low. The general impression is that there is not a reliable electricity supply and enough technical know-how to sustain EVs. The Ministry of Transport, together with sector agencies, would therefore lead a massive awareness creation programme with the aim of building support and demand for EVs. Activities involving information, education, and communication should be investigated using both the media and consultative engagements with key stakeholders and the grassroots. Major stakeholders in the road transport sub-sectors would be engaged quarterly to sensitize them to fully bring everyone on board for the e-Bus drive. These can be led by:

- Organization of capacity-building programs/ initiatives
- Organization of awareness campaigns and training programs for bus operators

7.3 Supply-side Measure

These are measures that would be put in place to encourage the supply of e-Bus in the country. The recommended supply-side policy measures include regulations to boost e-Bus supply, financial incentives, piloting of e-Buses, and capacity building. These address the key barriers pertaining to local e-Bus production and charging infrastructure. These measures are:

a) Zero Emission Vehicle (ZEV) Mandate for OEMs:

A ZEV mandate requires OEMs to sell a minimum share of ZEVs to meet the targets and earn credits for each ZEV sale. ZEV mandate will be important as Ghana does not have any specific target defined for OEMs to convert the conventional fleets into EVs. Globally, various countries like the U.S., China, Europe, Japan, etc., have transited to EVs significantly after implementing the ZEV mandate. Similarly, Ghana should develop and define the ZEV mandate for local automotive OEMs to drive increased e-Bus production.

One mechanism is introducing ZEV credits linked to ZEV sales and enforcing minimum ZEV credits for an OEM. The credits can be assigned based on each ZEV's technical specification or performance, including top speed, range, curb weight, vehicle efficiency, etc. For example, Ghana can use 'range' to be a basis for issuing the ZEV credit to the OEMs across different vehicle segments (in line with California's ZEV policy). This will ensure that the OEMs that produce higher vehicle quality (i.e., higher range) receive higher ZEV credits, which will act as a benchmark for the manufacturing industry. The benefit is that even at low sales volume (due to high vehicle cost), the ZEV credits would be higher for the OEMs that produce high-range vehicles. This will further help the OEMs to meet their ZEV targets of the bus portfolio.

b) e-Bus and Charging Infrastructure Standards and Guidelines:

There are different EV-related standards defined by different standards making global organizations like International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), Underwriters Laboratories (UL), the United Nations and others.

Ghana Standards Authority (GSA) has adopted the Customs Valuation Code (CVC) on charging protocols and equipment, which outlines the technical requirements and does not necessarily identify a specific protocol. In addition, compliance to the standards continues to be voluntary until the appropriate government agency passes a regulation mandating it. Thus, there is a need to formulate standards in alignment with the best global standards like:

- EVs Quality and Safety standards for safe import and local production
- Homologation standards and local testing facilities for EVs
- Introduction of EV Supplier Accreditation
- National standards for EV charging

c) Financial Incentives for manufacturing of e-Bus, parts, and components:

The Ministry of Transport and the Ministry of Trade and Industry should collaborate with relevant financial institutions to provide financial incentives to boost local manufacturing and assembling of EVs and their parts. This will generate the necessary supply to meet national demand. Also, in collaboration with the Ministry of Trade and Industry, a review will be conducted on the Ghana Automotive Policy to incentivise local manufacturing of EVs in the country. Following are some of the recommended provisions for financial incentives:

- import tariff exemption on raw materials
- VAT exemption on raw materials
- facilitation and lower cost on land and utilities
- production tied capital subsidy
- income tax holidays, etc.

d) e-Bus Demand aggregation by Government agencies

The demand aggregation is one of the most important steps for the initial success of the e-Bus program. This strategy can help to reduce Bus acquisition costs due to economies of scale. Globally in countries like China and India, this mechanism has been used and is helping stimulate the EVs demand.

To implement this strategy in Ghana, an appropriate agency can be authorized to aggregate Bus demands and bulk procurement of standardized and high-quality e-Buses at discounted prices. The demand aggregation can be done by assessing the e-Bus requirement so that it can be procured by the authorized agency and plan procurement size more appropriately. At the time of aggregation, the following are some useful technical parameters which can be helpful at the time of preparation of e-Bus technical procurement guidelines:

- Avg. expected travel distance per day
- Vehicle usage (Intra-city or inter-city)
- Avg. monthly fuel, vehicle maintenance and overall leasing expenses
- Others (charging space availability, preferred charging location, etc.)

The above exercise will help map the bus operator's needs with the various e-Bus models available in the market.

e) Disposal, reuse and recycle

Currently, Ghana does not have any policy on the scrappage of vehicles. As the total number of vehicles on-road is growing and expected to grow, it may be good for the government to consider a vehicle scrappage policy. There is a need to define and enforce guidelines for ICEV scrappage based on fixed end-of-life of vehicles and/or annual inspections (emissions and roadworthiness). It can have many positive impacts, such as

- It will ensure older and less efficient vehicles are removed from the system
- New employment opportunities can be generated in the scrappage industry
- It may influence people to opt for EVs when they are planning to buy new vehicles because of various fiscal and non-fiscal incentives
- Green tax/cess can be levied if vehicle usage is continued above the fixed end-of-life by 2030

For this, Ghana needs to develop:

- National guidelines for vehicle scrappage
- Environmental guidelines for battery re-use and recycle
- Incentivize investments in battery recycling

f) Research & Development (R&D), Pilots and capacity building:

The electrification of public transport and broader e-Mobility is evolving sector. EVs require underpinning technologies like Power Electronics, Electric Machines and Battery technologies. These technology areas are dynamic and continuously evolving to enable the functional requirements of EVs. So, it is important for countries to develop new knowledge, techniques, and technologies to make the EV ecosystem viable with respect to local conditions.

- Investments in R&D are vital to building the required competencies, capacities and indigenous technologies to reduce dependency on imports. Hence, Government should allocate grants which can help drive R&D on various aspects of e-Bus and charging infrastructure. This will also enable close industry participation for commercial R&D, patents, start-ups incubation and scalable deployments. Collaboration between industry and academia is key to catalyse innovation and growth in technology. While industry often focuses on addressing solutions that are of near-term commercial value and academia focuses on building new knowledge through research and imparting education to students, the combination can yield the accelerated development of new breakthroughs. Ministry of Transport shall establish an industry and academic centre of excellence (COE) and develop an EV training and capacity-building ecosystem. They should set up accreditation schemes for EV training institutions in collaboration with the National Road Safety Authority (NRSA), Drivers and Vehicles Licensing Authority (DVLA) and the National Vocational Training Institute (NVTI). They should also reactivate the Centre for Urban Transportation to facilitate research, provide expertise in urban transport, and provide technical assistance to policymakers.
- Pilots are one of the crucial elements to ascertain the feasibility of deploying e-Bus, identify potential shortcomings and help in developing the right interventions for large-scale deployments. For instance, some of the challenges for uptake of e-Bus are range anxiety, driving capabilities, apprehensions about operation and performance, etc. By virtue of pilot implementation, these perceptive barriers can be assessed that will enable city authorities and urban and transport planners to take corrective measures. These demonstrations will also lead to transformative uptake of e-Bus and associated charging infrastructure in the country. Financial and technical barriers often hinder the implementation of pilots as these are new technologies. So, the government's intervention in grants, subsidies, and technological test beds is important for encouraging pilot implementation in the country.

- Since EV technology is evolving, there is a need to bridge the gap between skills required for its development versus skills possessed. These pieces of training will ensure that the EV industry is ready with the required skills to cater to the increased demand.
- The training on EVs can include different aspects such as technologies, business models, fleet management, life cycle assessment, pre-feasibility, feasibility assessment of deployment of EVs, etc. This training will help create new jobs in the country, ensuring sustainable employment of the youth in the industry. Government should encourage Technical Universities and Institutes to develop degree and vocational courses in e-Bus and broader e-Mobility. The National EV Skills Council must focus on EV/automotive skills development and certification across different roles in the EV value chain. This should be done in close association with Industry and Academia. Also, the government must facilitate Evs' training infrastructure through grant money and grow Regional Training Centres.

8. City Charging Infrastructure Guideline

For e-Bus operations, it is imperative to establish a robust and safe infrastructure. An essential part of this system is the charging infrastructure that enables the use of e-Buses. Among all the operating parameters, range, availability of charging infrastructure, and charging time potentially impact e-Bus service. Meticulously deploying the charging infrastructure hence becomes crucial for a bus service provider to ensure smooth operations and optimise the investment.

Another essential factor in planning e-Bus charging infrastructure is the size and volume of infrastructure required. Compared to light-duty vehicles, e-Buses have batteries ranging from 80 to 300 kWh and have a high-power requirement (demand) for such batteries, which can only be obtained directly through a separate set-up. This includes step-down infrastructure to pull power from the grid; chargers known as "electric vehicle supply equipment"(EVSE); power back-up; safety; and monitoring systems. Together, these components are cost-intensive and need a plan to use them judiciously. The type of chargers, charging strategy, charger rating, efficiency, etc., are some parameters that need to be pre-defined and deployed in a planned manner for the desired e-Bus specifications to serve selected routes efficiently.

The charging infrastructure guidelines given below will help make the right choices and fulfil the different technical, operational, and financial requirements for the e-Bus deployment.

8.1 Charging infrastructure for e-Buses: Global best practices

Table 29 Detailed summary of e-Bus charging systems and infrastructure best practices[24,25]


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.

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	Parameters	Justification of the Ideal Value	DC Plug-In	DC Pantograph	Inductive charging	Battery swapping
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
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			

Parameters		Justification of the Ideal Value	DC Plug-In	DC Pantograph	Inductive charging	Battery swapping
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 DTcon-nected to a HT line	Difficult; must be drawn only from 11/33 kV substation, which is not as accessible as a HTline	Moderately difficult; possible to draw electricity through a DT connected to a HTline	Moderately difficult; possible to draw electricity through a DT connected to a HTline
	Established precedence for charging buses		Yes	Yes	Limited	Limited
Best Practices Examples			CASE STUDY: SHENZHEN, 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 en-route, which are reported to charge the buses in approximately 40 minutes.	CASE STUDY: DC PANTOGRAPH CHARGING IN THE 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, 400kW** and **45 kW**. The 600 kW 'flash' charging stations which 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 for 5 and 30 minutes respectively.	CASE STUDY: WIRELESS CHARGING IN GUMI, 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%.	CASE STUDY: JEJU ISLAND South Korea is a unique market for e-buses where charging by conductive, inductive and battery swapping technologies have been employed. e-buses used in this project has 51 kWh (weigh approximately 760 kg) 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.

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 the required number of charging units (EVSEs/Pantographs/swapping system etc.). This will further be the basis to estimate the power load to be proposed.
	Power load estimation	Estimating the 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 to be calculated, including considerations for power losses at generation, transmission and distribution. Estimated peak power to be used to sanction the load to operate the e-Bus charging station.

For first deployment of e-Buses, charger sizing is done based on recommended e-Bus operations.

1) For the intracity operations in the Adenta-Tudu-Adenta route
   - **Scenario 1.1:** Charging @ Adenta depot only - 14 Chargers with 240 kW rating Or;
   - **Scenario 1.2:** Opportunity Charging @ Tudu depot and Overnight Charging @ Adenta Depot – 15 and 17 Chargers respectively with 240 kW rating.

2) For the intracity operations in the Tema-Tudu-Tema route
   - **Scenario 2.1:** Charging @ Tema depot only - 7 Chargers with 240 kW rating Or;
   - **Scenario 2.2:** Opportunity Charging @ Tudu depot and Overnight Charging @ Tema Depot – 7 Chargers at each depot with 240 kW rating.

3) For the intercity operations in the Accra-Kumasi-Accra route 3, 2, and 4 Chargers are required at Accra, Joffel and Kumasi depot, respectively, with 240kW rating. These chargers would be utilized for both opportunity as well as overnight charging.

Based on the existing peak power assessment, e-Bus deployment would add up to the existing power requirements for Accra due to intracity operations and the city of Accra and Kumasi for intercity operations.

- Scenario 1.1: 5.29 MW peak power more in existing peak demand for the city of Accra.
- Scenario 1.2: 12.09 MW peak power more in existing peak demand for the city of Accra.
- Scenario 2.1: 2.646 MW peak power more in existing peak demand for the city of Accra.
- Scenario 2.2: 5.292 MW peak power more in existing peak demand for the city of Accra.
- The intercity operations would add 1.886 MW peak power more in existing peak demand for the city of Accra and 1.512 MW for Kumasi.

This can be facilitated through special agreements between power generating and distributing agencies and the e-Bus operator (MMTL); to provide an uninterrupted and reliable power supply. It will be an added benefit if the energy is generated from renewable sources such as solar and hydropower.

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-uses. iii. Using public charging stations 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 iv) others (commercial malls, homes, kerb side parking, public parking, etc.)
2.	Accessibility to grid	• Suitable size of land to be undertaken, accounting for the spatial proximity of land and access to the grid. The proximity of the Grid connection will enable easy access and minimize the grid connection cost to bring electricity to the charging station.
3.	Area selection	• Metro cities and capital cities/ regions are experiencing a 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, and local government departments, power utilities, and existing fuel (oil) stations; (including power utilities, petrol fuel stations, etc.) **extending long-term, low-cost leases** for their available suitable **land** pockets will allow competitive EV charging infrastructure development.
4.	Area Requirement	• **Suitable sizing** of the land to be undertaken 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	• Suitable size of land to be undertaken, accounting for the spatial proximity of land and access to the grid. The proximity of the Grid connection will enable easy access and minimize the grid connection cost to bring electricity to the charging station.

Charging Location and integration with Urban land-use planning: The location of e-Bus charging is decided based on the start and endpoints of routes. The charging strategy adopted for e-Bus deployment is charging at the suburban end only and charging at both ends. As routes are operated from suburban ends, overnight charging stations are needed at Adenta and Tema depot for intracity operations in both scenarios. On the other hand, all the depots require charging infrastructure for the intercity operations as the route is longer and energy exhaustive. As both lands for Depot and Terminal are available with MMTL, it can be re-designed planned for utilizing existing space optimally for e-Bus parking and charging.

- Scenario 1.1: Charging stations are provided only at the suburban ends, i.e., Adenta depot
- Scenario 1.2: Charging stations are provided at both ends, i.e., Adenta depot and Tudu depot
- Scenario 2.1: Charging stations are provided only at the suburban ends, i.e., Tema depot
- Scenario 2.2: Charging stations are provided at both ends, i.e., Tema depot and Tudu depot
- Charging Stations for the intercity operations are provided at Tudu depot, Joffel depot and Kumasi depot.

Area selection:

Selected areas of Adenta Depot and Tema Depot at Accra; both have enough space to accommodate 50 and 25 buses, respectively. The lands for both Depot and terminal are available with MMTL, which saves the investment in land and reutilises the available public transport infrastructure. Further, if scenarios 1.2 and 2.2 are considered, even in that case, Tudu depot has availability of required 27 parking spots available under the jurisdiction of MMTL.

Area Requirement: An EVSE with 240 Kw capacity requires ~2.5 sq.m. A 12 m e-Bus would require a space of ~40 sq.m. Based on the fleet size and charging requirement.

- Scenario 1.1: Total charger space requirement is 35 Sq. m.
- Scenario 1.2: Total charger space requirement is 37.5 Sq. m @ Tudu and 42.5 Sq. m @ Adenta.
- Scenario 2.1: Total charger space requirement is 17.5 Sq. m.
- Scenario 2.2: Total charger space requirement is 17.5 Sq. m @ both Tudu and Tema.
- For intercity operations, the total charging space requirement is 7.5 Sq. m @ Tudu, 5 Sq. m @ Joffel, and 10 Sq. m @ Kumasi depots.

Accessibility to the grid: As per consultations with MoT and MMTL, 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, grid access, and power reliability. Both Depot and Terminal are in proximity to the grid connection, and it is doable for a local power distribution company to provide grid access.

8.2.3 Grid Infrastructure requirements

Sr. No.	Factor	Description
1.	Accessibility to grid infrastructure	• e-Bus charging stations, because of the combined high connected load (coming from multiple chargers), will require a high grid voltage access (13.2kV/220V) point and an appropriate distribution transformer. • Typically, the costs for providing grid connection from high voltage line to EV chargers is quite high (depends on distance, km) and is to be borne by charging station operator, which has potential to limit financial viability (specially in early EV market development time when. EVs demand will remain low for initial years).
2.	Electricity tariff	• Electricity cost (both fixed demand and variable energy charges) is a significant operating cost for charging stations. • Appropriate EV-specific separate tariff category or concession to existing applicable tariffs (both demand and energy charges) can support early market development.
3.	Grid interconnection and safety	• At e-Bus charging stations, the use of fast chargers (typically DC) leads to a high power load on the grid. This may cause power factor, load factor, harmonics, voltage deviations, etc., on the power grid, and hence should follow the country's grid code and regulations for overall grid safety.
4.	Integration with renewable energy (generation and storage)	• e-Bus will have a positive impact on operation, environment and economy if they can use renewable sources for charging. The source of renewable generation can be at the charging site and/or wheeled from a distant plant. • This renewable energy integration with a local battery energy storage system (BESS) at charging stations can allow cleaner EVs transition, healthier air, improved peak load management and lower cost of electricity.

As described in Chapter 5: Technical Assessment for e-Bus feasibility, e-Bus pilot will require 14 to 15 MW Peak power. To facilitate the power demand; for

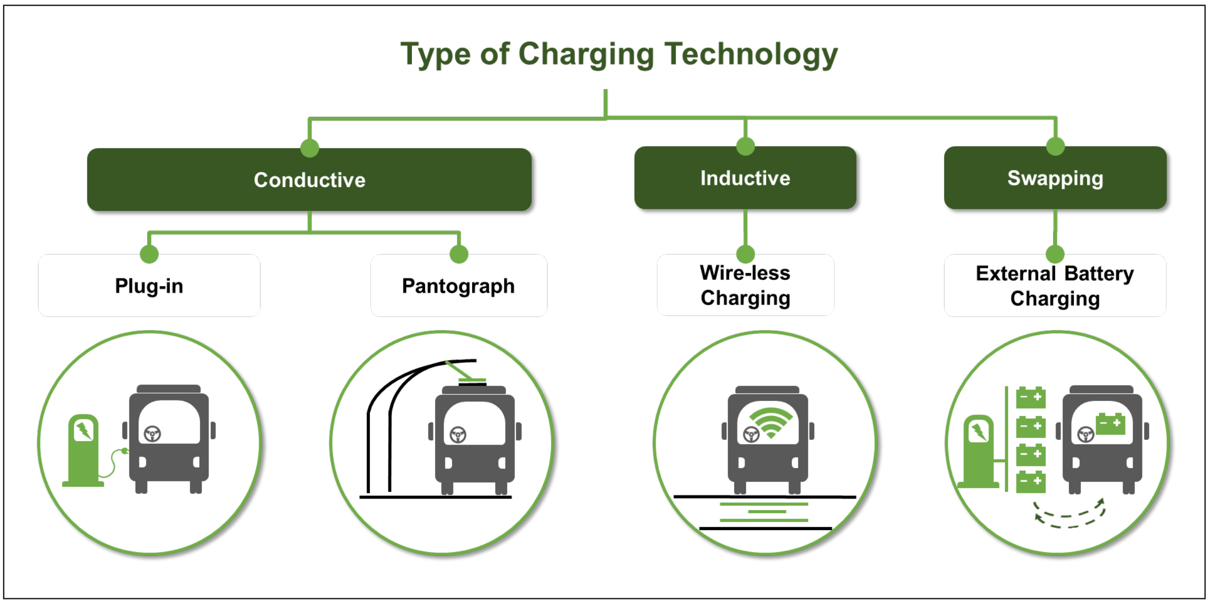
- Scenario 1.1: A grid voltage of 220 V and 0.03 MA is required at the Adenta depot. Or; for
- Scenario 1.2: A grid voltage of 220 V and 0.036 MA is required at Adenta depot, while the opportunity charging station at Tudu needs A grid voltage of 220 V and 0.032 MA.
- Scenario 2.1: A grid voltage of 220 V and 0.015 MA is required at Tema depot. Or; for
- Scenario 2.2: A grid voltage of 220 V and 0.015 MA is required both at Tema and Tudu depot.
- Scenario 3: A grid voltage of 220 V @ 0.006 MA, 220 V @ 0.004 MA, and 220 V @ 0.008 MA is required at Accra, Joffel and Kumasi depot

The required grid voltage and current are to be facilitated by GRIDCo[26] appropriately with a detailed demand assessment before deployment. Power distributors need to ensure uninterrupted and reliable power supply to the charging stations. The flexibility of augmenting the capacity in future has to be taken into account in case of the future expansion of e-Bus deployment.

Current tariffs of electricity are based on the unit consumed varies from 0.15 to 0.26 USD/kWh[27]. The tariffs are to be revised, and the Time of Use tariff system can be introduced to allow differential tariffs for EV charging based on peak and non-peak power. It is also necessary to plan for optimizing grid load requirements. Grid code regulations[28] are published by Energy Commission, which has to be followed while planning grid infrastructure for an e-Bus charging station to ensure interconnectivity and grid safety.

Integrating renewable energy would help eliminate well-to-tank emissions (WTT). It can be facilitated by enabling special contracts for clean energy provision; between e-Bus operator/PT Authority, Power distributor and Power Producer. Innovation and experiments with business models for e-Buses to be encouraged for integration of renewable energy.

8.2.4 Charging Technology Selection



26 Ghana Grid Company
27 https://gridcogh.com/) https://www.globalpetrolprices.com/Ghana/electricity_prices/
28 http://www.energycom.gov.gh/files/National%20Elect%20Grid%20Code%202009%20final%20EC.pdf

Sr. No.	Factor	Description
1.	Charging Technology used in electricity transfer	• Different charger technologies i) conductive charging (fixed chargers/ down pantograph/ up pantograph) ii) inductive or wireless charging iii) battery swapping existing and need to be rightly mapped to a 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 and overnight charging ii. Small battery with a mix of overnight charging and en-route opportunity charging iii. Battery Swapping: based on appropriate e-Bus operations planning for battery swapping; and others • This charging strategy needs to be designed considering the 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 the 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 to charging stations operated by different providers through a single application or platform. • Interoperability can also help in improving charging station utilization by share of e-Bus fleet chargers between; i. Other Public Transport vehicle segments (e.g., bus depot chargers shared with taxis, UV express and others) ii. Other non-PT vehicle segments (e.g., share of intra-urban public charging stations with private vehicles; share of inter-provincial bus charging stations with heavy commercial/freight vehicles like trucks).
6.	Charging standards	• There are existing different charging standards, including Combined Charging System (CCS), CHArge de MOve (CHAdeMO) and GB/T, which OEMs and countries are adopting (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 influence interoperability. • Charging standards for e-buses need to be developed in coordination with National standards for electric vehicle charging.

Plug-in charging (conductive) technology is suggested considering the first-time e-Bus deployment in the cities of Accra and Kumasi. E-Buses with 422 kWh and 350 kWh battery capacities are suggested for the first deployment, requiring DC (240 kW fast charging) charging at Depot and/or terminal both for Overnight and Opportunity charging. In contrast, the charger ratings may differ from 160 kW to 240 kW based on the charging strategy and charging schedule. The required charger ratings are specified in Chapter 8: City Charging Infrastructure Guideline.

For overnight charging, it is suggested to adopt DC Fast charger with 240 KW capacity, which would charge the battery with 0.25 to 0.5 C rates. The EVSEs have to be aligned/adjusted with the communication protocols of grid and battery and CPOs.

The suggested chargers are DC Fast chargers where cars and other light-duty vehicles cannot charge. E-Bus deployment will bring experience on e-Bus charging and their experience over the years. Until then, for the first deployment, it is suggested to provide dedicated charging for e-Buses with no integration other than e-Bus use (taxi, SUV and any other vehicle segments).

OEMs available locally, regionally and globally to be approached for required EVSEs their technologies. Inviting quotations and technical specifications of the EVSE products would help choose the required 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's terms and conditions. Charging model selection should ensure appropriate coverage of Public Transport routes and their local demand dynamics for suitable utilization (today and in future).
2.	Charging Optimi-sation	• The charging model should optimize and provide flexibility and capacity to cover dead milage for e-buses over and above daily billed travel distance from their typical daily operations.

The charging infrastructure sizing is undertaken based on an integrated analysis of route energy, battery sizing, and scheduling of both fleet and chargers. The analysis also takes into account the depot sizes and availability of parking spaces along with the passenger demand.

Scenario 1.1 and 2.1: There is only one charging event at the suburban end of the routes, i.e., at Adenta and Tema, to minimize the number of charging infrastructure and staff required and save on the TCO as explained in the next section of the report.

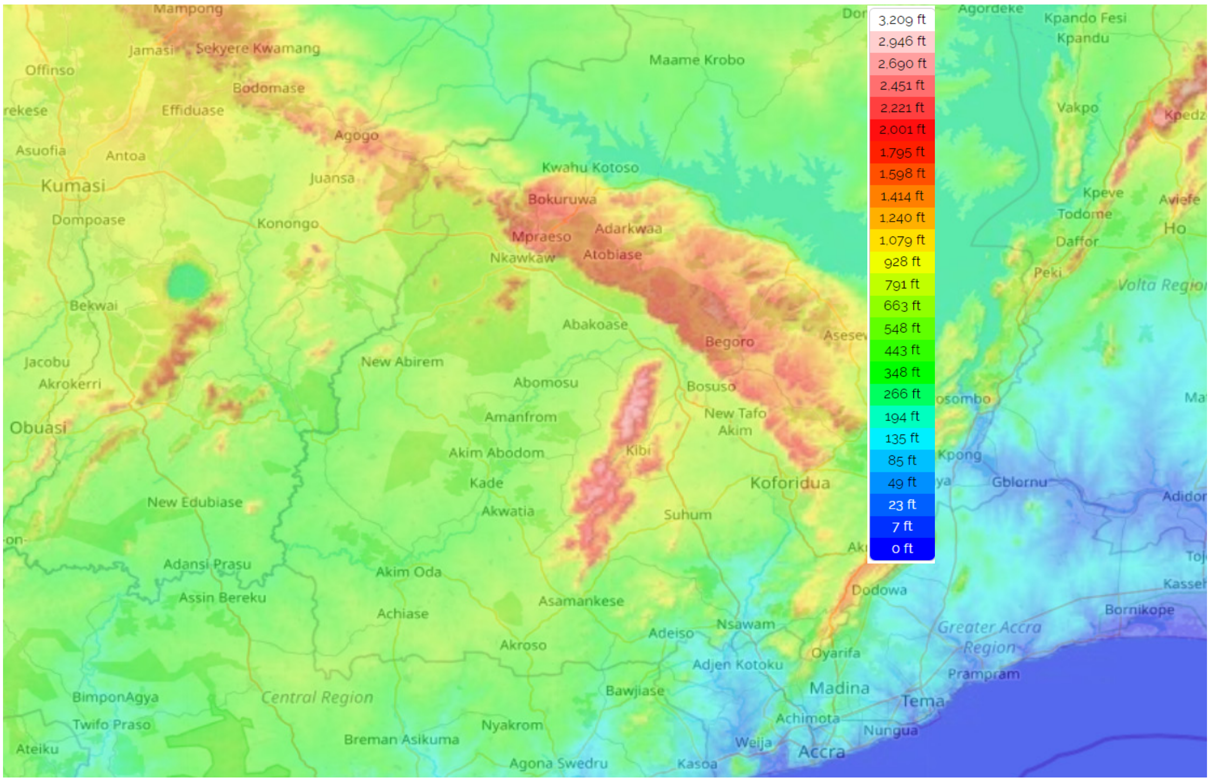
Scenario 1.2 and 2.2: In these scenarios, charging infrastructure is provided at both ends of the routes to properly accommodate the passenger demands during both the morning and evening peaks with minimal layovers. However, this results in a little higher TCO than in the above case.

Scenario 3: In this case, the charging infrastructure is provided in Tudu, Joffel, and Kumasi depots, as the route is quite an energy exhaustive and lengthy, providing intercity operations from Accra to Kumasi. Thus, after every leg of the journey, the e-Bus required charging, i.e., Accra to Joffel and Joffel to Kumasi and back.

8.2.6 Charging Infrastructure Safety

Sr. No.	Factor	Description
1.	Disaster resil-iency	• The land topography should be checked for any natural and man-made disasters like floods, earthquakes, 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 consideration.

The city of Accra encompasses a low-lying terrain with an altitude of 61 m and increases up to about 187 m towards Kumasi, which encompasses a hilly terrain and can be visualized from the map below. The intracity routes are low-lying, whereas the intercity route involves moving uphill from Accra to Kumasi. The routes chosen for e-bus deployment currently are not vulnerable to natural disasters. However, man-made hazards have to be taken into consideration. It may include major accidents, mishandling of public infrastructure, riots, etc. As the weather is moderate in Ghana, e-Buses are likely to suit and perform well in the cities of Accra and Kumasi. The actual operation of e-buses and their performance further will vary once operations start. The first deployment will help gather the experience and apply it for the future deployment of e-Buses.



8.2.7 Business Model Selection

Factor	Description
Cost of charger and charging infra-structure	• The cost of chargers and required supporting associated infrastructure has high implications on cost overall project cost. This becomes further challenged with lower charger utilization in early market development years if the e-Bus fleet is small. • The number of chargers needs to be judicially calculated, including contingency considerations, before purchasing chargers and charging infrastructure. • Government fiscal incentives on EV chargers and the required associated infrastructure can allow better business viability for charging infra providers and operators.
Charging infrastructure investment and ownership model	• Potential business models for providing the charging infrastructure; to be explored 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 where a. ▪ EVSE OEMs would invest and/or Operate charging stations or ▪ Energy Distribution companies (public and or private) would invest and/or Operate charging stations i. Full ownership of infrastructure and sub-contracting Operations and Maintenance to OEMs; and others
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.
Pricing Model	• Depending on the charging infrastructure ownership model and e-Bus types, there can be different pricing models for charging stations like 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

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

9.1 Investment Requirements

e-Bus is still in the pioneering phase in the country; thus, the need to adequately prove its technical and financial acceptability before private sector investments may be expected. This is particularly important considering that e-Bus fleet investments are very expensive and at least cost twice than conventional units. In lieu of this, the **total investments required to run 81 intracity buses and 17 intercity buses sum up to 40 million USD.**

Key Assumptions considered:

- Grid Costs around 100 USD/kW-peak
- Charging cost of 85 USD/ KW
- Installation and commissioning charges are considered 15 % of the overall charging cost

Table 30 Investment Requirements for Intracity and Intercity e-Buses

Parameter		Unit	Intracity	Intercity
			e-Buses (BYD K9) - Intracity	e-Buses (Yutong E10) - Intercity
Fleet	Fleet Size	#	81	17
Capital Cost (Vehicle + Battery)	One vehicle cost (without battery) including taxes	USD/vehicle	254,103	254,103
	Battery Size	kWh	324	422
	Battery cost	USD/kWh	200	200
	Effective tax rate on Battery	%	44%	44%
	Battery Cost (without subsidy)	USD/vehicle	92,988	121,114
	One vehicle cost with battery, including taxes	USD/vehicle	347,091	375,217
	Subsidy from Government	USD	-	-
	One vehicle cost with battery and including subsidy	USD	347,091	375,217
	Total Fleet cost with battery (and including subsidy)	USD	**28,114,371**	**6,378,689**

Parameter		Unit	Intracity	Intercity
			e-Buses (BYD K9) - Intracity	e-Buses (Yutong E10) - Intercity
Charging Capitalization Cost	Charger Size	kW	240	240
	Charger Cost	USD/charger	28,930	28,930
	No. of chargers required	#	33	9
	Grid Infra cost	USD/charger	82,800	82,800
	Installation and commissioning charges	USD/charger	16,759	16,759
	Overall cost of charger and infrastructure	USD/charger	128,489	128,489
	Overall charging capitalization cost	**USD**	**4,240,138**	**1,156,401**
Land Capitalization Cost	Land Required per charging station cum service station cum workshop (assuming idling area)	Ha	Existing Depot Used	0.162
	Land Cost per Hectare (including Land Acquisition)	USD/Ha		20,000
	Total Land Cost	**USD**	**-**	**3,240**

Total CAPEX	**USD**	**32,354,509**	**7,538,330**
	Million USD	**32**	**8**
Total Pilot Project Cost	**USD**	**39,892,840**	

Operational Cost	Annual Vehicle kms	kms/year/ vehicle	68,985	162,936
	Total Annual kms	kms/year	5,587,785	2,769,912
	Electricity consumption	kWh/year	9,803,132	4,859,495
	Annual Electricity Cost/Fuel Cost	**USD/year**	**1,264,604**	**626,875**
	Maintenance cost	USD/km	0.0100	0.0100
	Manpower cost	USD/km	0.0300	0.0300
	Annual Maintenance Cost	**USD/year**	**223,511**	**110,796**
	Annual insurance and other charges	**USD/year**	**27,540**	**5,780**

Total OPEX	**USD/year**	**1,515,655**	**743,451**
	Million USD/year	**1.52**	**0.74**

9.2 TCO analysis

It can be observed from Figure 48 that TCO/kilometre for Intracity diesel and e-Bus are 0.7 USD/km (5.32 Ghanaian Cedi/km) and 1.26 USD/km (9.57 Ghanaian Cedi/km), respectively. Similarly, TCO/ km for Intercity diesel and e-Bus is 0.44 USD/km (3.37 Ghanaian Cedi/km) and 0.82 USD/km (6.27 Ghanaian Cedi/km), respectively.

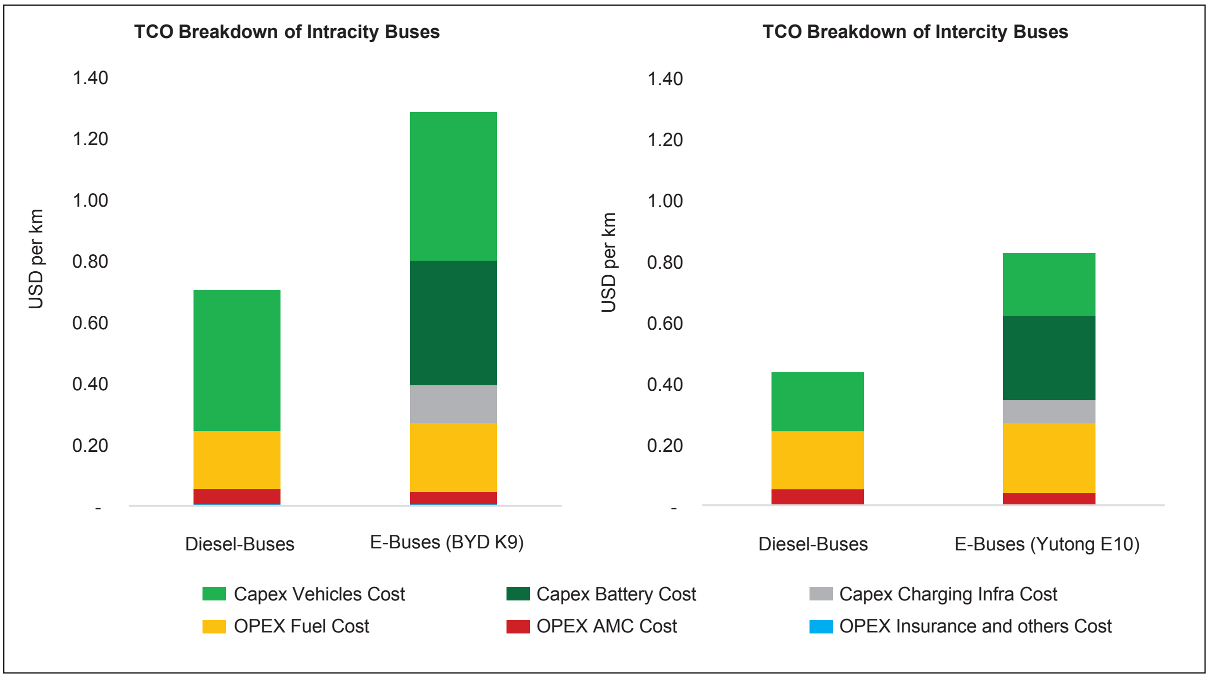


Figure 49 ICE vs EV TCO Analysis for Intracity and Intercity e-Bus

9.3 Financial Analysis

The lack of parity between electric and conventional buses is the major barrier to market penetration unless government interventions are introduced. As mentioned earlier, the comprehensive road map of the electric vehicle industry pushes for the inclusion of e-Bus operations. Financial analysis between e-Bus and ICE Bus provides net operating income (NOI) as negative due to more capital & operational cost of e-Bus, which suggests the need for intervention for costs reduction for e-Bus to make it feasible. Based on stakeholder discussion, grants, loans, and operational subsidies are identified to achieve parity with e-Bus. Henceforth, detailed analysis has been performed separately for intracity and intercity routes as both have different financial and operational requirements.

Coupling price reductions with grant/loan on a vehicle, battery and charging points and partly supporting personnel cost, electricity and loan amortization (7 years) by the government of Ghana (GoG) would be enough to make the project financially attractive. This provides a 20% incremental rate of return for the intracity route and 24% for the intercity route, highlighting that the added investment is worth it for the public project and benefits for the larger cause.

Table 31 Financial Analysis of Route Infrastructure Deployment

Component	For Intracity Routes	For Intercity Routes
Business Model		
Vehicle (w/o battery) capitalization cost	20% grant (climate finance), 30% grant (GoG) and 50% loan @10% interest rate for amortization period of 5 years	20% grant (climate finance), 30% grant (GoG) and 50% loan @10% interest rate for amortization period of 5 years
Battery capitalization cost		
Charging infrastructure capitalization cost		
Charging services	Operated by SPV and e-Bus OEM (cost recovered from collected revenue)	Operated by SPV and e-Bus OEM (cost recovered from collected revenue)
Interest rate subsidy	5% interest rate (50% subsidy) by the Government of Ghana (GoG)	5% interest rate (50% subsidy) by the Government of Ghana (GoG)
Electricity cost	20% subsidy over industrial tariff by the Government of Ghana (GoG)	20% subsidy over industrial tariff by the Government of Ghana (GoG)
Maintenance cost	Operated by SPV and e-Bus OEM (cost recovered from collected revenue)	Operated by SPV and e-Bus OEM (cost recovered from collected revenue)
Annual insurance cost	Cost recovered from collected revenue	Cost recovered from collected revenue
Annual registration/ renewal cost	Cost recovered from collected revenue	Cost recovered from collected revenue
Battery replacement	Cost recovered from collected revenue	Cost recovered from collected revenue
Land capitalization	NA	NA
Total Project Capitalization Cost (USD)	**33,217,128**	**8,678,653**
Vehicle (USD)	20,582,343	*4,827,957*
Battery (USD)	7,532,028	*2,301,166*
Charger (USD)	5,102,757	*1,546,290*
Land (USD)	-	*3,240*
Support and Subsidies		
Grant		
Vehicle (USD)	*From Climate Finance: 4,116,496* *From GOG: 6,174,703*	*From Climate Finance: 965,591* *From GOG: 1,448,387*
Battery (USD)	*From Climate Finance: 1,506,406* *From GOG: 2,259,608*	*From Climate Finance: 460,233* *From GOG: 690,350*
Charger (USD)	*From Climate Finance: 1,020,551* *From GOG: 1,530,827*	*From Climate Finance: 309,258* *From GOG: 463,887*
% of Total Project Capitalization Cost	*50%*	50%
Loan		
Vehicle (USD)	*10,291,172*	*2,413,979*
Battery (USD)	*3,766,014*	*1,150,583*
Charger (USD)	*2,551,379*	*773,145*
% of Total Project Capitalization Cost	*50%*	*50%*
Operational Subsidy by GoG		
Electricity cost (%)	*20%*	*20%*
Interest Rate Subsidy (%)	*50%*	*50%*
Total Operational Subsidy (USD)	*15,673,919*	*5,583,478*

Component	For Intracity Routes	For Intercity Routes
Projected Monthly Net Revenue		
Year 1 to 7 average (USD)	*3,806,837*	*1,824,381*
Year 8 to Year 15 average (USD)	*4,688,062*	*2,246,698*
All years average (USD)	*4,247,450*	*2,035,540*
Economic Performance		
Modified Internal Rate of Return (MIRR in %)	*13%*	*17%*

9.4 Deployment Plan

In this paragraph, the phases of the e-Buses' deployment are defined, and an estimated amount of time has been considered to complete the process. To realize the project phases, three phases in the project group are defined in terms of planning, procurement, and manufacturing. The short-term deployment phase continues till the third year from the initial deployment of the e-Bus pilot, wherein the first 100 e-Buses are deployed in the cities of Accra and Kumasi. The complete built unit is to be imported[29]. The fourth- and fifth-year plans refer to the medium-term deployment phase where an additional 500 e-Buses are to be deployed in Accra, Kumasi and other cities. In this phase as well, the complete built unit is to be imported. Beyond the fifth year, the long-term deployment vision is to scale up the deployment across Ghana with larger fleet sizes. However, this phase is earmarked for the "Made in Ghana" initiative, supporting local manufacturing. Table 31 reflects the deployment strategy as explained above.

Table 32 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 100 e-Buses deployment in Accra and Kumasi	Additional 500 e-Buses in Accra, Kumasi and other cities	Scale-up phase & higher deployment
Import/Local Manufacture	Import of Complete Built Unit (CBU)	Import of Complete Built Unit (CBU)	Local Manufacturing

9.5 Environmental Impact

The environmental impact assessment is done to compare an ICE bus with an e-Bus, as shown in Table 32.

It is found that tailpipe emission (Tank to Wheel) saving of e-Bus is 100% than that of ICE bus. But a similar analysis done over the lifecycle of a bus (Well to Tank & Tank to Wheel) causes 45% more GHG emissions from e-Bus than the existing grid scenario.

The table below presents the emission factors to calculate the implied emissions per vehicle-km. It is found that the Grid factor will greatly influence the GHG impact of e-Bus. For the year 2021, the Business-as-usual scenario (BAU) with a grid dominated by fossil fuel sources (0.28% renewable mix) causes 45% more GHG emissions from e-Bus. Therefore, only operating e-Buses will not meet the greener target

29 Ghana imports Cars primarily from United States ($212M), United Arab Emirates ($78.4M), Canada ($51.1M), Japan ($38.4M), and South Korea ($24.8M). The fastest growing import markets in Cars for Ghana between 2019 and 2020 were United States ($47.2M), United Arab Emirates ($9.21M), and Japan ($4.14M).

unless the source of electricity is coming from a cleaner grid (with more share of renewables). Ghana overall is working in the scenario of optimizing and bringing more renewables to mitigate both tailpipe and lifecycle emissions so as to meet the GHG mitigation target mentioned in the national roadmap.

Henceforth, the Business-to-be scenario (BTB) has been formulated, which recommends a 35% renewable mix for e-Bus charging as using green power lowers electricity costs and GHG, contributing to less pollution. The project need not wait till 2030 for the grid to become clean. There are mechanisms like solar purchase power agreement, leasing solar power, etc., that are available in the country, which provide solar power to a similar tariff as that of electricity in the country.[30]

Table 33 Implied Emission per Vehicle-km of e-Bus and ICE Bus

Engine Type	Average Distance Travelled	Operational Days[31]	Fuel Efficiency	Emission factor (EF)	GHG Emission	VKT	Implied Emission/ Veh-km
	V-km/day	days/year	Litres/100 kms or kWh/100 kms	$kgCO_2e$/ Litres or $kgCO_2e$/ kWh	$kgCO_2e$/ year	V-km/year	$kgCO_2$/V-km
	A	**B**	**C**	**D**	**E = (AxB) x (C/100) x D**	**F = (AxB)**	**G = E/F**
Diesel	210	329	33	3.20[32]	73,676	68,985	1.07
BAU: Electric with 0.28% renewable mix	210	329	175	0.87[33]	104,547	68,985	1.52
BTB: Electric with 35% renewable mix	210	329	175	0.56	68,146	68,985	0.99

With the BTB scenario, e-Buses emits ~50% lower GHG emission over the life cycle, as illustrated in Table 34. Additionally, as the electricity mix continues to decarbonise, the life-cycle emissions gap between e-Bus and ICE Bus increases substantially.[34]

30 Solar power is available at 9 US cents per kWh in Ghana (Energy expert)
31 90% days of the year are assumed to be operational days
32 Well to Wheel EF = Well to Tank + Tank to Wheel; For Tank to Wheel emission: 1 L of diesel consumption can produce about 2.67 kg of CO_2 & Well to Tank emission is assumed as 20% of Tank to Wheel emission
33 In case of electric, tank to wheel emission of vehicle is 0, whereas well to tank is based on countries grid mix and share of electricity production from renewable source. For grid EF of Ghana, IGES report is referred
34 BTB Scenario is modelled with 70% renewable share for electricity generation required to charge e-Bus by 2030 and 100% by that of 2040.

Table 34 GHG Emission and Economic Saving

GHG Emission Saving (over lifetime)				
No of Buses		**ICE Bus**	**e-Bus**	**GHG Emission Reduction Potential of e-Bus vs ICE Bus**
1	kgCO_2	1,107,175	640,334	466,841
100	kgCO_2	110,717,489	64,033,393	46,684,096
	Tonnes CO_2			46,684

Economic Saving (over lifetime)		
Economic Cost of CO_2	USD/Tonn	100
Economic Saving of CO_2	USD	4,668,410

With each bus, there is a potential of about 466 Tonnes of kgCO_2 reduction, resulting in estimated economic savings of about 46 thousand USD over a lifetime of 15 years. In proportion to 100 e-Buses, this will result in 46,684 Tonnes kgCO_2 of GHG saving and 4.6 Million USD of economic saving.

10. Conclusion

The proposed project is earmarked to be implemented on two major road corridors in Accra and the Accra-Kumasi corridor. Other corridors within the city would also be operationalized to increase electric bus ridership. Under the proposed Project, the daily trips of 24,000 passengers daily in Accra and 2,000 commuting between Accra and Kumasi, for example, on diesel-fired paratransit buses, will be made by 100 high-occupancy electric buses on zero-emission fuel. Phase one of the project should only focus on intracity e-bus operations in Accra. Subsequently, the Accra-Kumasi e-bus services may be undertaken based on the technical analysis presented in this report. Overall, the e-bus services for both intracity and intercity will generate multiple benefits over the implementation period on the selected corridors where the electric buses will be in service. Like, exposure to black carbon emissions from many street vendors will be minimized, reducing the health risk associated with local air pollution. Many local artisans, start-ups, training on maintenance, transport service operators and parts replacement of the e-Bus would be potential beneficiaries of this project.

Even though the original intent of this project is to introduce e-Bus, the charging infrastructure can also be extended to private individuals who may own electric vehicles in the city. The network of charging stations dotted at vantage locations in these cities would encourage other potential vehicle owners to procure electric-powered vehicles instead of fossil fuel-based ones.

Being the first of its kind to be introduced in Accra and Kumasi, the electrification of the e-Bus would drive Ghana’s green development initiatives and significantly leverage the gradual decarbonization of urban transport systems across the country. The Project would be a suitable model for implementing Ghana’s National Electricity Mobility Policy and the realization of the transport emission reduction objectives under Ghana’s NDCs. Regarding technology transfer impacts, the Project will be a ground-breaking initiative and an ambitious effort to give meaning to the realization of electric mobility not only in Ghana but across the sub-region. By far, the electric bus project would further demonstrate Government’s commitment to modernizing urban transport by entirely shifting from fossil-fuel-based systems to green electric mobility. The Project will 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 Accra will be scaled-up to over 1,000. The Project will have substantial leverage with the efforts to promote the penetration of solar energy.

11. References

The World Bank Group (2022). Ghana: Overview

https://www.worldbank.org/en/country/ghana/overview#1

12. Appendix

Sr. No.	Policy Elements			e-Bus specific Policy Options (Draft)			General Policy Options for EV
	Element	Sub-element	Description	National-level	For the region of Accra		
					Intracity level	Intercity level	
TARGETS							
T1	Targets	Clear Targets and Timelines	Target setting for e-Bus penetration in yearly sales	Systematically deploy e-Bus for Urban transportation aiming to achieve at least 16% of the total vehicle fleet mix by 2030	Commence pilot operations with 70 e-buses by 2023 and work towards upscaling to 1,000 high capacity e-buses by 2030	Commence pilot operations with 30 e-buses by 2023 and work towards upscaling to 300 e-bus by 2030	
T2			Target setting for public charging infrastructure (AC and DC)	Collaborate with the Private Sector to set up at least one charging Hub in each of the 256 local government administrations/ District Assemblies aiming for 2,000 charging points by 2030	New building regulations to require new Commercial Buildings with more than 20 parking spaces to have EV Charging Points.	New Guidelines to require all new rest stops along intercity road corridors to have Charging points by 2025 and existing rest stops by 2030	Increase rapid charge points up to 35% of the total installed charging points in collaboration with the private sector
T3			Target setting for local e-Bus production	Collaborate with the Private Sector to setup e-Bus production/assembly by 2040	Collaborate with OEMs to begin component manufacturing for e-Bus by 2030	Collaborate with OEMs to begin component manufacturing for e-Bus by 2030	Collaborate with the private sector to set up a BEV Assembly by 2040
DEMAND SIDE MEASURES							
D1	Financial incentives on purchase and use for e-Bus operators	Lower Purchase Cost of e-Bus	Reduction of taxation on e-Bus	Zero Rate E-buses by 2024			
D2			Allocation of Capital subsidy on purchase of e-Bus	In consultation with Banks, develop guidelines for financing e-Bus purchases by 2024			
D3			Exemption of annual vehicle registration charges on e-Bus	Develop regulations to exempt e-buses from payment of road user fees			

Sr. No.	Policy Elements			e-Bus specific Policy Options (Draft)			General Policy Options for EV
	Element	Sub-element	Description	National-level	For the region of Accra		
					Intracity level	Intercity level	
D4	Non-financial incentives for e-Bus operators	Convenience and Ease	Introduction of preferential franchisee benefits for e-Bus operators	Facilitate the creation of e-bus only routes in collaboration with local government authorities by 2040	Select high demand BRT corridors for e-bus only routes to facilitate intra-city travels		
D5	Fleet mandate for e-Bus operators	Increase e-Bus uptake with operators	Provision to mandate % e-Bus share in operators fleet	In collaboration with the National Road Transport Service Regulator, develop new legislations to mandate 25% e-Bus fleet operators share by 2030			
D6	Disincentives on ICE bus	Discouragement on the use of ICE Bus	Introduction of excise taxes on ICE Bus	Review legislation to increase excise taxes on ICE buses by 2030			Review legislation to increase excise taxes on ICE buses by 2025
D7			Introduction of a Green tax on petrol and diesel				
D8	Ensure Proper Technical Support	Regulate e-Bus suppliers	Introduction of e-Bus Supplier Accreditation	legislation to set standards and specifications for the importation/ assembly/ manufacturing of e-Bus by 2030			
D9	Stakeholders Awareness	Capacity building of national and local government agencies	Organization of capacity building programs/ initiatives for government stakeholders (both national and local level)	Institute mandatory training programmes for e-bus operators and garages in collaboration with the NRSA, DVLA and the NVTI			
D10		Mass awareness programs for e-Bus operators	Organization of awareness campaigns, drives and training programs for operators	Undertake quarterly sensitization programmes for transport operators			
SUPPLY-SIDE MEASURES							
S1	Stricter Emission Standards	Stricter Vehicle emission standards for ICE Bus	Strengthen vehicle emission standards for ICE Bus	Develop regulations for emission levels limit by 2023			
S2		Stricter fuel standards	Strengthen fuel standards for petrol and diesel	Enforce compliance to 50ppm limit and lower			

Sr. No.	Policy Elements			e-Bus specific Policy Options (Draft)			General Policy Options for EV
	Element	Sub-element	Description	National-level	For the region of Accra		
					Intracity level	Intercity level	
S3	EV and Charging Infra Standards and Guidelines	e-Bus Quality and Safety standards	Formulation of e-Bus Quality and Safety standards for safe import and local production	Legislation to set Quality and Safety standards and specifications for e-Bus local production by 2025			
S4			Formulation of homologation standards and local testing facilities for EVs	legislation to set homologation standards and specifications for local testing facilities by the end of 2025			
S5		National standards for e-Bus charging	Definition of national standards for e-Bus charging (AC and DC charging across vehicle segments and locations)	Collaborate with the Ghana Standards Authority to develop standards and regulations for the charging infrastructure by 2023			
S6	Local e-Bus industry Capability Building Program	Design and Process Mentoring Program	Provision of Technical Assistance (TA) on e-Bus design and production process mentoring program	incorporating design and mentoring programs on e-Buses into technical schools curriculae			
S7		Access to Quality Parts and Components	Facilitation of BTB programs with other countries for parts supply	Collaborate with OEMs to set up a network of EV parts supply by 2025			
S8		Facilitation of Technology Partnerships	Facilitation of joint product development initiatives with reputable technology companies	Developing a national policy with industry players in the EV industry to facilitate joint product development initiatives by 2024			
S9	Financial Incentives for manufacturing of e-Bus, parts, and components	Lower e-Bus setup and production cost	Provision of fiscal incentives on manufacturing of e-Bus, parts and components	Collaborate with the Ministry of Trade and Industry to review the Ghana Automotive Policy to incentivise the manufacturing of EVs and their parts by 2023			
S10		Increased localisation	Localisation targets for different e-Bus vehicle segments				
S11	e-Bus Demand aggregation by Government agencies	Government entity driven PT EVs aggregation and bulk procurement	Aggregation of e-Bus demand and stimulating local supply	Provide financing to quasi-Government Transport operators for the acquisition of e-Buses			
S12	Disposal, reuse and recycle	Vehicle scrappage guidelines	Definition of National guidelines for vehicle scrappage	Develop guidelines and framework for vehicle scrappage by 2025			
S13		Battery re-use and recycle guidelines	Development of environmental guidelines for battery re-use and recycle	Develop guidelines and framework for battery re-use and recycling by 2025			
S14		Incentivize investments on battery recycling	Establishment of battery R&D and inclusion in SIPP	Creation of a special R&D department within the Ministry of Energy by 2024			

Sr. No.	Policy Elements			e-Bus specific Policy Options (Draft)			General Policy Options for EV
	Element	Sub-element	Description	National-level	For the region of Accra		
					Intracity level	Intercity level	
S15	Pilots and Capacity Building	National R&D Centres on EVs	Establishment of Industry-Academia EVs Centre of Excellence (COE)	Reactivate the Centre for Urban Transportation to serve as a Centre of Expertise in urban transportation and facilitate the conduct of research into urban transportation, provide technical assistance and knowledge on urban transport to policy makers and for related matters by 2024			
S16		EV Pilots and Deployment	Provision to support for EV pilots and experimentation	Budget allocation for the piloting and experimentation of EVs			
S17		EVs Training and Capacity Building	Development of EVs Training and Capacity Building ecosystem	Setup accreditation scheme for EV Traning Schools in collaboration with the NVTI, DVLA and NRSA			
S18			Strengthen EV repairs and services across the nation	Collaborate with Technical and Vocational Institutions to build the capacity of Garages and Workshops on Evs			

TCO Methodology

Total Cost of Ownership (TCO) analysis helps to understand the different cost elements across the vehicle's life cycle, including various capital costs, taxations, and operational costs. It offers a more accurate assessment of the economic efficiency of an e-Bus over an ICE Bus (Diesel Bus). The methodology and assumptions considered for TCO calculation for the analysis are shown in Figure 49.

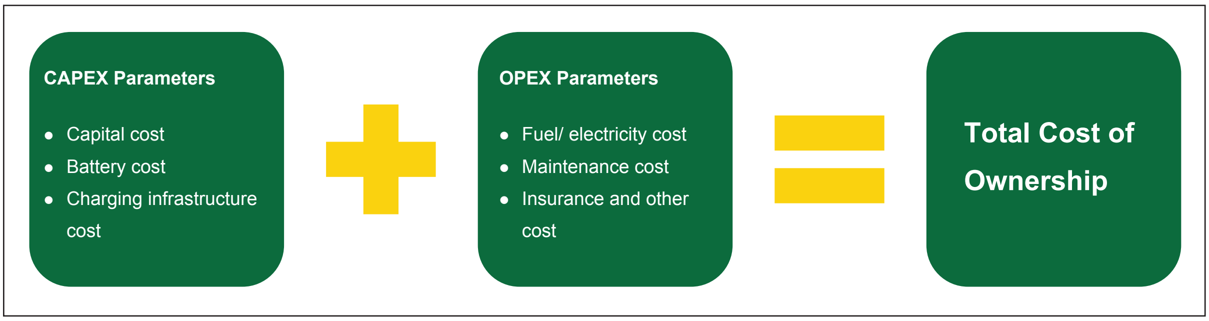


Figure 50 TCO Methodology

The different CAPEX and OPEX costs are annualized (i.e., adjusted to reflect a value on an annual basis) to arrive at the total yearly cost, which is then used to derive TCO per km. The TCO analysis also considers existing government incentives for EVs (currently, GoG is not giving any incentives). Battery replacement cost is accounted for depending on battery life for each vehicle segment. The vehicle segment-wise TCO analysis is shown in the following.