RENEWABLE POWERED ELECTRIC BUS DEPOT DESIGN AND STRATEGIES

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RENEWABLE POWERED ELECTRIC BUS DEPOT DESIGN AND STRATEGIES

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List of Abbreviations

AC	Alternating Current
AIS	Automotive Industry Standards
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
BOOT	Build Own Operate and Transfer
CAN	Controller Area Network
CAPEX	Capital Expenditure
C&I	Commercial and Industrial
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
COD	Commercial Operation Date
CPO	Charge Point Operators
DC	Direct Current
DISCOM's	Electricity Distribution Companies
DT	Distribution Transformer
EHV	Extra High Voltage
EN	European Standard
EV	Electric Vehicles
EVSE	Electric Vehicle Supply Equipment
GEOA	Gujarat Electricity Open Access
GHG	Green House Gas
GST	Goods and Services Tax
GUVNL	Gujarat Urja Vikas Nigam Limited
GWh	Giga watt hours
HT	High Tension
HVAC	Heating, Ventilation and Air Conditioning
HV RMU	High Voltage Ring Main Unit
ICE	Internal Combustion Engine
IEC	International Electrochemical Commission
IS	International Standard
IT	Information Technology
kVA	Kilo Volt Ampere
kW	Kilowatt
kWh	Kilowatt Hours
LoS	Level of Service
LT	Low Tension
LV S-Board	Low Voltage Switchboard
MHI	Ministry of Heavy Industries
MoHUA	Ministry of Housing and Urban Affairs
MoP	Ministry of Power

MoRTH	Ministry of Road Transport and Highways
MW	Mega watt
MWh	Mega watt hours
NDC	Nationally Determined Contribution
NEC	National Electrical Code
NFPA	National Fire Protection Association
OA	Open Access
OEM	Original Equipment Manufacturers
PCS	Public Charging Stations
PCS	Public Charging Stations
PF	Power Factor
PLC	Power Line Communication
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PSS	Power Sub-Station
PT	Public Transport
PV	Photovoltaic
RE	Renewable Energy
REC	Renewable Energy Certificate
RESCO	Renewable Energy Service Company
RPO	Renewable Purchase Obligation
SCADA	Supervisory Control and Data Acquisition
SDG	Sustainable Development Goals
SERC	State Electricity Regulatory Commission
SLB	Service Level Benchmark
SOP	Standard Operating Procedures
SPS	Solar Power System
STU	State Transport Undertakings
ToU	Time-of-Use

About the Report

This report presents a comprehensive and practical guide for the development of RE- Powered Electric Bus (E-Bus) Depots, aimed at supporting India's transition to a sustainable, low-emission public transport system. It is designed to assist policymakers, public transport authorities, and technical experts in making informed decisions related to site planning, energy sizing, capital expenditure (CAPEX) optimisation, and the overall planning, design, implementation, and operation of energy-efficient e-bus depots.

A key focus of the report is to present the conceptual framework of RE- powered e-bus depots, by integration of renewable energy sources (e.g., rooftop solar) along with the implementation of energy-efficient systems, and optimised operational practices. It also explores design principles, implementation challenges, and best practices from domestic and global case studies. Special emphasis is placed on integrated depot design[1] to enhance energy efficiency, cost optimisation, and operational sustainability. It also provides technical guidance on infrastructure planning, covering charging station placement, space allocation, grid integration, and Electric Vehicle Supply Equipment (EVSE) deployment. This framing helps translate the broad concept of "greening[2] " into practical strategies that support low-emission, resource-efficient depot operations.

For technical experts, planners, and key stakeholders—both directly and indirectly involved in public transportation—this report provides structured methodologies for developing energy strategies. It includes approaches for analysing route-specific energy and power consumption patterns, as well as estimating energy and power requirements to support future fleet expansion. In addition, the report incorporates relevant regulatory and safety standards pertaining to electric vehicle (EV) charging infrastructure, with a particular focus on e-bus depots. This study is aligned with the Ministry of Power's 2022 framework and its subsequent amendments, along with the latest 2024 directives draft issued by the Bureau of Energy Efficiency ((BEE), 2024).

A dedicated section addresses renewable energy integration, focusing on rooftop solar deployment, demand estimation, cost analysis, and environmental benefits assessment. Additionally, the report examines the role of Electricity Distribution Companies (DISCOMs) in ensuring reliable and cost-effective power supply, with a comparative analysis of power procurement mechanisms, including net metering, gross metering, and open access.

The report concludes with strategic recommendations and a way forward, translating technical insights into actionable policy measures and institutional capacity-building pathways. It aims to equip national and state-level agencies with the knowledge to develop climate-resilient, financially viable, and technically sound green mobility infrastructure.

[1]Integrated depot design refers to a planning approach where all key facilities and systems needed for operating electric buses—such as parking, maintenance, charging infrastructure, energy supply (like rooftop solar), staff areas, and traffic flow—are planned together in a coordinated way. This helps ensure efficient space use, smooth operations, and long-term cost savings while supporting clean and sustainable transport

[2] Greening" in the context of e-bus depots refers to the adoption of environmentally sustainable practices, including the integration of renewable energy (such as rooftop solar), energy-efficient systems and appliances, eco-friendly infrastructure design, and operational strategies that reduce carbon emissions and resource consumption.


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Introduction

1.1 Background of the study

Over the last decade, cities across India have begun transitioning toward cleaner public transport systems. Electric buses (e-buses), powered by grid-based and or renewable electricity, are emerging as a viable alternative to conventional diesel-powered Internal Combustion Engine (ICE) buses in India, major metropolitan cities such as Delhi, Mumbai, Bengaluru, and Pune have launched large-scale e-bus adoption programs through their State Transport Undertakings (STUs), catalysing the shift from ICE fleets to electric mobility. This transition has also gained traction in tier 2 and tier 3 cities, supported by central government schemes and peer learning from metro cities. To support these transition policies like the FAM`E-II (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles), PM e-Bus Sewa scheme and state-level efforts have accelerated e-bus deployment (MHI, 2025; MoHUA, 2023). The government's PM E-bus Sewa Scheme, launched in August 2023, targets the deployment and operation of 10,000 e-buses in 169 cities with populations under 4 million, as part of a broader effort to enhance sustainable mobility. (Ministry of Housing and Urban Affairs, Government of India, 2023).

As part of the initial implementation phase, 7293 e-buses have been approved for deployment across 14 States and 4 Union Territories. To support this rollout, the government has sanctioned ₹983.75 crore for the deployment of depot infrastructure – comprising ₹563.34 crore for power infrastructure in 66 cities and ₹420.40 crore for civil depot

Sr. no.	State/UT	1st tranche released (rupees in crore)	Year
1.	Bihar	87.55	Financial year 2024-25
2.	Gujarat	9.06	
3.	Chandigarh	11.87	
4.	Assam	6.47	
5.	Chhattisgarh	30.18	
6.	Maharashtra	200.18	
7.	Odisha	47.72	
8.	Rajasthan	44.46	
Total		437.50	

Table 1: PM E-Bus Sewa scheme status quo

facilities in 64 cities. The actual deployment of these e-buses is contingent upon the readiness of the associated depot infrastructure and the fulfilment of the condition's precedent outlined in the PM e-Bus Sewa Tender. In development so far, ₹437.50 crore has been disbursed for the development of power and civil infrastructure in 7 States and 1 Union Territory in Financial Year 2024-25 as described in Table 1

As per the Scheme guidelines, 2 cities of Telangana namely, Warangal and Nizamabad are eligible for 100 and 50 e-buses respectively. However, these cities have not participated under the scheme. Cities having population more than 40 Lakhs as per census 2011 including Hyderabad are not eligible under the scheme. To further accelerate the adoption of e-buses, the government has outlined plans under scheme announced at central level (PM E-DRIVE and PM E-BUS SEWA) to induct over 24,000 additional e-buses. This includes 14,028 e-buses under the Prime Minister Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) scheme, targeting cities with populations exceeding 4 million such as Delhi, Mumbai, Kolkata, Chennai, Ahmedabad, Surat, Bangalore, Pune, and Hyderabad (MHI, 2024). And under the first phase of PM E-Drive 10,900 e-buses have been allocated across five cities: Bengaluru - 4,500, Delhi – 2800, Hyderabad – 2,000, Ahmedabad – 1,000, Surat – 600 that leaves 3,128 of the original 14,028 units still unassigned (potentially repurposed or in planning).

Effective management (particularly for energy procurement, charging infrastructure, and other logistical arrangements required for smooth on-road operations) is essential not only for logistics but also as a foundation for sustainable public transport. While e-buses offer a cleaner alternative to conventional public transport, several systemic integration challenges remain. Operational issues such as inefficient energy management, limited charging infrastructure, lack of technical know-how on charging optimisation, and weak battery lifecycle planning highlight the need for standardised depot design and management frameworks, especially for replication in second- and third-tier cities.

To support this transition, the Ministry of Heavy Industries (MHI), in collaboration with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, is implementing the Promotion of Transformation to Sustainable and Climate-Friendly E-Mobility project. This initiative, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) under the Indo-German Green Urban Mobility Partnership (GUMP), aims to support India's transition to sustainable urban transport. As part of this effort, GIZ has commissioned a study titled Climate-Friendly Electric Mobility Transition, Implementation, and Knowledge Dissemination for Surat, to be conducted by the Centre of Excellence in Urban Transport, CRDF. This study seeks to develop actionable guidelines for designing renewable energy (RE)-powered e-bus depots, using Surat as a representative case study.

1.2 Need of the study

A major challenge in scaling e-bus adoption is the mismatch between current depot infrastructure readiness and the operational requirements of e-bus fleets. While procurement plans are ambitious, many depots lack the necessary energy capacity, charging systems, and spatial layout to support efficient operations. Bridging this gap is critical to ensure timely deployment and sustainable performance of electric public transport systems. Driven by favourable policies, regulatory frameworks, national funding schemes, and operational learnings from early adopter cities, the transition from traditional ICE buses is gaining momentum. However, many existing bus depots, some of which are several decades old, are not equipped to meet the specific requirements of e-buses. These depots often lack adequate charging infrastructure, renewable energy integration, and the necessary technical upgrades to support a sustainable e-bus ecosystem.

Moreover, the absence of standardised and updated technical guidelines for e-bus depots in India, combined with outdated design practices and fragmented norms, highlight the urgent need for a structured, forward-looking approach. In response, the concept of a **'RE-Powered E-Bus Depot'**, is proposed as a systematic solution - integrating renewable energy, optimised spatial planning, and energy management systems.

RE-powered e-bus depots are purpose-built facilities designed to accommodate the operational needs of e-buses while prioritising sustainability. They incorporate smart technologies, renewable energy solutions, and efficient fleet management systems to minimise reliance on fossil fuels and reduce carbon emissions. By incorporating passive design features, energy-efficient layouts, and solar integration, the depots lead to reduction in life-cycle emissions while aligning with **India's Nationally Determined Contribution (NDC) targets and Sustainable Development Goals (SDG) 11 objectives.**

Developing comprehensive guidelines for RE-powered e-bus depot design is essential to standardising this transition, improving operational efficiency, and delivering long-term environmental and economic benefits for India's urban mobility systems.

1.3 Objectives of the study

The transition from ICE buses to e-buses demands a robust, sustainable, and well-integrated energy infrastructure to support the e-buses deployments within depot environments. The Bus operators and other key stakeholders responsible for delivering efficient public transport services require clear, actionable guidance to manage both current and anticipated expansions of e-bus fleets across urban and intercity networks. This RE-powered e-bus depot design and strategies have been developed to address that need.

By integrating assessments of **Distributed Solar Rooftop (DSR) potential with the energy requirements for e-bus charging,** the report serves as a strategic planning resource for stakeholders within the public transport ecosystem.

By leveraging rooftop solar installations at bus depots and incorporating smart charging strategies, this study aims to:

- **Enhance energy efficiency** by maximising the use of renewable power sources.
- **Reduce greenhouse gas (GHG) emissions** by substituting grid-based or diesel-generated electricity with on-site solar and clean power procurement.
- **Improve cost-effectiveness through optimised power planning and energy management,** via time-of-day charging, banking mechanisms, and transformer capacity optimisation.

In additional to strategic guidance, the study offers technical, financial, and operational insights to support data-driven decision-making. It is designed to enable a scalable, cost-effective, and resilient transition to clean public transportation. Developed with a dynamic and adoptive approach, it aligns with national sustainability goals and supports transport and energy planners in:

- Assessing depot energy needs and clean energy generation potential

- Designing and deploying appropriate e-bus charging infrastructure

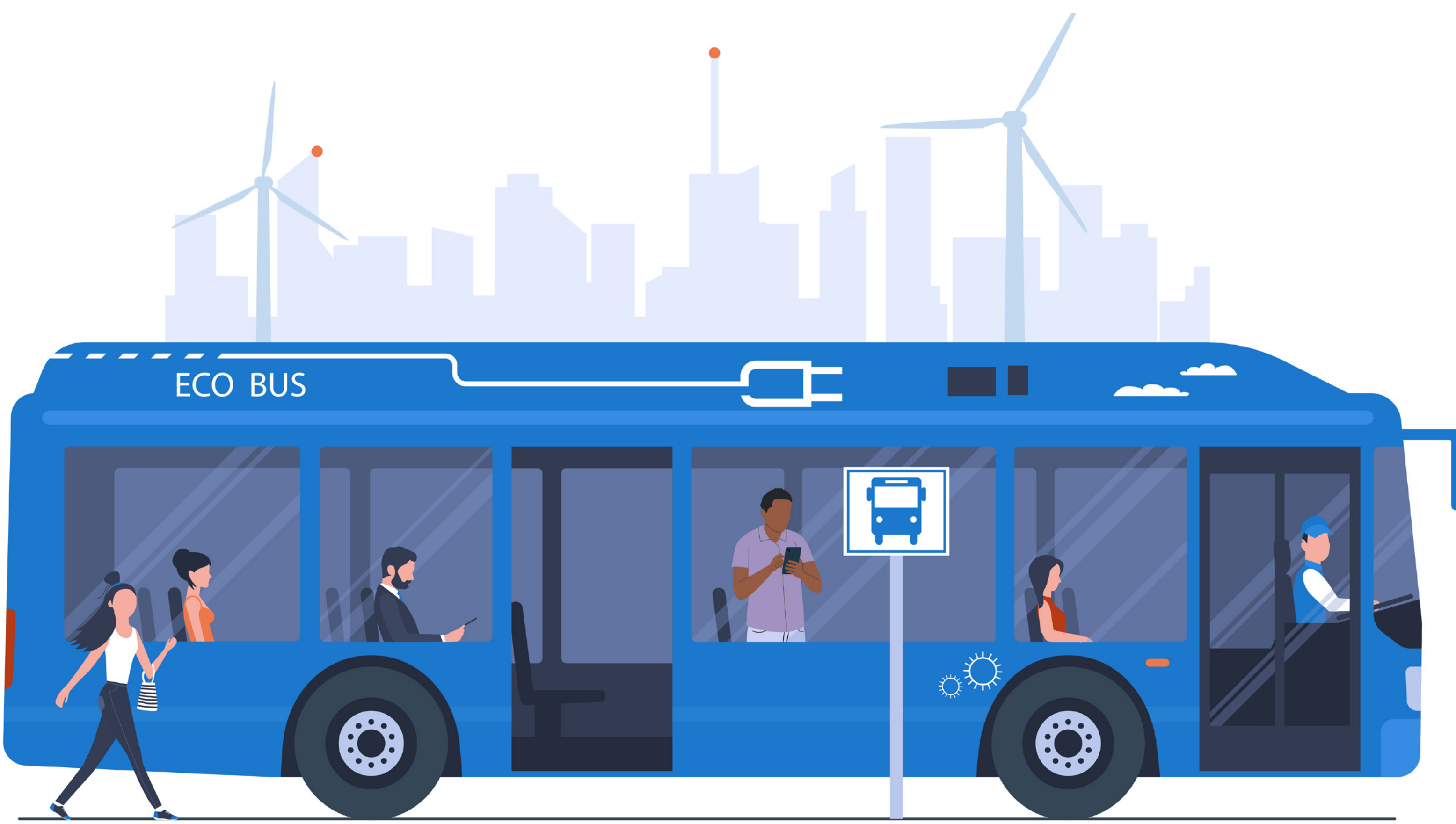
- Strategically planning for long-term energy security in depot operations

Furthermore, the study emphasises optimal utilisation of depot shade-free areas, maximising solar energy harvesting. It integrates this with a holistic energy management framework tailored for e-bus operations, thereby ensuring a future-ready, energy-secure, and environmentally sustainable public transit ecosystem.

1.4 Beneficiaries from the study

This study on **RE-Powered E-Bus Depot Design and Strategies** is a comprehensive resource developed to support planners, government authorities, infrastructure designers, and decision-makers in addressing the diverse and evolving requirements of various depot typologies tailored for e-bus operations. It equips stakeholders with the necessary tools and frameworks needed to define and finalise both functional (such as energy & infrastructure) and spatial requirements (including charging infrastructure and integration of solar energy). This ensures that depot designs are fully aligned with the specific operational demands of e-bus fleets. By addressing scalability and operational efficiency, the guideline enables the seamless adoption of e-buses while aligning with broader goals of sustainability and smart urban development. Furthermore, standardising approaches to RE-powered depot development, the study promotes improved service reliability, reduced operational costs, and enhanced environmental objectives.

Ultimately, the study delivers substantial value to all stakeholders by enabling the efficient operation of e-bus ecosystems and supporting the nationwide shift towards cleaner, greener, and future-ready public transportation systems.



State Transport Undertaking (STUs)/Transit Operators	Urban Planners and Engineers
• **Operational clarity:** Offers clear technical specifications for depot layouts, charging systems, and fleet management, simplifying the transition to e-bus operations. • **Enhanced efficiency:** Incorporates smart technologies and renewable energy solutions, reducing downtime and operating costs. • **Future readiness:** Ensures depots are scalable and adaptable to future advancements in e-bus technologies and fleet expansions.	• **Technical reference:** Acts as a comprehensive guide for designing and constructing depots tailored to e-bus requirements. • **Sustainability focus:** Encourages the use of eco-friendly materials and renewable energy, contributing to green urban infrastructure development. • **Risk mitigation:** Reduces the likelihood of design errors or oversights, ensuring depots are built to handle the technical demands of electric fleets.

Renewable Energy Providers and Private Sector/Investors
Market opportunities: Facilitates the integration of renewable energy solutions, such as solar panels and battery storage, into depot operations, creating growth potential for energy providers and private investors. **Collaborative ventures:** Promotes public-private partnerships and smart grid technologies, fostering synergy between energy providers, transit operators, and investors to optimise energy demand and depot functionality.

02

Understanding of RE-Powered E-bus Depot

2.1 RE-powered e-bus depot

Transitioning to e-buses involves far more than simply new vehicles - it requires a fundamental rethinking of the supporting infrastructure that ensures their safe, efficient, and sustainable operation. Among the most critical components of this ecosystem is the bus depot, which functions as the physical and operational anchor of e-bus fleet.

A RE-powered **e-bus depot** is a purpose-built or retrofitted facility designed to meet the complete lifecycle needs of electric buses through environmentally responsible, energy-efficient, and technologically advanced infrastructure. These depots serve as integrated operational hubs that typically include:

- Charging infrastructure tailored to fleet requirements
- Transformer-based power distribution systems
- Battery storage and safety management zones
- Fleet monitoring and control centres,
- Maintenance and service workshops.

What distinguishes the proposed RE e-bus depots is incorporation of renewable energy solutions - such as rooftop or elevated solar photovoltaic (PV) systems alongside energy-efficient layouts, and smart technologies. These may include Supervisory Control and Data Acquisition (SCADA) systems, load balancing algorithms, and digital energy metering. Collectively, these elements not only ensure reliable daily operations of e-bus fleets, but also to contribute meaningfully to long-term emission reduction and climate resilience goals.

2.2 Strategic role of RE-powered depots in sustain able urban mobility

By embedding clean energy integration, optimised charging, and safety compliance at the design phase, **RE-powered e-bus depots** sever as critical enablers of India's broader ambitions for sustainable urban mobility and decarbonised public transport. Their planning and operation aligned with emerging national and global standards, including:

- The Ministry of Power's Electric Vehicle (EV) Charging Guidelines (2022)
- The Central Electricity Authority's (CEA) technical codes for power infrastructure
- State electricity board regulations related to open access, load management, and demand forecasting.

Transitioning to e-buses therefore extends well beyond vehicle acquisition - It necessitates the creation of robust and future-ready depot infrastructure. A RE-powered e-bus depot is central to this transition, acting as a command centre for sustainable fleet operations. Through the integration of renewable energy sources, advanced energy management, and smart fleet coordination, these depots reduce dependency on fossil fuels and enhance the operational resilience of electric bus services. Ultimately, Re-powered e-bus depots represent a strategic investment in building cleaner, more efficient, and environmentally sustainable public transport – contributing directly to national climate goals and the vision of a greener urban future.

2.3 Application of RE-powered e-bus depot design

The transition from legacy ICE bus fleets to electric buses presents both significant opportunities and complex infrastructure challenges. While many existing bus depots - originally developed for diesel bus operations - will continue to be used as operational bases for electric fleets, these facilities often require substantial retrofitting. Upgrades are needed to accommodate high-power charging systems, energy-efficient layouts, and safety protocols tailored to electric mobility.

Simultaneously, the growing pace of urbanisation and public transport rapidly expanding cities has created a pressing need for the development of entirely new depot infrastructure. These facilities can typically be classified into two categories:

- **Brownfield depots,** which involve retrofitting or upgrading existing facilities to meet the electrical, spatial, and operational requirements of e-bus fleets.

- **Greenfield depots,** which are built from scratch on undeveloped land, offering the opportunity to optimise depot design from the outset, including the layout of chargers, substations, maintenance bays, and renewable energy systems.

This RE-powered e-bus depot is designed to be applicable to both greenfield and brownfield contexts. It provides a structured planning and design framework that addresses the technical and functional requirements of electric buses across both scenarios. These include:

1. Integration of scalable, modular charging infrastructure.

2. Load forecasting and energy planning for depot electrification.

3. Allocation of space for EV-specific maintenance, battery storage, and grid equipment.

4. Compliance with safety, fire protection, and power distribution standards.

By applying the principles outlined in this study, city and state agencies can ensure that both new and existing depots are future-ready, energy-efficient, and aligned with India's sustainability and urban mobility objectives. Whether through the renovation of ageing ICE-era facilities or the development of purpose-built electric depots, the Re-Powered E-Bus Depot Design and Strategies provides a comprehensive and adaptable guide for enabling a seamless, cost-effective, and environmentally sound transition to electric bus operations.

2.4 Components of RE-powered e-bus depot

The design and development of a RE-powered e-bus depot requires meticulous technical planning and coordinated execution to ensure that the facility is energy-efficient, operationally robust, and aligned with long-term sustainability and safety objectives. Unlike conventional depots developed for diesel fleets, e-bus depots necessitate substantial electrical infrastructure upgrades, integration of renewable energy sources, and system-wide smart controls to manage high-power loads and optimise energy use. The core components of a RE-powered depot can be categorised into three primary domains:

- Charging and electrical infrastructure
- Renewable energy integration
- Safety, security,and environmental management

Additionally, several traditional depot features – such as operational, maintenance bays, internal circulation, and staff amenities, must be reconfigured to support electric bus-specific requirements.

A. Charging and electrical infrastructure: RE-powered depots must be equipped with well-designed charging systems that align with the operational cycle of the fleet and local grid constraints.

I. Charger optimisation and placement: Determining the number, capacity (e.g., 60 kW, 120 kW, 180 kW), and optimal positioning of slow (overnight) and fast (opportunity) chargers based on route length, battery size, and turnaround schedules.

II. **Power substation and evacuation design:** Planning dedicated High Tension (HT) substations within or near depot premises to supply continuous, reliable power. Layout should account for transformer capacity, safety clearance, cable trenching routes, and contingency provisioning (e.g., dual feed).

III. **Information Technology (IT) and automation systems:** Integrating load management software, energy dashboards, and smart metering tools to optimise charging schedules, avoid peak demand penalties, and monitor power quality in real time.

B. Renewable energy integration: To reduce dependency on grid electricity and cut operational emissions, the depot must leverage on-site renewable energy solutions:

I. **Solar PV deployment:** Installation of rooftop or elevated solar panels on depot sheds, parking structures, or adjacent land parcels. Designs should be guided by shadow analysis, structural load capacity, and estimated solar potential (e.g., kWh/m²/year).

II. **Battery energy storage systems (BESS):** Sizing and deploying energy storage systems to store surplus solar energy and provide backup during peak hours or grid downtime. Integration with the Energy Management System (EMS) is critical.

III. **Smart grid and Vehicle-to-Grid (V2G) integration:** Preparing depots for eventual integration with smart grid systems. While Vehicle-to-Grid (V2G) remains under pilot stages in India, bi-directional chargers and V2G-enabling electrical architecture may be provisioned in forward-looking depots where state DISCOM regulations permit.

C. Safety, security, and waste management: Given the high-voltage systems and flammable battery components involved, depot safety and environmental management must be robust and standards-compliant:

I. **High-voltage and fire safety systems:** Installation of battery isolation units, HT earthing grids, temperature and smoke sensors, and fire suppression systems (preferably clean agent or inert gas-based) in compliance with NBC 2016 and IEC 60364.

II. **Waste and battery management:** Designation of battery recycling zones and secure storage for spent lithium-ion batteries as per CPCB guidelines. Systems for wastewater reuse (e.g., from bus washing) and solid waste segregation should be integrated into depot operations.

III. **Security and surveillance:** Deployment of CCTV monitoring, perimeter access controls, and lighting systems to ensure physical security and uninterrupted operations, especially in depots with 24x7 fleet movements.

In addition to these e-bus-specific systems, RE-powered depots must also accommodate standard elements of a traditional bus depot:

- **Maintenance bays and administrative blocks** for periodic servicing and staff coordination.
- **Structured internal parking and queuing systems,** aligned with charger positions and safe movement paths for articulated or large-format e-buses.
- **Driver rest zones, training rooms, and staff parking** to meet ergonomic and operational requirements of depot personnel.

By integrating these operational, infrastructural, and sustainability-focused components, a RE-powered e-bus depot functions as a resilient, scalable, and future-ready infrastructure node capable of supporting the expansion of electric mobility in Indian cities. It facilitates not only the safe and reliable operation of electric fleets but also aligns with national sustainability goals and international climate commitments.

2.5 Existing depot manuals and guidelines

In the Indian context, two reference documents have provided foundational guidance for the planning and design of bus depots:

- The Bus Depot Design Guidelines by Shakti Sustainable Energy Foundation (2017), and
- The Manual for Planning, Design and Implementation of City Bus Depots by the Ministry of Housing and Urban Affairs (MoHUA) (2020).

These documents serve as useful resources for consultants, architects, transport planners, and civil engineers on key elements such as site selection, depot layout, internal workflow design, parking arrangements, and maintenance facilities. However, both documents are fundamentally tailored for depots designed to support ICE buses, and they provide limited or no reference to the specific infrastructure, electrical, and energy-specific requirements of electric bus fleets. While this study addresses essential infrastructure dimensions such as space allocation, structural design, and operational workflow needed for e-bus operations, including:

- High-capacity charging infrastructure integration
- Power demand estimation and transformer sizing
- Energy management strategies
- Battery safety, storage, and lifecycle considerations
- Renewable energy and battery storage system (BESS) integration

To address these limitations, **Convergence Energy Services Limited (CESL)**, under the National Electric Bus Program (NEBP), has developed a **Standard Operating Procedure (SOP)** for the development of upstream infrastructure in e-bus depots. The SOP focuses on technical aspects such as:

- Load requirement estimation based on fleet size and operational schedules
- Procedures for securing grid connection and coordination with the with electricity distribution companies (DISCOMs), charging interface selection and EVSE specifications
- Land allocation requirements for electrical infrastructure
- Coordination timelines for survey, approval, and energisation

While CESL SOP is a valuable operational guide, primarily focused on the technical and procedural aspects of upstream infrastructure. However, it does not serve as a comprehensive design guide addressing broader aspects for depot architecture, layout, or long-term energy optimisation.

In this context, the present study on the RE-Powered E-Bus Depot Design and Strategies aim to address this critical gap by providing an integrated framework for energy-efficient and future-ready depot design. This includes detailed guidance on:

- Renewable energy utilisation through rooftop or ground-mounted solar installations
- Cost-effective power planning and demand-side management
- Integrated load forecasting and charging strategies
- Safety, resilience, and scalability of depot infrastructure

This study is thus intended to serve as a **complementary technical resource,** building upon the foundational principles of earlier guidelines, but extending them to address the real-world needs of India’s e-bus transition. By integrating energy systems planning, smart infrastructure design, and sustainability considerations, the study supports more informed, data-driven decision-making for both brownfield retrofits and greenfield depot developments.

2.6 Key observations, challenges and case examples

Global experience highlights that the successful integrating renewable energy into e-bus depots requires a coordinated approach across three dimensions: **technical systems, operational workflows, and financing structures.** Without strategic alignment across these areas, even well-designed depot infrastructure may fall short of its energy efficiency and sustainability potential.

Table 2 presents selected international best practices that demonstrate scalable and replicable models for RE-powered depot design. These case studies showcase how cities around the world have leveraged smart infrastructure, renewable energy deployment, and innovative financing mechanisms to develop future-ready e-bus depots.

Sr. no.	Application area	Use-case implemented globally
1.	Optimal solar rooftop utilisation & energy management	• Los Angeles Metro (USA) – Deployed **5MW solar and battery storage** to power electric buses, achieving significant **operational savings** and reducing reliance on the grid (Smart Energy Decisions, 2021). • Shenzhen Bus Group (China) – Integrated s**olar panels across bus depots,** supplying **30% of total e-bus energy demand** through renewables (Institute for the Environment, 2019) (The University of North Carolina at Chapel Hill, 2019).
2.	Integrated charging infrastructure with smart grid solutions	• Hamburg Hochbahn (Germany) – Integrated **smart grid and solar charging depots,** reducing grid impact by **20%** and optimising electricity costs (Sustainable Bus, 2023). • Singapore's Land Transport Authority (LTA) – Adopted **fast charging stations with solar-supported infrastructure,** ensuring seamless energy use (The Straits Times, 2021).
3.	Financial & business model innovations for renewable energy integration	• Delhi Transport Corporation (India) – Partnered with a **solar developer** under a Power Purchase Agreement (PPA) model to install **122kW solar rooftop systems** for e-bus charging. (Sinha, 2024) • London TfL (UK) – Integrated **carbon offset mechanisms and green bonds** to support the transition to an e-bus fleet with renewable energy. (Transport for London, 2025) ,

4.	Future-ready electrification & renewable energy expansion	• Oslo Ruter (Norway) – Piloted **solar + hydrogen hybrid charging** infrastructure, ensuring 100% renewable-powered e-bus operations. • Stockholm E-Bus Project (Sweden) – Integrated a**rtificial intelligence (AI) for smart energy management,** optimising energy usage by 25%.
5.	Policy & regulatory alignment for renewable energy adoption	• Netherlands Public Transport – Implemented national policy requiring all **new bus depots** to integrate **renewable energy sources.** (UITP, 2023) California Zero-Emission Bus Mandate – Enforced **policy-driven solar and storage investments f**or all e-bus depot infrastructure (U.S Department of Energy, 2018).

Table 2: Global use-case integrating RE and smart solutions

Key strategies observed across global examples include:

- Deployment of **rooftop and elevated solar PV systems** for on-site clean energy generation
- Integration of **Battery Energy Storage Systems (BESS)** to manage intermittency and peak load demands
- Use of **smart load management systems** to optimise charging schedules and reduce grid stress
- Adoption of **policy mandates and incentive frameworks** to promote renewable energy integration and financial viability.

These approaches have not only helped in reducing operational costs but have also enhanced the energy resilience and carbon footprint of public transport systems. The insights reinforce the importance of embedding renewable energy planning into the earliest phases of depot design—particularly in rapidly urbanising cities across India, where land and energy constraints are acute.

2.7 Application in the Indian context: Case examples from Surat

Building on these international best practices, the next chapter focuses on two operational case studies from Surat City— specifically the Bhestan and Althan depots—where electric bus fleets are currently in service. These depots serve as **real-world test beds** for evaluating depot-level energy utilisation, spatial efficiency, and infrastructure readiness. Through detailed assessments of these two sites, the report examines:

- **Daily and peak-hour charging operations** and load profiles
- **Fleet-to-charger ratios** and operational charging efficiency
- **Spatial layout optimisation** and depot circulation
- **Readiness of electrical and auxiliary infrastructure**

These case examples provide a **practical framework** to estimate energy demand, guide infrastructure design, and support scalable planning for both brownfield retrofits and greenfield depot developments. They also offer insights into operational challenges such as load balancing, transformer capacity constraints, and vehicle queuing logistics—making them highly relevant for transport authorities, planners, and energy regulators working on India's electric bus transition.

The subsequent chapter builds upon this operational evidence to outline the **technical and spatial requirements** essential for designing, implementing, and managing a high-performance **RE-powered e-bus depot.** It provides practical design criteria, planning considerations, and integration strategies to support sustainable, efficient, and resilient depot infrastructure development across diverse Indian contexts.

03

Efficient Infrastructure Design for RE-Powered E-bus Depot

In a traditional bus depot, diesel fuel keeps the ICE fleet running - but in a e-bus depot, electricity takes centre stage replaces diesel with electricity as the primary energy source – placing charging systems and integrated electrical networks at the core of daily operations. Instead of fuel pumps and bowser refuelling, electric buses rely entirely on **battery charging systems** and a seamlessly integrated electrical network to keep buses powered up and ready for service. This shift demands specialised engineering expertise to design a seamless, high-capacity electrical ecosystem capable of supporting both overnight and opportunity charging without disrupting service schedules.

A well-designed charging setup involves more than just chargers and cables. It includes power supply from electrical substations, load management software, and a layout optimised for space and operational efficiency. Crucially, sourcing this energy from **sustainable and renewable sources** significantly enhances the environmental benefits of e-bus deployment. Key differences from ICE depot design include:

- The **need for scheduled recharging,** as e-buses cannot "top-up" on the road as diesel vehicles can.
- The importance of **scaling infrastructure** to meet future fleet demands.
- The inclusion of **smart charging systems, energy storage, and renewable energy integration.**

When planned and executed effectively, the charging infrastructure becomes the backbone of a sustainable urban mobility system, delivering operational reliability, cost-efficiency, and reduced emissions.

3.1 Depot infrastructure planning overview

Effective infrastructure planning is fundamental to a successful RE-powered e-bus depot. Unlike traditional depots designed around diesel storage and refuelling speed, electric depots require a carefully engineered electrical and spatial layout that supports high-power charging, energy management, and seamless operational flow. At its core, depot infrastructure planning ensures that every component—from **charging stations and power distribution networks to battery storage and grid connectivity**—works in harmony.

Key planning considerations include:

1) Charging capacity & layout – Determining the number of chargers, their power ratings, and optimal placement to minimise downtime while maximising spatial efficiency.

2) Grid integration & procurement – Ensuring the local power supply can handle peak demand without overloading, potentially incorporating renewable energy or battery storage integration.

3) Operational workflow – Aligning charging schedules with bus routes to keep vehicles running smoothly without delays.

4) Scalability: Planning for future fleet expansion, emerging technologies, and additional energy requirements.

Since e-buses rely entirely on batteries—unlike diesel buses that can refuel anywhere—depot design must also consider **future scalability.** Will the infrastructure support a growing fleet? Can it adapt to new fast-charging technologies? By addressing these considerations from the outset, depot planning transforms the facility into a **smart energy hub**—not just a parking and maintenance site, but a key enabler of zero-emission public transport.

3.2 Charging and circulation layout design

An e-bus fleet demands meticulous planning of both civil and downstream electrical infrastructure to ensure efficient, safe, and scalable operations. Civil components such as layout configuration, EVSE placement, parking zones, and maintenance facilities must be tailored to the specific needs of electric buses, including wider turning radii, charging queues, and safety zones. Simultaneously, downstream electrical infrastructure—comprising internal distribution, charging station placement, transformers, and energy management systems—must be designed to accommodate high energy demands while supporting smart operations and safety protocols. Strategic integration of these elements:

- Ensures uninterrupted operations
- Reduces congestion and turnaround time
- Enhances long-term energy performance
- Supports phased fleet expansions.

3.2.1 Allocation of space for charging stations

The physical arrangement of charging infrastructure (EVSE) within an e-bus depot is a **make-or-break factor** in ensuring smooth, safe, and scalable operations. Unlike conventional fuel stations, where buses refuel quickly and move on, e-bus depots require **strategic placement of chargers, circulation lanes, and supporting infrastructure** to maximise efficiency while minimising bottlenecks.

Efficient space utilisation allows for smooth entry and exits of buses, minimising congestion and ensuring safe interaction between buses and charging equipment. Additionally, adequate spacing is necessary for accommodating different types of charging systems (e.g., plug-in), along with associated infrastructure like transformers, switchgear, and energy storage units. A well-planned space arrangement also improves operational efficiency by allowing simultaneous (multiple buses charging at once) requires charging schedule to suffice the recharging needs for e-bus fleets, reducing downtime and supporting quick turnaround times for buses in transit.

Key considerations in layout design:

1.Optimised bus movement & accessibility

- The layout must allow **uninterrupted flow** of buses entering, charging, and exiting—preventing congestion during peak hours.
- Example: A **one-way loop** system can streamline movement, ensuring buses don't block each other while accessing chargers.

2.Charger placement & ratio

- A common industry practice is a **4:1 bus-to-charger ratio** (four buses sharing one charger), balancing cost and charging needs.
- **Simultaneous charging** (multiple buses charging at once) requires smart power management to avoid grid overload.
- Example: Overnight charging (slow, full capacity) vs. **opportunity charging** (short, high-power top-ups during the day).

3.Safety & compliance

- Clearances must follow local electrical codes (e.g., National Electrical Code (NEC), International Electrochemical Commission (IEC)) and fire safety norms (e.g., National Fire Protection Association (NFPA), European Standard (EN) 50620 for EV infrastructure).

- Emergency lanes, fire suppression systems, and maintenance access must be integrated into the design.

4.Scalability & futureproofing

- Space should allow for **additional chargers or upgraded systems as the fleet expands.**

- Modular designs (e.g., pre-wired bays) enable easier upgrades without major reconstruction.

A well-planned EVSE layout not only ensures operational efficiency and safety but also supports future fleet scaling and compliance with national and international standards. Based on the existing e-bus models operational in Surat City and the walk-through assessments conducted at the depots, the following considerations must be thoroughly evaluated prior to initiating civil and electrical works.

1. Availability of the existing electrical infrastructure

E-bus fleets demand a substantial and aggregated power supply (for example, a fleet size of 100 e-buses considering 4 e-buses per charger of 180kW capacity would requires ~ 4.5MW of contracted load) requiring connectivity to high-voltage lines or feeders capable of meeting the depot's power needs both in the short and medium term. Futureproofing the depot's operations hinges on ensuring that the electrical infrastructure can handle anticipated load increases as the fleet grows. A significant challenge in retrofitting depots lies in the cost of establishing both upstream and downstream infrastructure, from securing a local high-voltage access point to extending connections to EVSE units within the depot. These costs often represent the most variable expense during retrofitting projects, emphasising the need for strategic planning and investment.

Upstream and downstream infrastructure in an electrical power system (Paradigm Controls, 2025)

Upstream infrastructure refers to the generation and high-voltage transmission components of the power system. It includes power plants (renewable and conventional), high-voltage substations, and transmission lines that deliver electricity from generation sources to distribution networks.

Downstream infrastructure involves the distribution and end-user consumption of electricity. It includes distribution substations, transformers, local power grids, EV charging stations, and consumer connections that deliver power to homes, businesses, and electric mobility infrastructure

Effective coordination between upstream and downstream infrastructure is critical, necessitating early coordination with DISCOMs for high-voltage access and capacity planning. In the context of e-bus charging depots, upstream infrastructure would cover the grid connection, substations, and renewable power generation while downstream infrastructure would include on-site energy storage, charging stations and depot-level energy management systems.

2. Placement of EVSE units and parking space arrangement

Integrating additional infrastructure such as cabling, chargers and transformers into an electric depot can reduce the space available for traditional depot activities like parking and bus movement. EVSE siting should avoid blocking key bus circulation paths. Use of elevated cable trays, underground trenching, or modular charging blocks can help manage space constraints. Choosing compact and space-efficient charging infrastructure can further mitigate space constraints. However, in depots with severe space limitations, operational adjustments such as reducing fleet size or adopting alternate infrastructure solutions may be necessary to accommodate the e-bus fleet effectively.

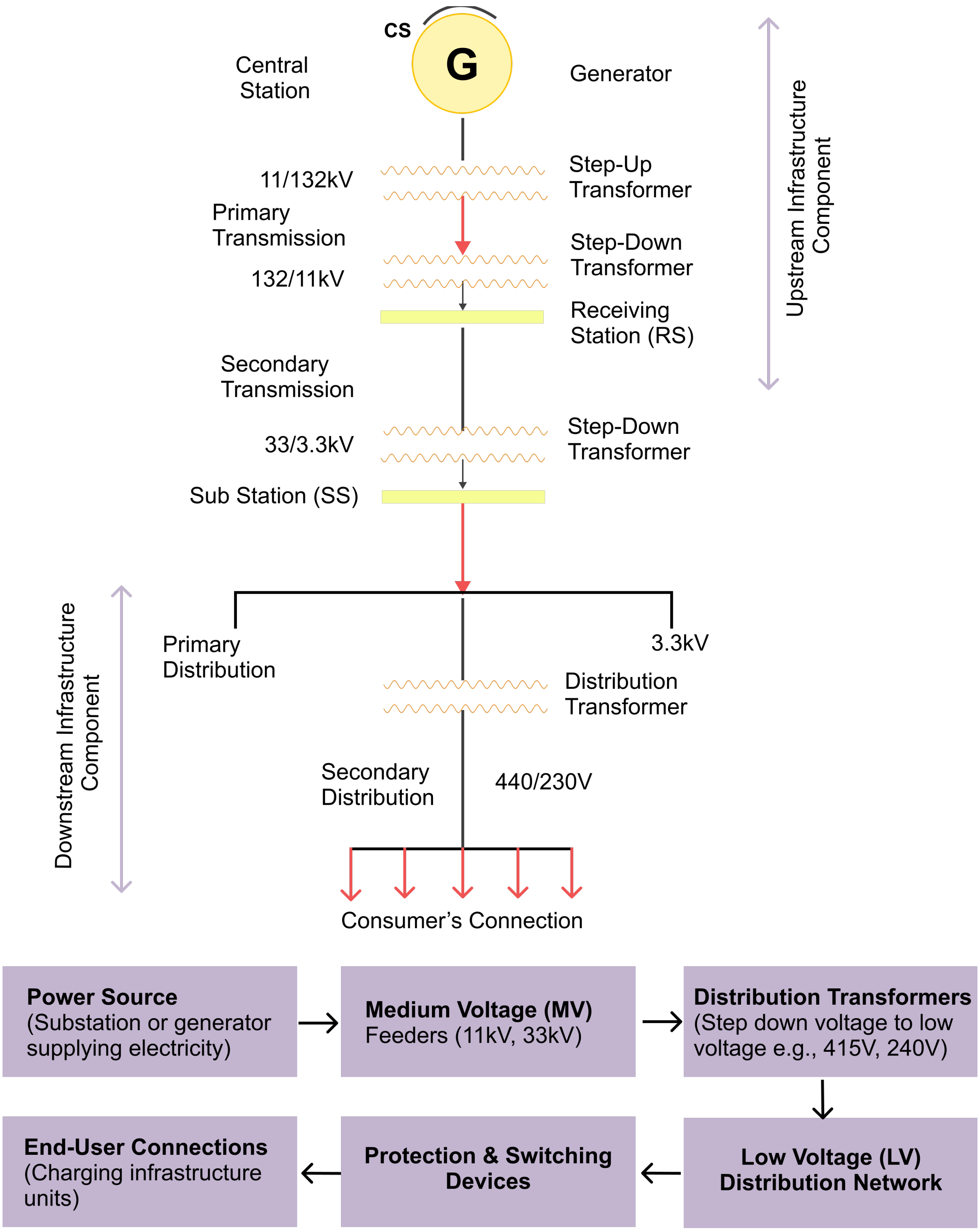


Figure 1: Electrical layout design - generation to consumer's connection (Csanyi, 2025)

3. Sequential placement of activities within the depot

E-buses require less maintenance than diesel buses due to fewer mechanical components. However, in e-bus depots, efficient integration of charging with other nighttime activities is essential. This often involves frequent bus repositioning, making effective circulation planning and a well-designed layout crucial to minimise internal movement, optimise space, and maximise operational efficiency. In Surat, the Bhestan e-bus depot case has been studied to understand the sequencing of activities within such a setup, as discussed below.

Case study: Bhestan depot, Surat

To better understand charging patterns and operational workflows at the electric bus depot, a comprehensive night survey was conducted at Bhestan depot in collaboration with Sitilink and Surat Municipal Corporation (SMC) staff. This survey tracked all bus arrivals, their movements within the depot, the activities performed, the time taken, and the State of Charge (SoC) levels buses arrive and depart. The primary objective of the survey was to assess the efficiency of depot utilisation and the effectiveness of operating practices.

At Bhestan depot, there are 75 e-buses which follows the activity sequences, as detailed below:

Sr. no.	Sequential workflow of the activities in the depot throughout the night	% of buses
1	Entry-Parking-Charging-Parking-Washing/Maintenance-Parking-Exit	49%
2	Entry-Charging-Parking-Washing/Maintenance-Parking-Exit	20%
3	Entry-Parking-Maintenance/Washing-Parking-Charging-Parking-Exit	14%
4	Entry-Parking-Washing/Maintenance-Parking-Charging-Parking-Exit	17%
	Total	100%

Table 3: Sequential workflow – A case of Bhestan depot

Source: Primary night activity survey at Bhestan depot, Surat, conducted on June 5-6, 2024

Case: Bhestan depot Surat - A sequential workflow of the activities in the depot throughout the night

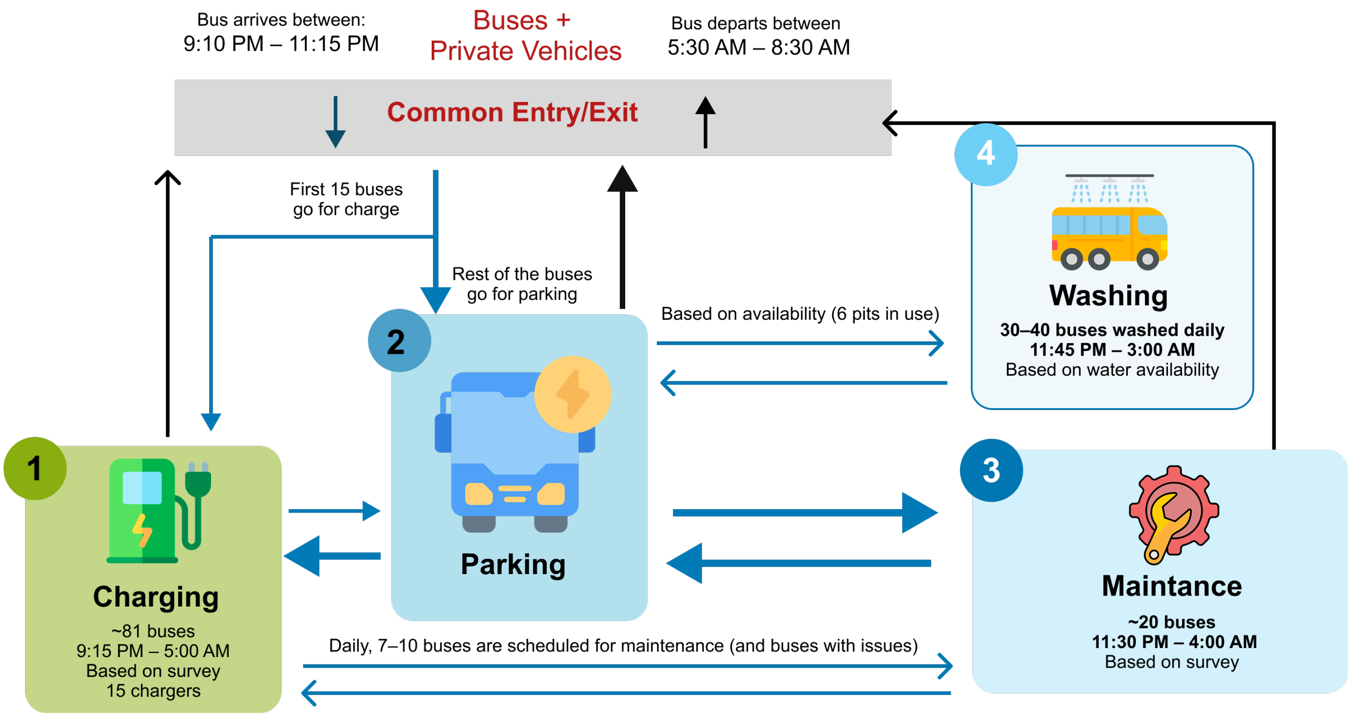


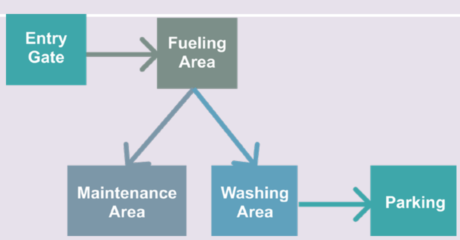
Figure 2: Schematic diagram of sequential workflow in Bhestan depot, Surat

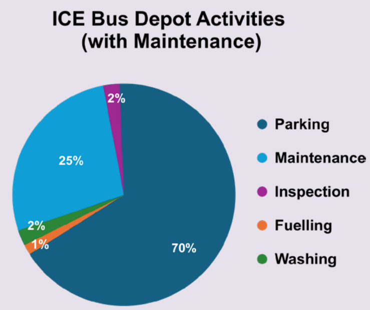
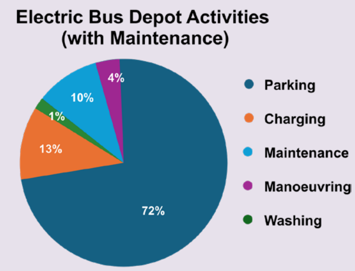
The Figure 2 below illustrates sequential workflow of e-buses within the Bhestan depot as one of practical example.

The above **Table 3** and **Figure 2** indicate that depot operations remain active throughout the night to align with the next day's schedule. Therefore, the design requirements for internal circulation vary between e-buses and ICE buses, primarily due to differences in fuelling/charging infrastructure and maintenance needs.

3.2.2 Learnings from e-bus depot operation in Surat

Based on the assessment of the Bhestan depot night activity and other e-depots of Surat, the key differences between the e-bus depot and the ICE bus depot are discussed below:

Aspect	ICE bus depots (Ministry of Housing and Urban Affairs, Government of India, 2020)	E-bus depots (Surat depot case study)
Fuelling/charging	Requires dedicated fuelling stations with pumps, typically located near bus entry points.	Requires charging stations integrated into depot infrastructure, requiring space for chargers, sub-stations and ducting for cabling.
Maintenance (Maintenance schedule: 10 buses in every 10 days or after assured vehicle kilometre travelled)	Needs routine checks for engines, exhaust systems, and fuel systems, requiring specialised areas (e.g., maintenance pits, inspection pits, driver complain pit). (Generally, 8 pits for 100 buses as per Section 5.4.5 of the MoHUA guidelines (Ministry of Housing and Urban Affairs, Government of India, 2020, p. 70))	Needs maintenance for electrical systems, batteries, and motors, requiring designated spaces for electronics repairs and battery checks. (Generally, 4 pits for 100 buses as per Clause 6.1.3 of the CESL Tender (CESL, 2024, p. 79))
Battery management	Maintenance and health management of lead acid batteries, and collection of scrap batteries.	Requires space for safe handling, storage, and recycling of discharge lithium-ion batteries with specific safety measures as per CPCB Battery Waste Management Rules, 2022 clause 14 w.r.t electric vehicles (CPCB, 2022).
Circulation	Layout focuses on streamlining entry/exit paths, minimising vehicle conflicts with fuelling stations placed near entry/exit points.	Requires considerations charging infrastructure, clear entry and exist points, required larger circulation space to avoid accidents and conflict
Typical sequential of workflow	 Source: Section 5 (Ministry of Housing and Urban Affairs, Government of India, 2020, p. 53)	Refer to **Figure 2,** based on the primary depot night activity survey conducted at the Bhestan depot.
Area requirement per bus (sqm)	For 12m bus, 50 buses: 260 sqm/bus 100 buses: 202 sqm /bus 150 buses: 186 sqm/bus 200 buses: 180 sqm/bus	For 100 buses of 9 m: 150 -190 sqm/bus For 100 buses of 12 m: 190-200 sqm/bus

	(As per Section 1.3 (Ministry of Housing and Urban Affairs, Government of India, 2020, p. 25))	The depot shape, size and placement of activities also matters in defining the area per bus. (As observed from e-bus depots of Surat, Ahmedabad and other cities under PM E-Bus Sewa)
Percentage of time occupied by each activity in the depot (Considered total 8 hours buses stay at depot both in ICE and e-bus)	 The bus manoeuvring time is negligible	 Here, the bus manoeuvring time accounts approximately 4% (i.e. appx 20 minutes) of total time buses are at depot (i.e. 8hours).

Note: The case presented is of Bhestan depot; where charger capacity is 240 kW and bus battery capacity are 261 kWh with 14 charges. A bus to charge fully, it takes 50-60 mins with dual gun.

Table 4 Difference between e-bus and ICE bus depots

Based on operational assessments of e-bus depots in **Surat city**, several critical factors have emerged:

A. **Availability of existing electrical infrastructure:** Retrofitting depots is often limited by the proximity of high-voltage access points and the cost of downstream integration.

B. **Space allocation and cable trenching:** Civil works must account for transformer placement, EVSE layout, switchgear rooms, and clearances.

C. **Cost and timeline variability:** The most variable element in retrofitting is the cost of upstream connectivity and downstream electrical works, which underscores the importance of early planning.

By addressing these interlinked elements—layout design, charging optimisation, energy infrastructure, and scalability—RE-powered e-bus depots can be transformed into **future-ready, high-performance transit hubs** supporting India's e-mobility ambitions.

3.3 Measure and safety standards for EVSE installation

The **Central Electricity Authority (CEA),** under the **Ministry of Power (MoP),** has amended its safety regulations and installation guidelines[4] to specifically address **Electric Vehicle Supply Equipment (EVSE)** requirements. These updated provisions aim to ensure the safe deployment and operation of EVSE units within depot environments, safeguarding both personnel and electric buses.

Key Regulatory Mandates:

1.Safety compliance:

- All EVSE installations must adhere to CEA's revised electrical safety standards
- Protection measures must be in place for high-voltage EVSE installations to mitigate risks such as electrical faults, overheating, and fire hazards.

2.Depot layout specifications:

- Mandatory clearance zones around charging units must be maintained for safe bus movement and emergency access.
- Charging bays should be segregated from other depot operations, particularly maintenance and staff areas.
- Adequate ventilation is required for any enclosed charging infrastructure to prevent overheating or gas accumulation.

3.3.1 EVSE installation safety guidelines (CEA, 2023):

Based on CEA regulations and field experience from operational depots, the following measures must be observed during EVSE installation:

- The foundation of the charger should adhere to the standards and safety guidelines set forth by the Central Electricity Authority (CEA) – to safeguard against potential risks such as floods and other weather-related external factors, ensuring utmost safety.
- All electric vehicle charging points EVSE Units shall be installed so that **any socket-outlet of supply is at least 800 millimetre above the finished ground level (clause chapter XI Clause 123 sub-clause (2).**
- The electric vehicle parking place shall be such that the connection on the vehicle when parked for charging shall be within 5m from the electric vehicle charging point.
- Suitable lightning protection system shall be provided for the electric vehicles charging stations as per **IS/ IEC 62305.**
- The wiring and earthing of all electric vehicle charging stations shall be **as per IS 732/IS 3043.**

These requirements ensure that EVSE deployment within RE-powered e-bus depots meets the highest standards of safety, reliability, and compliance.

[4] Measures Relating to Safety and Electric Supply Archives - Central Electricity Authority

3.3.2 EVSE unit sub-component: Cable and connector standards

The design and selection of **charging cable assemblies** are critical to the operational safety, flexibility, and efficiency of e-bus depot charging. Based on standard practices in India and consultations with Original Equipment Manufacturers (OEMs) and fleet operators, the **optimal cable length** for 9–12 metre e-buses typically falls between **5 to 7 metres.** This provides sufficient flexibility for vehicle positioning while avoiding excess slack, which can pose a tripping or wear hazard. This length provides sufficient flexibility for bus manoeuvring while minimising the risk of cable damage and tripping hazards. **However, it's essential to conduct a detailed site assessment for each specific bus depot to determine the most appropriate cord length based on the EVSE and e-bus charger connector position.**

Charging cable assembly: As per **Section 10 of Automotive Industry Standards (AIS) 138 Part 1 and CEA measure and safety guidelines** (CEA, 2023), except the functional characteristics defined as below:

- As per the additional safety requirements for e-buses charging stations CEA guideline Section 124 of chapter XI of measure & safety guidelines sub-section (2) "Socket-outlet of supply of electric vehicle charging points shall be installed at least 800 millimetre above the finished ground level".

- Sub-section (3) A cord extension set, or second supply lead shall not be used in addition to the supply lead for the connection of the electric vehicle to the charging point and shall not be used as a cord extension set.

    - Functional characteristics: The maximum cord length will be 5 meters, straight cable.

    - Cable Connection Type: supply cable will be with EVSE as per ***Case C*** defined in section

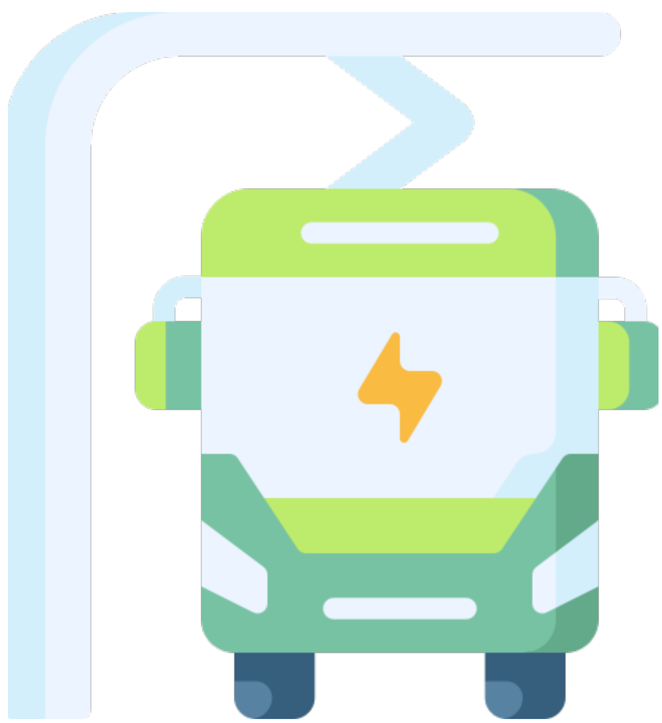
    - Cord Extension Set: No extension cord to be used, **as per Section 6.3.1. of AIS 138 Part 1**

    - Adaptors: No adapters to be used as per **Section 6.3.2 of AIS 138 Part 1**

    - Storage means of the cable assembly and vehicle connector: EVSE should have storage for cable and connector when not in use, at a height between **0.4m to 1.5m above ground level, as per IEC 61851-23 Section 101.1.3**

    - IEC 61851-21: Part 21: Electric Vehicle Requirements for conductive connection to AC/DC supply.

By adhering to these safety and technical specifications, depot operators can ensure that EVSE units are installed and operated in a manner that is safe, reliable, and compliant with national and international standards. These provisions also support long-term durability, ease of use, and seamless integration with various e-bus models deployed across Indian cities.



3.3.3 EVSE and downstream electrical layout design

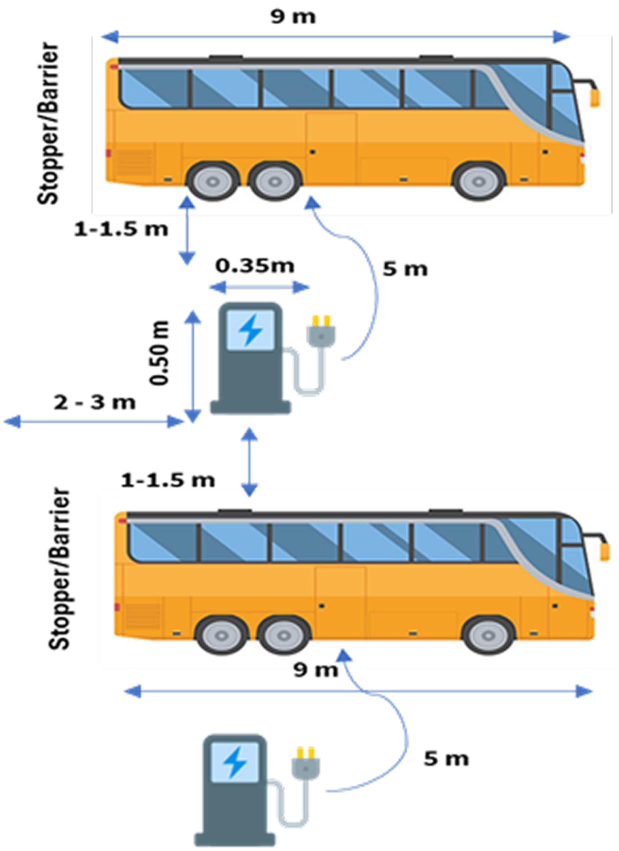


Figure 3: Reference layout for placing EVSE units[5]

The stopper or barrier should be positioned just behind the rear wheel, and the distance i.e., 2- 3 m from the rear end wall should be measured from the back side (end frame) of the electric bus.

The Figure 3 illustrates a setup for EVSE (Electric Vehicle Supply Equipment) installation along a roadside or parking area. Charge posts are installed at the curb next to parking bays and connected to the power grid via either an existing mini pillar or a new interface pillar. Power can be supplied through direct connections or a T connection from the main power cables running along the footpath. This design ensures efficient use of existing power infrastructure while allowing flexibility for future expansion.

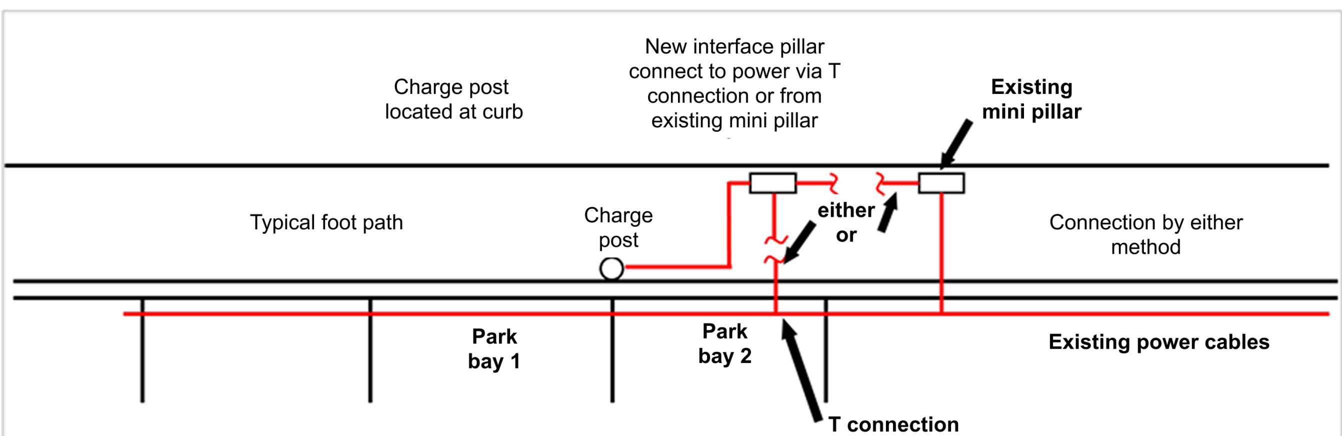


Figure 4: Electrical layout for charging unit installation

Figure 4 illustrates the electrical infrastructure setup for a curb side EV charging post installation, showing the connection pathways to the power supply.

Key components and interpretation:

1) Charge post location:

a. The EV charging post is installed at the curb, near designated **parking bays (Park Bay 1 & Park Bay 2)** for electric vehicles.

[5] Note: This is a representative layout; the actual design may vary depending on space and location availability.

2) Power supply connection options:

a. The charging post receives power via an **underground connection** from either:

- A **new interface pillar** (installed along the footpath).
- An **existing mini pillar**, which is already connected to the power grid.

3) T-connection method:

a. A **T-connection** is used to tap into the **existing power cables** running along the underground grid.

b. This T-connection provides power to the new interface pillar or directly to the charge post.

4) Footpath & infrastructure integration:

a. The setup is designed to **minimise disruption** to the footpath while ensuring power accessibility.

b. Connections are made either from the **new interface pillar** or directly from the **existing mini pillar,** allowing for flexible installation approaches.

This diagram represents a standardised method for integrating EV charging posts into urban power grids, ensuring accessibility for parked vehicles while leveraging existing electrical infrastructure for cost-effective deployment.

A. Space requirement for sub-station for charging station

If the electrical load of a newly constructed or upgraded e-bus depot exceeds 1 MVA at the high tension (HT) level, provision must be made for allocating space to install a grid substation. This is critical to support the infrastructure required for high-voltage power supply and to meet the depot's significant energy demand. Refer to the table below for various types of substations applicable to 66/11 kV distribution lines. Furthermore, e-bus depots operated by State Transport Undertakings (STUs) must also set aside additional space for distribution transformer (DT) substations. These are necessary to access low-tension (LT) power supply or to obtain LT service connections from the Distribution Company (DISCOM).

This additional space, approximately equivalent to **five times the area of 4 meters by 3.3 meters,** is necessary. STUs are responsible for coordinating with the relevant DISCOM to obtain approval for the allocated space and layout arrangements.

Sr. no.	Substation type size (meters)	Size (meters)
1	Air – insulated Sub-station – 66/11 kV Grid sub-station with 2PTR	80M x 60M
2	Air – insulated Sub-station – 66/11 kV Grid sub-station with 3PTR	90M x 80M
3	Air – insulated Sub-station – 33/11 kV Grid sub-station with 2PTR	45M x 35M
4	Gas – insulated Sub-station – 66/11 kV or 33/11kV	50M x 30M

Table 5: Dimensions for various substation types (meters)[6]

[6] Standard Operating Procedure (SOP) for developing up upstream depot infrastructure for e-bus operations (Convergence Energy Service Limited, 2022)

B. Distribution transformer placement

The **Figure 5** represents **schematic layout** of an **11kV below-ground substation with a single transformer,** illustrating key infrastructure components and spatial arrangements.

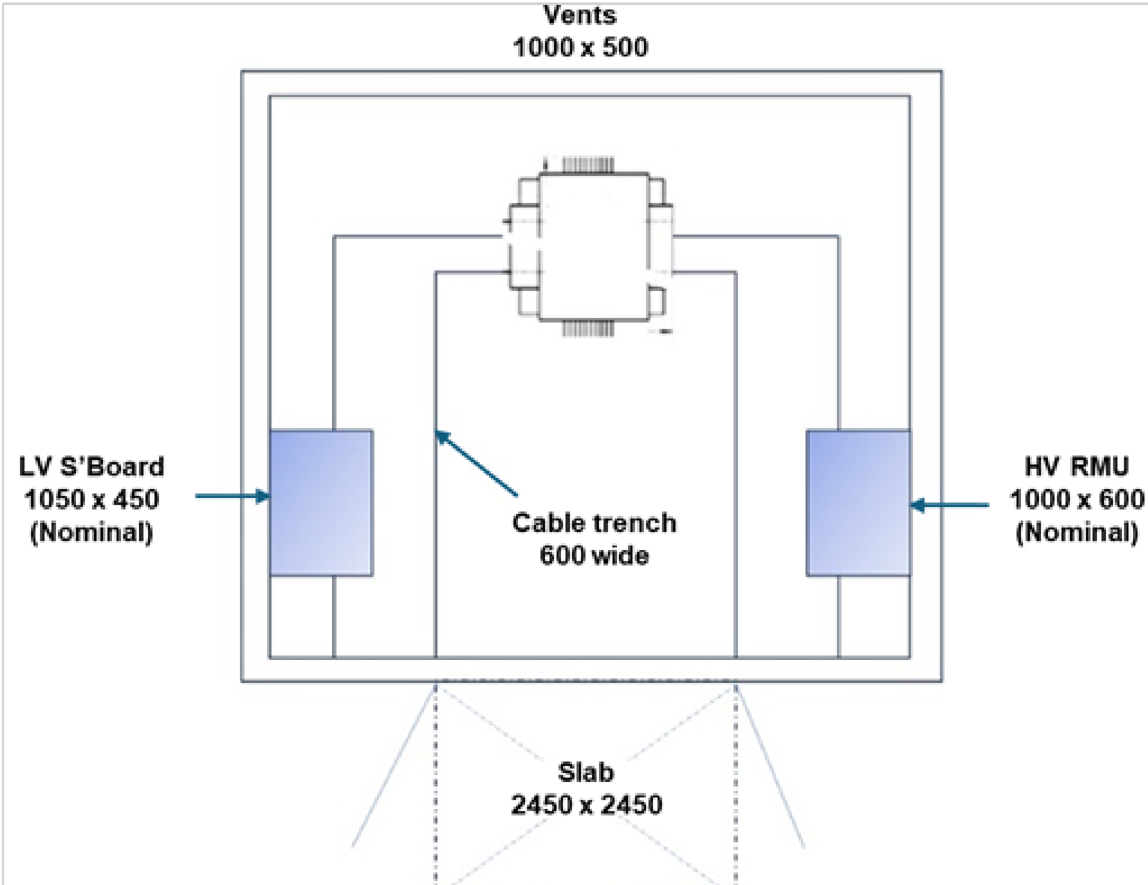


Figure 5: Layout for 11KV below sub-stations with single transformer (Central Public Works Department, 2019)

Key elements in the layout:

1. **Transformer Placement:** The central transformer is the primary component of the substation, distributing power at lower voltages.

2. **High Voltage Ring Main Unit (HV RMU) -** 1000 × 600 mm (Nominal): Located on the right side, it ensures safe switching and protection of the 11kV network.

3. **Low Voltage Switchboard (LV S-Board) -** 1050 × 450 mm (Nominal): Positioned on the left side, it manages the low-voltage output from the transformer for downstream distribution.

4. **Cable Trench (600 mm wide):** This is an underground cable routing area that allows for the secure connection of cables between different components.

5. **Slab (2450 × 2450 mm):** A foundation base supporting the transformer and ensuring structural stability.

6. **Vents (1000 × 500 mm):** Located at the top, these provide ventilation to dissipate heat and maintain optimal transformer performance.

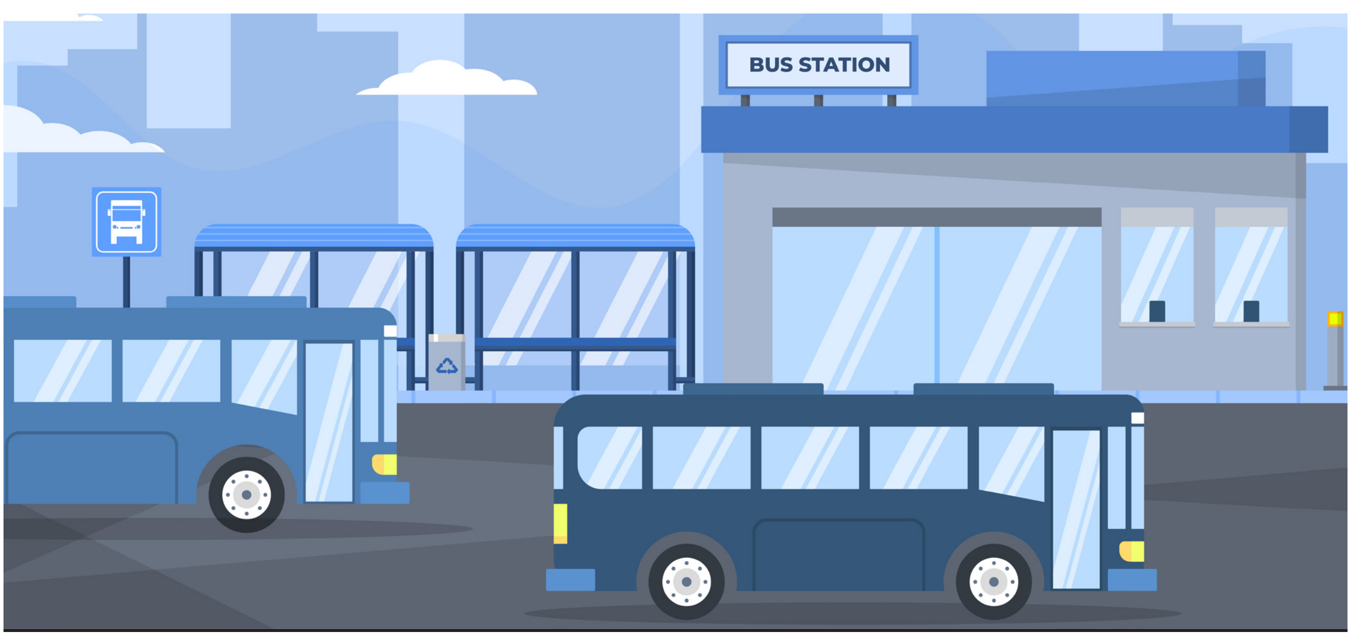
04

Planning for Charging Infrastructure Energy and Power Load Requirements

The transition from diesel-powered buses to electric buses represents a fundamental shift how energy is sourced, distributed, and managed within public transport depots. Unlike conventional fuelling – which is relatively low in energy demand and decentralised - EV charging requires **high-capacity, time-sensitive power delivery** and grid compatibility that must be carefully integrated with the local grid infrastructure. This paradigm shift calls for **strategic power load forecasting, energy demand estimation,** and the development of robust electrical infrastructure that can support both current operational needs and future fleet expansion.

4.1 Aligning decarbonisation with energy planning

The electrification of bus fleets plays a crucial role in India's broader **decarbonisation agenda and energy security strategy.** By substituting diesel and petrol with electricity, the shift not only reduces greenhouse gas emissions but also supports long-term national goals of reducing fossil fuel dependence. However, achieving these outcomes requires c**omprehensive planning.** For **State Transport Undertakings (STUs)** and urban bus operators, the success of e-bus programmes depends on ensuring a **reliable, uninterrupted, and scalable supply of electrical energy.** To enable a smooth and sustainable transition to electric buses, STUs and transit authorities must address several interlinked planning components:



Power Grid Integration

a) The local grid connection must be strong enough to handle high, time-bound loads—especially during overnight or peak charging periods.

b) Early coordination with Distribution Companies (DISCOMs) is essential to secure sufficient contracted load capacity and enable future upgrades.

c) For large depots, connection to High Tension (HT) lines and establishment of dedicated substations may be necessary.

Depot Electrical Infrastructure Design

a) New and retrofitted depots must incorporate internal electrical distribution networks that are safe, efficient, and designed for high-power throughput.

b) This includes transformer sizing, circuit protection, load distribution panels, earthing systems, and energy metering infrastructure.

c) Scalability is critical—designs should accommodate future increases in fleet size and charging demand without major overhauls.

Charging Schedule Alignment

a) Charging operations must be synchronised with fleet deployment schedules to ensure that buses are fully charged and ready for service each day.

b) Use of smart charging systems and load management software helps avoid peak demand penalties and ensures balanced energy distribution across chargers.

Energy Resilience and Redundancy

a) To safeguard operations against power outages or grid fluctuations, depots should consider Battery Energy Storage Systems (BESS), dual-feed power lines, or clean energy backups such as rooftop solar.

b) Integration of Energy Management Systems (EMS) enables real-time monitoring, fault detection, and performance optimisation.

Furthermore, new and renovated depots must incorporate well-designed internal electrical distribution networks. These networks should prioritise safety, efficiency, and scalability to accommodate the growing energy demands of e-buses. Advanced systems that link charging operations to fleet schedules are also crucial. These systems must ensure that all buses are fully charged and operational at the start of each working day, thereby supporting seamless and reliable service delivery.

By addressing these critical factors from the outset, STUs and operators can develop a resilient, efficient and future-ready energy ecosystem for a e-bus operations. Well-designed energy infrastructure not only ensures seamless day-to-day operations but also reinforces broader objectives related to climate action, urban air quality improvement, and sustainable mobility.

The shift to e-buses is a game-changer, replacing diesel with electricity to drive cleaner cities and reduce fuel dependency. With robust energy infrastructure and smart depot systems, e-buses can seamlessly charge and operate efficiently, powering a sustainable future for urban transportation.

4.2 Assessment of electrical infrastructure requirements: energy and power demand

Understanding the electricity requirements at the depot level is a critical first step in accurately estimating the power demand essential for efficient and reliable e-bus operations—comparable to fuelling in a traditional diesel-based Internal Combustion Engine (ICE) fleet. This insight enables transport operators and planners to identify necessary **upgrades to existing electrical infrastructure,** particularly in determining:

- The appropriate **kVA rating and capacity of Distribution Transformers (DTs)**
- Network sizing to support **peak charging loads**
- **Voltage drops** control and **fault level** compliance to ensure grid stability

A comprehensive assessment also facilitates the **integration of renewable energy,** particularly distributed solar PV systems, into the depot's electrical ecosystem. However, striking the right balance between energy supply, infrastructure capacity, and charging demand introduces complex technical and financial challenges. It is important to recognise that **there is no one-size-fits-all solution.** The optimal configuration for each depot depends on several contextual factors, including:

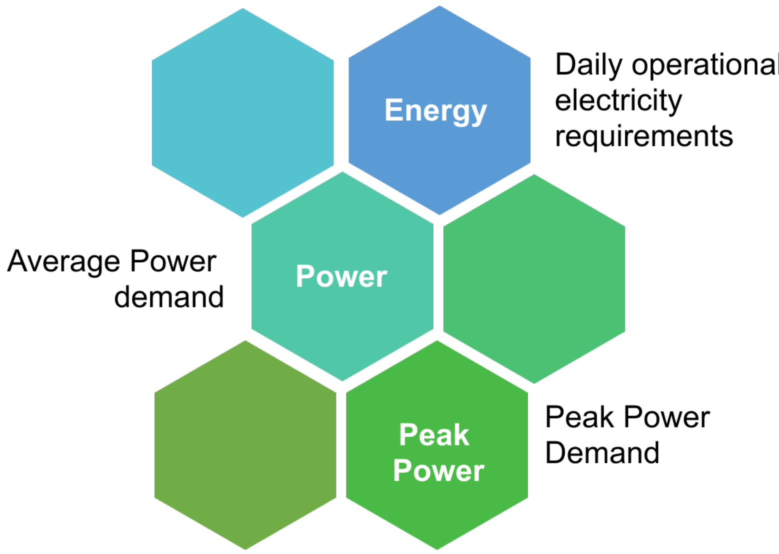
- Operator-specific priorities and transition goals
- Available land and electrical infrastructure
- Fleet size and operational schedule
- Regulatory and grid conditions

While some operators may prioritise **minimising upfront capital costs,** others may focus on **long-term sustainability, energy resilience, and total cost of ownership.** Therefore, the design and planning approach must be **tailored** to meet each depot's unique objectives while ensuring energy security and charging reliability.

- Firstly, there is a need to minimise installed power while ensuring that the infrastructure can adequately support the charging needs of the e-buses.
- Secondly, there is the consideration of the additional costs associated with infrastructure upgrades, including the installation of charging units and distribution transformers.
- Lastly, there is the desire to optimise charging schedules to take advantage of cheaper electricity rates during off-peak periods. In order to passively support and deter the grid infrastructure upgrades.

It is important to acknowledge that there is no universal solution to this challenge. The optimal approach must be tailored to specific circumstances and is influenced by several factors, including the operator's strategic priorities and transition goals. While some operators may focus on minimising initial capital expenditure, others may place greater emphasis on long-term sustainability and overall cost-efficiency. Ultimately, the chosen solution must strike a balance between these competing priorities while still meeting the operational requirements of the depot and ensuring reliable and efficient charging for the e-bus fleet.

To figure out how much energy and power certain e-buses need each day at the depot, operators must carefully look at their needs and come up with plans to make them work as well as possible and last a long time. This means they need to understand how much electricity the buses use and how fast they need it, then figure out ways to make everything run smoothly and in a way that's good for the environment. When preparing to electrify a depot and meet its additional needs, various calculations come into play:



"Charging Ahead: Aligning Daily Energy Needs, Average Demand, and Peak Power for a Seamless Re-Powered Depot Operation"

4.2.1 Electricity requirements for EVSE & efficiency

Accurate energy and power demand estimations are essential to design depot infrastructure, size electrical components, and evaluate grid impact. These formulas can be adjusted to fit specific operational conditions and requirements.

$$E_{req} = \frac{(E_{Route} + E_{Battery} + E_{HVAC} + Enon\ critical)}{F_{Drive}}$$

Where:

E_{req} – the electricity requirements for the depot under a conservative scenario.

E_{Route} – the electricity requirements for the route (typically calculated as kilowatt-hours per kilometre, kWh/km).

$E_{Battery}$ – energy remaining in the battery at the end of the operational period (typically around 20%).

E_{HVAC} – energy consumed by non-critical components of the bus such as heating, ventilation and air conditioning (HVAC) through the operational period.

F_{Drive} – a contingency factor for driver efficiency for drivers inexperienced with regenerative braking (typically, this should improve over time).

4.2.1.1 Daily operational need for e-bus

The average power demand during the designated charging window—defined as the time frame allocated for charging e-buses—can be determined using the calculated electricity requirement (E_req). The duration and timing of this charging window are influenced by multiple factors, including the selected charging strategy (e.g., slow charging, fast charging, or opportunity charging), prevailing electricity tariffs, and the operational schedules of the e-bus fleet. These factors play a critical role in optimising energy usage while minimising costs and ensuring fleet readiness. To enhance accuracy in energy planning, the efficiency of the charging process must be accounted for in energy consumption calculations. Incorporating charging efficiency allows for more precise estimation of actual energy requirements. If the efficiency factor is known, the adjusted energy consumption can be calculated using the formula:

$$E_{adjusted} = E/\eta$$

Where,

$E_{adjusted}$ = *Adjusted energy consumption (kWh)*
E = Original energy consumption (kWh)
n= Charging efficiency (expressed as a decimal, e.g., 0.9 for 90% efficiency)

This ensures that the energy calculations reflect realistic power demand, facilitating better infrastructure planning, grid management, and operational cost control. By considering these variables, stakeholders can design charging windows that align with depot capabilities, fleet needs, and energy optimisation goals.

Tentative e-bus operational energy requirement		Depots				
Particular	UoM	Magob	Vesu	Palanpur	Althan	Bhestan
E_{Route}	kWh/km	0.96	0.93	1.19	1.14	1.28
$E_{Battery}$	%	30%	30%	30%	30%	30%
F_{Drive}	%	90%	90%	90%	90%	90%
E_{HVAC}	kWh	5	5	5	5	5
$Running_{km/day}$	km/Day	225	222	287	240	239
$Total_{operational\ hr}$	no.	15	15	15	15	15
Contingency power demand	%	10%	10%	10%	10%	10%
Number of electric buses obtained (total)	No.	85	65	75	75	100
Average Life of bus	No.	11	11	11	11	11
E-bus battery capacity	kWh	151.55	151.55	195	195	261
Operational days per year driven	Days/yr	365	365	365	365	365
E_{req} Tentative energy requirement for e-bus operation	kWh/ e-bus	435	420	634	527	578

Case Study: Table 6: Theoretical energy estimation for e-buses operation

4.2.1.2 Average power and peak power demand

A medium and fast-charging approach (Alternate Current (AC) and Direct Current (DC) fast Charger) is being implemented across all depots, with the designated charging window set between the hours of 12:00 AM and 06:00 AM, spanning 6 hours during the night parking period. This strategy aims to fully charge multiple e-buses at the same time, leveraging the off-peak hours to optimise resource utilisation and minimise operational costs as well as opportunity charging during the daytime on given time period as per tender. By aligning the charging window with operational demands and leveraging fast charging capabilities, operators can efficiently manage the average power demand during charging sessions, ensuring reliable and cost-effective e-bus operations in the city.

$$P_{Demand} = \frac{E_{req}}{C_{window}}$$

While additional considerations may come into play, such as opting for slow chargers for a more conservative approach or determining whether ultra-fast chargers should be deployed citywide to alleviate the need for grid upgrades, calculating the average charger size needed is crucial for understanding the required infrastructure scale.

Peak power demand

Now, peak power demand plays a pivotal role in this evaluation, as it directly influences several aspects of the electrical infrastructure. After determining the capacity of the EVSE charger, it becomes crucial to assess the requirements of other electrical infrastructure components, such as the size of the transformer. Firstly, the peak power demand dictates the size of the transformer necessary to meet the changing needs of the e-buses effectively. A higher peak power demand necessitates a larger transformer to ensure sufficient electricity supply to the charging stations. Secondly, peak power demand also impacts the overall electricity infrastructure required to support e-bus charging operations. Adequate infrastructure, including cabling and distribution networks, must be in place to handle the peak loads efficiently. Moreover, the total capacity of electricity to be purchased from the utility provider is influenced by peak power demand. Higher peak loads may require purchasing electricity at premium rates during peak demand periods, leading to increased operational costs.

Therefore, accurately estimating peak power demand is essential for proper planning and optimisation of the electrical infrastructure supporting e-bus charging. It ensures that the infrastructure is adequately sized to handle peak loads efficiently while minimising costs associated with electricity procurement.

$$P_{Peak} = (P_{Demand} \times N_{buses}) + P_{Cont}$$

Where,

P_{Demand} = the average power demand over the given charging window.

N_{Buses} = the number of buses

P_{Cont} = the contingency power demand

P_{Peak} = the peak power demand of the depot given in Kilowatts (kW) or megawatts (MW)

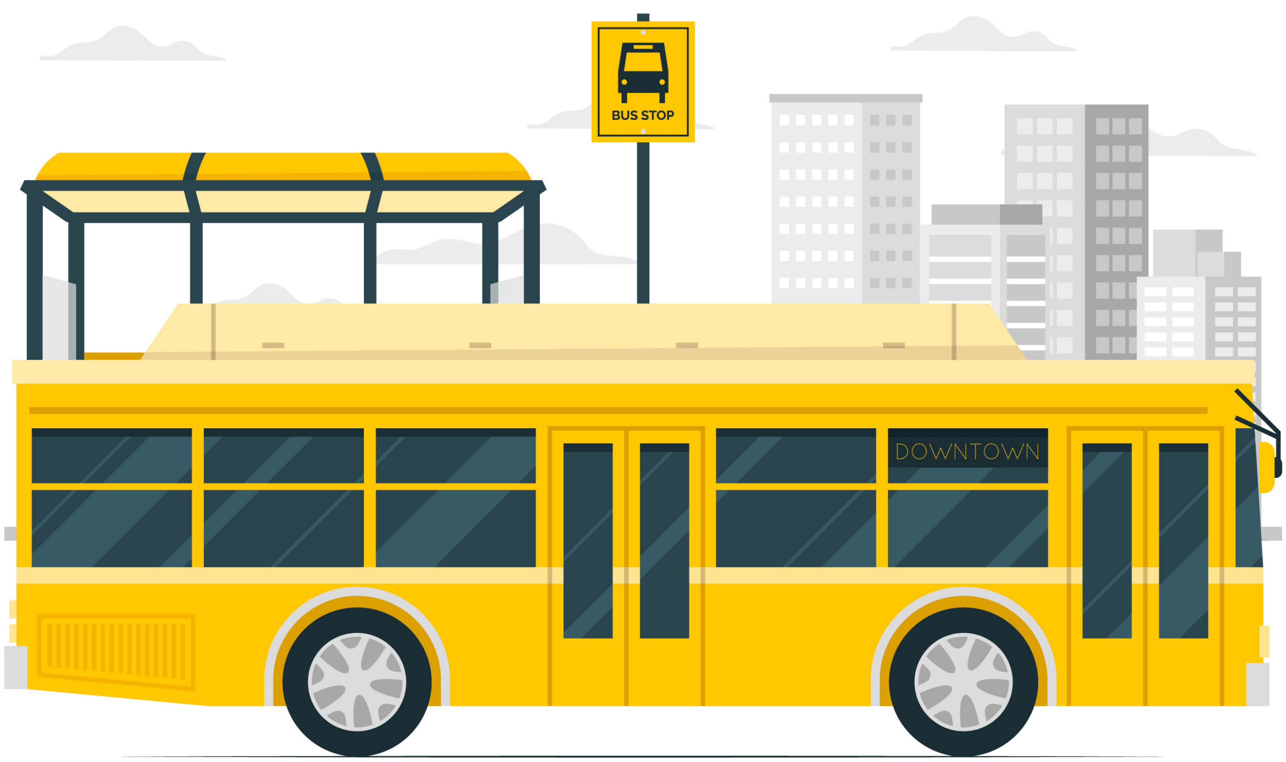
Table 7 presents a theoretical estimation of peak power requirements for e-bus operations across five different depots in Surat: Magob, Vesu, Palanpur, Althan, and Bhestan. The analysis considers the EVSE requirements per bus, energy consumption, charging efficiency, and the total power demand for each depot.

Tentative e-bus peak power requirement		E-bus depots of Surat				
Particular	**UoM**	**Magob**	**Vesu**	**Palanpur**	**Althan**	**Bhestan**
EVSE requirement for charging per e-bus	#	5	5	5	5	5
E_{req} Tentative energy requirement for e-bus operation	kWh/ e-bus	435	420	634	527	578
Contingency power demand	%	15%	15%	15%	15%	15%
EVSE charger capacity	kW	180	180	180	180	240
Charger efficiency	%	95%	95%	95%	95%	95%
Expected energy delivered by each charger	kW	171	171	171	171	228
Ideal time taken to charge complete battery @30% SoC	hr. (min)	53	53	68	68	69
E-bus to charger ideal ratio (capable with single unit EVSE) – Overnight charging	No.	7.00	7.00	6.00	6.00	6.00
E-bus to charger ideal ratio (capable with single unit EVSE) – Opportunity charging	No.	1.00	1.00	1.00	1.00	1.00
Total number EVSE requirements (overnight)	No.	12	9	13	13	17
Total number EVSE requirements (opportunity)	No.	85	65	75	75	100
Average power demand given charging window for a single e-bus	kW/ e-bus	36	47	49	41	34
Total EVSE requirement for e-buses	#	17	13	15	15	20
Aggregated EVSE demand - Capacity at depot level	**MW**	**3.06**	**3.06**	**3.68**	**3.08**	**3.40**
Peak power demand for depot - Power Sub-Station (PSS) capacity	**MW**	**3.52**	**3.51**	**4.23**	**3.54**	**3.91**

Table 7: Theoretical estimation of power requirement e-bus operation (Surat Case Study)

Each e-bus has a varying energy requirement, ranging from 420 kWh (Vesu) to 634 kWh (Palanpur). A contingency power demand of 15% is considered across all depots to account for fluctuations. The EVSE charger capacity is standardised at 180 kW for most depots, except Bhestan, which operates at 240 kW. Given a charger efficiency of 95%, the expected energy delivered per charger remains approximately 171 kW, except for Bhestan, where it is 228 kW. Charging duration at 30% State of Charge (SoC) ranges from 53 minutes at Magob and Vesu to 69 minutes at Bhestan. The e-bus-to-charger ratio, assuming a single EVSE unit, varies between 6:1 and 7:1. The total overnight EVSE requirements are highest at Bhestan (17 units) and lowest at Vesu (9 units). The opportunity charging needs are also considered, with values ranging from 65 units at Vesu to 100 units at Bhestan. The average power demand per e-bus during the charging window varies, with Palanpur having the highest demand at 49 kW/e-bus, while Bhestan has the lowest at 34 kW/e-bus. Consequently, the total EVSE power requirement for all e-buses at a given depot ranges from 13 units at Vesu to 20 units at Bhestan.

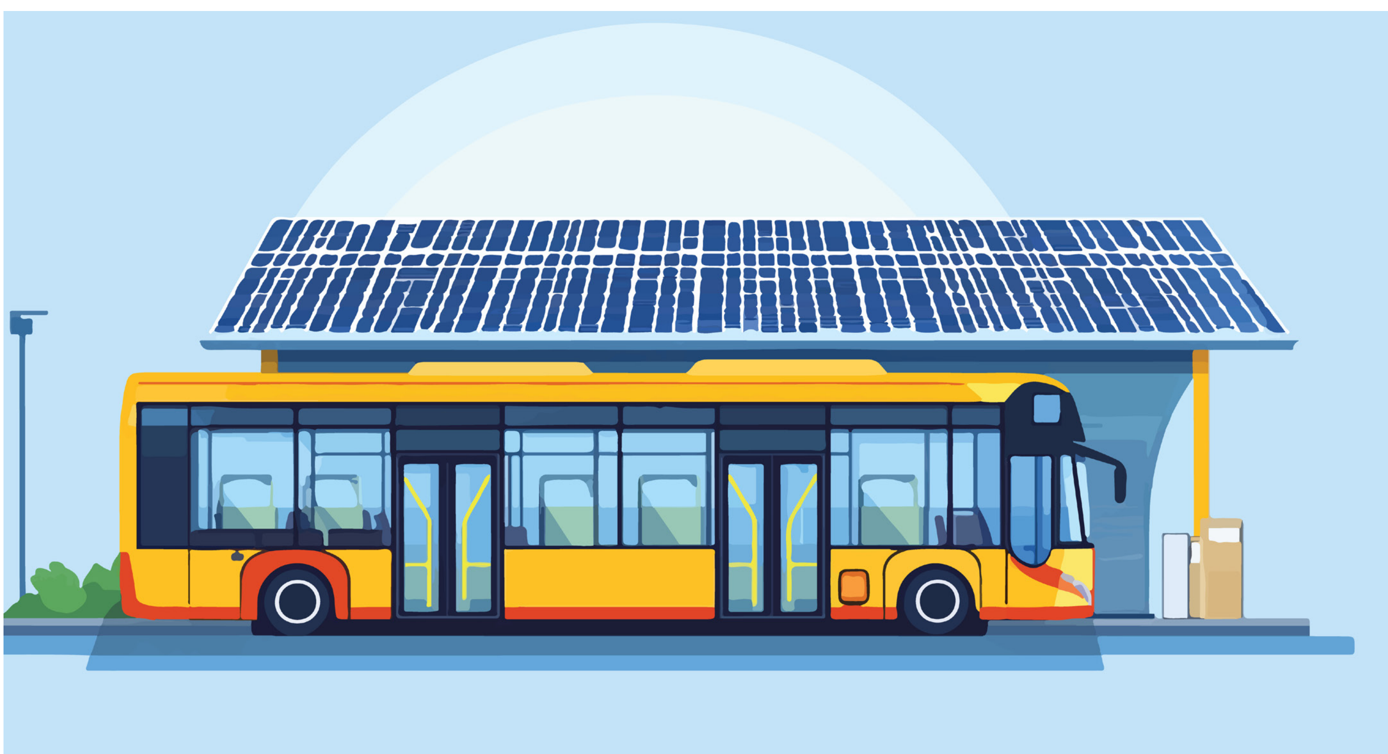
In terms of aggregated EVSE demand at the depot level, the required power capacity spans from 3.06 MW (Magob and Vesu) to 3.68 MW (Palanpur). The peak power demand at the depot level, including power substation capacity considerations, is slightly higher, with Palanpur requiring the most at 4.23 MW. This analysis provides an essential framework for planning the charging infrastructure, ensuring adequate power availability, and optimising EVSE allocation across different depots to meet operational requirements efficiently.



4.2.2 Review of regulatory and standards requirements: Depot design and charging infrastructure (BEE, 2024)

Requirements	Guidelines
Operational requirements	Visual aids shall be provided for driver/users at Public Charging Stations to navigate through the charging process effectively.
	Details of specifications of EV charger at EV charging station, shall be displayed. (All technical information published)
	Trained personnel to safely operate the EV chargers, shall be deployed in case of EVSEs installed at EV charging stations are more than 4 in numbers.
	Parking space at EV charging station shall be clearly demarcated and shall be kept free from encroachments and any nearby hindrance.
	Arrangement should be made for tracking the charger usage per user, automatic billing, and bill generation and payments.
	Adequate space for charging and entry/exit of vehicles should be provided.
Safety requirements	Appropriate cabling & electrical works ensuring safety including Type-1 & Type-2 protection as per Indian Standard Code IS / IEC 62305-4/IEC 61643-12 © IEC: 2008 (Edition 2.0 2008-11).
	All electrically charged equipment in the EV Charging Stations shall comply with the provisions of Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2023 (as amended) and Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations, 2023, as amended from time to time.
	The EVSE shall be placed in covered space to protect from rain and an appropriate fire protection equipment and facilities.
	Each EVSE model having (if) different power ratings, communication protocol, shall be type tested by OEM of the equipment in accordance with the Bureau of Indian Standards (BIS) standards by an agency/lab accredited by National Accreditation Board for Testing and Calibration Laboratories (NABL) from time to time. Validity of the Type Test certificate of the EVSE Models shall be 3 years. (if possible, OEM needs to furnish the certificate to beneficiary/Operators)

Tariff for supply of electricity	The tariff for supply of electricity to EV Charging Stations shall be a single part tariff and shall not exceed the "Average Cost of Supply" till 31st March 2026. The beneficiary must align with their existing tariff if power is drawn from the current reserve capacity. If additional capacity is required, they should obtain approval from the discom to establish the electricity connection in accordance with the EV charging infrastructure guidelines set by the Ministry of Power (MoP).
	The cost of supply by Distribution Licensee to EV Charging Station will be 0.7 times of Average Cost of Supply (ACoS) during solar hours and 1.3 times ACoS during non-solar hours. Solar hours mean 9:00 AM to 4:00 PM time and non-solar hours mean the remaining period of the day.
	Separate metering arrangements shall be made for EV charging stations so that consumption may be recorded and billed as per applicable tariff for EV charging stations. If the beneficiary and/or operator is drawing power from the current reserve capacity, it is advisable to consult with the respective discom to install a separate meter dedicated to the EVSE units.



4.2.3 Provision for e-bus depot: Centralised charging infrastructurefrastructure (BEE, 2024)

Provision	Regulatory clause	Implications
General requirements	Open access: Public charging stations can procure electricity from any source, not just the local distribution company.	Competition: This clause promotes competition in the electricity market, allowing charging station operators to negotiate better electricity prices.
	Timely provision: The electricity distribution company must provide open access within 15 days of receiving a complete application from the charging station operator.	Faster setup: The 15-day timeline for providing open access is intended to expedite the setup of charging stations.
	Charges: The charging station operator must pay:	Cost recovery: The imposed charges are designed to recover costs incurred by the electricity distribution company for providing open access.
	1. A cross-subsidy surcharge (capped at 20% as per tariff policy guidelines)	
	2. Transmission charges	
	3. Wheeling charges	
	No additional charges: Apart from the above-mentioned charges, no other fees or surcharges can be imposed.	
Depot, on-route/ public charging stations for long range EVs and/or heavy duty EVs	The clause outlines the minimum requirements for public charging stations that cater to long-range electric vehicles (EVs) and heavy-duty EVs like trucks and buses. These stations must provide fast charging capabilities.	**High power charging:** The clause mandates high-power charging infrastructure to accommodate the energy needs of long-range and heavy-duty EVs.
	Fast charging requirement: Public charging stations serving long-range and heavy-duty EVs must offer fast charging facilities.	**Charger standards:** The requirement for compliance with Power Level 3 or 4 ensures interoperability and safety standards.
	Charger capacity:	**Flexibility:** The clause offers two options for charger configuration to provide flexibility to charging station operators.
	Option 1: At least two Electric Vehicle Supply Equipment (EVSE) units with a minimum capacity of 250 kW each. Each EVSE should have a single charging gun.•	**Future proofing:** The provision for liquid-cooled cables anticipates the evolving battery technologies in EVs.

Provision	Regulatory clause	Implications
Depot, on-route/ public charging stations for long range EVs and/or heavy duty EVs	Option 2: A single charger with a minimum capacity of 50 kW to 250 kW and dual guns. Each gun should be capable of delivering at least 250 kW.	
	In both cases, the chargers must comply with Power Level 3 or 4 as specified in Table 8.	
	Liquid cooled cables: Charging stations might need to provide liquid-cooled cables to support high-speed charging for EVs with fluid-cooled batteries, if required.	
Location of charging stations	**Charging network:** The clause aims to create a robust charging network for long-range and heavy-duty EVs, facilitating their adoption.	**Charging network:** The clause aims to create a robust charging network for long-range and heavy-duty EVs, facilitating their adoption.
	Range anxiety mitigation: By ensuring the availability of fast charging stations at regular inter vals, the clause addresses range anxiety concerns for EV users.	**Range anxiety mitigation:** By ensuring the availability of fast charging stations at regular intervals, the clause addresses range anxiety concerns for EV users.
	Strategic location: The specified locations for charging stations are strategically chosen to cater to the specific needs of long-range and heavy-duty EVs.	**Strategic location:** The specified locations for charging stations are strategically chosen to cater to the specific needs of long-range and heavy-duty EVs.
	Infrastructure development: The implementation of this clause will require significant investment in charging infrastructure.	

Provision for e-bus depots charging stations	**Charger capacity and type:**	**High power charging:** The clause emphasises the need for high-power charging infrastructure at e-bus depots to ensure efficient charging of electric buses.
	E-bus depots can install chargers with a minimum capacity of 250 kW.	**Charger standards:** Compliance with Power Level 3 or 4 ensures interoperability and safety standards.
	These chargers must comply with Power Level 3 or 4 as outlined in Table (8&9).`	**Flexibility:** The clause offers flexibility in terms of the number of chargers and connector guns.
	Each charger can have a single connector gun or there can be at least one charger with dual guns, each capable of delivering 250 kW.	**Future proofing:** The provision for liquid-cooled cables anticipates advancements in battery technology.
	Liquid cooled cables:	
	The clause mandates the provision of liquid-cooled cables for high-speed charging if required by the e-buses. This is specifically for EVs with fluid-cooled batteries.	
	Open access: E-bus depots can procure electricity from any source through open access.	**Competitive pricing:** Open access allows e-bus depots to potentially procure electricity at competitive rates.
	Timely provision: The electricity distribution company must provide open access within 15 days of receiving a complete application from the e-bus depot.	**Faster setup:** The 15-day timeline for providing open access can expedite the charging infrastructure setup.
	Charges: The e-bus depot must pay: • A cross-subsidy surcharge (capped at 20% as per tariff policy guidelines) • Transmission charges • Wheeling charges	**Cost recovery:** The imposed charges are designed to recover costs incurred by the electricity distribution company for providing open access.
	No additional charges: Apart from the above-mentioned charges, no other fees or surcharges can be imposed.	
	Application for electricity connection: The operator or owner of the e-bus depot is responsible for applying for the necessary electricity connection to power the charging infrastructure.	**Responsibility:** The onus of obtaining electricity connection lies with the depot operator or owner.
	DISCOM approval: The electricity connection will be granted according to the provisions outlined in the minimum requirements of (section 3.5 DISCOM responsibility) the guidelines.	**Compliance with guidelines:** The process of obtaining the electricity connection must adhere to the specific requirements mentioned in paragraph 5(b) of the guidelines.

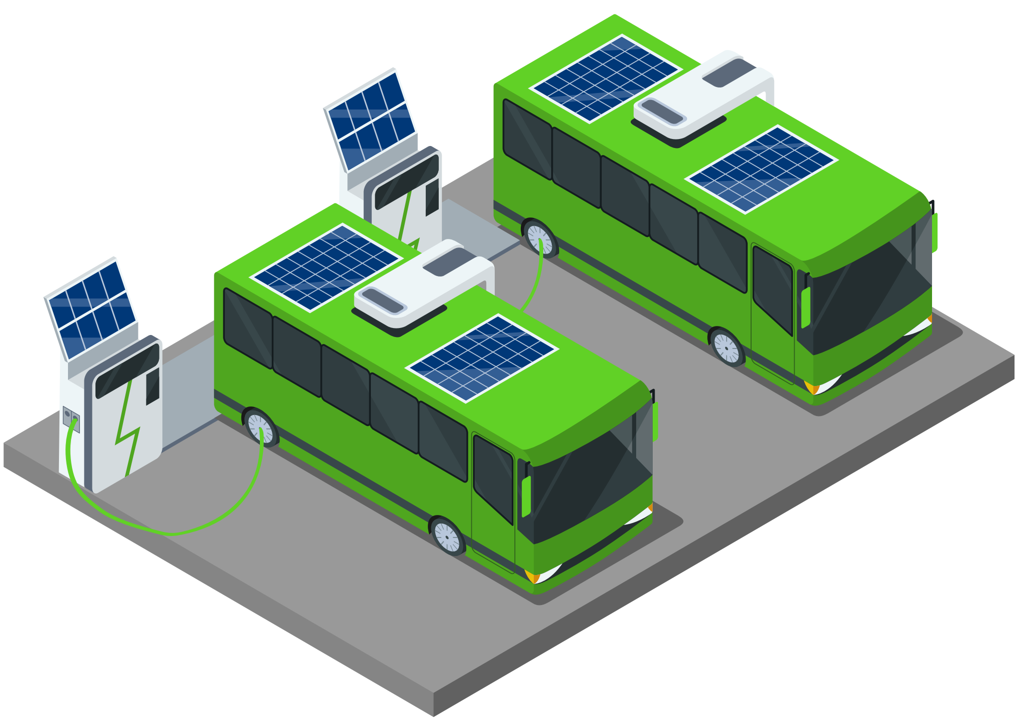
Power level 3	Charging device/protocol	EV-EVSE communication	Charge point plug/socket	Vehicle inlet/ connector
DC 50 kW to 250 kW	IS-17017-23	IS-17017-24 [CAN] IS-15118 [PLC]	IS-17017-2-3	IS-17017-2-3

CAN-Controller Area Network; PLC- Power Line Communication

Table 8: DC charging protocol (for 4W (M1 category), buses and trucks (M3)

Power level 4	Charging device/protocol	EV-EVSE communication	Charge point plug/socket	Vehicle inlet/ connector
DC High Power (250 kW --> 500 kW)				
Dual Gun Charging Station	IS-17017-23-2	IS-15118 [PLC]	IS-17017-2-3	IS-17017-2-3
Automated Pantograph Charging Station	IS-17017-3-1		IS-17017-2-3	IS-17017-2-3

Table 9: EVSE tech specification - e-bus and trucks charging station (M3 category)



4.2.4 Minimum requirement for EVSE connection

Timelines for electricity connections: Charge point operators may apply for connections with the respective DISCOM. Connections shall be provided as per the timelines outlined in rule 3(i) of the Electricity (Rights of Consumers) Rules 2024 (MoP, 2024).

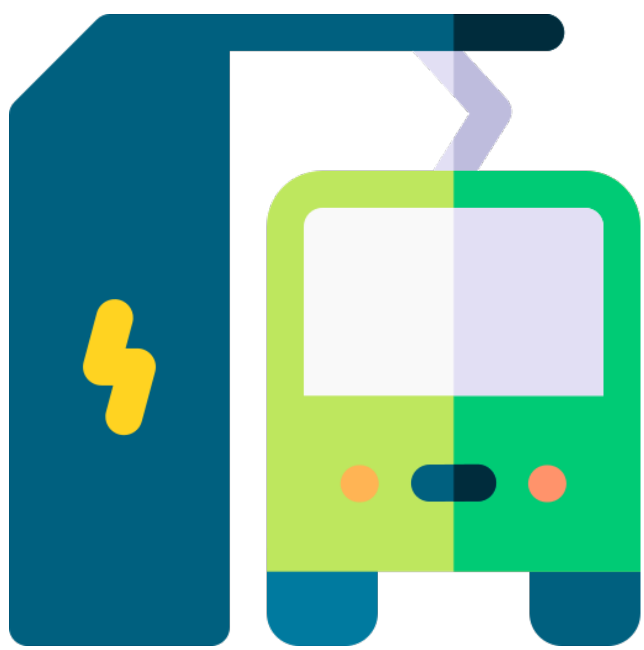
- As per the Commission's guidelines, distribution licensees must provide or modify connections within three days in metropolitan areas, seven days in other municipal areas, and fifteen days in rural areas. For rural areas in hilly regions, the maximum time is thirty days after the complete application is submitted.
- If the electricity supply requires extending distribution mains or commissioning new substations, the distribution licensee must provide the connection within 90 days after completion of these works.
- The distribution licensee, in consultation with the Appropriate Commission, may provide LT connections of up to 150 kW for public, community, workplace, and bus depot charging stations.

4.3 Regulatory and Safety Standards: Downstream Infrastructure

4.3.1 EV charger-specific safety standards (MoP, 2022)

- **Charging station safety:** Ensure chargers are compliant with BIS IS 17017-1 and IS 17017-2 (covering safety and EMC requirements).
- **Protection against electric shock:** Ensure proper protection from electric shock through the use of Residual Current Devices (RCDs) and insulation monitoring devices.
- **Cable and connector safety:** Use high-quality, flame-retardant cables and connectors that comply with the standards laid out in IS/IEC 61851 (Electric vehicle conductive charging system) and IS 12360 (Voltage ratings for electrical installations).
- **IS/IEC 61851 -** Electric vehicle conductive charging system

  I. The IS/IEC 61851 series is an international standard that provides the requirements for electric vehicle conductive charging systems. It is divided into several parts, each addressing different aspects of EV charging. This standard has been adopted in India by the Bureau of Indian Standards (BIS) as IS 61851, aligned with the IEC 61851.



Part 1: General Requirements

- Defines the basic safety and performance requirements for the conductive charging of electric vehicles.
- Covers different types of charging modes (Mode 1 to Mode 4), from simple charging to fast DC charging.
- Specifies the electrical characteristics for the charging system, including the voltage, current, and power limits.
- Protection against electrical shock, mechanical hazards, and fire hazards is covered.
- Communication between the EV and the EVSE (Electric Vehicle Supply Equipment) for charging management.

→

Part 21: Electric Vehicle Requirements for Conductive Connection

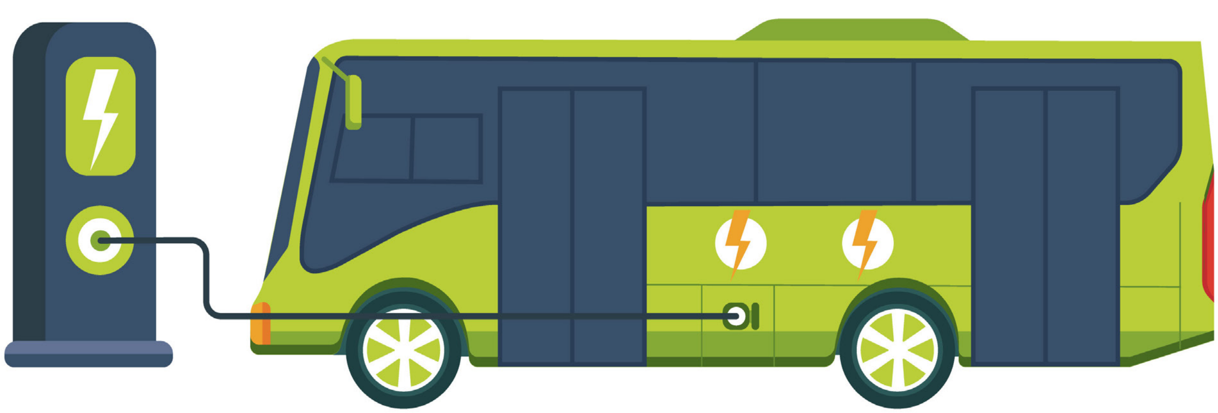
- Defines the requirements for electric vehicles concerning conductive charging.
- Specifies characteristics like the charging inlet, voltage levels, and current characteristics.

→

Part 23 & 24: DC Electric Vehicle Charging Station

- Focuses specifically on the requirements for DC fast charging stations.
- Covers the functional requirements for DC chargers, including the safety measures, electrical ratings, and performance standards.
- Specifies the types of connectors (e.g., CCS, CHAdeMO, etc.) and their electrical specifications.
- Digital Communication Between a DC EV Charging Station and an EV for Control of DC Charging:Defines the communication protocol for control and monitoring during DC charging.

Figure 6: Key specifications for EVSE units' implementation & operation



05

Strategic Energy Planning for E-bus Depot Operations

5.1 Energy assessment strategy

Ensuring a reliable energy supply to meet the operational demands of e-buses necessitate a strategic, data-driven assessment energy assessment. This involves forecasting short-and long-term energy needs, including peak loads occurrences, and analysing charging behaviour to inform depot infrastructure design and power planning. A comprehensive energy assessment strategy was developed through **structured data collection and field** evaluation during site visits to the selected depots. The following key datasets were obtained, analysed, and triangulated to build an accurate energy utilisation profile of the e-bus fleet:

- **Charging station registry data:** Detailed logs from Charge Point Operators (CPOs) and e-bus operators were obtained to examine charging frequency, duration, timing, and energy draw per event.

- **Electricity bills paid by operators to discoms:** Utility bills paid by depot operators to DISCOMs were reviewed to estimate total energy consumption, cost trends, and seasonal variations.

- **E-bus operation and charging schedule data:** Internal depot records, including vehicle dispatch logs, route plans, and charging schedules, were analysed to correlate charging behaviours with operational timelines.

- **Operational and maintenance data:** Additional inputs such as uptime ratios, maintenance schedules, battery performance, and downtime records were assessed to identify performance deviations and operational risks.

These data points were synthesised to develop a comprehensive operational energy profile for the depot and fleet, providing insights into both real-time consumption and long-term capacity requirements. Key outcomes of the energy assessment include:

1. **Energy demand forecasting:** Identification of both average and peak energy demand based on route length, fleet size, battery capacity, and operational schedules.

2. **Charging efficiency insights:** Detection of charging inefficiencies, idle time, and sub-optimal charger utilisation patterns affecting service reliability.

3. **Operational benchmarks:** Establishment of baseline metrics for energy consumption per kilometre, per bus, and per depot to guide performance optimisation.

4. **Maintenance-performance linkages:** Correlation of vehicle downtime with energy use anomalies, enabling predictive maintenance planning and service reliability improvements.

This **data-backed energy assessment** provides the foundation for informed depot electrification planning. It enables operators to design tailored charging strategies, prioritise capacity enhancements, and build a robust, energy-secure system for current operations and future fleet expansion. Detailed findings and analytical outputs from this assessment are presented in the following sections.

5.2 Case study: Energy and power assessment of Bhestan depot

This section presents a detailed analysis of energy consumption patterns and electricity billing trends at **the Bhestan e-bus depot,** which has emerged as a key operational hub under Surat's electric bus rollout. Serving route no. 11, the depot achieved full fleet deployment progressively during the first half of 2024. The period from February to July offers valuable insights into the **scaling of e-bus operations** and corresponding impact on energy infrastructure requirements.

Energy consumption trends

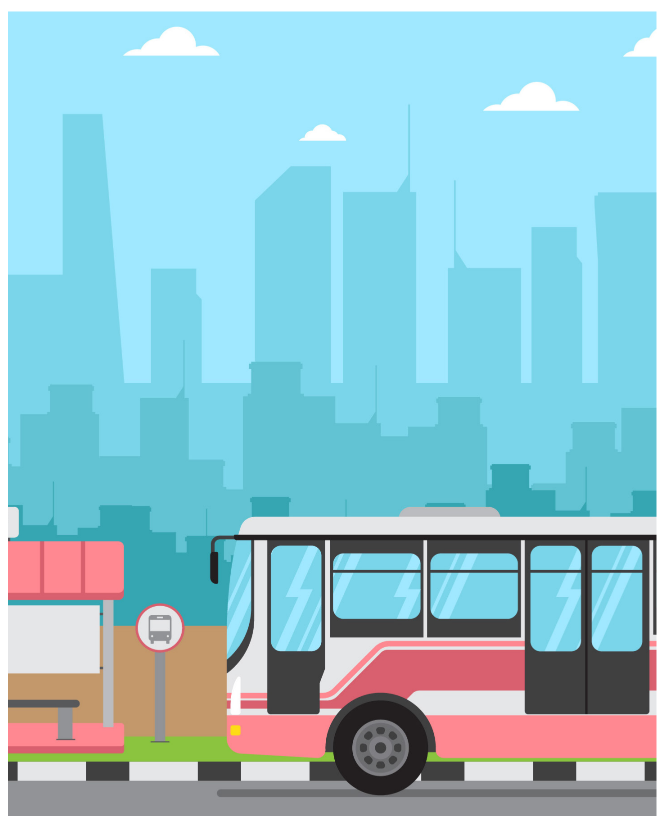
Over the six-month period, energy consumption increased consistently, beginning from a modest 3.78 MWh in February and peaking at 358.5 MWh in June. This upward trend closely aligns with the gradual operationalisation of additional buses and indicates 100% fleet utilisation by mid-year. In July, energy consumption saw a marginal decline to 333.2 MWh, which may be attributed to seasonal route adjustments, temporary operational constraints, or the early effects of energy efficiency measures introduced during the period.

Time-of-day charging patterns

An assessment of time-of-day energy usage (see Figure 7) highlights the predominance of night-time charging, which accounted for the majority of energy draw across all six months. This pattern reflects a deliberate strategy to align charging operations with off-peak tariff periods as defined by the distribution utility. By doing so, the operator effectively minimises per-unit energy costs and reduces load pressure on the grid during peak demand hours. Starting from April, there is a noticeable uptick in afternoon charging, likely a response to increased daytime service frequency and the growing need for opportunity charging during shift transitions. Despite this increase, energy usage during Time-of-Use (ToU) tariff windows—typically the costliest period—remained consistently low, indicating strong operational planning and tariff optimisation.

Key observations

- The depot's energy usage closely tracks fleet expansion, reinforcing the importance of synchronising infrastructure planning with service rollout.
- Night-time charging continues to be a cost-effective and grid-friendly approach for large-scale depot operations.
- Early signs of adaptive charging strategies—including daytime top-ups—suggest an evolving operational model responsive to fleet demands and service expansion.
- The low utilisation of high-tariff ToU windows demonstrates effective cost management through smart scheduling.
- This case study illustrates how real-time monitoring of energy usage, combined with tariff-aware planning, can support scalable, cost-effective, and operationally resilient e-bus depot management. The Bhestan depot experience serves as a practical reference for similar depot electrification efforts across other Indian cities.



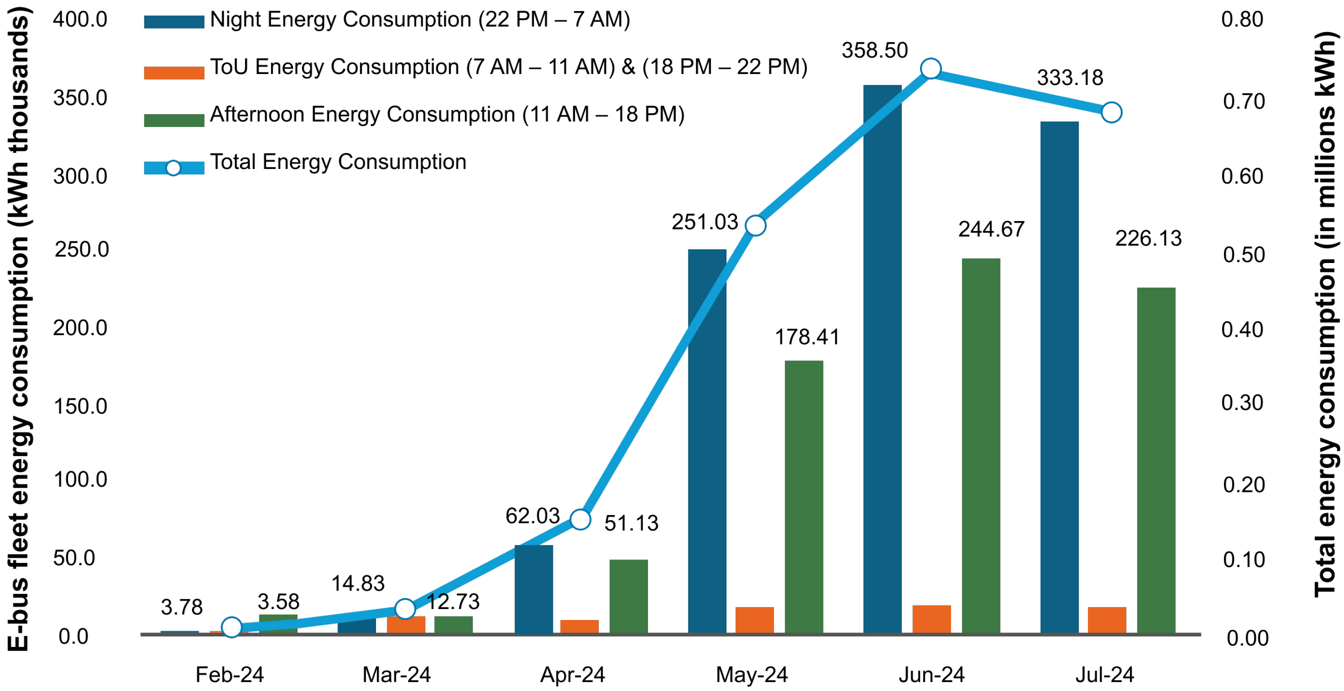


Figure 7: Energy consumption pattern Bhestan depot route no.11

Electricity billing trends

The electricity billing trends for the Bhestan depot (see Figure 8) closely mirror the upward trajectory observed in energy consumption. Monthly electricity expenditure rose from ₹3.34 lakh in February to ₹61.42 lakh in June, reflecting the cumulative impact of:

- Increased energy demand due to expanded fleet operations
- Higher charger utilisation
- Likely revisions to the contracted demand agreed with the DISCOM

The slight reduction in billing for July, with costs declining to ₹57.17 lakh, aligns with the modest drop in total energy consumption recorded during the same month This may also indicate the early impact of improved charging schedules or targeted load management interventions introduced at the depot.

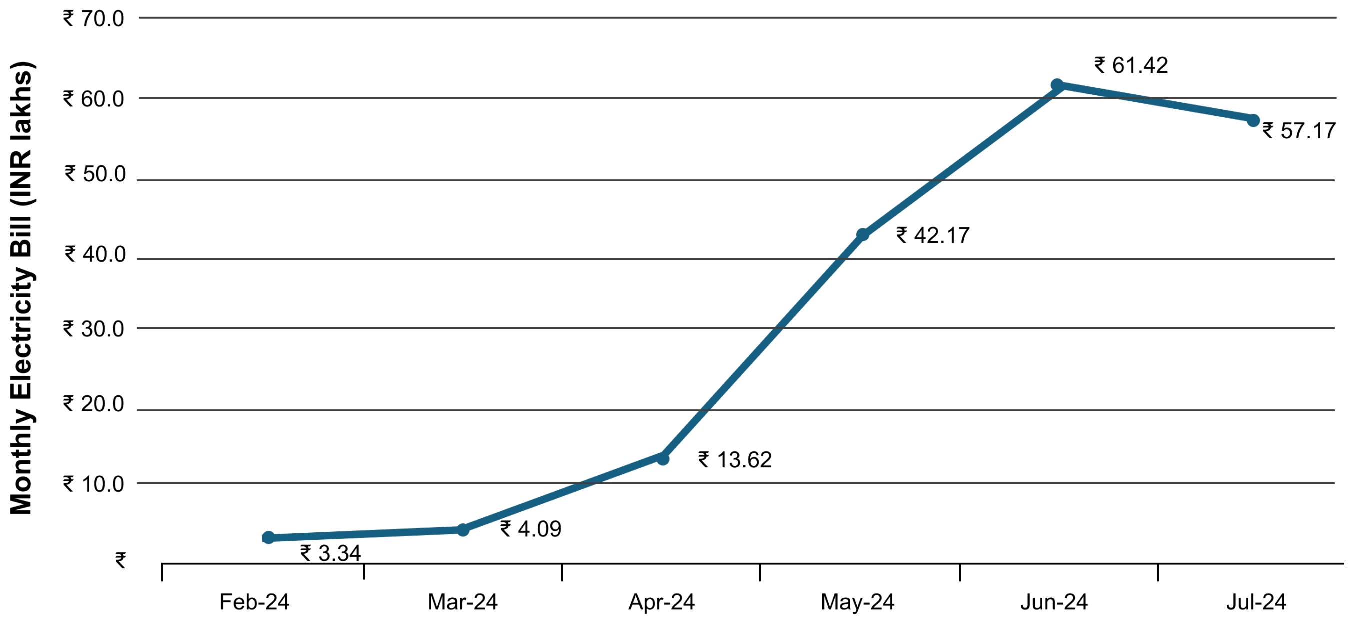
Strategic and financial implications

The data clearly demonstrates that Bhestan depot's energy management strategy has effectively leveraged off-peak tariff windows, allowing the operator to reduce per-unit energy costs while ensuring full fleet availability during service hours. However, the sharp escalation in energy and associated cost between April and June signals the need for proactive infrastructure planning. As fleet sizes grow and additional depots are brought online the following aspects will become increasingly critical:

- **Transformer capacity** and power evacuation readiness
- **Sanctioned demand thresholds** and potential penalties
- **Tariff structuring and load shifting** opportunities in coordination with the DISCOM

Key takeaways

This case not only offers evidence of well-structured initial energy planning but also points to areas where further load balancing, infrastructure upgrades, and integration with renewable energy sources (such as on-site solar or open-access procurement) may be required to maintain financial and operational resilience.



Sources (such as on-site solar or open-access procurement) may be required to maintain financial and operational resilience.

Figure 8: Electricity bill paid over period of 6 months

- Total energy consumption peaked at 358.50 thousand kWh in June, with a slight decline in July (333.18 thousand kWh).

- Electricity costs surged from ₹3.34 lakh in February to ₹61.42 lakh in June, mirroring the increase in consumption.

- Night-time energy usage dominates, indicating a preference for off-peak charging.

- Afternoon consumption grew steadily, suggesting increased fleet activity during the day.

- Minimal ToU energy consumption suggests effective cost-saving strategies.

- July saw a slight drop in both total energy usage and cost, hinting at possible optimisations in energy management. The Bhestan depot showcases the benefits of early-stage energy planning, aligning infrastructure capabilities with fleet rollout timelines.

- The effectiveness of tariff-optimised charging underlines the value of night-time scheduling as a cost-control measure.

- The significant month-on-month cost increases emphasise the need for scalable energy infrastructure, particularly in the areas of contracted load, transformer upgrades, and distribution capacity.

To sustain long-term operational and financial resilience, further strategies should be explored, including:

- **Integration of renewable energy sources** (e.g. rooftop solar or open-access solar procurement)

- **Battery Energy Storage Systems (BESS)** for load smoothing and peak shaving

- **Advanced energy analytics and load balancing tools** to optimise usage patterns

This case illustrates that while the Bhestan depot has navigated the initial scale-up phase effectively, continued investment in electrical infrastructure and clean energy integration will be essential to support the next phase of Surat's electric bus transition.

5.2.1 Energy and power assessment – Bhestan depot

Power demand and power factor trends

In addition to the upward trend in energy consumption and electricity billing observed earlier, a closer examination of recorded power demand and power factor at the Bhestan depot offers deeper insights into its operational energy dynamics and electrical efficiency. As illustrates in Figure 9, the actual recorded demand surged from 258 kVA (2.58 hundred kVA) in February 2024 to 3,481 kVA (34.81 hundred kVA) by July 2024. This thirteen-fold increase directly corresponds with the ramp-up of fleet operations, longer service hours, and higher charger utilisation, reinforcing the direct relationship between operational scale and energy demand. Simultaneously, average power factor improved significantly—from 0.621 in February to 0.981 in both June and July. A high-power factor indicates efficient utilisation of electrical energy with minimal reactive losses. This improvement suggests the deployment of power correction systems, such as capacitor banks or automated power factor correction (APFC) panels and reflects proactive load balancing through intelligent charger scheduling.

These trends highlight Bhestan depot's strategic focus on electrical efficiency and cost optimisation while scaling operations. However, the growing demand trajectory calls for timely infrastructure upgrades, particularly. However, it also signals the need for strategic infrastructure upgrades, especially in terms of substation capacity, distribution transformers, and upstream grid connectivity. If left unaddressed, continued growth in demand could risk overloading the system or incurring peak load charges. The Bhestan case demonstrates how scaling electric bus operations can be effectively managed when backed by sound energy planning and real-time performance optimisation.

These learnings can serve as critical input for the planning of future depots under similar fleet electrification programs.

Key outcomes:

1. The depot's actual recorded demand increased more than thirteen-fold in six months, illustrating rapid scale-up and growing charger utilisation.
2. The combination of high demand and high-Power Factor (PF) demonstrates strong electrical planning but also signals the need for future infrastructure reinforcement.
3. Bhestan depot offers a scalable reference model for electrification planning under similar urban e-bus programmes.
4. The near-unity power factor contributes to lower operational losses and helps avoid DISCOM penalties, thus supporting long-term cost efficiency.
5. The depot's recorded actual demand increased more than thirteen-fold over six months, reflecting the rapid scale-up of fleet operations and corresponding rise in charger utilisation.
6. Power factor improvement from 0.621 to 0.981 highlights effective reactive power management through power correction systems or infrastructure upgrades.
7. The combination of high-power demand and strong PF underscores the need for proactive grid infrastructure augmentation, including transformer resizing and substation reinforcement.
8. Bhestan depot provides a scalable reference model for future depot planning, demonstrating how demand growth can be managed without compromising power quality or operational efficiency.
9. The near-perfect power factor is a positive outcome, reducing energy wastage and lowering operational costs.

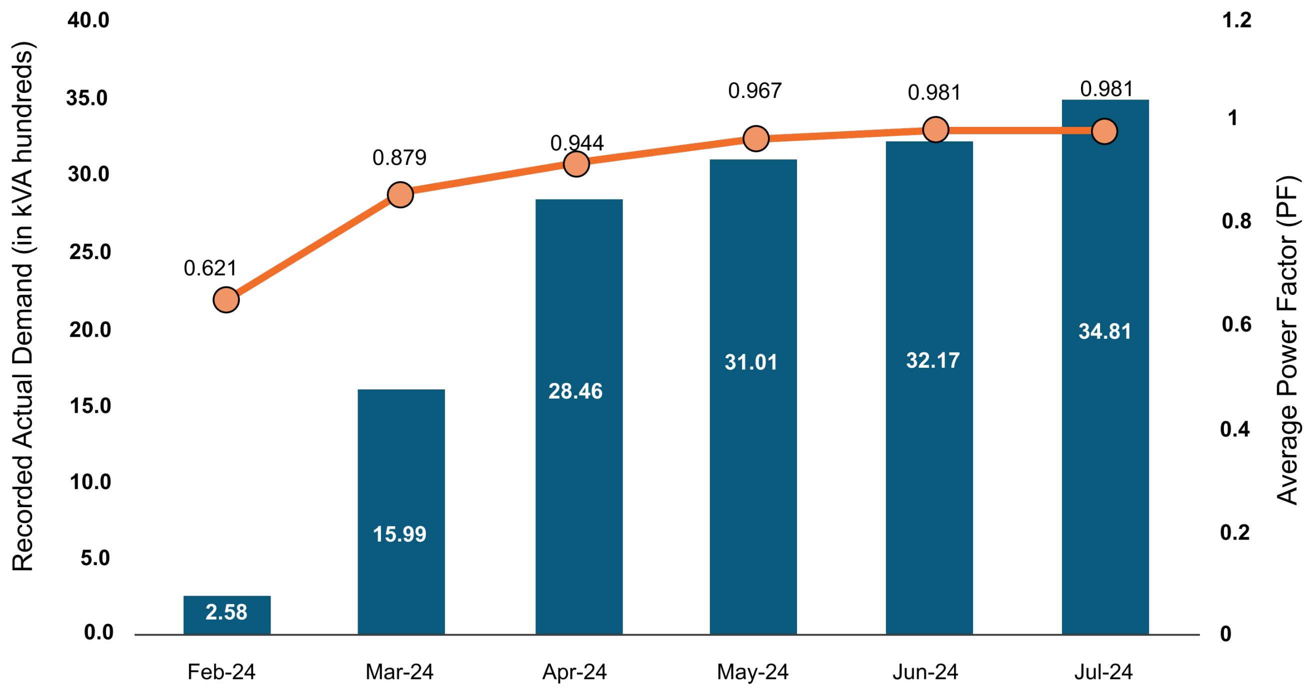


Figure 9: Recorded power demand by e-bus fleet @Bhestan depot

5.2.2 Route-based analysis

1) Route no. 11: Operational energy and efficiency trends

The daily energy consumption analysis for route no. 11 (Figure 10) at Bhestan Depot from 19 to 25 April 2024 reveals a moderate decline in overall energy demand, dropping from 3,554 kWh/day to 3,180 kWh/day. This downward trend is primarily attributed to a sharper fall in the energy draw from the 2nd operational cycle (from 1,357 to 1,191 kWh), while the 1st cycle maintained relatively stable consumption (2,197 to 1,989 kWh).

This pattern indicates:

- Operational refinements that reduced dependency on back-to-back battery cycles.
- More efficient route planning or reduced load intensities during the second half of daily operations.

Figure 11 presents route no. 11's average daily distance run, and energy consumed. The energy consumed in operation declined steadily from a peak of 274 kWh on 20th April to 219 kWh on 25th April. Correspondingly, operational efficiency, measured in km/kWh, showed a dip mid-week (1.13 km/kWh on 22nd April) but improved to 1.19 km/kWh by 25th April. This indicates an eventual recovery in energy-use performance, potentially due to revised deployment strategies or reduced dwell times.

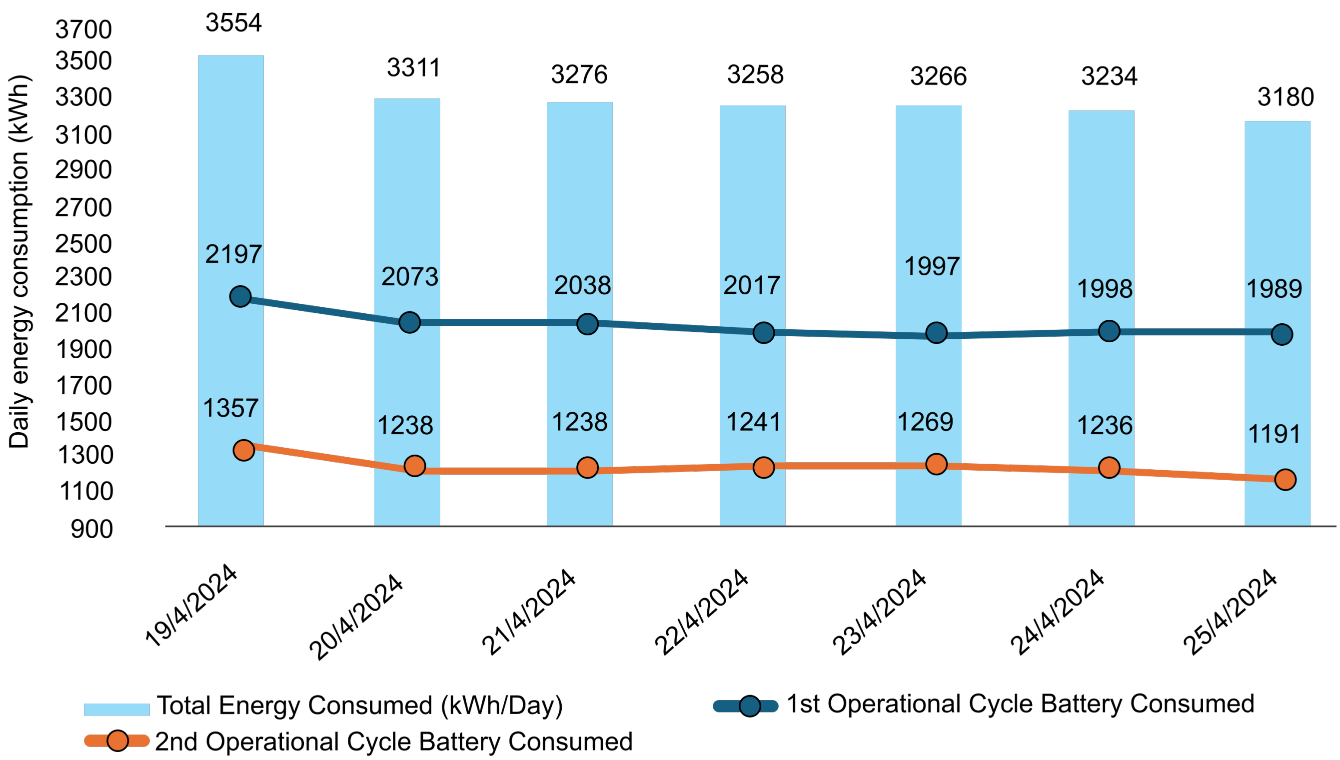


Figure 10: Energy consumption pattern Bhestan depot - route no.11

2) Route no. 12: Depot-level energy consumption and stability

Route no. 12 (Figure 12), also operating from Bhestan Depot, showed a higher overall energy profile than Route 11, with total consumption ranging between 5,541 kWh/day to 5,889 kWh/day. The energy usage remained steady, with a notable dip on 22nd April, possibly caused by reduced vehicle deployment, maintenance downtime, or partial shift operations. Energy drawn from both battery cycles followed the same trend, confirming a depot-level operational dip rather than route-specific inefficiencies.

In contrast to route no. 11's fluctuating trends, route no. 12 demonstrated greater operational consistency, marked by uniform energy distribution across the 1st and 2nd cycles and a relatively flat efficiency curve.

Figure 13 details operational efficiency for Route 12 over the same period. While daily distance covered remained in the 250–300 km/day range, a gradual decline in energy consumption per kilometre was observed, falling from 1.15 kWh/km to 1.04 kWh/km. This improvement indicates:

- Effective route energy management.
- Lower auxiliary loads or optimised driving behaviour.
- Potential improvements in road conditions or external factors (e.g., reduced congestion).

Key outcomes:

1) Route 11 showed clear gains in operational efficiency despite mid-week volatility, suggesting real-time performance adjustments.

2) Reduction in 2nd cycle energy draw on Route 11 indicates smarter fleet cycling or strategic load balancing.

3) Route 12 maintained steady operational and energy profiles, with one short-lived anomaly, indicating robust backend planning.

4) The improved energy efficiency on Route 12 (decline in kWh/km) reinforces the importance of ongoing data-driven optimisation.

5) Daily distance and energy variations across both routes highlight the need for route-specific energy management and predictive scheduling al-

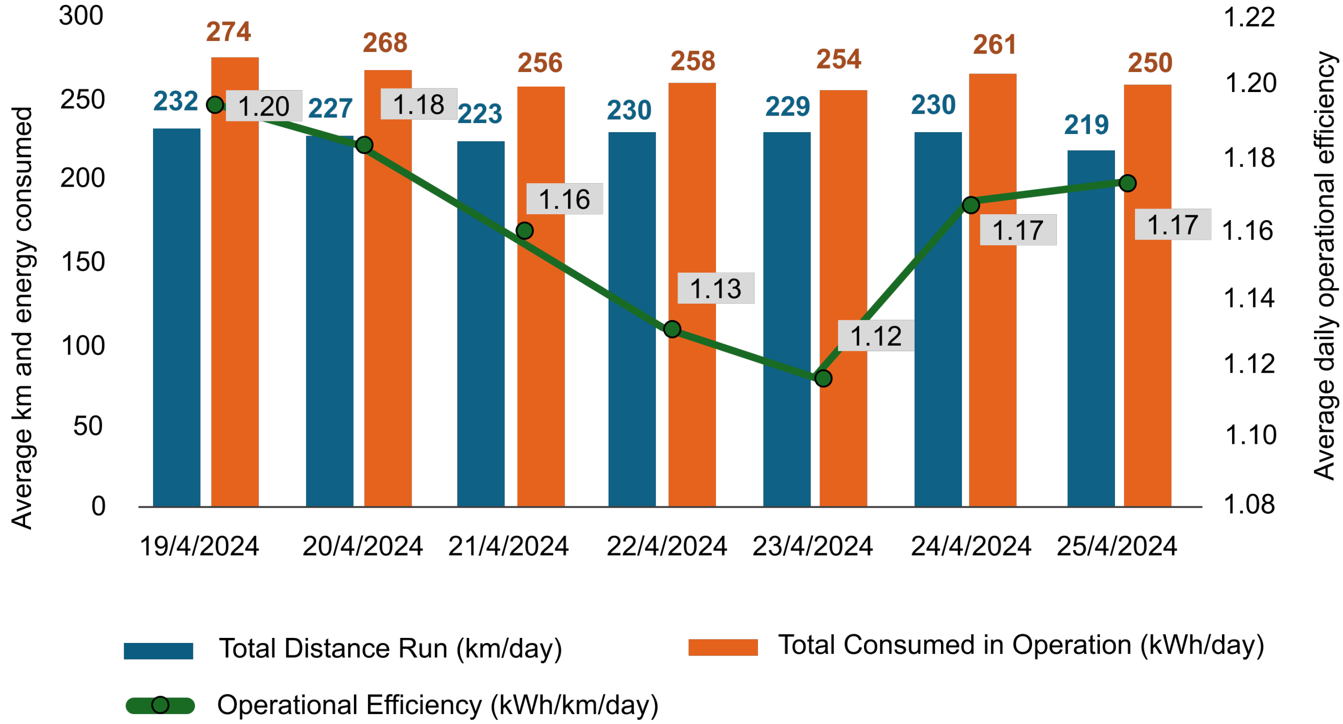


Figure 11: Operational parameter analysis- route no.11

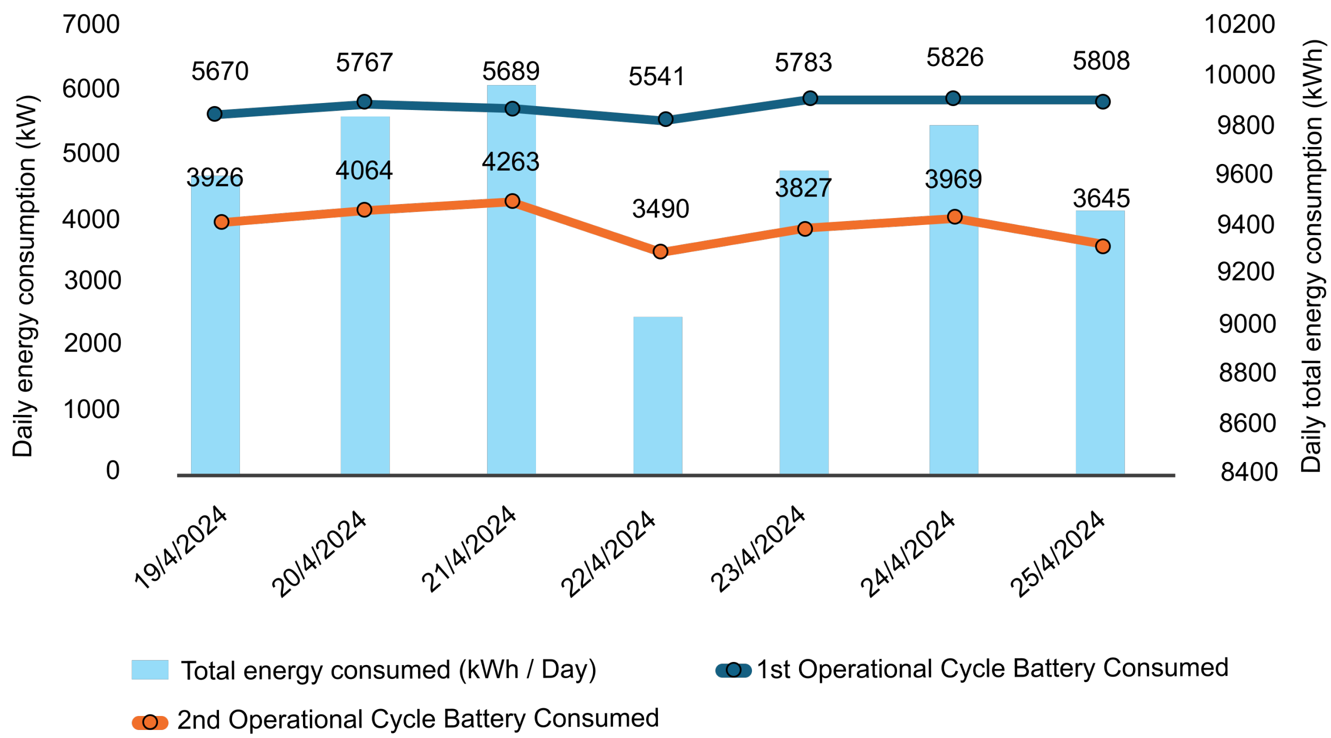


Figure 12: Energy consumption pattern Bhestan depot - route no.12

Key outcomes:

1. Route no. 11 showed improved operational efficiency and reduced energy consumption by the end of the period, despite a mid-week performance dip.
2. Route no. 12 (Bhestan depot) maintained consistent daily energy consumption with well-balanced use of battery cycles.
3. A notable drop in energy use on 22-Apr in route no.12 suggests a brief operational disruption, likely due to maintenance or reduced fleet activity.
4. Overall, both routes demonstrate effective energy and fleet management, with opportunities for further optimisation and anomaly tracking.

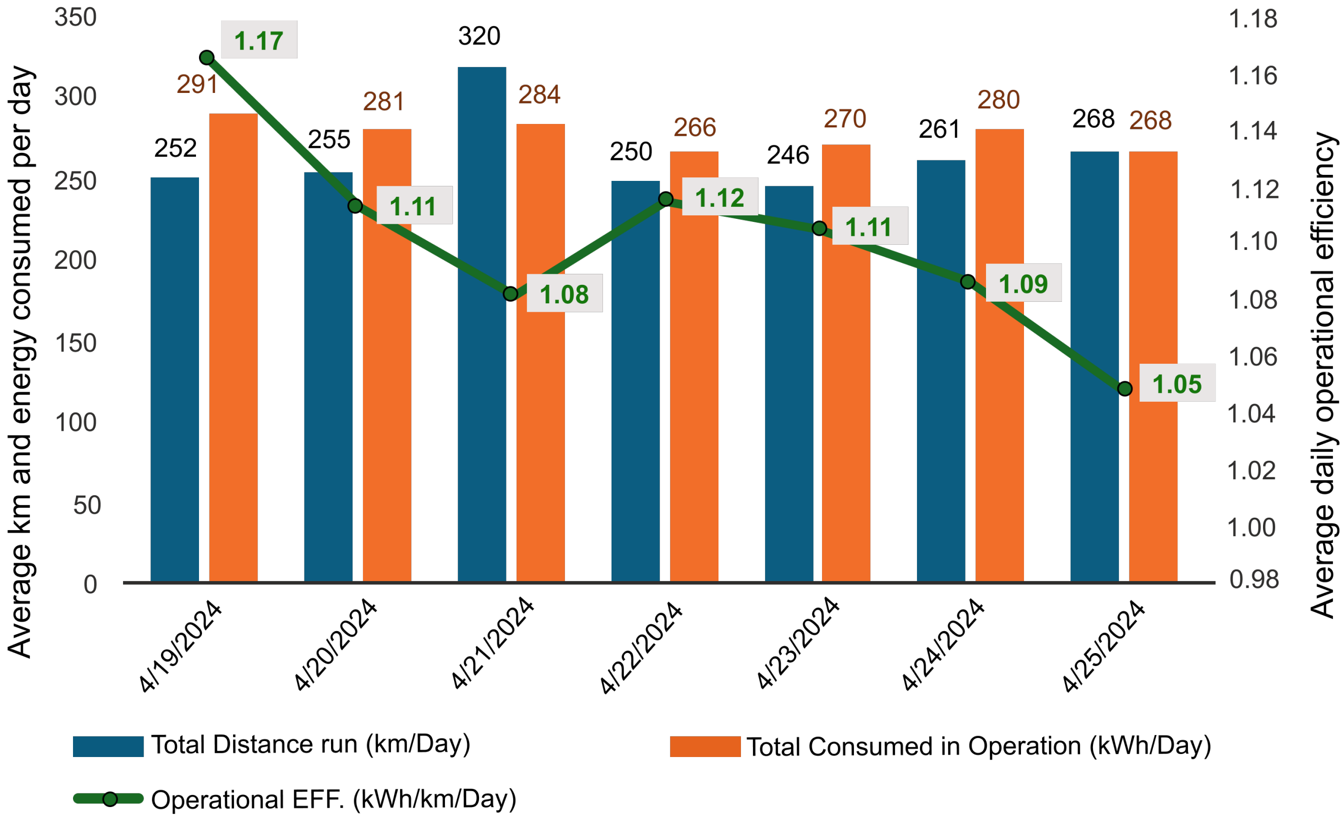


Figure 13: Operational parameter analysis- route no.12

5.2.3 Observation and recommendations – E-bus route analysis

Final observation

The route-level energy and operational analysis of Bhestan depot's electric bus fleet reveals meaningful progress toward sustainability and system efficiency, yet also highlights areas for refinement:

- **Sustainability and cost-effectiveness:** Both route 11 and route 12 reflect a clear shift toward more energy-efficient operations, demonstrated by reduced overall energy consumption and improved operational efficiency metrics. These improvements directly support reduced carbon emissions and lower operating costs.

- **Operational optimisation:** The consistent energy usage pattern in the first operational cycle highlights battery reliability and effective overnight charging strategies. Meanwhile, the decreasing reliance on the second cycle implies evolving charging discipline and improved planning. However, fluctuations in daily energy draw and fleet mileage signal a need for tighter control on scheduling and charging predictability.

- **Systemic challenges and future potential:** Despite positive trends, the variation in operational efficiency and energy draw across days and routes underscores unresolved operational variability. Addressing these gaps through targeted interventions can unlock additional efficiency and enhance long-term system resilience.

Recommendations:

- **Root cause analysis:** Identify specific factors contributing to variations in energy usage and route performance, such as driving patterns, vehicle load, or external environmental conditions, to guide mitigation strategies.

- **Data-driven scheduling:** Leverage historical energy and route data to enhance fleet dispatching, reduce idle times, and distribute charging loads more evenly across operational hours.

- **Enhance battery utilisation monitoring:** Evaluate second operational cycle usage in detail. Determine if reduced energy draw is due to improved planning or underutilisation and realign as needed for cost efficiency.

- **Establish real-time performance dashboards:** Develop integrated monitoring tools to track energy consumption, SoC (State of Charge), battery cycling, and depot-level performance in real-time.

- **Improve human and technical capacity:** Strengthen driver training programmes focused on efficient driving practices, while simultaneously enhancing preventive maintenance systems to reduce unscheduled downtime and battery degradation.

The Bhestan depot case offers a robust, scalable template for managing e-bus energy operations. With ongoing refinement and infrastructure planning, it can serve as a benchmark for depot electrification efforts across India's growing e-mobility ecosystem.

5.3 Learnings

The study offers the following conclusive learnings, critical for scaling up e-bus fleet operations sustainably:

- **Energy Sustainability and Operational Efficiency:** The ongoing transition toward electric mobility is reflected in declining per-kilometre energy consumption and increasing operational discipline, resulting in economic and environmental benefits.

- **Charging Strategy Optimisation:** A clear dominance of night-time charging highlights successful cost optimisation via off-peak tariffs. However, rising afternoon energy demand requires future-proofed strategies to manage midday loads without grid stress.

- **Power Demand Escalation and Infrastructure Readiness:** The rapid rise in peak power demand, particularly at Bhestan depot (up to 4.23 MW), necessitates urgent capacity augmentation of both upstream and downstream grid infrastructure.

- **Efficiency Trends in First vs. Second Charging Cycles**: Operational efficiency gains are primarily concentrated in the first battery cycle. The role and performance of the second cycle remain variable and must be actively monitored for optimisation.

- **Renewable Energy Integration:** Depot electrification needs can increasingly be met by integrating distributed rooftop solar, supported by BESS (Battery Energy Storage Systems), to reduce grid dependency and achieve tariff stability.

5.4 Recommendations for transit operators and municipal authorities

To accelerate the operational maturity and long-term sustainability of electric bus operations, the following recommendations are proposed:

1. Data-driven operational optimisation

- Conduct deeper analyses into route-specific and day-wise consumption patterns to isolate inefficiencies.
- Utilise historical data analytics to refine scheduling, balancing charging loads across different periods to prevent peak congestion.
- Implement a predictive energy demand model for better load forecasting.

2. Charging infrastructure expansion and grid readiness

- Expand charging infrastructure, ensuring that peak depot-level power requirements (3.52 MW to 4.23 MW) do not strain the existing grid.
- Invest in smart charging solutions that prioritise vehicles based on energy needs and fleet schedules.

3. Battery performance and lifecycle optimisation

- Investigate 2nd operational cycle battery performance to improve utilisation.
- Conduct regular battery health assessments to maximise efficiency and lifespan.

4. Renewable energy integration & energy efficiency measures

- Implement solar PV installations at depots to offset power demand and reduce reliance on grid electricity.
- Explore Energy Storage Solutions (ESS) such as Battery Energy Storage Systems (BESS) to manage demand fluctuations.

5. Training and maintenance improvements

- Enhance driver training programs to improve energy-efficient driving behaviour.
- Strengthen preventive maintenance schedules to ensure vehicle efficiency and avoid unexpected downtime.

6. Continuous monitoring and feedback mechanism

- Establish a real-time monitoring system to track energy usage, battery health, and fleet efficiency.
- Use automated reporting tools for data-driven decision-making and continuous operational refinement.

By implementing these structured, data-backed interventions, transit authorities and city governments can ensure that electric bus depots evolve into cost-efficient, reliable, and climate-resilient infrastructure systems that meet India's ambitious urban mobility goals.

06

Synergising Renewable Energy with e- Bus Depots

6.1 Need for renewable energy in e-bus depots

The transition to e-buses has become a crucial step in achieving sustainable urban mobility, providing an eco-friendly alternative to traditional fossil fuel-based public transport. Increasingly, public transit authorities and operators have adopted e-buses to reduce maintenance costs, mitigate the volatility of diesel prices, and improve operational reliability. However, the rapid pace of e-bus deployment has led to a significant surge in electricity demand, particularly for depot-based overnight and opportunity charging. This growing demand places additional pressure on the existing power distribution network, which are already strained by concurrent residential, commercial, and industrial loads – particularly during peak hours. Against this backdrop, the integration of renewable energy sources—with a particular emphasis on solar power—has become a strategic imperative for e-bus depots. Solar energy can play a pivotal role in:

- **Offsetting auxiliary energy loads** within the depot
- **Reducing reliance on grid-supplied electricity,** especially during daytime charging
- **Minimising exposure to high electricity tariffs** through on-site generation
- **Improving depot energy resilience** during outages or demand spikes

By replacing a portion of grid electricity with solar power, transit authorities can significantly lower operational costs associated with high electricity tariffs for e-bus charging. Additionally, on-site solar generation enhances energy resilience, ensuring a more sustainable and cost-effective approach to e-bus deployment.

6.1.1 Role of solar rooftop systems in meeting charging demands

With over a decade of experience in renewable energy, India has witnessed an unprecedented shift toward solar power, establishing its economic viability and competitiveness against coal-based generation. This transformation highlights the potential of solar energy as a cost-effective and sustainable solution for various applications, including public transportation infrastructure. Unlike traditional ICE depots, e-bus depots require specialised architectural planning, optimised spacing, and advanced technical configurations. The parked e-buses rely on multiple charging units to meet their energy demands, not only for propulsion but also for other depots auxiliary consumption. As a result, operators must secure a stable and cost-effective electricity supply, often depending on local grid providers. However, with the right technical and economic feasibility assessments, depot operators, including STUs, have the opportunity to generate their own clean energy within the depot, transforming them into “prosumers”—both producers and consumers of electricity.

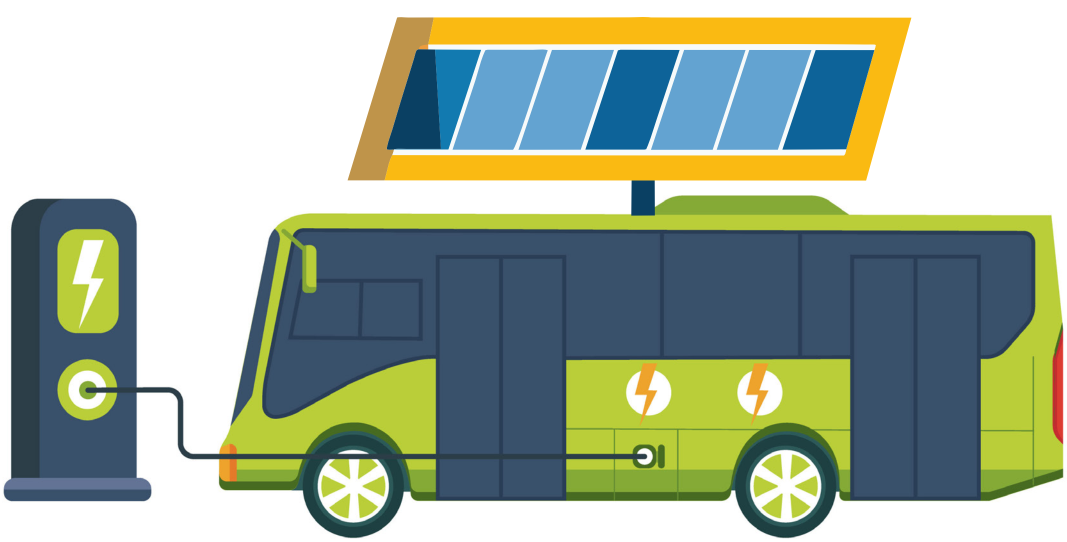
Surat case study : Assessment of solar rooftop feasibility in e-bus depots

As part of this study, a comprehensive evaluation of existing and planned depot layouts and architectural designs was conducted to assess the feasibility of installing rooftop solar systems. The findings indicate that depots have substantial shade-free areas available, particularly on parking zones, charger canopies, washing and maintenance areas, and administrative buildings. These spaces present an ideal opportunity to harness solar energy, supplementing the depot's electricity requirements and reducing dependence on external power sources.

To quantify this opportunity, the Table 10 and Figure 14 illustrate the estimated solar rooftop potential across multiple depots, considering varying percentages (20%, 30%, and 50%) of available rooftop space for solar installations. This assessment highlights the feasibility of generating substantial clean energy within depot premises, directly supporting the sustainability of e-bus operations.

Area required per kW solar rooftop (Sq. m) = 10				
Percentage of space available (%)		Min	Avg.	Max
		20%	30%	50%
Depot name	Depot area – sq m	Solar rooftop potential (MW) - Min	Solar rooftop potential (MW) – Avg	Solar rooftop potential (MW) - Max
Altan	20,119	402	604	1006
Palanpur	19,386	388	582	969
Magob	18,562	371	557	928
Vesu	4,666	93	140	233
Bhestan	18,806	376	564	940
Aggregated potential (MW)		1,630	2,447	4,076
Yearly generation (MWh)		2.713	4.073	6.784

Table 10: Solar rooftop potential across all depots in Surat



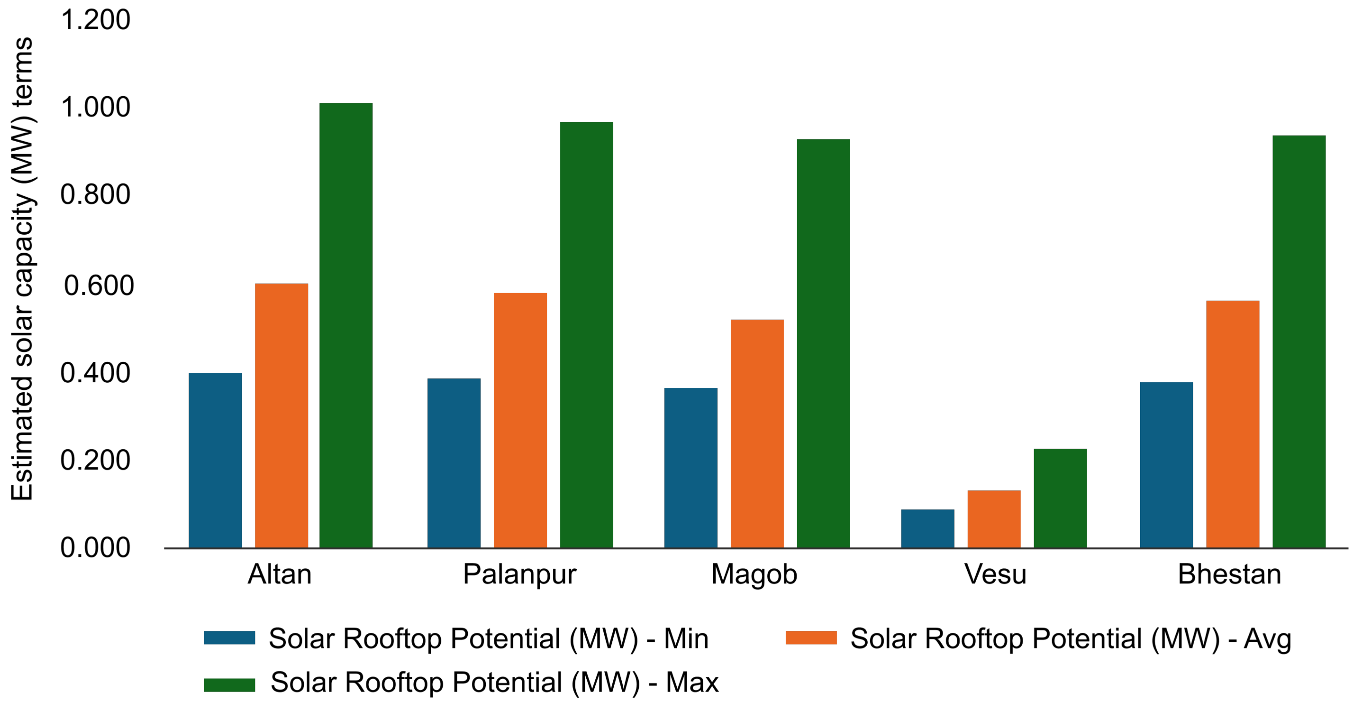


Figure 14: Solar rooftop potential across all depots

1) Significant solar generation capacity

- The aggregated minimum potential across all depots is 1.630 MW, with an average potential of 2.447 MW and a maximum capacity reaching 4.076 MW.

- This energy generation translates into a yearly electricity output of 2713 MWh (minimum) to 6784 MWh (maximum), significantly contributing to depot energy demands.

2) Reducing dependence on grid electricity

- By utilising rooftop solar energy, depots can offset a substantial portion of their electricity needs, reducing reliance on conventional power grids and minimising operational costs.

- The ability to generate on-site clean energy transforms depots into self-sustaining energy hubs, enhancing energy security and reducing exposure to electricity price fluctuations.

3) Supporting e-bus charging infrastructure

- The high solar generation potential directly supports charging infrastructure for e-buses, ensuring reliable and cost-effective energy supply.

- With optimised energy storage solutions, excess solar power can be stored and utilised during peak charging hours, improving efficiency and grid stability.

4) Environmental and economic benefits

- Transitioning to depot-based solar power reduces carbon emissions, aligning with clean mobility and sustainability goals.
- It also offers long-term financial benefits by cutting electricity procurement costs and leveraging government incentives for renewable energy adoption.

The study demonstrates that integrating solar rooftop generation across depots can play a pivotal role in achieving energy self-sufficiency for e-bus operations. The vast solar potential, if fully harnessed, not only supports sustainable transport initiatives but also enhances operational resilience, making the transition to electric mobility more economically and environmentally viable. By integrating solar rooftop generation, e-bus depots can enhance energy sustainability, lower operational costs, and contribute to a cleaner and more resilient urban transport system.

6.2 Assessing energy demand and charging infrastructure

To effectively assess the energy demand and determine the projected number of EVSE units required to meet the recharging needs of a growing e-bus fleet, this section presents a comprehensive data analysis. The insights derived aim to answer key questions that will support relevant stakeholders in making informed decisions for strategically planning fleet expansion in the near future. This analysis provides a structured approach to understanding energy consumption patterns, charging infrastructure requirements, and operational efficiencies to facilitate a smooth transition towards large-scale e-bus deployment.

- What are the total energy and power requirements needed to meet the recharging demands of an e-bus fleet?
- How does the electricity consumption of e-buses vary across different charging periods, such as overnight charging, afternoon opportunity charging, and early morning charging?
- What is the typical electricity cost incurred by operators when purchasing power from DISCOMs for e-bus charging?
- How many EVSE or charging units are necessary to adequately support the charging needs of an e-bus fleet at a specific depot?
- How will the number of required EVSE units scale proportionally with the anticipated growth of the e-bus fleet in the near future?
- What would be the estimated cost savings on diesel fuel and the reduction in GHG emissions resulting from the adoption of e-buses?
- What are the infrastructure and grid upgrade requirements needed to support large-scale e-bus fleet electrification?
- How does charging efficiency impact the overall operational cost and energy utilisation of an e-bus fleet?
- What are the optimal charging strategies (e.g., fast charging vs. slow charging) for balancing energy costs, battery longevity, and operational efficiency?
- What are the potential financial incentives or policy support mechanisms available to operators for deploying EVSE and e-bus fleets?

6.2.1 Charging infrastructure estimation

Based on the projected number of e-buses under the service level benchmark (SLBs) and the assumed public transport (PT) share (Level of Service (LoS) 3), as outlined in Annexure A (detailed assumptions), the estimation of the required number of charger units has been conducted to meet the fleet's charging demands effectively. Figure 15 illustrates the projected growth of e-buses inducted into the fleet within a depot (represented by orange bars) and the corresponding number of EVSE (charger units) required (depicted by the blue line). The x-axis represents future years from 2025 to 2036, while the left y-axis indicates the total number of e-buses, and the right y-axis shows the projected number of chargers. Over time, there is a significant increase in the number of e-buses, growing from 450 in 2025 to 2000 by 2036. This trend highlights an ambitious fleet expansion strategy, aligning with a higher public transport (PT) share target.

Similarly, the number of chargers follows a linear growth pattern, maintaining a 1:1 ratio with e-buses in the initial years. In 2025, the fleet and charger count are both projected at 72, gradually increasing to 400 chargers for 2000 buses by 2036. This indicates a structured and consistent expansion of charging infrastructure, ensuring that the growing fleet's energy demands are met efficiently.

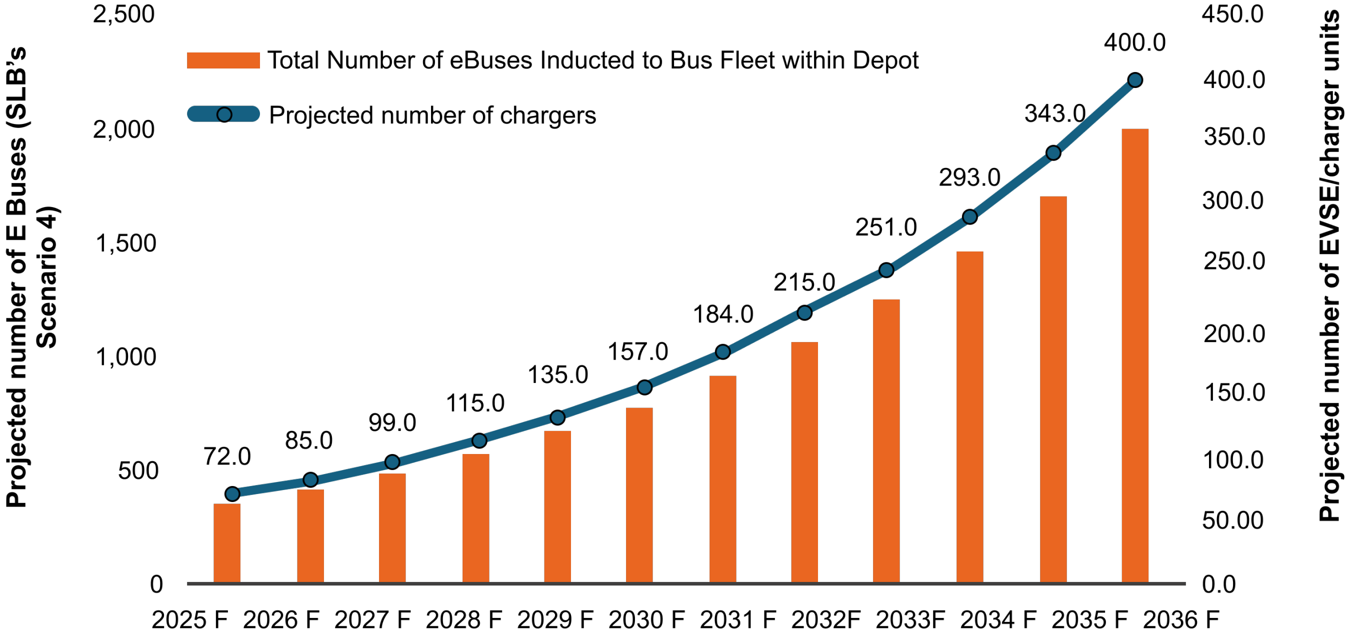


Figure 15: Charging infrastructure projection with future fleet size as per SLB LoS 3 scenario

The projected expansion of e-buses follows a structured approach under the service level benchmark (SLBs), with the assumption of a public transport (PT) share aligned with LoS 3. The LoS 3 represents a practical and achievable target, emphasising moderate growth while ensuring sustainable infrastructure development. The gradual and well-managed increase in e-bus deployment corresponds with realistic funding availability, grid capacity enhancements, and systematic expansion of the charging network. This approach ensures that the required number of charger units is strategically estimated and deployed to efficiently support the growing fleet's charging needs, as outlined in Annexure A (detailed assumptions).

Key outcomes and implications:

1 Infrastructure planning & investment:

a. The steady rise in chargers indicates the need for continuous investment in charging infrastructure.

b. Power grid capacity must be expanded to support the increasing energy demand.

2 Operational efficiency & depot capacity:

a. With a projected fleet of 2000 e-buses by 2036, depot planning must ensure efficient charging schedules and land availability for parking and charging.

3 Energy demand & grid load management:

a. The increasing number of EVSE units implies a significant rise in electricity demand, requiring grid upgrades and smart charging solutions to avoid overloading.

4 Reduction in emissions & fuel cost savings:

a. With a shift from diesel to electric, substantial savings in fuel costs and a reduction in GHG emissions are expected.

b. Government incentives, subsidies, and policies supporting fleet electrification would further enhance sustainability goals.

5 Feasibility of achieving PT share LoS 3

6 Given the projected growth, the PT share under LoS 3 appears feasible if supported by:

a. Sufficient funding & policies

b. Continuous public transport adoption incentives

c. A well-planned EVSE deployment strategy

The projected expansion of e-buses and EVSE units under PT share LoS 3 follows a structured and practical approach, ensuring that charging infrastructure development keeps pace with fleet growth. Strategic planning is crucial to optimise energy utilisation and maintain grid reliability while accommodating the increasing demand for electrified public transport. This forecast serves as a realistic roadmap for public transport electrification, highlighting the importance of investments in energy infrastructure, depot capacity enhancements, and the deployment of smart charging solutions to support sustainable and efficient operations.

6.2.2 Projecting future energy needs for fleet expansion

Figure 16 illustrates the projected maximum yearly energy consumption (in GWh) alongside the number of e-buses under the Level of Service (LoS 3) scenario from 2025 to 2036. The x-axis represents the forecasted years, while the left y-axis indicates the estimated energy consumption in GWh, and the right y-axis represents the projected number of e-buses in operation.

The number of e-buses follows an exponential growth pattern, reaching 2000 buses by 2036, reinforcing the commitment to public transport electrification under LoS 3. This expansion aligns with the previously analysed charging infrastructure (EVSE) projections, ensuring that depot capacity and charger availability scale proportionally with fleet growth. As the fleet expands, energy consumption also rises significantly, increasing from 360 GWh in 2025 to approximately 2,723 GWh by 2036. This upward trend highlights the growing electricity demand, emphasising the need for grid planning, power supply enhancements, and smart energy management solutions to support the large-scale transition to e-buses. The relationship between energy consumption and fleet size remains proportional, underscoring the importance of efficient charging strategies and load management to prevent peak demand stress on the power grid.

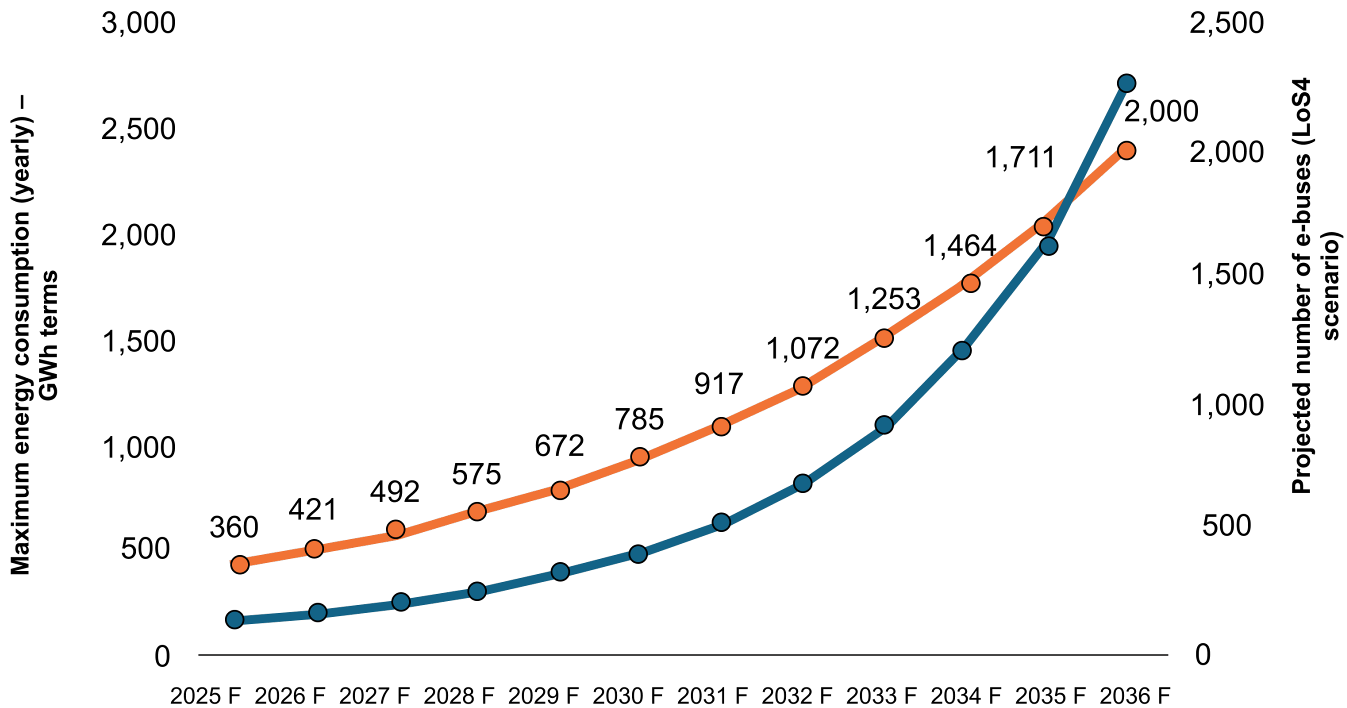


Figure 16: Annual energy consumption by the project e-bus fleet

Key outcomes and implications

1 Energy infrastructure investment

- The substantial increase in electricity demand requires grid capacity expansion and upgrades to substations to support large-scale e-bus charging.
- Utilities and policymakers must consider renewable energy integration to reduce dependency on fossil fuel-based electricity sources.

2 Charging optimisation and load management

- To manage rising energy demand, time-of-use charging strategies and smart charging infrastructure must be implemented.
- Depot charging operations should align with off-peak electricity pricing models to optimise costs and prevent grid overload.

3 Operational cost and sustainability benefits

- The transition to e-buses, despite increasing electricity demand, will lead to significant savings in diesel fuel costs and a drastic reduction in GHG emissions.
- The previous analysis on EVSE deployment highlights how stra tegic infrastructure expansion can ensure seamless fleet electrification while minimising operational disruptions.

4 Policy and financial support

- Government incentives, subsidies, and financing models will be crucial to support the increasing energy demand and infrastructure needs.
- Strategic public-private partnerships can accelerate the deployment of charging networks and ensure affordable electricity supply for e-bus operators.

Building on the previous analysis of fleet expansion and charging infrastructure development, this energy consumption projection highlights the critical role of power supply planning in ensuring a smooth transition to electric public transport. With e-bus deployment increasing significantly, a well-coordinated approach involving investment in energy infrastructure, smart charging strategies, and policy support will be essential to achieve the targeted PT share under LoS 3 while maintaining operational efficiency and sustainability.

6.2.3 Cost savings and environmental benefits of solar integration

To estimate and understand the impact of distributed solar generation in offsetting grid electricity consumption, an 8 MW solar rooftop plant has been considered, along with its positive environmental implications. Additionally, the estimation incorporates key assumptions outlined in Annexure B, aligned with service level benchmarks (SLBs) and the PT share under LoS 3. Figure 17 illustrates a comparative analysis of the projected energy demand from the e-bus fleet (in GWh/year) and distributed energy generation from solar power plants (in GWh/year) from 2025 to 2036.

The analysis explores the trajectory of energy demand based on the projected e-bus fleet size and solar distributed generation capacity. Energy consumption from the e-bus fleet follows an exponential growth trend, increasing rapidly from 2025 onwards and reaching nearly 2,800 GWh by 2036. In contrast, solar power generation gradually declines over time, decreasing from approximately 13.6 GWh in 2025 to around 12.4 GWh by 2036. This trend reveals a widening gap between renewable energy generation and the electricity demand of the e-bus fleet, highlighting concerns about supply sustainability and increased grid dependency. A critical intersection is projected between 2033 and 2034, where e-bus energy demand surpasses the available distributed solar energy supply. This shift underscores the urgent need for additional energy sources, grid reinforcements, and alternative renewable energy solutions to maintain a sustainable, efficient, and reliable fleet operation.

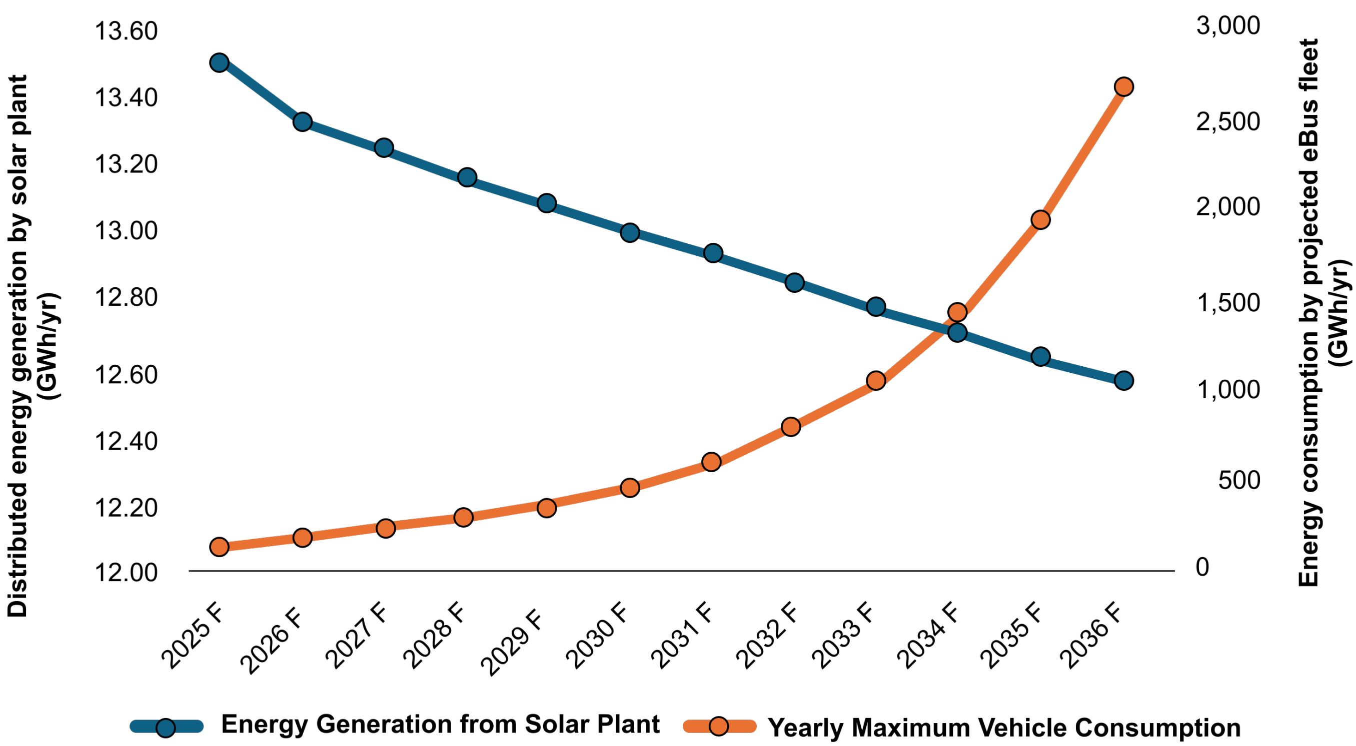


Figure 17: Projected energy demand vs distribution generation

This analysis further reinforces the previous projections on e-bus fleet expansion and its corresponding rise in energy consumption. As highlighted in earlier charts, the fleet is expected to grow exponentially under LoS 3, pushing the total annual electricity demand beyond 2000 GWh by 2036. The previously analysed EVSE deployment and energy consumption trends emphasised the importance of strategic grid planning and energy optimisation to accommodate this growth. However, the disparity between solar power availability and increasing electricity demand underscores the urgent need for additional energy sources, energy storage solutions, or smart grid integration to prevent operational challenges and ensure a reliable, sustainable charging infrastructure.

Key outcomes and implications

1) Need for additional renewable energy integration:

- The declining solar energy generation trend suggests that current solar capacity alone will be insufficient to meet the rising energy demand.
- A diversified energy strategy, including wind power, battery storage, or hybrid energy sources, must be explored to maintain sustainability.

2) Grid dependency and stability challenges:

- As e-bus energy demand surpasses distributed solar generation, the dependency on grid electricity will increase, necessitating grid upgrades and load-balancing strategies.
- Time-of-use charging and demand response mechanisms can help optimise energy distribution and prevent overloading.

3) Financial and policy implications:

- Higher reliance on grid electricity could lead to higher operational costs, requiring government incentives or tariff regulations to keep costs manageable for operators.
- Policy measures should encourage greater investment in renewable energy projects tailored to meet the specific needs of the public transport sector.

Building upon previous analyses, this chart highlights a critical energy supply-demand gap that will emerge as e-bus adoption accelerates. While the transition to electric buses aligns with sustainability goals, relying solely on distributed solar energy is not sufficient to support large-scale fleet operations. Proactive planning is essential, focusing on energy diversification, storage solutions, and grid enhancements to ensure a stable, cost-effective, and sustainable electrification of public transport under LoS 3 objectives.

i Distributed solar energy offset percentage

Figure 18 illustrates the percentage of energy offset by solar power in e-bus operations (maximum potential contribution) from 2025 to 2036. In 2025, solar power offsets approximately 8% of the total energy demand for e-bus operations. However, over time, this percentage steadily declines, falling below 2% by 2033 and nearing 0% by 2036. While solar power initially provides some relief, its relative contribution diminishes significantly as the overall energy demand for the e-bus fleet grows exponentially. This trend indicates a growing dependence on grid electricity, raising concerns about energy costs, supply reliability, and long-term sustainability.

Earlier analyses reinforced the rapid expansion of the e-bus fleet, with electricity demand projected to exceed 2800 GWh by 2036. The exponential rise in energy demand surpasses the stable or declining distributed solar generation, leading to a sharp reduction in the percentage of energy offset by solar power. The previous evaluation of energy demand versus distributed solar generation already pointed to a widening gap between e-bus energy consumption and available solar supply, further validating the need for additional renewable energy sources, energy storage solutions, or hybrid power integration to reduce dependency on the grid.

Moreover, the EVSE deployment strategy relies on the availability of power sources, meaning that a lower solar energy contribution will increase grid dependency. This underscores the urgent need for grid reinforcements and advanced load management strategies to ensure a stable, cost-effective, and sustainable transition to an electrified public

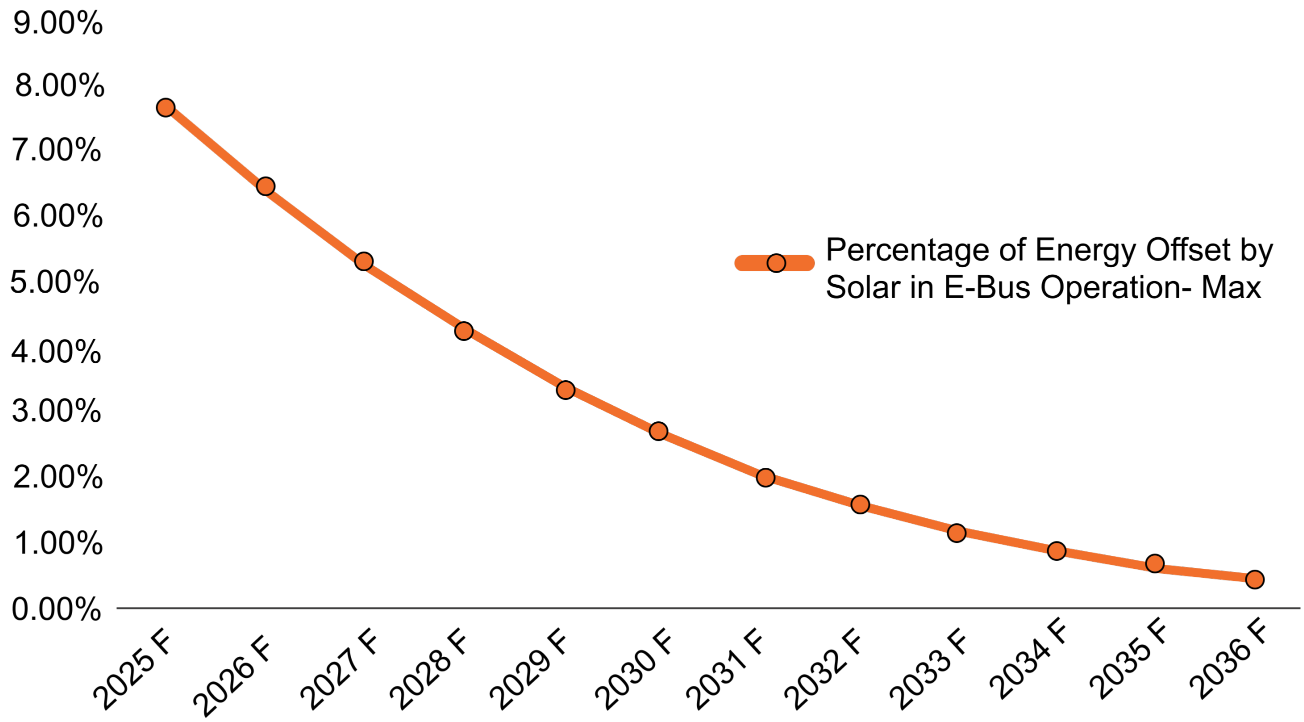


Figure 18: Percentage share of distributed solar energy offset

Key outcomes and implications

1) Urgent need for diversified renewable energy sources:

- Since solar alone cannot sustain e-bus operations, investments in wind energy, battery storage, or hybrid renewable solutions are essential to support long-term sustainability goals.

2) Smart charging and load management strategies:

- With an increasing reliance on grid electricity, charging optimisation strategies, such as time-of-use tariffs, demand response programs, and battery storage integration, will be critical in managing energy costs and grid stability.

3) Financial and policy considerations:

- The decreasing solar energy offset percentage highlights the need for stronger policy support for renewable energy expansion in public transport.

- Financial incentives and subsidies for energy storage and alternative renewable sources could help mitigate the rising dependency on conventional grid electricity.

This analysis, in connection with previous findings, highlights the increasing challenge of sustaining e-bus operations with solar power alone. While solar energy provides an initial offset, its relative contribution declines as electricity demand skyrockets. This emphasises the urgent need for energy diversification, strategic grid planning, and the adoption of advanced charging solutions to ensure a sustainable and cost-effective transition to electric public transport under LoS 3.

ii. Environmental impact with e-bus fleet

Figure 19 illustrates the avoided CO_2 emissions (in thousand metric tonnes) due to the adoption of an e-bus fleet from 2025 to 2036. The transition to e-buses is projected to prevent 71 thousand metric tonnes of CO_2 emissions in 2025, with avoided emissions steadily increasing each year as the fleet expands. By 2032, avoided emissions surpass 200 thousand metric tonnes, eventually reaching 392 thousand metric tonnes by 2036. This trend highlights the strong environmental benefits of e-bus adoption, playing a crucial role in climate change mitigation and urban air quality improvement. The increase in avoided CO_2 emissions aligns directly with fleet growth, reinforcing the importance of public transport electrification in reducing the carbon footprint. However, the effectiveness of emission reductions will largely depend on the energy sources used for charging—greater reliance on grid electricity from fossil fuels may limit net CO_2 savings, whereas higher integration of renewable energy sources such as solar, wind, or energy storage solutions would maximise environmental benefits.

Earlier analyses projected a steady rise in the number of e-buses under LoS 3, leading to an exponential increase in electricity consumption. This analysis confirms that as the fleet expands, so do the carbon savings, reinforcing the long-term sustainability benefits of bus electrification. However, previous findings indicated a declining contribution of solar energy to e-bus operations, resulting in greater dependence on grid electricity. If the grid continues to rely on fossil fuels, the actual net CO_2 savings could be lower than projected. Therefore, to sustain maximum emission reductions, there is a critical need for increased integration of renewable energy sources, including solar, wind, and energy storage solutions.

With growing grid dependency, adopting strategic charging optimisation, energy diversification, and smart grid solutions will be essential in maximising CO_2 reductions. Investments in smart charging infrastructure, demand-response mechanisms, and time-of-use electricity pricing can further enhance energy efficiency and minimise emissions associated with e-bus operations. This underscores the importance of policy interventions, infrastructure investments, and clean energy transitions to ensure the full environmental benefits of electrified public transport.

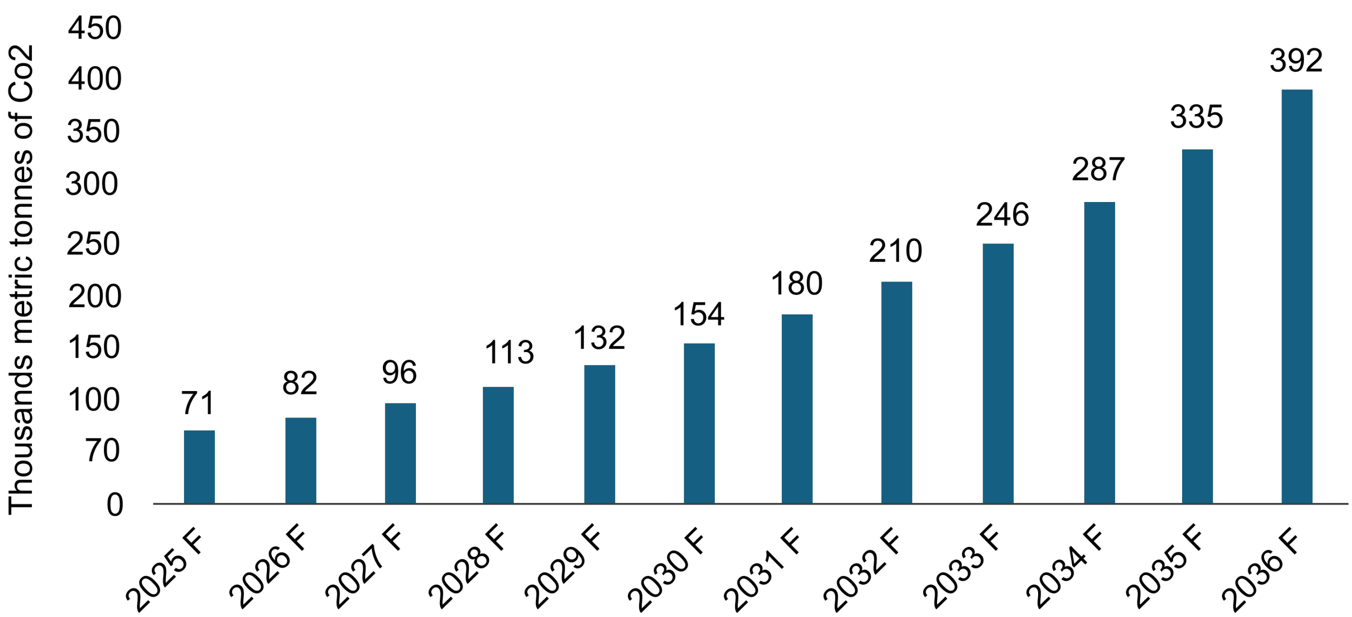


Figure 19: Avoided CO2 emission with e-bus fleet

Key outcomes and implications

1) Strong environmental benefits and policy support:

- The continuous rise in avoided CO_2 emissions highlights the significant contribution of e-buses toward climate goals and air quality improvements.
- Policymakers should leverage these insights to implement incentives, carbon credits, and subsidies for fleet electrification.

2) Need for a cleaner energy mix:

- To maximise emission reductions, efforts must be made to reduce reliance on fossil fuel-based grid electricity and increase the share of renewable energy sources.
- This requires investment in large-scale renewable energy projects and battery storage solutions to ensure cleaner charging for the growing e-bus fleet.

3) Economic and public health benefits:

- Avoiding 392 thousand metric tonnes of CO_2 by 2036 will result in improved air quality, reduced respiratory diseases, and lower healthcare costs.
- Transitioning to e-buses will also contribute to reduced fuel imports, operational savings, and lower total cost of ownership over time.

This analysis, in conjunction with previous findings, highlights the substantial environmental benefits of e-bus deployment, with significant CO_2 emission reductions as fleet size expands. However, to achieve the full potential of emission savings, it is critical to integrate more renewable energy sources into the charging infrastructure. With strategic energy planning, policy incentives, and smart charging solutions, e-bus electrification can serve as a cornerstone of sustainable urban transport, climate change mitigation, and energy security. Integrating renewable energy sources, energy storage, and smart grid solutions is essential to achieving maximum CO_2 emission reductions from e-bus operations.

By adopting progressive policies, financial incentives, and advanced energy management technologies, public transport authorities can ensure that electrification in buses delivers its full environmental and economic benefits. Strategic planning, cross-sector collaboration, and sustained investment in clean energy infrastructure will be crucial in creating a net-zero public transport ecosystem.

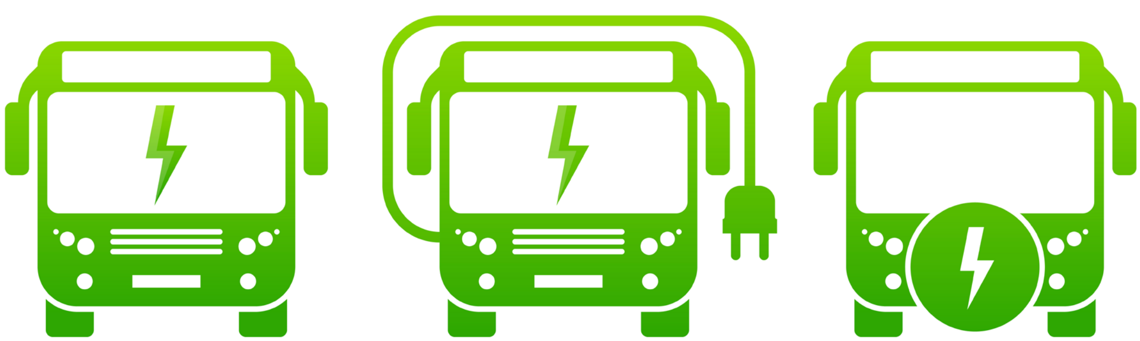
07

Electricity Distribution Companies' Responsibility

As cities pursue large-scale electrification of public transport, the development of well-equipped e-bus depots with robust and resilient charging infrastructure becomes indispensable. While integrating renewable energy sources such as solar has demonstrated significant potential in enhancing energy sustainability at the depot level, the scale and reliability of power supply still depend heavily on the capabilities of the regional DISCOMs. DISCOMs are uniquely positioned to act as enablers in this transition, given their deep understanding of local grid conditions, existing demand patterns, and technical infrastructure. To streamline the deployment of charging infrastructure and ensure uninterrupted power supply for e-bus operations, DISCOMs must serve as nodal agencies at the state level. This role involves not only grid planning and system upgrades but also proactive coordination with public transport agencies to provide timely and customised technical assistance.

As a critical first step, DISCOMs should work closely with STUs, bus operators, and city authorities to assess the energy requirements of proposed depots, identify optimal feeder connections, and guide the siting of substations. By facilitating timely power connections and overseeing infrastructure compliance, DISCOMs can significantly reduce implementation delays and optimise energy flow to charging stations.

In addition to supporting infrastructure planning, DISCOMs must establish clear protocols and standard operating procedures (SOPs) for demand estimation, grid integration, and safety compliance. These SOPs should reflect evolving supply codes and regulatory mandates, ensuring that infrastructure development aligns with both operational needs and legal obligations.The subsequent sections detail DISCOM's key responsibilities—including demand estimation, consumer classification, and the procedural framework for supply connectivity—while outlining the infrastructural and regulatory provisions required to support seamless e-bus charging. Through a structured and collaborative approach, DISCOMs can play a pivotal role in enabling a resilient and future-ready electric public transport system.



Load estimation for PSS

Based on the depot transition plan for e-bus, the appropriate Power Sub-station (PSS) is designed through the capacity of EVSE.

→

DISCOM connection process

STUs must finalise depot plans for e-buses, including a layout designating parking and charging areas. After calculating electricity needs, they should apply for an HT/EHT connection to the local DISCOM, submitting all required documents and fees.

→

Pre-assessment of identified land

DISCOM will assess the STU's application through technical and commercial feasibility studies. This includes determining the necessary electrical substation space on-site, which will vary based on voltage and load requirements as outlined in the DISCOM's supply code.

→

Agreement between STU & DISCOM

An agreement will be signed between the DISCOM and STU after the DISCOM takes over the allocated space. The STU must adhere to the DISCOM's agreement template.

Sr. no.	Consumer category	System of supply
1	For all installations up to and inclusive of 6 kW of Connected Load, subject to motive power load other than irrigation pump not exceeding 2 HP in the aggregate.	230 V- Single Phase
2	For all installations exceeding 6 kW of Connected Load (motive power load exceeding 2 HP and up to 150 HP in the aggregate) and up to 100 kVA/kW of Contracted Demand.	400 V- Three Phase
3	For all installation with Contract Demand exceeding 100 kVA/kW and up to 4000 kVA/kW. However, for the existing 22 kV consumer, the Contact Demand limit shall be extend ed up to 8000 kVA/kW subject to undertaking from consumer for reverting back to 4000 kVA/kW limit in case of change of system to 11 kV under system conversion scheme.	11 kV and 22 kV - Three Phase
4	All installation with Contract Demand exceeding 4000 kVA/ kW.	At 33 kV and above- Three Phase

Table 11: System of supply and classification of consumers[7]

7.1 Demand estimation by DISCOM

In order to provide resilient power to newly constructed and or planned charging stations, the DISCOM will issue a demand note for the electricity supply required to meet the load demand up to the boundary of the Charging Station (CS) to STU at the 11kV voltage level. This supply will be governed by the DISCOM's supply code regulations (4)[8,9]. To establish the distribution infrastructure from the 11kV level to the proposed charging station location, the STU has two options:

1) Deposit work scheme: The STU can opt for the DISCOM's Deposit Work scheme, where the DISCOM will develop the required infrastructure upon receiving a deposit from the STU.

2) Self-execution: Alternatively, the STU can independently construct the upstream infrastructure (High Tension/Extra High Tension) in compliance with the DISCOM's supply code regulations for such connections. In this case, the STU will be responsible for paying the DISCOM's supervision charges.

Regardless of the chosen option, the STU must provide the following:

- Comprehensive test reports and safety certifications for all EV chargers to be installed at the charging station.

- Necessary clearances for DISCOM personnel and electrical inspectors to inspect and approve all High-Tension equipment used on-site.

These requirements are essential to ensure the safe and reliable operation of the charging infrastructure and compliance with relevant regulations.

[7] GERC: Electricity Supply Code & Related Matters (access here)
[8] https://gercin.org/wp-content/uploads/2019/08/Supply-code.pdf
[9] https://gercin.org/wp-content/uploads/2020/01/GERC-Elec.-Supply-Code-Related-Matters-2nd-Amendment-Regulations-2020-1.pdf

7.1.1 Electricity supply code and related matters regulations Gujarat (GERC, 2023)

Following to issuance of a demand note by the DISCOM and the selection of the infrastructure development method—whether through the Deposit Work scheme or self-execution—it becomes imperative for the STU (or the e-bus operator) to comply with relevant supply codes and safety regulations governing electrical installations. These regulatory provisions ensure that the charging infrastructure is not only operationally efficient but also aligned with mandated safety and reliability standards.

As per the Gujarat Electricity Regulatory Commission (GERC) Supply Code Regulations, 2023, and in adherence to the Central Electricity Authority (CEA) Safety Regulations, 2010 (and subsequent amendments), the consumer—defined in this context as the STU or e-bus operator—bears certain responsibilities for the safe integration of their infrastructure with the DISCOM's distribution network. These include the proper maintenance of all transformers, switchgear, and associated electrical apparatus connected to the grid.

Key consumer's responsibilities:

- **Provision of space:** The consumer must allocate adequate and accessible space within their premises for the installation of electrical assets such as transformers, switchgear, service meters, and related infrastructure.
- **No financial charge to licensee:** This space must be offered at no cost to the licensee (DISCOM).
- **Mutual agreement:** The exact size and location of the space shall be finalised through mutual consent between the consumer and the DISCOM.

Licensee's (DISCOM) Responsibilities:

- **Equipment Installation:** The DISCOM is responsible for installing the necessary infrastructure, including transformers, switchgear, meters, and service lines, within the designated area.
- **Ownership and Control:** All such equipment remains the property of the licensee, who also retains operational control and maintenance authority.

Furthermore, in cases where the **contract demand exceeds 1 MVA at the high-tension (HT) level,** the STU is required to provide additional land for the installation of a grid substation, in accordance with **CEA measures related to safety and electric supply,** and the **CEA guidelines for distribution utilities.**

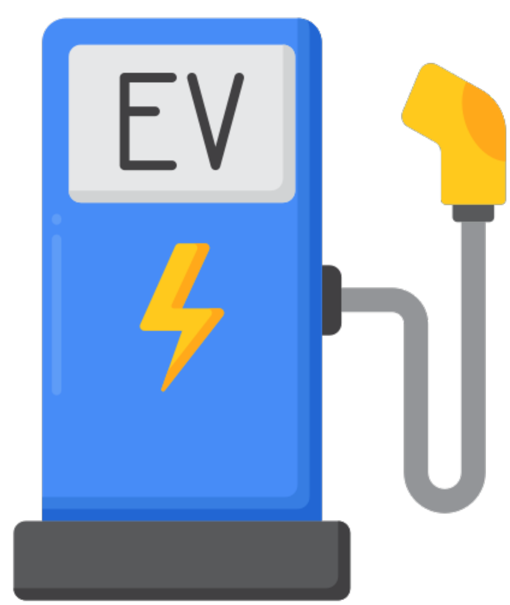
This includes:

1 Additional space for a Distribution Transformer (DT) substation for low-tension (LT) service connections.

2 Compliance with spatial standards, e.g., for multiple DT bays—approximately 5 bays of size 4 m × 5.3 m may be required.

3 The STU must submit the proposed layout to the DISCOM for review and approval to ensure conformity with technical and safety norms.

This regulatory framework ensures that the integration of high-demand e-bus charging infrastructure with the existing power distribution system is safe, efficient, and scalable. Adhering to these provisions not only facilitates timely electrification but also minimizes risks to equipment, personnel, and public infrastructure.



7.1.2 Land and space requirements for substation infrastructure

To support high demand charging infrastructure, particularly for depots with a contract demand exceeding 1 MVA, STUs must allocate additional land for setting up grid substations in line with applicable regulations. The type of substation—whether Air Insulated Substation (AIS) or Gas Insulated Substation (GIS)—and its capacity will determine the specific spatial requirements.

These requirements are guided by technical standards issued under CEA guidelines and reference estimates such as those provided by Convergence Energy Services Limited (2022). The Table 12 below outlines typical land area needs for various substation configurations:

Sr. no.	Substation type size (meters)	Size (meters)
1	Air – insulated sub-station – 66/11 kV grid sub-station with 2PTR - 2x10 MVA S/S	~3500 sq m (70x50 sq m
2	Air – insulated sub-station – 66/11 kV grid sub-station with 3PTR - 3x25 MVA S/S	~ 6800 sq m (80x85 sq m
3	Gas – insulated sub-station – 33/11 kV grid sub-station with 2PTR - 2x10 MVA S/S	~ 1600 sq m (40x40 sq m
4	Gas – insulated sub-station – 66/11 kV or 33/11kV - 3x25 MVA S/S	~ 2400 sq m (60x40 sq m)

Table 12: Land/space requirements for AIS & GIS sub-station (Convergence Energy Service Limited, 2022)

These estimates serve as planning guidelines for STUs and urban planners in selecting suitable land parcels within or adjacent to depot premises. Notably, GIS substations, while more compact, may involve higher upfront capital investment compared to AIS systems, but they offer operational advantages in space-constrained urban areas.

Accordingly, STUs must consult with DISCOMs early in the planning process to finalise land allocation, layout designs, and technical specifications. This ensures that substation installations meet both the power demand profile of the e-bus depot and regulatory standards, while aligning with long-term electrification plans.

7.1.3 Substation selection guidance for e-bus depot electrification

Selecting the appropriate type and capacity of substation is critical for supporting the growing energy needs of e-bus depots, especially under high-demand scenarios projected through service level benchmarks (SLBs). The choice between Air Insulated Substations (AIS) and Gas Insulated Substations (GIS) must consider multiple factors, including spatial availability, fleet size, long-term scalability, capital costs, and operational environment.

Key considerations for substation selection:

1) Contracted load and future expansion:

For depots with initial demands above 1 MVA, but with significant projected growth (e.g., depots scaling up to support 100+ buses), planning for 25 MVA or higher transformer capacity is advisable.

Choosing a 3PTR configuration (3×25 MVA) provides operational redundancy and scalability, especially under high fleet utilisation and peak charging loads.

2) Land availability:

- AIS substations, while cost-effective and technically proven, require large land parcels—up to 6800 sq.mt. for a 3PTR setup.
- In contrast, GIS substations offer a more compact footprint, needing just 1600–2400 sq.mt and are better suited for space-constrained depots in dense urban areas.

3) Urban vs. peri-urban locations:

- Urban depots, often limited by available space and higher land values, may benefit more from GIS solutions, despite higher capital expenditure.
- Peri-urban or greenfield depots can accommodate AIS infrastructure more easily, allowing for easier maintenance access and potential cost savings.

4) Environmental and operational conditions:

- GIS systems offer better protection in polluted or coastal environments, as they are enclosed and less exposed to environmental degradation.
- AIS systems require more routine maintenance due to their open configuration but are generally easier to service and expand.

5) Coordination with DISCOMs:

- The final substation layout, sizing, and technical configuration must be approved by the DISCOM based on system load studies, voltage criteria, and safety clearances.
- STUs should initiate early-stage technical consultations with DISCOMs to align depot electrification timelines with substation construction and commissioning.

Depot type	Recommended substation type	Justification
Urban/infill depot	GIS – 33/11 or 66/11 kV	Compact footprint, suitable for land-scarce locations
Large peri-urban depot	AIS – 66/11 kV (3×25 MVA)	Ample land, lower cost, easier expandability
Medium-sized depot	GIS – 2×10 MVA or AIS – 2×10 MVA	Depends on site availability and environmental conditions
High-growth node depot	AIS – 3×25 MVA (futureproofing)	Anticipated fleet growth, enhanced system reliability

Table 13 Substation selection as per the depot type

Strategic substation planning is foundational to ensuring uninterrupted and scalable electrification of e-bus operations. A judicious selection between AIS and GIS configurations, grounded in technical, spatial, and operational criteria, will not only minimise implementation delays but also enhance system efficiency and lifecycle reliability.

As India scales up its electric mobility infrastructure, such forward-looking substation planning will be vital to sustainable urban transport electrification.

08

Comparative Analysis of Power Procurement Options

Building upon the previous discussions around the planning, sizing, and installation of substations for e-bus depots—with a central role played by DISCOMs in enabling reliable and adequate power supply—the next critical consideration involves evaluating how electricity is sourced for charging infrastructure. While physical infrastructure and regulatory compliance form the foundation of electrified depot operations, cost-effective and reliable power procurement mechanisms are equally essential to ensure financial viability and operational continuity. As EV adoption accelerates, particularly within public transport fleets, the economic efficiency of charging operations has become a focal point for both public and private stakeholders. In response, the MoP has introduced progressive guidelines aimed at liberalising the EV charging ecosystem. These include the de-licensing of charging station setups and clarification of the status of CPOs as service providers rather than electricity resellers—facilitating increased private sector participation.

Despite these policy enablers, many CPOs continue to face high electricity tariffs under traditional procurement models, adversely impacting the affordability of EV charging services. Moreover, with charging demand per depot potentially exceeding the capacity of typical distribution lines, the pressure on DISCOMs to forecast, manage, and supply electricity during peak periods is intensifying. To address this dual challenge—supply-side planning by DISCOMs and demand-side flexibility for CPOs and fleet operators—a range of power procurement models are now available, particularly for Commercial and Industrial (C&I) consumers. These include both conventional utility-based supply from DISCOMs and more competitive alternatives under Open Access (OA) frameworks.

The following section provides a comparative analysis of these procurement pathways, illustrating how institutional roles, policy frameworks, and market mechanisms converge to shape the evolving EV tariff landscape. Figure 20 offers a schematic overview of these power sourcing options and their implications for cost, reliability, and energy autonomy.

8.1 Power purchase options for C&I consumers

In India's evolving electricity market, Commercial and Industrial (C&I) consumers—including charge point operators (CPOs) and public transport authorities operating e-bus fleets—are increasingly exploring flexible and cost-effective power procurement mechanisms to meet their growing energy needs. Under a competitive environment and consumer-friendly tariff structure, commercial and industrial (C&I) consumers have two primary options for power procurement: 1) Open Access (OA) transactions and 2) DISCOMs.

Figure 20 below offers a simplified overview of these power procurement options, showcasing the flexibility available to C&I consumers in selecting between traditional utility services and alternative arrangements. These choices empower consumers to optimise cost-efficiency, enhance energy reliability, and align with sustainability objectives.

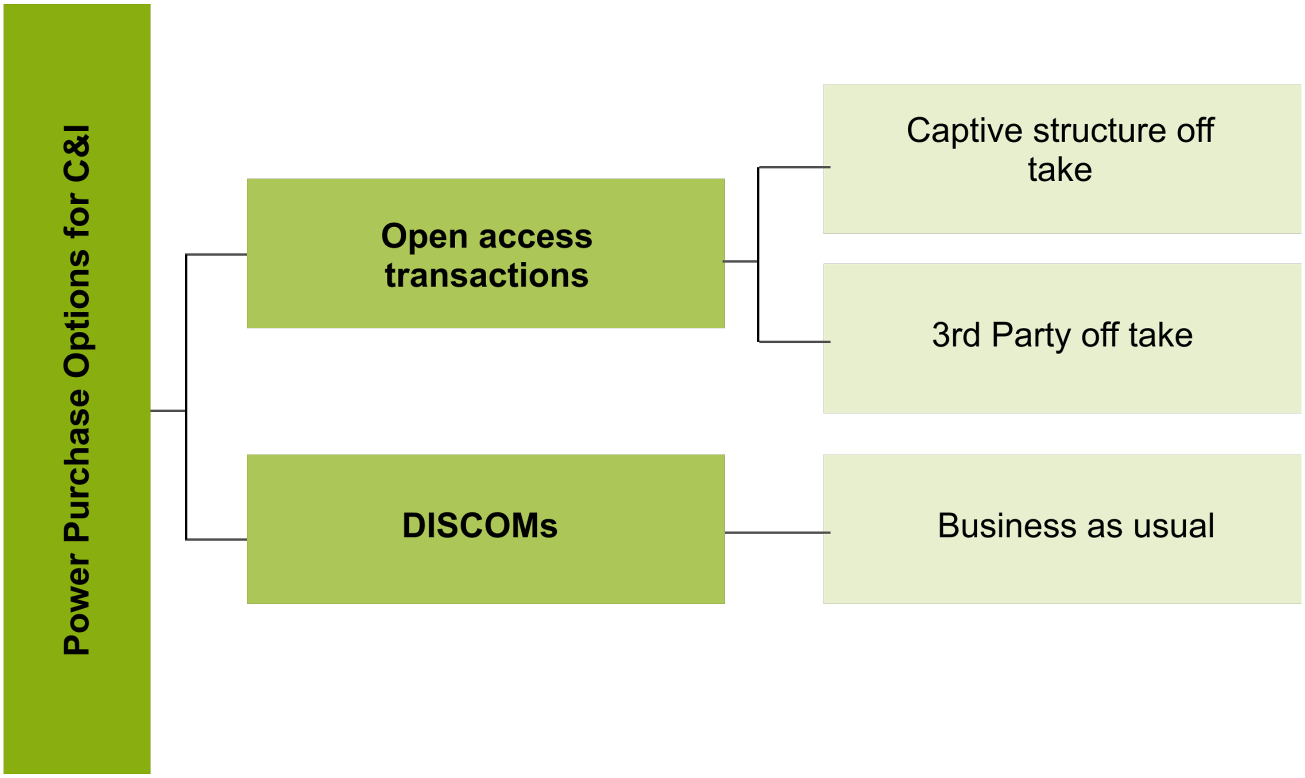


Figure 20: Procurement of power options (C&I)

1 Procurement through distribution companies (DISCOMs):

This is the conventional method where electricity is purchased directly from the local DISCOM at regulated retail tariffs. While this option offers ease of access and minimal administrative overhead, the applicable tariff structure may include:

1) Demand charges

2) Time-of-day pricing (if applicable)

3) Cross-subsidy surcharges

4) Other regulatory levies

These costs can significantly affect the operational expenditure of EV charging facilities, particularly for large depots with high and variable load profiles.

2. Open Access (OA) mechanism:

Given the rising energy demand from electric bus depots and the growing need for cost optimisation and sustainability, many C&I consumers—including public transport agencies and charge point operators—are exploring alternatives to traditional DISCOM-based electricity procurement. One such alternative is the Open Access (OA) mechanism, which offers greater flexibility in sourcing electricity.

1) Independent power producers (IPPs)
2) Renewable energy developers
3) Power exchanges

This route provides opportunities for:
A. Accessing renewable energy (e.g., solar or wind)

B. Negotiating lower tariffs through bilateral contracts or market participation

C. Enhancing energy cost predictability and long-term sustainability

However, it also comes with its own set of regulatory and financial considerations, such as:

- Transmission and wheeling charges
- Open access surcharges
- Banking provisions (for renewable energy)
- Scheduling and deviation penalties

- Captive/Group captive projects are projects set up by a developer with equity contributions from interested captive consumers and generation from such projects are consumed by such captive consumers

- Major part of equity contribution is done by developer and equity contribution from consumers are statutory

- Captive structure based off-take provides great deal in saving costs from existing transaction for captive users

- Solar Captive/Group captive projects offer further advantage of reduced charges in energy transaction – Waiver of CSS

- Third Party Off-take provides relatively cheaper option than energy purchase from DISCOMs.

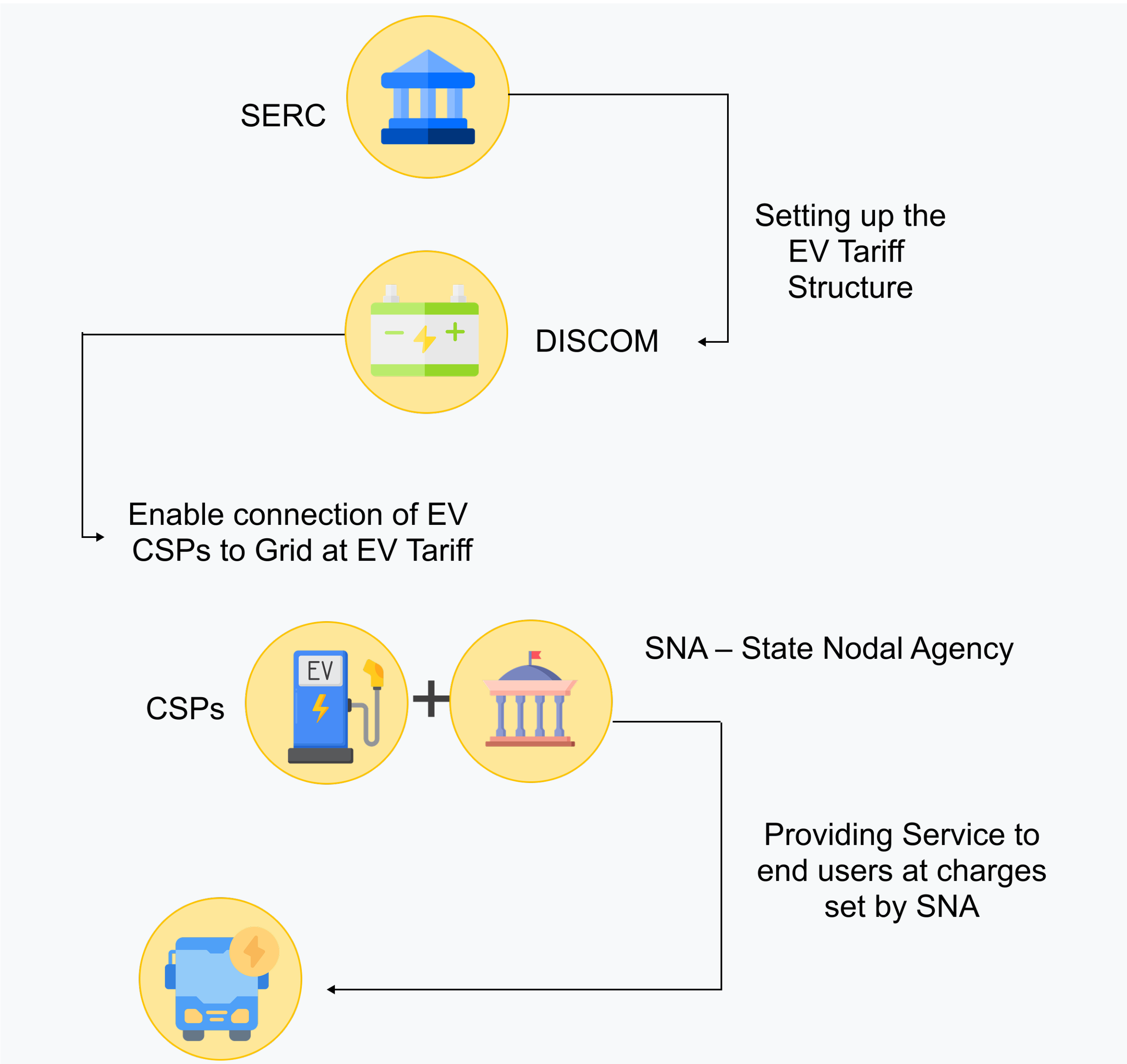


Figure 21: Framework for EV tariff development

Issuance of guidelines and standards for EV charging infrastructure in January 2022 by MoP, with subsequent amendments in November 2022 and April 2023. These guidelines are as follows:

1.Enables EV owners to charge vehicles at residences/offices using existing electricity connections.

2.Prescribe revenue – sharing model for land provision at promotional rates for public charging stations.

3.Ensure timely electricity connection to Public Charging Stations (PCS).

4.Implement a single-part EV tariff for public charging stations not exceeding the Average Cost of Supply (ACoS) until March 31, 2025.

5. Specify ceiling tariffs for slow AC charging (INR 2.50 per unit solar, INR 3.50 per unit non-solar) and DC fast charging (INR 10 per unit solar, INR 12 per unit non-solar) at PCS.

6. Provide a 20% rebate on at ACoS by DISCOM to PCS during solar hours and impose a 20% surcharge during other times.

For public e-bus operators and CPOs, selecting the right procurement model is crucial. While DISCOM-based supply ensures reliability and administrative simplicity, open access can offer lower costs and environmental benefits if managed effectively. However, open access also involves navigating a more complex regulatory framework and bearing additional charges, particularly for public transport entities that do not qualify for certain exemptions. To make informed decisions, a comparative techno-economic analysis of both models—considering tariff structures, policy incentives, and operational needs—is essential. This enables fleet operators and CPOs to align their energy sourcing strategies with long-term financial sustainability and decarbonisation goals.

The following section outlines the key enablers required to leverage renewable energy, net metering, and open access mechanisms for sourcing electricity from renewable energy to charge electric vehicles. It also highlights that public e-bus operators, as consumers, may be subject to additional open access charges—reinforcing the need for a comparative analysis to fully understand the economic implications of these options.

8.1.1 Open access of electricity

Open access refers to the regulatory provision that enables eligible electricity consumers, generators, or traders to utilise the existing transmission and distribution networks to purchase or sell power from a supplier of their choice. By decoupling electricity procurement from the local DISCOM, open access promotes market competition, improves cost transparency, and empowers consumers to align their energy sourcing strategies with economic and environmental objectives. Under this framework, public e-bus operators can procure power directly from renewable energy developers or power exchanges, potentially reducing tariff burdens and accelerating green energy adoption. However, while open access offers significant advantages, it also entails navigating a more complex regulatory environment, particularly concerning eligibility, charges, and compliance obligations.
The subsequent sections explore how open access can be operationalised for EV charging infrastructure, along with the associated benefits, challenges, and regulatory considerations that stakeholders must account for when evaluating this power procurement route.

Key features of open access in electricity:

1) Consumer choice: Large/bulk electricity consumers, such as industries or commercial entities, can procure power directly from generators or renewable energy producers rather than being limited to their local distribution companies (DISCOMs) through competitive pricing.

2) Regulatory framework: Open access is governed by electricity regulators, such as state electricity regulatory commissions (SERCs) or national bodies, depending on the country. These regulations ensure fair access and pricing.

3) Types of open access:

- Intra-State Open Access: Within a state, where electricity is procured using the state's grid.

- Inter-State Open Access: Across states, using the national or regional grid.

4) Wheeling and transmission charges: Consumers or suppliers using the grid for electricity transmission pay wheeling (distribution network) or transmission charges, as well as other applicable fees.

5) Promoting renewable energy: Open access policies often encourage renewable energy adoption by allowing industries to procure power directly from solar, wind, or other renewable sources.

8.1.1.1 Modes and framework for open access

While considering regulations put in place by appropriate commissions, covers various dimensions of OA transactions including the duration, type of contract, and location of buyers and sellers (Figure 22). Each mode of OA transaction has different procedure for application, grant of connectivity, charges, and scheduling, as specified in the regulations. Before GEOA rule 2022, the open access is made available for high tariff paying consumers, typically with the maximum power exceeding 1MW and above however, this has been changed post 2022 rule, who mainly belong to industrial and commercial categories. The Central Electricity Regulatory Commission (CERC) regulations on open access specify the duration for different types of OA transactions, namely, short-term open access, medium-term open access, and long-term access, as up to 1 month, 3 months to 5 years, and more than 7 years, respectively. Variances are, however, noted regarding the duration of open access in the regulations specified by some of the SERCs.

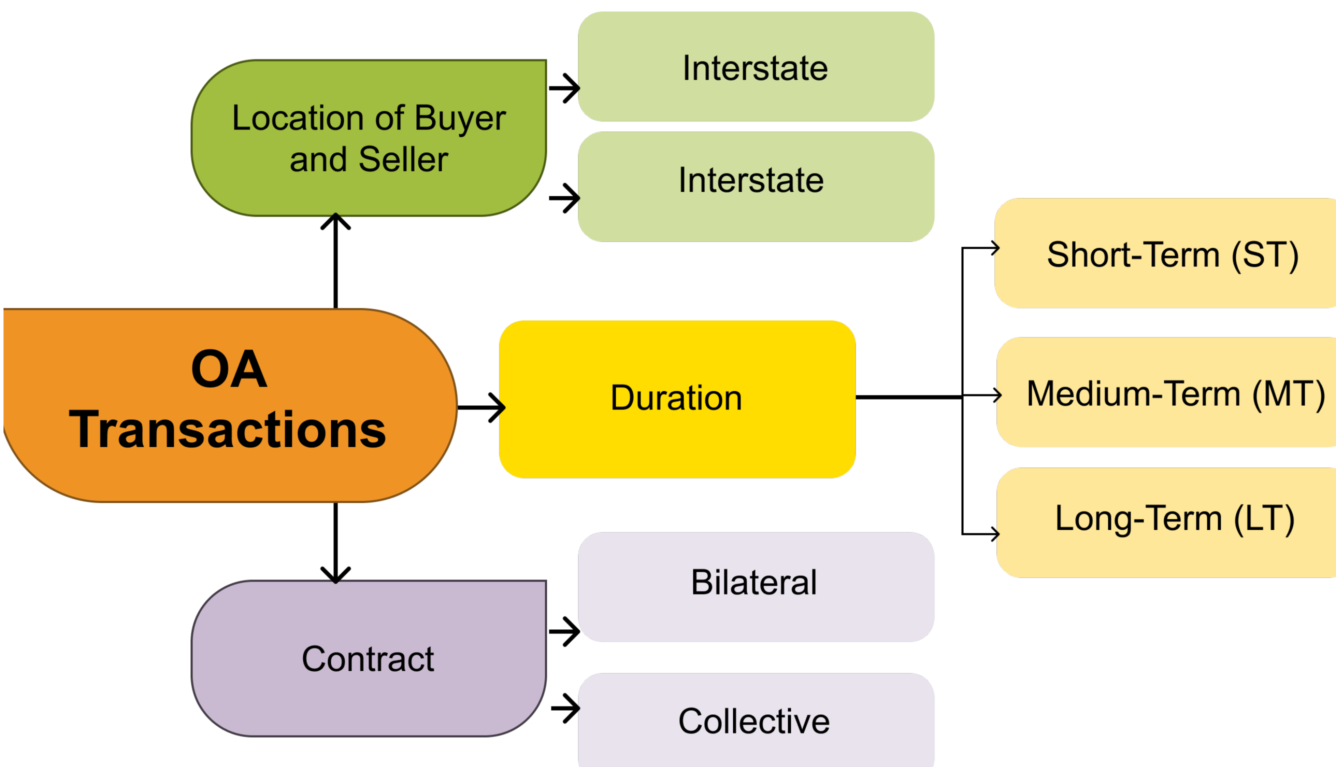


Figure 22: Various modes of OA transactions

8.2 Net metering and green energy open access rules

EV charging stations have been reclassified as 'Prosumer', indicating a dual role of consumption and production, while the act of charging has been officially recognised as a 'service'. Furthermore, the MoP has instructed distribution companies (DISCOMs) to expedite electricity connections to public charging stations, aligning with the timelines stipulated in the "Electricity (Rights of Consumers) Rules 2020". According to these rules, connection to a public charging station must be provided within 7 days in metro cities, 15 days in other municipal areas, and 30 days in rural areas, although the appropriate Commission may establish shorter timeframes if deemed necessary.

Net metering and or gross/net billing: Net metering allows EV owners to offset their electricity consumption by exporting excess power to the grid. Under this framework, the energy supplied to the grid is subtracted from the energy consumed from the grid, and the EV owner is billed or credited accordingly. Net metering tariffs can encourage EV owners to participate in V2G programs and maximise the utilisation of renewable energy. Recently introduced Ministry of Power Electricity (Rights of Consumers) Rules 2023 has introduced Net Billing as alternative to Net Metering.

MoP has notified Electricity (Promoting Renewable Energy Through Green Energy Open Access) Rules, 2022 on 06.06.2022 in order to further accelerate ambitious renewable energy programmes, with the objective of ensuring access to affordable, reliable, sustainable and green energy for all. The reduction of Open Access Transaction limit from 1 MW to 100 kW and appropriate provisions for cross-subsidy surcharge, additional surcharge, standby charge, will incentivise the common consumers to get power from renewable energy sources at reasonable rates. Further, since the rules also address other issues that have hindered the growth of open access, the common consumers can now get access to renewable energy power easily. The salient features and benefits to common consumers from 'Green Energy Open Access' are as follow :

- These rules are notified for promoting generation, purchase and consumption of green energy including the energy from Waste-to-Energy plants.
- The Green Open Access is allowed to any consumer, and the limit of Open Access Transaction has been reduced from 1 MW to 100 kW for green energy, to enable small consumers also to purchase renewable power through open access.
- Consumers are entitled to demand supply of Green Power from Discoms. Discoms would be obligated to procure and supply green power to eligible consumers.
- These Rules will also streamline the overall approval process for granting open access. Time bound processing by bringing uniformity and transparency in the application as well as approval of open access through a national portal has been mandated. Approval for Green Open Access is to be granted in 15 days or else it will be deemed to have been granted.
- Commercial and Industrial consumers are allowed to purchase green power on voluntarily basis.
- Provide certainty on open access charges to be levied on Green Energy Open Access Consumers which includes transmission charges, wheeling charges, cross-subsidy surcharge and standby charges. Cap on increasing of cross-subsidy surcharge as well as the removal of additional surcharge, incentivise the consumers to go green.

- There shall be a uniform Renewable Purchase Obligation (RPO), on all obligated entities in area of a distribution licensees. Green Hydrogen/Green Ammonia has also been included for fulfilment of its RPO.

- Consumers will be given Green Certificates if they consume green power.

As elaborated in previous section, public charging stations, or networks thereof, are also eligible to source electricity directly from power generation (Independent and Green Electricity) companies through open access. This has to promote market competitiveness, Charge Point Operators (CPOs) have been empowered to procure electricity through open access channels. In line with this initiative, the MoP introduced a draft notification on August 16, 2021, titled “Draft Electricity (Promoting Renewable Energy Through Green Open Access) Rules, 2022”. These rules allow for sourcing up to 100 kW of power from green sources (Renewable generators and consumers selling and buying electricity though open access including self-generation, electricity exchange, and bi-lateral contracts), presenting an opportunity for CPOs to consolidate demand and for larger consumers like depots to optimise their electricity expenditure by exploring alternative supply routes, while also considering the associated economic factors. Moreover, access to open access electricity must be granted within 15 days, with applicable charges limited to cross subsidy charges (not exceeding 20 percent as per Tariff Policy Guidelines), transmission charges, and wheeling charges.

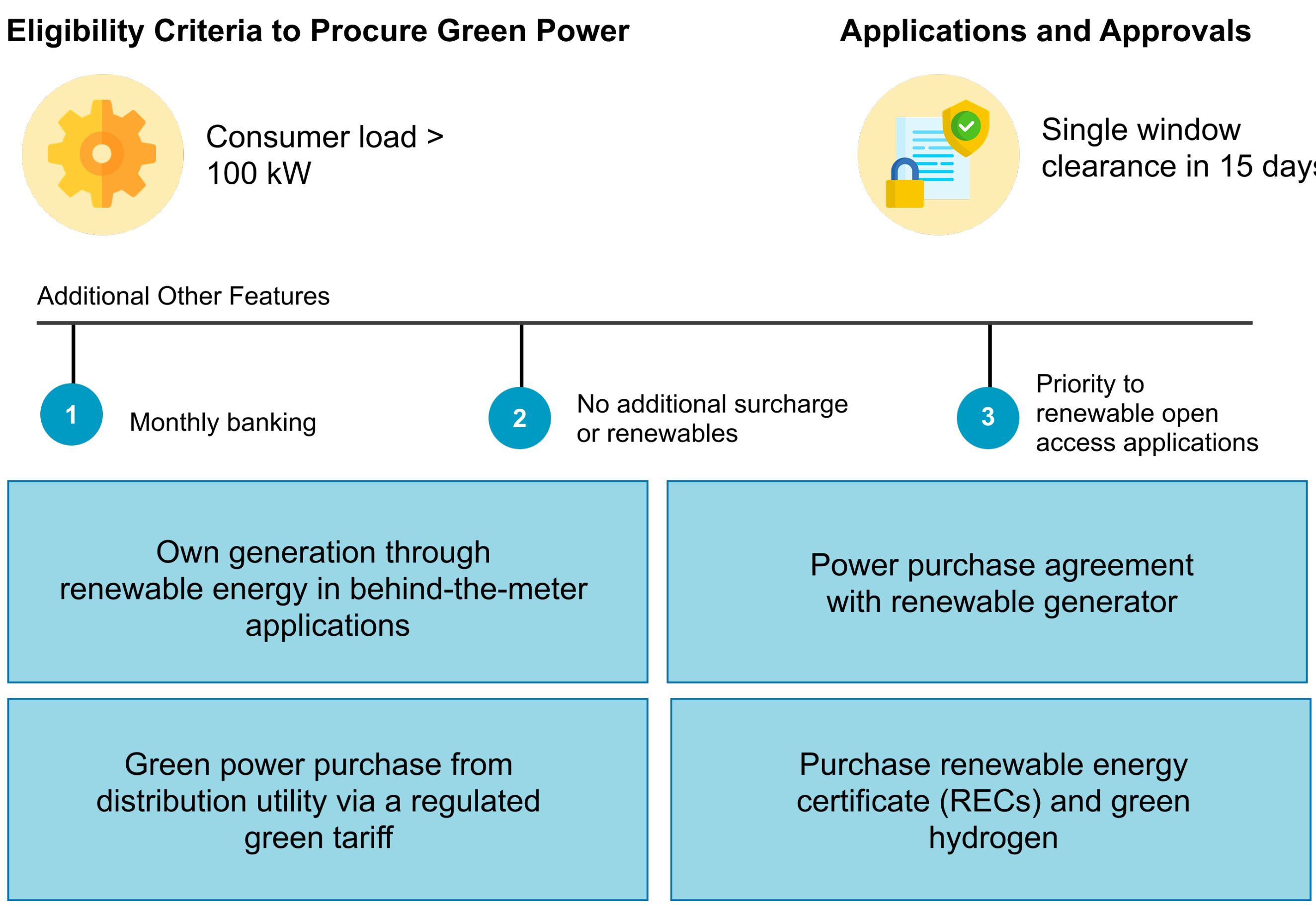


Figure 23: Green open access rule benefits & features

The MoP (Electricity Rights of Consumers) Rules 2020 and its subsequent amendment attempted to address the regulatory interventions of net metering/net billing. In this regard, the MoP in June 2022 introduced Electricity (Promoting Renewable Energy Through Green Energy Open Access) Rules, 2022 (hereinafter referred as 'MoP Green OA Rules') (Ministry of Power, 2022). This has eased installation of solar rooftop by any public charging stations and states as herein below:

- (2) Any entity, whether obligated or not may elect to generate, purchase and consume renewable energy as per their requirements by one or more of the following methods: -
- Own Generation from renewable energy sources. –There shall not be any capacity limit for installation of power plants from renewable energy sources, by entities for their own consumption and such plants may be set up at any location in India and power shall be transmitted by using open access:
- Provided that the generating plant may be set up by the entity itself or by a developer with which the entity enters into a power purchase agreement

The afore mentioned not only allowed public charging stations to install without any capacity limit but also allowed to avail green open access for offsite renewable plants. In order to counter the open access eligibility under respective state regulations, the MoP Green OA Rules specifies as herein below:

"Green Energy Open Access. – (1) To provide Green Energy Open Access to consumers of green energy, the appropriate Commission may, if necessary, amend the relevant regulations made by it and such regulations shall be consistent with these rules. All applications for open access of green energy in this regard shall be allowed by the nodal agency within a period of fifteen days:

Provided that only consumers who have contracted demand or sanctioned load of hundred kW and above shall be eligible to take power through Green Energy Open Access and there shall be no limit of supply of power for the captive consumers taking power under Green Energy Open Access:

Provided further that reasonable conditions such as the minimum number of time blocks, which shall not be more than twelve-time blocks, for which the consumer shall not change the quantum of power consumed through open access may be imposed so as to avoid high variation in demand to be met by the distribution licensee.

Banking. – (1) Banking shall be permitted at least on a monthly basis on payment of charges to compensate additional costs, if any, to the distribution licensee by the Banking and the Appropriate Commission shall fix the applicable charges.

(2) The permitted quantum of banked energy by the Green Energy Open Access consumers shall be at least thirty percent of the total monthly consumption of electricity from the distribution licensee by the consumers."

Explanation: For the purposes of this rule, the expression—banking means the surplus green energy injected in the grid and credited with the distribution licensee energy by the Green Energy Open Access consumers and that shall be drawn along with charges to compensate additional costs if any.

Provided that the credit for banked energy shall not be permitted to be carried forward to subsequent months and the credit of energy banked during the month shall be adjusted during the same month.

According to the aforementioned provisions, public charging stations that install their own renewable energy generation are exempt from load restrictions. This provision effectively caters to the fluctuating traffic and intermittent power demands of these stations and permits renewable energy banking with existing distribution licensees. Consequently, this incentivises CPOs with sufficient charger capacity installed at public locations and or depots to take advantage of such provisions. However, due to the firm load requirements stipulated by the Central Electricity Regulatory Commission (CERC) IEGC Regulations 2023 (referred to as the 'Grid Code'), public charging stations face constraints in accessing Green Open Access. This prompted the ministry to propose rule amendments allowing public charging stations to procure green electricity from their existing distribution licensee under the green tariff framework.

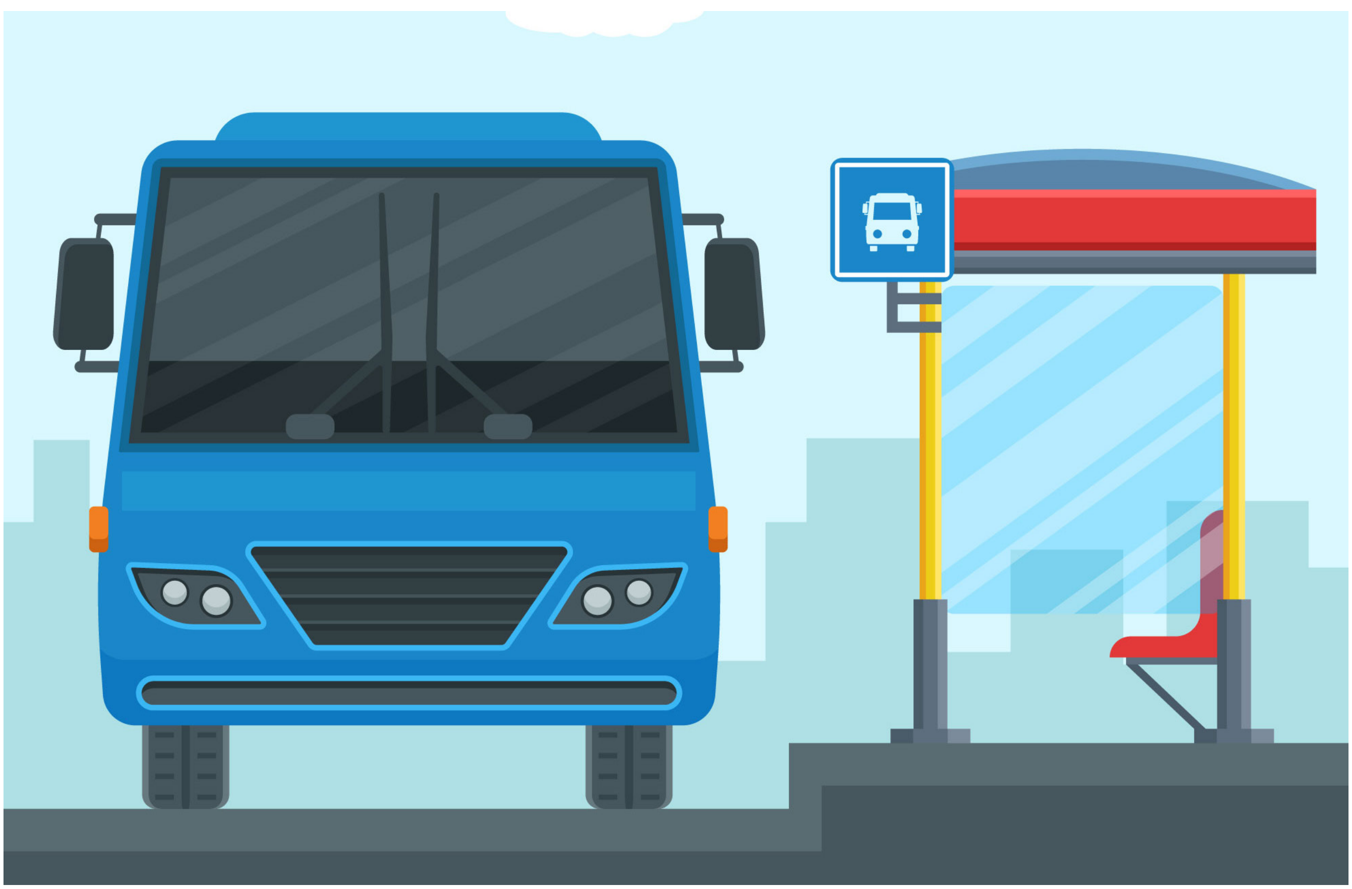
"(a) Any consumer may elect to purchase green energy either up to a certain percentage of the consumption or its entire consumption and they may place a requisition for this with their distribution licensee, which shall procure such quantity of green energy and supply it and the consumer shall have the flexibility to give separate requisition for solar and non-solar;"

"Provided that the credit for banked energy shall not be permitted to be carried forward to subsequent banking cycles and shall be adjusted during the same banking cycle:

Provided further that the un-utilised surplus banked energy shall be considered as lapsed at the end of each banking cycle and the Renewable Energy generating station shall be entitled to get Renewable Energy Certificates to the extent of the lapsed banked energy."

Despite the necessity for firm loads in public charging stations, the regulatory conflict for fast charging stations was addressed by the MoP Green Open Access Rules 2022. Additionally, subsequent amendments to the MoP Green Open Access Rules 2023 have introduced a transformative incentive for public charging stations. This incentive applies to stations with a cumulative load exceeding 100 kW, but individual point drawl loads below 100 kW within a distribution licensee's jurisdiction.

This amendment enables the aggregation of multiple public charging stations, each with loads below 100 kW, to reach a combined load of 100 kW or more within the distribution licensee's area. Consequently, these aggregated stations become eligible to access green open access benefits.



8.2.1 Gujarat – net metering rooftop solar PV grid interactive systems

The GERC introduced its third amendment regulation in 2022, delineating provisions for solar power generation systems installed on rooftops. Under these updated regulations, net metering is authorised for rooftop solar systems ranging from 1 kW to 1 MW in capacity (GERC, 2024). Additionally, gross metering is sanctioned for rooftop solar systems with capacities between 10 kW and 1 MW. The latest regulations specify that residential or government consumers can deploy rooftop projects under the gross metering mechanism on their premises. However, in such cases, ownership or legal possession of the premises must be transferred to the DISCOM as per the policy for the development of small-scale distributed solar projects outlined in 2019.

Furthermore, for projects established under the Renewable Energy Certificate (REC) mechanism, whether for captive use or third-party sale, solar installations are permissible up to the sanctioned load. Additionally, solar project capacities intended to meet Renewable Purchase Obligation (RPO) requirements will be allowed, irrespective of their sanctioned load. Projects set up under the captive use the regulation has set forth specifically for high end consumers the following key points:

- The captive use of electricity for self-consumption within the same premises or at different premises by the consumer must having ownership of Solar Power System (SPS) shall be as specified in the Electricity Rules, 2005 and amendments made thereto from time to time.
    - No capacity restrictions shall be applicable under this category subject to consideration of the limit provided for Rooftop projects
- In case of solar projects set up by High Voltage (HT) / Extra High Voltage (EHV) consumers for captive use, the energy set-off shall be allowed between 07.00 hours to 18.00 hours of the same day which means the generated solar energy during a day shall be consumed by High Tension (HT) or Extra High Voltage (EHV) consumer during 07.00 hours to 18.00 hours on the same day. The surplus energy after the specified period shall be purchased by Distribution Licensee at rates specified under these Regulations.
- The surplus energy, not consumed during the above-mentioned period by the consumer after set-off, shall be compensated by distribution licensees by following surplus Injection compensation (SIC) rates.

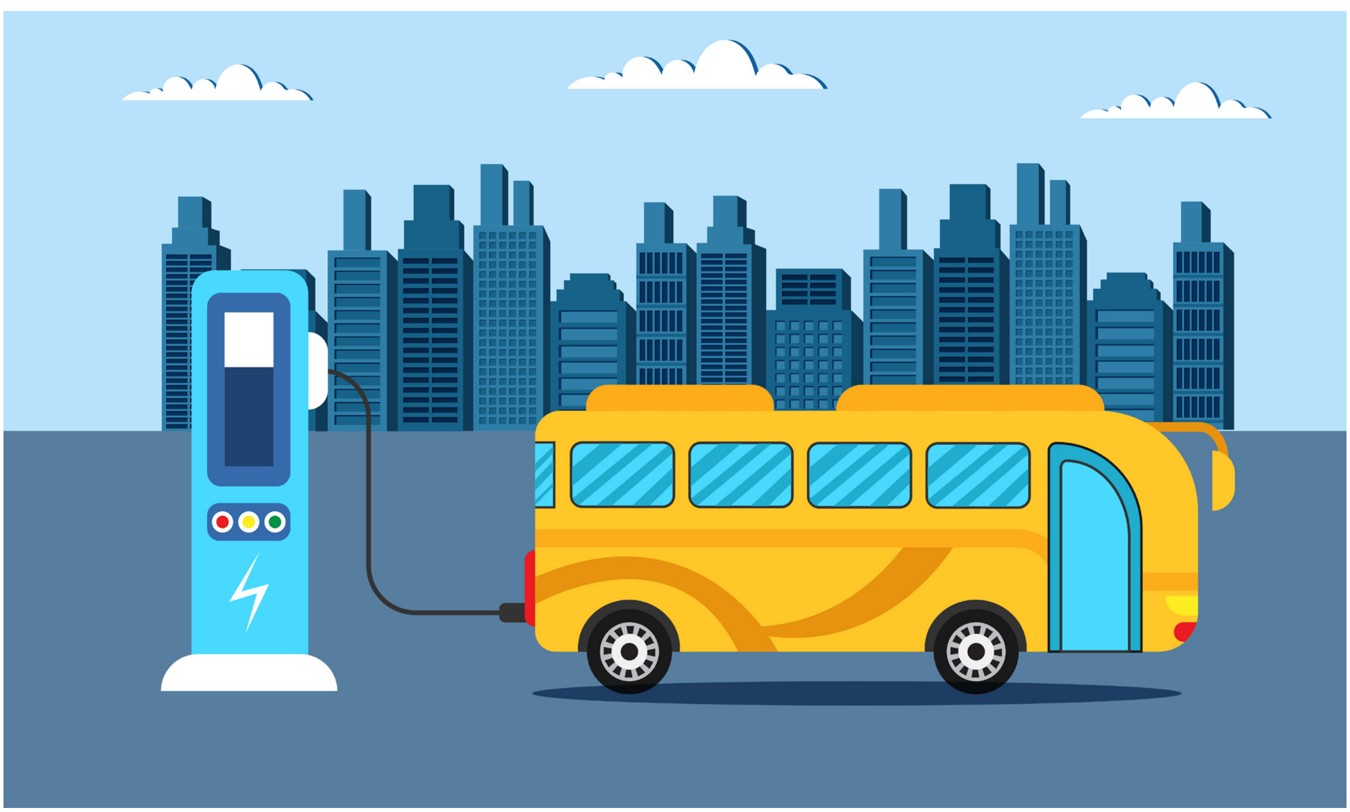
For manufacturing companies that are not classified as MSMEs, the solar power rate will be set at 75% of the average price discovered through competitive bidding by GUVNL for regular (non-park) solar projects during the last six months—either April to September or October to March, depending on the project's start date commercial Operation Date (COD). This rate will stay the same for the entire duration of the agreement. Solar projects set up for self-use (captive use) will be allowed to switch to selling power to the electricity distribution company—but only once during the project's lifetime. If they choose to switch, the rate they will get for selling power will be the lowest tariff found through GUVNL's competitive bidding for regular (non-park) solar projects, as on the date the project starts operating (COD). If a consumer generates more solar power than they use during the allowed time period, the extra (surplus) energy will be purchased by the electricity distribution company. They will pay 75% of the average rate found through GUVNL's recent competitive bidding (either from April to September or October to March, depending on when the project starts operating). This rate will stay the same for the full term of the agreement.

Explanation: The outlined regulations for high-end captive consumers, including residential or government premises, emphasise ample opportunities for CPOs and depot charging stations to capitalise on. They can do so by installing solar rooftop projects on various structures such as charging station canopies, administrative buildings, or parking areas. This strategic utilisation of space not only aligns with the regulations but also presents a sustainable approach to power generation within these premises. An illustrative computation demonstrates the substantial saving potential of the regulatory interventions of net metering or gross/net billing that may help improve the financial viability of public charging stations and hence charging stations at depots.

8.2.2 Cost comparative analysis: Local DISCOM vs open access

The EV charging stations with cumulative load above 100 kW can avail green open access under third party open access transactions or may consider setting up their respective captive generating stations. The charging station operators with a total load of 1 MW - using both fast and slow chargers and solar power connected with 33kV – can use green open access within the Torrent Power area. This helps not only enable green charging but also reduce operating costs due to lower rates compared to the DISCOMs power. This analysis indicates that the commercial viability of opting for green open access is primarily feasible for captive transactions. In this scenario, EV charging point operators establish renewable energy capacity specifically to meet the demands of EV charging infrastructure. However, a review of open access regulations and directives from regulatory commissions reveals a regulatory gap where cross subsidy surcharges and additional surcharges for EVs as a consumer category are not clearly defined. This regulatory gap presents a challenge for public charging stations seeking to access green open access through third-party transactions without the mandate for equity participation in renewable energy setup.

The Electricity Act 2003 provides consumers with the option to procure electricity from sources other than their current distribution licensee, utilising the distribution and transmission network while adhering to applicable open access charges and ensuring technical feasibility. Within the open access framework, two transaction types exist: bilateral and collective. Collective transactions occur on power exchange platforms, while bilateral transactions involve interactions between an open access consumer and a generating source. Bilateral transactions can occur through captive or third-party arrangements. Captive transactions involve consumers sourcing electricity from a generating plant established for their own use, contingent upon meeting Captive Eligibility conditions outlined in the Electricity Rules 2005.



Sr. no.	Particulars	UoM	Captive	3rd party OA
1	Contract demand	kVA	5000	5000
2	Specific generation	MWh/MWp/Year	1544	1544
3	Capacity	MW	3.00	3.00
4	Gross generation PLF	%	19%	19%
5	Units delivered to injection point	Mn kWh	4.632	4.63
6	Less: Transmission losses	%	4.40%	4.40%
7	Less: Wheeling losses	%	10%	10%
8	Banking charges	Rs/kWh	₹ 1.50	₹1.50
9	Units delivered to with-drawal point	Mn kWh	3.965	3.96
10	Impact of losses	Rs/kWh	₹ 0.59	₹0.70
11	Tariff at generation bus bar	Rs/kWh	₹ 3.50	₹4.15
	Add: Open access charges			
12	Transmission charges @ 50%	Rs/kWh/Day	₹ 3.26	₹ 3.26
13	Wheeling charges @ 50%	Rs. /kWh	₹ 1348	₹ 0.1348
14	SLDC charges	Rs/kW/Month	₹ 0.05	₹ 0.05
15	Cross subsidy charges (HV 1 consumers)	Rs/kWh	₹-	₹ 1.80
16	Additional charges	Rs/kWh	₹-	₹ 0.93
17	Total open access charges + losses	Rs/kWh	₹4.03	₹ 6.87
18	Tariff to consumer at delivery point	Rs/kWh	₹7.53	₹ 11.02
19	Gujarat tariff (A) EV charging tariff	Rs/kWh	₹4.00	₹ 4.00

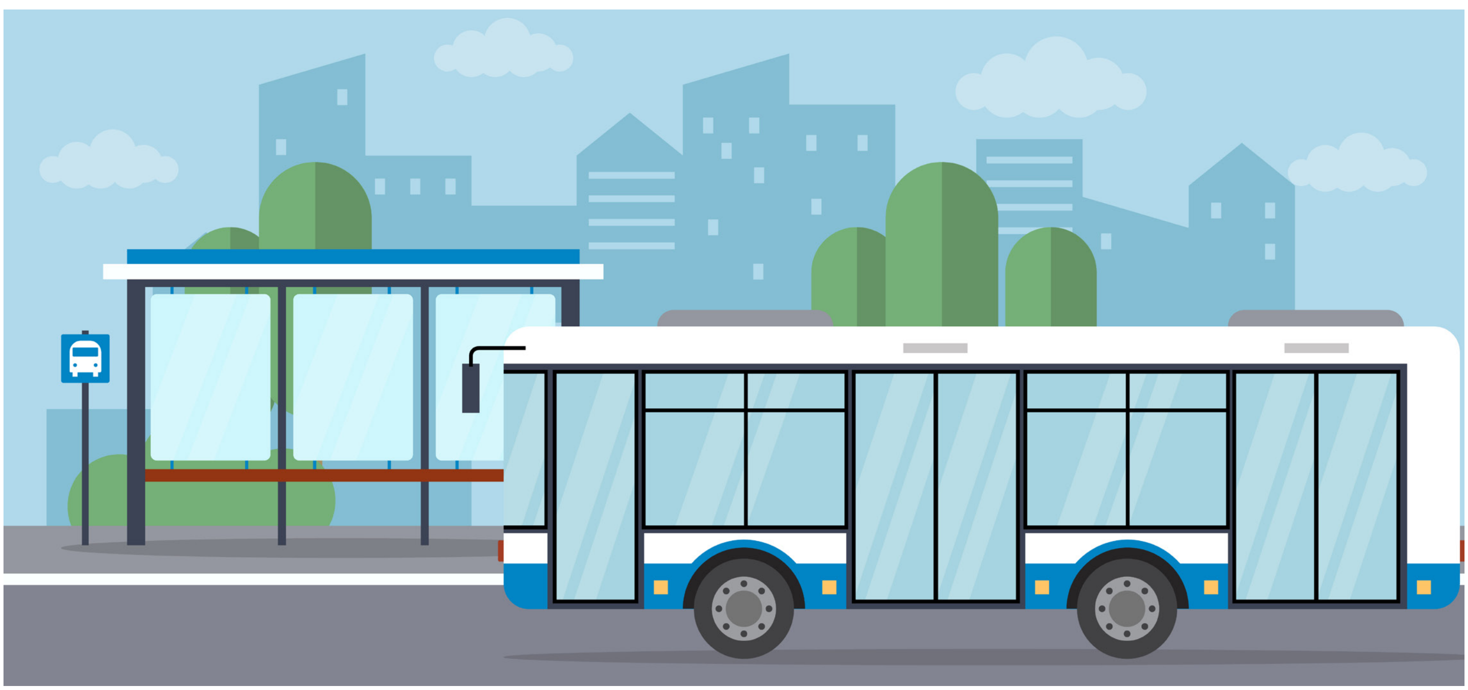
20	Regulatory surcharge @ 4.28%	Rs/kWh	₹-	₹ -
21	Electricity duty @7.50%	Rs/kWh	₹0.30	₹ 0.30
22	Gujarat replaceable tariff (A+B)	Rs/kWh	₹4.30	₹ 4.30
23	Discount offered to consumers	Rs/kWh	₹ -3.23	₹ -6.72

Note: FAC not included in the landed cost computation

Table 14: GJ captive model landed sheet at 33 kV-HV-1

A specific illustrative analysis was conducted in the state of Gujarat to evaluate the commercial viability and potential incentives for CPOs to offer charging services at depots or aggregated depot locations in the near future. The findings indicate that the cost savings through green open access in Gujarat are either negligible or, in some cases, negative making the proposition commercially unattractive. Regulatory commissions have kept EV tariffs relatively low to promote the adoption of electric vehicles. However, the inclusion of open access charges significantly hampers the economic feasibility of open access models across many states. Further compounding the challenge, DISCOMs are reluctant to introduce additional incentive mechanisms for such installations. Their concern stems from the potential revenue under-recovery and the increased burden of cross-subsidisation on other consumer categories.

At present, green open access remains the only possible pathway for CPOs—primarily benefiting those who can install captive power generation systems at their charging locations.



09

Final Recommendations/ Way Forward

1)Need standardised protocol for managed charging strategy and demand response

The utilities are required to invest in upgrading and designing the network to cater to peak system demand, which is capital-intensive. The regulator ought to create a mechanism for demand response products in the ancillary market, allowing charging service providers to participate in it. Several new technologies related to managed charging of EVs have initially been introduced through pilot platforms. These require large-scale technology deployment. While standards and guidelines in India include provisions for communication protocols between EVSE and other stakeholders, there has been a lack of pilot initiatives on largescale managed charging projects. To promote the adoption of managed charging of EVs, it is crucial for DISCOMs and regulators to undertake pilot initiatives to demonstrate the potential advantages and challenges.

The Central Electricity Authority (CEA), in conjunction with DISCOMs, also need to generate short and long-term demand projections for EV penetration based on available charging data. There is currently no regulatory mandate for DISCOMs to incorporate the CEA forecasts into their planning processes.

2) Design a suitable tariff that increases feasibility of operation of charging infrastructure facilities even at low asset utilisation level

Electricity demand charges i.e., "Fixed Demand Charges in EV tariff" pertain to fixed fees imposed on charging station operators, determined by the connected load, regardless of the actual usage of the charging station facility. For chargers located along e-bus routes for opportunity charging, initial phases might witness low asset utilisation, and the application of electricity demand charges can present challenges for high-capacity chargers to achieve break-even points. Allow recovery of network investment cost through regulatory provisions and tariff determination. Adapt energy utility rate structure to accelerate the cost-effective electrification of e-buses. The cost of supply is higher than the approved EV tariff (accrual of EV tariff subsidy committed by government). Even if this allows recovery of utility capital costs it may discourage the electrification of the e-buses innovative EV tariff should be adopted to be an enabler.

3) Smart charging techniques

This may also enable new services to optimise the cost of charging, mitigate the secondary peak, encourage to utilise clean source of energy, and delay the infrastructure augmentation, if compensated appropriately. Assess the resilience and requirements of infrastructure along highways and key locations. Ensure connectivity and safety measures.

4) Enable stakeholder collaboration for establishing charging network

The vehicle OEMs, start-ups involved in e-bus fleet development, financial institutions, charging service providers, charging equipment providers, and infrastructure companies need to align and coordinate to plan charging locations (specially for on-route charging/opportunity charging), upgradation of grid along the identified locations for opportunity charging, expressways, economic corridors. This also requires empirical estimation of investment required for both charging infra and procurement of electricity.

Also, logistic service providers, fleet operators, and OEM's have the opportunity to engage with private sector stakeholders and financial institutions to create innovative business models, partnerships, and institutional mechanisms. By doing so, they can effectively leverage financing resources required to achieve their transportation electrification objectives.

Evaluate existing bus depot locations considering factors such as proximity to key bus routes, grid infrastructure, available space, environmental impacts, and potential for expansion. Work with utility providers to ensure the local grid infrastructure has adequate capacity, stability, and resilience to support increased electricity demand for e-bus charging.

5) Tax measures to reduce operational costs

The incentives, road tax credits, and rationalisation of Goods and Services Tax (GST) etc. can help to lower the operational and charging expenses of e-buses specially for opportunity charging using ultra-fast chargers along the way.

6) Implement carbon credit trading system to mobilise resources and investment

There is already a regulatory provision of carbon trading system under the Energy Conservation Act and Bureau of Energy Efficiency is developing this mechanism for the vehicles. Bring e-bus fleet within the scope and enable companies operating e-bus fleet to earn credits based on their reduced carbon emissions and meeting of the emissions reduction obligation.

7) Strengthen fuel economy standards for ICE buses for quicker electrification

Provide the timeline for successive improvement in fuel economy improvement targets and advancement in testing protocol to give a longer-term policy visibility of the pathway. This may be supported by a suitable timeline for zero emissions mandate while modifying the EV super-credit multiplier and disclosure of test data.

8)Charging infrastructure and data analytics

The public bus electrification brings with it a significant increase in data related to vehicle and energy usage. This is an opportunity to design effective policy measures based on data to improve vehicle performance, charging patterns, and overall energy consumption. This information can be utilised to develop targeted incentive programs and financial incentives. This needs seamless communication and data sharing standards, use of data analytics for performance optimisation, enhanced fleet management etc. This can also enable environmental and safety reporting.
Encourage deployment of Digital Energy Management System at depots to monitor, optimise, and forecast energy consumption patterns, renewable generation, and storage usage for cost-effective operations.

9) Leveraging renewable energy for e-buses/ depot powering

Currently, the EV charging stations with solar rooftop with load above 10kW, become eligible for availing the regulatory benefits in terms of net-metering or net-billing or net feed-in (gross metering). However, since most of the state electricity regulatory commissions identify the eligibility for net metering by consumers category, this creates a regulatory ambiguity over eligibility of EV charging stations to avail net metering benefits.

The EV charging infrastructure providers may be allowed to install solar/micro wind with regulatory incentives of net-metering and net-billing. This can also reduce the cost of running the electricity infrastructure. A clarification is needed to be issued from the MoP to consider EV charging stations to be classified as eligible consumers as part of the net metering/net billing incentives.

The infrastructure for EV charging should be categorised as an eligible consumer, enabling it to access the benefits of net metering or net billing mechanisms. This classification would not only facilitate a more dynamic and efficient use of energy resources but also incentivise the adoption of renewable energy sources for EV charging stations. Allowance for yearly Renewable Energy (RE) banking should include the flexibility for adjustments within both peak and off-peak time of day (TOD) periods.

Include solar PV system integration as a core component in depot planning and design guidelines, with standardised layouts, load calculations, and power infrastructure provisions.

Encourage innovative Public Private Partnership (PPP) models such as Renewable Energy Service Company (RESCO), Build-Own-Operate-Transfer (BOOT), or lease models to attract private investment in solar infrastructure.
Establish full name (PPAs) with renewable energy providers to secure clean and affordable electricity supply when on-site renewable generation is insufficient.

10) Upgradation of distribution grid and timeline

Although shared infrastructure can be created as load projections grow, laws normally demand that utilities respond to consumers' demands for electric service rather than foresee them. Nowadays, practically all DISCOMs in every state demand that consumers pay for system expansion. To save customers money and avoid wasteful infrastructure, electric utilities are regulated to respond to service requests. While shared infrastructure can be built as load forecasts increase, generally regulations require that utilities respond to customers' electric service requests rather than anticipate them. The electrical infrastructure to be upgraded by electric utilities can include distribution lines, local stations, breakers, transformers, and switchgears. Electricity grid upgrades are necessary where on-site power availability is not sufficient. Grid upgrades can range from minor, such as only upgrading the breaker and distribution transformer, to major upgrades of the distribution lines and substation. It is necessary to illustrate the tentative cost for new infrastructure upgrades and average timelines for each set-up.

11) Enable third-party aggregators to engage in the aggregation of distributed energy resources, encompassing EVs, through regulatory measures

This participation aims to facilitate grid services, which in turn promote the effective deployment of Vehicle to Grid (VG) projects, optimising a wide array of resources for enhanced efficiency.

12) Remedial solutions to prevent the stress

Addressing the grid challenges posed by e-bus fleets requires multiple solutions rather than a single fix. Fleet operators, logistics service providers, and charging service providers must acquire new skills related to power procurement, charger installation, and managing charging power and time.

Institutional role and implementation responsibilities

Activity	Lead agency	Supporting stakeholders	Key roles & responsibilities
Grid infrastructure up grades (short-term, Must- Do)	DISCOM	SMC, State Nodal Agencies, OEMs	Assess depot power needs, plan upgrades, invest in transformer/sub-station enhancement, ensure timely implementation
Design and implement EV-specific tariff structures	State Electricity Regulatory Commission (SERC)	DISCOM, MoP, State Energy Dept	Revise tariff orders to reflect operational realities, introduce demand-charge waivers or ToU pricing, ensure recovery of network investment
Clarification on net metering eligibility for CPOs	Ministry of Power (MoP)	SERCs, DISCOMs	Issue directive including EVCS in eligible consumer category under net metering/net billing
Pilot and scale managed charging programs	DISCOM	BEE, CEA, OEMs, Private CPOs	Design pilot schemes, develop grid-responsive charging protocols, analyse load data, enable large-scale deployment
Introduce digital energy management systems at depots	SMC / STU	DISCOM, CPOs, OEMs	Deploy monitoring tools, integrate SoC, charging patterns, depot load forecasting
Rooftop solar deployment in depots	SMC / STU	GEDA, DISCOMs, EPC contractors	Identify suitable areas, conduct feasibility, tender RESCO/BOOT contracts, monitor performance
Promote green open access for public charging stations	MoP / CERC	DISCOMs, STUs, Power Traders	Amend regulations to reduce surcharges, allow aggregation across depots, streamline approval
Develop EV charging infrastructure PPP models	State Nodal Agency / ULBs	Private investors, Infra cos., FIs	Facilitate land access, define business models (BOOT, RESCO), ensure regulatory support
Enable carbon credit market participation	BEE	MoP, MoEFCC, STUs	Finalise methodology for e-bus credits, create MRV systems, allow trading through C-trade platform
National-level demand forecasting & power planning	CEA	DISCOMs, STUs, State Planners	Use depot and route data to model electricity demand growth, integrate in transmission planning
Strengthen fuel economy norms for ICE buses	Ministry of Road Transport and Highways (MoRTH)	BIS, OEMs, Testing agencies	Define phase-wise targets, update test cycles, disclose comparative data
Enable third-party energy aggregator participation	CERC / State ERCs	DISCOMs, Energy aggregators, Tech vendors	Define aggregation rules, enable participation in ancillary/grid services markets

Table 15: Institutional role and implementation responsibilities

Prioritisation and phasing roadmap

To ensure effective and actionable implementation of the proposed recommendations, a phased road-map is presented below. It categorises interventions into two tiers:

- Must-Do: High-priority actions essential for enabling immediate scalability, cost-effectiveness, and operational continuity of e-bus depot electrification.

- Nice-to-Have: Medium- to long-term supportive actions that enhance system efficiency, innovation, and market readiness but are not prerequisites for initial rollout.

Each action is mapped to a phasing horizon—Short-Term (0–2 years), Medium-Term (2–5 years), and Long-Term (5+ years)—to guide sequencing and resource allocation.

I) Must-do actions

Priority area	Recommended action	Timeline	Rationale
Grid infra structure	Upgrade transformers, sub-stations, breakers to support depot electrification	Short-Term	Critical to support rising demand and avoid downtime or costly delays
Tariff reform	Introduce EV-specific tariff design (e.g., Time-of-Day, demand charge waivers)	Short-Term	Improves commercial viability for CPOs, especially during low utilisation phases
Net metering clarification	MoP directive to include EVCS under eligible consumer category	Short-Term	Enables rapid deployment of rooftop solar and cost savings for depot operators
Managed charging pilots	Launch DISCOM-led de-mand response pilots at high-capacity depots	Short-Term	Builds evidence for cost-efficient load management and grid stability
Digital energy monitoring	Deploy energy management systems across high-load depots	Short-Term	Allows optimisation of charging schedules, SoC tracking, and forecasting
Solar integra tion in depot design	Integrate rooftop solar lay-outs and load planning into depot infrastructure guidelines	Short-Term	Lowers electricity bills and supports sustainability mandates
Open access rule align ment	Allow aggregation of loads below 100 kW for Green OA eligibility	Short-Term	Unlocks access to low-cost renewable power for distributed depot networks

Table 16: Priority areas for e-bus depot electrification

II) Nice-to-have actions

Priority area	Recommended action	Timeline	Rationale
Carbon credit system	Include e-buses under BEE's carbon trading platform	Medium-Term	Monetises emissions reductions and attracts climate-linked finance
Third-party aggregators	Enable DER aggregators for V2G/grid services participation	Medium-Term	Enhances flexibility and builds new business models for EV energy management
PPP models for charging infra	Promote RESCO, BOOT, lease structures for solar and infra buildout	Medium-Term	Attracts private investment while reducing public CAPEX burden
Fleet-wide electrification mandate	Link fuel economy norms with phase-out dates for ICE buses	Medium-Term	Provides long-term visibility and demand certainty for eco-system players
Long-term open access contracts	Facilitate PPA-based access to RE at large de-pots via power exchanges	Long-Term	Supports decarbonisation and tariff stability for mega charging hubs
TOD-based banking framework	Introduce flexible bank-ing for renewable energy including peak-hour adjustment	Long-Term	Improves value of stored RE and supports cost-effective charging operations

Table 17: Other supportive areas for e-bus depot electrification

This phased roadmap is designed to provide strategic clarity to policymakers, DISCOMs, city transport undertakings (CTUs), and private operators, ensuring that the transition toward a fully electrified, renew-able-powered e-bus ecosystem is both technically feasible and financially viable.

Annexure A

Particular	UoM	Electric depot				
		Magob	Vesu	Palanpur	Althan	Bhestan
Battery capacity (kWh)	kWh	151.55	151.55	195	195	261
E-bus operational life	Yr.	11	11	11	11	11
Battery degradation factor	%/yr.	1.95%				
Yearly increment in energy consumption	%/yr.					
Total charger (as-in scenario)	#	12	12	5	6	30
EVSE requirement for charging per e-bus	#	5				
EVSE capacity	kW	180	180	180	180	240
Efficiency of charger	%	95%	95%	95%	95%	95%
Degradation in efficiency Y-O-Y	%	1.75%	1.75%	1.75%	1.75%	1.75%
Opportunity time	hr.	0.75	0.75	0.75	0.75	0.75
Overnight charging	hr.	6	6	6	6	6
Times of opportunity per day	#	2	2	2	2	2
Average vehicle run	[km/Day]	188	188	247	205	214
Maximum vehicle run	[km/Day]	225	222	287	240	239
Average energy consumption	[kWh/km]	0.96	0.93	1.19	1.14	1.28
Total number of e-buses	No.	75	60	75	75	75
Bus depot capacity (no. of e-bus/depot)	No.	80				
Approx area for bus depot	Sq.mt	34,000				

Years		2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PT share (LoS 1)	%	3%	3.81%	4.85%	6.2%	7.8%	10.0%	12.7%	16.1%	20.4%	26.0%	33.0%	42.0%
PT share (LoS 2)	%	3%	3.8%	4.69%	5.9%	7.3%	9.2%	11.5%	14.3%	17.9%	22.4%	28.0%	35.0%
PT share (LoS 3)	%	3%	3.6%	4.27%	5.1%	6.1%	7.3%	8.7%	10.3%	12.4%	14.7%	17.6%	21.0%
PT share (LoS 4)	%	3%	3.5%	3.97%	4.6%	5.3%	6.0%	7.0%	8.0%	9.2%	10.6%	12.2%	14.0%
No. of buses (LoS 1)	[#]	360	465	600	775	1001	1293	1670	2157	2786	3597	4646	6000
No. of buses (LoS 2)	[#]	360	457	581	738	937	1190	1512	1921	2440	3099	3936	5000
No. of buses (LoS 3)	[#]	360	437	529	642	778	944	1144	1388	1683	2040	2474	3000
No. of buses (LoS 4)	[#]	360	421	492	575	672	785	917	1072	1253	1464	1711	2000
Ideal range with single charge (@80% SoC)	[km]			126		130		131		137		163	
Avg. SoC consumed	%			29%		33%		48%		46%		38%	
Diesel fuel Price	INR			₹ 95.00									
Fuel price escalation over the years	%			2.00%									
Annual compounded growth rate in electricity price (type 1 station)	%			3.50%									
CAPEX													
Per unit price of EVSE chargers @180kW	INR Lakh /unit			₹ 18.33									
Per unit price of EVSE chargers @240kW	INR Lakh /unit			₹ 24.50									
Shade free available roof/open to sky area	Sq.mt			18,562		4,666		19,386		20,119		18,806	

Annexure B

General Assumptions											
General assumptions	RE-powered e-bus dep			Other			Loan Durations and Interest,				
Currency		INR		Depreciation period (years)	Years	20	Interest rate Term loan A	%	8.3%		
First operational year	Year	2026		Yearly capital expenditures (CAPEX)	INR	0	Interest rate Term loan B	%	9.5%		
Forecast period	Years	25		Days Receivables	Days Sales	60	Term loan A	Years	20	80% of the PPA tenure	
Electricity price escalation	%	3.00%	this is actually yellow cell	Other current assets	Days Sales	0	Term loan B	Years	5		
Cost Inflation	%	3.93%		Other current liabilities	Days Sales	0					
				Interest on Capital	%	10.9%	Discounting Factor	%	9.8%		
				Receivables	Months	2					
				O&M	Months	1					
				Spares	% of O&M	15%					
Taxes on Income				Depreciation Rates							
Corporate taxes											
Gross revenue above 400 crores	%	30.0%		Book depreciation as Companies Act	%	5.83%					
Gross revenue upto 400 crores	%	25.0%		WDV depreciation as Income Tax Act	%	15.00%					
Minimum Alternate Tax (MAT)	%	15.0%		Accelerated depreciation as per Income Tax Act	%	40.00%					

Installed capacity and solar energy production

Installed capacity				Power Pricing (Solar)		
Installed capacity		KWp	8,154	Market price for Electricity	INR/kWh	₹ 6.50
Investment cost		INR/kWh	₹ 42,000	Solar Energy Certificate	INR/kWh	₹ 0.50
Useful lifespan project		Years	25	Annual certificate price reduction	%	0%
AD benefit availed			YES	Duration of the certificate	Years	20
Area required for per kW solar installa-tion		Sq.m/kWp	10			
Energy production						
Specific yield	Guaranteed	kWh/kWp/year	1,649	Guaranteed yield	kWh	1649
CUF		%	19.00%	Estimated yield	kWh	1700
Annual production degradation - 1st yr.		%	1.25%	Auxillary Energy Consumption	kWh	0.50%
2nd Yr. onwards		%	0.60%			
Plant degression		%	0.80%			
Cost structure						
Variable costs				Variable Costs		
Insurance		INR/kW	₹ 125	Variable Costs	INR/Year	₹10,396.35
Security		INR/kW	₹ 100			
Technical operations mgt		INR/kW	₹ 25			
Commercial operations mgt		INR/kW	₹ 50			
Operation & maintenance		INR/kW	₹ 735	Fixed Costs		
Roof lease		INR/kW	₹ 240	General & Admin (G&A)	INR/Year	₹ 20,000
Total variable costs		INR/kW	₹ 1,275	Other fixed costs	INR/Year	₹ 10,000

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