

Exploring Enabling Energy Frameworks for Electric Mobility in Rwanda

Technical Report
June 2025



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AMPERSAND

NYABUGOGO SWAP STATION



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Abbreviations and acronyms

AAGR	Average Annual Growth Rate
BEB	Battery Electric Buses
BEV	Battery Electric Vehicles
BRT	Bus Rapid Transit
CAPEX	Capital expenditure
CIF	Climate Investment Funds
CIT	Corporate Income Tax
CoK	City of Kigali
CPO	Charging Point Operators
CPP	Critical peak pricing
DBL	Dedicate Bus Lane
DFID	UK Department for International Development
DSO	Distribution System Operators
DT	Distribution Transformer
EDCL	Energy Development Corporation
EEE	Electrical and electronic equipment
EIB	European Investment Bank
EIF	Ecosystem Integrity Fund
ELMC	Electric Last Mile Connectivity
EOL	End-of-life
EPR	Extended Producer Responsibility
EPRS	Extended Producer Responsibility Schemes
ESG	Environment Social Governance
ESMAP	Energy Sector Management Assistance Programme
EUCL	Energy Utility Corporation Limited
EV	Electric vehicle

EVCI	Electric Vehicle Charging Infrastructure
FONERWA	Rwanda Green Fund
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse Gases
GoR	Government of Rwanda
IBT	Increasing block tariff
ICE	Internal combustion engine
IFC	International Finance Corporation
ITF	Infrastructure Trust Fund
LCPDP	Least Cost Power Development Plan
LDCF	Least Developed Countries Fund
LFP	Iron-phosphate
LIB	Lithium-ion battery
LV	Low Voltage
MSW	Municipal solid waste
MV	Medium Voltage
MW	Megawatts
NDC	Nationally Determined Contribution
O&M	Operations and maintenance
OPEX	Operational expenditure
PG&E	Pacific Gas and Electric
PGCIL	Power Grid Corporation of India Limited
PHEV	Plug-in-Hybrid electric vehicles
PPF	Project Preparation Facility
PV	Photovoltaic
REG	Rwanda Energy Group
REMA	Rwanda Environment Management Authority
RSB	Rwanda Standards Board

RTDA	Rwanda Transport Development Agency
RTP	Real-time pricing
RUMI	Rwanda Urban Mobility Improvement
RURA	Rwanda Utilities Regulatory Authority
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
TCO	Total cost of ownership
ToU	Time-of-use
ULAB	Used lead-acid batteries
US	United States
USAID	United States Agency for International Development
VGI	Vehicle-grid integration
VPP	Variable peak pricing
WB	World Bank

Acknowledgements

This study was conducted under the guidance of a World Bank task team led by Tarek Keskes, Energy Specialist, and composed of Akiko Kishiue, Senior Urban Transport Specialist; Arun Singh, Senior Energy Specialist; Adam Stone Diehl, Senior Transport Specialist; Clementine Umugwaneza, Energy Specialist; and Alphonse Nkurunziza, Consultant for the Rwanda Urban Mobility Improvement Project. The team expresses gratitude to Almud Weitz, Transport Practice Manager, and Sahr Kpundeh, Country Manager for Rwanda, for their guidance; Mits Motohashi, Lead Energy Specialist and Program Leader, for his review and input; Jonathan Davidar, Senior Knowledge Management and Learning Officer, for his creative direction and editorial support; and Yvette Umutoni, Team Assistant, and Mwiseneza Huguette, Senior Program Assistant, for their administrative assistance in preparing this report.

The study was executed by a consortium led by Economic Consulting Associates (ECA) with Energynautics and Green Resources. The consultant team was led by Seth Landau and comprised of Rana Imam, Andrew Tipping, Eckehard Troester, Richard Mori, Gilbert Ntabakirabose, François Zirikana, Jean Pierre Munyeshyaka, Camille Nyamihana, Thorsten Schlößer, Nicolas Jacob, and Marta Calore.

The World Bank team is deeply thankful to all the institutional partners in Rwanda for sharing their invaluable insights and comments. We extend our sincere thanks to Deo Uwimpuhwe and Gaelle Nsengiyumva from Rwanda Energy Group / Energy Utility Corporation Limited for serving as focal points for the study and for providing their technical support.

Financial and technical support from the Quality Infrastructure Investment (QII) Partnership and the Energy Sector Management Assistance Program (ESMAP) for the work is gratefully acknowledged.

QII: The World Bank Group and the government of Japan established the Quality Infrastructure Investment Partnership with the objective of raising awareness and scaling-up attention to the quality dimensions of infrastructure in developing countries. These include maximising the positive impact of infrastructure, raising economic efficiency in view of life-cycle cost, integrating environmental and social considerations, building resilience against natural disasters, and strengthening infrastructure governance. The QII Partnership accomplishes this goal through financial support for project preparation and implementation, as well as knowledge dissemination. The QII Partnership aligns to the G20 Principles. The QII Partnership is managed by the Infrastructure, PPP & Guarantees (IPG) group, housed within the Infrastructure Vice Presidency of the World Bank Group. The Partnership includes the following components: Component 1: Project Grants to enhance QII in operations; and Component 2: Analytical Work.

ESMAP: The Energy Sector Management Assistance Program is a partnership between the World Bank and 18 partners to help low and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group, ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable and modern energy for all. It helps to shape World Bank Group strategies and programs to achieve the World Bank Group Climate Change Action Plan targets.



Key messages

Rwanda's transition to electric mobility holds promise but requires careful infrastructure planning and energy sector development.

The successful implementation of electric vehicles (EVs), particularly battery electric buses (BEB), depends on establishing robust charging infrastructure and ensuring grid stability. The electric mobility (E-Mobility) transition must be managed alongside Rwanda's broader electricity demand growth, which requires careful attention to power supply reliability and infrastructure capacity. The increasing electrification across sectors has already led to supply-demand imbalances, prompting the government to explore alternative energy sources and plan more efficiently for future investments. With a specific goal to electrify 20 percent of buses in the country by 2030 and an expected growth of the bus fleet to over 4,100 by 2050, establishing comprehensive frameworks to meet these evolving needs is crucial.

Grid stability emerges as a key challenge to enable Rwanda's E-Mobility transition.

The Kigali network faces increasing challenges as active power losses are projected to rise from 3 percent in 2024 to 5 percent by 2030, with general load growth driving 1.9 percent of this increase and EVs adding 0.4 percent. By 2024, the maximum line loading had already exceeded safe limits at 136 percent. Without upgrades, this could theoretically increase to 235 percent by 2030 due to general growth, and 251 percent when including EVs. As a result, the number of overloaded lines is expected to rise from 9 to about 38 without EVs and 41 with EVs by 2030. To maintain grid stability, it will be necessary to conduct network reliability assessments, upgrade lines, and implement both pricing strategies and technological solutions.

Network upgrades are critical and must be planned in an integrated manner, considering all drivers of electricity demand growth.

The load increase from non-E-Mobility related demand is expected to be ten times higher than the increase due to EVs by 2050. In a high EV adoption scenario where almost the entire fleet is EVs by 2050, the impact of EVs on the projected peak demand increase would account for 7 percent of the total load, alongside an anticipated 10 percent annual growth in general electricity demand. Kigali's peak power demand is projected to rise 64 percent to 144 MW by 2030 – even without EVs. Under a high EV adoption scenario, demand rises just 6 percent more, to 152.6 MW. This underscores the need for integrated network planning that accounts for both EV charging and broader demand growth.

The localised impact of EV charging on distribution grids, particularly in urban areas like Kigali, also demands careful attention.

The urban areas are likely to see a higher concentration of EVs, with uncoordinated charging at specific points posing a risk of straining existing infrastructure. Additionally, harmonics introduced by EV chargers can distort the electrical waveforms if not properly managed. This could lead to power supply reliability issues and challenges in managing local grid capacity. Addressing these localised impacts will be essential for maintaining network stability and performance.

A unified roadmap is necessary to address policy fragmentation and ensure cohesive progress of E-Mobility initiatives.

This roadmap should detail specific transport electrification projects and policies, with strengthened coordination among agencies like the Ministry of Infrastructure (MININFRA), Rwanda Energy Group (REG), and the Rwanda Utilities Regulatory Authority (RURA). Establishing a sustainable transport working group with a focus on electrification will facilitate efficient planning and collaborative implementation of initiatives.

A robust regulatory framework, supported by technical guidelines and adherence to international standards, is vital for long-term system compatibility.

The adoption of standards such as CCS2 and GB/T ensures compatibility, reduces risks of obsolescence, and provides a seamless user experience. Dual-standard chargers enhance flexibility, allowing public transport operators to source BEBs from diverse manufacturers. Prioritising global standards will future-proof Rwanda's EV Charging Infrastructure, ensuring compatibility with emerging technologies.

Smart charging strategies offer a promising solution for maintaining grid stability and optimising infrastructure investment.

Through PowerFactory simulations, smart charging has demonstrated the potential to reduce network stress by 5-15 percent, particularly at the low voltage level where most EV charging occurs. By shifting charging times to off-peak periods and aligning with solar production, smart charging can help balance electricity supply and demand while reducing the need for costly infrastructure expansion. This is particularly important as hydropower is expected to remain the dominant electricity source until 2030, with solar PV set to grow significantly between 2040 and 2050.

Cost-reflective pricing for EV charging is crucial for the sustainability of E-Mobility initiatives, with time-of-use tariffs being a key starting point.

Currently, EV charging is billed at industrial rates, which may not fully reflect the additional strain on the grid. Any tariff used by EVs should account for the true cost of service. Time-of-use tariffs can support more dynamic pricing and incentivise grid-supporting services like demand response, helping manage charging behaviour while ensuring utilities can recover costs and maintain reliable service. They can also encourage charging during periods of high solar PV generation, reducing grid strain, promoting renewable energy use, and aligning electricity demand with renewable generation to further support grid sustainability.

Data-driven planning is a cornerstone of Rwanda's E-Mobility transition.

Integration of GIS systems, real-time charging data, and comprehensive charging profiles enables precise infrastructure deployment and proactive grid management. This systematic approach allows utilities to anticipate potential grid constraints, optimise charging station locations, and efficiently allocate resources for network upgrades. The combination of granular network monitoring with EV adoption tracking creates a feedback loop that supports evidence-based decision-making, helping planners balance the dual objectives of expanded EV adoption and grid stability. By maintaining visibility of both network performance and EV market development, Rwanda can adapt its infrastructure investments and policy interventions to evolving needs while minimising costs and maximising system reliability.

Innovative financing mechanisms, including public private partnerships (PPPs), green bonds, and government guarantees, are essential for scaling Rwanda's E-Mobility sector.

Blended financing options can mobilise resources, with institutions like the Rwanda Green Fund (FONERWA) playing a pivotal role in attracting private investment. Public entities such as REG can lead infrastructure development, while private players contribute expertise and capital. Existing private sector actors investing in the sector like Ampersand, EVP, Kabisa, BasiGo, REM, and Spiro highlight the growing interest in the E-Mobility market. Additional mechanisms can help scale up the investments.

Rwanda has made progress in end-of-life (EOL) battery management, but there is still substantial room for improvement and market development.

Key actions include making recycling more accessible through incentives, implementing Extended Producer Responsibility schemes, and promoting urban mining. Raising public awareness via education and community engagement is essential. Public institutions and companies should also assess their battery stocks to develop strategies and attract investment in electronic waste management.

The transformation of the Nyabugogo multi-modal transit hub demonstrates the potential of decentralised energy in charging infrastructure.

The total investment for upgrading the hub, including 18 chargers, an 800 kW solar PV system, and 470 kWh of battery energy storage, is estimated at US \$7.7 million, with the solar and battery system projected to save a total net of around US \$150,000 over 25 years. These investments, while modest in returns due to subsidised electricity tariffs, could become more attractive with cost-reflective pricing. The hub's peak power demand of 2160 kW necessitates strategic grid planning, including two 1250 kVA transformers to ensure reliability and redundancy.

The Central Business District (CBD), Remera, Kimironko, Nyanza, and Kabuga are additional charging hub options due to their power connection capabilities and minimal network expansion needs.

The assessment shows that the CBD can handle up to 3 MW and 40 plugs at 75 kW each, while Remera and Kimironko can each support 1.5 MW and 20 plugs. Nyanza can accommodate 3.2 MW with 42 plugs, and Kabuga offers two options: a direct connection with 3.8 MW and 51 plugs or an alternative requiring significant line upgrades. These locations are strategically chosen to ensure the efficient deployment of charging infrastructure across the city, minimising disruptions and costly grid upgrades.

Key recommendations

Drawing from the analysis of key energy challenges, a set of recommendations has been developed to support Rwanda's E-Mobility transition. These proposals aim to address critical energy issues, promote sustainable growth, and encourage investment. Implementing these recommendations can help refine policies, improve infrastructure, and mobilise resources to achieve electrification goals while maintaining grid stability and supporting long-term sustainability. Some of these recommendations are expected to be implemented as part of the World Bank-funded Rwanda Urban Mobility Improvement Project. An overview of the key recommendations is provided in the figure and table below.

FIGURE 1. Overview of key recommendations

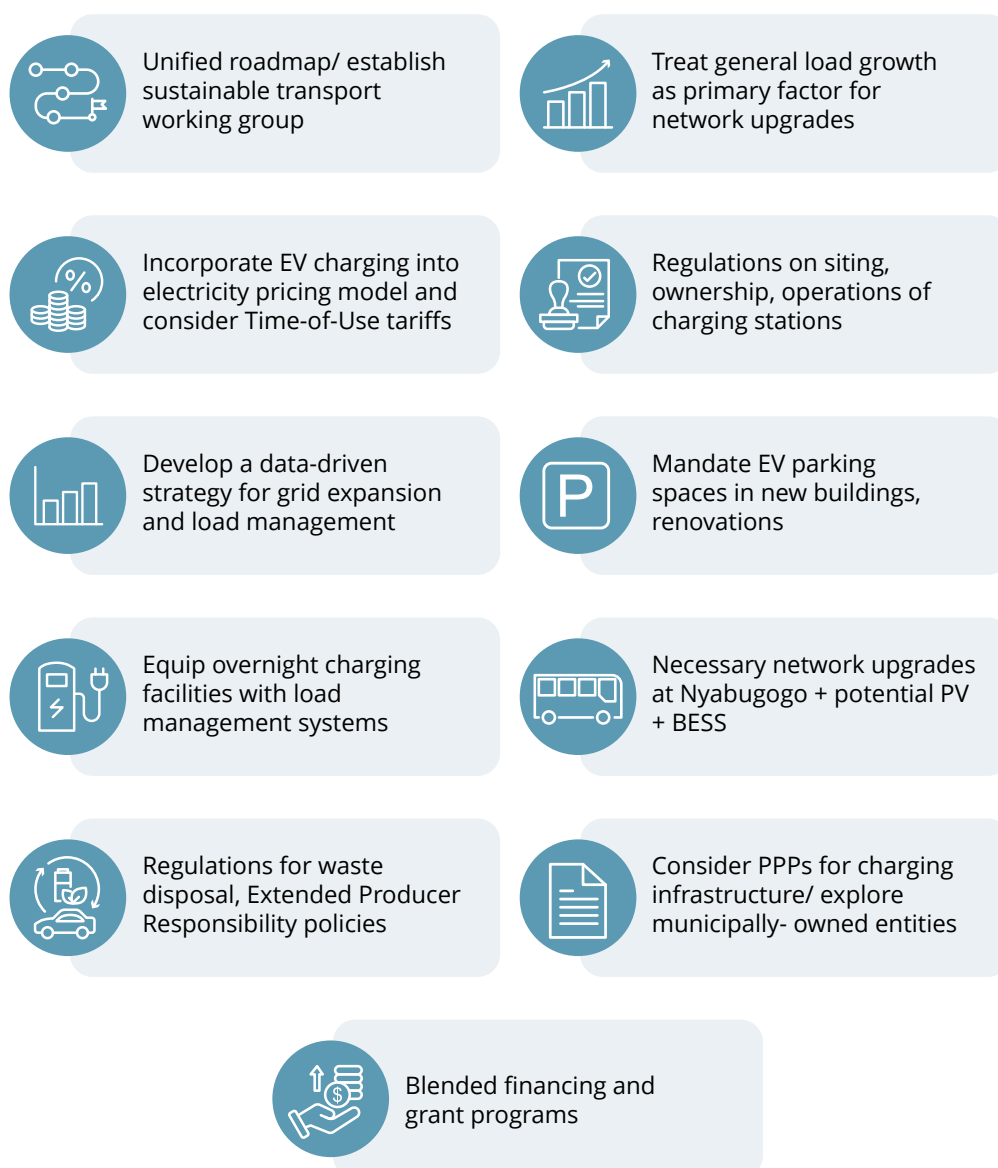


TABLE 1. Key recommendations

Challenge	Recommendation (Stakeholders; Timeline)
Disparate policies and plans	Develop a unified roadmap outlining specific transport electrification projects and policies. Establish a sustainable transport working group, including electrification. (MININFRA, REG, RURA; Short-term)
Increasing electricity demand	Treat general load growth as the primary factor driving network upgrades, with an additional 10 percent headroom for EV charging. (REG/EUCL, RURA; Short-term)
Inadequate electricity pricing for EV demand side management	Incorporate EV charging into the broader electricity pricing model and consider time-of-use tariffs. Regularly review pricing structures. (MININFRA, REG/EUCL, RURA; Short-term)
Lack of clear technical regulations and standards	Establish clear regulations for the planning, siting, ownership, and operation of charging stations. Develop technical guidelines for EV Charging Infrastructure. Consider adopting both European CCS2 and Chinese GB/T standards to ensure flexibility. Explore aligning national technical standards with international best practices, including ISO/IEC and GB/T standards. (MININFRA, Rwanda Standards Board (RSB), RURA, REG/EUCL, Cities; Short-term)
Lack of comprehensive data-driven strategy for managing EV grid integration	Develop a data-driven strategy for grid expansion and load management, including continuous monitoring of EV adoption, refining demand forecasts, and establishing a centralised system for both historical and real-time charging data. (MININFRA, Ministry of Information and Communication Technology and Innovation, REG/EUCL, RURA; Medium-term)
Insufficient charging infrastructure	Mandate EV parking space allocation in new buildings, major renovations, and commercial centres based on parking capacity and renovation scale. (MININFRA, Cities; Medium-term)
Potential grid strain from bus charging	Equip overnight charging facilities with load management systems to reduce peak load and monitor network constraints. (Bus operators, REG/EUCL; Medium-term)
Nyabugogo network design	Plan for necessary network upgrades, including a direct connection to closest MV line in 2027. Additional direct connection to 15KV NZOVE BB, with extension to Abattoir cabin, latest in 2032. Implement a load management system based on state of charge. Explore the installation of rooftop PV and the reuse of bus batteries as stationary storage. (City of Kigali; Medium-term)

Challenge	Recommendation (Stakeholders; Timeline)
Battery and E-Mobility waste management	Establish specific regulations for waste disposal. Enforce Extended Producer Responsibility policies. Invest in recycling infrastructure. (Ministry of Environment, RURA; Medium-term)
Limited private sector involvement in charging investments	Consider PPPs in the development and operation of charging infrastructure, ensuring a balanced market environment and fair competition. Explore the potential for municipalities to set up publicly-owned entities for specific projects, while maintaining a competitive market. (MININFRA, REG/EUCL; Long-term)
Lack of financing	Explore blended financing options, grant programs, guarantee mechanisms, and green bonds to support scaling up of investments. (FONERWA; Long-term)



The background image shows a yellow battery charging station for electric buses. A worker in a grey uniform with 'MEKSH' and 'MP/EN' on the back is standing near the station. The station has yellow metal frames and mesh doors. Inside, there are several charging units with fans. The scene is outdoors, with a building and some greenery visible in the background. A large white number '1' is overlaid on the top left, and a white line graphic is on the right side.

1 INTRODUCTION

This report presents the results of a study titled “Exploring Enabling Energy Frameworks for Battery Electric Buses in Rwanda”, conducted as part of the World Bank financed Rwanda Urban Mobility Improvement (RUMI) Project. The study assessed the energy sector's readiness to support E-Mobility, with an emphasis on battery electric buses (BEBs), and produced recommendations to enhance regulations, policies, institutional frameworks, and financing opportunities.

Rwanda is well placed in E-Mobility development within the African continent, given the stable energy sector institutions, electrification efforts, and sustainable transportation policy efforts. However, the electricity sector still faces challenges related to maintaining energy development and supply infrastructure, achieving a sustainable power mix, and stabilising the reliability of installed capacity. Furthermore, given increased electrification rates¹, the country faces a supply-demand imbalance, which the government is trying to address by promoting alternative sources of electricity, encouraging people to make productive use of the power on the national grid, and planning efficiently for future energy investments. The electricity sector also faces fiscal challenges. Until 2019, although Rwanda has tariffs that are among the highest in the region, the revenues of the REG fell below costs, requiring government subsidy payments from the budget to fill the gap.² However, since 2019 the government has implemented a series of changes in electricity tariffs to enhance cost recovery, developed a least cost plan and modernised utility operations thus reducing fiscal transfers to the electricity sector.³ Since 2019, Energy Utility Corporation Limited (EUCL) has been performing well with cost of debt decreasing from 8.1 percent to 4.3 percent in 2021. Since 2016, the electricity distribution system has also improved significantly, with system average interruption decreasing from 88 hours a year to 18.5 in 2022.⁴

Electrifying transportation will require careful planning to navigate existing challenges. While this applies to all vehicle types, battery electric buses (BEBs) demand special attention. These buses typically rely on fast charging stations rated between 150 and 180 kW⁵ – adding significant load to the grid. This demand could exacerbate current supply-demand imbalances and strain the power infrastructure.

The possible breakdown according to type of chargers for different types of vehicles is included in Section 2.2. This is particularly the case in Kigali which aims to significantly increase the number of electric buses. The Government of Rwanda has already been working towards transport electrification. Rwanda's 2020 Nationally Determined Contribution (NDC) outlines a goal to phase in electric buses, along with passenger vehicles, and motorcycles starting in 2020. It calls for up to US \$900 million for EV purchases and infrastructure development. On top of this, in 2021 the government committed to electrify 20 percent of all buses by 2030⁶ and published an electric bus feasibility study specifically for the City of Kigali. Already there are 9 operational e-buses in Kigali with 4 fast charging stations – 4 buses and two charging stations are managed by the private company BasiGO and leased to the bus operators on a per km basis, and 5 buses / 2 charging stations are managed by IZI. There are discussions of scaling this up to well over 100 e-buses in the coming years.⁷ Additionally, other EV companies are active – in particular for motorcycles (motos).

1 Cumulative connectivity rate is 75.9 percent with 54 percent connected to the national grid and 21.9 percent off-grid systems (Rwanda Energy Group, 2024)

2 *Lifting the burden of electricity subsidies while maintaining access*. ESMAP. 2019

3 Note that this has occurred with the support of the World Bank's Energy Subsidy Reform Facility.

4 <https://utilityperformance.energydata.info/>

5 Based on discussions with BasiGO

6 Government of Rwanda. Supercharging Rwanda's e-mobility transition. <https://www.environment.gov.rw/index.php?eID=dumpFile&t=f&f=55460&token=6003242e29667513f33c128466ffc760c62d81d8>

7 Based on discussions with e-bus companies carried out over the course of the assignment.

It is therefore key that planning - particularly by the publicly-owned electricity utility - accounts for the impacts of bus electrification and vehicle electrification more broadly, considering key aspects such as:

- Appropriate / customised electricity tariffs for electric bus and other vehicle charging;
- Ensuring the locations of charging stations can be accommodated by the grid;
- Ensuring that the generation requirements can be met by renewable energy and not simply inefficient diesel generation (which results in import of fuel and increased Greenhouse Gas (GHG) emissions).

The RUMI Project is expected to involve investment in 1) Public Transport Improvement through the Development of an improved Nyabugogo Multi-modal Transit Terminal and introduction of dedicate bus lanes (DBL), and 2) development of a Bus Fleet Renewal Scheme and Promoting electrical mobility (E-Mobility).

The study assessed the readiness of the energy sector for all types of EVs and derive recommended options specific to BEBs. This work provides input for energy policy options that can facilitate the sustainable electrification of buses in the country – with an eye towards understanding EVs' impacts on the power system more generally.

In parallel, there was also a relevant assignment being undertaken supported by the EU which is developing an EV charging Infrastructure Master Plan (hereinafter the EU study) (see Box 2 for more). To ensure there was no improper overlap between this study and the EU study, consistent communication was carried out. While the EU study focused more on the locations and potential business models for charging stations, this study focused on the implications / impacts on the energy and power system. Furthermore, the EU study was completed during August 2024, allowing for its use as an input into the assignment.

The Box 1 defines the electric vehicle and key terminology used in this study.

BOX 1. REPORT TERMINOLOGY

The types of EVs assessed in this report are:

- Personal electric two-wheelers;
- E-motos: electric two-wheeler motorcycle taxis;
- Passenger EVs: electric four-wheeler cars;
- E-taxis: electric four-wheeler taxis;
- E-buses: electric buses

Additionally, the term Electric Vehicle Charging Infrastructure is used to describe the structures, machinery, and equipment necessary and integral to support a EV, including battery chargers, rapid chargers, and battery swapping stations.

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2

DEMAND SIDE ANALYSIS



The demand side analysis presents data and analysis on how charging demand for EVs will impact electricity demand, as well as the power system and the utility.

2.1 Electric vehicle adoption outlook

2.1.1 Institutional setting

The National Transport Policy and Strategy, dated April 2021, from the Ministry of Infrastructure (MININFRA), is a key policy document in Rwanda promoting the development and support of EVs. The policy aims to encourage a shift from personal motor vehicles to walking, cycling, and public transport, with opportunities for integrating EV technology into shared transport services like bike-sharing. The policy is driven by national and international ambitions, including Rwanda Vision 2050, Transition Rwanda, the Paris Agreement on Climate Change, the United Nations 2030 Agenda for Sustainable Development, and the Sustainable Development Goals. The policy direction focuses on developing infrastructure and implementing incentives for investment in E-Mobility. The government's Strategic Paper for E-Mobility Adaptation, released in April 2021, outlines measures to encourage Rwanda's adoption of E-Mobility. Additionally, the most recent National Strategy for Transformation (2024-2029)⁸ explicitly includes actions for E-Mobility – noting that in urban areas, the focus will be on improving public transport services and promoting green transport (electric-mobility).

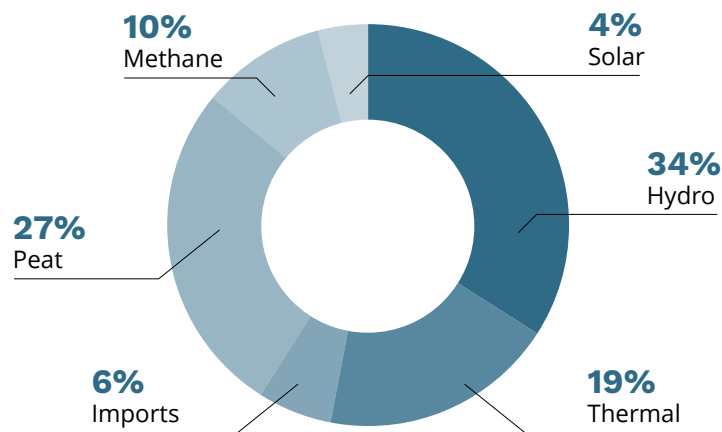
MININFRA is mandated to develop the public transport and energy policies and infrastructure. The Rwanda Transport Development Authority – Rwanda Transport Development Agency (RTDA) implements improvements to infrastructure and is under MININFRA. REG is responsible for energy infrastructure as a vertically integrated energy utility. The City of Kigali and other municipalities are also responsible for infrastructure development within the cities. Furthermore, they are mandated to enable and facilitate the operation of private companies providing public transport services and regulated by the Rwanda Utilities Regulation Authority – RURA. The charging infrastructure development and charging service provision will involve the trade ministry and Rwanda development board – RDB for investment mobilisation.

2.1.2 Least Cost Development Plan

The Least Cost Power Development Plan (LCPDP) outlines a significant increase in installed capacity to exceed 600 MW by 2030. This plan, covering the period from 2023 to 2050, is designed to guide generation expansion and meet anticipated demand. It is structured in two phases: the initial phase for committed projects (2023-2028) and the long-term phase (2028-2050). The plan includes forecasts for total energy and peak demands, which will be addressed through a mix of installed capacity and peak demand energy resources. The analysis indicates that photovoltaic (PV) installations offer a competitive generation price, leading to a greater emphasis on PV technology in the long-term strategy. As of 2023, Rwanda's total installed capacity is 332.6 MW, with an available capacity of 213 MW. The energy mix includes 56 percent from thermal power plants, 34 percent from hydropower plants, and 4.2 percent from solar photovoltaic (PV) sources. The share of installed capacity by generation source is illustrated in the figure below.

⁸ Available here : <https://www.minecofin.gov.rw/index.php?eID=dumpFile&t=f&f=112651&token=0d37e3b2e0b33ca65ec4fcc88d0c86132b3e6056>

FIGURE 2. Share of installed capacity by generation source



Source: Rwanda LCPDP Plan 2023-2050 - June 2023⁹

2.1.3 Overview of current and planned electric vehicle and charging stations in Rwanda

The table below shows an overview of the current and planned publicly available EV Charging Infrastructure (EVCI) or EV charging stations for buses in Rwanda, including details on specific city or region, geographic coordinates, charger types, and estimated annual energy consumption. The table also highlights the targeted end-users, primarily public transport operators, and outlines ownership and operational details. The chargers, mostly fast chargers rated between 120 kW and 160 kW, are designed to support fleets of electric buses, with charging strategies focused on overnight use. Each site serves between 5 and 20 e-buses, with ownership distributed between companies such as IZI Electric Ltd, BasiGO, Jali Transport, and Volcano Express Ltd.



⁹ [https://www.reg.rw/fileadmin/user_upload/Updated Rwanda LCPDP Plan 2023-2050 - June 2023.pdf](https://www.reg.rw/fileadmin/user_upload/Updated_Rwanda_LCPDP_Plan_2023-2050_-_June_2023.pdf)

TABLE 2. Charging infrastructure overview for e-buses

City / Region	Specific location (coordinates) X / Y	Type of charger (fast / medium / slow – with typical kW rating)	Expected consumption (kWh per year) ¹⁰
Kigali (Nyarutarama)	-1.9435817 30.1003474	Fast with 120 kW	748,610
Muhanga	-2.0786345 29.75104305	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Musanze	-1.4943695 29.6325197	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Rubavu	-1.6923525 29.2554132	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Karongi	-2.0538678 29.3487031	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Huye	-2.5934730 29.7412309	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Rwamagana	-1.9533377 30.4383009	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Gicumbi (Nyankeke)	-1.6345101 30.1358352	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Gicumbi (Byumba)	-1.5696237 30.0679911	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Ngoma	-2.1850283 30.4354201	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Nyagatare	-1.2851161 30.3348767	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440
Rusizi	-2.4762779 28.8955226	Fast with 120 kW per one charger (four chargers are anticipated)	2,994,440

¹⁰ The expected annual energy consumption was determined by multiplying the energy consumption per kilometres by the total Annual Vehicle Kilometres Travelled (VKT)

City / Region	Specific location (coordinates) X / Y	Type of charger (fast / medium / slow – with typical kW rating)	Expected consumption (kWh per year) ¹⁰
Kigali (Rwandex)	-1.9709917 30.08709163	Fast with 160 kW per one charger (five chargers are anticipated)	598,888
Kigali (Remera)	-1.9583601 30.1197447	Fast with 160 kW per one charger (five chargers are anticipated)	2,994,440
Kigali (Masaka)	-1.9797101 30.1873330	Fast with 160 kW per one charger (six chargers are anticipated)	2,994,440
Kigali (Nyanza)	-2.0043650 30.0922879	Fast with 160 kW per one charger (four chargers are anticipated)	2,994,440
Kigali (Nyamirambo)	-1.9624809 30.0607960	Fast with 160 kW per one charger (seven chargers are anticipated)	2,994,440
Kigali (Nyabugogo)	-1.9421325 30.0468444	Fast with 160 kW per one charger (five chargers should be installed)	2,994,440
Kigali (Nyabugogo)	-1.9402373 30.04623528	Fast with 160 kW per one charger (five chargers should be installed)	2,994,440

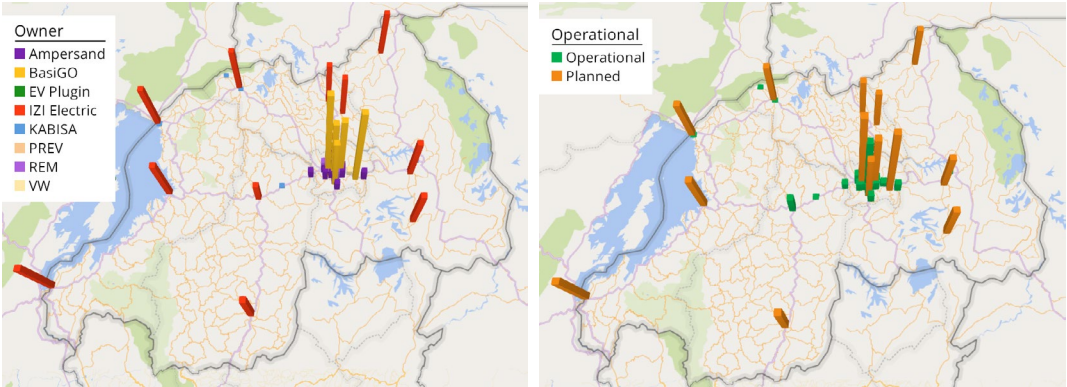
City / Region	Types of end-users, number of buses	Owners / operators / notes on operation (eg time of charging)
Kigali (Nyarutarama)	Public transport operators (5 e-buses)	Chargers are owned by IZI electric Ltd, and the charging strategy is overnight.
Muhanga	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Musanze	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Rubavu	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Karongi	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Huye	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Rwamagana	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.

City / Region	Types of end-users, number of buses	Owners / operators / notes on operation (eg time of charging)
Gicumbi (Nyankeke)	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Gicumbi (Byumba)	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Ngoma	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Nyagatare	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Rusizi	Public transport operators (20 e-buses)	Chargers will be owned by IZI electric Ltd, and the charging strategy is overnight.
Kigali (Rwandex)	Public transport operators (5 e-buses)	Chargers is owned by BasiGO ,and the charging strategy is overnight.
Kigali (Remera)	Public transport operators (20 e-buses)	Chargers will be owned by BasiGO, and the charging strategy is overnight.
Kigali (Masaka)	Public transport operators (20 e-buses)	Chargers will be owned by BasiGO, and the charging strategy is overnight.
Kigali (Nyanza)	Public transport operators (20 e-buses)	Chargers will be owned by BasiGO, and the charging strategy is overnight.
Kigali (Nyamirambo)	Public transport operators (20 e-buses)	Chargers will be owned by BasiGO, and the charging strategy is overnight.
Kigali (Nyabugogo)	Public transport operators (20 e-buses)	This is the proposed charger, and the owner shall be Jali Transport. The charging strategy is overnight.
Kigali (Nyabugogo)	Public transport operators (20 e-buses)	This is the proposed charger, and the owner shall be Volcano Express Ltd. The charging strategy is overnight.

Source: Based on market investigation and discussions with stakeholders about planned investments by the consultancy team

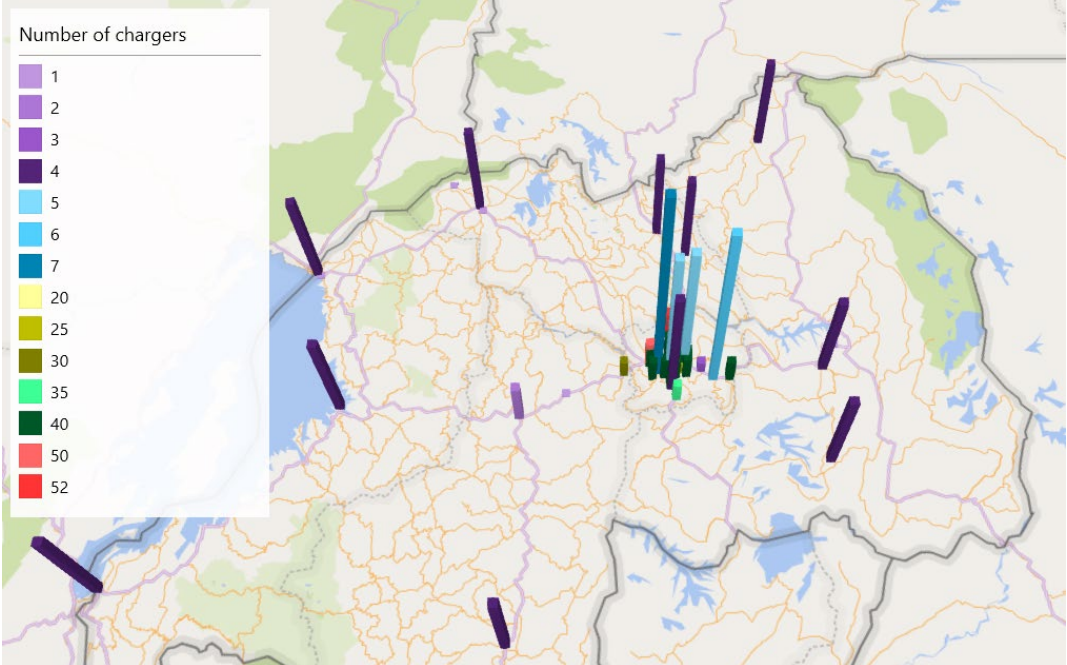
In addition to the charging stations outlined above, there are numerous smaller charging stations for private cars as well as battery swapping stations for two-wheelers (called motos) throughout Kigali. The figure below shows all operational and planned public charging stations, known to the consultants. The bar height represents the capacity of the complete charging station. Bus charging stations (BasiGO, IZI) have a significant higher capacity, compared to car charging stations (EV Plug-in, VW, Prev) or motorbike charging stations (Ampersand, Kabisa, REM), thus their impact on the electricity system is higher.

FIGURE 3. All known EV charging stations in Rwanda regardless of type by a) owner (regardless of operation status) and b) operation status (regardless of owner)



Note: Bar height represents station capacity in kW

FIGURE 4. All known EV charging stations in Rwanda and the number of installed chargers per site

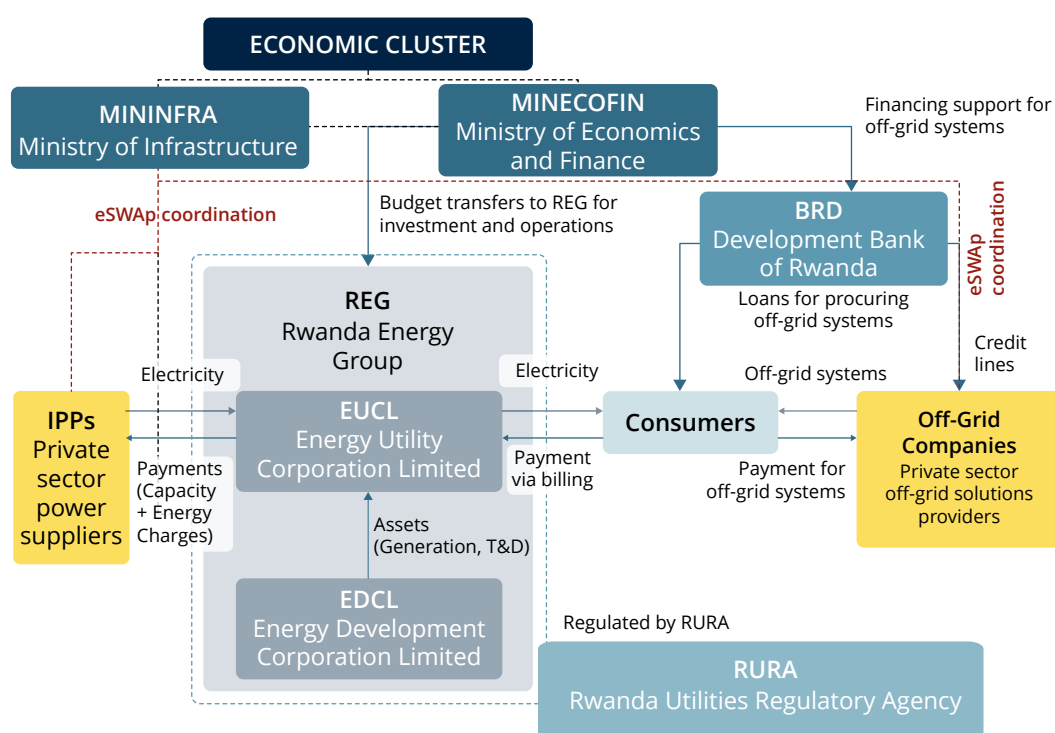


2.1.4 Review of existing and current E-Mobility policies, studies and plans

Institutionally, Rwanda is well placed to kick start an E-Mobility transition. In 2014, the energy sector undertook a substantial restructuring. As illustrated in Figure 5, the state-owned REG was set up to expand, maintain and operate the energy infrastructure in Rwanda through its two subsidiaries, the EUCL and the Energy Development Corporation (EDCL). Planning of generation and transmission as well as electrification projects are therefore the joint responsibility of MININFRA and REG.

Electric and water utilities are also separated, which now allows for better governance, financial accountability, and revenue and nonrevenue generating infrastructure development. The establishment of the Rwanda Utilities Regulatory Agency, an independent regulator, also enhanced the evaluation of the REG's revenue requirements and projects. As a result, Rwanda's energy sector is reasonably robust, since different sector responsibilities are adequately allocated to relevant sector entities with the mandate and legal foundation to perform their functions.

FIGURE 5. Institutional setup of the electricity sector in Rwanda after the 2014 reform



Source: Rwanda - Energy Access and Quality Improvement Project (English). Washington, DC : World Bank Group¹¹

Note: Economic Cluster: Cabinet Cluster overseeing the energy sector. T&D = Transmission and Distribution; eSWAp = Energy Sector-wide Approach.

¹¹ <http://documents.worldbank.org/curated/en/819241600653622828/Rwanda-Energy-Access-and-Quality-Improvement-Project>

In terms of electric transportation, the key institutions involved in development are:

- MININFRA – Oversees national infrastructure development including transportation and energy sectors. Published the Strategic Paper on Electric Mobility Adaptation in Rwanda (2021).
- Rwanda Environment Management Authority (REMA) – Focuses on environmental sustainability and plays a role in ensuring that E-Mobility initiatives align with environmental goals. It encourages public and private institutions as well as individuals to shift to EVs and join the effort to beat air pollution. REMA is also mobilising companies which supply EVs to install more charging stations around the country, to facilitate institutions and individuals outside Kigali to acquire EVs.
- RURA – Regulates public utilities, including transportation and energy sectors, ensuring compliance with standards and policies.
- RTDA – has been developing the business model for 2nd generation public transport services in the City of Kigali. The objectives of the project are to review the current bus operations, design a new public transport network and scheduled bus operation model, recommend traffic management improvements, prepare 2nd generation public transport contracts for Kigali.
- REG – Responsible for energy generation, transmission, and distribution, crucial for supporting EVCI.
- Rwanda Development Board – Supporting investment in green economy including E-Mobility infrastructure.
- City of Kigali – Which is developing E-Mobility infrastructure and supporting E-Mobility development in the city's public transportation system.

With regards to policy, the Government of Rwanda has defined targets for transport development and decarbonisation, contained within several documents such as the Rwanda Vision 2050, a long-term strategy to achieve economic growth and improved quality of life by 2050; the updated NDC; and the National Environment and Climate Change Policy. Targets focus on green mobility, including strengthening low-carbon transport systems, and transport sector mitigation measures, including the development of public transport infrastructure and the deployment of an E-Mobility programme. As a result of these measures, Rwanda aims to have 20 percent of all buses transition to electric by 2030, which will result in an estimated reduction of 72,000 tCO₂eq. So far, there is no target for the transition of the overall fleet. An overview of policies targeting E-Mobility are presented in Table 3. Furthermore, in the recently released National Strategy for Transformation (2024 – 2029) E-Mobility development is specifically included (see the table below).

TABLE 3. Overview of national policies targeting E-Mobility

Policy For E-Mobility Adaptation (2021)
The policy was approved in 2021 and contains the following incentives that apply to EVs, Plug-in Hybrid Electric Vehicles (PHEV) and hybrid EVs: • Electricity tariff for charging stations capped at the industrial tariff level (large industry category) and the vehicles will benefit from a reduced tariff during off-peak times; • EVs, spare parts, batteries and charging station equipment to be treated as VAT zero rated products, and an exemption of import and excise duties; • Exemption of Withholding Tax of 5 percent at customs; • Rent-free land for charging stations (for land owned by Government); • Provisions of EV charging stations in the building code and City planning rules; • Free licence and authorisation for commercial EVs; • Companies manufacturing and assembling electric and hybrid vehicles in Rwanda to be given other incentives such as 15 percent Corporate Income Tax (CIT) and a tax holiday; • Preference for EVs for Government hired vehicles.
Nationally Determined Contributions (2020)
Rwanda's NDC outlines a goal to phase in electric buses, along with passenger vehicles, and motorcycles starting in 2020. It calls for up to US \$900 million for EV purchases and infrastructure development. The NDC prioritised as key mitigation measures for the transport sector: • the development of public transport infrastructure, including BRT, bus lanes, and non-motorised transport lanes; • the deployment of an E-Mobility programme for phased adoption of electric buses, passenger cars, and motorcycles; and • the introduction of vehicle fuel economy standards and vehicle emission standards (including tax incentives and scrappage of older vehicles, and inspection). Rwanda's NDC also addresses the country's vulnerability to climate change, highlighting the importance of resilient transport infrastructure as a priority for human settlement development. Measures include the development of guidelines for climate resilient road infrastructure, the reduction of the length of roads vulnerable to floods and landslides, disaster risk monitoring, and the establishment of an integrated early warning system, and disaster response plans, among others.
National Environment and Climate Change Policy (2019)
Develops focus on green urbanisation and settlements and green mobility, including strengthening low-carbon transport systems, promoting non-motorised infrastructure, raising awareness through eco-driving courses and public events; and strengthening mitigation and adaptation in both planning and implementation, among others.
National Strategy For Transformation (2017-2024)
In the medium term, the National Strategy for Transformation (NST1)/Seven Years Government Programme (2017-2024) sets the priority for a green economy approach in its Economic Transformation pillar that promotes "Sustainable Management of Natural Resources and Environment to Transition Rwanda towards a Green Economy". Moreover, environment and climate change were highlighted in the NST1 as cross-cutting areas of policy concern which can be positively impacted by a range of development activities with priority given to agriculture, urbanisation, industries and energy.

National Transport Policy (2021)

The national transport policy of 2021 also has broadly prioritised E-Mobility under promotion of green and climate resilient transport. The policy actions are mainly on development of E-Mobility enabling infrastructure and incentives for investment. This policy has a gap in roles and responsibilities in terms of the clear role of the private sector in the implementation. It stipulates that transport infrastructure and services will be operated by private, public or private/public economic operators, however, the role of private investors is not defined in the policy implementation plan and all the cost related to construction of charging station for E-Mobility is attributed to MININFRA – which is the mandate of RTDA in the policy roles and responsibilities.

National Strategy For Transformation (2024 - 2029)

The updated national strategy includes specific actions for E-Mobility – noting that in urban areas, the focus will be on improving public transport services and promoting green transport (E-Mobility). Additionally, dedicated bus lanes will be introduced in the City of Kigali (CoK), and high-capacity road junctions will be constructed while rolling out smart traffic management systems to gradually ease traffic congestion at peak hours. Furthermore, the Strategy specifically includes activities related to building human capacity for the implementation of E-Mobility.

Green Growth and Climate Resilience Strategy

The strategy has been developed with a vision in mind for Rwanda to be a developed climate resilient and low-carbon economy by 2050. The 14 programmes of action include diversifying energy sources with low-carbon energy grid and promoting green technology and resource-efficient industries throughout all production levels from the primary stages, such as agricultural production and mining, to manufacturing industries in the secondary to tertiary public and private sector industrial activities, as well as transport and urban development.

The Government of Rwanda (GoR) is working with a range of partners to achieve sustainable mobility and an efficient and resilient transport system. Key partners are the Global Green Growth Institute (GGGI), UNEP, KfW, International Finance Corporation (IFC) and the World Bank (WB). A recent EV study carried out by the International Growth Centre recommended that the GoR should aim to convert 30 percent of motorcycles, 8 percent of private cars, 20 percent buses and 25 percent of mini and micro buses to electric power, by 2030, although senior officials and private sector firms have expressed their desire for a faster transition, especially in e-two-wheelers (e-motos).¹²

¹² Electric mobility in Rwanda: background and feasibility report, unpublished. SWECO. 2019. In: A roadmap for e-mobility transition in Rwanda. IGC. 2020

BOX 2. EV CHARGING INFRASTRUCTURE MASTER PLAN – EU AND MININFRA

In 2024, MININFRA, the Ministry of Finance and Economic Planning, and the EU kicked off a study supporting the development of a Master Plan for EV Charging Infrastructure in Rwanda.

The study developers engaged with EUCL and various stakeholders in the energy sector, including MeshPower, to gain an initial understanding of Rwanda's energy landscape and grid functionality. Key observations on the energy system included:

- Both rural and urban areas face challenges with grid capacity, as the peak demand for electricity continues to grow in both settings.
- REG remains responsible for ensuring proper connections.
- Private entities can either buy material through REG or purchase them on their own.
- Power generation currently meets the demand adequately, while the installed capacity is higher than the expected demand growth.
- Electricity tariffs receive substantial subsidies.
- Microgrids designed for peak shaving purposes could play a crucial role in power provision in rural areas and in facilitating the charging of electrical vehicles in those areas.

As for the transport system, activities were aimed at the identification of parking areas and charging infrastructure are underway. It was noted that transport models are available within MININFRA but that a licence to Cube is necessary to access them.

Engagement with stakeholders on charging infrastructure design and location showed that:

- Private transportation companies own and operate stations that are mainly concentrated in the City of Kigali.
- the CoK currently lacks predefined sites in its master plan for EV charging stations.
- public charging point operators are forming collaborations with petrol stations.
- RURA has not implemented standards for charging points and interoperability and technologies imported comply with both Chinese and European standards.
- Limited public land is available for charging facilities.

With regards to policy and regulation, the project aimed to delineate the roles and functions of public and private stakeholders in the emerging E-Mobility landscape. For example, the RSB is responsible for the implementation of standards, testing, product certification, accreditation, labelling, marking, and technical regulations, and E-Mobility service providers have provided and installed EVCI based on standards used in China (GB/T standards) and in Europe (IEC/ISO-based standards).

Regarding business models and financing, the project identified four key business models in Rwanda: privately-owned battery swapping infrastructure for e-two-wheelers (e-motos); privately-owned public charging infrastructure serving corresponding EV customers for EV private and commercial transport; private charging infrastructure for electric mini-buses and pay-as-you-drive for electric buses. Furthermore, E-Mobility service providers do not differentiate sources of financing for charging infrastructures from their E-Mobility business, and they often receive grant funding or are in partnership with several institutions.

Most studies so far have concentrated in the City of Kigali area, as illustrated in Table 4.

TABLE 4. E-Mobility studies for City of Kigali

Validation and definition of an AssetCo business model for electric bus provision in Kigali – JV CSC, TECOS Ltd., Panteia - CoK, financed by WB

This 2023 study builds on a 2021 IFC study which proposed an Asset Leasing Company (AssetCo) to procure and lease e-buses and infrastructure to private operators, described below. This model not only facilitates cost-effectiveness but also streamlines service coordination through integrated route planning. JV CSC, TECOS Ltd. and Panteia conducted a detailed techno-commercial feasibility study for the initial phase of e-bus deployment providing: a review of current institutional arrangements and regulatory review for the provision of bus services in the City of Kigali; a stakeholder readiness assessment to understand the current bus system processes and operations, and the potential to transition to electric buses, as well as stakeholders' concerns regarding this transition; a definition for a business model for the proposed AssetCo, including risk allocations and outlining the contracts required in such a model, with an evaluation of the various options through a market sounding, as well as identifying various entry points to ensure gender equality in the transition.

Pre-Feasibility study on introducing e-buses and smart transport systems in Kigali City – GGI

This 2022 report determines the operational, technical and financial viability of greening the Kigali public transport services through introducing electric buses and smart transport systems on suggested 3 bus routes. It finds that the smart and zero-emission public bus system will not only help the area to develop as a smart and sustainable city by reducing overall GHG emissions, air pollution, and traffic congestion, but also contribute to improving the area's clean image to the wider population. To assess the feasibility of EVs in the public transportation system, the report compares CAPEX and OPEX for internal combustion engine vehicles (ICE) and EVs finding that the total cost of ownership of ICE vehicles (US \$2,090,412) is a little higher than that of EVs (US \$1,735,424). EVs are less costly in terms of fuel and maintenance and that emit less CO₂.

Through smart bus management systems, electric buses are expected to be managed and served with absolute priority at most important junctions equipped with bus management systems. The project cost calculated in carrying out the first phase of ITS was estimated to be US \$1,858,000. Among them, the cost of the transport management centre was estimated at US \$1,050,000, and US \$808,000 for Bus Management System and Bus Information System for monitoring and managing the performances of electric buses and existing buses.

Inclusive and electric last mile connectivity study – EGIS, Cenex, World Bank

In order to support the GoR and the CoK initiatives on the development of E-Mobility in the country, in 2022 the World Bank published a study for the provision of additional technical support in Electric Last Mile Connectivity (ELMC). The study identifies viable business models using ELMC alternatives for private and public sector players: battery swapping and plug-in, which are both potentially viable. This has required an in-depth analysis of the existing situation, the passenger preferences, the market for ELMC options, the electricity supply and distribution, and the suitable institutional and regulatory framework to foster EV adoption.

Electric Bus Concept Validation in Kigali - IFC

This 2021 study compares bus technologies for Kigali to identify the most appropriate technology from a technological, environmental, economic and financial viewpoint, as well as the right routes on which to deploy electric buses. It additionally explores options for potential delivery structures (procurement, contracting and finance/funding) for deployment of e-buses. It subsequently analyses the financial viability and structuring of the deployment of e-buses and highlights specific social and gender considerations in improvement of public transportation.

The study recommends using fast-charged BEBs as technology of choice, due to its operational flexibility, its low total cost of ownership (TCO) and its positive environmental impact. The TCO benefit related to the transition to BEB occurs over a long period of time (as initial capex is higher and is offset by savings in operational expenditure over time) of approximately 10 years – and therefore probably reaches beyond available commercial market tenors for RWF-denominated financing, as well as beyond the assumed duration of a concession contract. This introduces a finance/residual value risk which requires an adequate commercial and financial structuring solution. The report highlights three typical commercial and financial structures for fleet and infrastructure delivery to address this (public sector-led, private sector-led (“PPP”) and public transport operator (PTO)-led delivery) and proposes an Asset Leasing Company (AssetCo) to procure and lease e-buses and infrastructure to private operators.

In terms of E-Mobility plans, the GoR has an E-Mobility programme for the phased adoption of electric buses, passenger vehicles (private cars and taxis) and motorcycles from 2020 onwards. At the city level, the 2020 Kigali Transport Master Plan sets out the strategy for enhancing urban and E-Mobility, and the Nyabugogo Multi-modal Transit Terminal project aims for the establishment of the standards for future bus terminal development.

Other players in EV charging station deployment are also emerging. These are private transportation companies that are penetrating the Rwanda E-Mobility market first through pilot programmes and e-transport sales.

TABLE 5. Private sector initiatives in E-Mobility

Ampersand
E-motorcycle pilot programme One of the first players into the e-motorcycle space has secured a \$3.5m investment from the Ecosystem Integrity Fund (EIF), Ampersand assemble and finance electric motorcycles that are cheaper, cleaner, better performing than most petrol motorcycle taxis that are in use across East Africa. Ampersand also build and operate a network of battery swap stations, allowing drivers to change batteries faster than refilling a tank. The pilot started in May 2019 and since then the fleet of 35 drivers have cumulatively covered more than 1.3 million kilometres - the company has a waiting list of over 7,000 drivers.
Ampersand
E-motos sale After testing their model, Ampersand is scaling up operations and has over 750 e-two-wheelers (e-motos) in operation served by over 11 battery swapping stations.
Safi Universal Links Ltd
E-motos sale Installed a fleet of 30 e-two-wheelers (e-motos) in operation with seven charging stations. Safi also set up a training centre set up for e-motorcycles.
Rwanda Electric Motorcycle Company (REM)
E-motos and Battery Electric Vehicles (BEV) sale REM focuses on assembling e-motorcycles and retrofitting ICEs into electric. Over 200 e-two-wheeler taxis (e-motos) on the road served through three charging stations. Also importing and selling BEVs, with over 20 sold to date. New partnership with Bank of Kigali to offer financing options.
Volkswagen
E-golfs sale Introduced 20 e-golfs fuelled by two charging stations operated by Siemens.
Victoria Motors Rwanda Ltd Limited
PHEV sale Victoria Motors Rwanda is a company set up to promote PHEV Outlanders and electric buses. It has sold 20 PHEVs that are in operation with corresponding domestic charging units and holds 60 PHEVs in stock.
Kabisa Electric Ltd
BEV sale & maintenance and charging stations Kabisa is a company importing EVs for sale and building up the EV ecosystem in Rwanda. This includes setting up an EV garage and building out a charge station network. Imported over 20 vehicles so far and installed over 10 public chargers across Rwanda, making it the largest charge point operator in the country.

KAS Auto
BEV sale and electric bus transport Importing electric pickups and buses. Currently operating a fleet of several electric buses for private hire.
BasiGo
Electric buses in Kigali \$1.5M from USAID to support expansion into Rwanda. Partnered with AC Mobility (Tap&Go) for user payments. Financing buses through pay-as-you-drive financing model. Aims to have 200 buses on the road end of 2024.

2.1.5 Electric vehicle uptake scenarios

Socio-economic assumptions

Three scenarios have been developed for the uptake of different EV types between 2030 and 2050, with a specific focus on the City of Kigali. The methodology involves two overarching steps. First, a model of current EV and ICE uptake, and second, a model of future EV uptake scenarios based on:

- Expected population growth.
- Different levels of climate commitments and infrastructure investments in transportation and urbanisation policies (Rwanda NDC Targets in reducing emissions). How many emissions will be avoided will also be included in the analysis.
- Differentiation in EV types by location (e-motorcycles may be more popular in urban centres while e-cars and e-vans in urban-rural transportation).

The population growth figures at the national level were based on the 2022 Fifth National Population and Housing Census,¹³ illustrated in Table 6.

TABLE 6. Population growth scenarios

2022 Population	2022 Urban Population	2035 Population growth (projected)		
		High Scenario	Medium Scenario	Low Scenario
13,246,394	3,701,245	17,553,613	17,494,219	17,431,549
		2050 Population growth (projected)		
		High Scenario	Medium Scenario	Low Scenario
		23,417,853	23,061,561	22,692,602

Source: Population and Housing Census (2022)

¹³ National Institute of Statistics of Rwanda. [5th Rwanda Population and Housing Census](#).

Forecast of the total fleet of vehicles

Historical EV and ICE estimations were carried out through consultation of experts and relevant official studies:

- 2024 Vehicle registration data (confidential), Rwanda Revenue Authority;
- 2023 Rwanda Statistical Yearbook, National Statistics Institute of Rwanda;
- 2022 Statistics in Transport Sector of Q4, RURA;
- 2019 Statistics in Transport Sector as of June, RURA.

The growth rate of EVs and ICEs was then expanded linearly for vehicle categories for which data was available.

Seven vehicle types / uses were considered for scenario development (see the table below).

TABLE 7. Types of vehicles and their characteristics – including power requirements

Type of vehicle	Description of characteristics	Power requirements
Personal two-wheelers	1-2 passengers	3-10 kWh battery, 1-11 kW charging
Taxi two-wheelers (motos)	1-2 passengers	3-10 kWh battery, 1-11 kW charging
Private cars (four-wheel vehicles)	1-7 passengers	40-120 kWh battery, 11-150 kW charging
Four-wheelers taxis	1-7 passengers	40-120 kWh battery, 11-150 kW charging
Buses	Up to 100 passengers	200-400 kWh battery, 22-250 kW charging
Light duty vehicles	Up to 10 tonnes	40-120 kWh battery, 11-150 kW charging
Bicycles	1 passenger	0.4-1 kWh battery, 1-2 kW charging

The underlying assumptions to forecast the total number of vehicles per type are presented in the table below.

Shift in vehicle use aligned with patterns with Gross Domestic Product (GDP) growth (eg, shift away from two-wheelers to four-wheelers as income levels rise) have not been considered in this study due to the high unpredictability of the trend, as well the limited relevance to the scope of the work.

TABLE 8. Total number of vehicles forecast assumptions

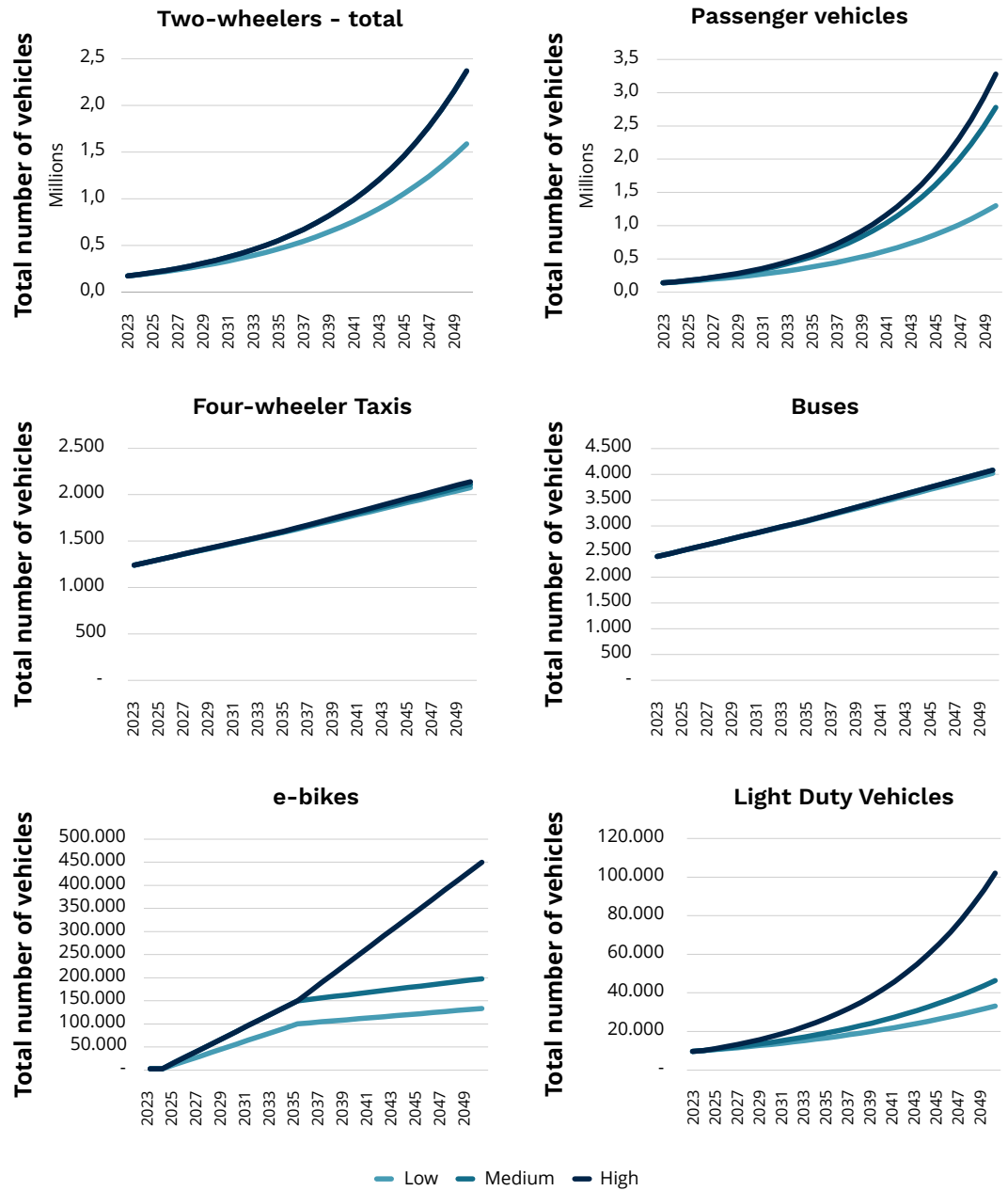
Type of vehicle	Low	Medium	High
Personal two-wheelers	AAGR: 8.6%	AAGR: 10.2%	AAGR: 12.4%
	The scenarios are based on historical trends. The low scenario includes the COVID-affected years and assumes that potential future economic downturns may slow growth. The medium scenario is based on a four-year historical average, while the high scenario reflects only the growth rate from 2023—a year expected to show strong economic recovery from the impacts of COVID.		
Taxi two-wheelers	AAGR: 8.6%	AAGR: 10.2%	AAGR: 12.4%
	Similar growth and number of vehicles expected as for personal two-wheelers.		
Private cars	AAGR: 8.6%	AAGR: 10.2%	AAGR: 12.4%
	Based on historical trends.		
Four-wheelers taxis	AAGR: 2.0%	AAGR: 2.0%	AAGR: 2.0%
	Increase in line with population forecasts per scenario.		
Buses	AAGR: 2.0%	AAGR: 2.0%	AAGR: 2.0%
	Increase in line with population forecasts per scenario.		
Light Duty Vehicles	AAGR: 4.7%	AAGR: 6.0%	AAGR: 9.3%
	Based on historical trends		
e-Bikes	AAGR: 15.7%	AAGR: 17.5%	AAGR: 21.3%
	Rwanda does not have an official bike count, so assumptions were made directly for the e-bike forecast. Assumptions regarding e-bikes market penetration are provided in the dedicated section.		

Source: Reasoning for assumptions is described in the table above. Note AAGR is Average Annual Growth Rate

The resulting forecasts per vehicle and per scenario are shown in the figure below. Note that two-wheelers and passenger vehicles are expected to grow exponentially due to increased incomes in the absence of strong programmes to encourage public transportation or other more sustainable modes of transportation. Even with this exponential growth, the number of vehicles per 1000 people projected in 2050 (approximately 57 passenger vehicles and 35 two-wheelers) would still be significantly less than the current EU average of 560¹⁴.

¹⁴ See <https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240117-1#:~:text=In%202022%2C%20the%20average%20number,cars%20per%201%20000%20inhabitants>.

FIGURE 6. Total number of vehicles forecast



Source: ECA assumptions

Electric vehicle market penetration

EV market penetration refers to the extent to which EVs are adopted within a particular market or region. It is typically measured as the percentage of EVs relative to the total number of vehicles in use. The medium case is aligned with EU study assumptions for percentage of EVs as confirmed in conversations with EUCL/REG. The resulting forecasts per vehicles and per scenario are shown in the table below.

TABLE 9. EV market penetration per type of vehicle and per scenario

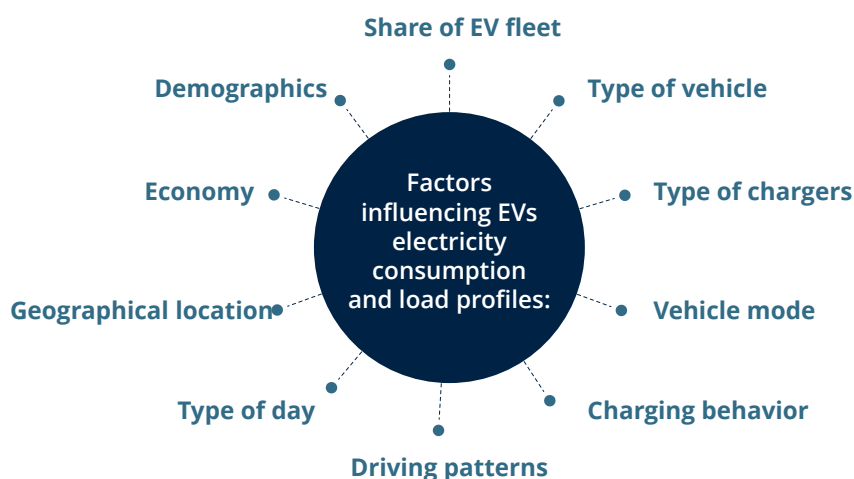
Type of vehicle	Scenario	2024	2030	2035	2040	2045	2050
Personal two-wheelers	Low	3.9%	15.0%	36.3%	57.5%	78.8%	100.0%
	Medium	3.9%	38.5%	67.3%	100.0%	100.0%	100.0%
	High	3.9%	100.0%	100.0%	100.0%	100.0%	100.0%
Taxi two-wheelers	Low	3.9%	15.0%	36.3%	57.5%	78.8%	100.0%
	Medium	3.9%	38.5%	67.3%	100.0%	100.0%	100.0%
	High	3.9%	100.0%	100.0%	100.0%	100.0%	100.0%
Private cars	Low	-	12.4%	28.0%	35.3%	42.7%	50.0%
	Medium	-	35.0%	70.0%	80.0%	90.0%	100.0%
	High	-	35.0%	70.0%	80.0%	90.0%	100.0%
Four-wheelers taxis	Low	-	9.9%	13.7%	17.5%	21.2%	25.0%
	Medium	-	12.4%	28.0%	35.3%	42.7%	50.0%
	High	-	25.0%	43.8%	62.5%	81.3%	100%
Buses	Low	2.1%	10.0%	13.8%	17.5%	21.3%	25.0%
	Medium	2.1%	13.0%	22.0%	31.3%	40.7%	50.0%
	High	2.1%	20.0%	40.0%	60.0%	80.0%	100%
e-bikes	The total number of e-bikes is forecasted directly.						
Light duty vehicles	Low	-	6.9%	12.7%	18.5%	24.2%	30.0%
	Medium	-	11.5%	21.2%	30.8%	40.4%	50.0%
	High	-	17.3%	31.7%	46.2%	60.6%	75.0%

Source: ECA Analysis

2.2 Charging demand analysis

With the increase in EVs, EV charging demand, and therefore electricity demand, is expected to rise. On top of this, EV charging is also expected to have major consequences on the power system load profile. Not only will this be affected by the type of EVs, but also by other several factors such as charging level, charging location, time and day of charging, driving behaviour, as illustrated in Figure 7.

FIGURE 7. Factors influencing EV load



Source: ESMAP. 2023. Electric Mobility and Power Systems: Impacts and Mitigation Strategies in Developing Countries. ESMAP Technical Report 22/23. Washington, DC: World Bank.

First, charging demand is highly dependent on the penetration of different modes and types of vehicles, which are characterised by diverse charging patterns, energy consumption and battery capacities. For example, buses, with their defined routes and schedules, have easy to forecast and manageable demand – including from depot overnight charging. Furthermore, electric car types also have different impacts on power requirements and load profile. In fact, BEVs are powered by batteries with larger capacities (17–100 kWh), while PHEVs have smaller battery sizes (4–17 kWh), allowing shorter electric driving ranges.¹⁵

Second, the following charging use cases exist, although not all use cases apply to each transportation mode. The charging power per use case depends on the vehicle type and the available time to recharge the vehicle.

- Residential charging – EVs used for individual mobility purposes (e-bikes, private cars) are often parked and charged close to residential buildings, either on private or public ground. The parking time (eg overnight) is usually substantially longer than the time necessary to recharge the electric vehicle battery, thus allowing for a flexible charging process.
- Workplace charging – The EV is parked at the workplace during daytime working hours. The parking time is usually longer, than the time necessary for recharging, thus also allowing for a flexible charging process.

¹⁵ ESMAP. 2023. Electric Mobility and Power Systems: Impacts and Mitigation Strategies in Developing Countries. ESMAP Technical Report 22/23. Washington, DC: World Bank.

- Depot charging – Happens outside operational hours and is used by fleet owners/operators. Flexibility to delay charging processes is typically available and often already used by the depot manager to reduce peak power.
- Opportunity charging – The EV is parked while the driver is executing various activities (eg shopping, driver-breaks, cargo loading). These activities of up to 4 hours duration provide further recharging opportunity. To receive a sufficient recharge within the given time, fast charging is ideal. Flexibility for delaying the charging process is very limited.
- On-route charging – Includes all charging scenarios, where the electric vehicle driver actively waits for the vehicle to recharge to continue the journey. There is no flexibility and the provided charging power should be as high as possible. This does not include battery swapping, where the charging could occur at a different / delayed time at a lower charging power.
- Battery swapping – Is not a traditional charging use case, since the recharge duration is not limited by the drivers need to continue their journey. The flexibility to recharge the spent battery is higher. Currently, the recharging process is similar to depot charging, with room for improvement depending on the local energy cost structure.

Third, charging demand is influenced by the charging behaviour and driving patterns, as well as type of day and time of day. For instance, on weekdays a peak is apparent in the evening as commuters return home, while consumption in the weekends is lower. Examples of charging behaviour are given below:

- Daytime charging – Taxis and other public transport may charge their vehicles during the day in central urban areas. This could result in the extensive use of public and third-party charging stations, reaping excess generation from rooftop solar installations, and alternative models such as battery swapping.
- Evening charging – Without smart technology and automated chargers, most private EV charging will occur when drivers return home from work in the evening.
- Overnight charging – Consumers may seek to benefit from lower overnight time-of-use tariffs by charging their EVs at night when electricity demand is lowest.

Demographic characteristics of EV users, such as driver gender, age, household location, and income, can influence charging patterns and affect total energy consumption and the local power grid. Studies have shown that males tend to drive more kilometres and start commuting earlier, while females drive less, and older EV owners exhibit earlier charging peaks. Drivers in urban areas generally drive fewer kilometres than those in rural regions, and higher income groups show slightly delayed charging peaks. Additionally, geographical location and the structure of a country's economy play a significant role in shaping the load curve, particularly in developing regions where peak loads occur in the evening due to limited industrial activity. For example extreme temperatures, road gradients, and other environmental factors, such as those experienced in mountainous regions, can also reduce EV range, influencing both energy consumption and vehicle preferences, as shown in recent studies.¹⁶

Based on the market penetration and using assumptions as described below, a model was developed to assess the additional electricity demand from EV charging and the hourly load profiles both at the national level and specifically for the City of Kigali. The charging demand analysis has been carried out through the following steps:

¹⁶ ESMAP. 2023. *Electric Mobility and Power Systems: Impacts and Mitigation Strategies in Developing Countries*. ESMAP Technical Report 22/23. Washington, DC: World Bank.

1. Assessment of typical charging cycles per vehicle type;
2. Bottom-up assessment of the hourly and annual demand associated with the total EV fleet charging;
3. Assessment of the impact of EV charging on the total electricity demand.

2.2.1 Step 1: Typical charging patterns by vehicle types

Setting and defining typical charging profiles for different types of EVs is essential when conducting a bottom-up analysis of their impact on the system's load. Different types of EVs, such as PHEVs and BEVs have distinct charging behaviours and energy requirements. Accurate load forecasting requires understanding these variations to predict the overall impact on the grid. The typical charging profiles will not only depend on the type of vehicle and usage of this vehicle, but also on the type of charger (fast vs low), as well as tariffs and consumer charging preferences. Typical charging profiles are shown in the following figures and the assumption behind the construction of these profiles is summarised in the below table.

TABLE 10. Typical charging profiles – assumptions

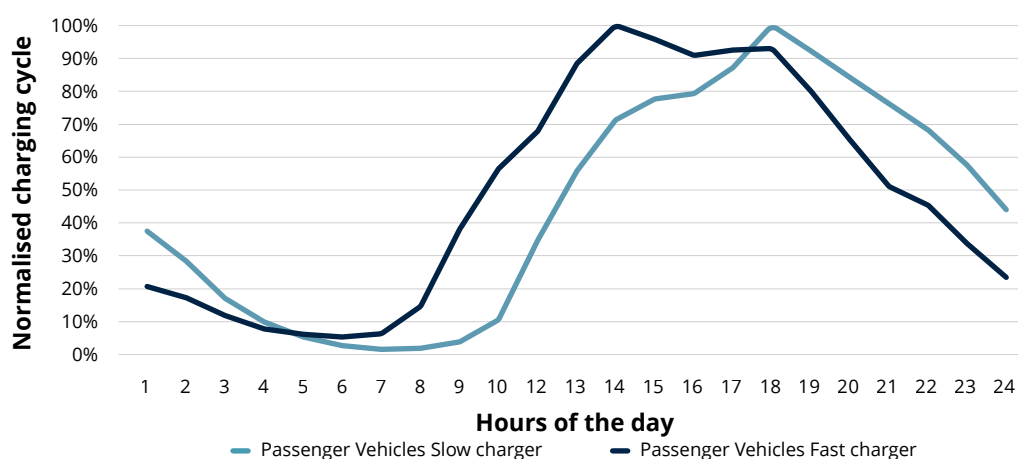
Type of vehicle	Charger type	Assumptions
Private Car	Slow	• Dedicated charger during parking and charging duration • Calculations based on https://www.mobilitaet-in-deutschland.de/index.html
	Fast	• Charging on an as-needed basis • Profiles taken from https://www.fastnedcharging.com/en/stories/why-fast-charging-stations-are-good-for-the-grid
Two-wheelers - personal	Slow	• Charging pattern same as private cars (similar local driving patterns)
	Fast	• No fast charging • Nighttime charging sufficient for operation
Four-wheelers - Taxi	Slow	• Private car charging profile adjusted by higher annual mileage and prolonged daily use compared to slow charging private cars. Recharging at dedicated charger
	Fast	• DC charging is more expensive than AC charging • Nighttime AC charging is sufficient for Taxi operation
	Depot	• Use of load management system
Two-wheelers - motos	Slow	• Booster of nighttime charging compared to private Motorbikes (own calculation) • Each motorbike has own charger • Recharging done at home or depot
	Fast	• Recharging during hours of low passenger frequency

Type of vehicle	Charger type	Assumptions
Buses	Depot (Fast)	- Recharging during non-operational hours 100 percent charger utilisation
	Opportunity (Fast)	- Recharging at end of transport line by different buses throughout the day 100 percent charger utilisation
e-bikes	Slow	Nighttime charging sufficient for operation
Light duty vehicles	Slow	Dedicated charger during parking and Charging duration
	Fast	Charging on an as-needed basis

Source: Energynautics analysis based internal knowledge on developed markets (EU,USA,China). No Rwanda specific aggregated data was available. Own assumptions used.

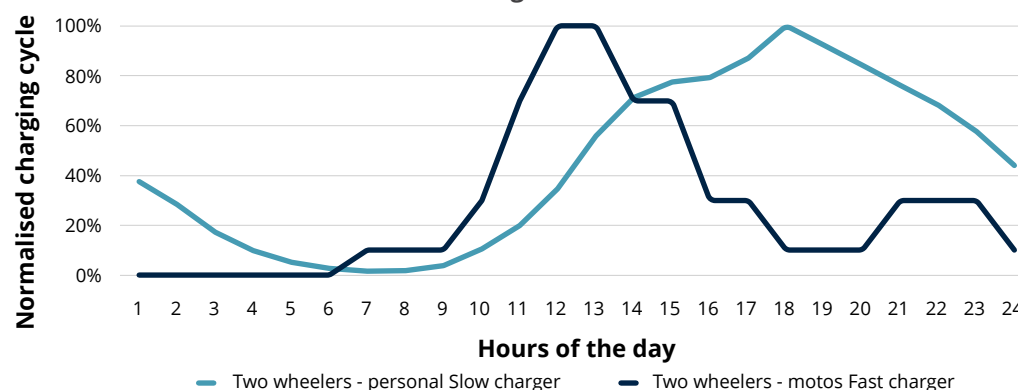
The graphs below show the typical schedule of charging according to different types of vehicles. Note that specific information from Rwanda was not available for this charging schedule – but in the future the model could be updated according to local data.

FIGURE 8. Passenger vehicles – slow v. fast chargers



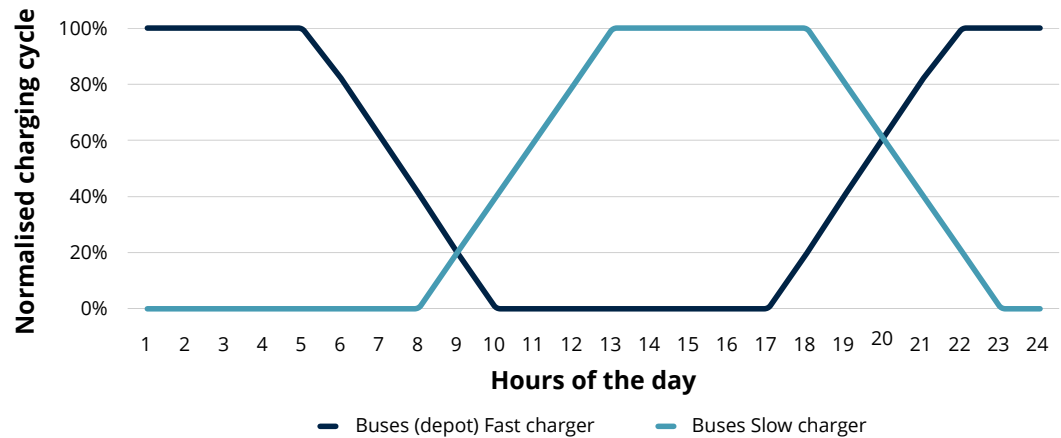
Source: Energynautics analysis

FIGURE 9. Two-wheelers – slow v. fast chargers



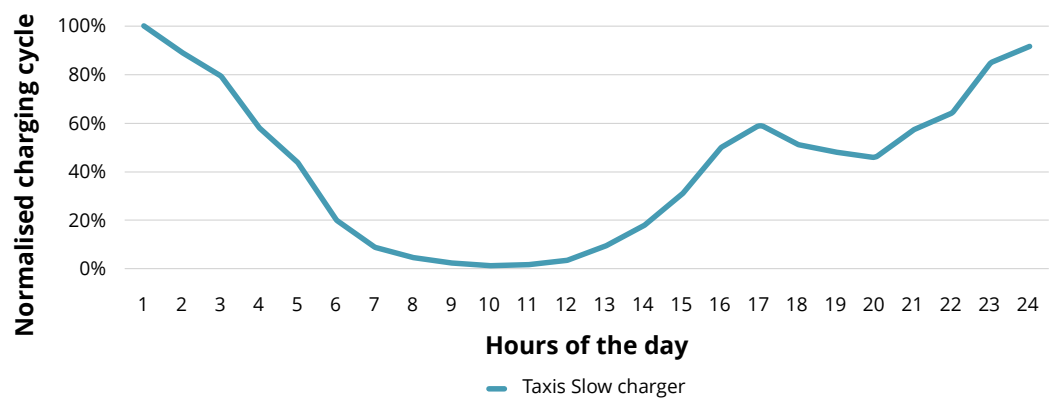
Source: Energynautics analysis

FIGURE 10. Buses – depot v. opportunity charging



Source: Energynautics analysis.

FIGURE 11. Four-wheelers Taxis – charging



Source: Energynautics analysis

2.2.2 Step 2: Bottom-up assessment of the load impact

The second step consists in assessing the impact of EV charging profiles on the aggregate demand and how it affects the overall electricity consumption at different times of the day. This helps in understanding peak demand periods and the potential for grid stress.

The starting point is the peak demand of each type of vehicle. This is calculated by combining number of parameters:

- **The km travelled per year per vehicle** – This will provide the total energy requirements per vehicles.
- **Average energy consumption per km** – This is estimated for both ICEs and for EVs.
- **The coincidence factor** – Measured to describe the probability or extent to which multiple EVs are charging simultaneously within a defined grid segment or network.
- **The peak load per EV** – This is directly derived from the charging profile.

TABLE 11. EV technical parameters

	km travelled per year per vehicle ¹⁷	Average electricity consumption	Coincidence factor ¹⁸
Units	km	MWh / 100 km	%
Two-Wheelers (personal)	6,570	0.01	22%
Two-Wheelers (motos)	91,980	0.01	22%
Private cars	9,855	0.015	10%
Four-Wheelers taxis	36,500	0.020	22%
Buses	60,116	0.120	75%

Source: ECA - Energynautics

2.2.3 Step 3: Electricity demand forecasts integrated with electric vehicle uptake

Hourly load impact

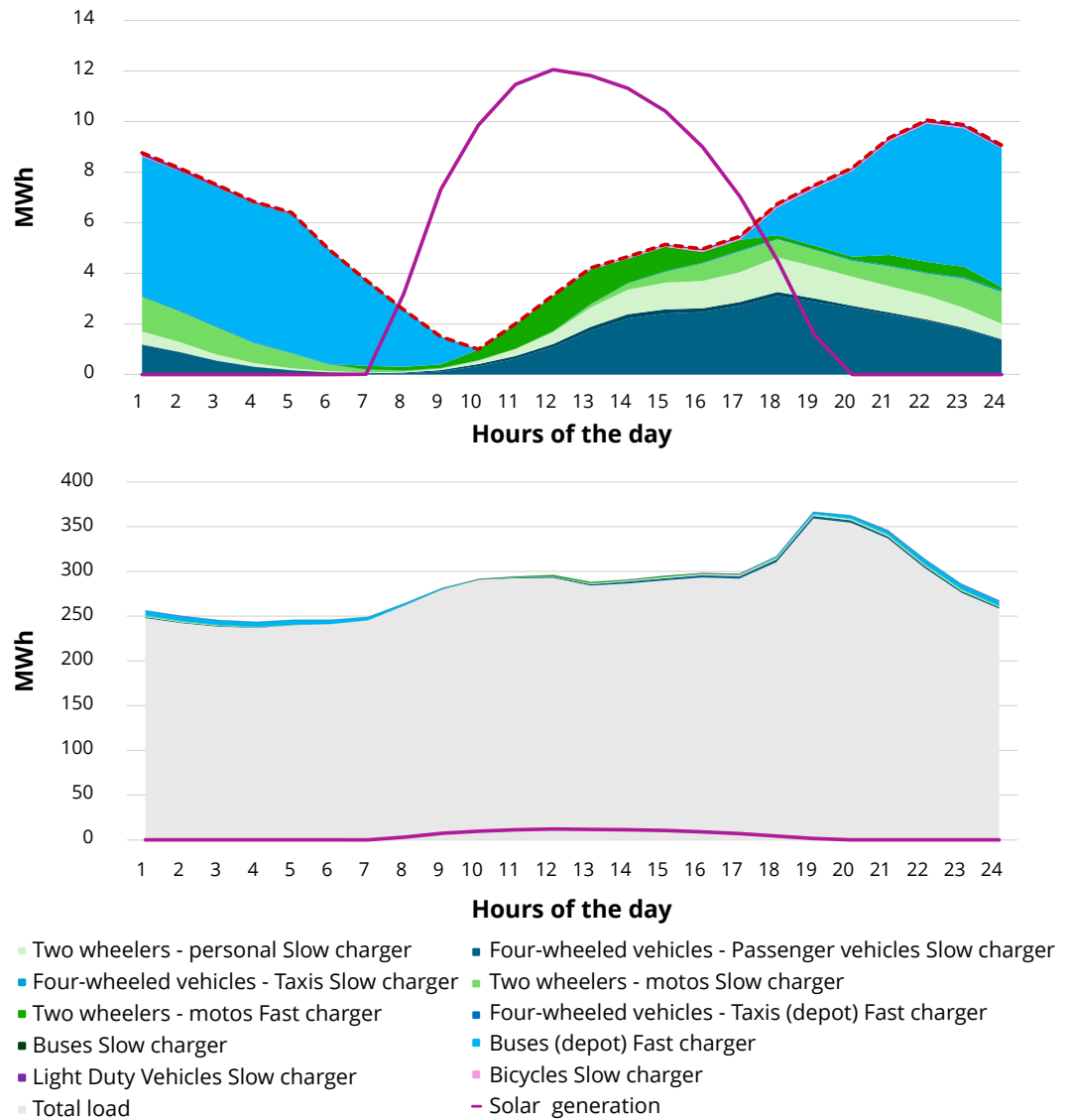
The figures below illustrate the hourly impact of EV charging on the load for two scenarios (Medium and High) in the years 2030 and 2050. These scenarios are selected because they demonstrate the highest impact. The first set of graphs shows the hourly impacts in isolation, highlighting the combined effects of charging timing and vehicle market penetration. The second set of graphs compares these impacts with the hourly average demand forecasted in the LCDP (2023), in order to provide an idea of the magnitude of EV charging load in comparison with the existing load. Each figure also includes the expected solar PV generation to indicate whether the anticipated grid-scale solar PV capacity can partially offset the additional EV load.



¹⁷ Based on information from market research conducted by consultancy team for a different study.

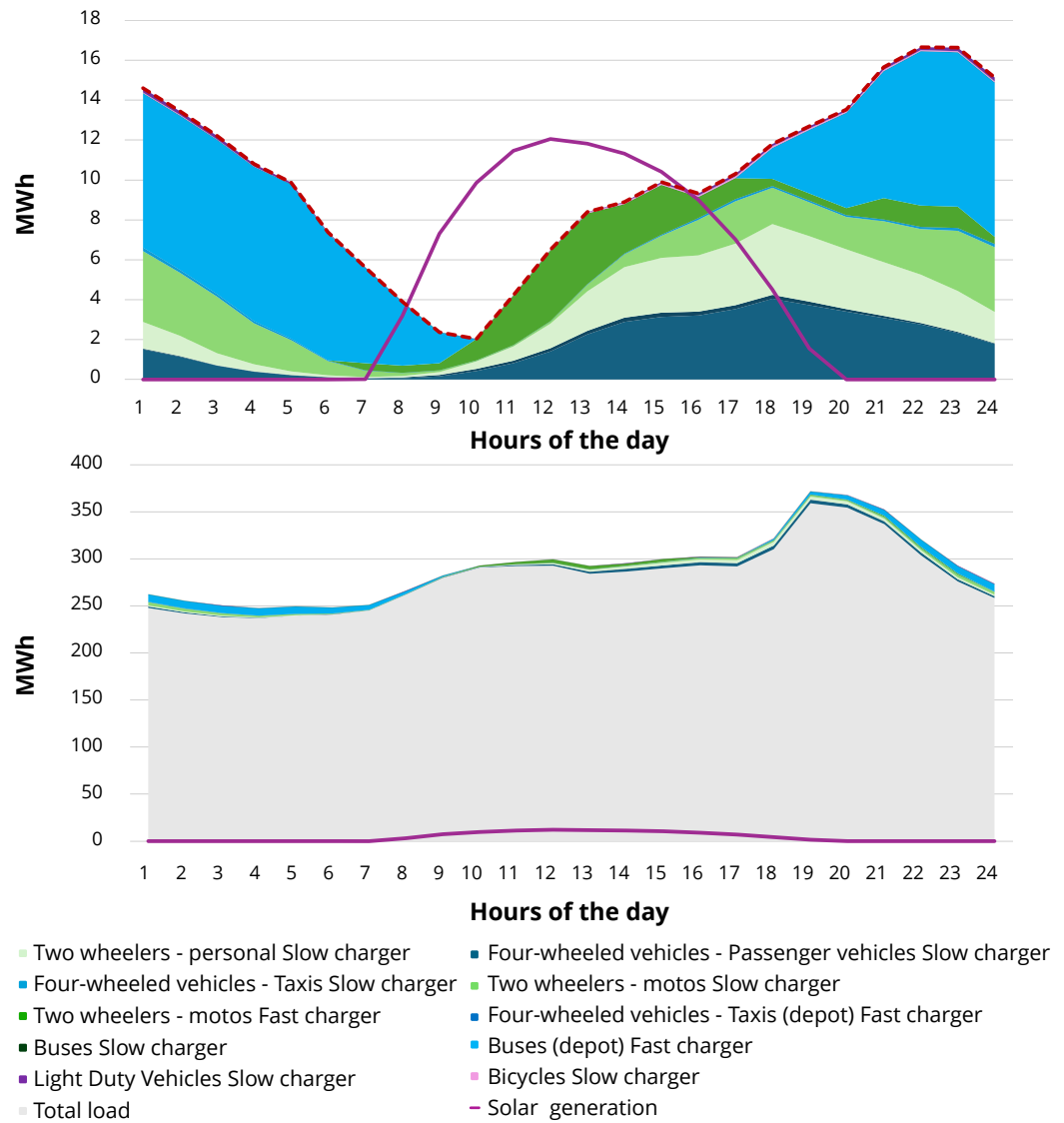
¹⁸ Note that the coincidence factors have been chosen based on international experience of the Consultant team.

FIGURE 12. Hourly load impact – Medium scenario – 2030



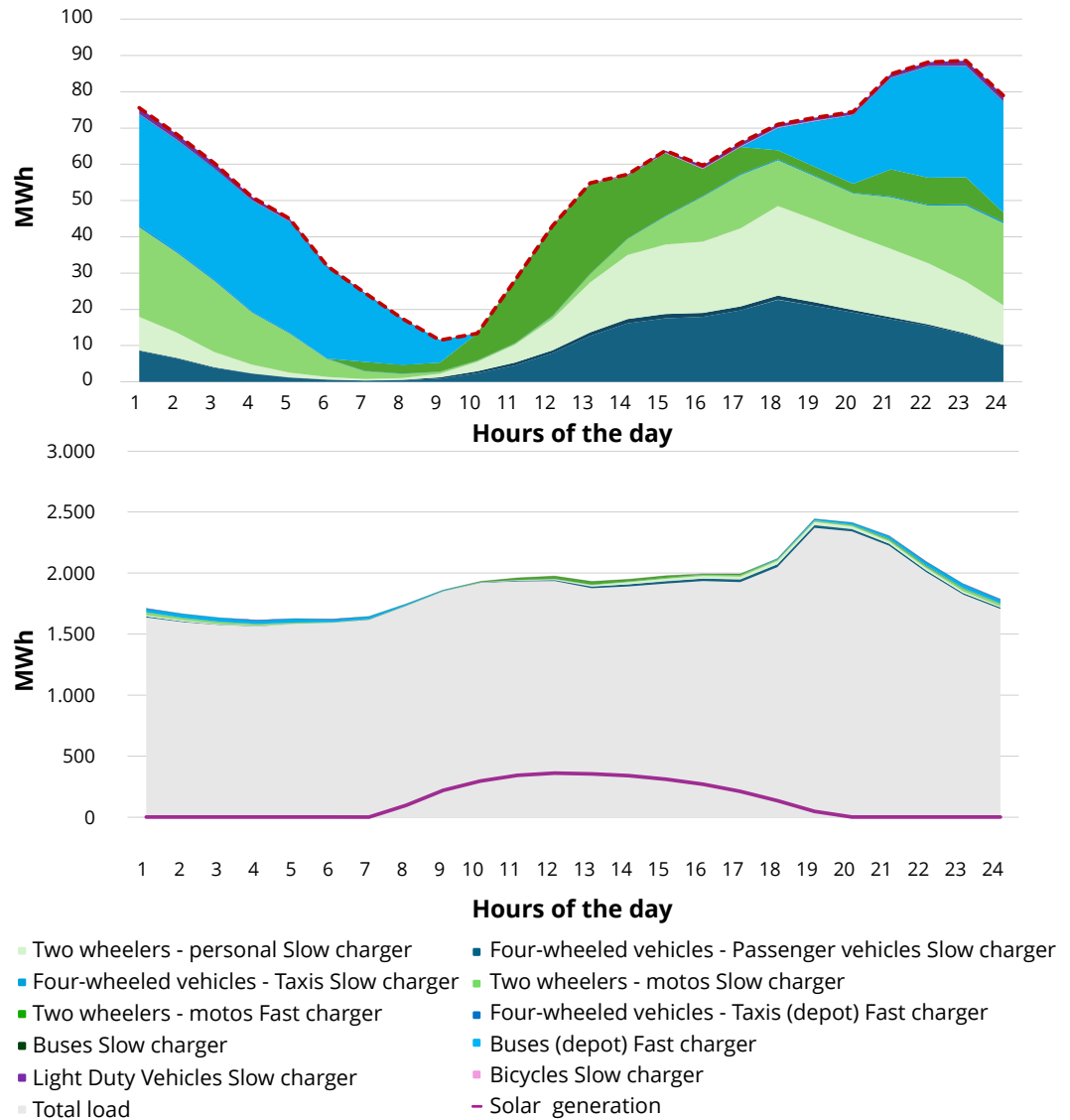
Source: ECA – Energynautics calculations

FIGURE 13. Hourly load impact – High scenario – 2030



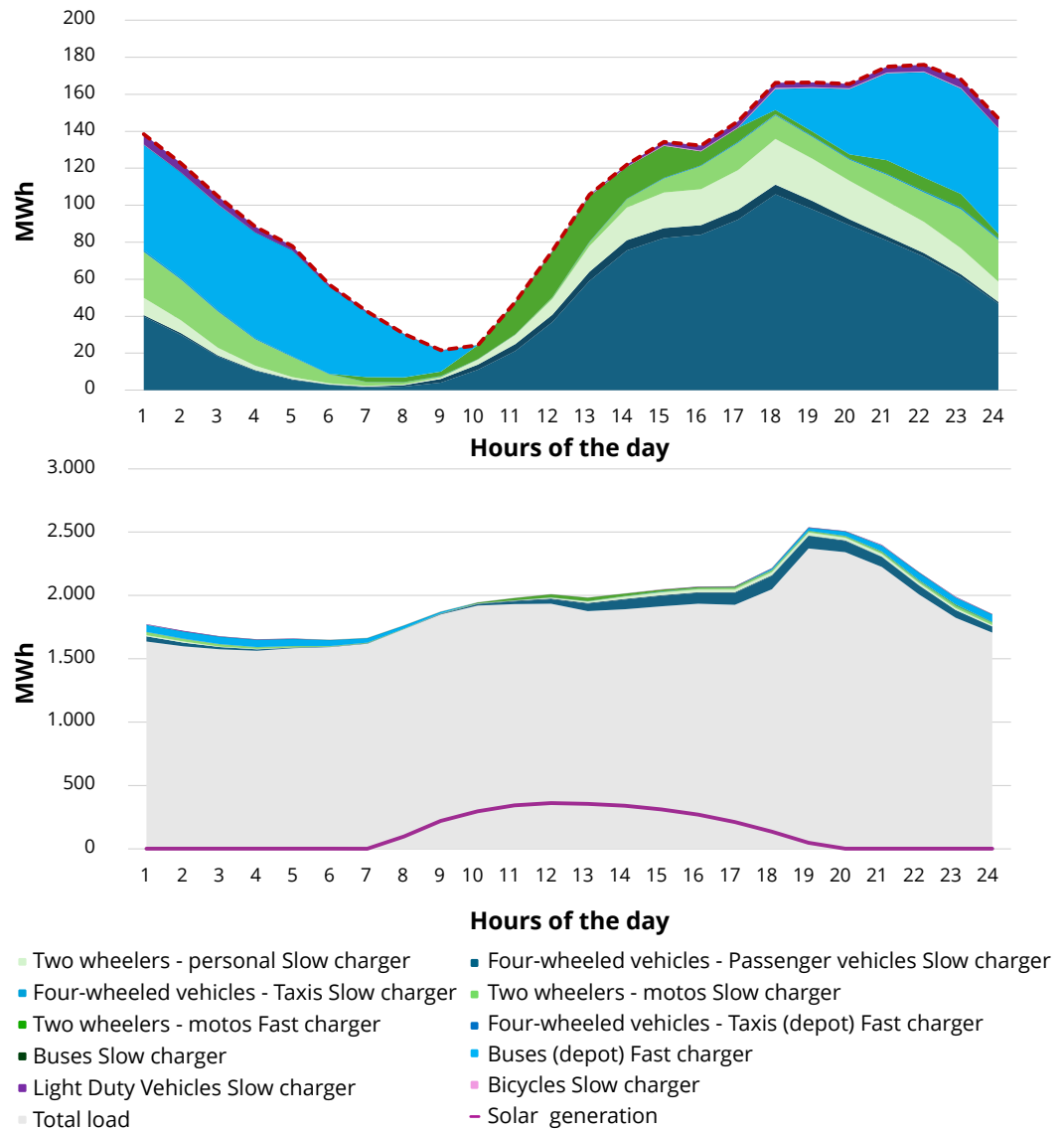
Source: ECA – Energynautics calculations

FIGURE 14. Hourly load impact – Medium scenario – 2050



Source: ECA – Energynautics calculations.

FIGURE 15. Hourly load impact – High scenario – 2050



Source: ECA – Energynautics calculations

In the high scenario, if no policies are implemented, EV charging could increase peak load by +6.1 percent.¹⁹ In 2030, the impact on the peak load is limited to 3.1 percent. The following table describes the impacts on the peak load, per scenario and for a selection of years.

TABLE 12. Average peak load impact

Scenarios	2030	2040	2050
Low	0.8%	1.2%	1.4%
Medium	1.9%	3.0%	2.7%
High	3.1%	4.9%	6.1%

Source: ECA – Energynautics calculations

However, the aggregate charging profile of EVs aligns closely with the existing load profile, indicating that most charging activities occur during peak demand periods. This synchronisation underscores the necessity for implementing new policies, such as time-of-use tariffs, to incentivise EV owners to charge their vehicles during off-peak hours. Such measures can help to alleviate pressure on the grid during peak times.

Moreover, the current charging load does not align well with the solar generation profile. This misalignment suggests that the additional load from EV charging cannot be adequately absorbed by solar energy generation, which predominantly occurs during daylight hours. Therefore, there is a need for strategies to better match EV charging times with periods of high renewable energy generation, potentially through coordinated charging schedules or enhanced energy storage solutions to optimise the use of solar power.

Energy demand (GWh) impact

The figures below illustrate projected energy demand (GWh) from 2023 to 2050 and the percentage impact, respectively. The initial energy demand forecast is the original demand forecast as presented in REG's Least Cost Development Plan (LCDP) (2023) and does not include the impact of EV penetration. This serves as a baseline, showing the expected energy requirements based on current trends without considering additional load from EVs. The low, medium, and high scenarios incorporate the expected impacts of EV penetration on energy demand. The low scenario represents a modest increase in energy demand due to a lower adoption rate of EVs. The medium scenario indicates a moderate increase in energy consumption, reflecting a balanced adoption rate of EVs. The high scenario projects a substantial increase in energy demand, assuming a high rate of EV adoption. Over time, all scenarios show an upward trend in energy demand, with the high scenario diverging significantly from the initial energy demand by 2050, indicating the considerable impact that high EV adoption could have on future energy requirements.

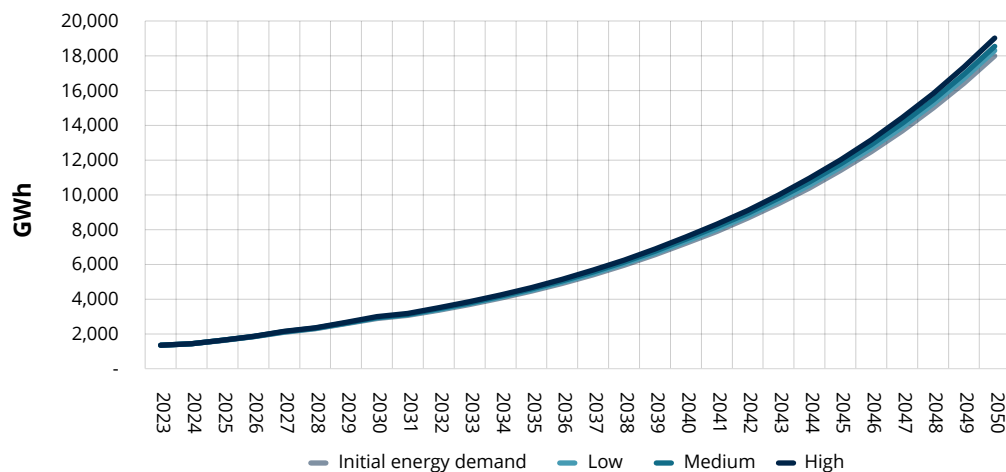
The table below shows the impact on total energy consumption in the medium and high scenarios versus the low scenario for 2030, 2040, and 2050.

¹⁹ This is consistent with similar analysis carried out by the Consultant team in Egypt and Israel for example.

TABLE 13. Additional electricity demand due to EV uptake

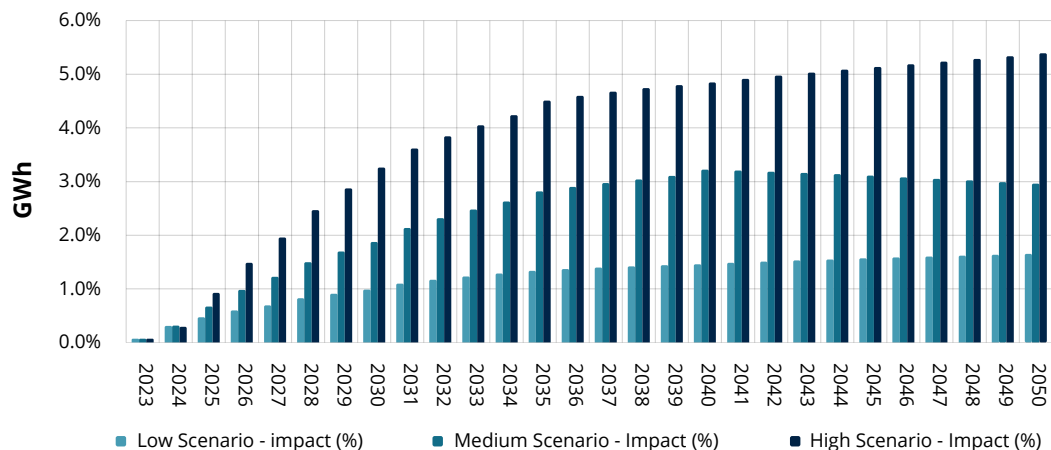
	2030	2040	2050
Baseline expected demand (GWh)	2,890	7,211	18,004
Additional GWh demand due to EVs (over the baseline demand) - Low scenario	28.8	106.9	302.5
Additional GWh demand due to EVs (over the baseline demand) - Medium scenario	55.2	240.2	549.0
Additional GWh demand due to EVs (over the baseline demand) - High scenario	97.4	367.4	1,025.5

FIGURE 16. Annual energy demand forecast impact (GWh)



Source: REG – Transmission Master Plan (2023) and ECA calculations

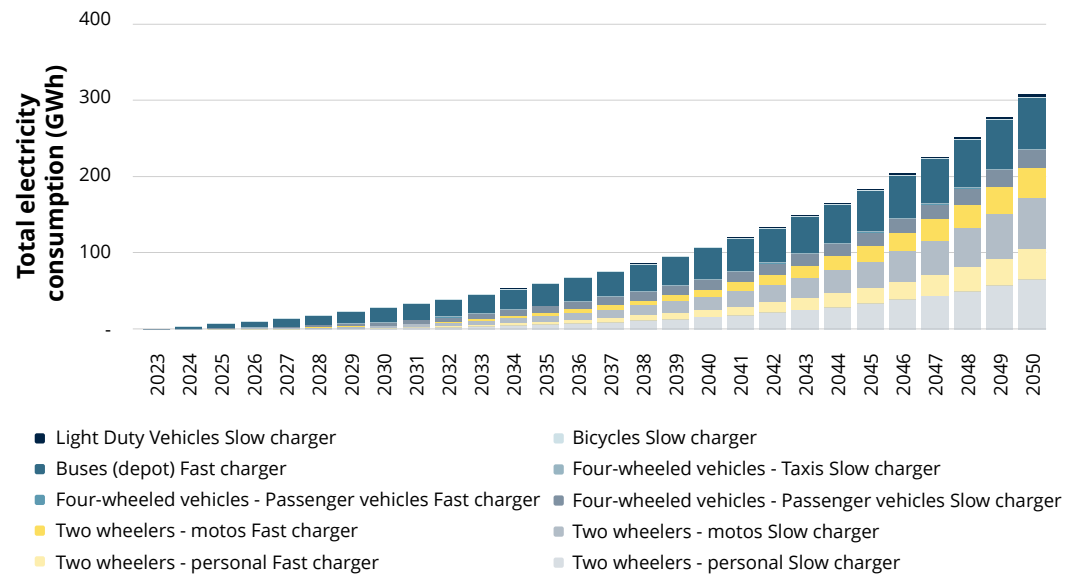
FIGURE 17. Annual energy demand forecast impact (GWh) - % impact



Source: REG – Transmission Master Plan (2023) and ECA calculations

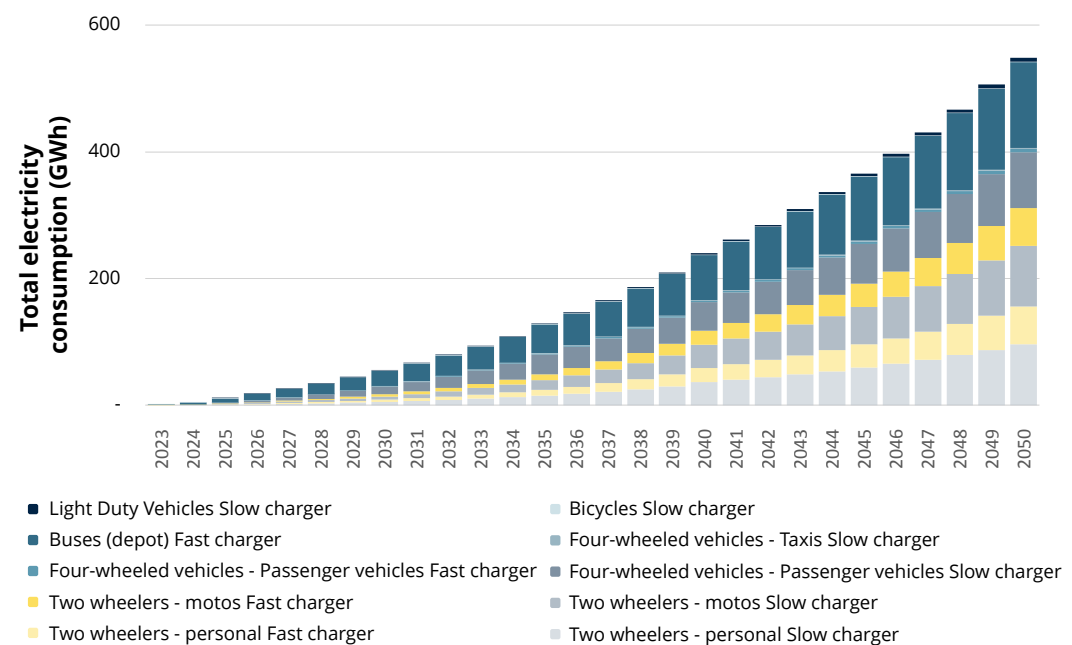
The breakdown of annual energy demand (GWh) impacts per vehicles is shown below for each scenario.

FIGURE 18. Annual energy demand forecast impact per vehicle type – Low scenario



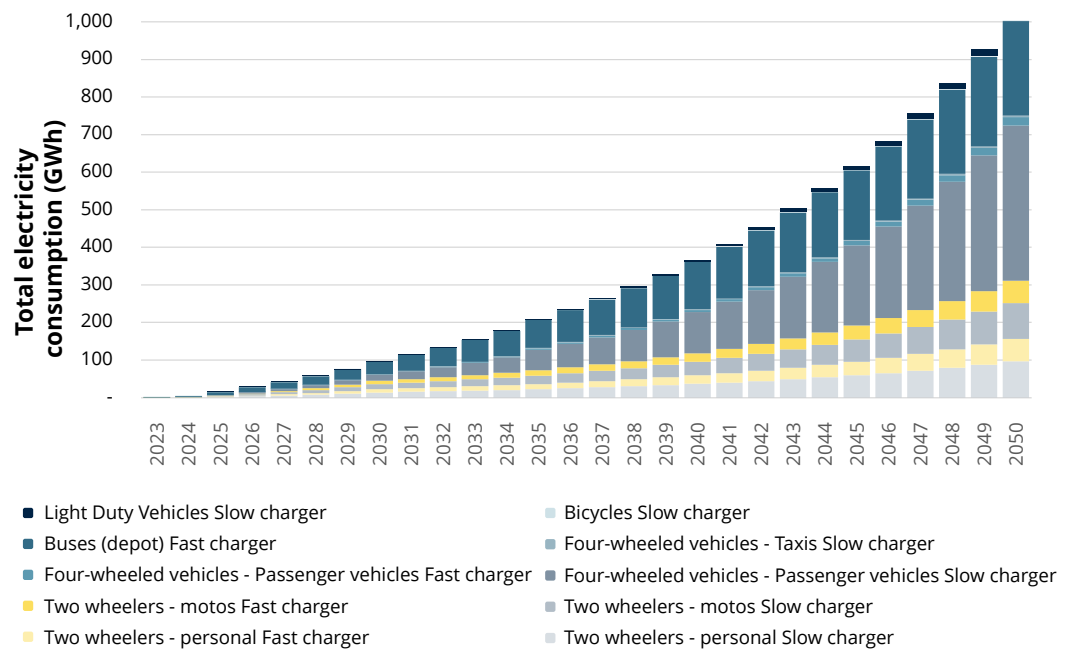
Source: ECA calculations

FIGURE 19. Annual energy demand forecast impact per vehicle type – Medium scenario



Source: ECA calculations

FIGURE 20. Annual energy demand forecast impact per vehicle type – High scenario



Source: ECA calculations

Peak demand (MW) impact

Understanding the peak load forecast is crucial when planning for grid investment because it directly influences the design, capacity, and reliability of the electricity grid. Accurate peak load forecasts help utilities anticipate the highest demand periods, ensuring that the grid can handle these peaks without failures or significant inefficiencies. This foresight allows for better optimisation of grid resources, reducing the risk of overbuilding or underbuilding infrastructure.

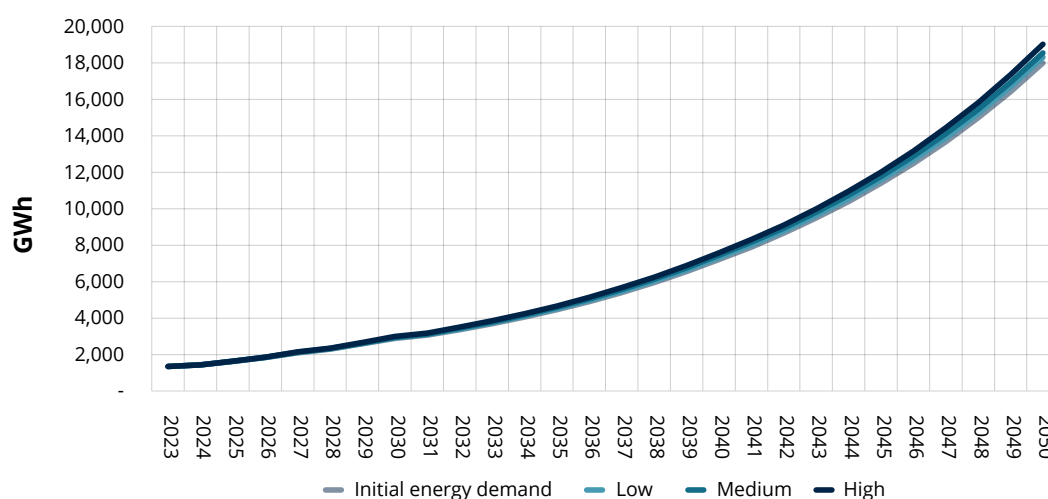
The impact of EV penetration on the peak load will not necessarily move in straight line as with the energy demand. The primary difference lies in the timing of energy use. While the total energy demand represents the cumulative energy consumed over a period, peak load refers to the maximum power demand at a specific time. EV penetration significantly impacts peak load because many drivers charge their vehicles upon arriving home in the evening, coinciding with peak electricity use. However, as shown in the previous section (2.2), not all vehicles peak charging times will coincide together.

The table below shows the additional peak demand due to EV uptake.

TABLE 14. Additional electricity peak demand due to EV uptake

	2030	2040	2050
Baseline peak demand (MW)	407.9	1,075.1	2,695.2
Additional MW peak demand due to EVs (over the baseline demand) - Low scenario	3.3	13.0	36.6
Additional MW peak demand due to EVs (over the baseline demand) - Medium scenario	7.5	31.9	71.9
Additional MW peak demand due to EVs (over the baseline demand) - High scenario	12.5	53.1	163.4

FIGURE 21. Annual peak demand Impact (MW)



Source: REG – Transmission Master Plan (2023) and ECA calculations

2.2.4 Charging infrastructure overview / Electric vehicle charging needs: Rwanda transport system and locations of charging stations

Rwanda's commitment to sustainable transportation is evident in its growing fleet of electric buses. However, a key factor in their successful operation is the availability of EVCI - including e-bus charging stations. Currently, the infrastructure is in its early stages, but promising developments are underway. One prominent player is IZI electric, which currently operates with two charging stations located at Centenary park Hotel Nyarutarama in Kigali with 120 kW capacity each. They can charge four e-buses at the same time. Employing an overnight charging strategy, IZI electric ensures their e-buses are fully charged and ready for the next day's operations. Importantly, IZI electric has ambitious expansion plans, aiming to extend

their charging network to the Rwandan countryside in the future. This expansion will be crucial to support the wider adoption of e-buses across the nation. BasiGo, another key player in Rwanda's e-bus revolution, also operates its own charging station. However, details regarding its specific location and capacity are currently limited. It is likely BasiGo's station primarily caters to their own fleet of e-buses, similar to IZI electric's current setup.

While the current infrastructure may seem limited, the Rwandan government is actively promoting the development of e-bus charging stations. Favourable electricity tariffs for charging stations are a significant incentive, making them more attractive investments. Additionally, with plans to introduce a significant number of e-buses in the coming years, the demand for charging stations will inevitably rise. This surge in demand is expected to trigger rapid development in the sector, leading to a more robust and widespread network of e-bus charging stations throughout Rwanda.

Policy makers should consider the following key factors when planning charging station locations.

- **Accessibility** – Position charging stations in high-traffic areas, near major roads, and within residential and commercial zones to ensure accessibility and encourage EV adoption. This could include, for example, charging points or charging points within parking lots.
- **Coverage** – Distribute the charging network across urban and rural areas to support long-distance travel and reduce range anxiety. This can be done through a variety of mechanisms – including requiring that charging stations be installed in commercial areas / places with larger parking lots²⁰. The installation of charging points would therefore naturally follow the development of traffic and parking patterns.
- **Grid capacity** – Select locations based on existing grid infrastructure and capacity to enable efficient deployment of high-power charging stations. Areas with low connectivity or insufficient demand, can be equipped with off-grid solutions like solar panels and battery storage. Check each charging point with a significant amount of power to be drawn (eg over 50 kW) against the grid capacity of the area.
- **Land use compatibility** – Integrate charging stations into land use plans to prevent disruption of urban functions and ensure compatibility with existing infrastructure. Preferred locations include parking lots, shopping centres, public transit hubs and service stations.
- **Future expansion** – Design urban plans and site layouts with flexibility to accommodate future expansion of charging points. Much of the installation can be decentralised if new developments are required to include charging points.

2.3 Power systems impact analysis

The power system must be adequately designed to ensure it can supply all loads at any given time. The integration of EVs will impact the network. Using the PowerFactory simulation software, the network adequacy was assessed at the MV level in Kigali up to 2030 to accommodate the anticipated EV loads (see Annex A4 for details). This analysis compared the impact of additional EV loads, followed by a network status report and an evaluation of the available capacity to host further EV charging.

²⁰ For example, in the EU, there is a requirement within the Energy Performance in Buildings Directive (Directive (EU) 2024/1275) of (partial list below):

- non-residential buildings with more than 20 car parking spaces should have the installation of at least one recharging point for every 10 car parking spaces, or of ducting / conduits for electric cables, for at least 50 percent of the car parking spaces to enable the installation at a later stage of recharging points for electric vehicles;
- for new residential buildings with more than three car parking spaces, the installation of at least one recharging point

2.3.1 Network impact of Electric vehicles

EV charging introduces additional load to the network. However, even under an ambitious scenario of high EV adoption (see chapter 2.1.5), the additional peak demand from EVs is projected to be only 7 percent of the total load, which is low compared to the expected 10 percent annual general load growth. As illustrated in Table 15, the impact of the expected overall load growth (2024 vs. 2030) is significantly higher than the impact from additional EVs (No EV vs. EV).

TABLE 15. Network impact of high EV share in 2030 in current network.

Global Parameter	2024			2030		
	No EV	EV	Diff.	No EV	EV	Diff.
P [MW]	87.9	89.1	+1.3%	143.9	152.6	+6.1%
Q [Mvar]	66.0	66.8	+1.3%	107.9	114.5	+6.1%
P_loss [%]	3.0%	3.0%	+1.2%	4.9%	5.3%	+6.5%
L_ave [%]	10.6%	10.7%	+1.3%	17.7%	18.8%	+6.4%
L_max [%]	136%	138%	+1.4%	235%	251%	+6.7%
L_nr_over [#]	9	9	0.0%	38	41	+7.4%
U_ave [p.u.]	0.96	0.96	0.0%	0.94	0.94	-0.4%
U_min [p.u.]	0.86	0.86	-0.2%	0.78	0.76	-1.7%
U_nr_under [#]	320	340	+6.3%	666	721	+8.3%

The following global network parameters are compared between 2024 and 2030 in the case of no EV in the network and the high EV penetration scenario:

- **P [MW]:** The maximum active *power consumption* in the Kigali network in 2024 is about 88 MW. It is expected to increase by 56 MW to 144 MW in case of no additional EV and by another 8,7 MW to 152.6 MW in case of the high EV penetration scenario. Therefore, the load increase, due to unconventional loads is significantly higher compared to the load increase coming from EVs.
- **Q [Mvar]:** *Reactive power* needs in the Kigali network behaves proportional to the active power requirements and is therefore not further described.
- **P_loss [%]:** The *Active Power Loss* in the Kigali network in 2024 is 3 percent and increases to about 5 percent in 2030, due to higher loading of the network. While general load growth attributes to most of the loss increase.
- **L_ave [%]:** The *Average line loading* indicates the load impact on the system. Although this value is typically not used to identify the need for grid upgrades, it is a good indicator for the utilisation of the grid assets. From 2024 to 2030, the average line loading has increased by about 75 percent.
- **L_max [%]:** The *Maximum line loading* of the highest loaded line in the network in 2024 already exceeds the permissible 100 percent loading level by 36 percent. Network upgrades are already necessary. In case no upgrades are made, the maximum line load overload

would theoretically increase to 150 percent above the permissible maximum load by 2030, resulting in real-world network outages. Again, the contribution of EVs is significantly lower than the increase attributed to the general load growth.

- **L_nr_over [#]:** *The Number of overloaded lines* in the network are expected to increase from 9 to about 40 by 2030. The general load growth is the most significant impact compared to additional EV loads.
- **U_ave [p.u.]:** *The Average voltage* in the network shows a persistent voltage problem already in 2024, with values close to the permissible 0.95 p.u. limit.
- **U_min [p.u.]:** *The Minimum voltage* in the network drops from 0.86 to 0.76 p.u. by 2030. Network upgrades are necessary, mainly due to general load growth.
- **U_nr_under [#]:** *The Number of terminals* experiencing undervoltage doubles from 2024 to 2030.

In addition to the direct changes between 2024 and 2030, the following figures depict the yearly adjustment of key parameters. Figure 22 shows the annual correlation between active and reactive power losses in scenarios with no EVs and high EV penetration, while Figure 23 indicates the cumulative impact of overload and undervoltage for both scenarios. It is evident from all graphs that the impact of general load growth is substantially more significant than the impact of EVs, at least until 2030.

FIGURE 22. Active power and losses on network, with and without EV

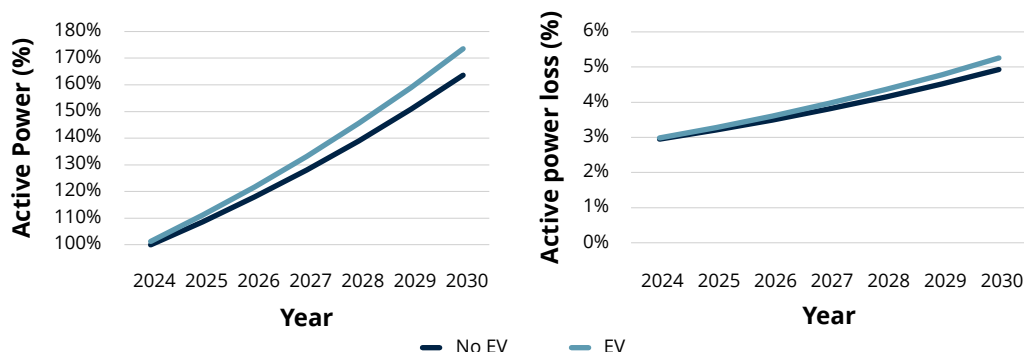


FIGURE 23. Number of line overload and undervoltage seen in network, with and without EV

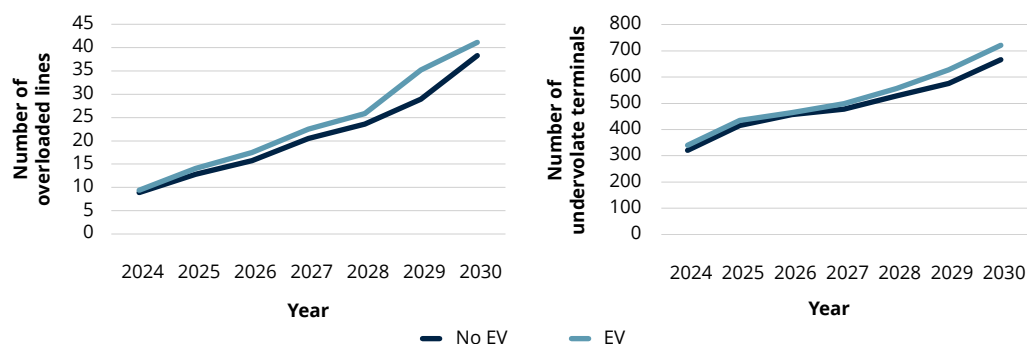
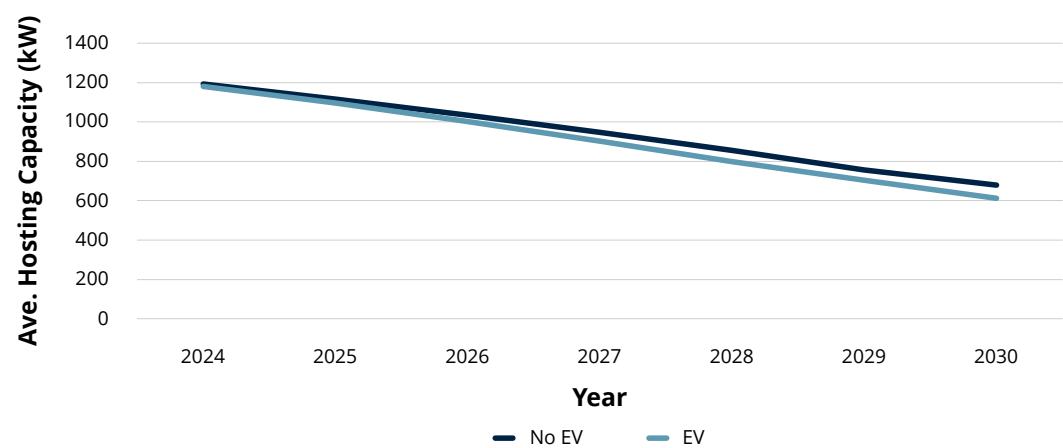


FIGURE 24. Average hosting capacity of network with and without EV



In addition to the time-dependent overview given above, Figures 25 to 27 provide a more detailed view of the network impact of EVs. The comparison is done for the base case without EVs and with high EV penetration rates in 2030. Figure 25 shows the number of transformers within the network, with a given hosting capacity at that time. Hosting capacity values below 300 kW are sufficient to allow for adding slow charging stations or charging hubs for electric motorbikes. Values above 300 kW are suitable for adding fast charging stations, with an increasing number of charging plugs. For large bus charging stations hosting capacity in the range of 2 MW is necessary. When comparing the hosting capacity with and without EVs, a slight decrease in hosting capacity becomes visible, due to the additional load from EVs, such as residential charging of cars and motorbikes.

FIGURE 25. Hosting capacity distribution in the case of no EV and high EV rate for 2030

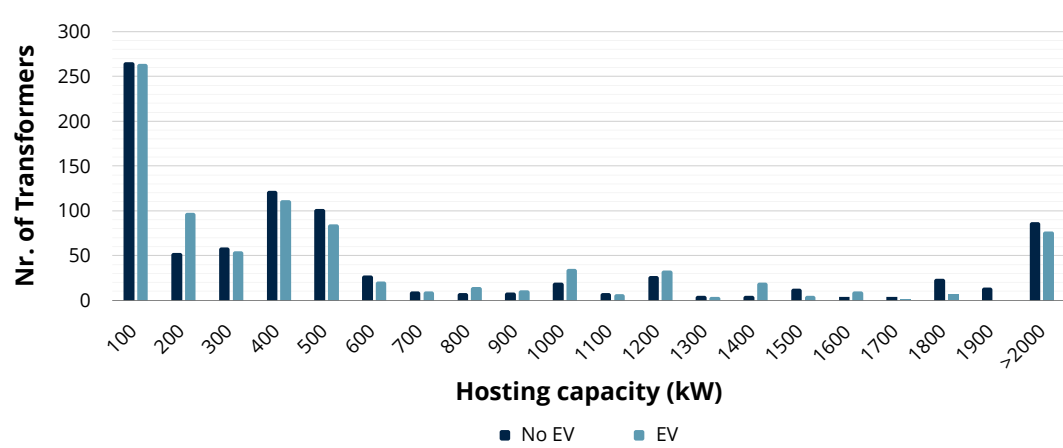


Figure 26 and Figure 27 depict the impact of additional EV load on the network. Both figures show that EV load has an impact, although it is rather low. Network voltages decrease by 0.005 p.u. on average, while the average line loading increases by 3 percent.

FIGURE 26. Network voltage distribution in the case of no EV and high EV rate for 2030

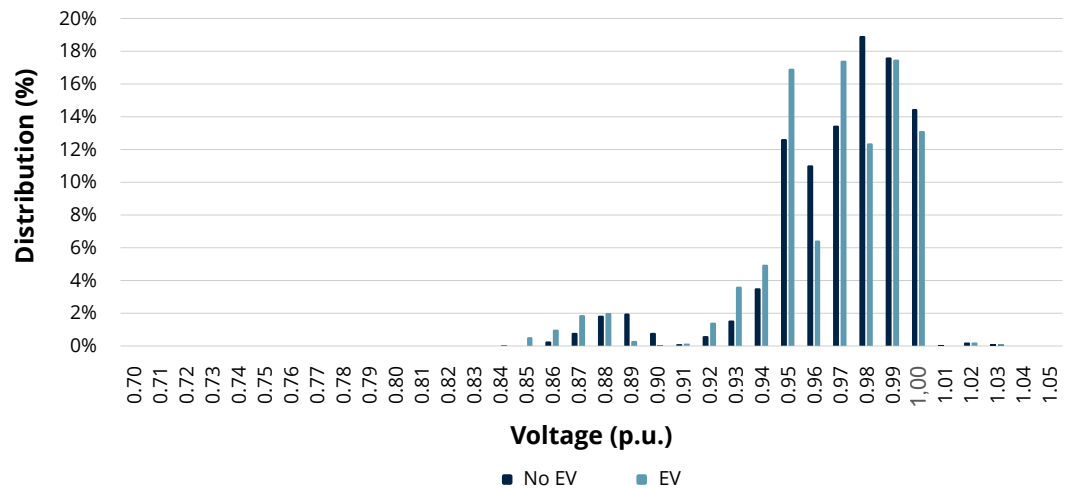
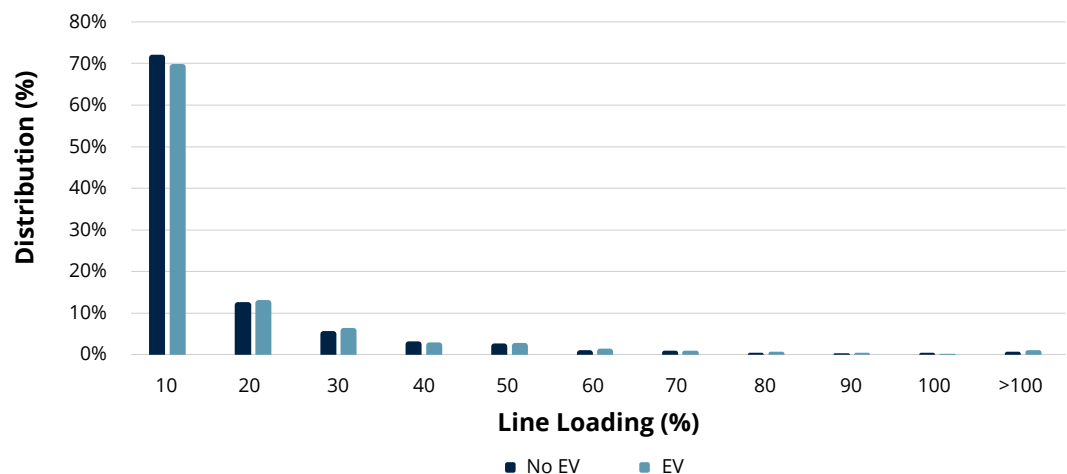


FIGURE 27. Line loading distribution in the case of no EV and high EV rate for 2030



Isolated Network impact of EV in 2030

Even though the annual general load growth is expected to be around 10 percent, a further analysis was carried out to evaluate a hypothetical case. It was assumed that all EVs expected for 2030 are already in use by 2024. This allows for further isolation of the EV impact on the network. Results are similar to the previous analysis, though the relative change is higher, since the overall base load is lower. Table 16 shows the change of important parameters, such as the increase of line loading and the average hosting capacity, similar to Table 15.

TABLE 16. Impact parameters for the addition of 2030 EV loads onto today's network

Global Parameter	No EV	EV	Diff.
P_loss [%]	3.0%	3.3%	11.1%
L_ave [%]	10.6%	11.8%	11.4%

Global Parameter	No EV	EV	Diff.
L_max [%]	136%	153%	12.5%
L_nr_over [#]	9	14	56.7%
U_ave [p.u.]	0.96	0.96	0.0%
U_min [p.u.]	0.86	0.86	0.0%
U_nr_under [#]	320	435	35.9%
Ave_host [kW]	1194	1181	-7.0%

Figure 28 to Figure 30 show the impact of additional EV load on hosting capacity, voltage and line loading in a granular distribution. Small distribution changes are visible, with a similar impact as has already been described in the previous section.

FIGURE 28. Hosting capacity distribution in 2024 with and without EV loads from 2030 added

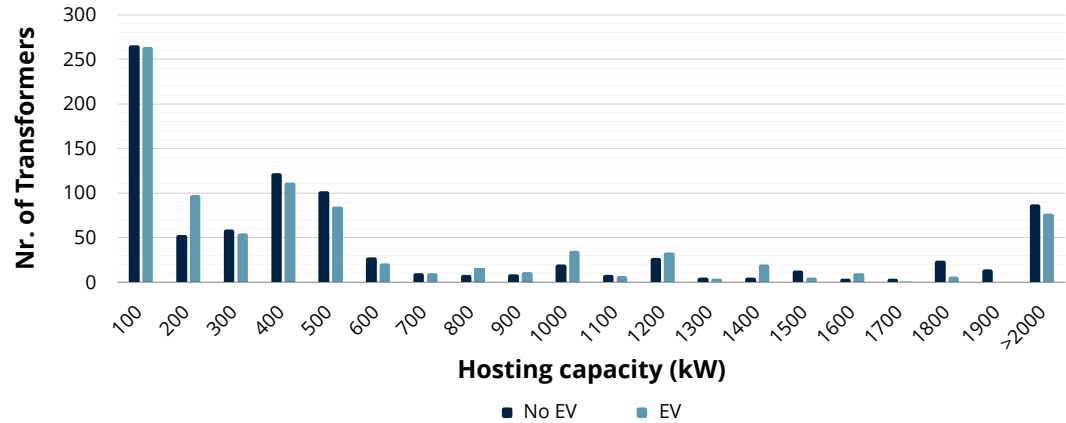


FIGURE 29. Voltage distribution in 2024 with and without EV loads from 2030 added

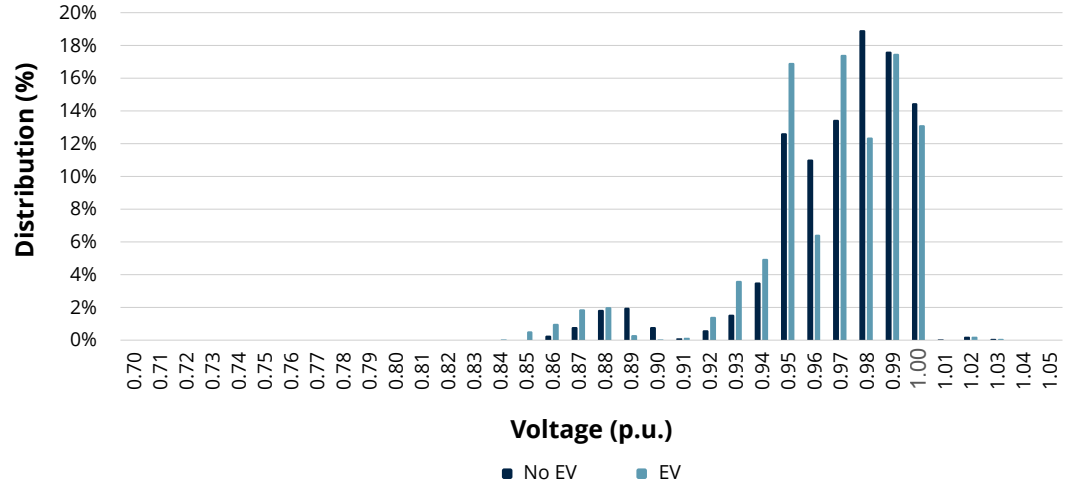
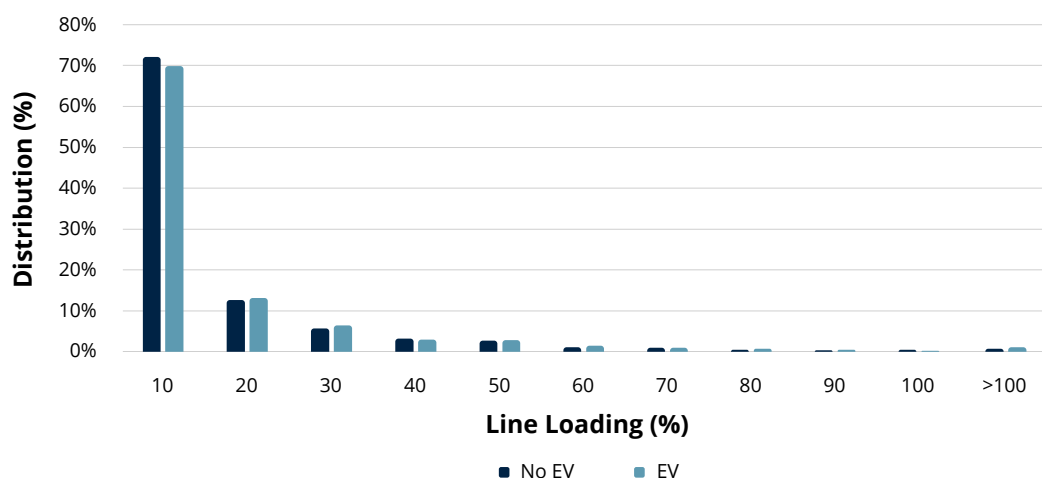


FIGURE 30. Line load distribution in 2024 with and without EV loads from 2030 added



Electric vehicle network impact summary

Network upgrades will primarily be driven by general electricity demand growth. Although additional capacity for EVs should be considered in the planning process, it is less critical than the annual overall energy demand increase. Through 2030 it can be expected that the share of network upgrades due to EVs will be well below 10 percent. The exact impact depends on the applied mitigation strategies (smart charging, etc.) (see section 2.4) and the often not yet known exact locations where electric vehicle charging stations will be built. Therefore, the main recommendation is to consider the general load growth as the main upgrade driving factor, while adding 10 percent additional headroom for EV charging. In principle, network upgrades should at least contain 100 percent headroom to be future-proof for the upcoming 10 years of operation under the expected annual 10 percent load growth. Exact sizing will depend on the location and other data, such as available finance.

2.3.2 Distribution analysis

The distribution analysis looks at how well the grid can handle the additional demand placed on it. Hosting capacity is a crucial part of this and refers to the maximum amount of energy resources that can be integrated into the grid without requiring significant infrastructure upgrades. By assessing hosting capacity, it is possible to determine how much new technology the grid can handle, guiding decisions on where investments or improvements are needed to accommodate increased loads and maintain stability.

Even though the previous chapter showed the need for network upgrades, some areas in the city are more affected than others. Certain feeders still provide sufficient capacity to integrate additional charging stations, for instance used by bus operators. While charge point operators must consider multiple factors, such as space availability, sufficient grid connection capacity is crucial. In areas with insufficient hosting capacity, projects are significantly delayed until network upgrades are completed, often resulting in higher costs.

Within the study, the available hosting capacity was calculated for various scenarios. An Excel tool was developed to allow decision-makers to adjust key parameters, such as the speed

of network upgrades, the year in question, and the expected uptake of EVs. The Excel tool is described in more detail in Annex A4.

For the evaluation within this study, the current network without any upgrades was chosen, along with the medium EV uptake scenario. The results represent the most likely conservative scenario, providing planners with realistic hosting capacity values for further evaluation.

Figure 31 displays the distribution of the available hosting capacity from 2024 to 2030. Constraints of existing transformers do not limit the calculated hosting capacity. In most cases, especially high power requirements, a dedicated transformer must be installed. It can be observed that the number of transformers with a hosting capacity below 100 kW increases significantly, while the overall hosting capacity decreases.

However, even in 2030, without grid upgrades, 40 percent of the transformers still have available capacity above 400 kW. It should be noted that the hosting capacity was calculated per site (see Annex A4). If the hosting capacity at a given site is utilised, it will significantly reduce the hosting capacity in the surrounding area. In most cases, the hosting capacity of surrounding sites will then be zero, as the capacity of one feeder has been used up. Therefore, the results should not be interpreted as the possibility to add loads to the hosting capacity limit at all sites.

FIGURE 31. Available hosting capacity at MV/Low Voltage (LV) Transformers from 2024-2030

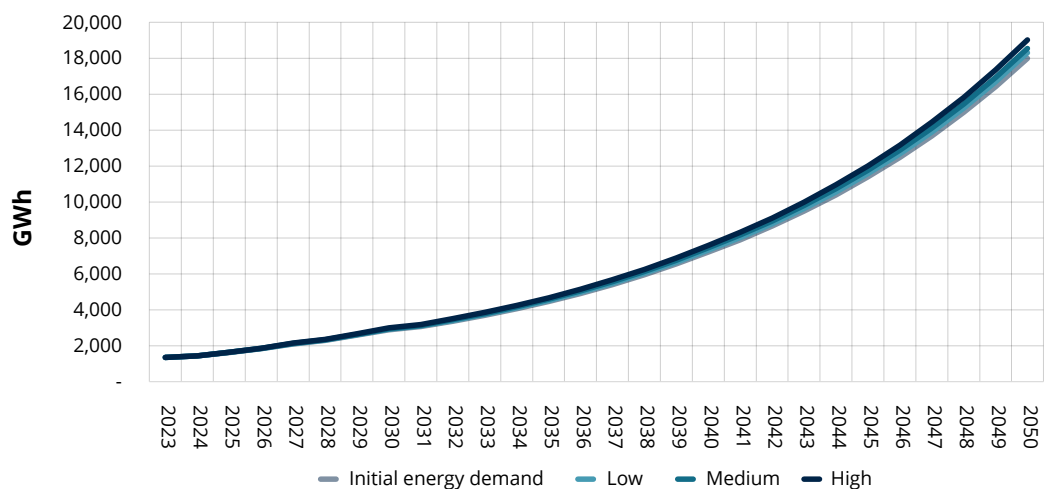


Figure 32 illustrates the available hosting capacity for 2024 and 2030 in a geolocated format. Hosting capacity is highest near the transmission network connection points, which are located towards the centre of Kigali.

Figure 33 provides information on the hosting limitations, categorised by external grid constraints (green), line overloading (red), and voltage issues (blue). In the outskirts of Kigali, voltage drops are most problematic, while in the centre, either line overloading or external grid constraints are the limiting factors. External grid constraints describe a potential overloading of the transmission network. Note that detailed evaluation of transmission network overload was not part of the study.

Charging station operators and network operators can use the Excel 3D map feature to dynamically assess the graphics. Additionally, they can search the location-based tables within the Excel tool to find the ideal location for the next charging station placement.

FIGURE 32. GIS-located reduction in hosting capacity from 2024 to 2030

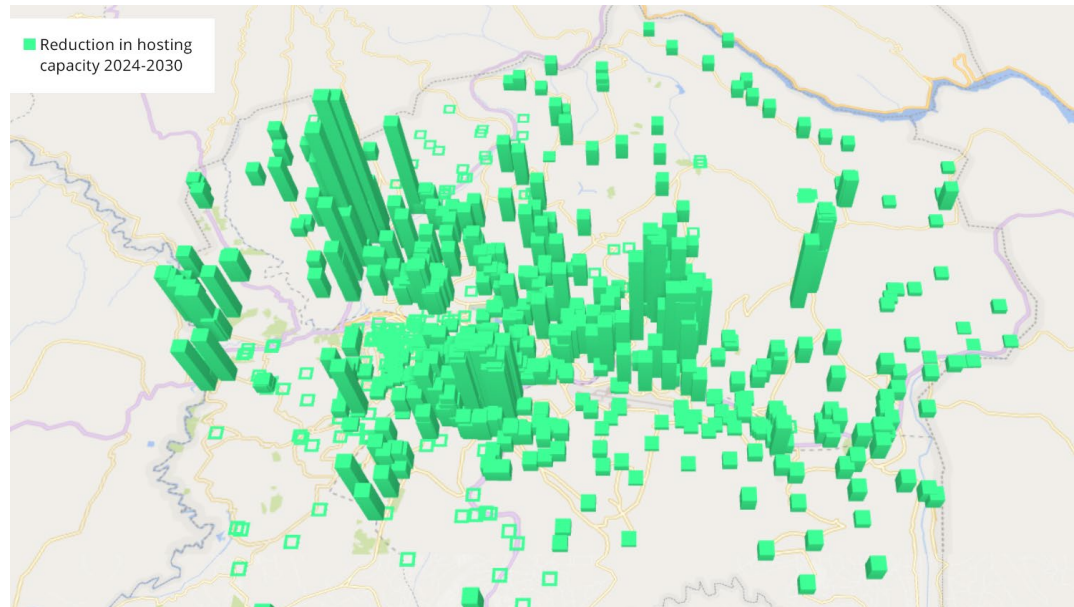
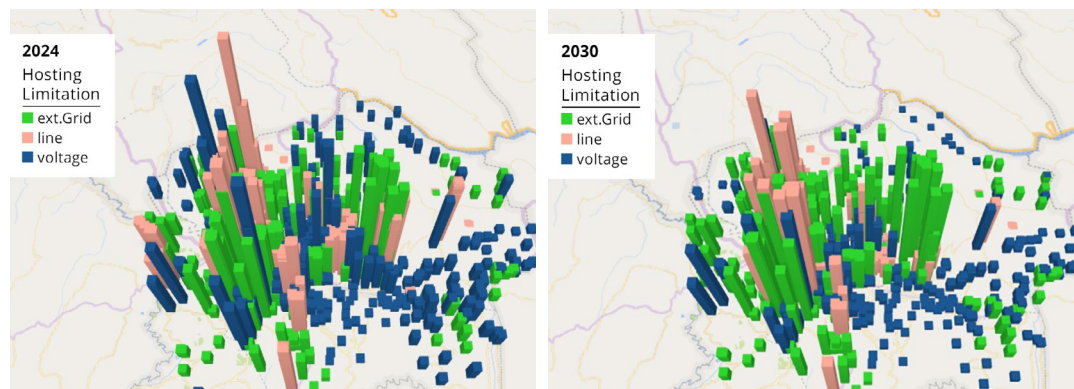


FIGURE 33. GIS-located hosting capacity in 2024 and 2030 and the corresponding hosting capacity limitations

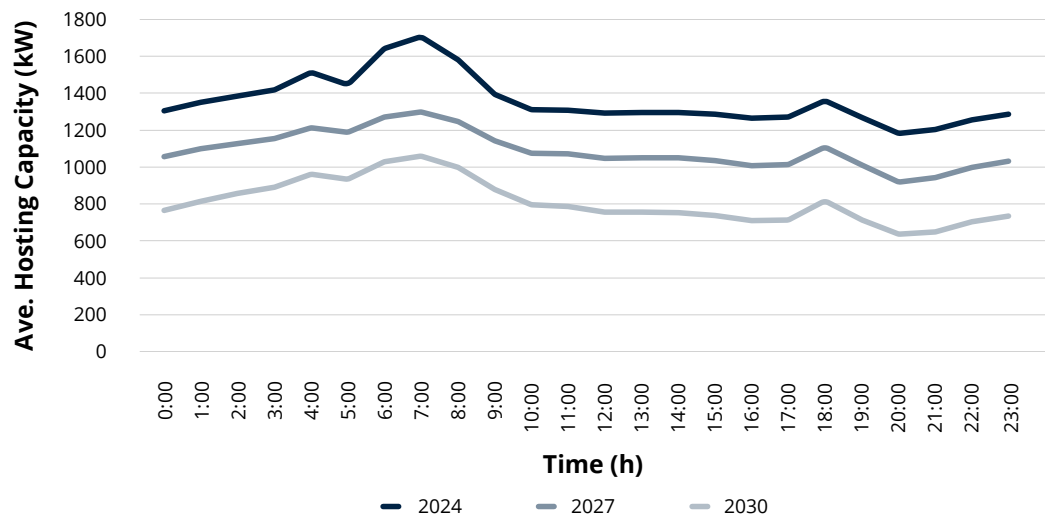


In addition to the minimum guaranteed hosting capacity evaluated above, the available hosting capacity varies throughout the day. If charging station operators have the option to charge outside peak load hours or utilise stationary buffer batteries, additional hosting capacity becomes available. The minimum available hourly hosting capacity is based on the yearly peak load at the given time interval. Most days, the hosting capacity will be higher, but using the peak load as a reference provides operators with planning certainty to offer their services throughout the year.

Figure 34 displays the calculation results for the minimal average hosting capacity throughout the day. In addition to the hosting capacity reduction from 2024 to 2030, the daily variation becomes apparent. While the hosting capacity is highest in the early morning hours, it drops to the absolute minimum around 8 PM. In the case charging station operators have the option

to recharge their vehicles in the morning hours, instead of late evening, projects might still be feasible in certain areas, without the need for network upgrades.

FIGURE 34. Time-dependent average hosting capacity for different years



Detailed time-dependent data is available via the Excel tool, either in tabular format or as a time-dependent 3-D tour.²¹

2.4 Utility impact and opportunity analysis

2.4.1 Impact on utilities

Network reliability assessment

The power system network is impacted by the general load increase, in addition to the newly emerging electric vehicle loads. In this assessment, the timewise change of the network status without any network build-out is evaluated first. This is followed by recommended network upgrades and their impact on network stability and hosting capacity.

Network status

The network health status and required network upgrades depend on asset loading during the yearly peak load. Figure 35 displays the line load distribution from 2024 to 2030. Although line loading increases over time, the proportion of overloaded lines in 2030 remains relatively low. Therefore, upgrading a few lines will already benefit the entire network.

²¹ A corresponding time-dependent tour is linked to this report as a movie file (see this link for the two files).

FIGURE 35. Distribution of maximum line loading in network from 2024-2030

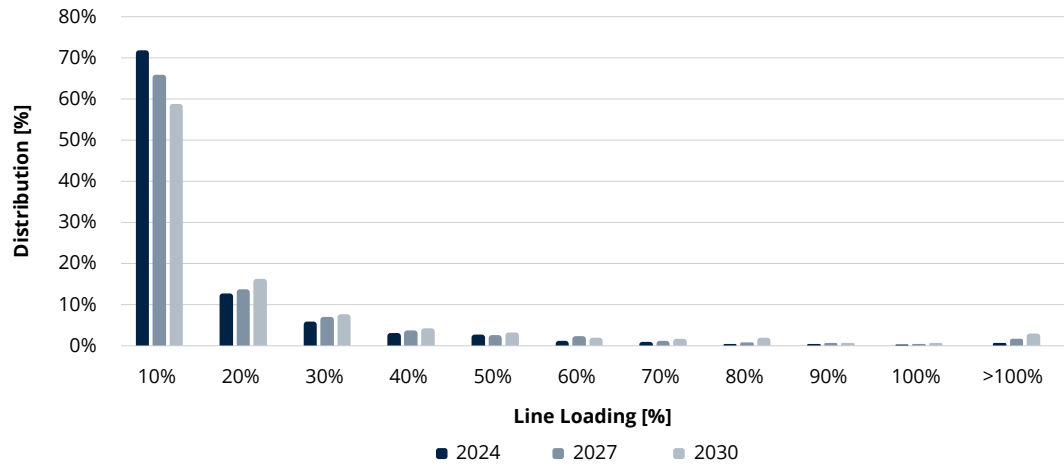
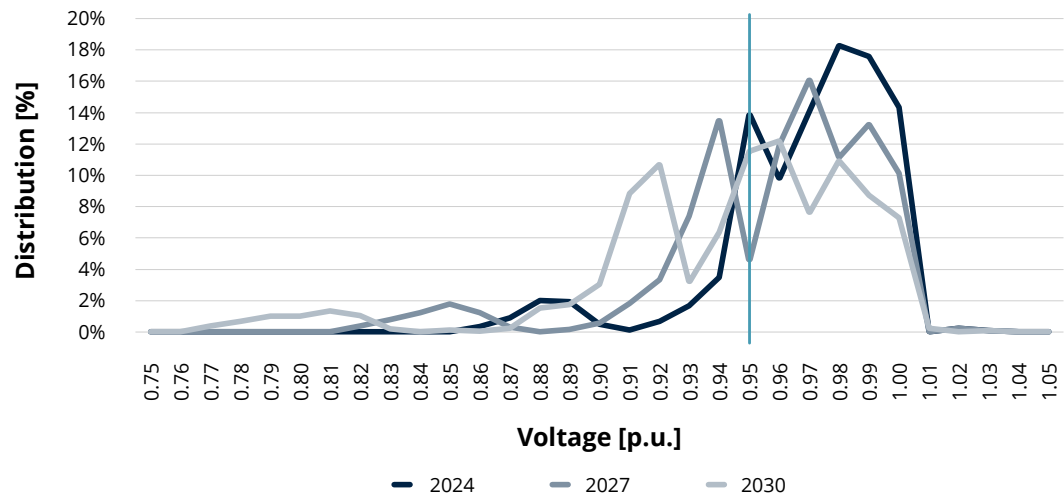


FIGURE 36. Distribution of minimum network voltages from 2024-2030



The situation is more challenging in the case of voltage deviations. As shown in Figure 36 severe undervoltage already occurs in the 2024 network, with the situation worsening by 2030. Fortunately, line upgrades will mitigate some of the voltage issues, while the remaining undervoltage problems can be resolved through the installation of capacitors and High Voltage (HV)/ MV transformer tap changes.

Additionally, Figure 37 and Figure 38 display the geographic locations of overloaded areas for 2024 and 2030. Each location represents one MV/LV distribution transformer. The voltage at the transformer is shown as a heat map blob, while line loading is represented through a column, indicating the maximum line loading of the feeder to which the transformer is connected. In 2024, the network situation is still within acceptable limits, even though some line overloading and undervoltage already occur. By 2030, network upgrades are needed due to severe line overloading and undervoltage. Recommended upgrades are described in the next section.

FIGURE 37. GIS-located minimum network voltage and maximum line loading in 2024

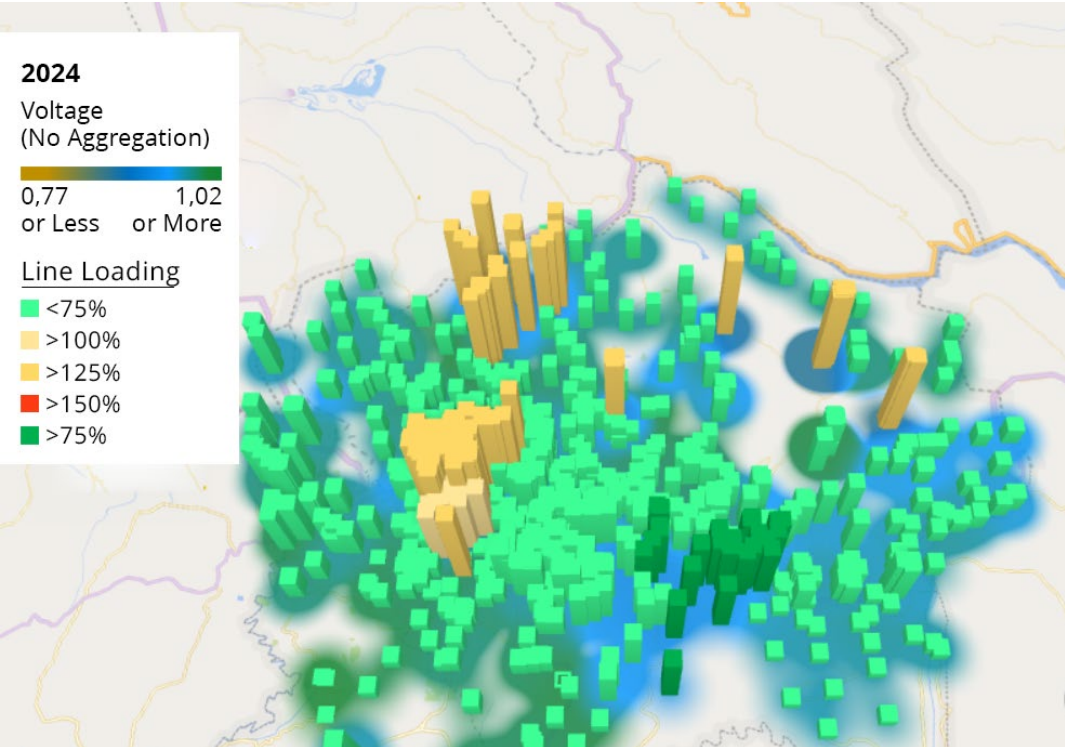
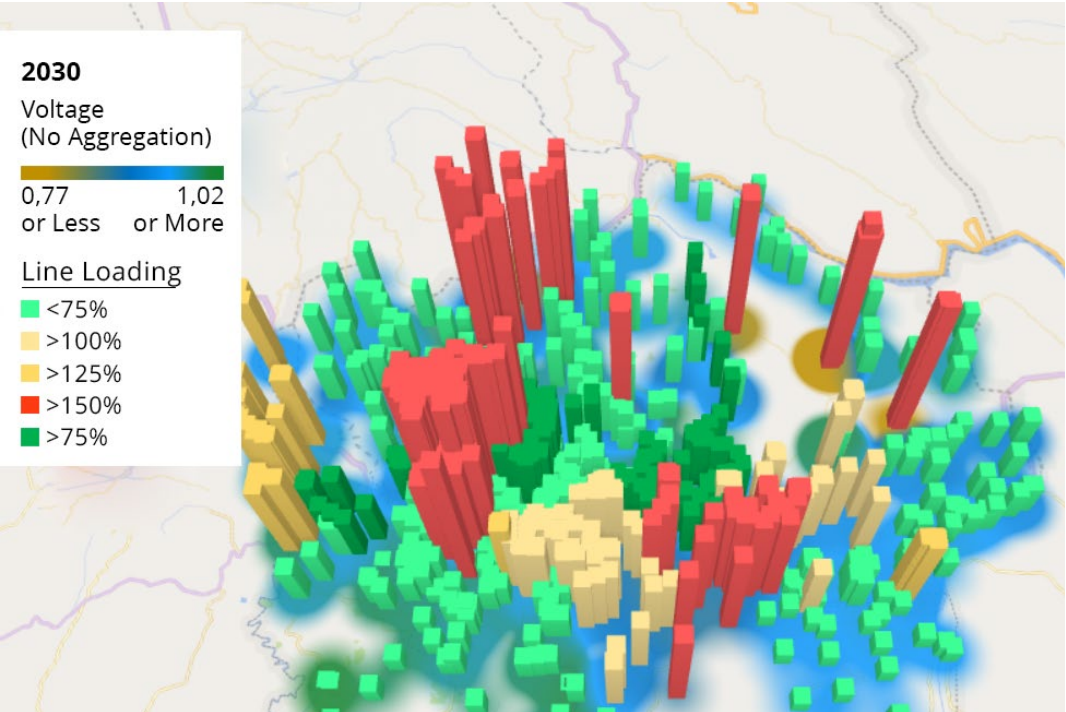


FIGURE 38. GIS-located minimum network voltage and maximum line loading in 2030



Distribution network updates

The projected increase in load demand from EVs and other consumers in the study evaluation period until 2035 will lead to significant system overloading. Consequently, updated assumptions were developed to assess the impact of EVs on the power system for different stages of total load increase. While the upgraded network offers a viable solution for the future grid, it does not replace a detailed network development plan²² and can only provide indications of where measures should be taken.

The analysis resulted in a plan outlining the necessary network upgrades at each stage of load increase. According to common technical requirements for electricity distribution networks, the voltage magnitude at the medium voltage level for all nodes must remain within ± 5 percent of the nominal voltage. Additionally, the loading of lines/cables must be below 100 percent, and the loading of distribution transformers must also be within acceptable limits. In the model, transformers are treated as loads, so upgrades were not considered in the evaluation.

The updated assumptions were developed using a PowerFactory model provided by REG in April 2024. During the analysis, network loading was gradually increased from 40 percent to 120 percent in 10 percent increments, reflecting the anticipated loading up to 2035. At each stage, a load flow study was conducted to examine the grid status. When any of the aforementioned network restrictions were encountered, one of the following potential updates was implemented to maintain the grid within acceptable limits.

1. **Increasing the voltage set points of HV/MV transformers on the MV side (eg, busbars at 15 kV or 30 kV):** This can be achieved by adjusting the tap changers of transformers in substations to meet voltage constraints.
2. **Upgrading distribution lines/cables:** This prevents overloading and supports voltage constraint compliance.
3. **Adding capacitors to the network:** This facilitates voltage constraint compliance.

The developed assumptions were further compared to GIS data containing the latest grid updates (received February 2025) and the Rwanda Electricity Distribution Master Plan (published June 2021). The comparison aimed to determine if upgrades identified through PowerFactory simulations are already in operation (GIS Model) or part of planning procedures (Distribution Master Plan).

The results are summarised in Table 17. The first column sets the load level, the second column indicates the recommended measures to meet technical constraints, and the third column specifies where the measures should be applied within the PowerFactory model. The following columns show the technical specifications (eg, voltage set point on the MV side of the power transformer, type of distribution lines/cables, and Mvar capacity of the added capacitor) before and after applying the measures. All recommended measures are sufficient to handle the 120 percent loading case, avoiding cost-intensive multiple upgrades in a short period. The last column compares the PowerFactory model-based upgrade assumptions to the GIS data and the Distribution Master Plan.

The detailed comparison of these upgrade assumptions to the GIS data and the Distribution Master Plan in Table 17 reveals the following main findings:

²² Beside the measures taken in our investigations, there are many other solutions possible, which should be considered in a network development plan. These are amongst others: topology adjustments, change of voltage level to 30 kV, new power transformers, etc.

- **Rutongo Line:** is not yet updated in the PowerFactory model, although included in the GIS data representing real-world operation, thus, aligning with the Distribution Master Plan and the study's upgrade assumptions at 40-50 percent load.
- **Utexurwa Lines:** The update is not yet included in the PowerFactory model, though already carried out as indicated by the GIS Model. Based on the assumptions, an upgrade would only be necessary starting at 70 percent loading.
- **Sonatube Line:** The update is not yet included in the PowerFactory model, though it is already carried out as indicated by the GIS Model. Based on the assumptions, an upgrade would only be necessary starting at 80 percent loading.
- **Line (799) in PowerFactory Model:** Has a different line type compared to the GIS Model and should be rechecked.
- **Planned Upgrades in the Distribution Master Plan:** Are not needed based on the PowerFactory Model alone, likely due to lacking data on newly emerging load centres.
- **Location Discrepancies:** Some upgrades mentioned in the Distribution Master Plan could not be located in the PowerFactory Model due to naming mismatches or zoning issues. Improved location indication would be required to eliminate these discrepancies.
- **Further Upgrades:** Identified by the study's assumptions, these are not part of the Master Plan or GIS model. Possible reasons include limited load growth in some grid sections or new lines constructed following the Master Plan providing more cost-effective relief to overloaded areas.

A number of conclusions can be drawn. First, a lack of data coherency was identified. The Rutongo, Utexurwa, and Sonatube lines are already upgraded but not yet included in the current PowerFactory model. Realignment is necessary. Furthermore, the manual creation of the PowerFactory model leads to misalignment errors, such as on Line (799). Automated PowerFactory model upgrades based on GIS data are highly recommended.

In terms of grid loading, the comparison revealed that the PowerFactory model indicates severe overloading of the Gikondo feeder in the coming years, with no mitigation action described by the GIS data or the Distribution Master Plan. REG is advised to review their strategy for this feeder to ensure timely upgrades, if not already carried out.

TABLE 17. Required network upgrades until 2030

Load Level	Type of Measure	Element
40%-50%	Increasing voltage	1. 15 kV busbar of Jabana substation
	Upgrading lines	1. First 160 m of the Rutongo line from the Jabana substation (Rutongo line) 2. 3.8 km of line starting from Distribution Transformer (DT) NYACYONGA CENTRE towards the Jabana substation (Rutongo line(1), (3), (45), (7), (9), (9)_a, (16), (17), (21)) 3. First 40 m of line starting from DT KIGALI SUD towards DT Kist ex cabin (Line(792))

Load Level	Type of Measure	Element
40%-50%	Adding capacitor	1. At the last 15 km of Rutonga line 2. Rutonga line, 2.5 km away from DT NGIRYI2, towards feeder end 3. 155 m from DT COL KARYANGO towards the end of the feeder
	Increasing voltage set point	1. 15 kV busbar of Gikondo substation 2. 15 kV busbar of Birembo substation 3. 15 kV busbar of Gasogi substation
50%-60%	Upgrading lines	1. 96 m of line between DT OXYGEN and DT Nyatanyi (Kano line(23)) 2. The lines between Gikondo substation and DT Mythos (Kigali south and Line(814)) 3. 500 m of line between DT Bureau pedagogique and DT Circle Sportif (Line(781))
	Adding capacitor	1. At Kiyu line, 17.5 km away from MontKigali substation
	Increasing voltage	1. 30 kV busbar of MontKigali substation
60%-70%	Upgrading lines	1. The lines between DT Mythos and DT Circle Sportif (Line(47), Line(50), Line(52) and Line(799)) 2. 110 m of line between DT Kist ex cabin and DT Bureau pedagogique (Line(786)) 3. First 196 m of line starting from Kist ex cabin towards DT KIGALI SUD (Line (791))
	Adding capacitor	1. At a node approx. 600 m away from DT Serubuga
	Increasing voltage set point	1. 15 kV busbar of Birembo substation 2. 15 KV busbar of NZOVE substation 3. 15 KV busbar of Gasogi substation
70%-80%	Upgrading lines	1. 265 m of line starting from DT Gasave1 towards the Jabana substation (Utx(13)) 2. 700 m of lines starting from DT Gasave1 towards the end of the feeder (Utx(14) and Utx(18)) 3. The line between DT Adarwa BAS AGAKIRO and DT UTEXIRWA WEAVING (Utx(23)) 4. The line between DT KIGALI SUD and DT BOULEVARD CENTRAL 1 (Line(31)) 5. The first 80 m of line starting from DT SOCLE SOPETRADE towards the Gikondo substation (Line(60)_a) 6. The first 300 m of line starting from NZOVE substation DT NYABARONGO (Skol line)
	Increasing voltage set point	

Load Level	Type of Measure	Element
70%-80%	Adding capacitor	1. At a node 1.6 km away from DT EPK RUKIRI towards the end of the feeder 2. At a node 23.6 km away from the end of Rutongo line 3. At a node 6.5 km away from Birembo substation on the Kiny line
	Upgrading lines	1. First 1.28 km of line starting from Gikondo substation towards DT PH SOPETRADE (kigali North and Line(817)) 2. 814 m of line between NZOVE substation and DT Skol industry (Skol line(8)) 3. The lines between DT BOULEVARD CENTRAL 1 and DT MINISTERE (Line(29) and Line(30)) 4. 830 m of lines starting from Gikondo substation towards the end of the feeder (Sonatube(1) and Line(139)) 5. The first 900 m of line starting from DT EXPO towards the Gikondo substation (Line(141)) 6. The lines between DT Utexurwa Spinning and DT UTEXURWA EXTERIEUR (Utx(24) and Utx(43))
80%-90%	Adding capacitor	1. Approx. at the last 14 km of feeder starting from MontKigali substation towards DT EPK RUKIRI 2. On the line between DT ISUMU NC and DT KARONDO, approx. 175 m away from the second one 3. At DT KAJAGALI AIRPORT
	Increasing voltage set point	1. 30 kV busbar of MontKigali substation
	Upgrading lines	1. The first 140 m of line starting from DT INYANGE TR1 NC towards Gasogi substation (iny line2) 2. The first 180 m pf line starting from DT Usine wasac Nzove1 towards NZOVE substation (Skol line(12)) 3. The line 900 m away from DT EXPO towards the Gikondo substation Line(140)
	Adding capacitor	1. At DT CHRISTUS
100%-120%	Increasing voltage set point	1. 15 kV busbar of Gikondo substation 2. 15 kV busbar of Birembo substation 3. 15 KV busbar of NZOVE substation 4. 15 KV busbar of Gasogi substation 5. 15 KV busbar of Ndera substation 6. 15 KV busbar of Jabana substation

Load Level	Type of Measure	Element
100%-120%	Upgrading lines	1. The first 770 m of line starting from Ndera substation towards the end of feeder (KSEZ1) 2. 220 m of line starting from DT POSTE GASOGI towards the end of feeder (Kano line(1) and Kano line(2)) 3. The lines between Gikondo substation and DT PYLONE 10 (Line(293) and Line(294)) 4. The first 2.7 km of line starting from Jabana substation towards DT Gasave1 (Utx)
	Upgrading lines	1. The line between DT BELLE VIE KARAMIRA and DT BELLE VIE KARAMIRA (Line(799)) 2. A line 1.28 km away from Gikondo substation with the length of 502 m towards the end of the feeder (Line(60)) 3. 1.4 km of line starting from DT PH SOPETRADE towards the end of the feeder (Line(62) and Line(63)) 4. A line 2.9 km away from Birembo substation with the length of 546 m towards the end of the feeder (Kiny(3)) 5. The line between DT BELLE VIE KARAMIRA and DT MINISTERE (Line(804))

Load Level	Type of Measure	Technical Specification- before measure	Technical Specification- after measure ²³	Measure part of Master Plan or GIS
40%-50%	Increasing voltage	1. 1.00 p.u.	1. 1.03 p.u.	1. Operation Measure
	Upgrading lines	1. 30kV 3 core PILC Cu 50 mm 2. 15 kV_35/6 ACSR 3. 15kV 3 core pex Cu 95 mm	1. 30kV 1 core pex Cu 240 mm 2. 15 kV_120/20 ACSR 3. 15kV 3 core Cu 120 mm 2 parallel	1. Part of GIS Model and Master Plan 2. Part of GIS Model and Master Plan 3. Not included
	Adding capacitor	1. 0 Mvar 2. 0 Mvar 3. 0 Mvar	1. 3 Mvar 2. 2.5 Mvar 3. 4 Mvar	1. No external data available (most likely not included) 2. No external data available (most likely not included) 3. No external data available (most likely not included)

²³ It should be noted that as long as the voltage level of the distribution network remains at 15 kV, upgrading one line type to another of the same size but higher voltage level cannot solve the overloading problem, since the current flowing through the lines will be the same. For this reason, line types with voltage levels higher than 15 kV were only used when either the original type was at a higher voltage level, or there was a type of line with a larger size that could provide higher capacity.

Load Level	Type of Measure	Technical Specification- before measure	Technical Specification- after measure ²³	Measure part of Master Plan or GIS
50%-60%	Increasing voltage set point	1. 1.00 p.u. 2. 1.00 p.u. 3. 1.00 p.u.	1. 1.02 p.u. 2. 1.02 p.u. 3. 1.02 p.u.	1. Operation Measure 2. Operation Measure 3. Operation Measure
	Upgrading lines	1. 15 kV_35/6 ACSR 2. 15 kV_120/20 ACSR 3. 15 kV_70/12 mm	1. 15 kV_70/12 mm 2. 33 kV 1xBEAR SC 124 2x7/0.104C EW, 2 parallel 3. 33 kV 1xBEAR SC 124 2x7/0.104C EW, 2 parallel	1. Not included 2. Not included 3. Not included
	Adding capacitor	1. 0 Mvar	1. 4 Mvar	1. No external data available (most likely not included)
60%-70%	Increasing voltage	1. 1.00 p.u.	1. 1.03 p.u.	1. Operation Measure
	Upgrading lines	1. 15kV120/20mm 2. 15 kV_120/20 ACSR 3. 15 kV_120/20 ACSR	1. 33 kV 1xBEAR SC 124 2x7/0.104C EW, 2 parallel 2. 33 kV 1xBEAR SC 124 2x7/0.104C EW, 2 parallel 3. 15 kV_120/20 ACSR 2 parallel	1. Not included 2. Not included 3. Not included
	Adding capacitor	• 0 Mvar	• 1.5 Mvar	• No external data available (most likely not included)
70%-80%	Increasing voltage set point	1. 1.02 p.u. 2. 1.00 p.u. 3. 1.02 p.u.	1. 1.03 p.u. 2. 1.02 p.u. 3. 1.03 p.u.	1. Operation Measure 2. Operation Measure 3. Operation Measure

Load Level	Type of Measure	Technical Specification- before measure	Technical Specification- after measure ²³	Measure part of Master Plan or GIS
70%-80%	Upgrading lines	1. 15 kV_35/6 ACSR 2. 15 kV_35/6 ACSR 3. 15kV 3 core PILC Cu 35 mm 4. 15kV 1 core pex Cu 240 mm 5. 15kV 3 core Cu 120 mm 6. 15 kV_70/12 mm	1. 15 kV_70/12 mm 2. 15 kV_70/12 mm 3. 15kV 3 core pex Cu 95 mm 4. 15kV 1 core pex Cu 240 mm 2 parallel 5. 15kV 3 core Cu 120 mm, 2 parallel 6. 15kV 70/12 mm, 2 parallel	1. Part of GIS Model 2. Part of GIS Model 3. Part of GIS Model 4. Not included 5. Not included 6. Not included
	Adding capacitor	1. 0 Mvar 2. 0 Mvar 3. 0 Mvar	1. 4 Mvar 2. 3 Mvar 3. 5.5 Mvar	1. No external data available (most likely not included) 2. No external data available (most likely not included) 3. No external data available (most likely not included)
80%-90%	Upgrading lines	1. 15 kV_120/20 ACSR 2. 15 kV_70/12 mm 3. 15kV 1 core pex Cu 240 mm 4. 15kV 3 core Al 95 mm 5. 15kV 70/12 mm 6. 15kV 3 core PILC Cu 35 mm	1. 15 kV_120/20 ACSR 2 parallel 2. 15 kV_70/12 mm, 2 parallel 3. 15kV 1 core pex Cu 240 mm, 2 parallel 4. 15kV 1 core pex Cu 240 mm 5. 15kV120/20mm 6. 15kV 3 core PILC Cu 50 mm	1. Not included 2. Not included 3. Not included 4. Update part of Master Plan 5. Update part of Master Plan 6. Included in GIS Model
	Adding capacitor	1. 0 Mvar 2. 0 Mvar 3. 0 Mvar	1. 2.5 Mvar 2. 2.5 Mvar 3. 4.5 Mvar	1. No external data available (most likely not included) 2. No external data available (most likely not included) 3. No external data available (most likely not included)

Load Level	Type of Measure	Technical Specification- before measure	Technical Specification- after measure ²³	Measure part of Master Plan or GIS
90%-100%	Increasing voltage set point	1. 1.02 p.u.	1. 1.03 p.u.	1. Operation Measure
	Upgrading lines	1. 15 kV_35/6 ACSR 2. 15 kV_70/12 mm 3. 15kV 3 core Cu 95 mm	1. 15 kV_70/12 mm 2. 15 kV_120/20 ACSR 3. 15kV 3 core pex Cu 240 mm	1. Not included 2. Not included 3. Included in Master Plan
	Adding capacitor	1. 0 Mvar	1. 0.96 Mvar	1. No external data available (most likely not included)
100%-120%	Increasing voltage set point	1. 1.02 p.u. 2. 1.03 p.u. 3. 1.02 p.u. 4. 1.03 p.u. 5. 1.00 p.u. 6. 1.03 p.u.	1. 1.04 p.u. 2. 1.04 p.u. 3. 1.04 p.u. 4. 1.04 p.u. 5. 1.02 p.u. 6. 1.04 p.u.	1. Operation Measure 2. Operation Measure 3. Operation Measure 4. Operation Measure 5. Operation Measure 6. Operation Measure
	Upgrading lines	1. 15 kV_120/20 ACSR 2. 15 kV_120/20 ACSR 3. 15 kV_120/20 ACSR 4. 15 kV_120/20 ACSR 5. 15kV 3 core Cu 120 mm 6. 15kV120/20mm 7. 15kV120/20mm 8. 15 kV_70/12 mm 9. 15kV 3 core pex Cu 240 mm	1. 15 kV_120/20 ACSR, 2 parallel 2. 15 kV_120/20 ACSR, 2 parallel 3. 15 kV_120/20 ACSR, 2 parallel 4. 15 kV_120/20 ACSR, 2 parallel 5. 15kV 3 core pex Cu 240 mm 6. 15kV120/20mm, 2 parallel 7. 15kV120/20mm, 2 parallel 8. 15 kV_120/20 ACSR 9. 15kV 1 core pex Cu 240 mm	1. Not included 2. Not included 3. Not included 4. Additional update not included in GIS 5. Update not included, also discrepancy between PF and IS Model 6. Not included 7. Not included 8. Part of GIS 9. Not included

Network impact of upgrades

In case the suggested network upgrades are implemented, no line overloading or undervoltage issues will occur within the network. Additionally, active power losses will decrease by 30 percent, and the average hosting capacity will more than double. Corresponding parameters can be found in Table 18.

TABLE 18. Global network parameter comparison between the base case (Base) and fully updated network until 2030 (100%L)

Global Parameter	Base	100%L	Diff.
P_loss [%]	5.1%	3.6%	-29.7%
L_ave[%]	18.4%	16.4%	-11.1%
L_max[%]	245%	91%	-63.0%
L_nr_over[#]	40	0	-100.0%
U_ave[p.u.]	0.94	1.00	6.3%
U_min[p.u.]	0.77	0.96	24.9%
U_nr_under[#]	702	0	-100.0%

Figure 39 shows the distribution of line loading after the proposed grid build-out: no line overloading occurs, and many lines still have sufficient headroom to host additional loads. Figure 40 displays the voltage profile changes within the network. Without network upgrades, about half of the terminals are below the reference voltage, which is rectified through the upgrades. A GIS-located visual representation of the network status is shown in Figure 41, highlighting the updated problematic network areas.

FIGURE 39. Impact of network upgrades on the line load distribution

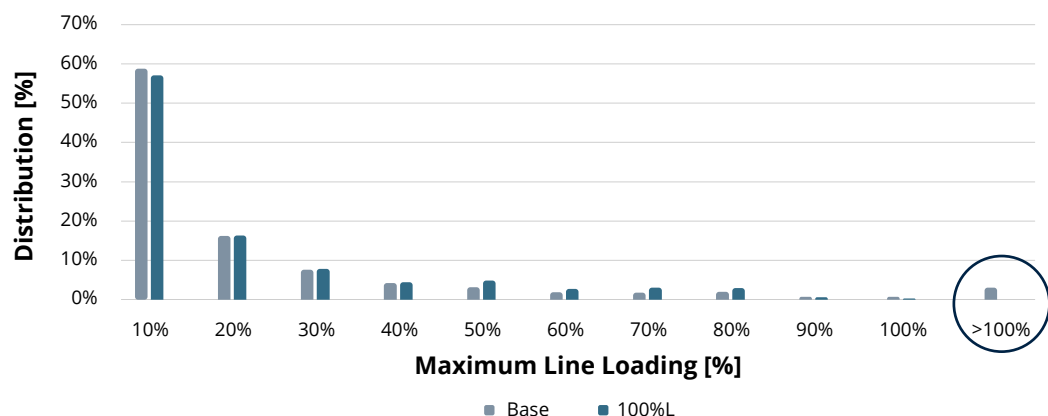


FIGURE 40. Impact of network upgrades on the voltage distribution

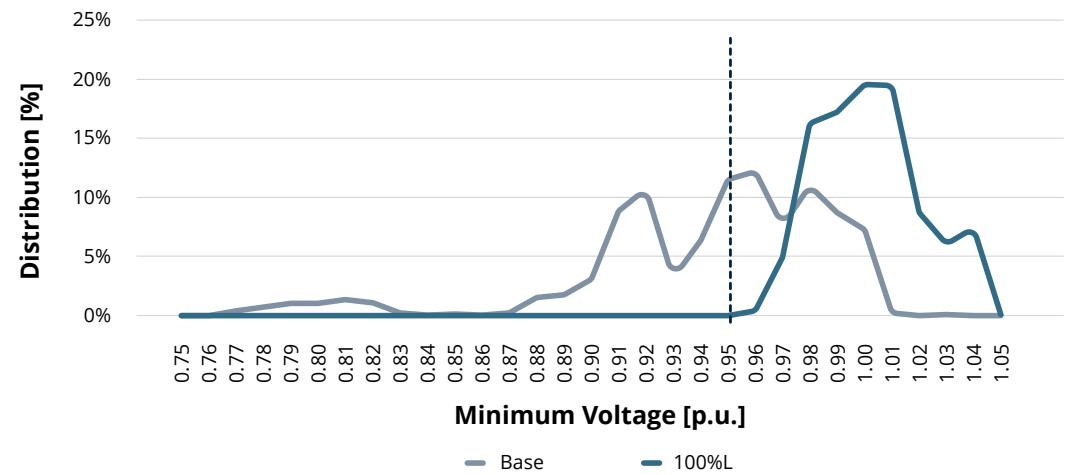
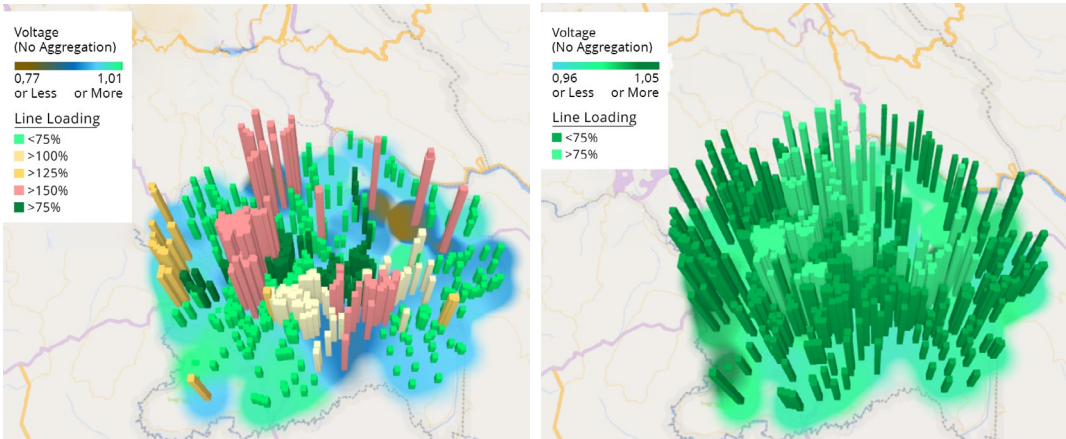


FIGURE 41. GIS-located line loading and voltage distribution for the base case in 2024 and the 100%L scenario in 2030



Hosting capacity impact

Implementing the suggested network upgrades will also impact the available hosting capacity to integrate additional EV loads. Figure 42 shows a significant change in available hosting capacity: At almost all sites, charging stations with a capacity above 400 kW could be installed, provided no further charging stations are installed on the same feeder. The change in available hosting capacity is further illustrated in geolocated Figure 43.

FIGURE 42. Impact of network upgrades on available hosting capacity

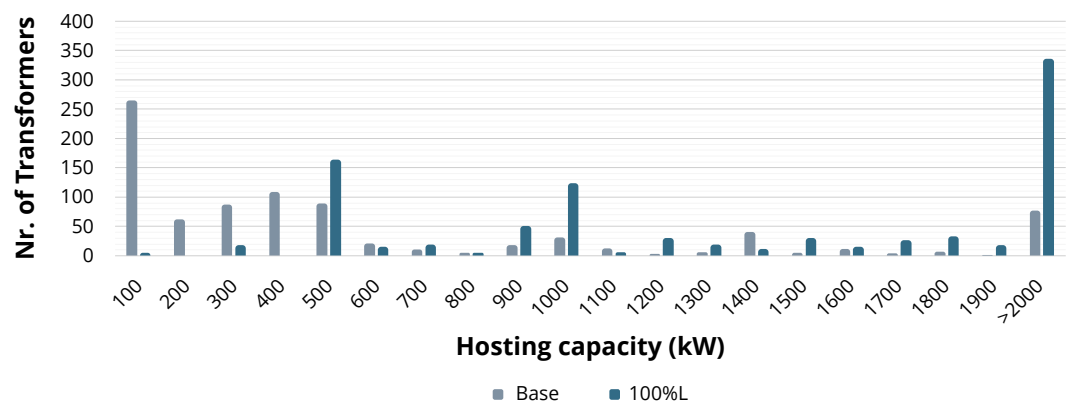
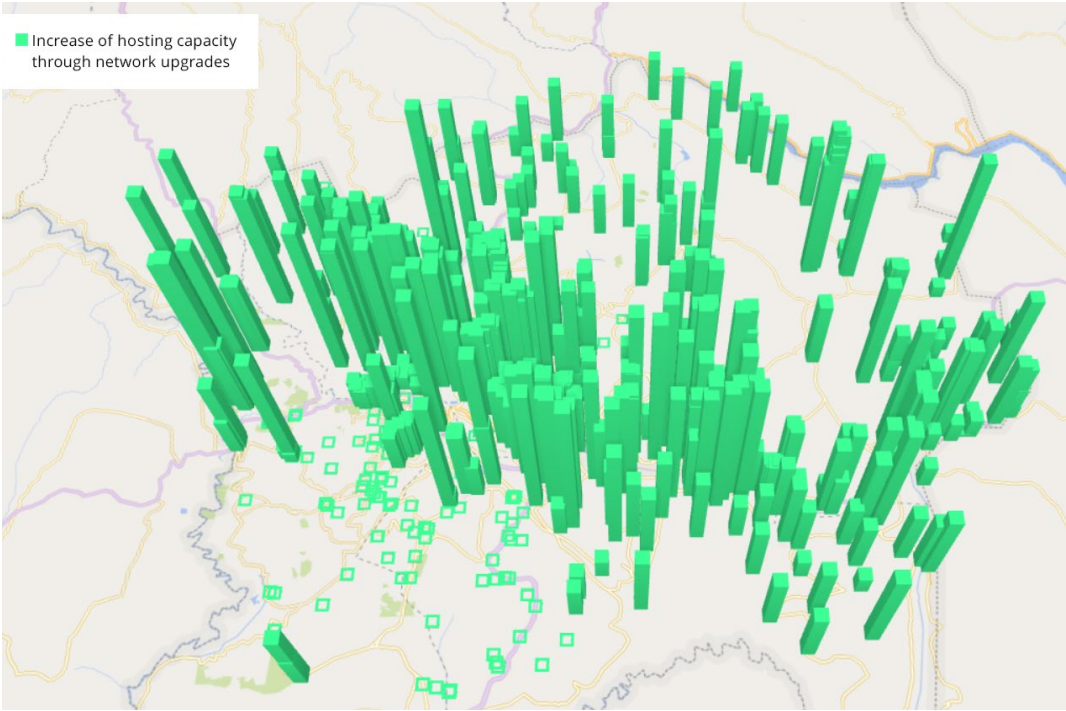


FIGURE 43. Increase of available hosting capacity before (Base) and after network upgrades (100%L)



Network reliability conclusion

The utility will need to invest in network upgrades to cope with the rising demand from substantial annual general load growth. These upgrades will be necessary regardless of EV adoption. While EV integration impacts the network, it is actually small compared to the expected annual load growth. Properly sized upgrades will support the rising demand from EV charging and provide ample opportunities for charging station operators to install their stations throughout Kigali.

Cost recovery

Charging costs significantly influence the financial viability of EVs. The degree to which the utility's financial position is impacted by electric vehicle charging depends primarily on the tariff level (ie, is the tariff 'cost-recovery') and the tariff structure (ie, is the tariff 'cost-reflective'). If both criteria are met, then the utility's cost recovery should not be negatively affected by EV charging²⁴. Setting cost-recovery tariffs is conceptually simple: tariffs must allow the utility to collect sufficient revenue to cover its costs. However, it is worth noting that cost recovery is already a challenge for EUCL. In the Fiscal Year 2023, EUCL's operating losses excluding subsidies was around 24 percent of their cost of sales, already requiring significant financial support from the Government for routine operations²⁵.

The more tariffs can reflect the underlying costs a customer or category of customers places on a network, the greater the potential for recovering costs of service and the stronger the incentives for efficient system use. For example, applying cost-reflective tariffs can utilise network capacity more efficiently, ie, minimise network expansion and utilise spare capacity, and align demand with times of the day when the most expensive generation is not being used²⁶. Cost-reflective tariffs may also incorporate an allocation of the costs of the ancillary services necessary to ensure network stability, eg, generation reserves to balance fluctuations in voltage or frequency. Such costs may be higher as EV uptake grows owing to the less predictable (temporally and spatially) charging patterns of EVs.

However, cost-reflective tariffs are more complex to design. The degree to which costs are allocated to any particular group of customers and recovered through tariffs structured per the structure of those costs is on a spectrum and depends on the granularity of the utility's cost data and the extent to which customers can understand and be willing to bear those costs. Even in the most developed markets with accurate data, customers are aggregated and customer groups find it difficult to understand complex tariffs, particularly those applied to them without adequate consultation.

²⁴ Utilities may also see opportunities for new revenue streams through EV charging business models, discussed further in Section 2.4.2.

²⁵ It is worth noting that cost recovery is already a challenge for EUCL. In the Fiscal Year 2023, EUCL's operating losses excluding subsidies was around 24 percent of their cost of sales, already requiring significant financial support from the Government for routine operations. See <https://www.reg.rw/public-information/reports-plans/> for the financial statements of REG/EUCL.

²⁶ The potential of managed charging is evaluated through simulation work in Section 3.2.

Recommendation for Rwanda

EV charging in Rwanda is currently charged through uniform residential or industrial tariffs. This means that charge point operators will be billed at close to US \$ 0.10 per kWh instead of around US \$0.20 per kWh for residential customers. EVs also plan to benefit from reduced tariffs during off-peak periods.²⁷

It is expected that EV customers' charging load patterns are different from those of residential or industrial customers, suggesting an opportunity for a new tariff category that is more cost-reflective. This need not be a dedicated EV charging tariff if other customers have similar enough load patterns or if it is impossible to disaggregate costs to the extent that they can transparently be allocated to EV charging. If the data exist to adequately determine EV charging costs, then more cost-reflective tariffs could be designed. If EV customers are willing to pay such tariffs, they could be implemented.

However, implementable and acceptable cost-reflective tariffs might not suffice in countries without cost-recovery tariffs in achieving utility cost recovery. In this case, additional elements may be considered alongside the tariff:

- **Additional payments or other rewards to avoid congestion and enhance load flexibility**, as they provide benefits to the utility (provided the cost of the reward is less than the benefit gained, or cost avoided, by the utility). This could also allow for vehicle-to-grid (V2G) activities – which would involve the vehicles serving as a back-up source of power during peak times.
- **Temporary government subsidies to the utility** to meet the shortfall between costs to serve and acceptable tariffs specifically for EV charging.
- **Ensuring tariffs and other rewards require EVs to be charged through dedicated charging points** rather than conventional household plugs, which reduce electrical safety.

EV charging policy and regulatory options

Rwanda's EV charging pricing regulations combine global best practices and local adaptations. This overview provides insights into pricing strategies and international standards, assisting in future regulatory developments. Table 19 provides a comprehensive overview of current and international regulations regarding pricing for EV charging.

²⁷ Ministry of Infrastructure, 2021. *Strategic paper on electric mobility adaptation in Rwanda*. Cliffe Dekker Hofmeyr, 2022. *Electric vehicle policies in Rwanda*.

TABLE 19. The current and international regulations on pricing for EV charging

Current practice in Rwanda	International best practice
EV charging tariff approaches	
Charging Point Operators (CPOs) benefit from industrial tariffs and off-peak rates. The current tariff for large industries is RWF 95 per kWh (RWF 94 per kWh off-peak). As a comparison, the commercial tariff is RWF 179 per kWh. CPOs set their own charging tariffs. After considering their investment and O&M costs, these tariffs are often set at a rate competitive with the equivalent petrol or diesel price. BasiGO estimated that the current equivalent price of diesel buses is RWF 1,500 per km. Under its pay-as-you-drive financing model, BasiGO offers a charging price of RWF 600 per km. KABISA's charging tariff is estimated to be around 30 percent higher than the industrial tariff to cover its capital and operational costs.	EV charging prices are typically set freely by the market without specific regulations. Business-to-consumer pricing schemes in Europe include: • Flat rate pricing: For example, €15 per month. • Transaction-based pricing: For example, €0.30 per kWh. This approach is familiar to EV owners as it resembles conventional electricity billing. • Time-based pricing: For example, €1.50 per hour of charging. CPOs may prefer this model to encourage turnover and maximise station usage. Some developing countries introduce lower and upper price caps for charging to protect consumers and stabilise the market.
Regulatory framework for EV charging	
The current regulations for electrical connections in Rwanda are specified in the Regulations Governing Electrical Installations (2023). This regulation stipulates the procedures and requirements for electrical installations and conditions, inspection, monitoring, and compliance. Electrical installations are classified for various voltage levels and specific installation works. Fees are also based on these classifications.	Requirements and fees for charging stations are similar to those for other consumption points. In some Latin American countries, fees are based on the cost of providing the new connection and are not differentiated for EV charging. In Germany, charging stations with a capacity of more than 12 kilovoltamperes (kVA) require approval from the network operator. Charging devices with less than 12 kVA output shall be registered with the distribution network operator. If a single EV charging point is connected to the LV grid, the connection is treated like any other. If the installation of a public charging station is made via a direct connection to the MV grid, the same regulation applies as with other devices connected to the medium voltage grid. To accelerate the installation of charging stations at common locations (supermarkets, hotels, restaurants, etc), the German Federal Ministry of Transport and Digital Infrastructure issues calls for tenders for the construction and operation of charging sites and charging points.

Rwanda should decide whether there is any need to or benefit from regulating CPO prices. International precedent is typically not to regulate prices, except when there is a motivation to protect consumers and stabilise the market. As CPO charging prices are currently benchmarked to equivalent fuel prices, there does not appear to be any uncompetitive behaviour or oligopolistic pricing, despite the lack of competition in the market. Similarly, there does not appear to be any justification for regulating price structures; international benchmarks suggest encouraging flexibility in price structures. For RURA, as the likely entity responsible, engaging in price regulation will require a reallocation or additional regulatory resources when the potential benefit appears uncertain. However, RURA should continue to monitor pricing, and if concerns about CPO pricing are raised by EV charging customers, they can investigate and consider introducing pricing regulation.

For many developing countries including Rwanda, providing grants or subsidies to cover private charger installation costs may create an unnecessary financial burden to the government. Perhaps an alternative option is for RURA to provide income tax deductions and other tax benefits related to the installation of domestic EV chargers. Concerning the EV charging tariff policy, extending the industrial tariff for private charging may require additional metering and transaction costs to both EV owners and distribution utilities. An alternative option is to increase the range of the lower tariff block of the increasing block tariff (IBT) scheme for residential customers to cover EV charging²⁸. In addition, new regulations could be introduced for multistorey residential buildings and office buildings to allocate parking spaces and install chargers for EVs.

2.4.2 Mitigation approaches for utilities

Successful E-Mobility implementation depends on grid resilience. Unmanaged charging can weaken the local grid and power quality; unpredictable changes in demand lead to voltage fluctuations, which may, in turn, increase energy costs. This challenge is exacerbated when peak EV charging coincides with system peaks.

There is a range of mitigation opportunities that Rwanda could consider to address potential power system constraints. Each seeks to shift EV charging behaviour, driven by a need to balance the load on the network and reduce the costs of the system peak.

The previous section concluded that Kigali is unlikely to face network constraints from forecast EV uptake in the next few years, or rather its network requires upgrades regardless of EV uptake. Similarly, while meeting evening peak demand is a concern, the impact of EV uptake on this is not large (just under 6 percent - see Section 2.1.5). Therefore, while the options presented in this section, particularly price-based mitigation instruments that may be applied more widely, may provide broader system benefits, they are not currently deemed necessary to mitigate any negative impacts of EV uptake. In addition, some of the options are not yet feasible for Rwanda even if action was necessary.

The options are:

- Price-based mitigation instruments;
- Managed charging;

²⁸ Increasing Block Tariff schemes involve an increasing price per unit of electricity sold as the level of consumption increases.

- Bidirectional charging and vehicle-to-grid;
- Innovative technical solutions

Box 3 at the end of this section includes detailed definitions related to managed charging and other solutions mentioned in this report.

Price-based mitigation instruments

Various price-based demand response mechanisms seek to change customer charging behaviour through electricity price signals and may be considered within tariff design. In this section²⁹ options are presented that Rwanda may consider today or in the near term and mention others that may be considered if Rwanda's market evolves sufficiently.

Price-based demand response mechanisms – which see tariffs change during the day – are a tariff mechanism that aligns tariffs with the cost of service at different times of day. The cost of service is driven by the marginal cost of generation and the constraints of load on the network at any time, or over a time window. Such time-differentiated tariffs both increase the likelihood of cost recovery and incentivise customers to alter their behaviour (by consuming electricity at cheaper times). The ability to choose a different approach depends on the granularity of cost data and market sophistication.

The four basic time-differentiated tariff types vary based on how closely they reflect grid and market conditions and are discussed below and summarised in Figure 44.

- **Fixed time-of-use (ToU) tariffs** are a static pricing mechanism, with the price of electricity varying according to preestablished time intervals, which may be daily or, in some cases, seasonal. If the challenge is to meet peak loads, the most common form of ToU is that in which tariffs differ for energy consumed during peak and off-peak hours (volumetric charges), typically just reflecting the difference in generation costs, although network costs can also be considered³⁰.
- **Critical peak pricing (CPP)** involves a dynamic rate wherein prices rise significantly on critical days when there is a risk of low reserves or even blackouts. The energy price during those days may increase several-fold, reflecting the underlying generation costs and providing a significant incentive for customers to adjust their load profiles. Under a CPP structure, the utility notifies customers a day in advance and sometimes even on the day of the event.
- **Variable peak pricing (VPP)** is a hybrid of ToU and Real-time pricing (RTP) (discussed below). With VPP, as with ToU pricing, peak and off-peak intervals are predetermined, but unlike with ToU, during the peak period VPP customers are charged a rate that varies dynamically according to the utility/retailer and usually reflects the wholesale price of electricity. Because peak prices emulate market prices for electricity, VPP rate designs more accurately match the cost of producing and distributing electricity. The risk of high power prices is shifted during peak periods to customers, who can respond by reducing consumption.
- Under **RTP**, the energy (MWh) component of tariffs to the end-users reflects spot-price variations (typically day-ahead) in the wholesale market.³¹ Some countries and regions have been trying various dynamic pricing mechanisms to provide a better linkage between

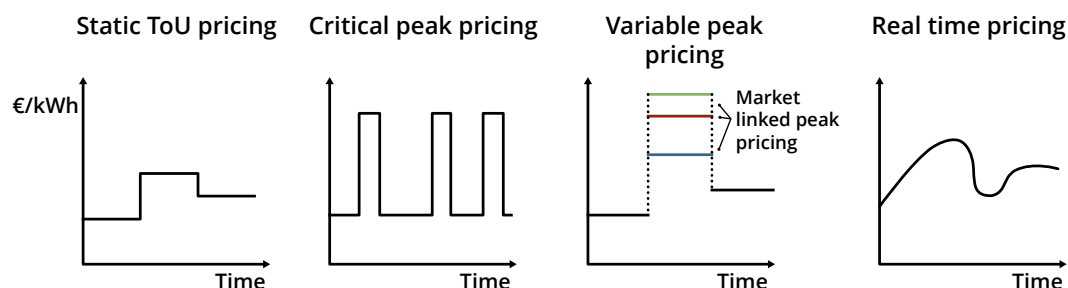
²⁹ Some of the material in this section is taken from a forthcoming World Bank publication, 'Harnessing the Potential of Flexible Demand Response in Emerging Markets: Lessons Learned and International Best Practices', for which ECA provided technical support.

³⁰ REG's industrial tariffs vary demand charges by the time of day while the energy charge remains constant throughout the day.

³¹ Spot prices may be calculated with different levels of granularity, ranging from five minutes to one day depending on the existing settlement rules in the wholesale market. In bilateral contracting markets using self-dispatch, a liquid power exchange may be referenced. Where no wholesale market exists, a shadow price may be derived from the system's short-run marginal cost.

prices at the wholesale and retail levels. For example, in several European markets and New Zealand, energy retailers in competitive markets have offered dynamic RTP tariff options to various customer categories. These offers stand alongside more traditional fixed and static ToU tariff options and are crafted to appeal particularly to owners of solar photovoltaic systems and EVs.

FIGURE 44. Types of price-based instruments



Source: IRENA 2019 a.

Note: kWh = kilowatt-hour; ToU = time-of-use.

As with ToU tariffs, locational tariffs can be set for different nodes in a network, with prices increasing in locations with congestion. Such pricing is uncommon, but could be implemented with appropriate technology to identify congestion per node and mechanisms to price this. Prices could be fixed by node or vary by the same time-based factors as discussed under the ToU tariffs.

Recommendation for Rwanda

Rwanda does not currently have ToU tariffs for energy charges. Industrial customers have ToU tariffs for demand charges, with three charging windows: peak, shoulder, and off-peak. Using these same windows, a generation dispatch analysis will provide marginal costs of generation, allowing for ToU tariffs for energy charges as well. Whether these are applied to EVs as a separate classification depends on the administrative costs of monitoring and applying the charges and EV customers' acceptability of them.

It is worth noting that, especially at the low voltage level, ToU charging has the potential to overload the grid when tariffs change between two time intervals. For example, if the price of electricity between 9:59 pm and 10 pm is drastically reduced from peak to nighttime prices, EV owners may put their vehicles on a timer that will start charging at 10 pm. A pilot project conducted in the UK has shown that EV owners will use timers, resulting in the described grid instability. Therefore, ToU tariffs should be adjusted in smaller increments and more frequently. The time difference between each adjustment and price change depends on the particular country. It is impossible to make general recommendations, as the price sensitivity of the local population, grid loading, and other factors must be considered.

Without having developed Fixed ToU energy tariffs, the other tariff options are unlikely to be feasible for Rwanda in the short term. Indeed, VPP and RTP (see below for more information about these concepts) will not be possible without a wholesale market, or at least a more dynamic system cost determination, and dynamic grid congestion prices are not used internationally.

Managed charging

Peak generation cost and grid overloading can be mitigated by managed charging, or V1G, during certain hours of the day through remotely controlling charging stations or private charging points. In this case, EVs are no longer solely seen as plug-and-charge appliances but as assets within the power system. For example, in Germany, as of 2024, the grid operator has the right to reduce the charging power in case of grid congestion down to 6 amperes per phase for private residential charging stations. EV owners are not reimbursed for the undertaken measures and methods to ensure compliance are in place. Similarly, customers can install their own 'flexible chargers' that can respond automatically to price signals ie, ToU tariffs of some form) or grid constraint notifications (of the sort that the utility might use when deciding when to control a charger remotely) from the utility. Managing these costs can avoid or at least defer grid expansion and reduce expensive peak generation.

When a flexible charger is owned by the consumer, it allows consumers to optimise for themselves when they charge their EV in response to market signals on price. When implemented effectively, Distribution System Operators (DSOs) can avoid upgrades to local grid connections while minimising costs for laying new cables, installing additional switches, and setting up new transformer stations. However, if countries do not have dynamic retail tariffs, or any way of monetising the deferred network investment, the benefits of a smart charger may not outweigh its costs, especially if being installed by the consumer when a simple timer will suffice³².

While making V1G mandatory may appear to be most effective, EV users may not be supportive without additional incentives, ie, payments for not charging, given the restricted charging ability. If the requirement were voluntary, then there would likely be greater acceptance and EV users could determine for themselves whether the compensation justified not charging during the window. Additionally, enforcement might be difficult in the case of smaller private EVs since EV charging can also be done, although slower, through a regular household socket connection. A further disadvantage is that many vehicles will start charging simultaneously when the blocked time window is over (as discussed above under ToU charges). The sudden change in power consumption can negatively impact frequency and voltage stability and potentially create a new power consumption peak. A solution to this would be to stagger the windows, if only by a few minutes.

Recommendation for Rwanda

In Rwanda, it is not expected to see grid constraints in the national power system as a result of EV uptake (see Sections 2.3 and 2.4.1 above), though broader constraints are expected (due to overall power demand). For countries with high EV uptake relative to the size of the power system, it could become more of a problem. Additionally, grid congestion could potentially become a problem at specific distribution nodes rather than nationally. We, therefore, do not see any requirement for managed charging capability in Rwanda.

³² See the results of a survey of EV owners in New Zealand undertaken by FlexForum.

Bidirectional charging and vehicle-to-grid

Vehicle-to-grid (V2G), a type of bidirectional charging (V2X), is when the energy stored in an EV battery can be discharged back into the network³³. Commercially viable V2G is still rare worldwide. The most common expectation of V2G is to provide ancillary services³⁴ in markets where private ancillary services provision is possible by connecting what is essentially a battery to the network and allowing the system operator to access that battery. As noted in Section 2.4.1, ancillary services are needed for any electricity network's safe operation, stability, and reliability and can include flexibility provision, frequency regulation, and demand response. These services help balance supply and demand in real-time, especially when integrating renewable energy sources like solar and wind, which are intermittent by nature, and with more variable demand, such as E-Mobility charging.

In most developing markets worldwide, including Rwanda, ancillary services are either provided by the utility, and the charges for them are incorporated into the utility's network costs (see the earlier discussion on cost-reflective tariffs), or in some cases by generators where they directly cause the instability, eg, through the provision of reactive power. In more developed markets with private sector participation, private operators can provide ancillary services, either mandated for generators or some large customers (eg, reactive power provision, critical voltage, and frequency support) or provided by third parties and managed through markets (frequency reserve). Such contracting arrangements require greater sophistication than most developing markets are currently able to manage.

V2G for ancillary services is particularly relevant when the EVs' charging behaviour increases the requirement for ancillary services and where the spatial distribution of EVs means they may be located on or close to the same nodes as the EV charging load. Pooling or aggregating EVs can provide primary frequency reserve, providing revenue for the EV owner(s). If the payment for this is lower than the cost the utility would otherwise pay/incur for ancillary services, it will also benefit the utility. Frequency reserve provision through EVs is currently taken from the pilot phase to wide scale application in some developed countries, such as Denmark and Germany.

Recommendation for Rwanda

Commercially viable V2G is rare worldwide, and it is unlikely to be a possibility for Rwanda in the short or medium term. Similarly, while it can be found in more mature electricity markets in regions like North America, Europe, and parts of Asia, there is currently no third-party private participation in ancillary services in Rwanda. For Rwanda to develop a market for ancillary services, its grid infrastructure, regulatory frameworks, and possibly the adoption of technologies that facilitate integrating and managing diverse energy sources would need significant advancements. As the country's energy sector evolves, particularly with increased renewable energy penetration, the need for ancillary services might become more pronounced, leading to the potential development of such markets.

As such, there is no short-term or medium-term expectation of bidirectional charging or V2G providing ancillary services or other benefits to the power system. A shorter-term solution for REG would be energy storage co-location at high-consumption charging stations.

³³ Providing the stored energy to other uses is also being explored in other countries.

³⁴ Ancillary services refer to functions that help grid operators maintain a reliable electricity system.

Storage and small-scale generation co-location

Energy storage systems can be useful when grid supply is insufficient, or network stability is compromised.³⁵ Such systems store energy during periods of low demand and then discharge it when the grid supply is inadequate or compromised. Co-located solar can be integrated into these storage systems whereby electricity generated by solar panels is stored in the battery storage system, discharged into vehicles, or exported to the grid.

Recommendation for Rwanda

Network reinforcement of the type described in this section should not be considered until it becomes more evident that the power system is likely to face constraints from EV uptake.

BOX 3. TECHNICAL SOLUTIONS GLOSSARY

Vehicle-grid integration (VGI) refers to technologies, policies, and strategies for EV charging that alter the time, power level, or location of the charging (or discharging) to benefit the grid while still meeting drivers' mobility needs. VGI encompasses various technologies and strategies contributing to grid stability, energy storage, and demand response.

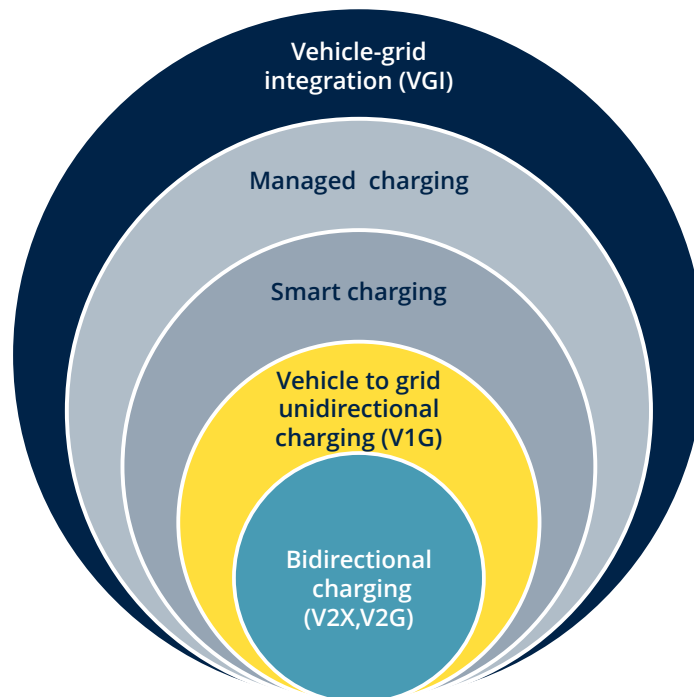
Managed charging is a form of VGI that may include both automated and scheduled interventions to manage charging behaviour for grid or cost efficiency, as explained in section 3.2.1. Managed charging can be achieved through different means, including smart charging methods and real-time, dynamic adjustments using advanced technology. Types of smart charging strategies include the following and are further explored in section 3.2.2:

- **Vehicle-to-grid unidirectional charging (V1G):** refers to the charging process in which the power system operator can control and modulate the charging duration and rate depending on electricity system needs.
- **Bidirectional charging: V2X** additionally allows discharging stored energy when it is most needed in another system. This system can be load (**V2L**), home (**V2H**), building (**V2B**), vehicle (**V2V**), or grid (**V2G**). Vehicle-to-grid (V2G), which involves two-way energy flow, where EVs not only charge from the grid but can also return stored energy to the grid, supporting grid stability, especially during peak demand periods.

The diagram below illustrates the concepts defined.

³⁵ Drawn from EY. 2022. *Power sector accelerating E-Mobility. Can utilities turn EVs into a grid asset?*

FIGURE 45. Technical solutions



2.4.3 New market participation opportunities for utilities

Utilities can identify some new services EVs require and work with other stakeholders to develop new markets to offer them. Some of these can be:

- EV operations and maintenance
- Installation, operation, maintenance, and servicing of charging points
- Software solutions for energy management and fleet routing
- Bundling charging with other services, such as parking and roadside assistance
- Vehicle battery management, leasing, and recycling

In some countries, distribution utilities are entering the charging infrastructure market as CPOs. These utilities typically use their own land to set up public EV charging facilities and operate them as paid services. Distribution companies may also provide bundled charging services for private EV owners and recover the capital and operating costs through electricity tariffs. Other stakeholders driving the service provider model of EV charging implementation include industrial companies that are moving into charging infrastructure, and EV manufacturers that are setting up charging infrastructure networks as allied services.

Business models

Based on these opportunities, utilities could also be aware of different business structures they can consider for EV charging. When considering the most appropriate model, it is important to understand which will be most effective for the type of driver and vehicle and the type of location where charging stations will be set up, as well as the costs incurred.

- **Loss leader model** – EVCI is provided for free. By attracting and retaining customers, the market share is expected to grow and the costs offset by the increased revenue.

- **Operational cost or total cost recovery** – EVCI plus the electricity is provided for a set fee which matches the operational costs and, if cost recovery is sought, an additional margin is added to pay back additional costs.
- **Profit making** – EVCI and electricity is provided for a higher fee which covers operational, hardware and installation costs, and also provides a profitable revenue stream. This would likely require a regulatory regime which calculates the appropriate profit possible.
- **Fully funded** – charge points are provided and installed for free by charging infrastructure providers (eg, requiring garage owners to install charging points). This requires a regulatory intervention.

On top of this, business models can be considered within system planning as an opportunity for utilities to expand their activities. The extent to which utilities in Rwanda can consider and operate these depends on their financial and infrastructural capabilities. Some business models are:

- **Battery swapping through third-party management** – a specialised service provider manages the exchange of depleted batteries with fully charged ones at designated swapping stations. This is an alternative to traditional EV charging, aiming to address challenges associated with long charging times and battery degradation.
- **Subscription models** – offering electric vehicle users ongoing access to services like charging, battery swapping, or energy management for a recurring fee. This model is gaining traction as it provides a steady revenue stream for utilities and simplifies energy costs for consumers.
- **Bundled charging** – offering electric vehicle owners a comprehensive package of charging services under a single plan or subscription. This model can combine various types of charging (eg, home, public, and workplace) along with additional perks or services, providing a one-stop solution for EV energy needs.

2.4.4 International experience with mitigation approaches and new market participation opportunities

Table 20 includes some examples of approaches utilities worldwide have taken or developed in the E-Mobility space to mitigate negative impacts of E-Mobility and develop new market participation opportunities.

TABLE 20. International experience of utility mitigation and new opportunity activities

Africa
The African E-Mobility market is nascent. Therefore, not many utilities have engaged with E-Mobility. However, the South African energy provider Eskom is taking steps to support the growth of E-Mobility and partake in it. First, it has submitted the residential ToU charging tariff to the National Energy Regulator of South Africa (Nersa) for approval, which will enable EV owners to achieve significant savings when using the off-peak and standard periods to charge their cars, encouraging EV uptake and boosting electricity sales. Second, it is seeking partners for the rollout of public charging stations on Eskom sites, as well as developing microgrids to address additional load shedding, which could be exacerbated by EV charging.³⁶

³⁶ Eskom. 2023. *Eskom is gearing up to support the growth of the E-Mobility sector in South Africa*.

Asia

Many utilities are investing in the development of widespread and reliable charging infrastructure. For example, state-run utilities in India like NTPC and Power Grid Corporation of India Limited (PGCIL) are setting up EV charging stations nationwide. In China, the State Grid Corporation of China has been aggressively expanding the EV charging network across the country. As of 2023, SGCC operates thousands of charging stations and aims to provide a fast charging network covering major cities and highways. They are also integrating renewable energy sources to power these stations.

In Japan, Kansai Electric Power Company is focusing on developing V2G technology and has been involved in pilot projects that test the integration of EVs with the grid to stabilise electricity supply. In Korea, Hyundai has partnered with the national utility company to develop a comprehensive EV ecosystem, including charging infrastructure and the implementation of V2G technology.

In some countries, utilities and governments collaborate to develop policies that enhance and support EV uptake. In Indonesia, the government is working closely with the utility Perusahaan Listrik Negara to implement policies that support EV adoption, including incentives for EV users and investments in charging infrastructure. In India, a joint venture of public sector undertakings under the Ministry of Power, Energy Efficiency Services Limited is involved in deploying EVs for government use and setting up charging infrastructure.

Europe

European utilities are mainly addressing energy management issues with smart energy management, trying to ensure that EV charging during peak demand does not lead to long-term supply and infrastructure issues.

- V2G - E.On, a German power company, EDF, based in France, and Enel in Italy, have partnered with Nissan to build V2G networks³⁷
- Solar distributed generation and storage co-location is increasingly prevalent across Europe to smooth demand.
- Northvolt in Sweden has deployed its first public battery energy storage system at an EV charging station which aims to reduce peaks in electricity demand at the station by more than 80 percent.³⁸
 - Shell in the Netherlands is also trialling a battery-backed ultrafast-charging system at a filling station, optimised to charge when renewable production is high keeping prices and carbon content low.³⁹
- Regarding pricing and tariffs, in the UK, Good Energy, a renewable energy supplier, has launched two new ToU tariffs to support EV drivers. It offers two overnight off-peak periods when drivers can charge their EVs at a cheaper rate. In trials, these were used by 98 percent of customers.⁴⁰
- With regards to new market opportunities, Centrica, a major utility in the UK and Ireland, offers installation of charge points in homes, workplaces and public spaces, as well as a smart software called Hive EV that helps make EV charging as efficient as possible by enabling consumers to monitor and control how energy is distributed. Centrica has also partnered with several charge point operators to develop a fleet charging management system that enables EV fleet drivers to plug in to any standard charger and be reimbursed of the charging costs.⁴¹

³⁷ Reuters. 2019. *European power firms aim to harness electric car batteries.*

³⁸ Northvolt. 2020. *Northvolt commissions its first public energy storage system in Sweden.*

³⁹ Shell. 2021. *Shell trials forecourt battery power storage system as it ramps up EV ambitions.*

⁴⁰ Good Energy. C2024. *Investor relations webpage.*

⁴¹ Centrica. 2021. *Electric vehicles are helping to drive a revolution in energy use.*

United States

In the US, the Smart Electric Power Alliance has defined three stages of utility involvement: early, where opportunity awareness exists but action has yet to be taken; intermediate, where utilities have begun to plan and implement EV-related activities; and late, where utilities have developed long-term strategic goals and are already actively engaging with customers. While most American utility companies are at the first or second stages, 50 companies are actively encouraging EV uptake. From offering rebates for buying electric cars, to offering support to schools to buy electric buses or businesses to install electric vehicle charging infrastructure, energy providers see the acceleration of the transition to electric transport as an opportunity to boost energy demand.⁴²

In California, which has been a leader in the US' EV adoption and zero emissions policy efforts, the utility companies Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E), have installed infrastructure to support more than 12,500 charging stations across the state. SDG&E has also been working with the Port of San Diego to install chargers for electric medium-duty/heavy-duty vehicles and forklifts.

South America

In Santiago de Chile, the utility Enel has been key in achieving the impressive electrification of the public transport system. Since 2018, Enel X has put 1,536 electric buses on Santiago's city streets working with Metbus (one of the city's six private bus operators working for public transport operator RED) and China's BYD, a manufacturer, in a public private partnership. The new e-buses are powered by 16 electro terminals, some with rooftop photovoltaic panels, and 324 electrical bus charging stations. Each electric bus contributes to a reduction in carbon emissions equal to the CO₂ produced by 33 cars.

Australia

In Australia, some utility providers are coupling EV charging and purchasing with additional utility services. For instance, drivers of Hyundai's Ioniq or Kona Electric get a discount for adding the Origin solar system to their homes as the main source by which to charge their EVs. If they already have the solar system, they will receive a discount on battery or electric tariffs.⁴³ The utility company Powershop is offering discount rates to EV owners who charge at night – between midnight and 4 am – to minimise the demand on the grid.⁴⁴ AGL, the major player in Australia's energy and gas market, is offering credits toward household electric bills to its traditional and solar customers who own EVs and charge them at home.⁴⁵

2.4.5 Opportunities for Rwanda Green Fund

The Rwanda Green Fund (FONERWA) facilitates access to international climate finance and streamlines external aid and domestic finance. So far, FONERWA has been successful in its objective of mobilising climate finance for Rwanda with total direct capitalisation of approximately US \$89 million from DFID, the German Development Bank (KfW), the GoR, and the Least Developed Countries Fund (LDCF) of the AfDB.

One investment area of the fund is sustainable transport and the stimulation of the development and operation of sustainable mobility and connectivity in Rwanda. In particular, FONERWA seeks to promote and scale up electric vehicle usage for public and freight transport between 2025 and 2030; to invest in climate resilient roads and infrastructure; to

⁴² Bloomberg. 2020. *Test a Tesla or buy a Bolt with the help from your electric company.*

⁴³ The Driven. 2019. *Hyundai and Origin cut solar deal to offer savings to Kona and Ioniq owners.*

⁴⁴ The Driven. 2019. *Powershop expands discount EV charging offer ahead of increased demand.*

⁴⁵ The Driven. 2019. *AGL upgrades EV charging plan as retailers move to engage electric drivers.*

deploy smart mobility technology; and to explore and invest in innovative and alternative models of mobilities.

FONERWA has been working on identifying financial resources for the implementation of its priority areas, including sustainable transport. So far, it has:

- **Identified four high-priority institutions** to target for the development and implementation of sustainable transport projects. The table below illustrates these institutions' relevance to FONERWA and interests and capabilities.

TABLE 21. Target institutions for funding of sustainable transport projects

Description	Relevance to FONERWA
African Export Import Bank (Afreximbank)	
The African Export Import Bank (Afreximbank) is a panAfrican, multilateral finance institution with a mandate to finance and promote intra- and extra-African trade and facilitate industrialisation. The Bank provides project financing and guarantees and targets projects that promote climate action. The Bank also launched its Project Preparation Facility (APPF), aimed at supporting preparation of viable projects and increasing transaction bankability.	Afreximbank is very familiar with Rwanda, having financed various Rwandan infrastructure projects with plans for further investment. The Bank is also placing renewed emphasis on the climate aspects of its support.
The Export-Import Bank of China	
The Export-Import Bank of China provides financial support to promote Chinese goods and services. This is done through export/import credits, and through preferential credit in the form of concessional loans and export buyers' credit lines. The Bank has an explicit climate mandate – the Green Development Concept – and promotes green finance to support emission reductions and sustainable development. Its Green Credit System provides financing in the form of transformational and environment protection loans. It has also set up Environmental Protection Equity Funds with partners internationally.	China is the largest (and arguably most advanced) producer of EVs and supporting infrastructure. It supplies electric buses and related services to clients globally, often facilitated through China ExIm Bank. The Bank has explicit goals to promote green mobility.
The EU-Africa Infrastructure Trust Fund (ITF)	
The EU-Africa ITF, managed by the European Investment Bank (EIB), promotes infrastructure investment in Africa. In particular, the ITF has a Sustainable Energy For All (SE4All) envelope which promotes access to modern and efficient energy. This is closely aligned with Rwanda's goal to invest in E-Mobility and supporting infrastructure. The ITF finances both project preparation and implementation.	The EU and EIB maintain explicit interest in urban transport opportunities in Africa. They have invested significantly in green mobility across Europe (ELENA facility), and it is believed they would have appetite for similar interventions in Rwanda. The ITF and SE4All envelope is one such mechanism for investment.

Description	Relevance to FONERWA
Shell Foundation	
The Shell Foundation supports the creation and scaling of business solutions that enhance access to energy and sustainable mobility. The Foundation provides patient support (in form of grants, tailored instruments, and leveraged additional financing) to transport businesses that are using technology to deliver more efficient, sustainable, and affordable mobility solutions.	The Shell Foundation has invested in numerous transport and mobility start-ups, including several in East Africa, providing incubation, scaling, and catalytic capital. They finance Tugende, a motorcycle leasing company with plans to soon expand into Rwanda.

Source: FONERWA. 2019. Resource mobilisation strategy.

- **Explored opportunities to optimise domestic revenue sources**, beyond those it has historically been empowered to direct, mainly from fines and penalties. Examples of these additional opportunities are illustrated in the table below, alongside an assessment of their suitability for exploration, in terms of complexity of implementation (length of time and administrative transaction costs to undertake) and revenue predictability (certainty and consistency of predictable, high-volume revenue).

TABLE 22. Sources of additional domestic revenue for FONERWA

Description	Suitability of exploration
Environment-related user fees	
Payments made by the public for the use and enjoyment of natural assets, such as: • National park or conservation area entry fee • Eco-tourism based fees	Relatively easy to implement, but relatively low revenue predictability.
International payments to Rwanda to preserve its natural resources	
Payments made by other countries or companies in recognition of global value of its natural capital. • Debt-for-nature swaps: debt owed by Rwanda to another country or to a private bank is purchased on the secondary market by an entity that wishes to catalyse environmental protection in Rwanda, and “forgiven” in exchange for conservation	Not particularly complex to implement, and high revenue predictability.
Environmental taxes	
Taxes meant to disincentivise or reduce environmentally damaging behaviour. • Carbon offsets • Fossil fuel levies • Fees on mining and drilling leases or permits • Earmark on timber and logging revenues	Not particularly complex to implement, and medium-high revenue predictability
Non-environmental taxes	

Description	Suitability of exploration
A portion of major taxes with reliable revenue streams could be ear-marked for FONERWA in national interest • Earmark corporate or sales tax • Surcharge on property tax • Surcharge on consumers' water bills • Tax on airline tickets • Airport departure fees framed as conservation fees • Lodging tax • Lottery revenues	Implementation and revenue predictability vary widely, with difficult implementation but high revenue predictability for property tax, corporate tax and water bills surcharges, and easy implementation but low revenue predictability for lottery revenues.
Philanthropic contributions	
Charitable donations sought domestically or internationally, incentivised as tax-deductible	Somewhat relatively easy to implement, but revenue predictability is medium-low.

Source: FONERWA. 2019. Resource mobilisation strategy.

- **Developed a resource mobilisation roadmap**, which identifies phased activities the fund can undertake to meet its priority targets and expand their fund base.

When it comes to project implementation within sustainable transportation, in 2021 FONERWA has launched the 'Accelerating the Deployment of E-Mobility through the Deployment of Electric Motorcycle Taxis (E-Motos) and E-Buses' project, which aims to catalyse the deployment of e-motorcycles by effectively substituting motos with e-motos in Kigali, thereby decarbonising the most popular and affordable means of public transportation in the city. The project will provide technical support and use financial mechanisms to stimulate demand for e-motos and help local manufacturers to scale up their productive capacities, while ensuring that robust framework conditions are in place. As a direct effect of the intervention, the project aims to support deployment of more than 50,000 e-motos in Kigali within the project's implementation period and in the following 10 years. It is expected that it will result in cumulative GHG emission reductions of more than 1 million tonnes CO₂eq. Beyond that, the project is planned to be recycled to support the Rwandan government in procuring e-buses, stimulating further decarbonisation of the public transport system in the country.⁴⁶

While efforts from FONERWA have been significant in terms of funding enhancement, the review of what other climate funds are doing in the E-Mobility space can provide insights on next steps and opportunities for project implementation. Some opportunities include:

- **Collaboration with transport electrification stakeholders** to ensure that projects can be implemented and scalable without governance challenges and risks – this could include providing direct, reflow investments (loans or equity investments) as blended finance, or even grant contributions. Likely this would deal with larger investors such as electric bus companies, moto companies, etc.

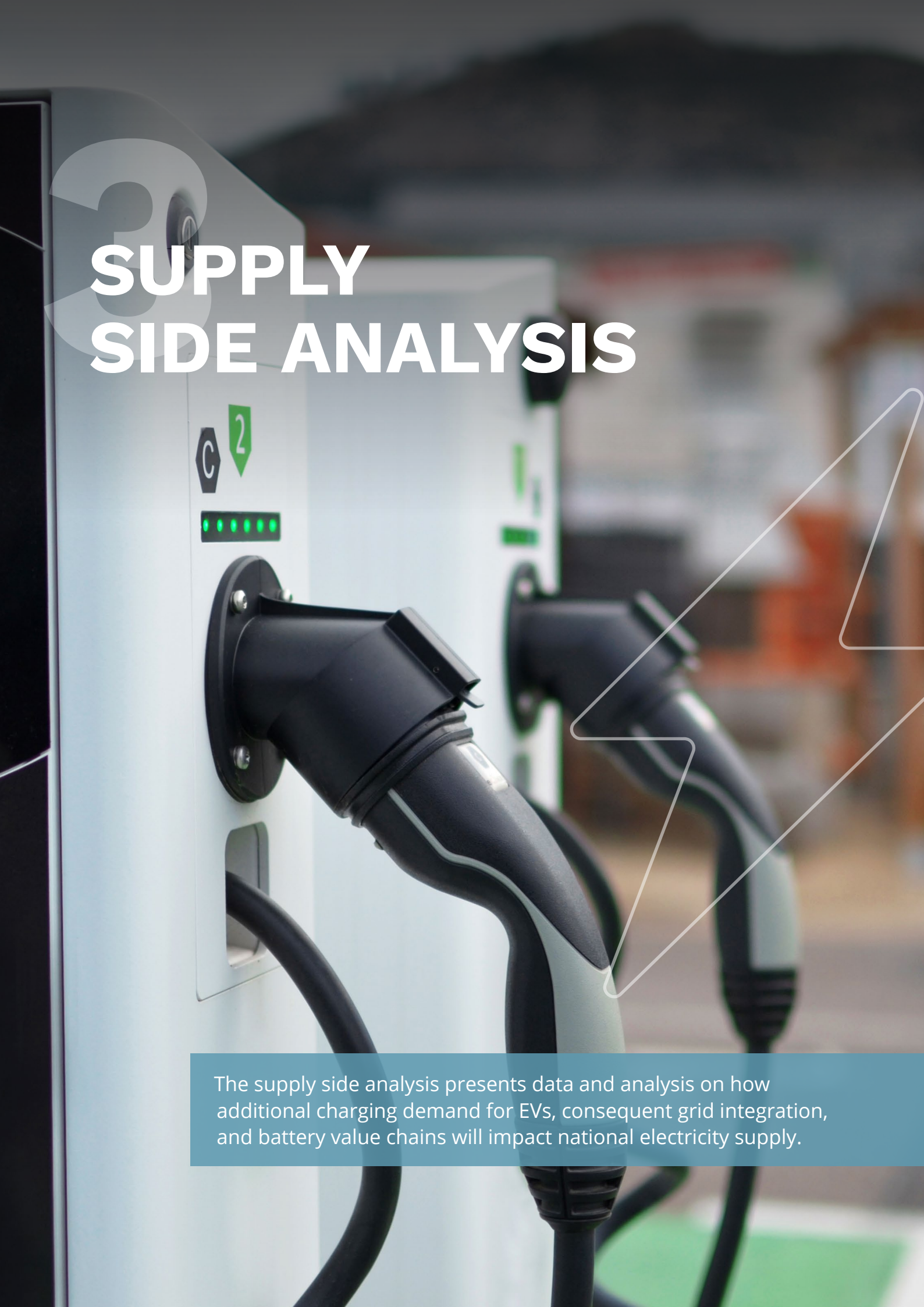
⁴⁶ Mitigation Action Facility projects page. 2021. Rwanda – Accelerating the deployment of electric motorcycle taxis and e-buses.

- **Development of blended reflow financing or grant mechanisms for the general population** including working with local financial institutions to set up advantageous financing products for the purchase of EVs or charging infrastructure. FONERWA financing could go towards:
 - Blending its loans with private financing to result in a lower interest rate or longer tenor.
 - Providing first loss / guarantee funds to allow for commercial lenders to provide lower-cost loans. The first loss guarantee could be as a grant or involve fees.
 - Providing a grant mechanism to end-users for the purchase of EVs. Note that this has been a popular mechanism internationally, but some questions of fairness could arise as people which are likely to take advantage of this scheme tend to be higher income.
- **Development of reflow financing or grant mechanisms for specific market segments.** This could include, for example, loan or equity investment mechanisms for private sector actors such as charging station installation / management companies, taxi services, moto owners / operators, etc. While this could include a grant mechanism, given the financial advantages of E-Mobility, it is likely that a mechanism to recoup the investment would be possible and allow for additional scale-up / re-investment of funds.



ELECTRIC

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3 SUPPLY SIDE ANALYSIS

The supply side analysis presents data and analysis on how additional charging demand for EVs, consequent grid integration, and battery value chains will impact national electricity supply.

3.1 Charging infrastructure deployment analysis

3.1.1 State of play in charging standards

The RSB is the main authority responsible for issuing technical standards, quality testing, metrology, and certification. Current standards in Rwanda are benchmarked against international standards, including those adopted by other African countries. No specific standards for EVs and charging infrastructures have been issued in Rwanda.

There are four standards for electric vehicle charging – particularly relevant for BEBs but also for other vehicles - which pertain to both the charging systems and the physical connection points between the charging infrastructure and the bus. Importantly, there is no operational or technical advantage associated with any specific standard, as each serves different regions or operational needs.

Alternate Current charging is gradually being phased out for BEB applications since it is generally slower than DC charging, making it an unsuitable choice for countries like Rwanda or cities such as Kigali. With the shift toward more efficient charging methods, AC is no longer considered a viable option for BEB infrastructure in these regions.

For Direct Current (DC) plug-charging, three international standards are currently in use:

- **Combined Charging System (CCS)** is rapidly becoming the dominant standard outside of China, especially in regions such as Europe and North America.
- **GB/T** is the primary standard in China, with the government heavily investing in BEB infrastructure to support this standard.
- **CHAdemo** is the preferred standard in Japan, which has established a unique BEB charging ecosystem.

There are ongoing discussions regarding the harmonisation of the GB/T and CHAdemo standards, which are expected to converge into one unified global standard in the future. Meanwhile, the CCS1 standard is primarily adopted in South Korea and the United States, while CCS2 is the standard used in Australia, Europe, and other parts of Asia. The technical specifications for the various charging connectors are outlined in the table below.

To further increase operational flexibility, dual and even triple standard chargers are available, capable of accommodating multiple charging standards. These chargers offer high versatility, enabling their use across different regions and countries, regardless of the specific standard in place.

TABLE 23. Technical specifications of different charging connectors

CHAdEMO	GB/T	CCS - Combo 1	CCS - Combo 2	Type 2 AC (Mennekes)
Capacity				
50-400 kW	60-237 kW	150 - 350 kW	350 kW	22 kW
Input voltage				
50-1000 V	250–950 V	200 - 1000 V	200 - 1000 V	480 V Three phase ⁴⁷
Maximum rating				
400 A	250 – 400 A	500 A	500 A	32 A
Development				
CHAdEMO and the Chinese GB/T are cooperating to harmonise the two standards into one.		CCS Combo 2 connector becoming the more dominant standard with possibilities up to 350 kW capacity.		Currently 10 percent of the market but phasing out; in demand for next 10–15 years.
Standards				
IEC 61851-23/4 IEC 62196-3 JEVS G105	GB/T 20234-3 IEC 62196-3	SAE J1772 IEC 61851-23/24 IEC 62196-3	IEC 61851-23/24 IEC 62196-3 DIN EN 62196-3	IEC 62196-2 IEC 61851-22/23

Source: Rivera, S., Kouro, S., Vazquez, S., Goetz, S. M., Lizana, R., & Romero-Cadaval, E. (2021). Electric vehicle charging infrastructure: From grid to battery. IEEE Industrial Electronics Magazine, 15(2), 37-51.

Globally, the two most widely adopted BEB charger types are GB/T and CCS2. These two standards are generally comparable in price, especially since leading Chinese manufacturers produce both types of chargers. If imported from China, the costs of these chargers are likely to be similar. However, the most significant price difference arises from the cost of the buses themselves.

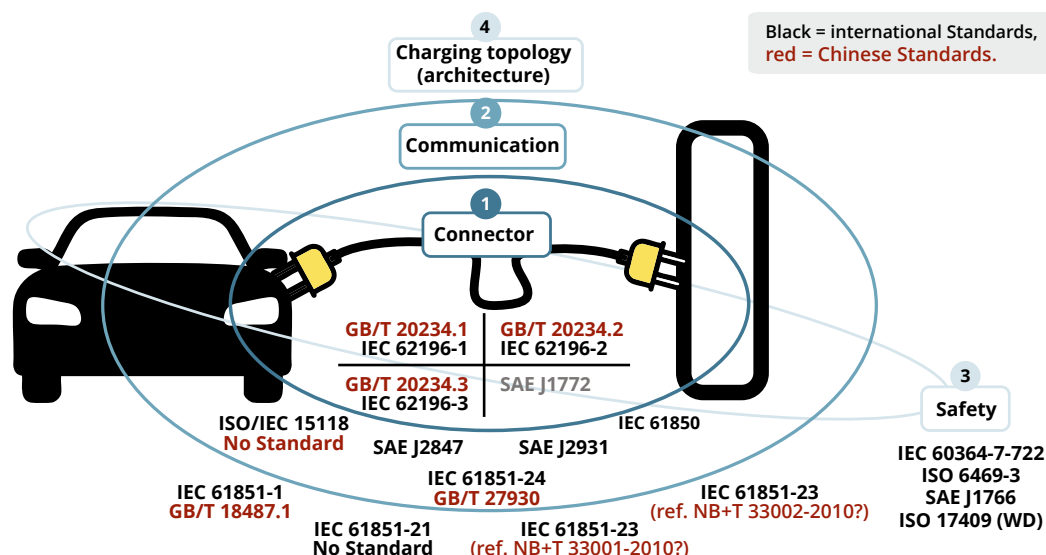
China's ability to offer competitively priced BEBs is influenced by economies of scale and government subsidies, which help reduce production costs. In 2022, approximately 138,000 e-buses were sold domestically, while over 617,000 e-buses were exported⁴⁸. As a leading producer of EV batteries, China has developed its own comprehensive national standards for EV infrastructure. These standards cover both Alternate Current and Direct Current (DC) charging protocols, addressing elements such as plug design, communication protocols, and energy efficiency to ensure compatibility, safety, and efficiency.

⁴⁷ Note that low voltage in Rwanda is 400/230 V ±10 percent. Type 2 AC chargers are rated to voltage levels above the 400/230 V low voltage network voltage for safety reasons. There are no relevant implications of this difference. These chargers can be installed into the network. AC Chargers in essence are just relays (on/off switches) with additional safety features. The safety features ensure that the power cable only become powered once it is correctly plugged in and the maximum drawn current by the vehicle does not exceed the rating of the AC charger and the network connection point.

⁴⁸ Chinabuses. (2023). China has exported 61,700 units buses & coaches in 2022. https://www.chinabuses.org/analyst/2023/0208/article_13062.html

The figure below illustrates the international standards in black alongside the corresponding Chinese standards in red for EV conductive charging. This comparison highlights the similarities and differences between global and Chinese charging protocols, providing valuable insight into China's approach to EV infrastructure.

FIGURE 46. Standards for EVs conductive charging



Source: David Reeck, International Programs to Promote Electric Vehicles, EV Roadmap 7 Conf, Portland, USA, July 24- 25. <https://www.evroadmapconference.com/program/index14.html>

The table below provides a comparison between the IEC/ISO standards for protocols and the GB/T standards from China. In terms of quality and safety for the grid, these standards can generally be considered comparable.

TABLE 24. Protocol comparison of IEC/ISO vs. GB/T standards

	ISO/IEC	China
System	IEC 61851	GB/T 18487 GB/T 27930
Charging Interface and Coupler	IEC 62196	GB/T 20234
Communication	ISO 15118	GB/T 27930 Q/GDW 398 Q/GDW 399
Battery Swap	IEC 62840	GB/T 29317 Q/GDW 488 Q/GDW 486 Q/GDW 685 Q/GDW 487 Q/GDW 686

Source: Bahrami, A. (2020). EV charging definitions, modes, levels, communication protocols and applied standards. Changes, 1 , 1-10.

BOX 4. NOTE ON THE GOVERNING STANDARDS FOR EVS

EVs are regulated by both the ISO and IEC. As road vehicles, EVs fall under ISO/TC22 – Road Vehicles, particularly ISO TC22/SC21 – Electrically Propelled Road Vehicles. As electrical equipment, they are also governed by IEC TC69 – Electric Road Vehicles and Electric Industrial Trucks. To prevent overlap, a 1996 agreement established that ISO would focus on the vehicle as a whole, while IEC would address electric components and infrastructure. This was formalised in the ISO/IEC Agreement on Standardization for Road Vehicles, signed in March 2011, ensuring coordinated efforts between the two bodies⁴⁹.

For a comprehensive understanding of the relevant standards for adopting E-Mobility, further details are provided in Annex A8.

Additionally, information and analysis of the role of harmonics in E-Mobility and charging is included in Annex A4.

3.1.2 Review of regulations on charging infrastructure in Rwanda

Rwanda has taken steps to encourage electric vehicle adoption through incentives like tax breaks and land allocation for charging stations. These efforts are commendable, but the country currently lacks a comprehensive regulatory framework for charging infrastructure though the existing regulations and standards are described below.

E-Mobility regulations

The advancement of E-Mobility initiatives in Rwanda has integrated several globally recognised practices, while certain other approaches have yet to be implemented. The following overview provides a comprehensive analysis of the current state of EVCI in Rwanda, highlighting existing practices and offering insights into the country's management of various aspects of EVCI.

The regulations governing electrical connections in Rwanda are currently delineated in the *Regulations Governing Electrical Installations (2023)*. This regulation outlines the procedures and requirements for electrical installations, as well as the conditions for inspection, monitoring, and compliance. Electrical installations are categorised according to voltage levels and specific types of installation work. Fees are determined based on these classifications.

At present, there are no specific regulations pertaining to public EV charging stations. However, the fiscal and non-fiscal incentives, along with the administrative measures outlined in the Strategic Paper on Electric Mobility Adaptation, are crucial for initiating the E-Mobility market and stimulating investments in EVCI. Government incentives include tax exemptions on charging infrastructure and the provision of free land to investors for the installation of charging infrastructure.

There are currently no incentives related to the installation of EV chargers in residential properties in Rwanda. Nonetheless, existing fiscal incentives for EV purchases, such as zero

⁴⁹ ISO/IEC Agreement Concerning Standardization of Electro-technology for Road Vehicles and the Cooperation Between ISO/TC 22 "Road Vehicles" and IEC Technical Committees, 2010.

VAT, exemption from import and excise duties, and exemption from withholding tax, also apply to charging equipment, indirectly benefiting private charging of EV. Additionally, current policy caps the electricity tariff for EV charging stations at the industrial tariff level, which is typically lower than residential tariffs. This policy makes public charging stations more affordable. Moreover, EV can take advantage of reduced tariffs during off-peak hours, further lowering the cost of charging and encouraging off-peak usage.

Standards

The RSB serves as the primary authority for implementing standards, testing, product certification, accreditation, labelling, marking, and technical regulations. While RSB has yet to establish specific standards for EVs, this presents an opportunity to develop a framework that aligns with international best practices.

To ensure the long-term sustainability and growth of Rwanda's E-Mobility sector, it is essential for the country to adopt internationally recognised standards for plugs, connectors, and other EVCI components. By implementing these standards, Rwanda can minimise the risk of technological obsolescence and ensure that future advancements in EV technology will remain compatible with existing infrastructure. This will promote seamless integration and continued functionality as technology evolves.

At present, Rwanda's EVCI infrastructure is based on international standards, either aligned with the GB/T standards from China or the IEC/ISO-based standards commonly used in Europe, as outlined in the previous section. The RSB has historically followed the practice of adopting ISO and IEC standards for various sectors, which could similarly guide the EV charging industry.

Regarding the choice of charging standards, it is advisable for the RSB to formally adopt both CCS2 and GB/T standards. These two standards, while originating from different regions, are comparable in terms of safety and performance. The adoption of both standards would provide flexibility for Rwanda's public transport operators, allowing them to source electric buses from both Chinese and European manufacturers without being constrained by differing regional standards. This approach not only encourages competition but also offers more options for Rwanda to diversify its EV fleet.

Furthermore, it is critical to align Rwanda's EV charging station technical standards with international norms. Collaboration between RURA and the RSB is recommended to review and align technical standards for charging stations with global best practices. Such alignment will ensure effective integration of EVs into Rwanda's transportation infrastructure, facilitating a smooth transition to electric.

Additionally, aligning technical standards for EV charging stations with international norms could contribute to the efficient integration of EVs into Rwanda's transportation infrastructure. Collaboration between RSB and RURA might help ensure technical standards align with global practices, supporting a smooth transition to E-Mobility.

Finally, the adoption of internationally recognised standards such as ISO/IEC and GB/T for safety, battery requirements, and vehicle-to-grid communication could also be explored. This approach may support the development of a robust and adaptable E-Mobility ecosystem in Rwanda.

Incentives

The table below provides a more specific overview of the policy measures described in the Strategic Paper for E-Mobility Adaptation:

TABLE 25. “Strategic Paper for E-Mobility Adaptation” measures

Fiscal incentives	Non-fiscal incentives	Administrative and other measures
Electricity tariff for charging stations be capped at the industrial tariff level (large industry category)	Rent-free land for charging stations (for land owned by Government)	Enforcement of existing emission standards to discourage the purchase of polluting vehicles
EVs to benefit from a reduced tariff during the off-peak time	Provisions of electric vehicle charging stations in the building code and City planning rules	Establish restricted zones for green transport
EVs, spare parts, batteries and charging station equipment be treated as VAT zero rated products	Green licence plate to allow EVs getting preferential treatment in parking, free entry into congested zones that will be determined	Regulate importation of used vehicles by imposing age limit
Exemption of import and excise duties on EVs, spare parts, batteries and charging station equipment	Free licence and authorisation for commercial EVs	Provide preference to EVs for Government hired vehicles
Exemption of withholding tax of 5 percent at customs	Access to High Occupancy Vehicle lanes (Dedicated Bus Lanes)	Companies manufacturing and assembling EVs (battery EVs, PHEVs and hybrid EVs) in Rwanda are given other incentives in the investment code such as 15 percent CIT and tax holidays (irrespective of the investment value)
To introduce carbon tax to discourage polluting vehicles		

The public sector plays a crucial role in establishing a regulatory framework for the E-Mobility ecosystem, but private stakeholders also play a vital role. Public authorities need to develop regulations for safety, interoperability, and fair pricing, while private companies bring innovation, capital, and operational expertise. Collaboration between the public and private sectors is essential for the development of a robust, accessible, and sustainable E-Mobility network in Rwanda. Private stakeholders manage physical charging stations, facilitate services like charging station access, payment solutions, and user interface applications, and contribute to the adoption and sustainable operation of E-Mobility solutions. Transport companies offering electric transportation services and businesses selling EVs also contribute to the ecosystem. The collaboration between public regulatory efforts and private sector innovation and investment is vital for developing a robust, accessible, and sustainable E-Mobility network in Rwanda. This synergy will accelerate the transition to E-Mobility, reduce the country's carbon footprint, and enhance transportation efficiency.

Currently, specific regulations on siting, ownership, and operations of charging stations are not in place. There's a need for clear guidelines on zoning, safety standards, grid connection procedures, and consumer protection. To address these gaps, Rwanda should develop detailed regulations covering all aspects of charging infrastructure.

Prioritising strategic siting based on population density and traffic patterns is crucial. Establishing clear ownership and operation models, coupled with simplified permitting processes, will encourage private sector investment. Adopting international charging standards will ensure interoperability and consumer convenience.

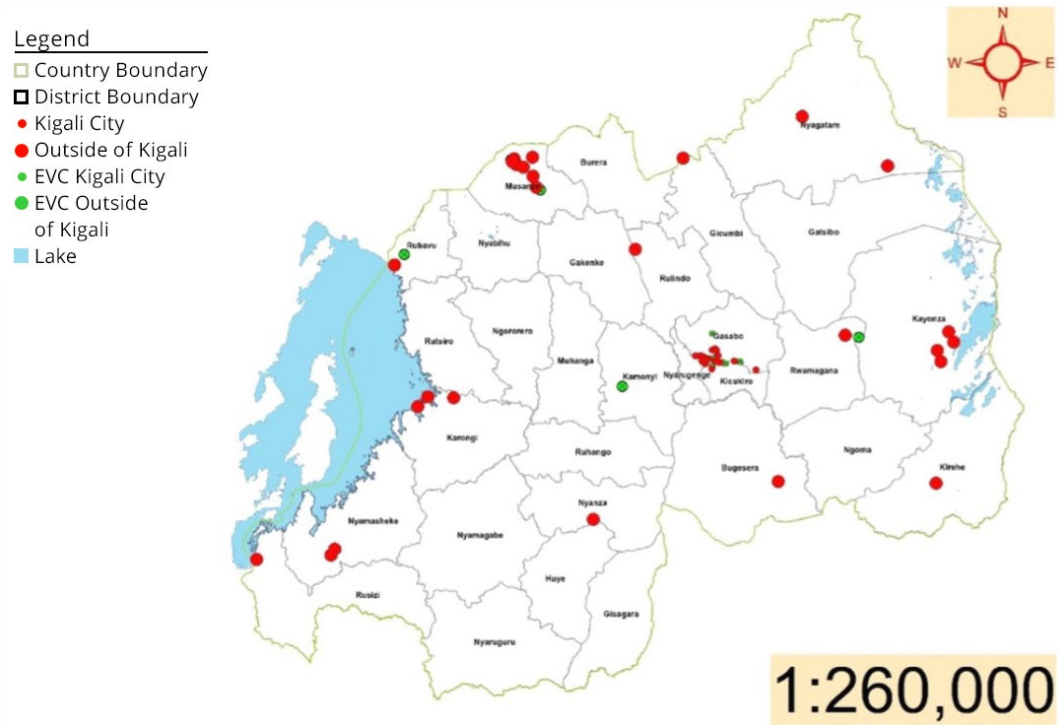
Furthermore, consumer protection measures, including transparent pricing, service level agreements, and dispute resolution mechanisms, are essential. By addressing these areas, Rwanda can create a conducive environment for the rapid expansion of charging infrastructure and accelerate the adoption of EVs.

3.1.3 Charging typologies

The following section is adapted from the EU study – which provides a very up-to-date overview of charging typologies and charging stations in Rwanda (as from July 2024). Regarding charging stations, there are currently 20 publicly accessible EV charging stations in Rwanda, 17 in Kigali with plans to install 28 more, and 5 charging stations in secondary cities. There are 28 private battery swapping stations in Kigali.

The following map shows the distribution of existing and planned charging stations in Rwanda.

FIGURE 47. Distribution map of existing and planned charging stations in Rwanda



The distribution of publicly accessible EVCI - both planned and existing - is concentrated in Kigali, primarily along the trans-city road from Downtown to Kigali International Airport. The Southern Province has minimal EVCI. Most planned EVCI are to be installed in tourist areas such as coffee shops and hotels, as well as SP petrol stations.

There are two main types of charging solutions in Rwanda:

- Battery swapping stations, serving primarily motorcycles, and
- Conventional charging stations, designed mostly for private cars / four-wheeler taxis and in some cases e-buses but also serving some motorcycles.

Charging stations are owned by key industry players, including Ampersand, EVP, Kabisa, BasiGO, REM, and Spiro. Additionally, some of these companies plan to install more charging stations across Rwanda.

The following table summarises the existing charging stations as of June 2024 in Kigali.

TABLE 26. Charging stations in Kigali

	Stations Operator	Types of EVs to be charged	Nr of existing stations	Nr of planned stations
Charging stations	BasiGo	Buses	1	27
	EVP	Personal cars, and motorcycles	6	-
	Volkswagen	Taxi cabs	2	-
	Kabisa	Personal cars	8	27
	IZI	Buses	2	44
Total			19	98
Battery swapping stations for motorcycles	Ampersand		26	-
	Spiro		12	
	REM		3	-
Total			41	-

Outside of Kigali, only Kabisa has started to install EVCI and plans to install more. These charging stations are primarily installed in tourist areas such as coffee shops and hotels. Each province has at least one EVCI already installed, with a few more planned. However, in the Southern Province, there is only one planned EVCI by Kabisa. The following table shows the number of both installed and planned charging stations as well as the district they were placed.

TABLE 27. Table of EVCI location and station count for existing and future planned stations outside Kigali

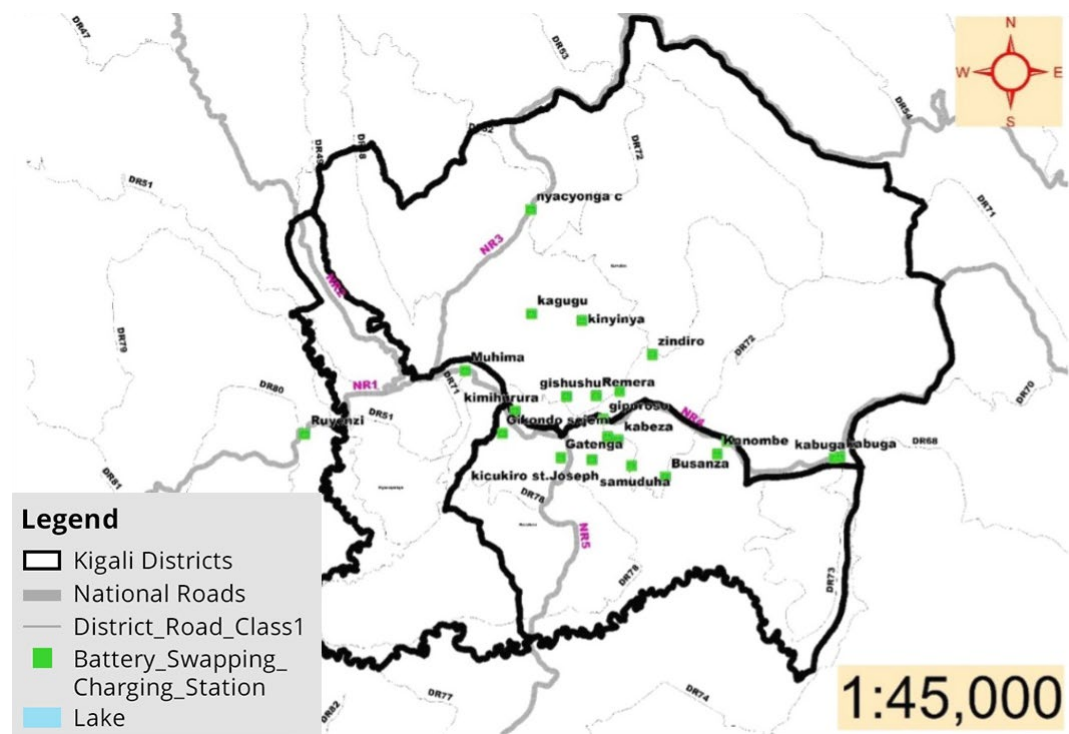
Province	Number of stations	Location (District or exact location)	Type
Existing			
Eastern	1	Kayonza - Imigongo Art Cafe	AC charger L2
Southern	1	Kamonyi – Stafford	AC charger L2
Northern	2	Kinigi - Dian Fossy campus Musanze SP	AC charger L2
Western	1	SP Rubavu	AC charger L2
Potential Sites			
Eastern	9	Nyagatare, Kayonza, Bugesera, Kirehe, Rwamagana	AC charger L2
Northern	9	Musanze, Gicumbi, Rulindo	AC charger L2
Western	7	Karongi, Rusizi, Nyamasheke, Rubavu	AC charger L2
Southern	1	Nyanza	AC charger L2

For more detailed information, the EU Study includes the specifications of the EVCI, including the station name, location, owner, latitude and longitude, the number of parking bays, power (kW), charging level, and connector type, among other specific information.

Regarding the form of EVCI which involves battery swapping, there are currently 28 stations with plans to install more as the number of two-wheeler taxis increases. However, their installation is demand-based, so owners are unable to predict the future locations of the stations at this time.

The following figure shows the distribution of battery swapping and charging stations in Kigali, strategically placed in residential zones and densely populated areas such as Kinyinya, Remera, Gikondo, Kimisagara, Kabeza, Busanza, and Kamonyi. These stations are located on national roads and major district roads, supporting the increasing number of electric motorcycles and promoting sustainable transportation in the city.

FIGURE 48. Distribution map of existing battery swapping stations in Rwanda



Furthermore, regarding the visits, the following additional observations arose:

- **Public Transportation and Parking:** A notable lack of EV charging stations within public parking areas was observed, with the only forthcoming project being BasiGo's installation near the Nyanza taxi park. This highlights a significant opportunity for EVCI development in public parking spaces to support electric public transport and private EVs.
- **Government Buildings:** Buildings hosting offices of governmental entities, such as ministries, municipalities, and other agencies (eg, RURA, WASAC, REG), were found to be viable locations for EVCI due to their strategic locations and high daily traffic, making them ideal for charging station installations.
- **Healthcare and Market Areas:** Hospitals and public markets with parking facilities were identified as potential sites for EVCI. However, it was noted that no charging stations were installed in these areas during the visit, highlighting an untapped potential for infrastructure expansion.

3.1.4 Deployment strategy

Chapter 3.1.3 provided an overview of different charging solutions which are currently being implemented. The future deployment strategy should be reactive to forecasted demand and sufficient to meet future needs. Additionally, it shapes the transport system by influencing the choices of future electric vehicle users and other stakeholders, encouraging a shift towards electrified transport based on the availability and quality of charging infrastructure. This in turn also shapes urban development meaning that EVCI should therefore also be integrated into urban planning.

A long-term deployment strategy for passenger vehicle charging infrastructure involves steps tailored to the local context. These steps include implementing a DC fast charging network to reduce range anxiety, establishing extensive AC charging networks for widespread use during extended parking periods (like overnight or at work), and introducing opportunity charging options for quick top-ups at places like retail chains, public service locations, and guest parking areas. Privately, AC charging can be set up at homes, apartment complexes, and workplaces, including corporate fleets. Publicly, AC charging can be implemented along public streets.

When it comes to location planning, several factors should be considered which are included in Section 2.2.4 Other factors to consider consequently are:

- **How to effectively meet demand** – Analyse parking space utilisation rates, numbers of EVs in use, projected EV sales, current and projected charging demand, data-driven insights, so that stakeholders can make informed decisions to effectively expand EVCI and meet the growing demand for electric vehicle charging services
- **Proactive charging infrastructure placement approaches** – Assess how public and private organisations should install infrastructure without a specific applicant or user for each charging location. This proactive approach ensures a well-planned and strategically placed charging network that meets the needs of the community, enhances the visibility of EVs, and adapts to growing demand.
- **Functions in charging infrastructure implementation** – Delineate what are the functions of the implementation model besides the setup of infrastructure. These can be land provision, electricity supply, charging software solutions, and customer services.
- **Development scenarios** – Outline the stages for charging infrastructure deployment. Usually these are current, intermediate and goal scenarios that delineate how charging infrastructure should eventually be like for different vehicles and locations.
- **Grid planning** – Leverage analysis on what successful grid and energy system planning looks like, especially when considering the expansion of transformer capacity in the distribution grid and renewable electricity generation needed to support a reliable charging infrastructure for various modes of transport
- **Regulatory framework** – Assess how the power grid is influenced by regulatory and policy frameworks and identify management structures, such as state-owned national utilities and privatised industries with separate transmission and distribution entities. Furthermore, as transformer funding is a bottleneck for expanding charging infrastructure, it is crucial to reassess and redesign regulatory frameworks for distribution grid operators. This would encourage investments needed for infrastructure expansion. E-Mobility goals could be integrated into a performance-based regulatory framework to incentivise strategic grid reinforcements for charging infrastructure.
- **EV charger solutions** – Assess different EV charger modular scenarios that can influence charging behaviour based on the Rwandan context.

3.2 Vehicle-grid-integration analysis

EVs should be integrated into the power system in a supportive manner. Often the parking duration of the EV is longer than the time required to recharge. The available flexibility can be used to move the charging process to a more beneficial time slot. Residential, workplace and depot charging often can be moved without affecting the user, while opportunity and on-route charging do not provide such flexibility.

Within this section first the possibilities of managed charging are highlighted, followed by a simulative analysis of the real-world potential for the City of Kigali.

3.2.1 Managed charging objectives

Managed aims to optimise a specific charging session towards optimal stakeholder satisfaction at minimum cost. Most notable interest groups are:

- Network and system operators
- Electric vehicle users
- Energy providers
- Mobility providers

Network operators are responsible for ensuring stability and quality of supply at minimum cost. This includes preventing network congestion (network operator) and frequency control (system operator). Electric vehicle users require a sufficiently charged vehicle without comfort loss at the lowest possible cost. Energy providers want to optimise demand to match low-cost generation profiles. Lastly, mobility providers aim to increase the utilisation of the installed charging infrastructure.

3.2.2 Smart charging methodologies

Application of managed charging can be achieved through different methods, varying in complexity, cost and effectiveness. The following methods exist:

- Load Management (ie setting a maximum load)
- V1G
- V2G

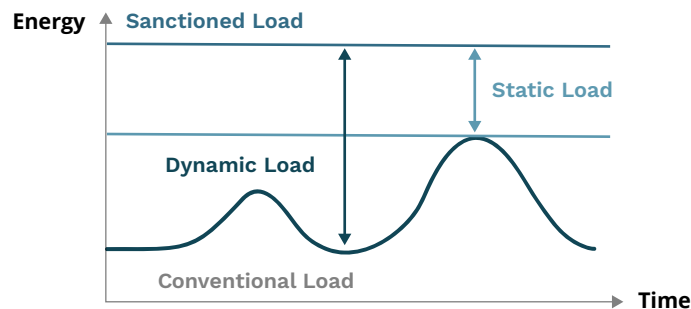
Load management (setting a maximum load)

Load management is used to limit the maximum power drawn from the grid at the connection point. In most countries, at least for commercial use, one must pay for the energy supplied and the maximum power drawn. Reducing the peak load allows considerable savings.

Load management does not consider external information, such as the current state of the grid or dynamic electricity price fluctuations. Load management can be set either statically or dynamically. Static load management will keep the maximum charging power of the electric vehicle below a constant value, while dynamic load management will also consider the power requirements of other devices behind the metre (see Figure 49). In general, load management makes sense if more than one charging station is installed at the same grid connection point, or the available power is limited. Several companies already offer charging stations with load

management capability, although they vary in sophistication. The most advanced systems will account for each vehicle's state of charge and departure times to determine which vehicle should be charged the fastest. Others will charge based solely on plug-in time.

FIGURE 49. Schematic static and dynamic load management system



V1G

V1G is the ability to adjust charging power based on external factors, such as grid congestion or dynamic price signals. For grid congestion management, the current grid status must be known through local measurements enhanced by state estimation. For instance, to manage grid congestion at the local street level, it is necessary to have information about the current load and voltage per feeder.

Smart charging can be used for all types of EVs, as long as flexibility is available. For electric 2- and 3-wheelers relays control (on/off) can be sufficient, while power consumption of larger vehicles should be modulated (0-100 percent), as is already possible with existing charging infrastructure and vehicles.

V2G

V2G, also called bidirectional charging allows reverse power flows, on top of reduction in charging power. Suggested applications are short-term frequency control, energy arbitrage as well as increased use of renewable energy. Another use case discussed is, for example, the reduction of evening peak load caused by air conditioning: excess PV generation during the mid-day hours can be buffered in EV batteries. Similar matches with other fluctuating loads, like heat pumps, are possible as well.

Proposed use cases are typically driven by objectives related to system level (generation and transmission). This implies the risk of not considering local network bottlenecks in the distribution system. With inadequate network design and protection, synchronised V2G vehicles' response may result in overloading, tripping of protection and power loss in certain LV network sections. Uncoordinated V2G activities in combination with distributed electricity generation further increases the risks. Dedicated monitoring, communication and control is a precondition for integrating V2G in distribution networks.

Compared to smart charging, V2G does not offer added value for mitigating local network congestion. Reducing the charging load in case of need by unidirectional charging management, ie without reverse power flow effectively avoids any overloading.

From a network planning perspective, V2G will never allow underrating distribution system assets with respect to other (new) loads, simply because the vehicles may not be available

when the relevant situation occurs. At transmission system level, in future it could be possible to plan with a certain V2G capacity to underrate the system.

Further optimisation

All charging methods mentioned above (Load Management / setting a maximum load, V1G, V2G) can be enhanced through the installation of a stationary buffer battery, local generation (eg PV), or other flexible consumers (eg heat pump users). Furthermore, battery swapping can add an additional amount of flexibility, as they can be charged at times when the vehicles are not present. Additional flexibility can then be used to reduce peak power or energy cost at the point of grid connection.

3.2.3 Mitigation impact on Rwanda's Grid

In this chapter, the potential of managed charging is assessed which could mitigate the negative effects of EVs on the network. Smart charging and bidirectional charging (V2G) serve different objectives within the electricity network, depending on the voltage level.

The flexibility an individual EV can provide at any given time is often unpredictable. For example, a driver might take an unplanned journey or forget to plug the vehicle into the charging station. Therefore, at distribution level, network planners and operators can only reduce the charging process of all currently charging EVs to zero (smart charging) but cannot rely on firm discharging capacity (V2G). At the transmission level, the situation differs. By pooling a large group of EVs, guaranteed bidirectional (V2G) flexibility can be provided, offering ancillary services such as frequency control.

Consequently, smart charging is crucial for stabilising the LV network, where simultaneous EV charging and high power demands frequently occur. At higher voltage levels, the effect diminishes due to aggregation. Conversely, aggregation at higher voltage levels better supports the use of V2G.

This study analyses the impact of smart charging and V2G at medium voltage level for the peak load case in 2030, considering high EV penetration within the network without any upgrades, to demonstrate the maximum impact of both charging cases. At this voltage level, EV pooling cannot provide firm capacity to support the network during the worst-case peak load scenario. Planning procedures at medium voltage level should not include EV discharging as a method to reduce the overall load, at least until 2030. In future years, with sufficient EVs in the network, pooling might become feasible at the MV level as well, but further studies will be required once EVs have become mass-adopted.

During uncontrolled charging processes, the network operator cannot reduce the charging power of EVs during peak loading, although load management is used at depot level, such as during the charging process of e-buses. In the context of the simulations, it is assumed that 80 percent of the vehicles offering flexibility will shift their charging process to a later time during peak loading. A typical charging use case that offers flexibility is slow charging of private vehicles, while fast charging usually does not offer flexibility.

Through PowerFactory simulations, the network impact of uncontrolled and smart charging is determined. Table 28 describes several global network parameters and their differences between uncontrolled and smart charging. Each parameter is detailed in the following bullet point list.

TABLE 28. Network impact of uncontrolled vs smart charging

Global Parameter	Uncontrolled	Smart	Difference
L_ave [%]	22.2%	18.8%	-15.0%
L_max [%]	258%	251%	-2.9%
L_nr_over[#]	47	41	-12.5%
U_ave [p.u.]	0.93	0.94	0.5%
U_min [p.u.]	0.75	0.76	2.0%
U_nr_under [#]	787	721	-8.3%

- **L_ave [%]:** The *Average line loading* is reduced by 15 percent in case smart charging is applied.
- **L_max [%]:** The *Maximum line loading* in the network is significant in both charging strategies. Network upgrades are required. The difference in maximum line loading between both charging strategies is insignificant.
- **L_nr_over[#]:** The *Number of overloaded lines in the network* drops by 12 percent, showing the advantage of network upgrade deferral through the use of smart charging.
- **U_ave[p.u.]:** The *Average voltage in the network* is increased through smart charging, although the effect is only minor.
- **U_min [p.u.]:** The *Minimum voltage in the network* increase through smart charging, although the effect is only minor.
- **U_nr_under [#]:** The *Number of undervoltage terminals* is reduced by 8 percent. Although network upgrades are still needed, the required capacity is lower.

Figure 50 displays a detailed comparison of line loading between uncontrolled and smart charging. A shift towards lower line loading is clearly visible, further indicating the advantages of smart charging. Figure 51 shows the voltage distribution for both charging methodologies. The shift towards higher voltage levels becomes apparent, highlighting the importance of smart charging at the medium voltage level.

In conclusion, the simulation results clearly indicate that smart charging will help stabilise the MV network. Although the main benefits of smart charging emerge at the low voltage level, where most charging stations are installed, the MV network will also benefit from this measure.

FIGURE 50. Line loading distribution in the case of uncontrolled and smart charging

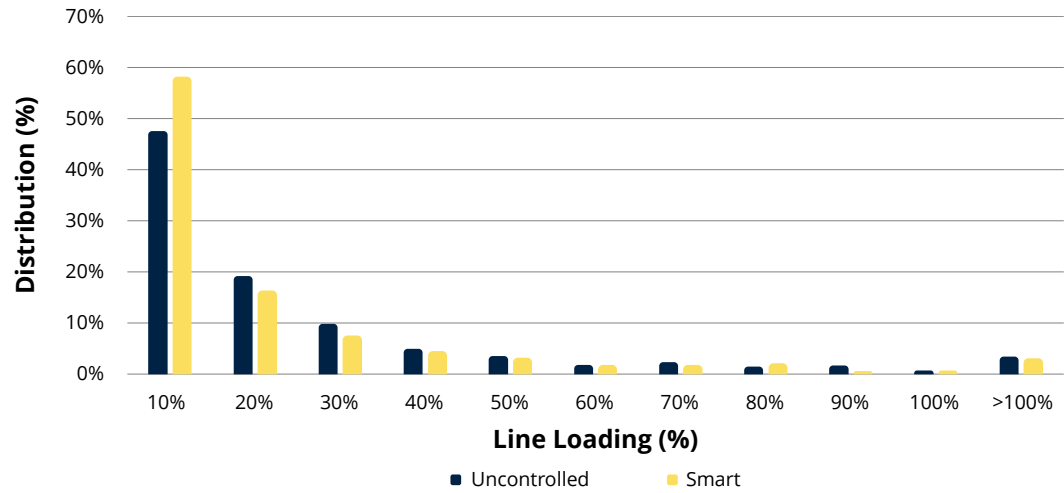
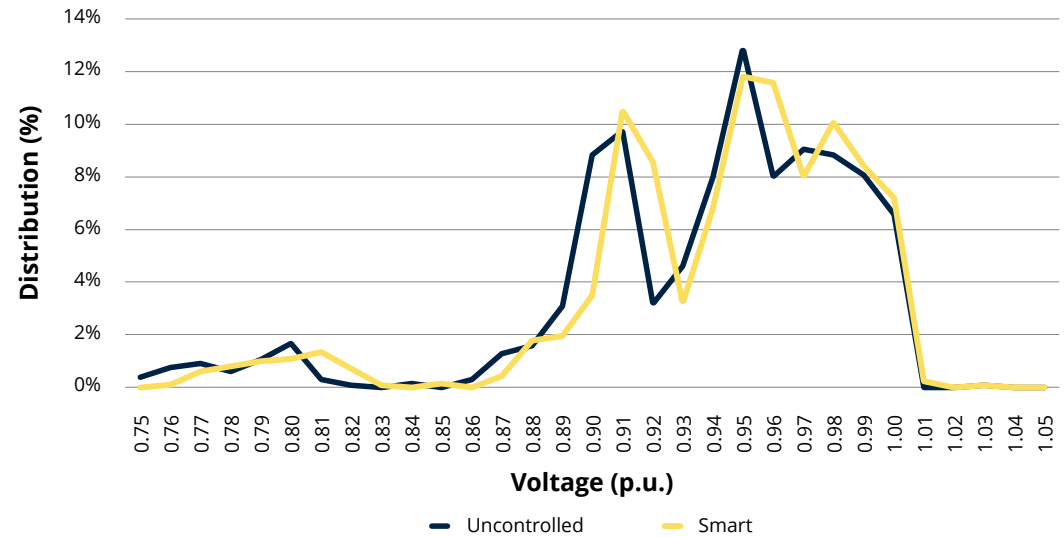


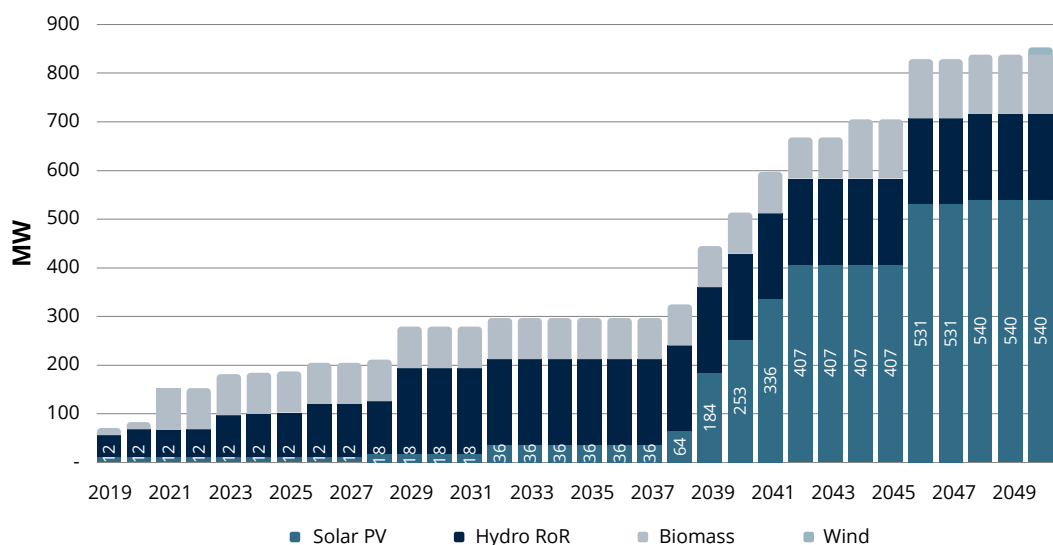
FIGURE 51. Voltage distribution in the case of uncontrolled and smart charging



3.3 Electricity supply

To calculate electricity supply capacity, the maximum load demand was determined by summing the power requirements of all connected devices and systems, as well as all planned ones. As illustrated in Figure 52, hydropower is likely to continue being a core electricity source until 2030, while solar PV is expected to grow considerably in the longer-term between 2040 and 2050.

FIGURE 52. Electricity supply capacity



As noted in Section 2.2, the level of additional power requirements for EVs are expected to be significantly lower than the additional PV which is expected to be added to the system. This means that one approach to powering vehicles could be to develop policies that encourage charging during times of PV electricity production.

3.4 Battery value chain analysis

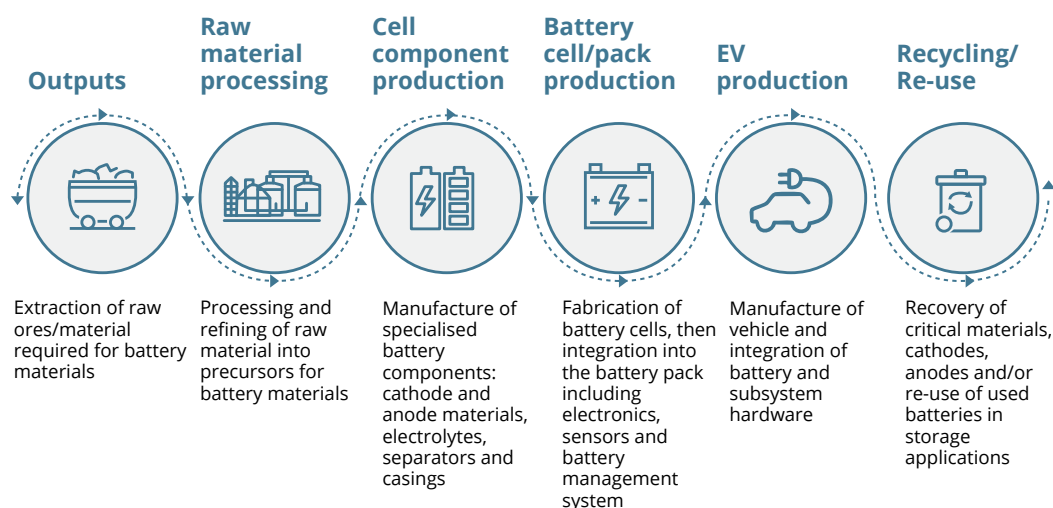
As the demand for EVs increases, so does the need to mitigate high economic, environmental and human costs associated with battery production and usage. Extraction and processing of critical minerals and raw materials is costly and lengthy, and as the expansion of raw materials demand will increase, so will the risks of unsafe working conditions, local air, water and soil pollution, and biodiversity loss.

Assuming a 10-year life span of batteries, the following table shows the amount of batteries which could be expected to reach the end of life of life in 2035, 2040, and 2050.

TABLE 29. Number of vehicle batteries reaching the end of life

Type of vehicle battery reaching the end of life	2035	2040	2050
Two-wheeled vehicles - Personal	5,901	9,894	37,545
Two-wheeled vehicles - Motos	5,901	9,894	37,545
Four-wheeled vehicles - Passenger vehicles	12,548	32,197	106,571
Four-wheeled vehicles - Taxis	54	63	89
Buses	87	138	195
Bicycles	13,364	13,364	20,000
Light Duty Vehicles	378	820	3,121
Total	38,232	66,370	205,066

Figure 53 illustrates the EV battery supply chain. As it can be seen, EV battery supply chains consist of multiple complex stages which are spread around the world. From extracting the necessary mineral ores, refining to form sufficient purity chemicals, then advanced materials synthesis to form cathode and anode materials. Similar complex supply chains characterise other battery components such as electrolytes and separators. Cells are then fabricated and housed in modules within a battery pack which is integrated into the EV.

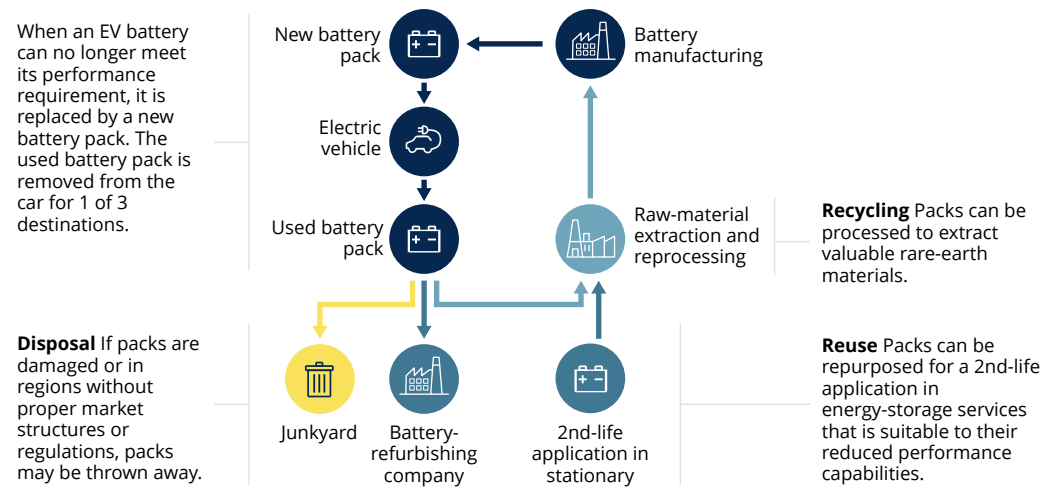
FIGURE 53. EV battery supply chain

Source: IEA. 2022. Global supply chains of EV batteries.

As the EV battery industry grows and matures, establishing a circular battery value chain will become vital for both supply chain and ESG responsibility. In a circular battery value chain, batteries reaching EOL are repurposed, re-used or recycled. As illustrated in Figure 55:

- Repurposing implies remanufacturing a battery for a different application from the one for which it was originally designed, ensuring it is certified to be of high quality before it re-enters the market (eg an EV battery is repurposed in a mini-grid application).
- Recycling means that the raw materials within a battery are recovered and made available for future industrial use.

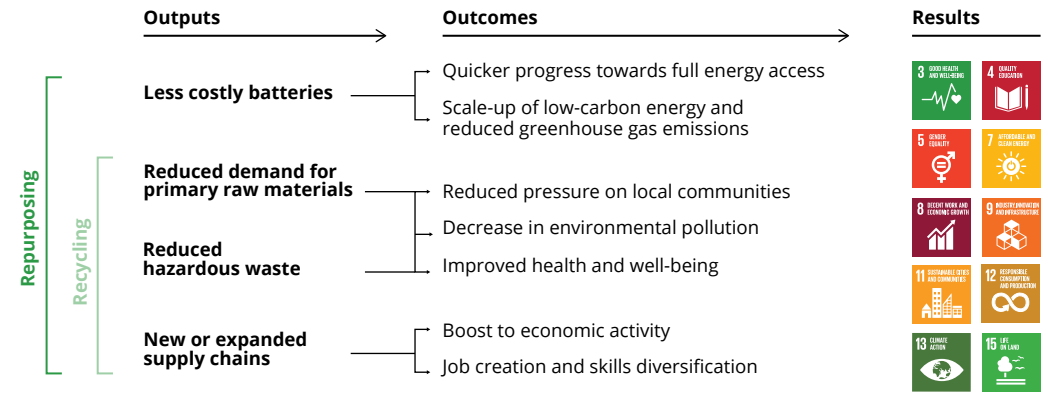
FIGURE 54. EV battery life cycle



Source: McKinsey & Company. 2019. Second-life EV batteries: the newest value pool in energy storage.

For African battery markets, increased circularity will establish more sustained and constant demand for raw materials reducing unsustainable extractive sector pressures. On top of this, it will help improve hazardous waste management and lower the costs of energy storage through repurposing. High quality recycling and repurposing also create additional co-benefits contributing to the achievement of the Sustainable Development Goals, for example through employment and upskilling opportunities, as illustrated in Figure 55 below.

FIGURE 55. Recycling and repurposing could support progress towards numerous SDGs



Source: World Economic Forum. 2021. Closing the Loop on Energy Access in Africa.

While African countries are heavily involved in mining and extraction of raw minerals within the global battery supply chain, only a small portion of battery manufacturing occurs locally. In the

context of second-hand product imports (such as second-hand vehicles), imports of second-hand batteries are common across the continent.

To address issues of EOL batteries, a regional approach would be beneficial in the context of Africa. This could present an opportunity for Rwanda to host the recycling and repurposing facilities of the region.

EOL management is nascent: a few companies across the continent are favouring repurposing activities since recycling is more costly while others are selling imported repurposed batteries. However, most repurposing activities originate from the treatment of waste and batteries from the off-grid solar market. Box 5 illustrates one of the very few academic studies which focuses on used EV batteries.

BOX 5. SECOND-LIFE EV BATTERIES USED IN SOLAR HOME SYSTEMS IN TANZANIA

The Fraunhofer Heinrich Hertz Institute studies the use of a photovoltaic system in conjunction with a 85 kWh second-life lithium-ion battery (LIB) from EVs as an off-grid hybrid system to electrify an island in Lake Victoria in Tanzania.

The socio-economic research finds that besides supplying an average of 42.31 kWh of energy per day and meeting the daily demand of key infrastructure such as local hospitals and schools, this repurposing project presents critical health and environmental co-benefits, including GHG emissions mitigation, hospital electrification and water supply reliability.

Source: Falk, J., Nedjalkov, A., Angelmahr, M. et al. 2020. Applying Lithium-Ion Second Life Batteries for Off-Grid Solar Powered System—A Socio-Economic Case Study for Rural Development.

When it comes to recycling, African countries are mainly active in the treatment of used lead-acid batteries (ULAB). While most recycling activities are focused locally and in informal conditions, involving informal battery-breakers and smelters, they have recently become attractive for investors who set up industrial scale facilities in major markets. Nigeria and Kenya have attracted considerable investment in industrial recycling facilities, which have also stimulated regulatory initiatives aimed at introducing standards for recycling practices and addressing pollution issues.

On the other hand, lithium-ion batteries have not yet appeared in larger volumes in waste streams and so far, there are no recycling facilities operating in Africa. Due to the absence of such infrastructure, batteries would need to be shipped to foreign destinations for recycling, which requires following the prior informed consent procedure of the Basel Convention, with transport also posing considerable fire hazards. Shipping agencies are reluctant to transport waste lithium-ion batteries and, if they do so, request heightened fire precautions, such as embedding cargo in sand.

Challenges to repurposing

Battery repurposing can help recover battery value at the end of life, helping improve the economics of batteries and accelerate market output, as well as can reduce the need for new batteries in the power sector.

Challenges to lithium-ion battery repurposing are illustrated in the table below. Worth special attention is the lack of supportive regulation across African countries, which hinders the scale-up of the circular value chain.

Regulatory structures affect several aspects of the battery value chain, which, if unlocked, would open up opportunities for repurposing and recycling adoption.⁵⁰ These aspects are:

- **Design of first-life batteries** – policy guidance and industry-led standards in the design of batteries ensure ease in disassembling
- **Supply of batteries for repurposing** – regulatory mechanisms and EPRS schemes encourage the local collection of batteries
- **Data availability** – battery data can help repurposing companies improve traceability. For example, battery passports make the assessment of a battery's performance after its first life transparent, quick and economical: supported by battery management systems and analytical tools that provide relevant battery state of health data and chemistry, and thus enable the selection and assessment of suitable batteries.
- **Repurposing projects safety** – standards providing for the safe repurposing of batteries can streamline the circular value chain. So far, only one standard exists, UL1974.
- **Consumer willingness to pay for repurposed batteries** – first-life and second-life batteries face no minimum standards or required warranties when sold in energy access applications, contributing to concerns about performance.

TABLE 30. Challenges to repurposed battery production and adoption

Type of vehicle battery reaching the end of life (2035)
Uncertain supply and logistics costs
• Local supply of EOL batteries is limited due to challenges linked to collection. • Imported supply of EOL batteries is uncertain due to high costs of battery shipments and competing demand outside of Africa.
Technical uncertainty
• Research in performance of batteries in first and second-life is underdeveloped.
Limited investor appetite
• There is a lack of proven and profitable business models due to fragmented nature of repurposing market • High and uncertain manufacturing costs driven by lack of data sharing within industry on battery health and fundamental technical uncertainties • High costs of logistics • Consumer demand uncertainty

⁵⁰ World Economic Forum and Global Battery Alliance. 2019. *A vision for a sustainable battery value chain in 2030*.

Challenges to repurposed battery adoption (2035)
Limited political appetite
Widespread scepticism in many African countries about the use and import of repurposed batteries
Consumer confidence
Uncertainty on performance and safety of second-life batteries limits consumer appetite
Cost competitiveness
Cost competitiveness is subject to uncertainties linked to the lack of data from real-world applications and the variability of battery type per application

Source: World Economic Forum. 2021. Closing the Loop on Energy Access in Africa.

Challenges to recycling

Recovering materials from EOL batteries limits the need for raw resources in the long-term, prevents unnecessary losses of valuable materials, and ensures economic and safe EOL management. In this activity regulatory frameworks are the underlying enablers for the circular value chain. These include harmonised regulations related to the transboundary movement of batteries, tightened recycling targets differentiated by material (rather than by average battery weight), and improved Extended Producer Responsibility schemes.

Challenges to battery recycling are illustrated in the table below.

TABLE 31. Challenges to battery recycling

Challenges to battery recycling	Battery type
Limited infrastructure	
- Lack of infrastructure for collecting batteries, as well as suitable recycling facilities, transportation networks, and waste management systems - Underdeveloped enforcement capacities - Underdeveloped strategies for integrating the informal sector	Lead-acid batteries
Limited financial incentives	
- Different recycling processes lead to different levels of profitability, but low-standard recycling leading due to informal sector competition over batteries - Sound collection and recycling is associated with increased costs which does not incentivise governments or private actors - Lacking regulative frameworks and financing mechanisms	Lead-acid batteries Lithium-ion batteries

Challenges to battery recycling	Battery type
Limited knowledge and awareness	
Some countries and stakeholders have identified low-standard recycling facilities as investments that primarily generate jobs, income and tax revenues and are unaware of the potentially devastating effects on human health and economic development	Lead-acid batteries
Limited access to technology	
Limited research and development capacities for pre-processing technologies	Lithium-ion batteries
Environmental and health risks	
Exposure to hazardous materials to human health and the environment	Lead-acid batteries Lithium-ion batteries

Source: World Economic Forum. 2021. Closing the Loop on Energy Access in Africa.

Two battery compositions (Lead-acid / Lithium-ion) are currently available in the market at a large scale. Depending on the battery type different recycling methods are needed, as described in the following:

Lead-acid battery recycling is a well-established and relatively simple process^{51 52}. The challenge lies in the toxicity of the recovered materials. During the recycling process at first, the battery pack is opened and the acid removed. In case of informal recycling, lead dissolved in the acid cannot be recovered and is often drained onsite, resulting in contamination. In the next step, remaining lead electrodes are smelted into raw lead ingots. Toxic fumes must be treated to avoid the negative impact of lead poisoning. Due to the low melting point of lead, smelting is also possible on open fire pits by the informal sector. Resulting contamination of the informal recycling process can have a severe impact on the intelligence development of children in addition to premature deaths. Bangladesh, suffering from a large informal lead-acid battery recycling industry, is estimated to have lost US \$15.9 billion in GDP, due to IQ decreases alone⁵³. Furthermore, deaths associated with lead exposures (4.3 percent of total deaths) have surpassed unsafe drinking water related deaths in Bangladesh. Consequently, industrial lead-acid battery recycling must be established to avoid similar impacts, and proper regulation developed to oppress informal recycling. Higher lead recovery rates also make industrial recycling economically more attractive compared to the informal sector. Regardless of the smelting process the raw lead ingots still need to be shipped to refineries, often located in developed countries for further purification prior to reuse in new batteries.

Lithium-ion batteries far exceed lead-acid batteries in energy density, charging capability and cycle life, although costs are higher. The toxicity of spent cells is lower compared to lead-acid batteries, but they still contain a range of hazardous substances such as hydrogen fluoride and toxic transition metals. Furthermore, poorly disposed lithium-ion batteries can be a fire risk,

51 <https://www.oeko.de/oekodoc/2549/2016-076-de.pdf>

52 <https://www.oeko.de/oekodoc/2316/2015-487-en.pdf>

53 <https://wedocs.unep.org/bitstream/handle/20.500.11822/36331/AIUL.pdf?sequence=3&isAllowed=y>

due to thermal runaway of the cells. Lithium-ion battery recycling is challenging. The recovery process is complex and numerous cell chemistries and shapes exist making standardised processes difficult.

The profitability of lithium-ion recycling is highly linked to the price of recovered material. Cells with high cobalt and nickel content (NMC/NCA) are more valuable to recycle, compared to iron-phosphate-based (LFP) cells. Electric vehicle batteries used to contain a high share of cobalt and nickel, due to high achievable energy densities. Continuous improvement on energy density and production cost reduction efforts have resulted in cells containing fewer valuable materials. Today, most electric buses operate on LFP cells, and the share of electric cars and motorbikes with LFP cells is increasing.

During the recycling process, the battery is first deep-discharged for safety reasons and then separated through several mechanical processes, resulting in the lithium rich black mass and further components. Black mass recycling is energy intensive and requires a sufficient plant size. Therefore, the black mass is often shipped to a central site with cheap available electricity⁵⁴. Further treatment is done through different thermal, pyrometallurgy or hydrometallurgy processes. Depending on the combination of processes the retrieval rate differs for the elements contained in the black mass and is individual to each recycling company^{55 56}. Lithium-Ion battery recycling is not yet applied at industrial scale, although new recycling mandates are resulting in large investments into the sector.

A comprehensive study on battery recycling opportunities and challenges in Africa, for further reading, can be found online at globalbattery.org⁵⁷.

3.4.1 Assessment of current local market on battery value chain

The Government of Rwanda started to address e-waste and battery waste issues more than 10 years ago and in 2016 passed the National E-Waste Policy, requiring producers and importers to finance and organise environmentally sound collection and recycling. While implementation began on a voluntary basis, the government announced mandatory enforcement starting in 2021.

The government has also set up an e-waste dismantling facility, operated by the private company Enviroserve Rwanda and used by solar off-grid companies to manage obsolete equipment. Enviroserve has accumulated 11 metric tonnes of lithium-ion batteries. Non-reusable batteries are currently stockpiled, as plans to export them for recycling were too costly to be sustainable. Enviroserve is exploring battery repurposing as one solution to waste battery accumulation, with tests suggesting that more than 50 percent of battery cells are suitable for repurposing.

With respect to EV batteries, the potential for E-Mobility in expanding the battery EOL activities and ensure they also contribute to energy access efforts is recognised by various players. Volkswagen has been assembling EVs in Rwanda since 2019 and local firms – Ampersand

⁵⁴ <https://www.electrive.com/2020/09/19/li-cycle-to-build-battery-recycling-hub-in-the-usa/>

⁵⁵ <https://www.nature.com/articles/s41586-019-1682-5>

⁵⁶ https://www.pem.rwth-aachen.de/global/show_document.asp?id=aaaaaaacgmlxvq

⁵⁷ <https://www.globalbattery.org/media/action-partnerships/energy-access/downloads/wef-closing-loop-energy-access-2021.pdf>

and Safi – also have plans to scale up their electric motorbike and vehicle operations in the market.⁵⁸

Notwithstanding Rwanda’s advanced position in the African continent with respect to EOL battery management, there is substantial room for enhancement and market development.⁵⁹

- **Make recycling easier for consumers** - there is a need to identify and employ appropriate incentives for consumer participation in EV battery waste management and recycling. Reducing costs of consumer participation has been shown to positively impact participation in e-waste recycling.
- **Extended Producer Responsibility Schemes (EPRs)** – legally require manufacturers and importers to finance the recycling of products placed on the national markets. Models that work with suppliers and importers can be developed to implement EPRs. Examples of EPR models include economic and market-based instruments that incentivise the implementation of environmental protection frameworks such as deposit refund schemes and disposal fees on waste.
- **Urban mining from e-waste recycling** – domestically extracting minerals from e-waste and undertaking domestic value-addition helps deplete fewer resources and control pollution, as well as create jobs. This however requires large investments from both the public and private sector.
- **Enhance awareness** – through community engagement and in formal education, for example in ICT school curricula and in Integrated Polytechnic Regional Centres
- **EOL assessment** – public institutions and companies should be encouraged to assess their estimated EOL stock, as this will help to determine what their EOL strategy will be, and it will also help investors who are willing to invest in e-waste management.

Waste collection in Rwanda is managed by private companies contracted by municipalities. After collection, there is no source separation, and typically all waste, including municipal solid waste (MSW), serviced, commercial, and industrial waste, ends up in landfills. Manual sorting by authorised waste pickers occurs at these sites, but a significant amount of plastic waste is still mingled with organic waste, posing environmental and health risks. There is no advanced waste processing; waste management is limited to sorting after collection, waste spreading, soil coverage, and lacks leachate treatment or gas management.

With the rising population, economic growth, and modernisation, the demand for electrical and electronic equipment (EEE) increases, leading to more e-waste. A survey conducted in 2014-2015 estimated Rwanda's potential annual e-waste generation at 9,417 tonnes, with 81.52 percent from individuals, 12.14 percent from public institutions, and 6.43 percent from private institutions. Rwanda regulates e-waste through its national e-waste Management Policy, restricting the import of used electronics to minimise adverse effects on health and the environment. Financial incentives are provided to individuals who collect e-waste and bring it to recycling facilities. In 2017, Rwanda’s Green Fund FONERWA invested in an e-waste collection and recycling facility run by Enviroserve in the Bugesera district. Additionally, innovative businesses like Wastezon use technology to connect homes with recycling facilities for e-waste management, complementing government efforts.

According to EnviroServe (based on a visit of the factory), the waste of EV batteries that are collected as of today are around 9 tonnes of EV batteries. EnviroServe work with most of the

⁵⁸ World Economic Forum. 2021. *Closing the Loop on Energy Access in Africa*.

⁵⁹ Kabera, Telesphore, Honorine Nishimwe, and Juvenal Mukurarinda. 2023. *E-Waste Management in Rwanda: A Situational and Capacity Need Assessment*. IGC. 2022. *Challenges and opportunities for e-waste in Rwanda*.

E-Mobility companies in the country including Ampersand, CFAO, SUL, etc. with the following key characteristics of the process:

- The EV waste management is currently undertaken specifically on batteries;
- The EV batteries are safely collected from the client;
- The battery waste is documented, inspected, and tested;
- The batteries determined to be high-performance cells are repurposed;
- Those that have tests with lower performance results are discharged and safely packed for recycling;
- Other than EV batteries, all lithium-ion batteries received undergo the same process and are reconditioned by packing cells into new packs with new battery management system and repurposed.

3.4.2 End-of-life batteries and waste recommendations

As the E-Mobility market segment grows, the number and variety of installed charging stations continue to rise presenting a challenge regarding their EOL management. The lifespan of a charging station is approximately 10 years, indicating that it will no longer function and provide its charging services after this duration. Since the supply chain of the charging stations is linear.

To tackle the challenge of waste accumulation from charging stations, it is crucial to explore strategies that extend the lifespan and value of the infrastructure thereby promoting sustainability in the E-Mobility sector. To manage waste from EVs, charging stations, and batteries in Rwanda effectively, it is necessary to integrate comprehensive strategies aligned with the National Circular Economy Action Plan and ongoing initiatives for waste disposal. Key recommendations include:

- Developing specific regulations for EV waste disposal and enforcing Extended Producer Responsibility policies to ensure manufacturers manage EOL products.
- Establishing designated collection centres in each district and investing in advanced recycling facilities will facilitate the processing and recovery of valuable materials from EV / other electronic waste.
- Encouraging modular design and manufacturing practices can also extend the lifespan of EVCI components and support refurbishment programmes.
- Additionally, education and awareness campaigns should promote responsible disposal and recycling
- Integrating EV waste management with existing e-waste policies and facilities can optimise resource recovery.



4

CONSIDERATIONS FOR BATTERY ELECTRIC BUSES



4.1 Charging infrastructure

The growth of electric buses in Kigali and across Rwanda is projected to accelerate significantly in the coming years. According to the E-Mobility Readiness Assessment conducted for this study, the total number of buses in Rwanda is expected to increase from 2,402 in 2023 to 4,143 by 2050, driven largely by population growth trends. In Kigali, where over 500 electric buses are already in consideration for operation, it is anticipated that many, if not all, of these buses will transition to EVs in the near future (ranging from 1,096 electric buses in 2050 in the “low” EV uptake scenario developed during this assignment to all 4,143 buses being electric in the “high” EV uptake scenario).

This section discusses the necessary charging infrastructure, the standards, and explore potential business models for public sector involvement, specifically focusing on the role of the public sector in charging infrastructure development.

4.1.1 Charging hub options

Charging infrastructure is central to the transition to BEBs, requiring strategic decisions on cost, efficiency, and operational needs. The investment capital for charging systems balances three critical factors: installation costs, battery requirements, and maintenance/operation expenses. An example bill of quantities for the installation – including the connection to the grid – is included in Annex A11. Among these options:

- **Depot charging** is a cost-effective method, minimising overall infrastructure expenses. It allows for overnight energy replenishment during off-peak hours, benefiting from reduced electricity tariffs and underutilised grid capacity. This approach typically eliminates the need for costly grid upgrades, making it ideal for intra-city buses. Moreover, it serves as a straightforward replacement for petroleum buses and allows operators to use the same buses across multiple routes, as the vehicles are not reliant on route-based chargers.
- **Enroute charging** offers smaller battery requirements, but it demands significant infrastructure investments. This method is better suited for intercity buses that operate longer routes and may require mid-journey charging.

Discussions with electric bus operators and city planners suggest that intra-city buses in Kigali will rely predominantly on depot-based overnight charging hubs. Current bus travel distances do not necessitate mid-day recharging, making overnight charging both financially viable and operationally efficient. However, opportunity charging stations, strategically located at transport hubs like Nyabugogo, are recommended to support intercity bus operations.

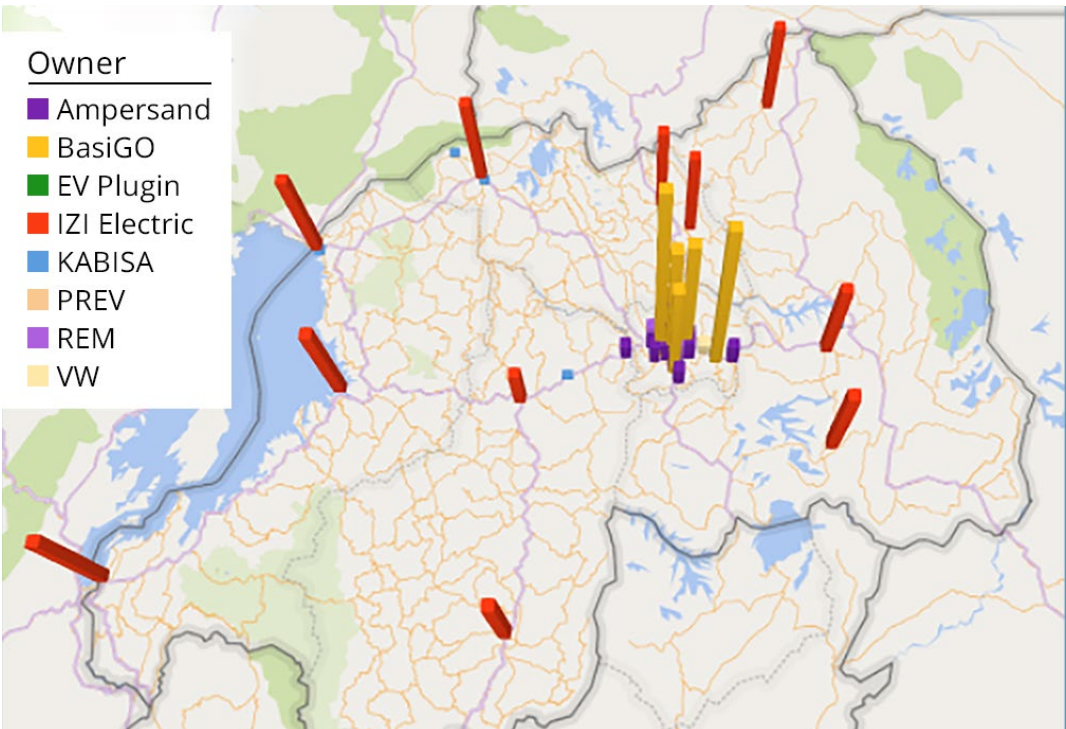
The installation of charging stations on a city-wide scale is not expected to be the primary driver of network expansion requirements (see Section 2.3.1 for more). However, installations may create localised network bottlenecks, necessitating timely upgrades. Currently, the two main companies planning to invest in electric buses - BasiGo and IZI - intend to install up to 9.5 MW of charging capacity in Kigali, which is significantly below the anticipated annual general load growth.

Although charging station installations are not currently, and are not expected to become, a severe issue for the network operator, proactive measures should still be taken to minimise potential impacts. Managed charging can significantly reduce the costs associated with network expansion.

It is recommended that all overnight charging facilities be equipped with load management systems. These systems control how much electricity each charging station uses when multiple electric vehicle supply equipment units are connected to the same circuit. Once configured, chargers automatically apply a chosen protocol to balance electricity usage. This approach reduces peak load, benefiting operators by lowering peak load demand charges. Ideally, the system would also monitor and respond to local network constraints, though this would require a contractual agreement between the network operator and the charging station operator.

The current and planned charging facilities—for buses, motos, and other key charging points—are illustrated in the figure below.

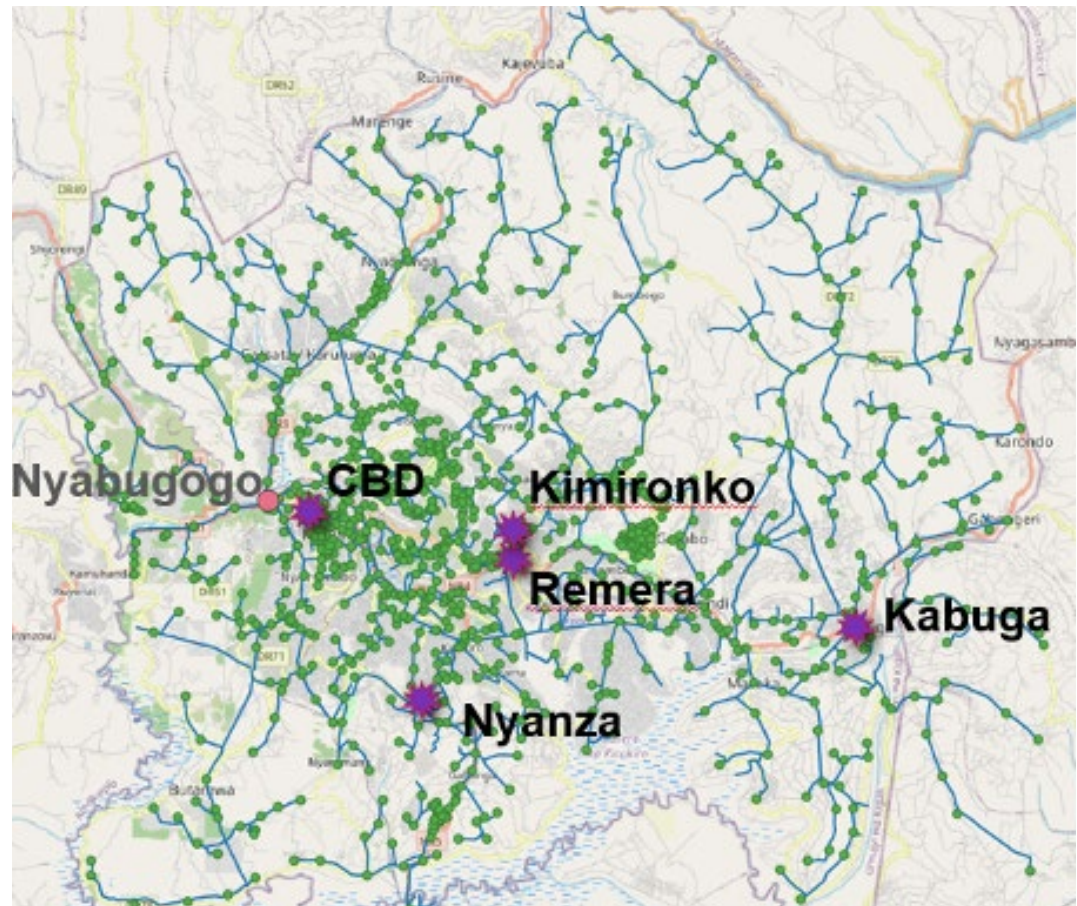
FIGURE 56. Distribution of existing and planned charging stations throughout Kigali



The impact of charging station development for buses at various locations was assessed, building on a previous study titled “Consultancy Services for Developing a Fleet Renewal Program, Including Transaction Advisory and Detailed Design for E-Bus Pilot Project.” Workstream 3 of that study assumed a charging capacity of 75 kW per charger for overnight charging. The assessed locations are presented in the table and figure below, along with a summary of connection restrictions and the power requirements associated with the planned charging points.

In general, the installation and utilisation of charging infrastructure for overnight bus charging at these hubs is not expected to pose significant challenges. While some upgrades may be necessary, these are anticipated to stem primarily from general load growth rather than the installation of charging stations.

FIGURE 57. Map of Kigali including planned future charging hubs in Kigali



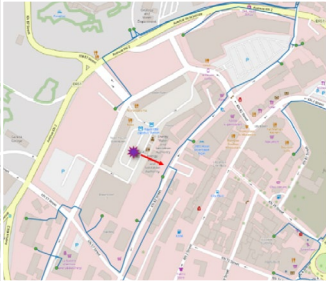
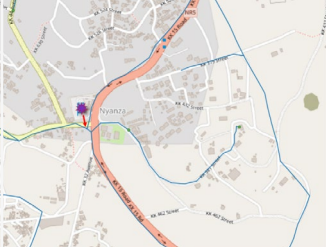
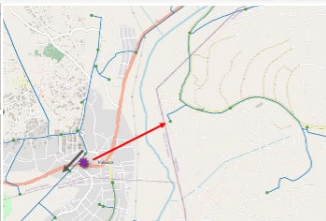
Note:

The green dots represent transformer stations.

The blue lines represent 15kV lines (the MV grid in Kigali)

Source: Map generated using GIS data was provided by REG/EUCL for the study – loaded into QGIS

TABLE 32. Potential bus terminals / charging hubs and their restrictions related to the network

Terminal	Power	Connection restrictions	Map of location
CBD	3 MW 40 plugs @ 75 kW	None – there is a possibility of a direct connection (60 metres) to the network and no network bottlenecks are foreseen before 2037	
Remera	1.5 MW 20 plugs @ 75 kW	Direct connection (100 metres) will be possible once the existing Gikondo feeder voltage issue is solved – eg there is a line upgrade Gikondo -> Pylon 20	
Kimironko	1.5 MW 20 plugs @ 75 kW	Direct connection should be possible for both lines (Impresco 120 metres & Rwahama 330 metres) and no network bottlenecks are foreseen before 2037	
Nyanza	3.2 MW 42 plugs @ 75 kW	None – there is a possibility of a direct connection (100 metres) to the network and no network bottlenecks are foreseen before 2037	
Kabuga	3.8 MW 51 plugs @ 75 kW	There are two options for this hub: <u>Option 1 (black):</u> • Direct connection is possible – Via a 500 m line – 0.9 capacitive power factor via a 4.2 MVA transformer • 6 km additional line upgrades will be necessary from 2030 independent of charging station <u>Option 2 (red):</u> • 13 km of line upgrades • This is not recommended	

4.1.2 Opportunities for the public sector

The development of BEBs is significantly influenced by the involvement of utility companies, such as REG and its subsidiary companies; EUCL and EDCL, as well as other public sector stakeholders, particularly publicly-owned entities. The public sector plays a critical role not only in advancing the electric vehicle market for both buses and other vehicle types but also in supporting the necessary infrastructure, particularly electric vehicle charging stations.

The core steps involved in the development of charging infrastructure, along with their connection to relevant business models, are outlined in the table below.⁶⁰ The table also includes comments on the role of public sector actors in these steps. It is important to note that municipalities, including Kigali, could potentially engage in all of these steps by establishing a publicly-owned company to implement them. As such, this is not explicitly referenced in the table. An analysis of potential business models for electric buses is provided in Annex A7.

TABLE 33. Steps in charging infrastructure development and their relevance for public bodies

Areas	Relevance
Manufacturing of EV infrastructure and equipment (including charging stations, connection cables, batteries, and buses)	Low relevance – Manufacturing of EV infrastructure and equipment is a highly complex and well-developed process, predominantly carried out internationally or by private sector actors. While there may be opportunities for local private sector investment in specific equipment components, these areas could potentially be supported by FONERWA.
Infrastructure installation (installation of charging stations and supporting grid infrastructure)	High relevance – REG/EUCL/EDCL already play a key role in supporting electricity infrastructure up to the charging stations. There may also be potential for REG/EUCL to assist in the installation of charging stations in commercial spaces (eg, shopping centers, parking lots). Additionally, repurposed vehicle batteries could be used in charging facilities as reserve power banks.
Retail Services / Selling of Infrastructure (sale of EVCI equipment to end-users)	Low relevance – The sale of charging equipment is primarily handled by private sector actors and is not aligned with REG/EUCL's core business operations. However, other government entities, such as FONERWA, could support private sector expansion in this area through financial mechanisms (eg, guarantee mechanisms).
Station Operation (ownership, maintenance, and management of charging stations where users pay for service)	Medium relevance – This business operation could be relevant for REG/EUCL, particularly for publicly available charging points and potentially for buses. If the utility is involved, public-private partnerships can optimize efficiency and expertise.

⁶⁰ See, for example this article for a good explanation of these steps: <https://zinstarevcharging.com/what-ev-charging-business-models-are-there/>

Areas	Relevance
Fleet Management (maintenance and management of charging stations and bus fleets)	Low relevance – Fleet management is currently undertaken by private sector actors and does not align closely with REG/EUCL’s operations. However, it could be explored through a PPP model if appropriate.
Online Application (development and management of mobile apps, subscription/membership fees for flexible user access to charging stations)	Medium relevance – Given REG/EUCL’s national-level presence, this could be a promising business model, although further investigation is required. More likely, this model would be suitable for private sector actors.

The analysis of the current situation in Rwanda highlights the potential for REG/EUCL to engage in the installation of charging infrastructure, the operation of charging stations, and the provision of mobile charging services. This involvement could also extend to exploring the feasibility of PPPs over a 2- to 3-year period. For some activities, it may be beneficial to consider establishing these operations as subsidiaries or separate entities from REG/EUCL, ensuring that they are properly managed and staffed.

For the installation and operation of EVCI, a hybrid ownership model could be a suitable approach. In this model, REG/EUCL would retain ownership of the charging infrastructure, while the maintenance and day-to-day operations would be outsourced to private operators. This structure allows the public sector to maintain oversight and ownership while leveraging the efficiency and expertise of private operators. The hybrid model offers several advantages, including improved operational efficiency, greater flexibility in service delivery, and potential cost savings. However, it would require careful management of contracts and performance to ensure that service quality meets the expectations of the public.

Estimating the financial requirements for these investments is challenging, as they depend on the level of ambition from REG/EUCL and the number of EVs in the market. For example, if there is a goal of establishing 25 to 50 charging stations for buses, the investment needed for the installations alone could range between US \$638,000 and US \$1,275,000. However, given the significant involvement of private sector actors in the market, focusing on the residential and commercial sectors may be more practical. In these markets, similar investment levels could yield a higher number of charging stations, depending on whether the chargers are fast or slow. The costs of installation can vary widely, ranging from a few hundred to several thousand US dollars, which would require further investigation and market research to refine.

A business model that involves charging higher electricity rates for vehicle charging could provide a mechanism for REG/EUCL to recover the investment over time. This would mean that the charging station charges the cost of electricity plus an additional amount which would cover the amortised investment costs and additional operations and maintenance costs. It would be site-specific for charging points and thus users would be paying for the convenience of using the charging stations. This approach could contribute to the financial sustainability of the charging infrastructure and make it more feasible for public entities to manage such a large-scale initiative.

As part of the Readiness Assessment report, three scenarios were created to estimate the market penetration of EVs. The "Low" scenario, shown in the table below, outlines the number of EVs by type, along with provisional estimates of the required charging stations. This provides the low range of the likely charging infrastructure required – with the higher range being significantly higher. This analysis suggests that thousands of charging points will be necessary to support these vehicles. While most of these stations will cater to personal four-wheel vehicles, other market segments will also contribute to the overall demand.

TABLE 34. Projections of the number of EVs in Rwanda through 2040 in the “low” market penetration scenario

Number of EVs			Number of vehicles per charging point	Number of charging points to be installed		
2035	2040	2050		2035	2040	2050
Two-Wheelers – personal						
170,274	449,227	1,185,179	20 ⁶¹	8,514	22,461	59,259
Two-Wheelers – motos						
170,274	449,227	1,185,179	20	8,514	22,461	59,259
Four-Wheelers - personal						
106,139	734,557	2,780,115	10 ⁶²	10,614	73,456	278,011
Four-Wheelers - Taxi						
300	1,114	2,139	4 ⁶³	75	278	535
Buses						
562	2,071	4,143	4 ⁶⁴	141	518	1,036
Light Duty Vehicles						
2,980	19,342	76,503	4 ⁶⁵	745	4,836	19,126

More specifically, the table below shows the number of charging points which would be required to charge electric buses in the three scenarios.

⁶¹ Estimate based on discussions with local experts

⁶² This is the current global average <https://www.iea.org/reports/global-ev-outlook-2023/trends-in-charging-infrastructure>

⁶³ Estimated to be the same as buses

⁶⁴ Estimate based on discussions with local companies

⁶⁵ Estimated to be the same as buses

TABLE 35. Number of electric buses and associated charging points through 2050 in all three scenarios

Scenario	Number of electric buses			Number of charging points to be installed		
	2030	2040	2050	2030	2040	2050
Low	306	650	1,096	76	163	274
Medium	397	1,171	2,227	99	293	557
High	562	2,071	4,143	141	518	1,036

4.1.3 Potential mechanisms for financing

This section explores a range of financing mechanisms that could support the scaling up of BEBs and EVCI. Among the various options, PPPs involving REG/EUCL or the city are particularly noteworthy. These partnerships enable the sharing of financial risks between the public and private sectors, making them a viable model for expanding charging infrastructure.

In addition to PPPs, FONERWA can play a critical role by leveraging its own resources, or those mobilised from other sources, to provide guarantees for investors in EVCI and BEBs. Another promising option is the green bond market, which offers the opportunity to raise debt investment at favourable terms for projects related to sustainability, such as E-Mobility.

While other financing sources are being explored, the mechanisms listed below hold particular promise for advancing electric vehicle adoption and the development of charging infrastructure in Rwanda.

TABLE 36. Potential financing mechanisms and their relevance for EVs and charging infrastructure

Current status	Advantages	Disadvantage	Recommendations
Private Sector / PPPs			
Growing interest in scaling electric buses (eg, BasiGo, IZI) and EVs	- Facilitates large-scale investments - Encourages private sector participation	- Complex risk-sharing arrangements - Private sector may be reluctant to take the initial investment risk	- Engage with private sector actors to leverage their resources for scaling - Pursue risk-sharing models through PPPs

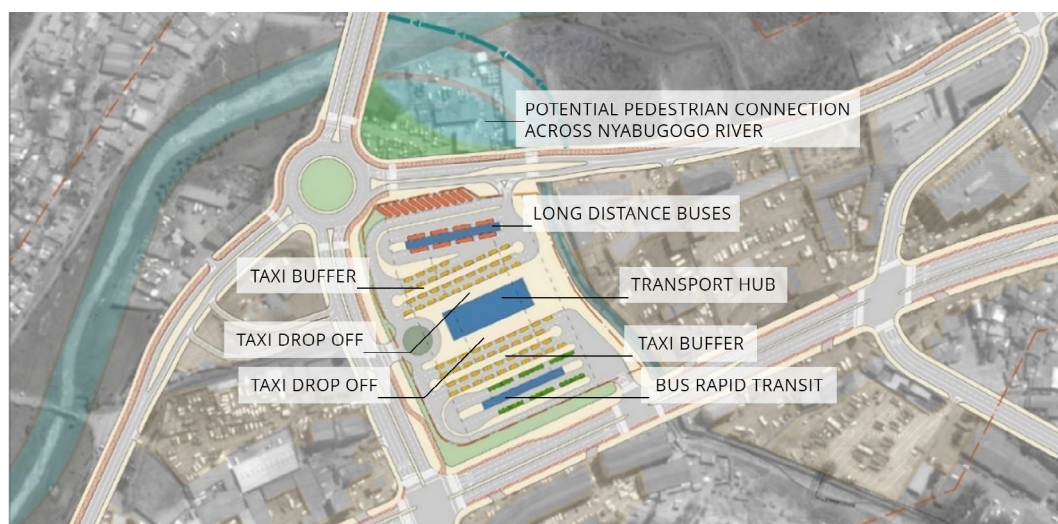
Current status	Advantages	Disadvantage	Recommendations
International Donor Grants			
Funding underway for various projects	• No repayment required • Useful for small-scale, early-stage projects • Supports building public infrastructure/ critical initial infrastructure, which can derisk private investments	• Typically limited in scale • Slow disbursement • May not foster long-term market sustainability	• Use for seed funding, capitalising funds, or technical assistance (TA) • Not suitable for large-scale investments
International Lending from International Financial Institutions (IFIs)			
Ongoing initiatives, such as RUMI	• Can be mobilised at scale • Offers long-term, low-interest financing • Supports building critical public infrastructure, which can derisk private sector investments	• Requires repayment • Stringent reporting and compliance requirements	• Explore linking IFI funding with PPPs to de-risk private sector investments • Use IFI funding for essential infrastructure development
Green Bond Markets			
Active in Rwanda, primarily for renewable energy	• Large-scale capital mobilisation • Low interest rates and long-term tenors	• Requires green bond framework verification • May involve lengthy approval processes	• Investigate green bond markets for scaling up PPPs • Explore for funding E-Mobility projects and infrastructure
Own Resources			
Available from FONERWA, City, REG-EUCL/EDCL	• Demonstrates commitment • Flexible, can generate returns • Can help attract additional external financing	• Competing priorities for limited resources • May not be sufficient for large-scale investments	• Leverage own resources to create a guarantee mechanism that attracts private investment • Use as seed funding for projects

4.2 Nyabugogo multi-modal transit hub case study

The Nyabugogo area in Kigali is considered a central location in the city's future urban development plans. As identified in the 2050 Kigali Master Plan, it serves as a critical commercial and transportation hub, with significant implications for the city's expansion. The development of an efficient transport infrastructure in Nyabugogo will support the growing population of Kigali, currently estimated at 1.7 million people, and provide a foundational centre for the city's future transit operations. This hub is envisioned as a multi-modal terminal, providing access to various forms of transportation, and is expected to become a key enabler of public transportation development, including BEBs.

In 2015, a study commissioned by the European Union, worked on an urban road plan for the Nyabugogo Transportation Hub.⁶⁶ This was one of the first studies carried out to assess the reconfiguration of the five intersections, taking into account hydraulic and environmental aspects, as shown in Figure 58.

FIGURE 58. Nyabugogo Transit Hub diagram



Source: Mic-Hub

Subsequent studies, particularly the 2021 World Bank/IFC study titled “Electric Bus Concept Validation in Kigali”, identified Nyabugogo as a potential EV charging hub for future BEB corridors. This presented a significant opportunity to explore and implement BEB infrastructure and further solidified the terminal’s role in Kigali’s sustainable mobility plans. In 2024, the Nyabugogo Multi-Modal Transit Hub Feasibility Study, aimed to assess the needs of passengers, operators, and commercial occupants while ensuring alignment with modern public transport requirements. This study provides valuable insight into how the terminal can be redeveloped to support the city’s growing transport network, especially in terms of integrating sustainable technologies like charging stations for BEBs and other EVs.

Further information about the planned configuration of the terminal and location options for charging within the terminal are included in Annex A6 – which has been largely taken from the Egis/WB report Task 10 preliminary design.

⁶⁶ Nyabugogo Transportation Hub. Mic-Hub.

4.2.1 Power system infrastructure assessment

The Nyabugogo bus terminal is expected to support opportunity charging of electric buses from 2027 onwards. The following analyses the network connection requirements, the potential of rooftop PV, the benefits from stationary battery systems and backup power needs.

4.2.1.1 Network connection

Power requirements

The Feasibility Study of Nyabugogo Multi-modal Transit Hub – Task 10 has developed two opportunity charging scenarios, with 12 or 18 chargers at 120 kW rated power. The analysis presented hereinafter will determine the “worst-case”⁶⁷ power requirements using the recommended option of 18 chargers. This equates to a peak power demand of 2160 kW. Large charging stations typically operate with a power factor of 1 at rated capacity, resulting in a 2160 kVA peak.

As recommended by the Feasibility Study, this report also suggests installing two transformers of 1250 kVA each. Two transformers of equal size provide redundancy in case of errors and the option to divide the installation process into two phases of nine chargers each. Moreover, the recommended total headroom of 340 kVA is essential to power other energy demands of the bus station, such as lighting, and to extend the lifespan of the transformer.

The current design plan of the Nybugogo bus terminal considers two transformers of 2000 kVA each, significantly surpassing the previous recommendation. Therefore, the “worse-case” option is evaluated in the following.

It is essential to understand the temporal consumption pattern to assess the network impact of the charging stations. The bus terminal will operate for 19 hours per day, from 5:00 am to 12:00 am. However, recharging will not be possible during three high-commute periods to prioritise bus movement and passenger service.

1. **Morning Peak (7:00 AM - 9:00 AM):** High demand for bus services as commuters travel to work.
2. **Afternoon Peak (12:00 PM - 2:00 PM):** Lunchtime rush for workers and shoppers.
3. **Evening Peak (5:00 PM - 7:00 PM):** End-of-day commuter traffic.

In 2023, the peak load in Kigali occurred at approximately 8:00 pm. Therefore, the charging closure times will not reduce the network connection requirements. Consequently, the network will need to supply up to 2500 kVA during peak network loading.

Initial connection

The Nyabugogo bus terminal is located very close to a 15 kV overhead powerline, as illustrated in Figure 59. The ideal solution would be to connect the bus station directly to the power line, with minimal modifications required.

⁶⁷ ie in terms of requiring more power

FIGURE 59. Location of the Nyabugogo Bus terminal in relation to the MV network.



The renovated / re-vamped bus terminal is scheduled to commence operations in 2027. Under consideration of the newly constructed parallel line connecting the NZOVE transformer to the Abbatoir cabin and an estimated 10 percent annual general load growth, the network is not expected to get overloaded before 2040. Corresponding PowerFactory calculations have confirmed that direct connection of the Nyabugogo Bus terminal to the closest MV line is possible.

Staging of installation

From a power system perspective, it is not necessary to stage the installation of the charging stations, since sufficient network capacity is available even in 2040.

Nevertheless, it is probable that not all planned routes will be electrified when the Nyabugogo charging hub goes into operation in 2027. Therefore, it is unlikely that all 18 chargers will be required from the beginning. The installation of nine chargers and one of the two transformers could offer monetary advantages through deferral of investment.

Potential disadvantages of staging the installation are:

- unavailability of funding for the second expansion stage, eg due to political changes
- too late completion of expansion, resulting in operational issues
- additional construction work

It is essential that all factors are considered by decision-makers. If funding, equipment, and workforce can already be secured for the second expansion, it is possible to stage the installation. In this instance, the site should already be prepared for the installation of the additional equipment that may be required, for example through the provision of adequate spacing and cabling. Since the network capacity is already available today it is not recommended to stage the installation of the chargers if direct construction is possible.

Load management system

Load management of electric bus charging has become a standard practice for bus depots to limit peak demand charges. In the event of overnight charging, there is sufficient flexibility to move the charging process to a later time. The objective of a simple system is to limit the

power consumption of a hub to a given value. Vehicles are charged in accordance with the first-in, first-charged principle. More sophisticated systems take into account the bus operation schedule and the battery state of charge.

At the Nyabugogo hub, opportunity charging with limited flexibility is used. It may still be beneficial to implement a load management system. It is recommended that vehicles with the lowest state of charge be charged first. Implementation is done by the charging infrastructure operator (eg bus terminal) to minimise the charging cost, based on price signals provided by the network operator. It is advisable to reduce the charging power during the high peak demand charge window, from 6:00 pm to 11:00 pm set by the utility, in order to generate monetary savings. Specific application depends on future bus schedules and possible changes in the utility price structure. Most load management systems available on the market today are suitable for this purpose.

4.2.1.2 Rooftop photovoltaic

One way to reduce electricity bill is to use self-generated rooftop PV to charge electric buses. This approach also offers the additional benefit of reduced CO₂ emissions. The following will investigate the technical and economic potential of self-generated PV.

The evaluation is done under the following restrictions and assumptions:

- Rooftop potential: 826 kW⁶⁸
- Installation cost: 880 US\$/kW⁶⁹
- Lifetime: 25 years⁷⁰
- Electricity price: 94 RWF/kWh (approximately US \$0.069 per kWh)⁷¹ Note that this is the subsidised industrial tariff which is applicable for charging stations.
- Energy is not allowed to be fed into the grid⁷²
- Bus operation: see chapter 4.2.1.1

The installation of PV does not impact the network connection introduced in the previous section. In situations with little or no sunshine, the network will have to serve the charging process on its own. It is not possible to downsize the network connection. Furthermore, the PV rooftop potential is well below the peak charging demand, so there is no need for increased transformer capacity, especially since feeding energy back into the grid is not allowed.

Figure 60 illustrates the projected profits of the PV plant over a 25-year lifetime after subtracting the initial investment cost. The profit (savings from using less electricity provided by the utility) is approximately US \$150,000 after subtracting the installation cost (over the entire lifetime of the PV plant). While the use of self-generated PV energy results in savings, the annual return is only 0.8 percent.

If financing is required to undertake the project given the industrial tariff, the interest rate will make the financial feasibility questionable. Most investment opportunities offer a higher annual return, particularly when considering the long lifetime of the project, with 20 years until

68 Based on the Feasibility Study of the Nyabugogo Multi-Modal Transit Hub

69 Based on international standard prices / Consultant experience

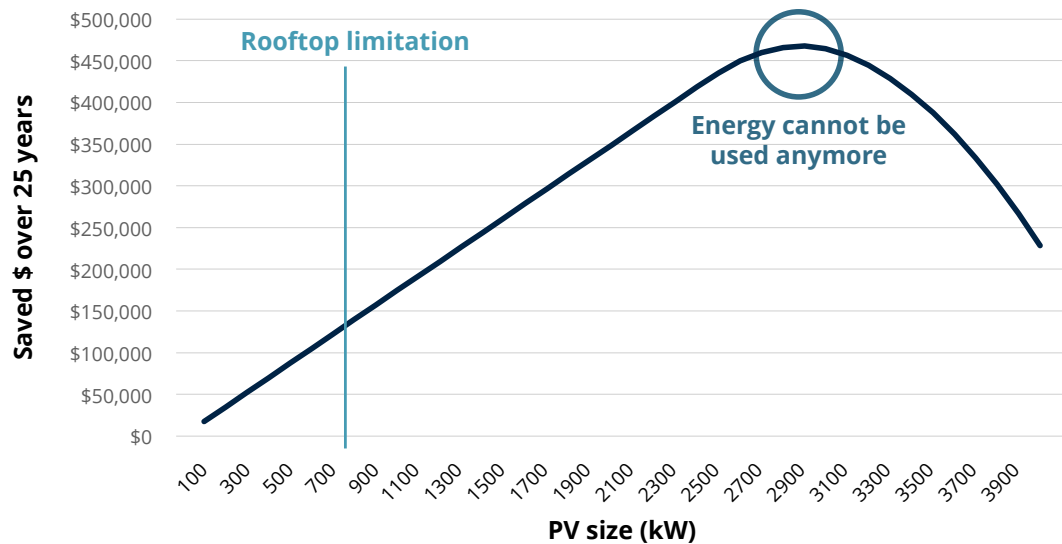
70 <https://solar.huawei.com/en/blog/en/2024/lifespan-of-solar-panels>

71 This is the current industrial tariff within Rwanda which is applied to EV charging stations

72 This is based on discussions with Rwandan experts

amortisation. In the event of a technical error, natural disaster, or similar event during this period, the project will result in a financial loss.

FIGURE 60. PV profit (electricity cost savings) over 25 years, based on self-developed calculation model



Source: Consultant calculations using Python programming and likely PV production / consumption patterns

The project can still be a viable proposition under certain conditions. For instance, the improved public relations image could offset financial considerations – by providing emission-free transportation. If the PV system was owned by REG/EUCL, then the relevant price for power would be higher (approximately 3x higher) – representing the actual costs of production. In this case, the return on investment would be significantly higher as power produced by the PV system would be power that would not need to be produced and distributed by REG/EUCL by some other means.

Furthermore, if it was possible to feed in PV power into the network, or if electricity prices increase the financial viability would be improved significantly. Furthermore, if reduced greenhouse gas emissions are included in the economic assessment (or somehow could be monetised), then this would also improve the economic / financial performance.

4.2.1.3 Stationary battery

The integration of a stationary battery can improve the financial viability of a PV system by leveraging the otherwise underutilised PV energy generated outside the charging windows and using excess energy. Furthermore, the battery can reduce the peak demand charge.

The evaluation is done under the following conservative restrictions and assumptions:

- Investment cost: 550 US\$/kWh⁷³
- Lifetime: 10 years⁷⁴

⁷³ Based on international standard prices / Consultant experience

⁷⁴ <https://www.7x24exchange.org/7x24-news/life-expectancy-for-a-lithium-ion-battery-in-a-stationary-application/>

- Cycle efficiency: 80 percent⁷⁵
- Max: 25 percent charge per hour to improve lifetime
- Peak demand charge: 7184 RfW/kW (6-11 pm)⁷⁶

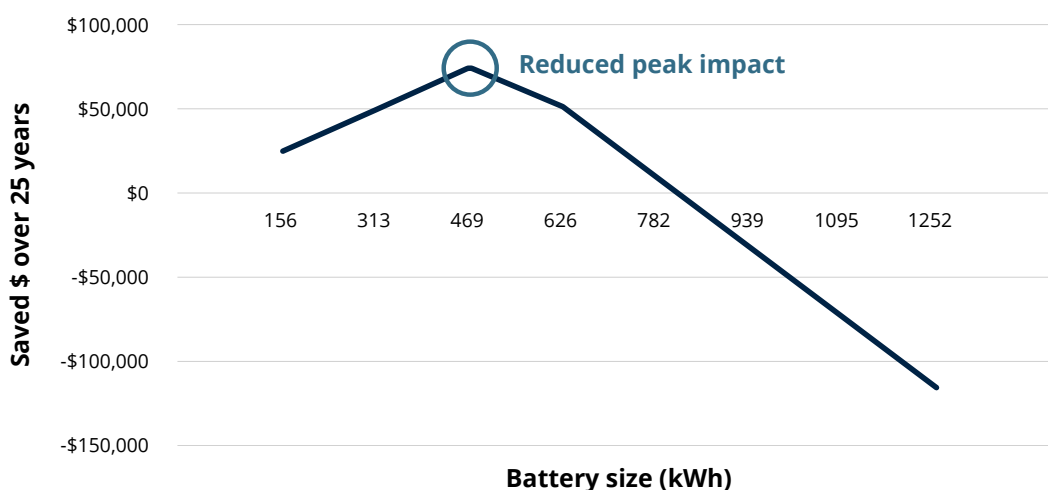
Figure 61 illustrates the profits of installing an additional battery after subtracting the initial investment cost. Profits are greatest if the system is approximately 470 kWh.

An increase in battery capacity will impact savings, as more energy is required to reduce the peak load and the load profile becomes flatter. For a 470 kWh battery, the annual return is just 0.5 percent.

The same note for the PV system alone (without a battery) applies for the system with a battery. If the system was owned by REG/EUCL, then the relevant price for power would be higher (approximately 3x higher) – representing the actual costs of production. In this case, the return on investment would be significantly higher as power produced by the PV + battery system would be power that would not need to be produced and distributed by REG/EUCL by some other means.

In the event that funds need to be borrowed or an irreparable defect occurs during the nine-year amortisation period, the project will no longer be financially viable. The financial viability of the additional battery improves with rising energy prices but will worsen in the event that PV energy can feed into the grid in the future, as is the case in most industrialised countries.

FIGURE 61. Additional battery (electricity cost savings) over 25 years, based on self-developed calculation model



Source: Consultant calculations using Python programming and likely PV production / consumption patterns

Given the risk that PV energy may in the future be allowed to feed in to the network in combination with falling battery prices and relatively simple retroactive installation, it is not recommended to install a stationary battery at the initial stage.

⁷⁵ <https://www.sciencedirect.com/science/article/pii/S2666955224000157>

⁷⁶ Current industrial tariff within Rwanda

Once bus batteries are no longer suitable for transportation, they can still be used in stationary storage applications. These batteries could then be installed at the Nyabugogo bus terminal after 5-10 years of transport operation.

A new financial analysis would be required at this stage, but stationary operation of old bus batteries seems promising.

4.2.1.4 Backup power and redundancy

Backup power can ensure continuous operation of the charging stations in case of electricity outages. In the event that the total power consumption of the charging stations is limited to 75 percent, 1.5 MW of backup power would be required, resulting in significant cost. Given the relatively low frequency of grid outages of about 4 hours per year, it is not advisable to install local backup generation power.

If the decision is made to initially connect the charging stations to the existing MV line and subsequently expand the connection through the construction of an additional direct line to the HV network, this presents a cost-effective opportunity for a redundant network connection, which should be pursued.

Conversely, if the Nyabugogo bus terminal is to receive an independent connection to the HV network from the start, the additional connection should be omitted to reduce costs.

4.2.1.5 Power system recommendations

Network connection of the Nyabugogo charging hub requires consideration of multiple factors described above. The following table summarises the main recommendations.

TABLE 37. Recommendations related to various aspects of the potential Nyabugogo charging hub

Aspect of the system	Recommendation
Network connection	Direct connection to closest MV line in 2027. Additional direct connection to 15KV NZOVE BB, with extension to Abattoir cabin, latest in 2032
Staging	In case second stage can be guaranteed, split installation capacity in half (2027&2032).
Load management	Use state of charge-based load management system to reduce monthly peak demand charge.
Rooftop PV	Install as much PV as possible to generate CO2 savings under the consideration of external factors, such as monetary availability.
Stationary Battery	Not recommended right now. In the case PV network infeed continuous continues to be not allowed, use old bus batteries as stationary storage.
System redundancy	No additional action recommended.

4.2.2 Financial implications of the power system

The following table summarises the financial implications of including EVCI and renewable energy / batteries in the Nyabugogo multi-modal transit hub. The total investment is dominated by the investment in the PV system. This investment is not highly profitable (has a rate of return of lower than 1 percent) which is mostly driven by the low electricity prices in Rwanda. If the electricity prices are adjusted to the levels of cost recovery, then the financial investment in PV (and / or batteries) will likely be more profitable (see Box 6). Conversely, though, if the price of electricity increases, then the relative benefit of electric buses instead of diesel buses is decreased. It is also noteworthy that if prices increase (due to inflation) then the investments will also increase.

TABLE 38. Financial implications of the upgrade of the Nyabugogo multi-modal transit hub to include charging stations

Investment description	Investment size (US\$)	Notes
Phase 1: 2027, 9 fast (eg 120 kW) chargers, 1 transformer (1250 kVA), direct connection	US \$229,000	Ensure that transformers are appropriately placed (eg avoiding flooding). Approximately US \$25,500 per charger (including transformer)
800 kW PV installation	US \$7,000,000	Low return on investment unless allowed to sell to the grid (in which case batteries aren't needed)
BESS installation (470 kWh)	US \$250,000	Low annual return on investment
Phase 2: 2032, 18 chargers (9 additional to Phase 1), 2 transformers (1 additional to Phase 1)	US \$229,000 for chargers	
Total	US \$7,708,000	



BOX 6. IMPLICATIONS OF USING THE NON-RESIDENTIAL TARIFF IN CALCULATING THE FINANCIAL ASPECTS OF PV PLUS BATTERY ELECTRIC STORAGE SYSTEMS (BESS) AT NYABUGOGO

The profitability of locally generated PV and BESS is highly dependent on the electricity tariff. If the tariff used in the calculation is the non-residential tariff of 255 RwF/kWh (approx. US \$0.184 per kWh) without peak demand charge instead of the industrial tariff of 94 RwF/kWh (approx. US \$0.069 per kWh, with monthly peak demand charges up to 7184 RwF/ kW US \$5.2 per kW used in the previous calculation.

Almost tripling the electricity price significantly improves the financial performance of the PV and BESS investments. In this case, the simple payback period of the PV installation alone is 8 years (versus a typical lifespan of 20-25 years).

Additional BESS would need to be sized correlated with the PV system size to make best use of excess PV energy. For the given location and bus recharging schedule, the battery capacity (kWh) is estimated to be about 1.5 times larger than the PV peak capacity (kW). In this the simple payback period for battery system would be approximately 7 years versus a conservative lifespan of 10 years.

Up to 3.5 MW PV peak generation capacity could be optimally added to the system. Above this limit, the generated energy cannot be used anymore, thus reducing savings. If the tariff used is based on the non-residential tariff, then the recommendation would be to use the complete potential, since the PV potential based on the roof space of the bus terminal (ca. 800 kW peak) is well below this limit.

Utilisation of the rooftop potential would not impact the network connection size and connected transformers. It should be noted that even though the operation cost under the non-residential tariff can be significantly reduced through use of local PV and BESS the overall operation cost compared to the industrial tariff previously evaluated is still higher.



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5

SUMMARY OF KEY CHALLENGES AND RECOMMENDATIONS



The key challenges discussed in the previous sections are summarized below.

1. **Disparate policies and plans:** Rwanda's transportation policy is not fully integrated with urban development trends, settlement patterns, or housing development. Transportation demand is influenced by the distribution of people, jobs, and services, but current planning does not align future transport corridors and infrastructure with these factors. Additionally, multiple government agencies—including MININFRA, RURA, REG, and REMA—are involved in the EV transition, but coordination among them is limited. The absence of a dedicated central body overseeing the process leads to fragmented policies, overlapping responsibilities, and slow implementation.
2. **Increasing electricity demand and load growth:** The annual growth in Rwanda's electricity demand is driven by economic development and urbanization. The additional demand from EV adoption further exacerbates this challenge, placing strain on the electricity network. Without adequate capacity expansion, rising electricity consumption could lead to supply shortages, grid congestion, and reliability concerns.
3. **Inadequate electricity pricing for EV demand side management:** The current electricity pricing structure does not fully accommodate the unique demands of EV charging and limits the potential of demand-side management. Without appropriate pricing mechanisms, EV charging demand can become misaligned with electricity supply, leading to grid congestion, higher operational costs for users, and increased pressure on transmission and distribution systems, especially during peak hours.
4. **Lack of clear technical regulations and standards:** Rwanda currently lacks a comprehensive regulatory framework for EV charging infrastructure, including clear guidelines on siting, ownership, and operation of charging stations. The lack of regulations on zoning, safety standards, grid connection procedures, and consumer protection creates some uncertainty. Additionally, there are no detailed standards for key EV components such as batteries, charging equipment, and vehicle safety, and the absence of certification processes for imported EVs and related technologies makes it more difficult to ensure consistent quality and safety.
5. **Lack of a comprehensive data-driven strategy for managing EV grid integration:** Rwanda currently does not have a centralized system to collect and analyse data on EV adoption, charging patterns, and their impact on the power grid. Without real-time and historical data tracking, it is difficult to anticipate charging demand, optimize infrastructure deployment, and ensure efficient grid management. This gap in data-driven planning increases the risk of network constraints and inefficient resource allocation.
6. **Insufficient charging infrastructure:** As EV adoption grows, the availability of charging stations must keep up with the increasing demand. The lack of charging infrastructure in key transport corridors further limits the potential for expanding EV adoption and poses challenges for long-distance travel and widespread use.
7. **Potential grid strain from bus charging:** The electrification of public transport, particularly buses, requires high-capacity charging stations, which could lead to significant load peaks. While there are no immediate concerns, as the fleet of battery electric buses grows, it will be important to monitor and manage charging demand. Without effective load management and scheduling, widespread bus charging could put pressure on the grid, leading to instability, voltage fluctuations, and potential power outages, particularly in areas with high charging demand.
8. **Nyabugogo network design:** Nyabugogo is a key hub for both national and city-wide bus infrastructure, making it a critical location for EV charging. However, without proper load management and necessary upgrades to the local grid, increased charging activity could lead to power disruptions and potentially impact surrounding infrastructure.

9. **Battery and E-Mobility waste management:** Rwanda currently does not have a comprehensive regulatory framework for managing the end-of-life of EV batteries and other E-Mobility components. The lack of clear processes for disposal, recycling, and repurposing could pose environmental and safety concerns over time. As EV adoption grows, addressing battery waste management will become an increasingly important consideration.
10. **Limited private sector involvement in charging investments:** Government resources alone may not be sufficient to fund the necessary investments in charging infrastructure. To encourage private sector participation, incentives and structured investment frameworks are essential for supporting the development of charging networks.
11. **Lack of financing for E-Mobility transition:** The transition to E-Mobility requires significant investment in vehicles, charging infrastructure, and grid upgrades. However, access to financing remains a major barrier, particularly for transport operators and private individuals.

Additionally, while not directly related to this study, it is important to note the existing traffic congestion issues in Rwanda, particularly in Kigali. These issues will not be resolved through increased E-Mobility alone but will require improved urban planning and the promotion of non-motorized transport, such as walking and cycling. While these aspects fall outside the scope of the study, they are worth mentioning.

The recommendations presented to address the key challenges are outlined in the table below and visually depicted in the figure. Some of these recommendations are anticipated to be integrated into the World Bank-funded Rwanda Urban Mobility Improvement Project (RUMI).

FIGURE 62. Overview of key recommendations

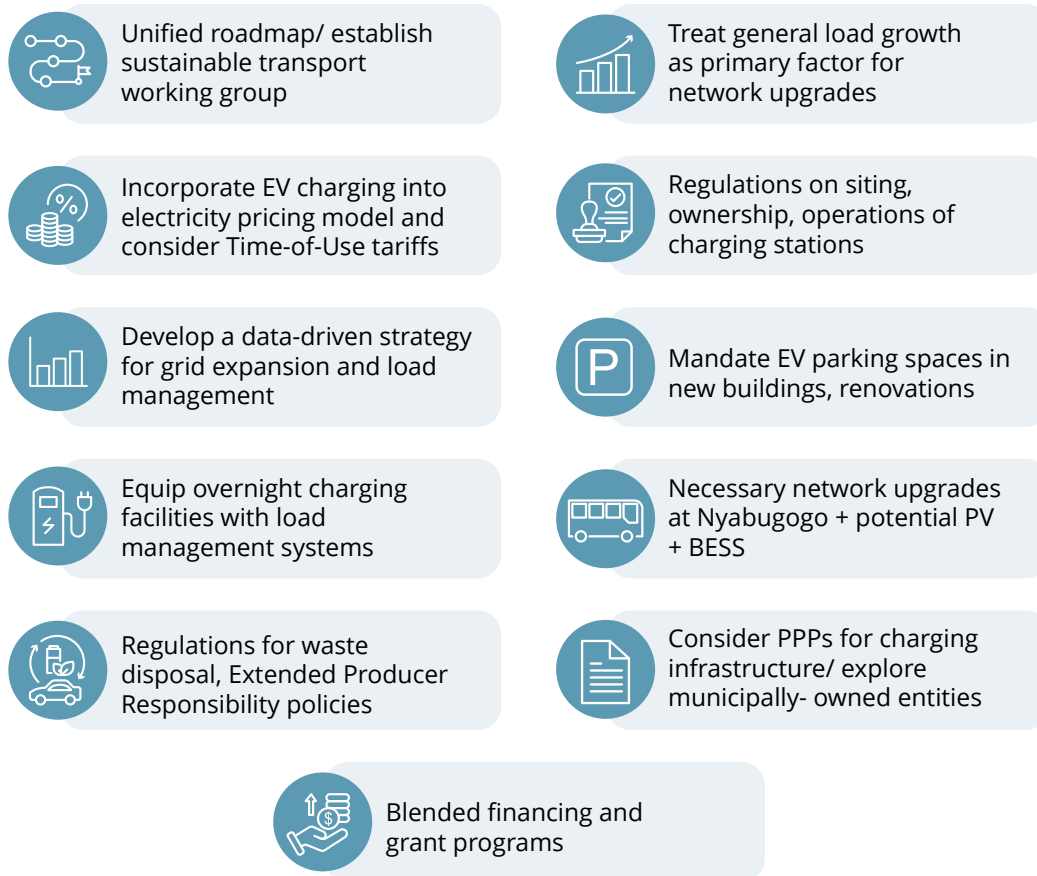


TABLE 39. Key recommendations

Challenge	Recommendation (Stakeholders; Timeline)
Disparate policies and plans	Develop a unified roadmap outlining specific transport electrification projects and policies. Establish a sustainable transport working group, including electrification. (MININFRA, REG, RURA; Short-term)
Increasing electricity demand	Treat general load growth as the primary factor driving network upgrades, with an additional 10 percent headroom for EV charging. (REG/EUCL, RURA; Short-term)
Inadequate electricity pricing for EV demand side management	Incorporate EV charging into the broader electricity pricing model and consider time-of-use tariffs. Regularly review pricing structures. (MININFRA, REG/EUCL, RURA; Short-term)
Lack of clear technical regulations and standards	Establish clear regulations for the planning, siting, ownership, and operation of charging stations. Develop technical guidelines for EV Charging Infrastructure. Consider adopting both European CCS2 and Chinese GB/T standards to ensure flexibility. Explore aligning national technical standards with international best practices, including ISO/IEC and GB/T standards. (MININFRA, Rwanda Standards Board (RSB), RURA, REG/EUCL, Cities; Short-term)
Lack of comprehensive data-driven strategy for managing EV grid integration	Develop a data-driven strategy for grid expansion and load management, including continuous monitoring of EV adoption, refining demand forecasts, and establishing a centralised system for both historical and real-time charging data. (MININFRA, Ministry of Information and Communication Technology and Innovation, REG/EUCL, RURA; Medium-term)
Insufficient charging infrastructure	Mandate EV parking space allocation in new buildings, major renovations, and commercial centres based on parking capacity and renovation scale. (MININFRA, Cities; Medium-term)
Potential grid strain from bus charging	Equip overnight charging facilities with load management systems to reduce peak load and monitor network constraints. (Bus operators, REG/EUCL; Medium-term)
Nyabugogo network design	Plan for necessary network upgrades, including a direct connection to closest MV line in 2027. Additional direct connection to 15KV NZOVE BB, with extension to Abattoir cabin, latest in 2032. Implement a load management system based on state of charge. Explore the installation of rooftop PV and the reuse of bus batteries as stationary storage. (City of Kigali; Medium-term)

Challenge	Recommendation (Stakeholders; Timeline)
Battery and E-Mobility waste management	Establish specific regulations for waste disposal. Enforce Extended Producer Responsibility policies. Invest in recycling infrastructure. (Ministry of Environment, RURA; Medium-term)
Limited private sector involvement in charging investments	Consider PPPs in the development and operation of charging infrastructure, ensuring a balanced market environment and fair competition. Explore the potential for municipalities to set up publicly-owned entities for specific projects, while maintaining a competitive market. (MININFRA, REG/EUCL; Long-term)
Lack of financing	Explore blended financing options, grant programs, guarantee mechanisms, and green bonds to support scaling up of investments. (FONERWA; Long-term)





Annexes

A.1 Bus operator questionnaires

Rationale

To understand the current state of public transportation, particularly regarding electrification, an electronic questionnaire was developed and distributed to public transport operators including electric bus operators. Operators provided feedback either by directly replying to the questionnaire or participating in interviews.

The questionnaire delved into several key areas: vehicle ownership (including number and types), charging station infrastructure (both current and planned), and the challenges faced. Additionally, it explored future expansion plans for both fleets and charging stations.

On the topic of energy and regulations, the questionnaire sought to understand the selection criteria for depot and charging station locations, as well as any challenges encountered in these areas. Finally, it focused on the specific challenges associated with electric vehicle charging infrastructure, including capacity, charging duration, and power supply limitations. Key vehicle parameters such as average daily distance travelled, fuel efficiency (converted to energy efficiency for EVs), and carrying capacity were also requested.

Inputs from bus operators

Ten bus operators participated in the survey, including Ruhire Express Ltd, Stella Express Ltd, Different Express Ltd, Kigali Bus Service Ltd, Nile Safaris Express Ltd, Excel Travel and Tours Agency Ltd, City Express Ltd, Kigali Coach Tours and Travel, IZI Electric Ltd, and BasiGo

Out of the ten participating bus operators, only IZI Electric Ltd and BasiGo currently operate electric buses. This represents just 20 percent of the surveyed companies.

The study prioritised understanding the experiences of existing electric bus operators. However, gathering insights into how traditional (ICE) bus operators plan to transition to electric buses was equally important. However, these ICE operators plan to lease e-buses, as this model is currently utilised by the two e-bus operators.

BasiGo is currently operating two 160 kW chargers at Rwandex. They have ambitious expansion plans, aiming to install a total of 27 chargers within the next two years. In line with this infrastructure development, BasiGo's electric bus fleet is also growing rapidly. They currently have 4 e-buses of 70 passengers carrying capacity in operation, with plans to expand to 85 buses over the next two years.

IZI Electric currently operates a charging station in Nyarutarama, Kigali, equipped with two powerful 120 kW chargers. These chargers can fully charge up to five e-buses of 70 passenger carrying capacity. With ambitious expansion plans, IZI Electric aims to install a total of 42 chargers within the next five years. Their electric bus fleet is also undergoing significant growth, with 5 currently operational and plans to reach 245 e-buses over the next five years.

To ensure their e-buses are fully prepared for daily operations, IZI Electric utilises an overnight charging strategy.

In terms of vehicle performance, the survey revealed an average daily travel distance of 183 kilometres (VTK). Fuel efficiency also differed between bus types: ICE buses averaged 42 litres per 100 kilometres, while electric buses consumed an average of 2.21 kilowatt-hours per kilometre (kWh/km).

According to both electric bus operators, key criteria for selecting depot or charging station sites include: availability of electricity, proximity to operational bus zones, and sufficient space.

Several challenges were highlighted, including the high up-front costs associated with electric buses and charging stations. Additionally, a lack of suitable space near operational zones creates issues with long distances between charging stations and bus routes.

Rwanda transportation survey form as distributed to bus operators

The Rwandan Ministry of Infrastructure (MININFRA) is working with the World Bank to develop the Rwanda Urban Mobility Improvement Project (RUMI) which aims to involve – amongst other things – electrification of the bus fleet. As part of the development of this project, the World Bank has engaged consultants to carry out a study “Exploring Enabling Energy Frameworks for Battery Electric Buses in Rwanda”. The study will:

- Provide inputs to the Government of Rwanda (GoR) in developing enabling energy policies that facilitate the sustainable electrification of buses in the country
- Assess the readiness of the energy sector for all types of electric vehicles and derive recommended options specific to battery electric buses.

This form aims to gather information on business operators engaged in transportation sector. Depending on how easily you have information available, it should take between 15 and 30 minutes to complete.

Contents of the questionnaire

Section 1: Company information

Company name:

Company email:

Company phone number:

Email address of the key person:

Phone number of the key person:

Section 2: Vehicle information

1. Vehicles owned: ICE vehicles (fully using diesel)

- Number of vehicles
- Number of these in operation
- Number of these in reserve

- Carrying capacity (number of seats)
- Fuel type
- Fuel efficiency (litres / 100 km)
- Average daily distance travelled (km)

2. Vehicles owned: ICE vehicles (fully using petrol)

- Number of vehicles
- Number of these in operation
- Number of these in reserve
- Carrying capacity (number of seats)
- Fuel type
- Fuel efficiency (litres / 100 km)
- Average daily distance travelled (km)

3. Vehicles owned: Electric hybrid vehicles (using both electricity and fuel)

- Number of vehicles
- Number of these in operation
- Number of these in reserve
- Carrying capacity (number of seats)
- Fuel type
- Fuel efficiency (litres / 100 km)
- Average daily distance travelled (km)

4. Vehicles owned: Electric vehicles (using only electricity)

- Number of vehicles
- Number of these in operation
- Number of these in reserve
- Carrying capacity (number of seats)
- Fuel type
- Fuel efficiency (kWh / 100 km)
- Average daily distance travelled (km)

5. Vehicles owned: Motor bikes (specify the type of fuel used)

- Number of vehicles
- Number of these in operation
- Number of these in reserve
- Fuel type
- Fuel efficiency (litres / 100 km)
- Average daily distance travelled (km)

6. Vehicles owned: other vehicles (specify the type of fuel used)

- Number and type of vehicles
- Number of these in operation
- Number of these in reserve
- Carrying capacity (number of seats)

- Fuel type
- Fuel efficiency (litres / 100 km)
- Average daily distance travelled (km)

Section 3: EV charging information

7. **Charging:**

- Number of charging stations:
- a. Name of station 1 / estimated capacity in kW or KVA / charging time of 1 EV or battery/rated charging capacity of 1 EV or battery: / / /

Repeat if more than 1 charging station

Section 4: Depots information

8. **Depots:**

- Depot name/depot capacity (no of vehicles /no of charging stations:.... / /

Repeat as needed

9. **Discussion:**

In bullet point discuss criteria you follow when selecting depots or charging stations sites

Section 5: Forecasting / Understanding company growth

10. **Future Plans (consider your planning horizon):**

- a. How do you plan to expand your fleet. Concise description is preferred
- b. How do your plan to increase EVs
- c. How do you plan to expand your business throughout the country

11. **Plan for charging stations:**

Discuss your master plan of charging system if any (location, number, power consumption), be as precise as possible

Section 6: Challenges and business model

12. **Discuss any challenges you are experiencing; focus on energy, regulations, etc.**

13. **How do you plan to procure / operate vehicles? (e.g. purchase + operations, leasing with maintenance included + operations, other?**

A.2 Broader information on climate finance

Climate finance

Climate finance promotes the uptake of EVs globally by helping overcome the financing requirements associated with EVs, such as high up-front costs, through a range of financial instruments. Key players in climate financing such as Green Climate Fund (GCF), Global Environment Facility (GEF), the World Bank Group and others, are providing funding for various activities related to E-Mobility, such as the deployment of EVCI, purchase of EVs, establishment of EV supply chains, and capacity building and training programmes for stakeholders.

From international experience, climate finance can:

- **Mobilise capital for sustainable transportation projects** – governments face several financial barriers when investing in sustainable transportation projects, such as limited access to capital markets and high levels of debt. Climate financing agents provide grants, concessional loans, guarantees and other innovative financing mechanisms to help countries access the capital needed, with the co-benefit of stimulating private sector investment (see the example below).

BOX 7. THE GREEN CLIMATE FUND IN LATIN AMERICA

Between 2023 and 2029, the GCF is funding US \$200 million worth of E-Mobility projects across nine Latin American Countries, mainly through two instruments:

- **Senior Loans** - The Programme links E-Mobility with sustainable urban transport system development and climate resilience in nine countries. It finances electric buses and electric vehicle fleets, electric boats and vessels, and supports hydrogen projects and vehicle-to-grid projects for urban mobility.
- **Grants** - The Programme works to establish E-Mobility frameworks, including gender actions plans, to promote transformative urban mobility that is resilient to climate change

The total project funding need is US \$450 million, 55.5 percent of which is provided by co-financing (such as loan, Inter-American Development Bank grants and government funding) and 44.4 percent by the GCF.

Source: GCF. 2023. Accelerating innovation and investments in Low-Emission Transport

- **Provide financing with concessional rates and extended repayment periods** – while sustainable transportation technologies require high up-front capital costs and operational risks, and commercial loans usually have very high interest rates, climate financing that provides financing at concessional rates can make the projects financially feasible and attractive (see the example below).

BOX 8. CLIMATE INVESTMENT FUNDS PROVIDE CONCESSIONAL FINANCE FOR E-MOBILITY PROJECTS

The Climate Investment Funds is a multilateral climate fund that delivers transformative investment programmes through predictable, at scale, flexible and highly concessional climate finance for investment in key sectors including energy and transport.

To date, CIF has supported over \$350 million in climate-smart transport projects, including

- Innovative hybrid bus investments in Colombia
- Climate resilience road standards and investments in Mozambique

The CIF is planning to finance the transport transition agenda including through innovative financing structures, such as 'pay-as-you-save' models to finance battery and charging stations, to drive low-carbon mobility in fast-growing cities.

Source: World Bank. 2021. Transition towards sustainable mobility – where is the financing?

- **Support EV pilots to scale up the sustainable transportation market** – pilot projects are key for the scale-up of EV technologies and for the development of insights and learnings on the technological, economic and operational aspects of sustainable transportation solutions that can be applied in large-scale programmes.
- **Enhance capacity building and training for stakeholders** – climate financing programmes can help bridge information gaps between stakeholders and ensure informed decision-making by providing resources for capacity building and technical assistance to investors, project developers and policymakers.

BOX 9. THE GEF FUNDS E-MOBILITY PILOTS AND ENABLES KNOWLEDGE SHARING

In 2019 the GEF launched the Global E-Mobility Programme, worth \$33 million, in order to help 17 developing countries pilot and deploy EVs at scale. The initiative is now expanding in size and scope to support an additional 10 low- and middle-income countries as they develop national E-Mobility roadmaps, policy frameworks, business models, and financing schemes to transition their transportation sectors to EVs.

- In 2023 the GEF has approved a \$2 million pilot in the Solomon Islands for electric buses in the capital city Honiara, with the aim of increasing the fleet over the next five years. The pilot will help assess the applicability and scalability nationwide, as well as the potential to support other e-vehicles. In addition to electric bus feasibility, the project also developed a National Electric Mobility Policy and Market Readiness Framework for the Solomon Islands and a roadmap for E-Mobility implementation.

The Programme also envisions that projects are equipped with tools and methods for capacity building, and enable knowledge exchange across countries. For instance, Regional Support and Investment Platforms have been designed to exchange knowledge and provide training, including on an E-Mobility online toolbox which acts as repository of knowledge to be shared across project countries.

Sources: GEF. 2019. GEF Global E-Mobility Programme to help developing countries go electric; UNEP. 2023. Solomon Islands gears up for electric buses.

While climate financing is already being directed towards the transport sector, the current levels of investment fall short of the estimated annual needs. The estimated cost for investment in sustainable transportation technologies, including EVs, is between \$2-2.8 trillion by 2030.⁷⁷

In particular, in 2022 the Climate Policy Initiative⁷⁸ has reviewed the landscape of climate finance in Africa and has gathered the following conclusions for the sustainable transport sector:

- While rising urbanisation and growing infrastructure are putting pressure on cities and their transport networks, transport sector investments comprise only 9 percent (US \$2.6 billion) of total finance, and only 30 percent of national climate change action plans include reference to public transport measures.
- Five countries received 74 percent of all transport finance – Egypt (36 percent), Kenya (22 percent), Morocco (6 percent), Nigeria (5 percent), and Ethiopia (4 percent). Multilateral DFIs (46 percent), bilateral DFIs (33 percent) and donor governments (15 percent) were the key providers of this finance. These projects were funded mainly through concessional loans (47 percent) and non-concessional loans (35 percent), followed by grants (11 percent).
- Low-carbon transport infrastructure investments face governance barriers since they depend on long-term public and urban planning, as well as political support.
- Additional challenges for investors are:
 - **Risks in early-stage investment** due to high up-front costs and lengthy preparation and construction processes
 - **Currency risks** due to the long-term nature of transport infrastructure investments
 - **Regulatory risks** due to low and uncertain development of standards and incentives
 - **Uncertain reliability** of electricity supply
 - **Underdevelopment** of charging infrastructure

⁷⁷ Climate Policy Initiative. 2022. *Global Landscape of Climate Finance*.

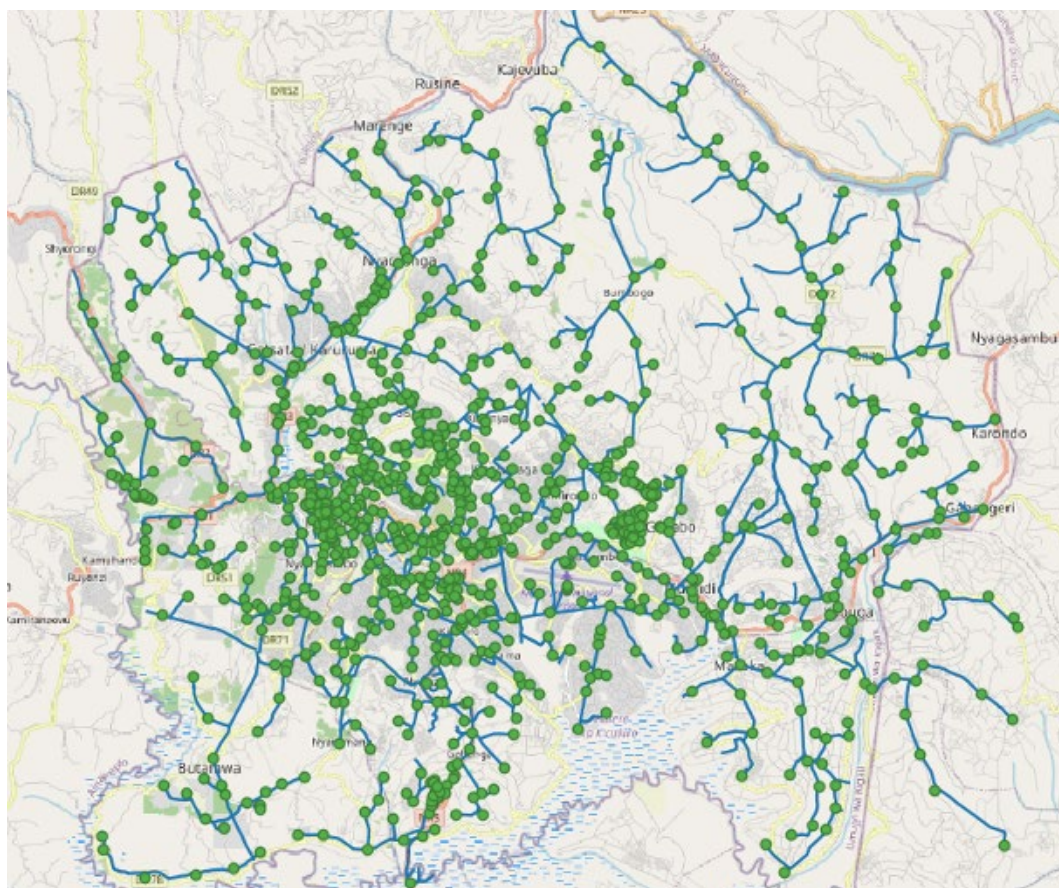
⁷⁸ Climate Policy Initiative. 2022. *Landscape of Climate Finance in Africa*.

A.3 GIS to PowerFactory matching

The EUCL of Rwanda has provided their current distribution network model in PowerFactory format, covering the entire country at the 15 and 30 kV voltage levels. In this model, the transmission system is represented as external grids, and the transformers connected to the low voltage level are included as loads, specified by name and maximum capacity. In the network analysis, the system load is downscaled to the current applicable load, using 40 percent as the peak load case for Rwanda's distribution network.

Additionally, network assets are available as GIS files that were shared. Figure 63 shows transformer and line locations in the Kigali network area. Corresponding transformer location data is not yet included in PowerFactory. To create location-based heat maps for integrating EV loads into the existing power system, the geolocation data must be linked to the PowerFactory model. The methodology used is briefly described below, with a more comprehensive explanation planned for the online workshop, subject to counterpart approval.

FIGURE 63. GIS line and transformer data in Kigali.



Kigali has over 1000 transformers installed for low voltage power supply, making manual GIS data matching impractical. Fortunately, PowerFactory can be controlled through Python, a universal and widely used programming language. Python allows GIS data to be read and manipulated through the Geopandas module. This provided an automated way to link GIS and PowerFactory data.

Two name matching algorithms were created to provide the most likely match between the "transformer" loads in PowerFactory and the transformer names in the GIS file. In cases of ambiguity, manual checks are conducted to decide on the most likely match.

The first algorithm uses a Python module called "fuzzywuzzy", which calculates a transformer name match value based on the Levenshtein Distance⁷⁹. Matches with the highest values are selected for further comparison with the second algorithm. Figure 64 shows possible match values. As shown, a high matching value does not guarantee a good match. For example, "GATAGARA PUMPING STATION" and "GAHANGA PUMPING STATION" have a match value of 89 percent, but likely do not represent the same transformer, while "NAHV Load" and "NAHV" have a match value of 62 percent but are likely correctly linked.

FIGURE 64. Fuzzy based name matching outcome

	Transformer	Value
Ponts et Chaussées Load	Paux et Chaussée	65
Miniplan Load	MINIPLANT	73
NAHV Load	NAHV	62
Minecofin Load	Minecofin	78
Ministere Load	MINISTERE	78
...	...	...
ACACIA PLAZA GRANDE UBUMWE HOTEL	Ubumwe Grand Plaza	72
ADVENTIST CLINIC	frontier polyclinic	57
GATAGARA PUMPING STATION	GAHANGA PUMPING STATION	89
KIVOMO	KIMO	80
Mark hotel Rwesero	LANDMARK SUITES HOTEL	67

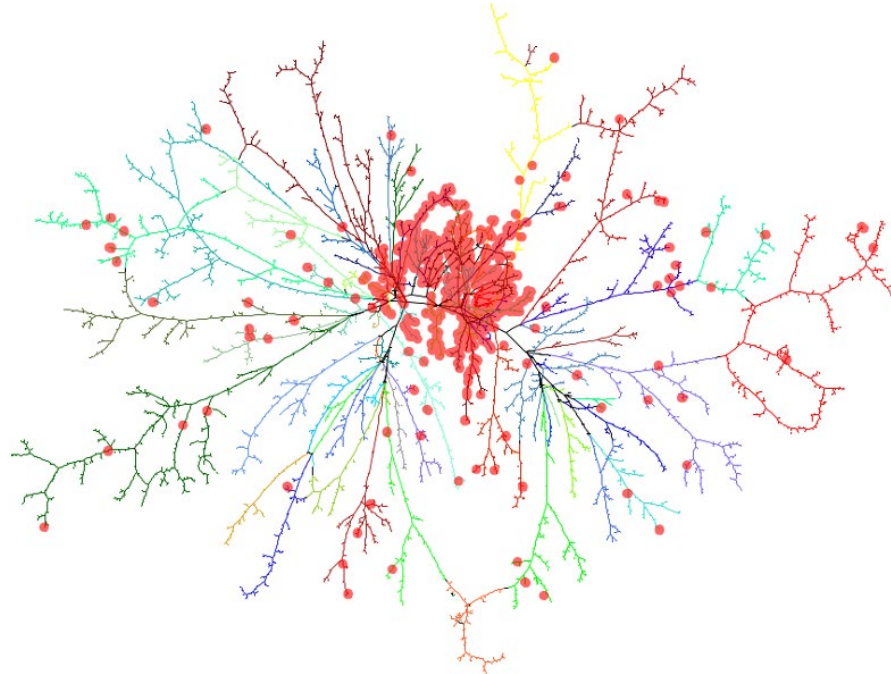
The second algorithm performs a word-based string comparison to confirm potential matches. In cases of unclear results, a manual selection is made between the two outcomes suggested by the algorithms. Word-based matching successfully geolocated 50 percent of all PowerFactory loads.

Next, the locations were added to the PowerFactory model using automated Python functions. This made it possible to isolate the Kigali network from the rest of the power system, in order to limit calculations to the capital. PowerFactory can create a graphical representation of the electrical network and mark all loads with included GIS data, as shown in Figure 65. Most of the geolocated loads are close to each other, but some are outside of Kigali, indicating the

⁷⁹ Levenshtein distance is a string metric to measure the difference between two sequences. The score value depends on the minimum number of single-character edits, with 100 percent representing a perfect match. https://en.wikipedia.org/wiki/Levenshtein_distance

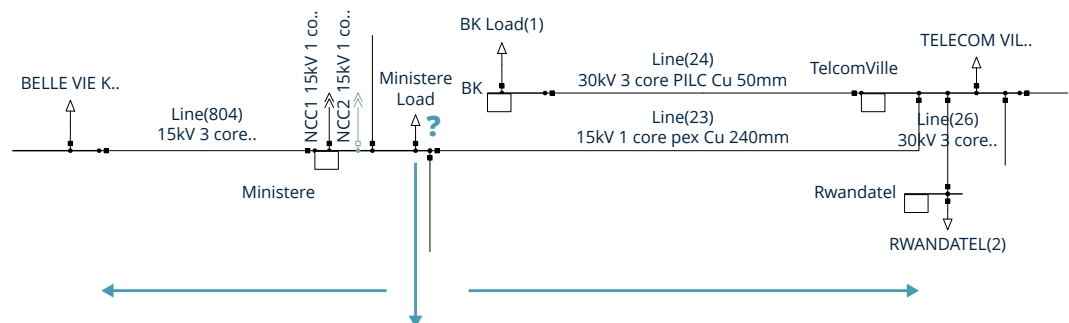
need for further processing to reduce matching errors and to increase the total number of geolocated loads.

FIGURE 65. PowerFactory electrical representation of Rwanda's electrical grid, including highlighted geolocated loads.



For this purpose, a topology based matching algorithm was developed. For all loads without geolocation information, the distance along connected lines to the closest load with geolocation information was calculated, as depicted in Figure 66. Based on the geographical distance to the closest geolocated loads compared with the line length to the given load, an approximation area was calculated. Within this area, the best fitting transformer was selected to find the GIS information of a given load. Lastly, manual checks were conducted to ensure data integrity.

FIGURE 66. Topology based matching algorithm



A.4 Distribution system Excel tool

The distribution system Excel tool allows users to dynamically assess the electric vehicle hosting capacity and the associated grid status. Users can select the reference year, the EV uptake scenario, and the grid expansion in question. All necessary grid data was pre-calculated with PowerFactory and is included in the tool.

The main sheet displays the most important grid status data, such as the graphical distribution of line loads and voltage profiles. With the built-in 3D maps visualisation option, GIS-located information on hosting capacity, voltage, and line loading profiles is also provided. Furthermore, detailed tabular information per transformer can be reviewed within the corresponding worksheets. A description of available datasets and a usage manual is included in the Excel tool itself.

FIGURE 67. Main page of Excel tool

User Manual

1. Select reference year, EV-Rate and Grid 2. Global Grid parameters are displayed below
3. Go to insert-> 3D maps => Tour ??
4. Refresh data (each time new input selection is made)
5. Explore Tour to review GIS located hosting capacity

Input selection

Year 2030
EV-Rate High
Grid Base case

Grid impact of electric vehicles

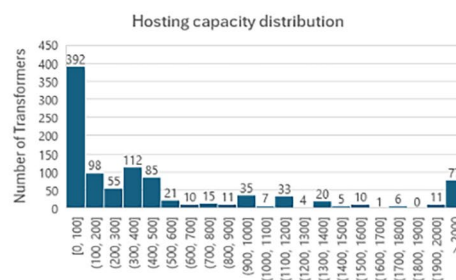
Global Param.	No EV	EV	Diff.	
P_loss [%]	4,9%	5,3%	6,5%	active power losses
Q_loss [%]	4,0%	4,8%	19,8%	reactive power losses
L_ave [%]	17,7%	18,8%	6,4%	average line loading
L_max [%]	235%	251%	6,7%	maximum line loading
L_nr_over [#]	38	41	7,4%	number of overloaded lines
L_tot_over [%]	1614%	1968%	22,0%	sum of overload
U_ave [p.u.]	0,94	0,94	-0,4%	average voltage
U_min [p.u.]	0,78	0,76	-1,7%	minimum voltage
U_nr_under [#]	666	721	8,3%	number of undervoltage terminals
U_tot_under [p.u.]	28,1	32,0	14,1%	sum of undervoltage
Ave. HostingCap [kW]		613		average excluding values above 2MW

Input:

Gxxx Host	Background data for hosting capacity
Gxxx_Health	Background data for grid health/status
EV Uptake	Number of EV per scenario
EV Charge	Nominal Charging Curves per charging use case
EV Load	EV system load calculated from charging use cases and EV
General Load	Annual maximum yearly system load
Total Load	Combined general and EV load

Output:

Hosting	Available hosting capacity per transformer over the day
Hosting min	Minimum available hosting capacity
Grid Status	Grid loading dependent on system load with and without EV

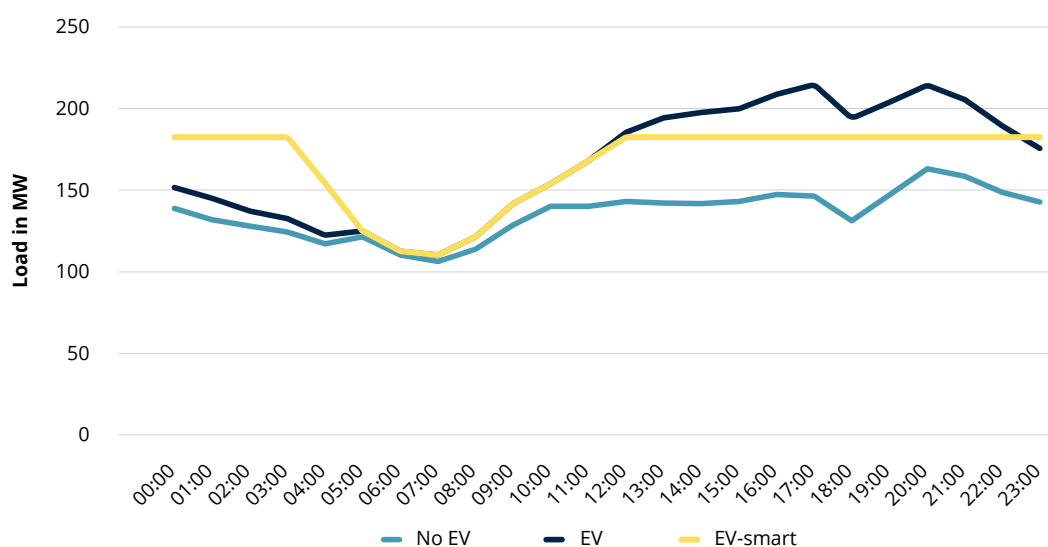


A.5 Implemented smart charging strategy

For the distribution system impact analysis, the gradual adoption of a valley filling smart charging algorithm is used. The algorithm ensures that smart charging vehicles do not increase the load above the peak load from all uncontrolled loads combined. It does so by postponing the charging process until sufficient capacity is available, as shown in the following.

EV charging impacts the overall system load, depending on the chosen charging strategy. Figure 68 shows the maximum expected load in the Kigali network on an hourly basis for different charging cases in 2024. The green load represents the base case without any EVs. The blue line shows a very high EV penetration rate of over 100,000 vehicles. While the given load is not realistic for 2024, it is chosen to explain the functionality of the smart charging algorithm (yellow). The smart charging algorithm ensures that the peak demand from all uncontrollable loads, including uncontrollable EV loads, is not exceeded by smart charging vehicles. This significantly reduces the overall system load by postponing smart charging processes throughout the day.

FIGURE 68. Maximum hourly system load dependent on the chosen EV charging strategies



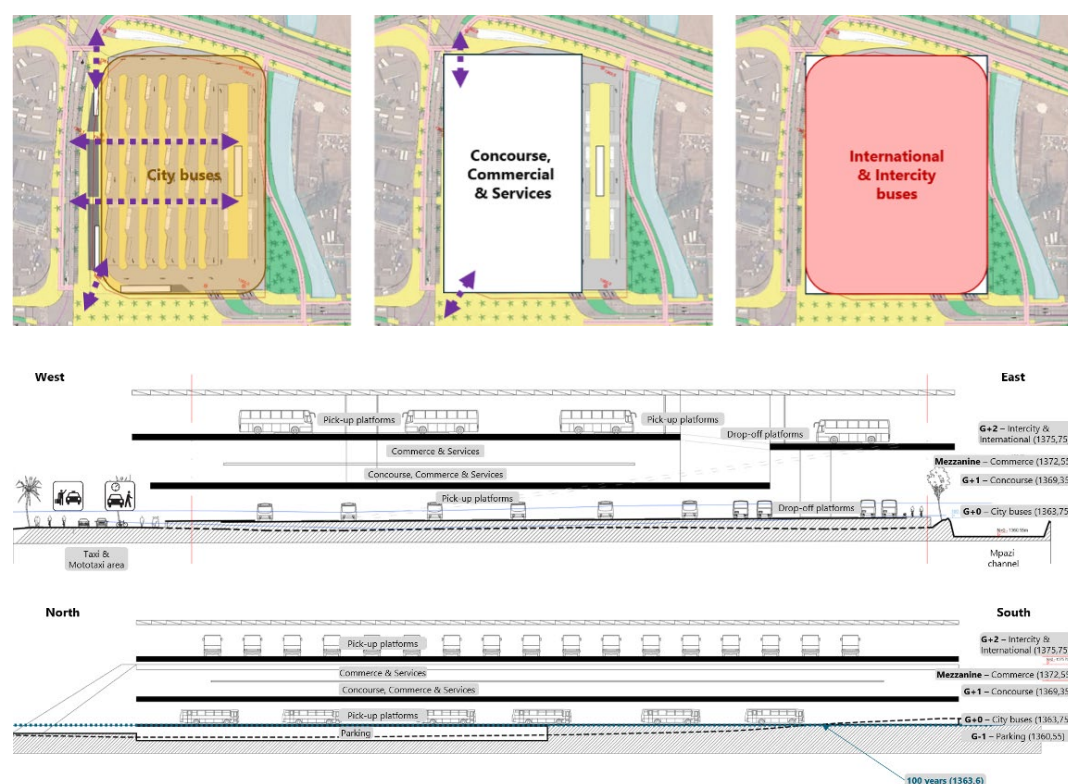
A.6 Information on the proposed Nyabugogo Terminal⁸⁰

A6.1 Configuration of Nyabugogo Terminal

The configuration of Nyabugogo Terminal is planned to be structured around a three-levels solution, planned to accommodate the entire functional programme of the Hub within the site. This multi-level approach enables an effective separation of transportation modes, enhancing the overall operational efficiency. The ground level would be dedicated to city buses, ensuring easy access and integration with the local transit network, while the G+2 level is reserved for the long-distance lines, with the International & Intercity buses.

Between these two levels lies an intermediary level exclusively for pedestrian use. This level not only provides better distribution of passengers, by creating distinct flows and reducing crowding, but also offers designated commercial and service areas. A mezzanine level further expands the commercial space, enhancing the overall passenger experience.

FIGURE 69. Layout of the proposed Nyabugogo Terminal



A.6.1.1 G+0 – City buses and access

The ground level would house the city bus terminal. Buses will enter from the southeast, where they first stop at a central drop-off platform. Passengers can then use a set of vertical circulation elements to easily access the concourse level. After dropping off passengers,

⁸⁰ This Annex is taken predominantly from the Egis report developed for the World Bank "Task 10 preliminary design"

the buses proceed to designated boarding platforms before exiting the terminal through a separate southeast access point.

The ground level will also serve as the primary connection point for urban inter-modality. All the pedestrian entrances are located on the western side of the terminal, giving access to the Hub facilities. At the southern end of the site, a welcoming plaza will offer a safe and comfortable entry point for pedestrians arriving from the surrounding commercial areas. Stairs, ramps, and podiums will guide them directly to the Concourse level. A secondary entrance at the northern end of the site further enhances accessibility to the terminal.

Along the western edge of the site, adjacent to Gatuna Road, two accessible entrances will lead directly to the City bus terminal. Layby areas are strategically placed along this road, providing drop-off points for taxis, moto-taxis, bicycles, and private vehicles. A well-designed sidewalk facilitates smooth pedestrian flow towards the Hub, while bicycle parking enhances the intermodal connectivity of the site.

Also, in line with the 2050 City Master Plan, a park and ride parking will be located further south of Nyabugogo so that users can leave their car and go to the Hub by foot to take their bus.



A.6.1.2 G+1 – Concourse, Commerce and Services

The Concourse level serves as the heart of the Hub, bringing together passengers and users. It is divided into three key zones: the commercial and service area, the operational area, and the transit area, all interconnected by generous, comfortable circulation spaces designed for smooth movement.

The commercial and service area is located at the southern end of the building, near the welcoming plaza entrance and facing the commercial district along KN 1. This layout creates a stronger connection with the city while effectively separating the flows of passengers in transit from those visiting the Hub for shopping or services.

At the northern end, the operational area is dedicated to essential passenger services, including travel information, ticketing, and long-term waiting areas. This zone also houses the Hub's offices, back-office facilities, and technical spaces, ensuring efficient management and operation.

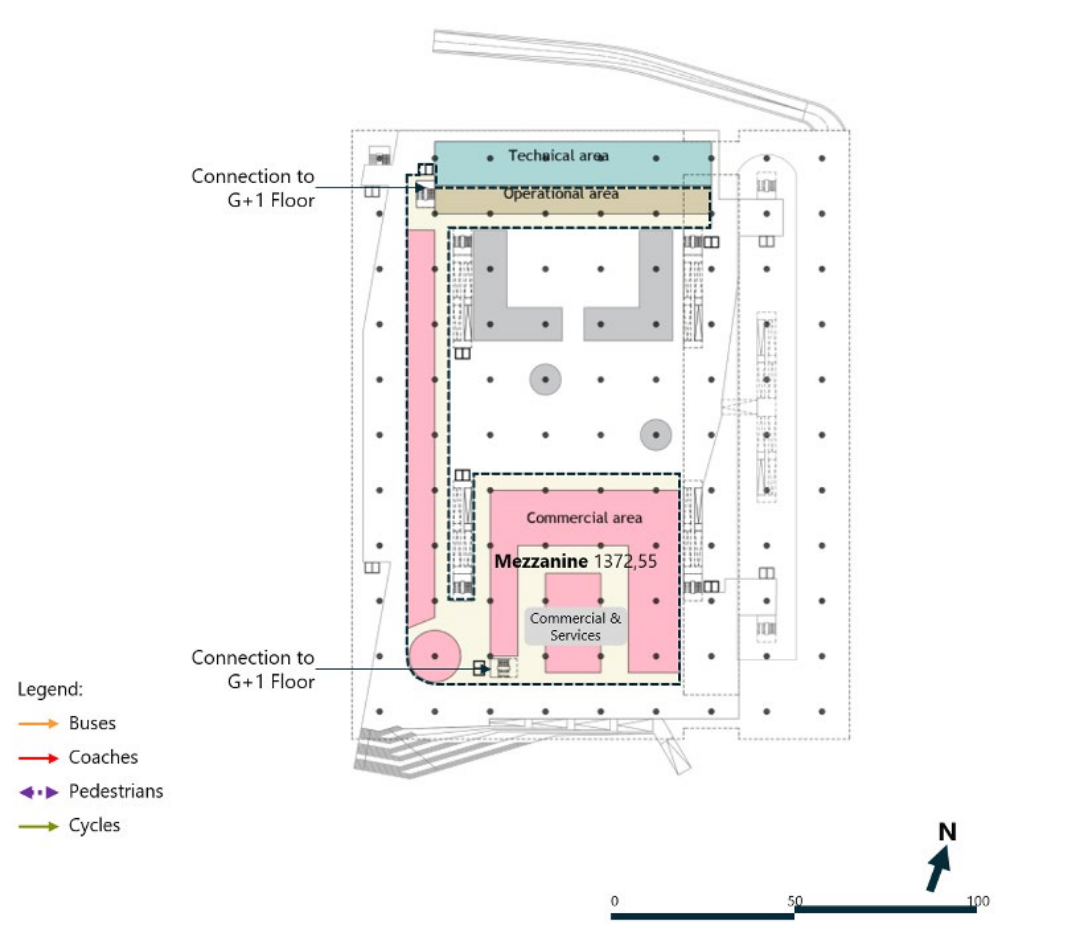
In the centre of the building lies the transit area, which organises all transit-related flows. A spacious and comfortable concourse, featuring a double-height ceiling, gives access to the City bus terminal on the ground level and to the Intercity and International bus platforms on the upper level. Short-term waiting areas and transit-oriented retail shops are strategically placed here to support and enhance the passenger journey.



A.6.1.3 Mezzanine – Commerce and Services

A mezzanine is created to expand the commercial area of the Hub, offering additional opportunities for shopping and amenities, enhancing the overall passenger experience while supporting economic activity within the terminal.

This mezzanine will primarily extend over the southern and western sections of the building, above the Concourse-level commercial spaces. Dedicated access points and vertical circulation elements will ensure the smooth separation of pedestrian flows, maintaining an organised and efficient environment.

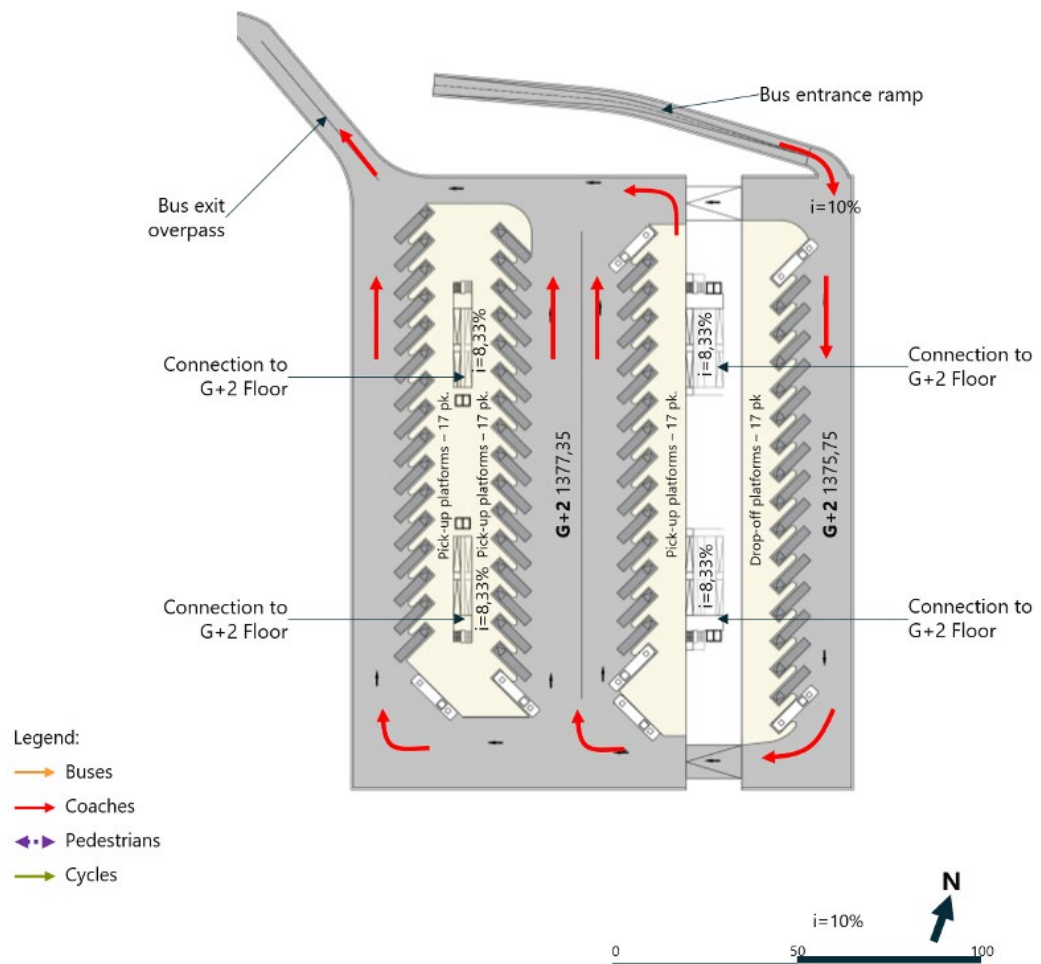


A.6.1.4 G+2 – Intercity and International Buses

The upper level is dedicated to long-distance travel, accommodating both Intercity and International bus lines. This level is divided into two distinct zones: alighting and boarding platforms, separated by a central circulation void.

Buses arrive at the first zone via a ramp from street level in the northeast, where the alighting berths and platforms are located. After passengers disembark, the buses continue up a gradual ramp to the slightly elevated second zone, where the boarding platforms are situated. Once boarding is complete, the buses proceed to the exit, taking an overpass that descends back to street level.

Passengers access this upper level directly at the platforms via vertical circulation elements, ensuring no interaction with bus traffic. The platforms are spaciouly designed to provide a comfortable and efficient boarding and alighting experience. Additionally, the entire level is covered by a lightweight metallic roof, offering full protection from rain and sun, significantly enhancing passenger comfort.



A.6.2 Location options for charging hubs

A.6.2.1 E-Bus operating assumptions at Nyabugogo Terminal

E-BUS FLEET DESCRIPTION

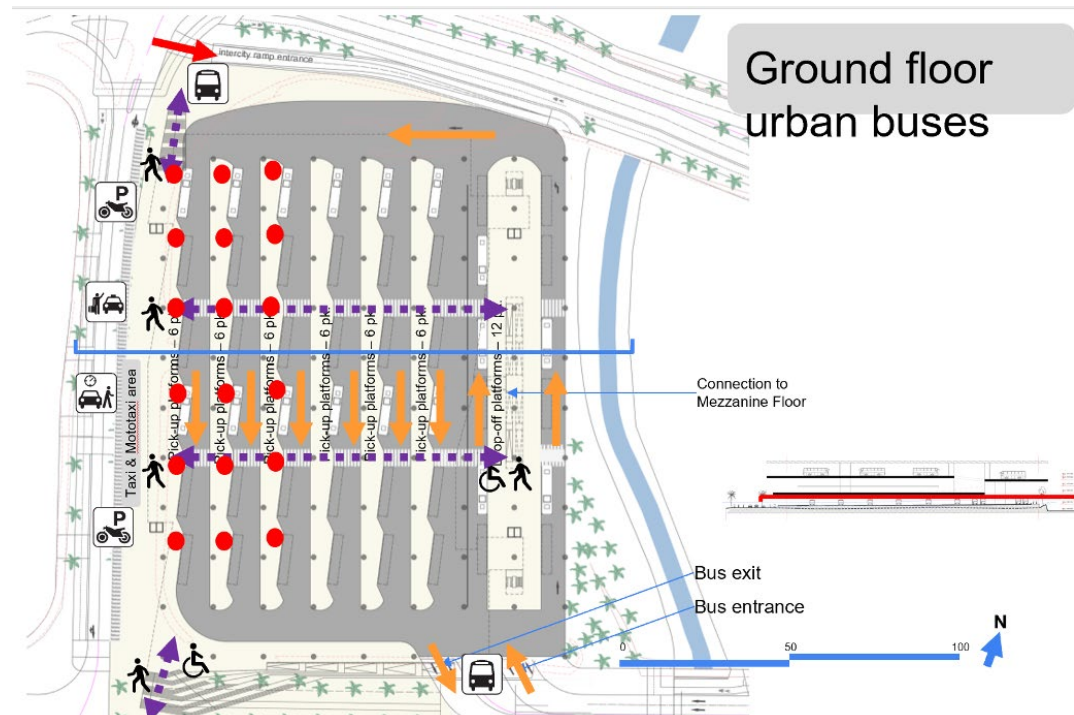
Types of buses

The Nyabugogo Terminal is designed to accommodate a fleet of 241 electric buses during the peak hour, each 12 metres in length. These buses are integral to the terminal's operations, providing a sustainable and efficient mode of transportation for urban passengers. The buses are expected to have a battery capacity of approximately 282 kWh, enabling them to cover significant distances on a single charge, with an estimated range of 220 kilometres.

Daily operations and expected bus traffic through the terminal

The terminal will see a high volume of daily traffic, with all 241 buses operating throughout the day. During peak hours, the terminal is expected to handle the movement of up to 241 buses per hour, emphasising the need for efficient scheduling and robust infrastructure to support these operations. The focus will be on city buses, including Bus Rapid Transit (BRT) and non-BRT services, which will use the terminal extensively. Intercity and international buses will not have charging facilities at this terminal; thus, their operations will be limited to pick-up and drop-off activities.

The following graphic shows the potential distribution of the chargers in red dots:



OPERATIONAL PARAMETERS

Average Distance Per Bus Per Day

On average, each bus is expected to travel approximately 232.3 kilometres per day. This estimation is based on operational data from five key routes connected to the terminal, which provide a comprehensive understanding of the typical distances covered by the buses. The data highlights that while most routes have consistent and reliable data, a couple of routes show anomalies, necessitating further investigation to refine these estimates.

Time Profile and Peak Hours for Bus Operations

The design of the Nyabugogo Terminal's e-bus charging operation requires a careful analysis of the time profile, peak hours, and operational constraints. This section details the planned charging scheme for two scenarios: one with 12 chargers and another with 18 chargers. The charging bays are scheduled to close during peak bus operational hours to avoid congestion, reducing the effective charging time to 13 hours per day.

Charging time profile assumptions

The terminal will operate 19 hours per day, from 5:00 AM to 12:00 AM. However, the charging bays will be closed during three peak operational periods:

1. **Morning Peak (7:00 AM - 9:00 AM):** High demand for bus services as commuters travel to work.
2. **Afternoon Peak (12:00 PM - 2:00 PM):** Lunchtime rush for workers and shoppers.
3. **Evening Peak (5:00 PM - 7:00 PM):** End-of-day commuter traffic.

During these peak hours, the bus charging bays will be closed to prioritise bus movement and passenger services, reducing the total available charging time to 13 hours per day.

Charging scenarios

We propose two charging scenarios, each based on different charger capacities to accommodate the 241 electric buses at the terminal. These buses are expected to use the opportunity charging system at least twice, with some buses charging up to three times per day in Scenario B. The chargers will operate with a power output of 120 kW, and each charging session will last approximately 20 minutes, replenishing about 14.2 percent of the bus's battery capacity.

Scenario A: 12 Chargers

- Number of Chargers: 12
- Charging Time per Bus: 20 minutes (0.333 hours)
- Bus Battery Capacity: 282 kW
- Charger Power: 120 kW
- Charging percent per Session: 14.20 percent
- Hours of Operation: 13 hours (excluding peak closures)
- Buses Charged per Day: 468

Scenario B: 18 Chargers

- Number of Chargers: 18
- Charging Time per Bus: 20 minutes (0.333 hours)
- Bus Battery Capacity: 282 kW
- Charger Power: 120 kW
- Charging percent per Session: 14.19 percent
- Hours of Operation: 13 hours
- Buses Charged per Day: 702

Operational Implications of Each Scenario

Both scenarios account for the bus fleet's need to charge multiple times throughout the day. The design of the terminal and the charging schedule is optimised to ensure the maximum number of buses can charge within the limited 13-hour window. The goal is to meet the daily charging requirements of the entire fleet (241 buses), with opportunity charging occurring twice per bus, and some buses charging up to three times as needed.

Scenario A (12 Chargers)

With 12 chargers available and 13 operational hours per day, approximately 468 buses can be charged each day. This scenario is sufficient for a fleet where the majority of buses charge twice, with a smaller number of buses requiring a third charging session. Given that the total number of buses is 241, this scenario can accommodate the fleet's needs under regular conditions.

- Average Buses Charged per Hour: 36 buses
- Required Charging Sessions per Bus: 2 sessions for most buses, with some buses needing 3 sessions
- Potential Bottleneck: During peak periods of the day, there could be a slight backlog if more buses than usual require a third charging session. Careful scheduling will be needed to avoid delays.

Scenario B (18 Chargers)

With 18 chargers, the terminal can charge approximately 702 buses per day. This scenario provides a greater margin for flexibility, ensuring that the entire fleet can comfortably charge twice per day, with more than enough capacity for buses requiring a third charge. This scenario is ideal for times of higher operational demand, such as special events or an increase in fleet size.

- Average Buses Charged per Hour: 54 buses
- Required Charging Sessions per Bus: 2 sessions for all buses, with ample room for additional charging if needed
- Improved Flexibility: This scenario offers better flexibility in handling unexpected demand and will reduce pressure during peak operational times.

Peak Hour Closure Considerations

The peak hour closures at 7:00 AM – 9:00 AM, 12:00 PM – 2:00 PM, and 5:00 PM – 7:00 PM, when the terminal experiences the highest passenger traffic, are key to avoiding congestion. The chargers will be unavailable during these periods, effectively shortening the charging window. This approach ensures that the charging infrastructure does not interfere with bus operations and that buses remain available for passenger services during critical periods.

CHARGING OPERATIONS STRATEGY AND SCHEDULE (OPPORTUNITY CHARGING)

The Nyabugogo Terminal will implement an opportunity charging strategy during operational hours to support the continuous operation of the electric bus (e-bus) fleet. Charging will take place at designated charging bays during the buses' layovers between routes. However, due to peak hour traffic constraints, the terminal's charging bays will only be operational for 13 hours per day. These 13 hours exclude three peak periods when the terminal experiences heavy bus and passenger movement: from 7:00 AM to 9:00 AM, 12:00 PM to 2:00 PM, and 5:00 PM to 7:00 PM.

The charging infrastructure is designed to handle rapid charging cycles. Buses will charge for 20-minute intervals at high-power 120 kW chargers, replenishing approximately 14.19 percent of their battery capacity during each session. This quick turnaround charging allows buses to return to service promptly, ensuring minimal disruption to bus operations.

Both scenarios ensure that the terminal can accommodate the fleet's charging needs, as buses are expected to charge twice or, in some cases, three times per day. The terminal's design and

strategic placement of chargers on the ground level will also protect the infrastructure from flooding risks, ensuring uninterrupted charging services throughout the day.

Night Depot Charging Assumptions

In addition to opportunity charging during the day, buses will also undergo full charging cycles at dedicated depots overnight. This nighttime charging ensures that buses start the day with fully charged batteries, capable of covering their required routes without needing immediate recharging during morning operations. Although the Nyabugogo Terminal will not provide overnight charging facilities, this system relies on coordinated operations between the terminal and external depots. The integration of both opportunity charging during the day and full depot charging at night will ensure the efficient operation of the e-bus fleet.

Bus Utilisation and Charging Needs

With the charging infrastructure operating for 13 effective hours per day, the terminal is designed to meet the charging needs of up to 24 buses per hour under optimal conditions. This capacity ensures that even with the closure of charging bays during peak periods, the terminal can maintain sufficient charging throughput for the entire fleet of 241 e-buses.

- **Scenario A (12 Chargers):** Allows for 468 bus charges per day, meeting the needs of the fleet under normal operating conditions.
- **Scenario B (18 Chargers):** Expands capacity to 702 bus charges per day, providing flexibility for increased demand or bus utilisation.

In conclusion, the charging strategy at Nyabugogo Terminal is designed to balance high bus traffic with charging efficiency. The integration of 13 hours of opportunity charging per day, combined with the flexibility offered by two different charger configurations, will ensure that the terminal can manage the daily charging needs of the fleet. This robust strategy is essential for supporting Kigali's transition to sustainable urban mobility.

A.6.2.2 Charging infrastructure concept design

CHARGING EQUIPMENT AND TECHNOLOGIES

Types of Chargers

For the Nyabugogo Terminal, a range of charging equipment has been considered to meet the diverse needs of the electric bus (e-bus) fleet. The types of chargers propose the following scenarios:

- **120 kW Chargers:** These high-power chargers are suitable for quick charging during peak operational hours. They are designed to recharge bus batteries rapidly, minimising downtime and ensuring that buses can return to service promptly, power is the highest demanded under this scheme.
- **100 kW Chargers:** Slightly less powerful than the 120 kW chargers, these chargers are still efficient for mid-range charging needs. They are ideal for buses that require a balance between charging speed and energy efficiency, infrastructure is optimised on cost and materials with some time increase.
- **80 kW and 60 kW Chargers:** These chargers are proposed for situations where slower, more controlled charging is sufficient. They can be used during off-peak hours or for buses that have longer layover times, however several chargers available under this power are not suitable to divide charging for two buses at the same time. These lead us to have double the quantity of chargers to keep operation proposed.

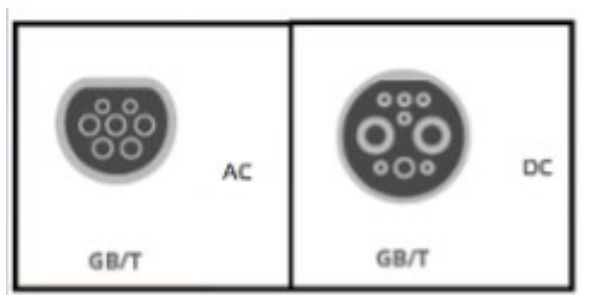
- **40 kW and 50 kW Chargers:** These lower power chargers provide an option for overnight charging or for buses with less urgent charging needs. They are cost-effective and can help manage the terminal's overall energy load efficiently. Same consideration as above, one charger per bus is required to fulfil operation. These chargers take us to the longest charging time. Between 5 to 6 hours from 20 percent to 95 percent on 284 KWh buses.

Connector Types and Compatibility with Buses

The compatibility of charging connectors with the bus fleet is crucial to ensure seamless operations. The proposed charging infrastructure at Nyabugogo Terminal will primarily utilise standard connectors compatible with the 12-metre e-buses expected to operate within the terminal. These connectors will support high DC power charging, ensuring that all buses can be accommodated regardless of their specific plug requirements.

Chargers will be equipped with connector type required by bus to handle the DC fast charging required that might be used by different bus manufacturers. This approach ensures future proofing the infrastructure against changes in bus technology or manufacturer preferences.

Chargers also need to be equipped and connected to ethernet to have a software for administration that register all charges on time and energy consumption by units, this way energy management will be recordable and handle a good implementation on energy demanded by bus fleet. Below the image on the right represents the universal connector GBT DC for the largest and most common bus manufacturers.



LOCATION AND INSTALLATION OF CHARGING INFRASTRUCTURE

Placement of Chargers within the Terminal (Ground Floor Level)

The proposed charging stations are to be located on the ground floor level of the Nyabugogo Terminal. This level is strategically selected for several reasons:

- **Proximity to Bus Operations:** The Ground level provides easy access to buses operating within the terminal, particularly those on urban routes. This placement allows for efficient opportunity charging, where buses can be charged during short layovers between trips.
- **Operational Efficiency:** Placing chargers on the G level ensures that they are out of the way of other terminal activities, reducing the risk of congestion and ensuring that charging operations do not interfere with passenger movement or other bus operations.

Discussion on Installing Chargers on the Roof to Mitigate Flooding Risks

Flooding is a well-known issue at the Nyabugogo Terminal, particularly on the ground floor. To mitigate the risks associated with flooding, one of the innovative solutions proposed is the installation of chargers on the terminal's roof. This approach offers several benefits:

- **Flood Protection:** By installing chargers on the roof, the risk of flood damage is eliminated, ensuring the reliability and longevity of the charging equipment.
- **Space Utilisation:** The roof offers a large, underutilised space that can be effectively used for installing chargers without impacting the terminal's operational areas, and

leaving this space with no people transit if possible, for public and general services areas, such as commerce.

- **Solar Integration:** The roof installation can be combined with solar panels, providing a renewable energy source that can directly power the chargers, reducing dependency on the grid and lowering operational costs.

FLOOD MITIGATION MEASURES

Analysis of Flooding Risks at Nyabugogo Terminal

The Nyabugogo Terminal is situated in an area prone to flooding, especially during heavy rains. The terminal's ground floor has historically been vulnerable to water accumulation, which poses a significant risk to any equipment installed at that level. The flooding risks are exacerbated by the terminal's proximity to water channels and its low-lying location.

Design Considerations to Elevate Charging Equipment

To address these risks, the design of the charging infrastructure includes several flood mitigation measures:

- **Elevated Platforms:** Chargers will be installed on elevated platforms on the ground level, well above the known flood levels. This elevation ensures that even in severe weather conditions, the charging infrastructure remains operational and safe from any damage. A well-designed hall with railings will allow operators to go upstairs on the indicated height below and take charger wire to place the connector into bus plug and let bus battery refill.
- **Waterproofing:** Additional waterproofing measures, such as sealed electrical conduits and weatherproof housing for the chargers, will be implemented to protect against moisture ingress.
- **Drainage Improvements:** Enhancement to the terminal's drainage systems will be considered to reduce the overall risk of flooding. This includes improving water runoff management and installing additional drainage channels where necessary.

SCENARIO ANALYSIS

Proposed Scenarios for Charger Installation

The feasibility study has outlined two primary scenarios for the installation of chargers at the Nyabugogo Terminal. Below is a representation of the charging profile for the two scenarios based on the 13-hour charging window:

Parameter	Scenario A (12 Chargers)	Scenario B (18 Chargers)
Number of Chargers	12	18
Charge Time per Bus	20 minutes	20 minutes
Charger Power	120 kW	120 kW
Percent of Charge in 20 min	14.19 percent	14.19 percent
Hours of Operation	13 hours	13 hours
Buses Charged per Day	468	702

Impact of Each Scenario on Bus Operation Efficiency and Terminal Capacity

Both charging scenarios have been analysed with respect to the operational efficiency of the terminal and its ability to handle the daily charging needs of the e-bus fleet, considering the 13 hours of effective charging time per day.

Scenario A: 12 Chargers

Scenario A, with 12 chargers, offers a balanced approach between capital investment, operational efficiency, and terminal capacity. Under this scenario, the terminal can charge up to 468 buses per day, assuming each bus charges for 20 minutes and some buses charge multiple times during the day. This scenario is well-suited for handling the regular operational demands of the terminal's 241-bus fleet, as it allows each bus to charge twice and some buses to charge three times if necessary.

The primary advantage of Scenario A is that it efficiently meets the daily charging requirements without overwhelming the infrastructure or power supply. However, as the fleet expands or if the demand for additional charging cycles increases, this scenario may eventually approach its capacity limits during periods of high utilisation. While capital costs and power requirements are lower than in Scenario B, Scenario A provides sufficient charging capacity to maintain the terminal's smooth operations under normal conditions.

Scenario B: 18 Chargers

Scenario B, with 18 chargers, significantly increases the terminal's charging capacity, allowing for up to 702 bus charges per day. This scenario provides a higher degree of operational flexibility, ensuring that even during periods of increased demand, the terminal can accommodate buses that require additional charging sessions. It offers more resilience to unexpected surges in bus traffic or charging needs, making it ideal for times of high demand or future fleet expansion.

The increased number of chargers in Scenario B reduces the likelihood of bottlenecks during busy periods, ensuring that the terminal can handle peak loads without operational delays. However, this scenario also demands a higher initial capital investment and increased power supply capacity to support the additional chargers. While this may not be necessary in the terminal's initial phase of operation, Scenario B provides a future-proof solution, offering scalability as the fleet grows or if operational demands increase.

The decision between these two scenarios should be guided by a combination of factors, including current and projected bus operations, budget constraints, and the strategic vision for the Nyabugogo Terminal's development.

A.6.2.3 Electrical Needs and Infrastructure at the Terminal

ELECTRICAL LOAD ANALYSIS

Estimated electrical consumption for bus chargers

The largest consumption for 18 chargers working together is around 2160 KWh on the peak demand energising 18 buses at the same, one charger per each bus, power that will be demanded for at least 2 hours during the day. Considering two dry transformers of 1250 KVA the total system power available will be 2500 KW for a short period.⁸¹ Remaining energy

⁸¹ Note that this is a recommendation from the Egis report developed for the World Bank "Task 10 preliminary design". From the point of view of the Consultant developing this report, any transformer type suitable to supply the load available at the best price could be used.

available for general purposes on the building is 340 KW from the utility grid, (it can be complemented by solar panel generation on the descriptions below) this remaining energy represents any type of lighting, air conditioning and fridges for the whole building. In order to assure not only one device is working with the total amount of energy the suggestion is to split on 2 dry transformers that in the case of any failure half of the system remains operational, also for maintenance backup.

Below is presented this ratio with estimation on different scenarios for arrangements on power chargers, note that for this table each charger only energises one bus at the time.

Peak and average power demand calculations

Peak demand		kW	
Charges qty	120 kW	100 kW	80 kW
18	2160	1800	1440
16	1920	1600	1280
14	1680	1400	1120
12	1440	1200	960

Charger		Battery BUS	282	Batteries / Time		220
1 calbe	1 bus	Battery %	kW	284 kW		Autonomy km
120 kw/hr	120 kw/hr	60%	169.2	1hr	25 min	132
		70%	197.4	1hr	39 min	154
		80%	225.6	1hr	52 min	176
100 kw/hr	100 kw/hr	60%	169.2	1hr	42 min	132
		70%	197.4	1hr	59 min	154
		80%	225.6	2hr	16 min	176
80 kw/hr	80 kw/hr	60%	169.2	2hr	7 min	132
		70%	197.4	2hr	28 min	154
		80%	225.6	2hr	49 min	176

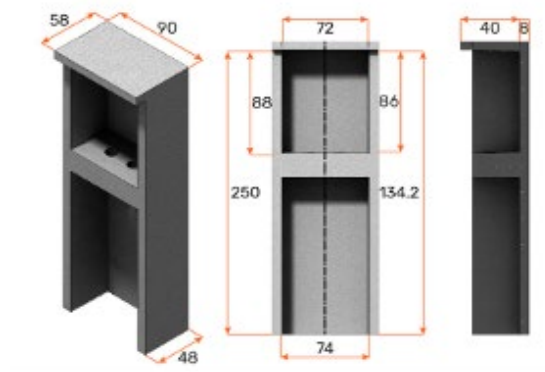
Electrical Infrastructure Design

Design of the electric room and distribution network: Depending on the size of chargers selected for the application and the time available to keep the operation running there are only two sizes to allocate all components into the building, one is 7 metres depth and 15 m long,

high is enough on the building floor, just consider 2.5 m in all cases. This space will include all the following: 2 MV transformers to low voltage, 2 distribution panelboards for protection to each charger and 2 regular low voltage transformers for building distribution for all building services. If the choice is to have a larger time on charging 5 hours with the minimum power demanded to utility the size of the space into the building is 4 m depth and same 15 m long to allocate all materials: 1 MV transformer, 1 distribution panelboard and 1 regular low voltage transformer for building services.

All this electric room is suggested on G+1 level - no flood permitted at all.

A main disconnect at street level is required to enable operations and take power from utility service to get inside the building. This device regularly is required on accessible public areas by utility officer operators and is totally exterior designed as well as flooded resistant in the case it happens. This main disconnect can have only one entrance - 2 exits for 2 transformers, but the best suggestion is to have 2 power sources incoming and 1 or 2 exits for the two transformers inside the building. The two entrances may take electricity from different circuits from official utility and have a redundancy application just in the case utility can configure different power incoming to supply at all time power to the whole system, if one goes the second will take place and on energy absence event and the condition is that never both of the incoming will close at the same time, only one at the time. Dimension of this device is 4 m length and 2 m depth by 1.5 m high, consideration for external use requirement is with exterior NEMA 3R Cabinet. Next to it the official utility metre is required for energy consumption fee payment. Dimensions: 4.5 m long x 1.5 m depth and 1.5 m height.



Note: Dimension in cm, can be built on concrete. Specifications for transformers, switchgear, and panel boards.

- Two MV transformers will be requested for interior usage and by regulatory international requirement this needs to be a dry transformer IEC60076 with no ventilation, the application inside the building forbids having oil transformers where there are people inside. These transformers are maintenance free and require 15000 KV to 380 V, Delta - Wye on the low voltage side, aluminium coil.

Dimensions: 2480 mm long x 1180 mm depth and 2200 mm height.

- Two Switchgear are connected to the low voltage side of each transformer with internal copper bus bars and at least 20 spaces for 3 pole breakers, 2000 A electromagnetic main breaker, working at 380 V ac, power metre and main breaker 1200 A. (breakers defined

by charger size, largest breaker 200A 3 poles, 8 for each charger and 2 extra for each LV transformer).

Dimensions: 1270 mm long x 1270 mm depth and 2250 mm height

- Two low voltage transformers 300 KVA require 380 V to 220 V altern current wye - wye configuration aluminium coil and interior Nema 1 configuration for interior use.

Dimensions: 850 mm long x 850 mm depth and 1000 mm height

- Two Panelboard - distribution power for 220Vca with thermomagnetic 800 A main breaker and 18 - 3 pole breaker spaces to allocate the whole chargers for the building on contacts and lighting operation as well as air conditioner.

Dimensions: 1050 mm long x 230 mm depth and 2200 mm height

Prices change due to the quantity and size of breakers, depending on the quantity of additional chargers some extra panelboards low voltage need to be considered by each floor.

INTEGRATION OF RENEWABLE ENERGY

Feasibility of installing solar panels on the terminal's roof.

Considering all areas on the top of the building, we are taking the new information of 19,000 square metres to place proper panels that generate 540 w maximum, each panel has a 1.8 square metre. 20 percent of the area needs to be used for maintenance, mounting and water drain, which take us to consider only 15,200 square metres usable. Total available space is suitable for 1530 panels.

This number of panels is selected because are enough green generation to have energy during working hours and after sun is gone no generation will be produced so at this period energy will be taken from the Utility. Typically, in several places not all energy returned to the grid is considered for bill return, so having a partial generation allows to reduce enough of our energy consumption from the grid but not giving energy that is not considered in the future for bill price reduction.

Expected energy contribution from solar generation.

This number of panels, 1530, can generate up to 826 KW/hr maximum during sunny days. Again for 2 transformers each one will allocate 765 panels and absorb/inject to the grid or to the loads 413 KW/hr depending on the consumption at that time of the day. Total amount average per day runs into 4,956 KW approx.. and the total consumption of terminal considering maximum 18 chargers 120 KW/hr for two hours and 450 KW general consumption during 12 hours 5,400 total is — 9720 kW per day whole terminal, getting a contribution up to 50 percent from solar generation on good generation days.

Proposal for a hybrid energy system (grid + solar).

1530 solar panels would require certain amount of connectivity, protection and combiner boxes that would collect energy for each panel. A larger size of combiner box is suggested to allocate 24 strings – with 144 panels connected to each 24-string combiner box. So, in the end, all 1530 panels would be feeding 11 combiner boxes to collect energy and then feed in energy into 35 inverters of 24 kW each (Fronius) to get the estimated 826 KW generation per hour under proper sun conditions. On this case, 2 distribution panel boards are required with 20 spaces each to collect all the generation from the 35 devices in low voltage 220 Vac and distribute green energy to the loads. In the case (at any hour during day) that not all 826 KW is

consumed the remaining energy will be directed to LV transformers that will elevate voltage to the main switchgears and feed into the general utility grid. Metres from the utility will operate in a negative way to subtract this energy from electricity bill and balance the real payment the system is consuming during the period.

DC current from panels to combiner box to inverter that takes out altern current injected to the system -protected by distribution panelboards.



BACKUP POWER AND REDUNDANCY

Consideration of battery energy storage systems.

Considering in using a battery storage system requires a very large space and a considerable weight that is suggested to have it in the ground floor, the most common size for 500 KW is a 40 feet long container and this is 60 percent of the estimated solar generation per hour, for total solar energy storage will be required double size. Today battery energy storage is financially justified when there is a very large energy price especially on the high peak hours of consumption. For this analysis a timely fee will be required from Nyabugogo system on MV 15000 KV and its ratio to carry out a calculation.

System on this design is considering that remaining energy not used at the time and that is available from solar generation is returned to utility to rest from the consumed powered KW and reduce energy bill each period.

Another argument is that battery systems need to be replaced every 7 to 8 years as well as battery buses that represent another additional maintenance consideration and proper disposal for lithium batteries. (not compatible now with any vehicle, since they are fixed operation, not for motion).

Planning for power outages or grid instability.

As described before, the main disconnecter is prepared to alternate and accept two incoming lines from the utility grid, on the drawing shared is estimated that these two lines come from different sources from utility and in the case one is farther from this side, will be requested to utility to make an additional construction plan to have an alternative feeding line to this point. On different terminals this is a good idea and practice that reduces any possible power absence depending only on one utility line and increases the availability from terminal operability.

A.7 Battery Electric Buses funding and opportunities

Although electric bus fleets are expanding globally, the initial capital costs for fully electric buses are generally higher than those of conventional ICE buses and timely battery replacements may be required.⁸² This underscores the need for sustainable financial strategies and business models.

Urban bus services can be provided through a range of public and private models, with varying levels of cost-sharing between the two sectors depending on the contract or structure in place. While cities have generally not made significant changes to their contracting methods when introducing electric or hybrid-electric buses, a new delivery model is emerging where third-party actors, such as manufacturers and leasing companies, are playing a larger role. More flexible procurement models allow bus manufacturers to offer operators the option to lease both buses and batteries, which helps mitigate technological and financial risks for operators. Regardless of the provision model, it is essential to consider social goals, performance metrics, and financial sustainability.⁸³

The core BEB business models are:

- The **public provision model**, which entails the ownership of transportation infrastructure by public entities, with bus services being operated by organisations like public transit agencies or branches of government. In a purely public sector framework, the transit agency is responsible for procuring and operating buses, covering all associated costs, including procurement, operations, and maintenance. These expenses are frequently subsidised by the government through various mechanisms, ensuring that public transit remains accessible and sustainable.
- A **hybrid approach of mixed ownership**, which entails that a public entity, such as a local government or transit agency, owns and oversees the bus system, while the actual bus services are contracted out to private operators. These private companies are tasked with investing in the vehicles and managing the day-to-day operations of the transit services. This arrangement allows public entities to leverage the efficiency and expertise of private operators while maintaining ownership and oversight of the infrastructure. This hybrid approach can provide various benefits, such as increased operational efficiency, flexibility in service delivery, and potential cost savings. However, it also requires careful contract management and performance monitoring to ensure that service quality meets public expectations.
- A **leasing model**, which entails manufacturers and other asset owners offering operators—both public and private—the option to lease buses instead of purchasing them outright. Leases may include not only the buses but also batteries and charging infrastructure. They can be provided by established manufacturers or financial institutions and may vary from straightforward leases to more complex arrangements like lease-to-buy or purchase-leaseback contracts. This flexibility helps operators manage capital costs and technological risks more effectively.

Public and private operators have three main options for financing electric and hybrid-electric buses: up-front purchases using public funds, debt financing, or leasing the buses instead of owning them. In practice, these approaches can be combined. For example, operators might purchase the buses while leasing the batteries. While the majority of electric and hybrid-electric buses are still funded through public budgets, including revenue from public transport systems,

⁸² World Resources Institute. 2019. *Barriers to Adopting Electric Buses*.

⁸³ World Resources Institute. 2019. *Financing Electric and Hybrid-Electric Buses: 10 Questions City Decision-Makers Should Ask*.

there is an increasing need for affordable financing solutions to bridge the up-front investment gap and support large-scale adoption. Table 40 illustrates the way different cities⁸⁴ are funding and financing electric and hybrid-electric buses.

TABLE 40. Examples of different payment and acquisition types

Type of acquisition	Source	Features
Cash Purchases	Investment incentives	• Cover up-front costs but time limited and irregular • Preferential pricing • In-kind incentives
	Operating budgets and budget transfers	• Used to cover operational or capital expenditures
Debt financing	Concessional loan	• Flexible lending conditions • Can encourage higher lending rates among local banks for environmentally beneficial investments
	Green bond	• Created to fund projects that have climate benefits • Backed by issuer's entire balance sheet
Leasing	Lease-to-buy contract	• Between operator and bus manufacturer • Operator pays rent over the course of the agreed upon lease period and then purchases the bus at a designated price at the end of the contract • Allows operators to purchase buses without tying up their cash
	Purchase-leaseback contract	• After selling an asset to a buyer, the seller then contracts with the buyer to lease the same asset • Often used in cities where third-party leasing companies are not allowed to purchase vehicles directly • Details of arrangement are made immediately after sale of the asset
	Battery lease	• Manufacturer owns the battery during the lease term and replaces it when needed
	Operating lease	• No residual value risks • Predictable cash flow and benefits • Payment paid out of operating income and offset against taxable profits

⁸⁴ The table is taken from a World Resource Institute series of studies, which explore the lessons learned from the experience of 16 cities across the world that were early adopters of electric buses.

Type of acquisition	Source	Features
Leasing	Financial lease	• Pay interest on outstanding value • Tax and VAT benefits • Trade-in value: profit from maintenance and careful use • Vehicle as asset on balance sheet

Source: World Resource Institute. 2019. Financing Electric and Hybrid-Electric Buses: 10 Questions City Decision-Makers Should Ask

Electric and hybrid-electric bus acquisitions generally involve some form of investment incentive to help lower the up-front costs. These incentives are typically non-reimbursable resources provided by one party, often a public entity, to make the investment more appealing to another party. In addition to government subsidies, three main types of investment incentives have been used to support electric and hybrid-electric bus investments: grants, preferential pricing, and in-kind incentives. Table 41 showcases some investment incentives used across the world.

TABLE 41. Summary of investment incentives in electric and hybrid-electric buses

Investment incentive	Advantages	Disadvantages	City examples
Capital expenditure grant	• Proven ability to utilise funding	• Can be limited in size and usage • Eligibility may be restricted • Diverts public funds	Auckland, New Zealand; Berlin, Germany; Bogotá, Colombia; Colombo, Sri Lanka; Gothenburg, Sweden; Gumi, South Korea; London and Milton Keynes, England; Nanjing, Tianjin, Shenzhen, and Zhuhai, China; Philadelphia, Pomona Valley, and Seattle, United States; Rome, Italy; Singapore; Stockholm, Sweden; Toronto, Canada
Operational expenditure grant	• Proven ability to utilise funding	• Can be limited in size and usage • Eligibility may be restricted • Diverts public funds	Berlin, Germany; Colombo, Sri Lanka
Land grant	• Clearly articulated city benefits • Coordination with different stakeholders	• Consensus may be difficult to reach regarding station locations	Pomona Valley, United States

Investment incentive	Advantages	Disadvantages	City examples
Preferential pricing	• Stable electrical grid • Coordination between utility, operators and transit authority	• Difficulties reaching consensus in deciding pricing scheme, especially as the electric grid and power generation are undergoing major changes	Pomona Valley, United States
Duty tax breaks	• Defined uses and regulations of tax breaks	• Poor enforcement	Bogotá, Colombia
Value-added tax reduction	• Defined uses and regulations of tax breaks	• Poor enforcement	Bogotá, Colombia
Reduced tax on corporate profit	• Defined uses and regulations of tax breaks	• Poor enforcement	Bogotá, Colombia; Curitiba, Brazil; Shenzhen, China

Source: World Resource Institute. 2019. Financing Electric and Hybrid-Electric Buses: 10 Questions City Decision-Makers Should Ask

A.8 Identified E-Mobility standards

Reference number	Title	Description
ISO 6469-1	Electrically propelled road vehicles — Safety specifications — Part 1: Rechargeable energy storage system (RESS)	Safety Standards
ISO 6469-2	Electrically propelled road vehicles - Safety specifications - Part 2: Vehicle operational safety means and protection against failures	
ISO 6469-3	Electrically propelled road vehicles - Safety specifications - Part 3: Protection of persons against electric shock	
ISO 6469-4	Electrically propelled road vehicles - Safety specifications - Part 4: Post-crash electrical safety	
ISO 17409: 2020	Electrically propelled road vehicles — Conductive power transfer — Safety requirements.	Vocabulary
ISO 18246: 2023	Electrically propelled mopeds and motorcycles — Safety requirements for conductive connection to an external electric power supply.	
ISO/TR 8713	Electrically propelled road vehicles – Vocabulary	
ISO/IEC 15118-1	Road vehicles - Vehicle-to-grid communication interface - Part 1: General information and use-case definition	

¹ The management of functional safety for ISO 26262-2: 2018 is considered equivalent to GB/T 34590.2, the Chinese national standards of 2022, but is missing part 1 which is the vocabulary related to the standard

² UL 2580 is the American standard ensuring the safety of electrical energy storage assemblies (EESAs) for on-road and industrial off-road vehicles, covering various tests like short-circuiting, overcharge, and vibration endurance

³ IEC 62660-2:2018 is a significant technical update and replacement to the 2010 edition, providing test procedures for secondary lithium-ion cells and cell blocks in electric vehicle propulsion systems

⁴ IEC 62660-3 has been prepared by IEC technical committee 21: Secondary cells and batteries. It is an International Standard. The second edition (IEC 62660-3:2022) cancels and replaces the first edition published in 2016

⁵ IEC 62133 is the main IEC standard for lithium batteries, IEC 62133 is the safety standard for lithium-ion batteries, ensuring high standards for design, construction, performance, and safety features. It prevents hazards like overcharging, short-circuiting, and thermal runaway, ensuring their safety for users

Reference number	Title	Description
ISO/IEC 15118-2	Road vehicles - Vehicle-to-grid communication interface - Part 2: Network and application protocol requirements	Vehicle-to-Grid Communication Interface
ISO/IEC 15118-3	Road vehicles - Vehicle-to-grid Communication Interface - Part 3: Physical and data link layer requirements	
ISO/IEC 15118-4	Road vehicles - Vehicle-to-grid communication interface - Part 4: Network and application protocol conformance test	
ISO/IEC 15118-5	Road vehicles - Vehicle-to-grid communication interface - Part 5: Physical layer and data link layer conformance test	
ISO 26262-2: 2018[1]	Road vehicles — Functional safety — Part 2: Management of functional safety	Missing Part 1; the Vocabulary for Management of Functional Safety
ISO 6722-1: 2011	Road vehicles - 60 V and 600 V single-core cables - Part 1: Dimensions, test methods and requirements for copper conductor cables	Cables
ISO 6722-2: 2013	Road vehicles - 60 V and 600 V single-core cables - Part 2: Dimensions test methods and requirements for aluminium conductor cables	
ISO 12405-4	Electrically propelled road vehicles —Test specification for lithium-ion traction battery packs and systems — Part 4: Performance testing	Lithium-Ion Batteries Testing
ISO 23274-1: 2019	Hybrid-electric Road vehicles — Exhaust emissions and fuel consumption measurements — Part 1: Non-externally chargeable vehicles	Hybrid Vehicles Performance
ISO 23274-2: 2021	Hybrid-electric Road vehicles — Exhaust emissions and fuel consumption measurements — Part 2: Externally chargeable vehicles.	
ISO 18300: 2016	Electrically propelled vehicles — Test specifications for lithium-ion battery systems combined with lead-acid battery or capacitor.	Li-Ion batteries Combined
UL 2580:2013[2]	Batteries for use in EVs	American Standard for Batteries

Reference number	Title	Description
IEC standards on EV and Batteries		
IEC 61851-1	Electric vehicle conductive charging system - Part 1: General requirements	Chargers and Charging Stations
IEC 61851-21-1	Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger electro-magnetic compatibility (EMC) requirements for conductive connection to AC/DC supply	
IEC 61851-21-2	Electric vehicle conductive charging system - Part 21-2: Electric vehicle requirements for conductive connection to an AC/DC supply - EMC requirements for off board electric vehicle charging systems	
IEC 61851-23	Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station	
IEC 61851-24	Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging	
IEC 61851-23	Electric vehicles conductive charging system - Part 23: DC electric vehicle charging station	Chargers and Charging Stations
IEC 61851-24	Electric vehicles conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging	
IEC 62196-1	Plugs, socket-outlets, vehicle connectors and vehicle inlets Conductive charging of electric vehicles - Part 1: General requirements	Plugs and Connectors
IEC 62196-2:2011	Plugs, socket-outlets, vehicle connectors and vehicle inlets Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories	
IEC 62196-3:2014	Plugs, socket-outlets, and vehicle couplers - conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for dedicated d.c. and combined a.c./d.c. pin and contact-tube vehicle couplers	

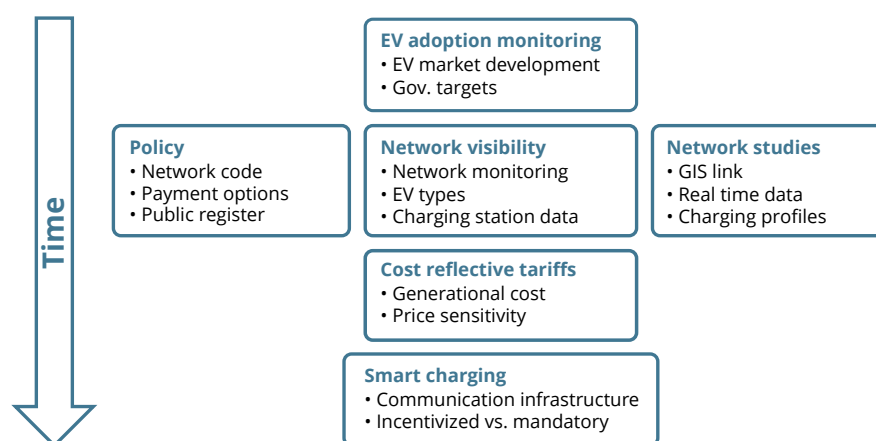
Reference number	Title	Description
IEC 62660-2:2010 Revised newer version 2018 [3]	Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing	Batteries (same as items 16,19,20 for ISO above)
IEC 62660-3:2016 Withdrawn newer version in 2022 [4]	Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 3: Safety requirements of cells and modules	
IEC 62752:2016	In-cable control and protection device for mode 2 charging of electric road vehicles (IC-CPD)	Communication same as items for ISO above)
IEC 62133 series[5]	Secondary cells and batteries containing alkaline or other non-acid electrolytes — Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications.	Batteries Safety Requirements

A.9 Data-driven strategy recommendations

In addition to the overall recommendations outlined above, there are specific recommendations related to EV-strategy development and the use of data-driven techniques for management of the sector.

The widespread integration of EVs into the power system from a utility perspective necessitates a dedicated, continuously evolving data-driven strategy. The figure below illustrates the key points to be addressed, based on the EV adoption rate, irrespective of vehicle type. Detailed explanations of the recommended steps are provided below.

FIGURE 70. Data-Driven EV-strategy recommendations



A.9.1 Electric vehicle adoption monitoring

Rwanda is in the early stages of EV adoption but is experiencing rapid growth, particularly in the electrification of buses and two-wheelers. Before implementing any EV-related measures, it is crucial to have dedicated knowledge about the current and future EV market development. The EV adoption rates developed in this study provide this essential information but require continuous updates, as projections are never completely accurate. Therefore, it is recommended to:

- Monitor EV sales data (eg, through country import or vehicle registration data)
- Track government targets
- Review EV policies
- Understand EV price trends (up-front cost vs. total cost of ownership)

REG should create the most likely adoption scenarios of EVs for internal use at least biannually. This recommendation is also valid for all other stakeholders involved in EVs, but REG should not rely entirely on external projections, as the goals of stakeholder groups are not always aligned. Considering REG's planning horizon, it is sufficient to consider the next 10 years of EV adoption.

It should be noted that under the current 10 percent annual general load growth projections, the additional peak load and energy requirements of EVs are not the driving factor for network expansion. However, continuous monitoring of EV adoption will ensure

that rapid developments are identified early, and necessary mitigation strategies are implemented in time.

A.9.2 Network policy

Once it is clear that EVs in the future will play a major role, as is the case for Rwanda, supporting policies should be put into place as soon as possible. Early establishment increases trust and reduces the risk of unnecessary retrofitting. However, policies should evolve over time to reduce the burden on early adopters. Network codes from countries with high EV adoption rates and international standards provide a good basis for structuring Rwandan policy.

From a utility perspective, integrating EVs into the network code is most important. The code should regulate:

- Personnel safety (eg, risk of electrocution)
- Network safety (eg, power factor)
- Certification process (eg, testing procedures)
- Charging station installation process
- Resale of electricity at charging stations
- Curtailment of charging power

Additional options to increase consumer trust, though typically not part of the network code, include:

- Uptime requirements for public charging stations
- Unified simple payment options (eg, credit card)
- National charging station registry

Uptime requirements ensure that public charging stations are operational and usable. For instance, in China, generous grants were provided for constructing public charging stations, but none for maintaining them, leading to many non-functional stations. This issue was remedied through policy changes.

Ease of use is another hindrance. Many regulations now require subscription-free payment options at all public charging stations, usually by installing credit card terminals.

Lastly a public charging station database provides users with important information, such as:

- Location
- Capacity
- Plug type
- Availability status
- Price

The database should be maintained by a government agency, with all public charging operators required to register. An API is necessary for stakeholders (eg, Google Maps, EV operators) to access the information. Ideally, a graphical interface should also be provided. For establishment, it is recommended to consult with government bodies of countries where such registries are already in place.

A.9.3 Network visibility

Real-time network status knowledge is essential to leverage the advantages of smart charging. Installing the necessary measurement equipment and establishing secure data exchange channels takes time. Therefore, it is recommended to start immediately, building on existing transformer monitoring at REG. For now, real-time loading values down to 15 kV are sufficient. If EV adoption monitoring indicates a substantial increase in private electric cars, monitoring down to the 400 V level may be necessary, as is the case in most developed countries. This needs to be studied for Rwanda, considering factors like Kigali's mountainous location, which complicates road network expansion and could lead to severe traffic congestion, emphasising the need to strengthen public transport.

In addition to monitoring the power network, all permanently mounted charging stations should be registered with the utility. Network access should only be provided if the location, capacity, and purpose of the charging station are shared with the utility through an online application form. This way, REG will have a comprehensive database of all charging stations, aligning with international best practices, and can base network expansion decisions on improved knowledge.

A.9.4 Network studies

Increased network visibility enhances the accuracy of network studies and readiness for smart charging. It is recommended to link GIS data with network modelling and real-time power system data. Corresponding training was provided to REG during the study, but full implementation is still pending.

Future network studies will also need to consider EV charging profiles. Currently, very limited data specific to Rwanda is available, so international profiles are used. Developing local profiles is time-consuming and requires either local mobility surveys or charging data. Mobility surveys better reflect long-term future charging needs, while real-world charging data better represents near-term needs but can be difficult to obtain unless the utility is a major CPO itself.

Since working and driving patterns are similar worldwide and the impact of EVs on overall load growth is expected to be small in Rwanda for at least the next 15 years, it is not recommended for REG to develop its own charging profiles yet. Only once data becomes easily accessible or significant deviations from international profiles are observed should REG conduct a detailed assessment.

A.9.5 Data needs for cost-reflective tariffs

EV charging negatively impacts the peak load to energy ratio. Cost-reflective tariffs, such as ToU tariffs, can mitigate this impact significantly and should be established. This recommendation applies to almost all customer groups but is especially relevant for EV charging. EVs can often shift their charging times without affecting users, making load management feasible. The impact of cost-reflective tariffs should be closely monitored to ensure they are set up correctly, avoiding under- or overreaction to price signals.

Knowledge of time-dependent power system operation costs is essential for developing cost-reflective tariffs. Often, generation costs per power plant are not well known. Establishing the necessary structures, down to dynamic fuel prices, is recommended. This strategy can also identify further savings opportunities, such as the installation of PV systems to reduce overall system costs, regardless of EV adoption.

A.9.6 Data needs for smart charging

Cost-reflective tariffs can mitigate much of the EV power system impact but do not ensure safe operation, since direct control is only possible with smart charging (V1G & V2G). Detailed benefits of smart charging are described in Chapter 3.2. From a data perspective, smart charging requires secure and well-functioning communication links, which is achievable if all previous recommendations are followed.

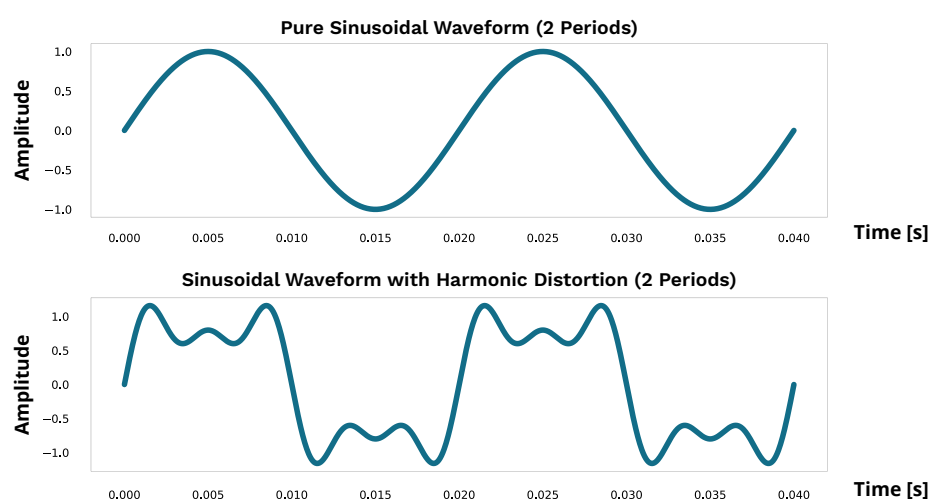
A.10 Harmonics and supraharmonics

Harmonics and potentially also supraharmonics pose a significant threat to power system stability if not properly managed. EV charging involves the rectification of AC to DC charging through power electronics, a process that inherently generates harmonics. The increasing number of electric vehicle registrations has raised power quality concerns among system operators, which will be addressed in this chapter.

A.10.1 Harmonics

Harmonics in power systems are voltage or current waveforms that are integer multiples of the fundamental frequency (eg, 50 Hz or 60 Hz). These harmonics distort the ideal sinusoidal waveform of the power supply, leading to various power quality issues. The primary cause of harmonics is non-linear loads, which draw current in abrupt pulses rather than in a smooth sinusoidal manner, as displayed in Figure 71. Common sources of these non-linear loads include power electronic devices like rectifiers and inverters (used for EV charging), variable frequency drives (VFDs), fluorescent lighting, and computers. The resulting harmonics are directly linked to the switching frequency. Correspondingly, the harmonic distortion depends on the rectifier design and whether countermeasures, such as filters, are installed within the charger⁸⁵.

FIGURE 71. Exemplary impact of harmonics on sinusoidal waveform found in AC networks



The presence of harmonics in a power system can have several detrimental effects. They can cause overheating in transformers, motors, and capacitors, leading to reduced efficiency and lifespan. Harmonics can also increase losses in the power system, resulting in higher energy consumption and operational costs. Additionally, they can interfere with the operation of sensitive electronic equipment, causing malfunctions or degraded performance. In severe cases, harmonics can lead to tripping of protective devices, resulting in power outages and potential damage to the electrical infrastructure.

Low-harmonic EV chargers or mitigation methods are essential to ensure needed power quality. Common mitigation techniques include passive filters, which block or reduce specific

⁸⁵ <https://evreporter.com/harmonic-pollution-and-ev-charging/>

harmonic frequencies through capacitors, inductors, or resistors, and active filters, which dynamically counteract harmonics by injecting currents of equal magnitude but opposite phase. Isolation transformers can also help by reducing harmonic transfer between different parts of the system. Additionally, employing power factor correction devices like capacitor banks and synchronous condensers can further mitigate harmonic effects.

A.10.2 Supraharmonics

Modern EV chargers, regardless of vehicle type and power consumption, operate with switching frequencies in the kHz range, resulting in supraharmonics. However, lower frequency harmonics from EV charging can still be observed at lower frequencies due to additional noise.

In the past decade, research in supraharmonic, has gained momentum to address the growing number of power electronics-based power consumption. Supraharmonic interference is a growing concern as it can lead to overheating of compensation capacitors and transformers, as well as the malfunctioning of protective devices. Additionally, supraharmonics occupy the same bandwidth as power line communication protocols, which can negatively impact the infrastructure for smart metering, communication, and control due to signal distortion^{86 87}.

A.10.3 Standards

Several standards have been established to ensure power system compliance⁸⁸:

- **IEEE 519** provides guidelines for harmonic control in electrical power systems, ensuring that harmonics are kept within acceptable limits to maintain power quality.
- **IEC 61000-3-2** specifies limits for harmonic current emissions for equipment connected to public low-voltage systems.
- **IEC 61000-2-2** addresses harmonic distortion with compatibility levels including supraharmonics.
- Informative testing and measurement methods for harmonic emissions are described in **IEC 61000-4-7, IEC 61000-4-30, IEC 61000-4-19, Digital CISPR 16-1-1, IEEE 519, and CENELEC EN 50065**.

A.10.4 Electric vehicle network impact assessment

As EV adoption grows, limiting this source of harmonics becomes increasingly important. Several studies have evaluated the impact of harmonics from EV charging on the power system. The exact hosting capacity derating value is case dependent based on the network impedance, the evaluated EV chargers, and most importantly the share of power electronics-based energy consumption. Transformer derating becomes significant once the EV charger induced load exceeds 80 percent of the overall load. Correspondingly at maximum penetration rates current on-board EV chargers can reduce the hosting capacity of local transformers by up to 3-10 percent, due to often failing to meet the standards mentioned above^{89 90}. These maximum

⁸⁶ <https://link.springer.com/article/10.1007/s40866-024-00195-4>

⁸⁷ <https://www.mirusinternational.com/downloads/Harmonic-Mitigation-for-EV-Fast-Chargers.pdf>

⁸⁸ <https://www.mdpi.com/2624-6511/5/2/27>

⁸⁹ <https://www.epri.com/research/products/000000000001000664>

⁹⁰ <https://www.intechopen.com/chapters/1162280>

penetration levels are not close to being reached in most distribution networks where EV charging is spread out. In these systems the harmonics impact is negligible.

The exception might be transformers dedicated for EV charging, such as at bus depots, where harmonics could cause life time reductions. For instance, there was a case in the UK where EV charging at a car dealership caused transformer failure due to critical frequency oscillations from charging the same type of vehicle at the same time. Regardless of these localised issues, the impact of harmonics decreases with distance⁹¹. The impact of harmonics from EV charging on nearby nodes was found to be negligible due to cancellation effects.

In general, power system issues due to harmonics from EV charging are rare, and no widespread issues are known. An exception might be Bangladesh, where very low-quality chargers are used to recharge so-called EasyBikes. EasyBikes are lead-acid battery-based electric three-wheeler taxis, with a typical range of 100 km at maximum speed of 40 km/h. To save costs, most chargers are essentially an aluminium coil transformer coupled with a single diode, chopping the AC input in half at the desired DC voltage. This DC pulse charge is tolerated by lead-acid batteries but not lithium-ion batteries. The efficiency and overall power quality of these chargers is very low, severely impacting the power grid.

For supraharmonics, very limited information is available since the potential negative effects are in the early stage of investigation. ElaadNL, a Dutch institute dedicated to the safe integration of electromobility into the power system, proposed supraharmonic emission limits for EV charging for low-voltage installations in 2023⁹². These proposed limits are loosely based on IEC 61000-2-2 and their own experiments. It was found that the summation and interaction of supraharmonics differ from harmonics. Due to interaction, increased emissions and time-varying effects can occur.

Based on the proposed limits, ElaadNL tested 43 different electric car AC chargers for compliance. It was found that about 50 percent of the chargers comply, and another 20 percent are close to meeting the optimal limit. The remaining 30 percent of electric cars induce severe supraharmonics. This shows that the lack of standards and incentives for manufacturers to improve power quality emissions from their products may negatively impact the grid, even though compliance is possible.

A.10.5 Recommendations for Rwanda

Electric vehicle chargers that comply with international standards on harmonics will not cause significant issues within the network. Charger compliance is typically demanded by national grid codes and should be adopted in Rwanda as well. The utility is recommended to have the right to test for compliance but should not make it a mandatory part of the network connection evaluation. However, if the utility has reasonable concerns that chargers do not comply, on-site testing could be conducted to evaluate the impact. If the charging equipment induces harmonics above the acceptable limit, the operator is responsible for rectifying the situation, for example, through the installation of additional filters. It makes sense for the operator to hold the charging station manufacturer responsible if the operation is outside of specification. Although corresponding risk management is part of the charge point operator's responsibilities.

⁹¹ https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1468&context=ece_fac

⁹² <https://elaad.nl/en/projects/tepgev/>

From the utility perspective, it is more important to monitor if a market for ultra-low-cost chargers, similar to those in Bangladesh, develops. In this case, active discouragement is needed. Since these chargers are closely linked to lead-acid battery charging, it probably will not become an issue, as lead-acid-based EVs will likely not reach mass adoption anymore. Still, close monitoring is suggested to ensure standard compliance of all chargers.

Electric vehicle charging always cause some level of harmonics, which can become problematic if a high percentage of EV charging at one location is reached. This is often the case for fast charging hubs, for example as at bus depots. It is recommended to consider sufficient headroom during the transformer selection process of up to 10 percent depending on the charger quality and other factors to avoid premature ageing. For instance current plans on transformer rating for the Nyabugogo bus terminal include sufficient capacity.

In most other charging scenarios, where EV charging is spread throughout the network, such as residential EV charging, the share of the overall power electronics-based electricity requirement is still low enough that transformer derating is negligible. As electric vehicle uptake in Rwanda is at an early stage the harmonics impact of EV charging does not yet have to be considered.

Lastly, it was shown that the switching frequency of modern EV chargers is in the supraharmmonic range. Current standards cover this frequency band only to some extent, although this might change in the future. With a growing number of inverter-based systems, supraharmonics might become problematic, and action will be required. International developments should therefore be evaluated on an annual basis.

In summary the following is recommended:

1. Chargers should comply with harmonics standards.
2. Monitor and potentially prevent the widespread adoption of low-quality chargers.
3. Consider headroom for harmonic impact during the selection of transformers dedicated to EV charging (eg e-bus depots).
4. Transformers with a low share of power electronic consumption do not require derating.
5. International uptake on supraharmmonic standardisation should be monitored.

A.11 Example bill of quantities for fast charging stations

The power supply to EV chargers requires a detailed assessment, including a site survey and the preparation of a bill of quantities. For example, a charging station with 2 x 120 kW chargers (serving 6 charging points) may require a transformer with a capacity exceeding 300 kVA. Commonly available transformer sizes include 315 kVA and 400 kVA, and the final selection would also need to account for any additional auxiliary loads that the transformer will need to support.

There are the minimum key points to consider while conducting a site survey. These include

- Understanding the voltage level of the existing network
- Installation type (Overhead or underground) for the existing line and new line
- Assessing whether the existing network can accommodate the new load
- Location where the transformer and charger will be installed
- Choosing the appropriate line route to the transformer and charger

The sizing of equipment and preparation of quotations should always adhere to applicable standards. The transformer will be connected to the MV network and below is the list of materials categories to consider when preparing a bill of quantities:

- MV line conductors or cables with accessories
- Cross arms with accessories
- MV switching and protection equipment with accessories
- MV lines support structures (Poles, towers) in case of overhead lines
- Transformer with accessories
- LV distribution board equipped with appropriate protection system
- LV line with all associated materials
- Earthing system

For the installation of the charging station, the table is below and is based on an example of a recently installed charging station in Rwanda which could accommodate 6 charging points.

TABLE 42. Itemised list of costs for installation of 2 x 120 kW charging station

	Item	Description	Unit	Quantity
Charging station	Charging station	2 x 120 kW cabinet with 6 total charging connections	Pcs	2
Station cabling	70 mm ² earthing cable - stranded	For main earthing - includes neutral at pole, pole to cabinet and earthing pit	m	45
	Cable ties	Bags	Pcs	2
	Heat resistant tape	For lugs and connectors	Pcs	5
	Pressure sensitive MV tape	For lugs and connectors	Pcs	5
	100 mm diameter PVC Elbow	For cable coming in and out of control unit, and coming in the pedestals	Pcs	10
	XLPE/SWA/PVC 4*120 mm ² CU cable	From last pole to cabinet (10 m)	m	20
	XLPE/SWA/PVC 4*95 mm ² CU cable	From last pole to cabinet (10 m)	m	20
	XLPE/SWA/PVC 4*95 mm ² CU cable	DC cable - 1 per charger cabinet	m	32
	50 mm ² earthing cable - stranded	DC charger pedestal earthing	m	64
	CU CAT6 cable	For communication	m	32
	EMT conduit	For shielded communication conduit	m	20
	EMT conduit - elbows	For shielded communication conduit	Pcs	2
	PVC 25 mm conduit	For AC power cabling for pedestals (4 m each)	Pcs	20
	PVC cable gland	PG9 cable gland	Pcs	14
	Cable lugs - DT120-12	Wiring into cabinet	Pcs	10
	Cable lugs - DT70-10	Wiring into cabinet - earthing cable	Pcs	2
	Cable lugs - DT95-10	Wiring into charger pedestals - DC cable	Pcs	28

	Item	Description	Unit	Quantity
Station cabling	Cable lugs - DT50-8	Wiring into charger pedestals - earthing cable	Pcs	8
	2x4mm ² cable	220 V supply cable for pedestals	m	32
Station cabling	Warning tape	To be placed above buried cable	m	52
	Earth rods - 1 m	For earthing network at the installation	Pcs	6
	50 mm brass SWA cable gland	For wiring at AC charger cabinet	Pcs	3
	50 mm brass SWA cable gland	For wiring at charger pedestals	Pcs	3
Civil works	Rebar - 10 mm	For foundation anchoring	Pcs	4
	Rebar - 12 mm	For foundation anchoring	Pcs	2
	Rebar - 14 mm	For foundation anchoring	Pcs	2
	M12 threaded rod	For anchoring chargers to foundations	Pcs	3
	Welder labour	For fixing the foundation rebar	Day	1
	PVC pipe - 110 mm	For entry into foundation cavity	Pcs	2
	Wooden board - 1000*800*1.5	For concrete mould	Pcs	4
	Wooden board - 450*286*1.5	For concrete mould	Pcs	1
	Sand - wheelbarrow	To be put above buried cable	Pcs	5
	Sand - wheelbarrow	For charger foundations	Pcs	10
	Gravel - wheelbarrow	For charger foundations	Pcs	10
	Cement - 25 kg bag	For charger foundations	Pcs	7
	Vibrator hire	For settling concrete	Day	2
	Fuel for vibrator	For settling concrete	Litre	5
	Bollards	For protecting pedestals and the cabinet	Pcs	9
	Mason labour		Day	2

	Item	Description	Unit	Quantity
Installation and logistics	Technician labour		Day	12
	Informal labour		Day	12
	Engineer labour		Day	5
	Management costs		Day	3
	Transport and logistics		Pcs	4
	Crane truck hire		Day	1
	Per diems		Day	17
Other	Earthing system	Earthing chemicals (Charcoal, salt etc...)	Pcs	1
	Trash bags		Pcs	10
	Plumbing materials	Moving the fire hydrant	Pcs	1
	Plumber wages	Moving the fire hydrant	Pcs	1
	Contingency		Pcs	1

	Item	Unit price (RWF)	Total price (RWF)	Total price (US\$)
Charging station	Charging station	15,000,000	30,000,000	21,367.52
Station cabling	70 mm ² earthing cable - stranded	15,130	680,850	484.94
	Cable ties	30,260	60,520	43.11
	Heat resistant tape	1,180	5,900	4.20
	Pressure sensitive MV tape	5,900	29,500	21.01
	100 mm diameter PVC Elbow	8,260	82,600	58.83
	XLPE/SWA/PVC 4*120 mm ² CU cable	130,000	2,600,000	1,851.85
	XLPE/SWA/PVC 4*95 mm ² CU cable	100,000	2,000,000	1,424.50
	XLPE/SWA/PVC 4*95 mm ² CU cable	100,000	3,200,000	2,279.20

	Item	Unit price (RWF)	Total price (RWF)	Total price (US\$)
Station cabling	50 mm ² earthing cable - stranded	10,250	656,000	467.24
	CU CAT6 cable	638	20,416	14.54
	EMT conduit	2,360	47,200	33.62
	EMT conduit - elbows	1,000	2,000	1.42
	PVC 25 mm conduit	2,714	54,280	38.66
	PVC cable gland	2,360	33,040	23.53
	Cable lugs - DT120-12	9,000	90,000	64.10
	Cable lugs - DT70-10	6,000	12,000	8.55
	Cable lugs - DT95-10	9,000	252,000	179.49
	Cable lugs - DT50-8	6,000	48,000	34.19
	2x4mm ² cable	2,200	70,400	50.14
	Warning tape	1,180	61,360	43.70
	Earth rods - 1 m	13,200	79,200	56.41
	50 mm brass SWA cable gland	13,125	39,375	28.04
	50 mm brass SWA cable gland	13,125	39,375	28.04
Civil works	Rebar - 10 mm	15,000	60,000	42.74
	Rebar - 12 mm	20,000	40,000	28.49
	Rebar - 14 mm	26,250	52,500	37.39
	M12 threaded rod	10,620	31,860	22.69
	Welder labour	27,765	27,765	19.78
	PVC pipe - 110 mm	17,700	35,400	25.21
	Wooden board - 1000*800*1.5	29,500	118,000	84.05
	Wooden board - 450*286*1.5	14,160	14,160	10.09
	Sand - wheelbarrow	5,412	27,060	19.27
	Sand - wheelbarrow	5,412	54,118	38.55
	Gravel - wheelbarrow	5,412	54,118	38.55
	Cement - 25 kg bag	13,800	96,600	68.80

	Item	Unit price (RWF)	Total price (RWF)	Total price (US\$)
Civil works	Vibrator hire	47,353	94,706	67.45
	Fuel for vibrator	1,900	9,500	6.77
	Bollards	57,500	517,500	368.59
	Mason labour	10,824	21,648	15.42
Installation and logistics	Technician labour	52,500	630,000	448.72
	Informal labour	20,761	249,132	177.44
	Engineer labour	106,250	531,250	378.38
	Management costs	250,000	750,000	534.19
	Transport and logistics	100,000	400,000	284.90
	Crane truck hire	216,200	216,200	153.99
	Per diems	5,882	100,000	71.23
Other	Earthing system	35,400	35,400	25.21
	Trash bags	694	6,940	4.94
	Plumbing materials	88,500	88,500	63.03
	Plumber wages	59,000	59,000	42.02
	Contingency	931,000	931,000	663.11
Total			45,416,372	32,347.84



