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ROLLING OUT ELECTRIC BUSES

A guidebook on route prioritization and implementation planning

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EXECUTIVE SUMMARY

Electrification of public bus transport ranks high on India's sustainable urban mobility agenda. Pivoting away from polluting Internal Combustion Engine-driven buses to a pure electric format will have many benefits, including accelerating the pathway to meet the country's 2070 net-zero target.

To unlock these benefits, electric bus rollout at scale is paramount. This guidebook intends to help transit agencies adopt a calibrated approach to induct zero-emission buses in their services.

HIGHLIGHTS

- The current scale of electric bus adoption in India remains minuscule, and the deployment must be ramped up to make the desired environmental and climate impact.
- Limited understanding of the interplay between route characteristics and electric bus operation, as well as inadequate assessment of whether and how a route should be electrified, are affecting the electric bus fleet rollout in the country.
- This guidebook intends to help public and private transit agencies adopt a calibrated approach to induct electric buses in their services to ensure that the technology shift neither disrupts the quality of the bus service nor becomes burdensome for them.
- This go-to-reference document sheds light on the technical and financial aspects of electric bus adoption through a six-step approach that can potentially help a transit agency prepare and chart out a detailed plan for the current and future deployment of electric buses.
- The transit agencies should not treat bus fleet electrification as a one-time activity; they should adopt a roadmap for phased transition to an all-electric fleet.

CONTEXT

The adoption of electric buses (e-buses) to make passenger road transport cleaner and greener is a key focus of the governments at the national and sub-national levels in India. Public transit agencies have made some early progress in transitioning to e-buses with support from Government of India's flagship subsidy scheme, Faster Adoption and Manufacturing of Electric vehicles (FAME). However, the scale of e-bus adoption remains minuscule, and e-bus deployment needs to be ramped up to make substantial positive environmental and climate impact. In this regard, consultations with transit agencies and e-bus OEMs (original equipment manufacturers) reveal three major implementation-related challenges: shortcomings in planning to induct e-buses in daily operations, lack of clarity in procurement tenders about e-bus-related operational requirements, and a straitjacketed approach to e-bus charging. The root cause of these issues is found to be the limited understanding of the interplay between route (and depot) characteristics and e-bus operation, as well as inadequate assessment of whether and how a route should be electrified.

It is important to recognize that converting the entire bus service to 100% electric in one go may not be realistic, and that the transition is a journey in itself.

ABOUT THE GUIDEBOOK

The guidebook intends to help public and private transit agencies adopt a calibrated approach to induct e-buses into their services. This is to ensure that the technology shift neither disrupts the quality of the bus service nor becomes burdensome for the transit agencies. Such phased implementation hinges on several technical and financial considerations, including route and depot features, e-bus performance characteristics and procurement costs, charging technologies with upstream electrical infrastructure and associated costs, and public transport-related service-level benchmarks (Li et al. 2019). These factors are often inter-linked and limited by some constraints.

VALUE PROPOSITION

The guidebook sheds light on the technical and financial aspects of e-bus adoption that can potentially help a transit agency prepare and chart out a detailed plan for the current and future deployment of e-buses. The guidebook suggests a six-step approach and proposes a decision tree for transit agencies to refer to. The decision tree for route prioritization and implementation planning has two parts. Part I deals with the technical feasibility of rolling out an e-bus fleet on a given route, and Part II focuses on the financial sustainability of the deployment.

Further, the guidebook suggests a set of follow-up steps to link the prioritization exercise to the e-bus procurement process, which is the final stage of implementation. It also emphasizes the need to periodically reassess the merit of electrifying more routes and review the priority lists. This ensures that the evaluation remains relevant as market conditions change. The guidebook also draws attention of transit agencies toward planning for electricity supply for e-bus charging and land for setting up support infrastructure – important for e-bus deployment.

Besides transit agencies, e-bus and charging infrastructure OEMs can benefit from the guidebook. They can get a sense of the required specifications of the solutions (such as the range of an e-bus, the power rating of chargers, etc.) to support the electrification efforts of transit agencies.

The guidebook also helps policymakers better understand the technical and financial aspects of e-bus adoption. This would assist them to set goals for e-bus penetration in existing bus fleets and gauge the degree of financial support required. It also highlights that the state and city authorities not only can help by providing subsidies or funding, they can potentially play a constructive role in arranging land and electricity at concessional rates to support e-bus adoption for public transport.


NO SMOKING

INTRODUCTION

Adopting electric buses (e-buses) to make passenger road transport cleaner and greener is a key focus of the governments at the national and sub-national levels in India. State Road Transport Undertakings (SRTUs), municipalities, and Smart Cities Mission–driven Special Purpose Vehicles have made some early progress in transitioning to e-buses. Zero tailpipe–emission vehicles are important in reducing harmful emissions, and achieving air quality and climate change mitigation targets, and are rapidly being adopted around the world (Graham 2020). However, the current scale of e-bus adoption is minuscule[1] (Gulia and Thayillam 2020), and e-bus deployment needs to be ramped up. Transit agencies face a bumpy road in this endeavor. Consultations with them and e-bus Original Equipment Manufacturers (OEMs) reveal three major implementation-related challenges:

- **Shortcomings in planning to induct e-buses into daily operations**
  Transit agencies that have deployed e-buses have mixed feedback on the technology. While some consider e-bus rollout fruitful, others have faced challenges in smoothly operating e-buses due to their limited driving range and charging requirements. They also find that the actual on-road performance of e-buses is substantially lower than the assured ranges indicated by e-bus OEMs. However, they do find e-bus deployment successful on low-frequency and uncongested routes.

  A major reason for the mixed experience is that transit agencies often do not go into the details of the required conditions for deploying e-buses and of how route characteristics can potentially impact e-bus operation. The feedback also indicates unfamiliarity-related issues to establish high-tension upstream electrical infrastructure at bus depots to support e-bus charging.

- **Lack of clarity in procurement tenders about e-bus related operational requirements**
  A common challenge that e-bus OEMs or bus operators face is the lack of relevant details of routes or existing fleet operations in tender documents and also during pre-bid consultations. This makes it difficult for bidders to understand operational requirements and enter into service-level agreements with transit agencies. This information gap is largely attributed to transit agencies' limited understanding of e-bus operation and their lack of preparedness prior to issuing tenders.

  A review of the tender documents for e-bus procurement shows that apart from stipulating the daily running kilometers for e-bus operation, there is hardly any information given regarding route(s), serving depot(s), or service-level benchmarks. This results in high risk perception amongst bidders, and that often translates to higher price quotations in bids in order to hedge risks. There have been several instances of tenders being canceled due to a limited number of bids or high price quotations.

- **Straitjacketed approach to e-bus charging**
  Transit agencies are not accustomed to the nuances of e-bus charging and are biased in favor of night-time charging of e-buses. This is reflected in e-bus procurement tenders and leads to excessive reliance on large-size battery packs, which are generally more expensive. This is avoidable, and the cost of e-buses can be reduced by suitably accommodating range-extending e-bus charging during bus service hours without affecting the daily operation schedule. This requires a nuanced approach to e-bus operation.

The root cause of these issues is a limited understanding of the interplay between route (and depot) characteristics and e-bus operation, as well as an inadequate evaluation of whether a particular route merits electrification. This can be costly. Shifting to electric mode requires significant capital expenditure (CAPEX) in terms of procuring e-buses and setting up support infrastructure including augmenting the electricity distribution network that may require more land to build. Hence, meticulous planning and effective coordination between different agencies, such as the SRTU, the electricity distribution utility, and the urban local body, is necessary to make the investment worthwhile.

OBJECTIVES AND SCOPE OF THE GUIDEBOOK

Electric drivetrain–based bus operation is a new format of mass transport. It is understandable that converting an entire bus fleet to 100% electric may not be achievable in one go. Recognizing that the transition to e-buses is a process, the journey in itself is important. The guidebook thus intends to help public and private transit agencies adopt a calibrated approach to induct e-buses into their services. Prioritizing routes for electrification with required preparedness is central to this planning. It helps ensure that the technology shift neither disrupts the quality of the bus service nor becomes burdensome for transit agencies.

Such phased implementation hinges on several technical and financial considerations, including the route and depot features, e-bus performance characteristics and procurement costs, charging technologies with upstream electrical infrastructure and associated costs, public transport–related service-level benchmarks, etc. These factors are often interlinked and limited by some constraints. For example, e-buses cannot offer enough autonomy[2] to match a conventional bus. Similarly, there is a minimum time required for charging to add a certain range to an e-bus. Additionally, deciding on the configuration for electrification (e-bus battery capacity, charging technology, charger power rating, etc.) involves important trade-offs. Weighing all these factors is no doubt a complex challenge for most transit agencies, which are yet to get accustomed to the format of electric mobility. The fact that the sector is evolving makes it more complicated for transit agencies to plan e-bus deployment. However, there are important lessons to learn from cases of e-bus planning, financing, and deployment from around the world (Sclar et al. 2019).

Taking the aforementioned factors into account, this guidebook is aimed at the following objectives:

- To provide a systematic approach for prioritization of bus routes for electrification to ultimately attain a 100% e-bus service
- To shed light on the technical and financial aspects of e-bus adoption that can potentially help a transit agency prepare for implementing the transition, and to chart out a detailed plan for current and future deployment of e-buses

In light of the objectives stated above, the guidebook's scope must be noted. The guidebook, in order to explicate the technical and financial aspects of e-bus adoption, touches upon technical specifications and costs of e-buses, charging and upstream electrical infrastructure, operational parameters of bus routes, and service; level benchmarks of public transport. The guidebook does not elaborate upon all and sundry ecosystem-level factors pertinent to e-bus adoption in India, such as supply chain considerations, end-of-life asset management and disposal for e-buses and supporting infrastructure, and procurement models, funding options, and financing mechanisms for bus-based public transport in India.

While suggesting route prioritization, the guidebook does not allude to any need to limit the number of routes to consider for electrification, as deploying e-buses on all routes in the longer term is necessary for mass implementation (Li et al. 2019). The phased roll-out of e-buses is to help adopters prepare in advance and avoid a kneejerk reaction to this new bus service format (Agrawal et al. 2019). This will help prevent inordinate delays in e-bus service commissioning due to inadequate planning – something often seen in current deployments. Having positive experience in operating an e-bus fleet in the initial phase is crucial to embark on the future scaling up of e-bus deployment. Route prioritization is the not the goal; rather, it is an effective means to reach the goal of a 100% e-bus fleet.

Besides transit agencies, e-bus and charging infrastructure OEMs can also benefit from the guidebook. They can get a sense of the required specifications of solutions (such as the range of an e-bus, power rating of chargers, etc.) to support the electrification efforts of transit agencies. Policymakers can also gain an understanding of various technical and financial aspects of e-bus adoption. This would help them set goals for e-bus penetration into the existing fleet, and gauge the degree of financial support required for this.

THREE KEY BENEFITS OF THE GUIDEBOOK

- The guidebook helps public and private transit agencies develop a calibrated approach to induct e-buses into their services while ensuring that the technology shift neither disrupts the quality of the bus service nor becomes burdensome for the transit agencies.
- It helps e-bus and charging infrastructure OEMs get a sense of the required specifications for solutions to support the electrification efforts of transit agencies.
- It enables policymakers to set goals for e-bus penetration into the existing bus fleet and gauge the degree of financial support required to this end.

SIX REASONS WHY THE GUIDEBOOK IS IMPORTANT FOR TRANSIT AGENCIES

The following features of the guidebook make it the go-to reference for transit agencies for planning route electrification:

- The guidebook presents an easy-to-apply decision-making framework for route prioritization and phased e-bus rollout, comprised of both technical feasibility and financial sustainability analyses, the two pillars of the decision to electrify.
- It is comprehensive, as it covers both intra-city routes as well as the challenging intercity/state routes, and discusses all the important elements such as e-bus models, charging technologies and strategies, ancillary electrical infrastructure, operating costs, and financial service-level benchmarks of public transport.
- The suggested six-step integrated approach helps connect the dots in the endeavor of route electrification, and highlights the importance of each detail.
- The guidebook includes some case-based demonstrations that can help relate plans to real-life situations and enable on-ground problem solving.
- It lays out a clear-cut process for prioritizing routes for electrification using metrics familiar to transit agencies in India.
- Its implementation approach allows for seamless e-bus adoption in an existing bus transport service without unduly affecting the duty cycle or service level, thus debunking the myth that e-bus deployment can be disruptive.

In a nutshell, the guidebook underscores that route electrification requires a change in planning approach and not in the bus service.

HOW TO REFER TO THE GUIDEBOOK

At the outset, the guidebook sheds light on the decision-making framework, which consists of two segments: the technical feasibility assessment and the financial sustainability evaluation. Following the introduction of the framework, the guidebook takes a deep dive into the six major steps covering the technical and financial aspects that allow a user to have a comprehensive understanding of the different associated issues and the required strategy. The guidebook concludes by suggesting a way forward that helps the user link route prioritization and deployment planning with the subsequent activities of phase-wise implementation.


JBM
NMMT
ELECTRIC


150KW直流充电柜
GREEN
PMPML
HARGING PORT

DECISION-MAKING FRAMEWORK — THE BASIS FOR ROUTE PRIORITIZATION

A transit agency's decision to roll out e-buses on a route hinges on two main considerations:

- Whether it is **technically feasible** to operate e-buses on that route; that is, whether e-buses can satisfactorily meet the requirements of its duty cycle
- Whether it is **financially sustainable** to deploy e-buses on the route; that is, that the costs do not overburden the transit agency after taking into consideration the revenue earned on that route

How can a transit agency undertake these assessments and take appropriate decisions? The rationale of the decision-making process needs to be customized for e-bus service. To this end, the guidebook offers transit agencies a stepwise approach by means of a decision tree.

What is a decision tree?

A decision tree is a powerful and popular decision-making tool that uses a tree-like model of decisions and their possible consequences. The advantage of using a decision tree is that it can visually represent decisions and decision-making. This tool helps decision-makers break down a complex problem into simpler questions, whose answers can lead to different outcomes. The user can then take an appropriate decision and find a suitable strategy to solve the problem (Magee 1964).

What is a decision point?

A decision tree has multiple decision points, or junctures at which decisions have to be made. In order to make a decision — at the relevant decision point — certain inputs are required, as depicted in Figure 1. The output(s) stemming from the decision point represent all potential outcomes.

The decision tree for route prioritization and implementation planning has two parts. Part I deals with the technical feasibility of a possible rollout of an e-bus fleet on a route (figure 2), followed by Part II, where the financial sustainability of the deployment is examined (figure 3).

The decision tree for the technical feasibility assessment starts with the consideration of the operational characteristics of an e-bus fleet and the features of the concerned route. Through multiple decision points, Part I of the decision tree helps to understand the following:

- Whether an existing e-bus model and charging technology can satisfactorily cater to the duty cycle of the bus service on a given route
- What the suitable e-bus performance characteristics are
- Whether it is possible to reduce the battery-size of the e-bus through opportunity charging
- What the appropriate charging strategy should be

Provision of public transport services is a state-led and state-regulated activity in India. Hence, despite cost-recovery being vital for public transport services, fares must be kept affordable for all income groups. Aligned with this idea, for public transport operations, instead of financial viability, financial sustainability is measured through relevant service level benchmarks. To the same end, Part II of the decision tree helps evaluate whether electrification of a particular bus route (if feasible, in the first place) is financially sustainable, in addition to ascribing a priority to the route for electrification.

Note: For achievement of financial viability, cash inflows must exceed cash outflows for a project or an entity. However, "financial sustainability" is differently conceptualized for public transport operations in Indian cities, wherein cash outflows can exceed cash inflows by a margin of up to 50% (Ministry of Housing and Urban Affairs 2013), and extra costs of service provision may be met through Viability Gap Funding (VGF)[3] from the government.

Figure 1 | General flow of the decision tree

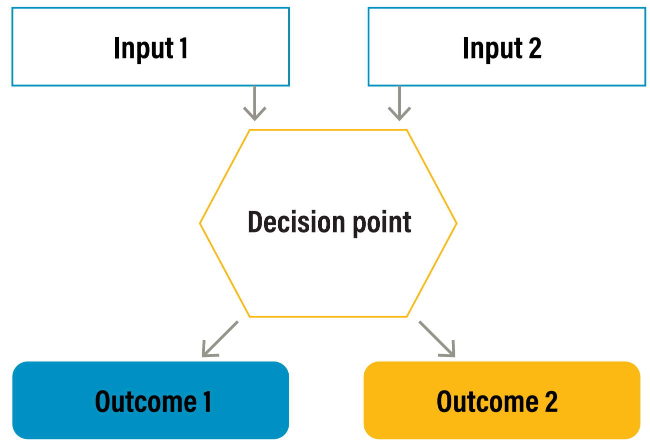
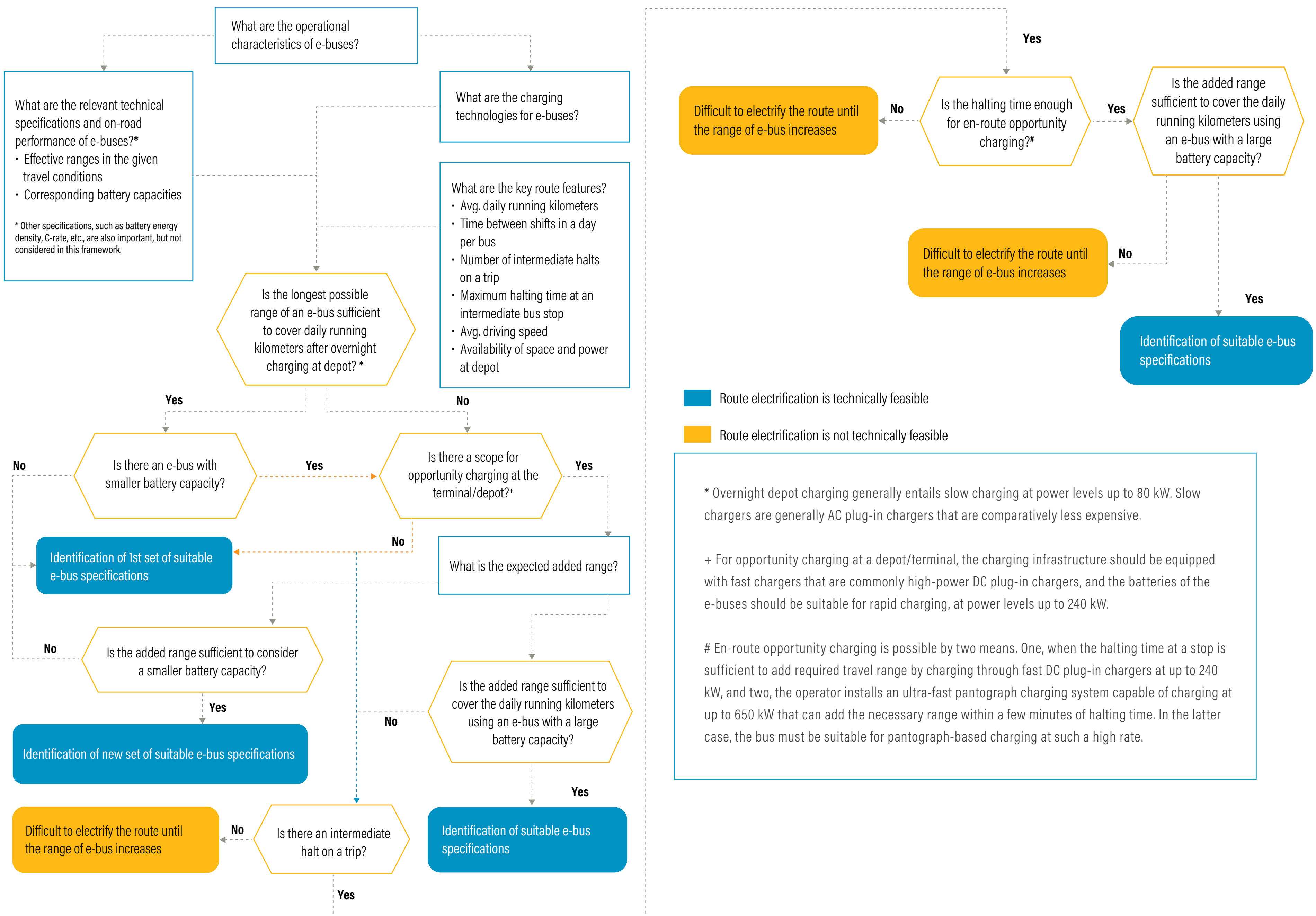


Figure 2 | Part 1 - Technical feasibility determination

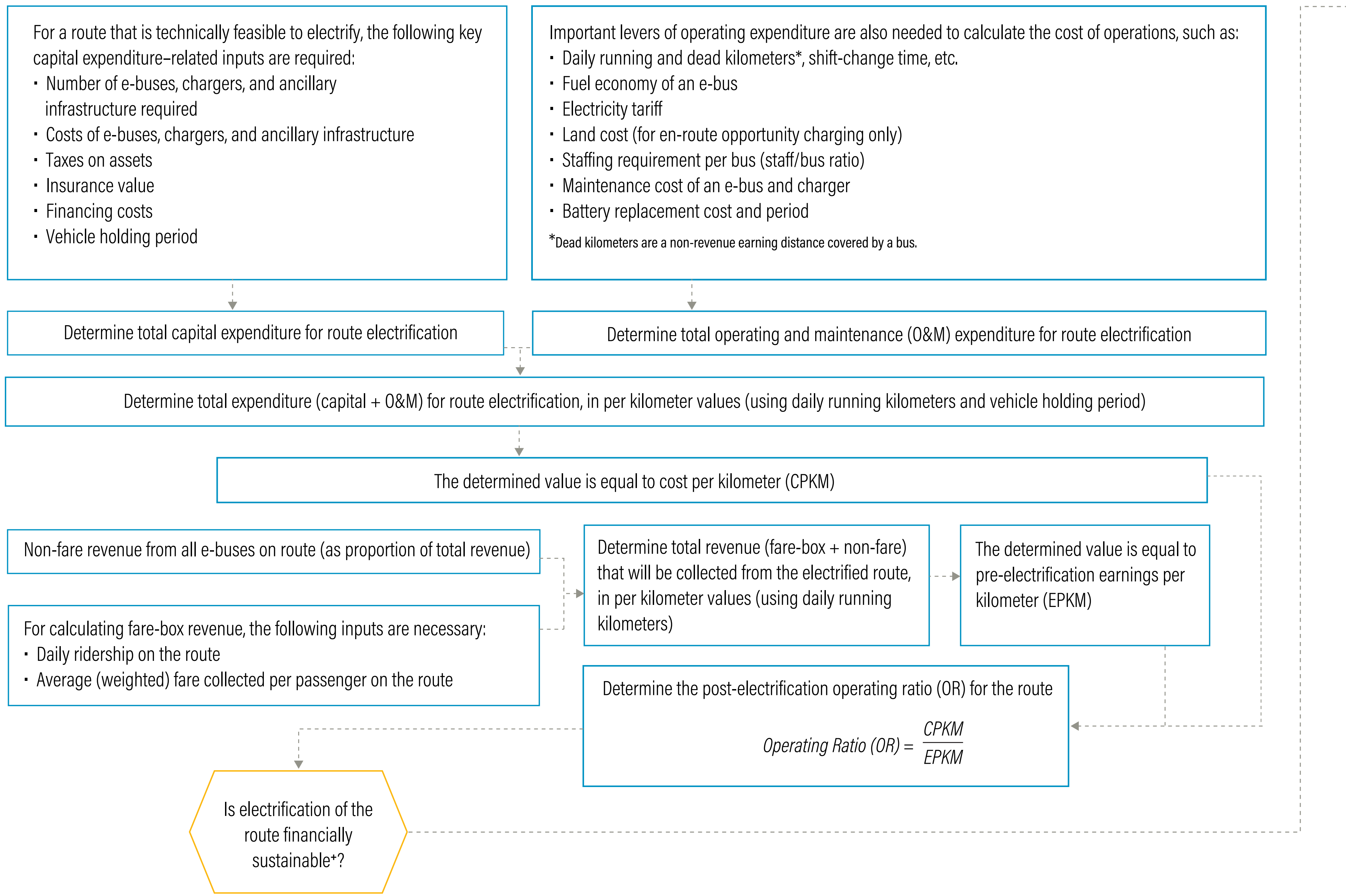


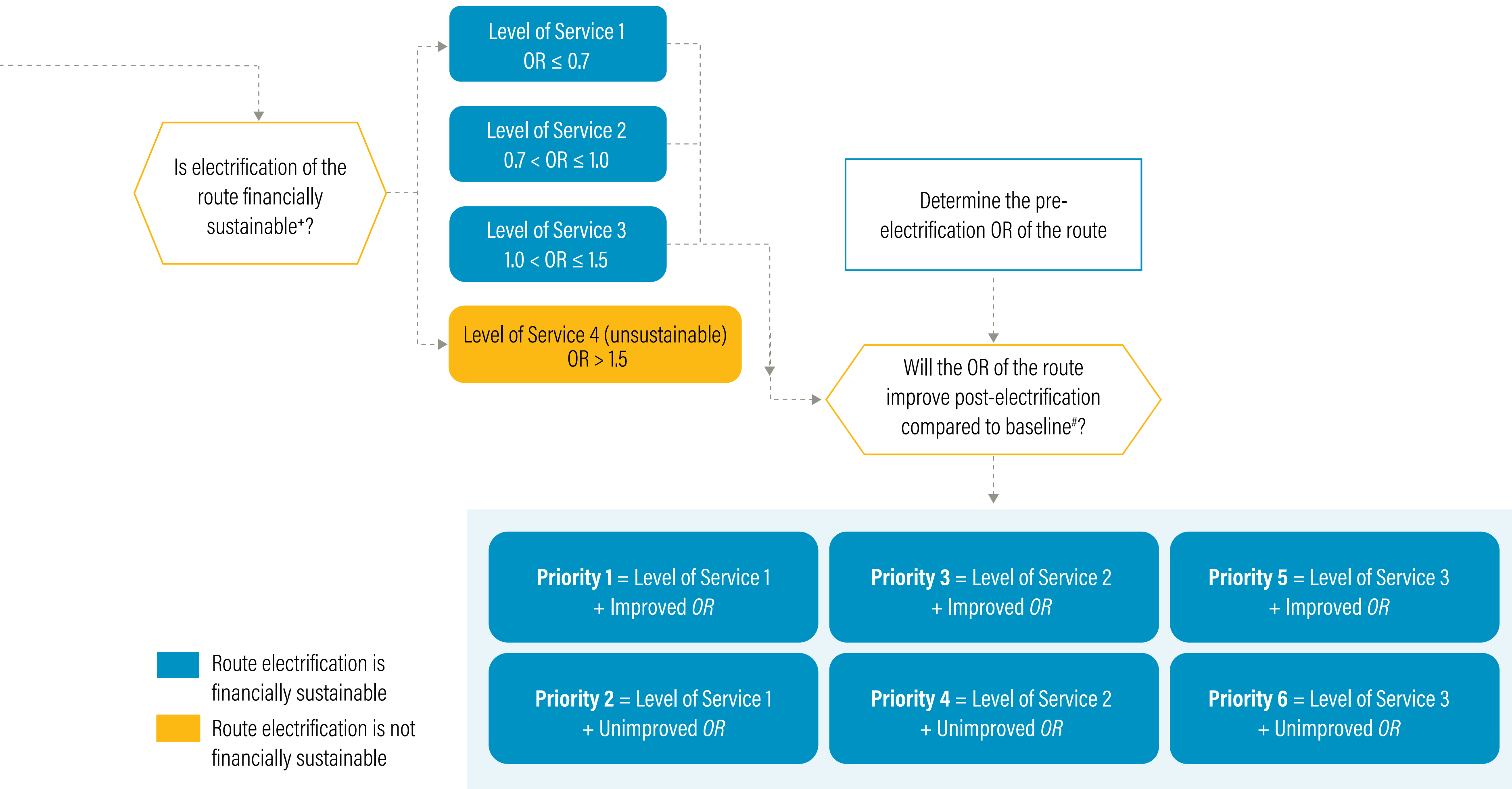
* Overnight depot charging generally entails slow charging at power levels up to 80 kW. Slow chargers are generally AC plug-in chargers that are comparatively less expensive.

+ For opportunity charging at a depot/terminal, the charging infrastructure should be equipped with fast chargers that are commonly high-power DC plug-in chargers, and the batteries of the e-buses should be suitable for rapid charging, at power levels up to 240 kW.

En-route opportunity charging is possible by two means. One, when the halting time at a stop is sufficient to add required travel range by charging through fast DC plug-in chargers at up to 240 kW, and two, the operator installs an ultra-fast pantograph charging system capable of charging at up to 650 kW that can add the necessary range within a few minutes of halting time. In the latter case, the bus must be suitable for pantograph-based charging at such a high rate.

Figure 3 | Part 2 - Financial sustainability assessment





+ For assessing the financial sustainability of a public transport route, the following values of operating ratios and levels of service must be referred to:

1. Level of service (LoS) **1** (best financial case) : **Operating ratio** < 0.7 (Financially sustainable)
2. Level of service **2 : 0.7 < Operating ratio < 1.0** (Financially sustainable)
3. Level of service **3 : 1.0 < Operating ratio < 1.5** (Financially sustainable)
4. Level of service **4** (worst financial case) : **Operating ratio > 1.5** (Financially unsustainable)

For achievement of financial viability, cash inflows must exceed cash outflows for a project or an entity. However, financial sustainability is differently conceptualized for public transport operations in Indian cities, wherein cash outflows can exceed cash inflows by a margin of up to 50% (Ministry of Housing and Urban Affairs 2013), and extra costs of service provision can be met through VGF from the government.

If the operating ratio of the route decreases post-electrification, then it means that the operating ratio has improved. If the value of the ratio does not change or increases post-electrification, then it is not an improvement.

For transit agencies to plan for inducting e-buses into their fleets in a calibrated manner, the guidebook details a six-step process which can be followed, in tandem with the decision trees explicated above. It must be noted that the decision trees represent the decision-making process in a consolidated manner, whereas each of the steps of the guidebook dive deep into the finer aspects of the same process, touching upon all important factors that need to be considered at each of the following steps:

Step 1. Understand the fundamentals of interplay between e-bus operation and route characteristics

Step 2. Take stock of the current e-bus market and performance characteristics of e-buses

Step 3. Understand charging methods and their impact on e-bus operation

Step 4. Take into consideration the ancillary electrical infrastructure and space requirement

Step 5. Assess the financial sustainability of e-bus operation

Step 6. Adopt a prioritization approach to classify bus routes

PATULI
ElectricB
WBTC

SANDY
Think
2472141
GA-01
Z-9915

STEP 1. UNDERSTAND THE FUNDAMENTALS OF INTERPLAY BETWEEN E-BUS OPERATION AND ROUTE CHARACTERISTICS

Electric drivetrain is a new vehicle-powering technology which makes the modus operandi of an e-bus distinct from that of a conventional diesel or CNG[4] bus. An e-bus fleet requires different treatment, and falling back on existing conventional bus fleets for reference may lead to misjudgment of e-bus operation and disruption in the overall service of the bus fleet on a given route. It is a prerequisite to understand the key functional characteristics of e-buses and their interlinkages with route features (Sclar et al. 2019).

CHARGING REQUIREMENT

As part of the electrification planning process, the transit agency should find out the possible charging requirement of an e-bus on the route. How much charging an e-bus battery requires on a daily basis depends on the energy the e-bus spends to complete its duty cycle on the route in a day.

The daily running distance of a bus on that route is the primary parameter to consider — the energy requirement is directly proportional to this. The mileage (kWh[5]/km) of the e-bus is the other parameter as in the case of a conventional bus. Thus,

Daily requirement of charge (kWh)=Energy spent (kWh)=Daily running distance (km)×Bus mileage (kWh/km)

This estimated energy spent needs to be replenished daily through charging. Unlike refilling fuel in a conventional bus, which generally takes five to ten minutes, time required to fully charge an e-bus battery pack could be up to a few hours. Thus, vehicle downtime increases manifold compared to a conventional bus. This may potentially affect the operational schedule of the public bus fleet. Hence, an e-bus charger of an appropriate power rating must be used in order to manage the downtime for charging. The minimum time required for charging an e-bus can be deduced using the following formula:

$$\text{Minimum time required for charging (hours)} = \frac{\text{Requirement of charge (kWh)}}{\text{Maximum power rating of a charger (kW)} \times \text{Efficiency of charger (\%)}}$$

$$\text{Minimum time required for charging (hours)} \leq \text{Time available for charging within the duty cycle (hours)}$$

The daily requirement of charge and the minimum time required for charging are two important data points to start with when planning e-bus adoption on a route. The minimum time required for charging must be assessed against the time available for charging within the duty cycle. It is important to note that when determining the time available for charging within the duty cycle, one must consider the total time available for shift interchange — and then deduct the time consumed by an e-bus to traverse the dead kilometers, and in-shedding and out-shedding time at a depot. More nuances of e-bus charging are discussed in the ensuing steps.

LIMITED TRAVEL AUTONOMY

The distance between the origin and destination of a bus route has never been an issue while deploying a conventional bus fleet. Transit agencies take for granted the ability of the bus to travel the distance, due to the assured long driving range of a diesel bus[6]. But the autonomy of an e-bus is limited by the size of the vehicle's battery pack. In this context, daily running distance or route length[7] is an important factor. With a one-time full charge, the e-bus may not be able to serve a high daily duty cycle or long routes, and it may require top-up charging in the course of its daily service. For e-bus deployment on a route, the following condition needs to be satisfied.

Daily running distance or route length
<< (Driving range of e-bus)
or (driving range of e-bus
+ Added range through top-up charging)

While a large battery pack can be adopted, it would considerably increase the e-bus

procurement cost[8] (Department of Heavy Industry 2020). A bigger battery pack also increases the bus's curb weight, which can reduce the efficiency (distance traveled per unit of energy) of the vehicle, necessitating more frequent bus charging.

The issue of range anxiety of an e-bus may get compounded if suitable charging stations are not available along the long-distance bus routes. More details are presented in the next steps.

COST EFFECTIVENESS OF E-BUS ROLLOUT

Transit agencies that traditionally operate conventional buses often attach greater importance to vehicle fuel economy to maximize fuel cost savings, and are less wary about the upfront cost of those buses. In contrast, the adoption of e-buses entails much higher CAPEX than conventional buses, but e-buses have a strong competitive advantage in terms of very low operational cost. In a nutshell, the higher the running kilometers of an e-bus, the greater the cost savings a transit agency can realize, and the better the economics of e-bus adoption. Hence, it is preferable for an e-bus to have more daily running kilometers. However, as highlighted above, limited bus autonomy is a constraint. The fact is, it is a balancing act between keeping a check on the battery pack size of an e-bus and maximizing daily running kilometers. This is why transit agencies must meticulously plan routes for e-bus deployment.

RESTRICTED INTERCHANGEABLE ROUTE

In the pre-electrification scenario, a transit agency could purchase or contract a fleet of diesel or CNG buses and deploy them on any route. The same bus could operate on different routes if needed. However, this may not be the case for e-buses. Inter-operability of an e-bus is restricted primarily due to three factors: one, the daily running requirement vis-à-vis the driving range of the e-bus; two, service frequencies on different routes in relation to bus charging time; and three, whether the serving depot or terminal(s) is equipped with the required charging infrastructure[9]. This is another reason for thorough route planning by the transit agency, especially during the early stage of electrification of the bus service.

CASE-BASED DEMONSTRATION OF THE UNDERSTANDING SO FAR

A transit agency intends to induct midi non-AC (air-conditioned) e-buses into its fleet of diesel buses that currently operate from multiple depots and on different routes, with daily running distance requirements varying from 150 km to 350 km. Based on its long experience of procuring and operating diesel buses, the transit agency plans to procure a set of e-buses with the same battery size and range and operate them across its routes from a fixed number of depots.

The transit agency wants to make a preliminary assessment regarding the charging requirements and whether the bus deployment plan can be effective. What could be the possible outcomes?

- Based on the equations provided in Step 1, the transit agency could estimate that the daily requirement of charge for each e-bus on the different routes, i.e. — the energy spent in a day — would vary from 120 kWh to 370 kWh[10], and the corresponding minimum charging output required per charger would range from 43 kW to 130 kW[11].
- The results seem practical to implement. However, daily charging requirements along with the required charger power are found to be widely different across the fleet routes (more than three-fold difference).
- Opting for e-buses with the same battery size and range for all the routes would lead to either serious range anxiety and possible disruption in bus service, or sub-optimal utilization of the e-bus range; that is oversized batteries leading to unnecessarily higher costs. By procuring e-buses with the right driving range based on the route duty cycles, the transit agency can avoid these issues.
- The transit agency should explore ways to satisfy the duty cycles of longer routes using smaller battery pack sizes with range addition by top-up charging, conditioned on the availability of time to recharge. Further, the agency can explore using existing ICE buses[12] as a buffer for the e-bus fleet, in case it has to change the duty cycle of the fleet or tackle operational challenges.

- Operating e-buses across routes from a fixed number of depots may increase the dead kilometers[13] of the bus operation, resulting in higher energy consumption and less economic value. However, merely equipping all the depots with charging infrastructure could unnecessarily drive up the upfront investment. The balance lies in the number of e-buses charged at a depot and the proximity of the starting or end points of the served routes to the depot.

KEY POINTS:

- Falling back on the existing conventional bus fleet for reference may lead to misjudgment of e-bus performance and sub-optimal use of the electric drivetrain technology.
- It is important to understand the connection between route features and e-bus operation and to evaluate the fundamental parameters related to route electrification.
- Unlike the refueling of a conventional bus, which takes five to ten minutes, replenishing the charge of an e-bus battery pack takes up to a few hours. This increases vehicle downtime and could affect the operational schedule of the fleet.
- An e-bus does not have as much autonomy as a conventional bus, primarily due to the limited battery pack size.
- Keeping a check on the battery pack size and maximizing the daily running kilometers of an e-bus in order to increase fuel savings and improve returns is a challenging balancing act.
- Inter-operability of an e-bus is restricted due to three factors: one, daily running requirement vis-à-vis the driving range of the e-bus; two, service frequencies on different routes in contrast to bus charging time; and three, whether the serving depots or terminals are equipped with the required charging infrastructure.
- An e-bus fleet should not be deployed and managed using the same performance standards that are applied to a conventional bus fleet.
- A one-size-fits-all approach is not an effective way to electrify routes with different duty cycles.
- A bus agency may explore the option of utilizing existing ICE buses as a buffer for the e-bus fleet and to mitigate potential operational challenges, breakdowns, and interoperability issues of e-buses.


NO SMOKING
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PURE ELECTRIC
PMPML
Olectra
E-038
meil
MH.12
RN.4579
रेनबो
RAINBOW

STEP 2. TAKE STOCK OF THE CURRENT E-BUS MARKET AND PERFORMANCE CHARACTERISTICS OF E-BUSES

In order to develop a route-level plan for e-bus rollout, it is crucial to take into account the specifications of existing e-bus models. Ultimately, the success of bus service electrification is tied to the effective adoption of available products.

However, limited publicly available details of e-bus specifications and lack of access to on-ground data on current e-bus operation are major obstacles for proper evaluation of e-bus performance. This study has to largely depend on publicly available information complemented by some details collected through consultation with transit agencies and e-bus OEMs.

STEP 2.1. TAKE NOTE OF RELEVANT SPECIFICATIONS OF E-BUS MODELS AVAILABLE IN INDIA

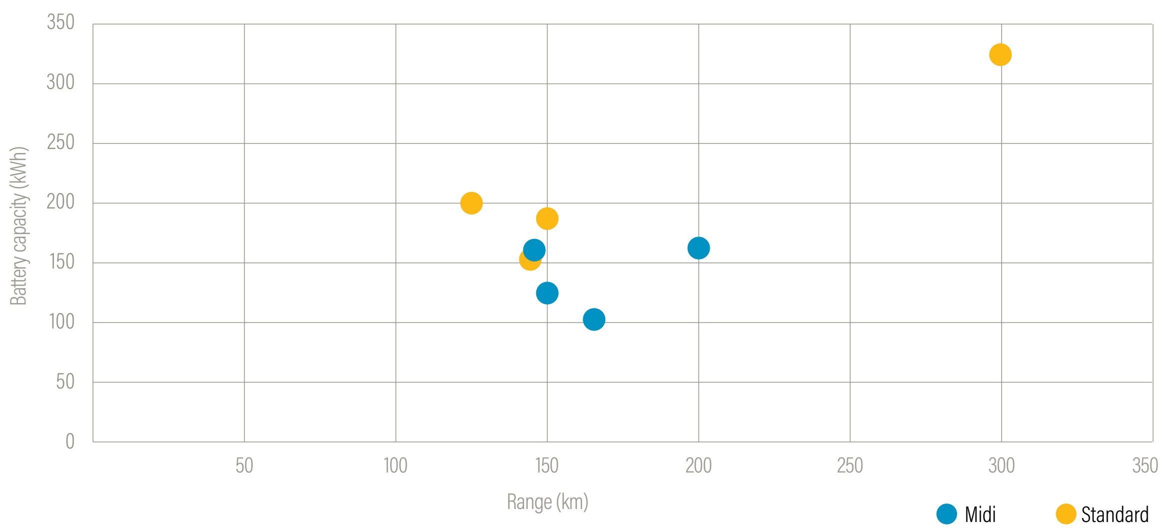
Five major bus OEMs have cumulatively supplied or won contracts for over 90% of e-buses in India to date: Tata Motors, Olectra Greentech Ltd., Foton-PMI, Ashok Leyland and JBM-Solaris. Each of them has a number of e-bus models in its portfolio[14]. Most of these models have both AC and non-AC variants.

The specifications of interest of an e-bus model should include (but are not limited to) the assured driving range and battery capacity. In some cases, the information of these parameters may not be publicly available, and the transit agency should reach out to OEMs for updated information. Also, OEMs sometimes report values in terms of maximum possible range and not assured range. The realizable range when air conditioning is in use is not reported in most cases. Figure 4 is a scatterplot that captures the assured ranges and battery capacities of a sample of e-bus models (non-AC variants) in the midi and standard segments.

STEP 2.2. TAKE INTO ACCOUNT THE ON-ROAD PERFORMANCE OF E-BUSES

One should be mindful that the reported value for the driving range of an e-bus model is based on lab testing. **The on-road performance is envisaged to offer about a 10% lower range, depending on operating conditions such as the state of the road, average speed, weather, and more (Li, et al 2020). Cooling load can bring down the range by as much as 30% for an AC variant of an e-bus[16]. Further, an e-bus consumes up to 10% more energy per km in hilly areas as compared to flat areas.**

Figure 4 | Array of e-bus models in standard and midi segments with different battery capacities and ranges



Source: Based on market research by authors[15]; the values are expected to change

Some other performance characteristics of e-buses — such as mileage (kWh/km) — are also crucial for route planning for e-bus deployment. However, most OEMs do not report this information publicly. Based on preliminary analysis and feedback from e-bus OEMs and transit agencies, Table 1 indicates the per-kilometer energy consumption of e-buses in urban and highway conditions.

It is important for the transit agency to note here that the energy consumption of an e-bus may vary significantly across the different routes of its public transit network. Further, the per-kilometer energy consumption values furnished by OEMs may be for a specific duty cycle that is ideal for minimizing energy consumption and related losses. **Therefore, the transit agency must solicit accurate and elaborate per-kilometer energy consumption values from the OEMs. To that end, the agency must specify the characteristics of different routes to OEMs for which it intends to understand the energy consumption. The route-specific**

Table 1 | Per-kilometer energy consumption by e-buses

Bus Type	Energy consumption per unit of distance (kWh/km)	
	Urban conditions (intracity routes)	Highway conditions (intercity/interstate routes)
Midi non-AC	0.80	0.60
Midi AC	1.04	0.78
Standard non-AC	1.30	0.98
Standard AC	1.69	1.27

Note: AC e-buses consume 30–40% more energy than non-AC e-buses, especially during summer months, due to AC operation. The listed values are representative in nature, and must be used with caution.

Source: Based on consultations with e-bus OEMs, transit agencies, operators, and subject-matter experts.

information that an OEM may require would cover trip length, journey speed, road conditions and terrain, ambient temperature, and passenger load.

CASE-BASED DEMONSTRATION OF THE UNDERSTANDING SO FAR

A transit agency serves a city that experiences hot summer months. It intends to electrify an existing route with low-floor midi AC e-buses. The route requires a daily running distance of 150 km per bus, and has high service frequency. Hence, only overnight charging is possible. The route includes steep slopes at some places. The transit agency is trying to evaluate whether there are suitable e-bus models. What should be the key things it should consider to shortlist e-bus models?

- First and foremost, the transit agency should make a list of the e-bus models available in the market in the low-floor midi category having an AC variant.
- It should gather information about the range of these e-bus models as certified by labs authorized by ARAI[17]. In most cases, these values are reported for non-AC variants.
- As the given values of the e-bus range are based on lab conditions only, and the on-road performance of these buses is likely to differ, particularly during summer months when the cooling load is high, the agency may consider a 30% reduction in the reported range value for each e-bus model.
- It should also take into account the effect of the gradient of roads on the range and, therefore, may again make a downward adjustment of up to 10%, to be on the conservative side, when estimating the assured range of an e-bus.
- After shortlisting the e-bus models that offer sufficient autonomy, the transit agency should seek out information about the battery pack size of these e-bus models to calculate the ratio of battery pack size (in kWh) to daily running distance (i.e., 150 km). It is better to avoid e-bus models with a high ratio, as such vehicles would have either larger battery capacity than required or low mileage; both would lead to inefficiency in vehicle use. The performance and efficiency eligibility criteria for e-buses under FAME-II[18] stipulates minimum fuel economy for midi and standard e-buses as 1 kWh/km and 1.4 kWh/km, respectively (Department of Heavy Industry 2019). High ratios may also translate into longer opportunity charging durations, shorter e-bus ranges, and decreased passenger-carrying capacities.

KEY POINTS:

- Battery capacity and assured ranges vary considerably between midi and standard categories as well as in each of these segments.
- In midi e-bus models, battery sizes range from 102 kWh to 160 kWh, with assured travel ranges between 145 km and 200 km (as reported by OEMs based on lab testing). On the other hand, standard e-bus models are powered by batteries with a capacity of 152 kWh to 324 kWh, offering ranges of 125 km to 300 km (as reported by OEMs based on lab testing).
- Based on preliminary analysis and feedback from e-bus OEMs, transit agencies, and e-bus operators, per-kilometer energy consumption in urban conditions by a midi non-AC e-bus and a standard non-AC e-bus are found to be approximately 0.8 kWh and 1.3 kWh, respectively. In AC variants, the corresponding mileages are seen to decrease to about 1.04 kWh/km and 1.69 kWh/km, respectively, during summer months.
- For highway travel, e-buses consume less energy per kilometer than what is reported for urban (intracity) conditions — quite akin to ICE buses. Specifically, a midi non-AC e-bus consumes 0.6 kWh/km, and its AC variant consumes 0.78 kWh/km. In case of a standard e-bus, the non-AC variant consumes 0.98 kWh/km, whereas the AC variant consumes 1.27 kWh/km.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STEP 3. UNDERSTAND CHARGING METHODS AND THEIR IMPACT ON E-BUS OPERATION

The battery is the heart of an e-bus. Thus, charging it after a certain extent of operation is a critical function for an e-bus operator and an important element of route planning for a transit agency. Considering the possible size of the battery pack of an e-bus, which may range from 100 kWh to over 300 kWh, periodic charging demand is expectedly high.

STEP 3.1. TAKE COGNIZANCE OF THE MAJOR CHARGING TECHNOLOGIES FOR E-BUSES

The conductive way of energy transfer through a physical connection between the charger — also known as EVSE (Electric Vehicle Supply Equipment) — and the vehicle is the most common method for charging an e-bus. It is of two types: plug-in charging and pantograph charging.

In plug-in charging, the plug of a charging gun or charging outlet is inserted into the socket or inlet of an e-bus (Figure 5). Currently this is the predominant method of charging e-buses globally.

The power output of a plug-in charger can be either AC (alternating current) or DC (direct current). This is an important characteristic of a charger, and a battery can only be charged by DC power. In case of charging with AC power output, the e-bus should have an on-board charger with a suitable power rating. Based on the type of the output power, plug-in charging technology can be sub-categorized into AC plug-in charger (or simply, AC charger) and DC plug-in charger (or simply, DC charger).

As the conversion of AC power, which is available in the electricity grid, to DC power happens at the EVSE itself, in the case of a DC charger, the latter offers a faster rate of charging than an AC charger of a similar capacity. The capacity of the on-board charger of the e-bus could also be a limiting factor for the charging rate of an AC charger. Then why not use only DC chargers? The primary reason is the cost. A DC charger is usually much more expensive than an AC charger of a similar output power. The fact is that every charging option has certain trade-offs.

The current EV market in India has seen adoption of a range of AC or DC chargers for charging public e-bus fleets. Table 2 and Table 3 present the key characteristics of a representative AC charger and a DC charger, respectively, based on current e-bus charging practices in India.

Pantograph charging uses an automated pantograph system that provides DC charging at a very high power level. Contact is established between the bus and the charger without manual intervention, through either an on-board bottom-up or an off-board top-down pantograph

Figure 5 | Plug-in charging of an e-bus in India

Source: The Economic Times

Table 2 | Technical specifications of a representative AC plug-in charger for e-bus

Output power	80 kW			
Bus type	Midi non-AC	Midi-AC	Standard non-AC	Standard-AC
Approximate bus downtime for charging to add 200 km of range (hours)[19]	2.00	2.60	3.25	4.25

Source: Calculated by authors

Table 3 | Technical specifications of a representative DC plug-in charger for e-bus

Output power	240 kW			
Bus type	Midi non-AC	Midi-AC	Standard non-AC	Standard-AC
Approximate bus downtime for charging to add 200 km of range (hours)[20]	0.67	0.90	1.09	1.41

Source: Calculated by authors

system, and the e-bus needs to be designed accordingly (Figure 6). This type of charging requires specific battery chemistries that offer high resilience and can absorb charging at very high power.

The salient feature of pantograph charging technology is its overhead design and ultra-fast charging. **Because of the high cost of the charging system and of a suitable e-bus, this charging technology has seen limited uptake internationally, and there is reportedly no precedence of its adoption in India**. Table 4 presents the key characteristics of a representative pantograph charger.

Figure 6 | An e-bus charging through a pantograph

Source: sustainable-bus.com

Apart from the conductive mode of charging, there are a few other charging techniques that have been applied for e-buses, such as wireless charging and battery swapping. However, as the scale of adoption of these methods of charging remains at a pilot level and empirical research on the trade-offs of their adoption are not encouraging et al. 2019), it is advisable that the transit agencies consider mainstream charging technologies while planning the electrification of routes. The transit agencies may undertake pilot projects to test new technologies if they have separate funding for such purposes.

Table 4 | Technical specifications of a representative pantograph charger for e-buses

Output power	240 kW			
Bus type	Midi non-AC	Midi-AC	Standard non-AC	Standard-AC
Approximate bus downtime for charging to add 200 km of range (hours)	0.25	0.33	0.40	0.52

Source: Calculated by authors

STEP 3.2. EVALUATE DIFFERENT STRATEGIES FOR E-BUS CHARGING

The transit agency should take into account the following points to devise a plan for e-bus charging:

- The time to charge an e-bus varies and depends on a range of factors including charging technology, battery chemistry, extent of range to be added to the e-bus, ambient temperature, etc.
- Considering that the prevailing electric mobility market in India has largely adopted plug-in charging, the time taken to fully charge[21] (et al. 2019) an e-bus may go over an hour, which results in considerable downtime for the vehicle.
- One full charge may not be sufficient for the e-bus to complete its allotted number of daily trips or even a single trip in the case of a long-distance route (for example, intercity or interstate).
- An e-bus may require charging more than once a day. Accommodating the charging-related downtime into the daily e-bus operation schedule needs to be properly thought through.
- An e-bus may arrive late at a depot for charging, due to delays because of traffic congestion and operational hurdles. Such delays should be considered when planning for e-bus charging, as well as a possible requirement for spare e-buses. Adequate time- and distance-related buffers should be built in during the planning process to manage the fleet's operational schedule.

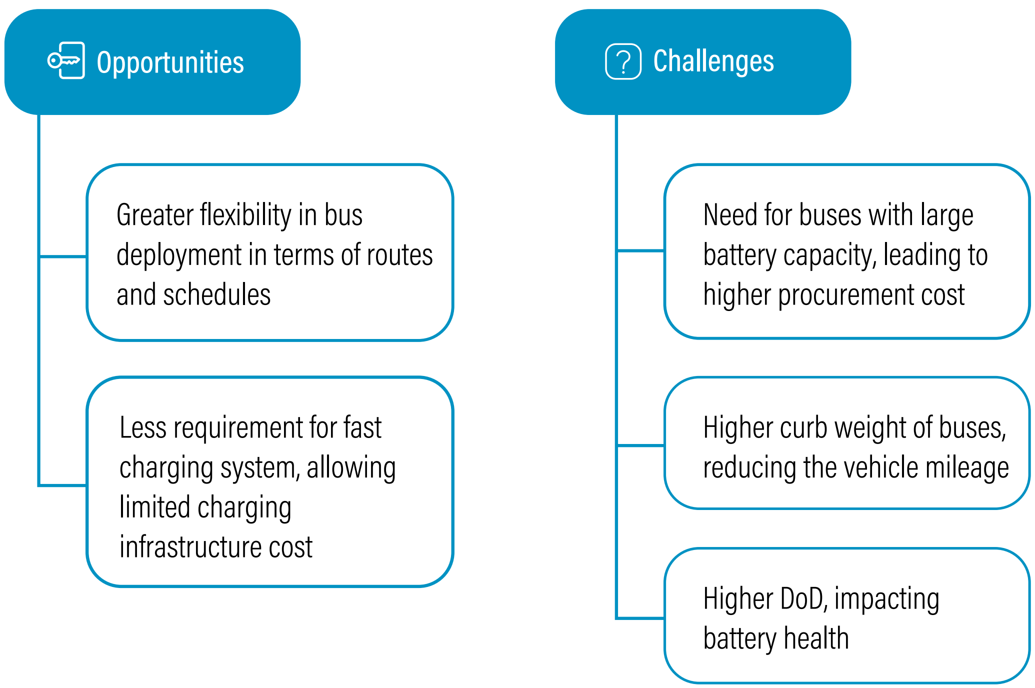
E-bus operators in India and around the world use different charging strategies to manage e-bus charging demand. These strategies vary with the adopted charging technology, the battery pack size of the e-bus, and the time available for charging in a day. Three salient strategies for bus charging can be observed, which are explained below.

OVERNIGHT CHARGING AT THE DEPOT WITHOUT OPPORTUNITY CHARGING

Typically, bus operation on a route pauses during the night, during which the crew carries out bus cleaning, maintenance, and next-day preparation — and, of course, gets some rest. In case of an e-bus fleet, this overnight time is often utilized for charging. As about five to eight hours are available for charging overnight, operators charge all the e-buses in the fleet to the full battery capacity to make them ready for the next day's duty cycle. Generally, operators do slow charging, and low-power chargers, which are comparatively less expensive, are suitable (et al. 2021).

The fleet can bank on only overnight charging, with no provision for range extension during operation, if the e-buses have enough battery capacity to have continuous autonomy for a full day's operation. It is feasible when the daily operating distance of a bus on a route and the capacity of the battery pack are in harmony. Considering that the majority of public bus schedules in India are based on 200 km of daily running distance of a bus, it would require a battery pack of about 270 kWh for a midi AC e-bus, and approximately 440 kWh for a standard AC e-bus, to attend to the duty cycle solely through overnight charging[22]. The rated capacity of the battery pack required is high in this case, as batteries of e-buses must have a maximum Depth of Discharge (DoD)[23] (et al. 2019) of 60%, which reduces the useful battery capacity. Buses with such large battery packs are more expensive, and hence, this would increase the procurement cost for the transit agency. Also, to sustain the full-day duty-cycle, the battery may undergo high DoD, which could lead to faster battery degradation. However, **where a route has very short headway[24] and shift changeover time, overnight charging becomes the only option to charge an e-bus serving on the route.** Figure 7 captures the possible pros and cons of depending on only overnight charging of an e-bus fleet.

Figure 7 | Opportunities and challenges of overnight-only charging



OVERNIGHT CHARGING WITH OPPORTUNITY CHARGING

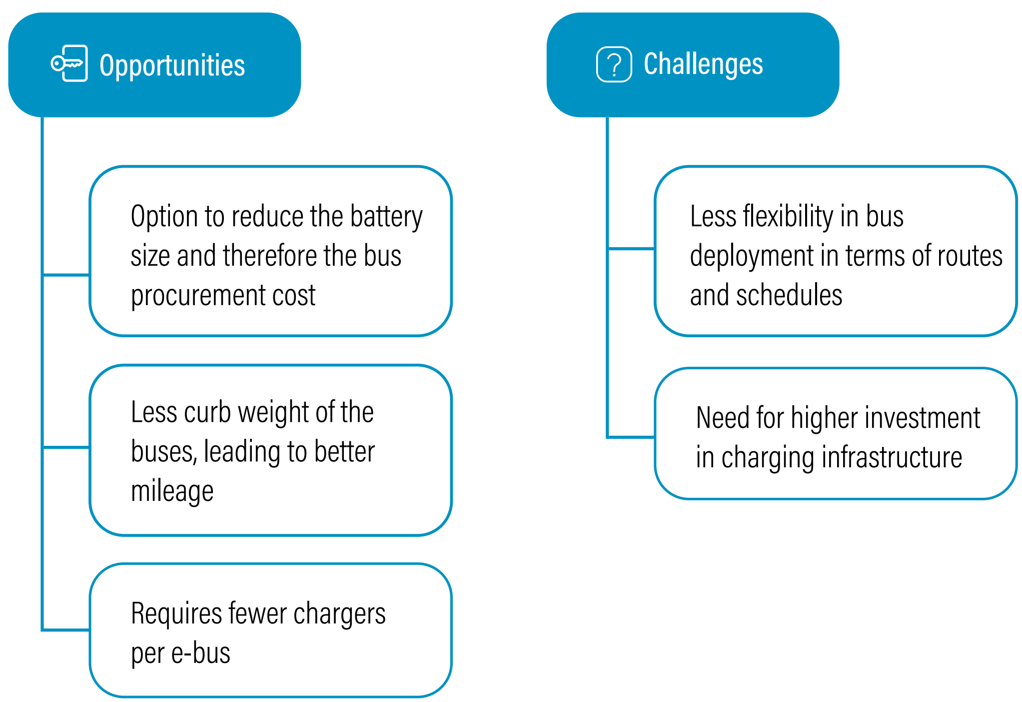
Bus operators often complement overnight charging of the e-bus fleet with charging during operating hours. Overnight charging remains the mainstay of the e-bus fleet, and when the daily schedule on a route has a break of about an hour[25], operators may take this "opportunity" for rapid charging of the e-bus at a depot or route terminal. Generally, the purpose of such charging is to add range and not necessarily to do a full charge. Hence, this complementary charging is also called range extension charging.

As the operator does not have to depend on only overnight charging to support the full-day duty cycle of an e-bus fleet, it can opt for a smaller capacity battery pack in the buses. This helps reduce the bus procurement cost. However, the charging infrastructure at the depot or the terminals should be equipped with fast chargers, which are commonly high-power DC chargers[26]. The possible trade-offs of such charging protocol are shown in Figure 8. This strategy may be an alternative to overnight-only charging. Opportunity charging can be advantageous on longer urban routes.

DEPOT-BASED OVERNIGHT CHARGING WITH OPPORTUNITY CHARGING ENROUTE

This is similar to the previous strategy, where overnight charging of the e-bus fleet is supported by opportunity charging. The key difference, however, is the place where opportunity charging is done. In this case, **the bus operator does rapid charging at one or more intermediate halting points or bus stops. This is possible by two means: one, when the halting time at a stop is sufficient to add required travel range by charging using fast DC plug-in chargers, and two, the operator employs an ultra-fast pantograph charging system capable of adding the necessary range within a few minutes of halting time[27]. In the latter case, the bus has to be suitable for pantograph-based charging.**

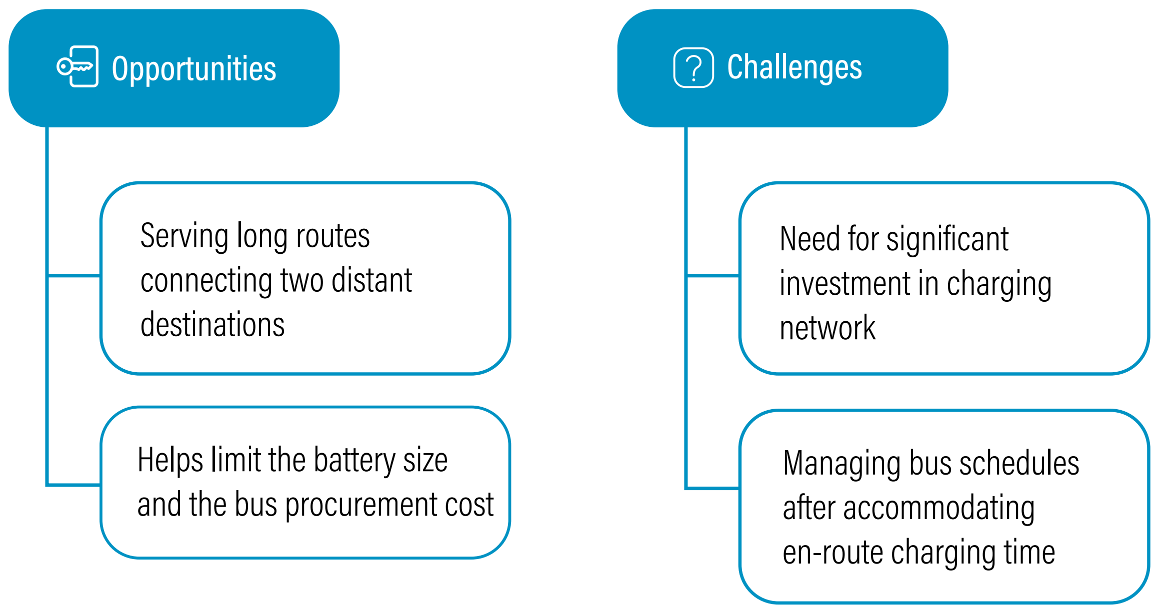
Figure 8 | Opportunities and challenges of overnight charging supported by opportunity charging at depots



En-route opportunity charging is found to be useful to support e-bus operation on long routes (for instance, route length over 250 km) such as intercity or interstate, as the assured range of an e-bus may not be sufficient for the duty cycle. Choosing fast DC plug-in charging or ultra-fast pantograph charging would depend on the time available at intermediate halting points. Figure 9 highlights the advantages and disadvantages of this charging strategy.

It is quite evident that each charging strategy has trade-offs, and it is important that the transit agency takes these into account while developing the route plan to roll out an e-bus fleet. It is critical to appreciate that there is no one-size-fits-all strategy to electrify all bus routes. One has to consider the charging protocol based on the route characteristics and duty cycle of a fleet operation.

Figure 9 | Opportunities and challenges of opportunity charging enroute



CASE-BASED DEMONSTRATION OF THE UNDERSTANDING SO FAR

A transit agency plans to electrify three bus routes, namely R10, R20 and R30, with low-floor standard non-AC e-buses. They are served by a common depot, but have different trip starting and end points. Following are the salient route characteristics:

The transit agency is developing a plan to electrify these three routes, and is assessing the required bus range and battery capacity and how to charge the fleets.

- The transit agency should first estimate the required average daily running kilometers of a bus on each of these routes and benchmark by the assured ranges of the available bus models in the low-floor standard non-AC segment. The required average daily running kilometers for R10, R20 and R30 are about 144 km[28], 128 km, and 310 km, respectively. The assured ranges of the e-bus models in the given category are found to vary from about 125 km to 300 km[29] (as reported by OEMs based on lab testing) which, translate to on-road ranges of 112 km to 270 km.
- It is evident that an e-bus can offer enough range to cover the average daily running kilometers of R10 and R20. However, the maximum possible range of an e-bus falls way short of the required daily running kilometer in case of R30. This means that overnight charging of the e-buses at the depot would suffice for R10 and R20 by opting for an e-buses with on-road ranges of about 144 km and 128 km, respectively, but not for R30.
- The transit agency would have the option to electrify R10 or R20 by deploying e-buses with a rated 320-kWh battery pack[30] and carrying out only overnight charging with slow (~80 kW AC) plug-in chargers.
- The transit agency should explore the scope

	R10	R20	R30
Number of daily trips per bus[a]	4	6	1
Route length[b] (km)	35	20	310
Time between shifts in a day per bus (mins)	60	30	720
Distance from depot to starting point (km)	1	2	0
Number of intermediate halts on a trip	15	10	1
Maximum halt time at intermediate bus stop (mins)	2	3	40

[a]The journey of a bus from the origin terminal (or starting point) to the destination terminal (or endpoint) is regarded as one trip of the bus.
[b]The distance from the origin terminal (or starting point) to the destination terminal (or endpoint) of a route is the route length.

for optimization. R10 has a 60-minute window per bus between shifts, which is enough time for opportunity charging at the depot. This would help avoid the requirement of 144 km autonomy of an e-bus and consequently reduce the battery capacity. Therefore, the electrification strategy for R10 could be: carry out opportunity charging at a depot during a shift change using a DC plug-in charger (~240 kW), which would help replenish about 80 kWh and add a range of about 61.5 km in 40 minutes (a full 60 minutes would not be available for charging). This would reduce the required battery pack size to about 179 kWh[31]. As a result, the price of the e-bus would be lower.

- To electrify R30, the transit agency should explore opportunity charging enroute, in the absence of an e-bus model with enough range. With about 30 minutes available for opportunity charging (a full 40 mins would not be available for charging), it can replenish about 60 kWh of energy by charging using a high-power (~240 kW) DC plug-in charger that could add a range of about 46.2 km. Thus, a standard e-bus with a full-charge range of 300 km (effectively 270 km on the road) plus range extension through opportunity charging enroute would cover a maximum of 316.2 km, which can meet the running requirement of 310 km. Therefore, in the present context, an e-bus can be deployed on R30, if en-route charging is considered.

KEY POINTS:

- Charging time is a key factor that potentially impacts e-bus deployment and therefore should be considered in route planning.
- Accommodating vehicle downtime due to charging in the daily e-bus operation schedule poses a major challenge to the bus operator. E-bus operators in India and around the world employ various charging strategies to manage e-bus charging demand. These strategies hinge on the adopted charging technology, battery pack size of the e-bus and time available for charging in a day.
- Overnight charging at the depot without opportunity charging is one of the three strategies that e-bus operators employ. In this case, the battery capacity of the e-bus should be large enough to support a full-day duty cycle.
- Complementing overnight with opportunity charging at a depot or terminal can help limit the battery capacity, but may require fast chargers. This is an alternative strategy to overnight-only charging.
- En-route opportunity charging may be required to support e-bus operation on very long routes such as intercity or interstate, where the assured range of an e-bus may not be sufficient for the duty cycle. Choosing fast DC plug-in chargers or ultra-fast pantographs for opportunity charging would depend on the time available at the intermediate halting points.
- There is no one standard way of charging an e-bus fleet.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STEP 4. TAKE INTO CONSIDERATION THE ANCILLARY ELECTRICAL INFRASTRUCTURE AND SPACE REQUIREMENT

It is important to note that an e-bus charging event involves the transfer of electricity at a high power level, and could pose a safety hazard if proper safeguards are not put in place. Therefore, chargers are not the only electrical equipment required to carry out e-bus charging. EVSEs must be supported by ancillary electrical infrastructure which ensures safe handling of electricity and avoids any adverse impact on the electrical grid.

Ancillary electrical infrastructure primarily includes a dedicated Distribution Transformer (DT), HT/LT (high-tension or low-tension) switchgear, distribution panel box, liquid cooled cables, protection relays, and SCADA (Supervisory Control and Data Acquisition) systems. Among these, the DT is the core component, and its capacity (or size) depends on the estimated total power demand at the charging facility (a margin in DT capacity can be maintained to support future expansion of the charging infrastructure).

The bus operator also takes the help of Information Technology solutions for monitoring, communication with the power distribution company (DISCOM), management of the fleet, and data analytics. However, these are not part of the core electrical assets and have not been widely employed in the current e-bus services.

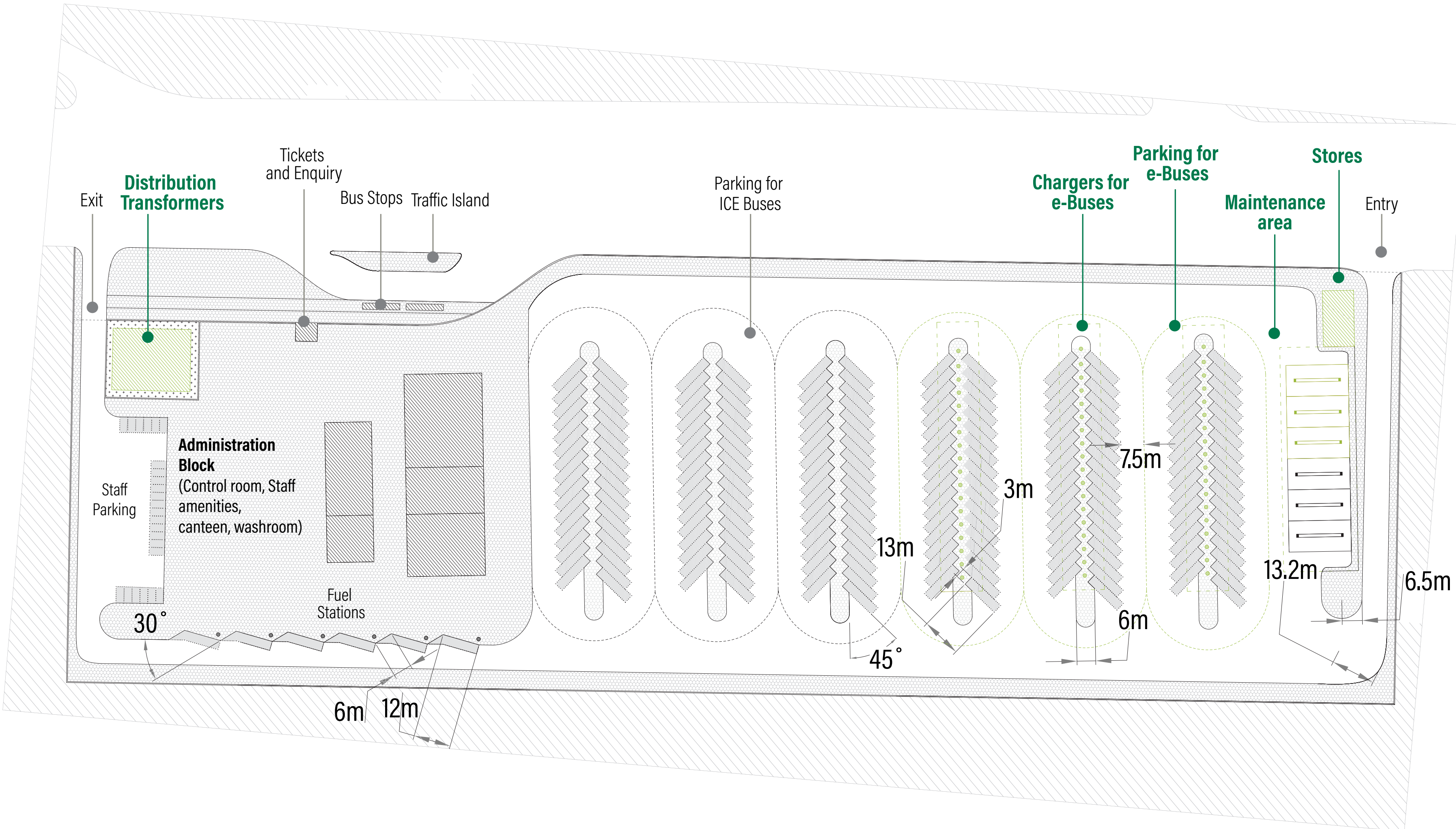
A prerequisite for developing the charging and ancillary infrastructure is space availability. Be it at a depot, terminal or intermediate bus stop, charging infrastructure would require considerable space. Some important points include the following:

- Installing an EVSE requires about 42 sq. m., whereas the parking bay of a standard e-bus takes up about 65 sq. m.
- The orientation of the depot, terminal, or the en-route charging station and the charging protocol (a key factor is how many buses are charged simultaneously) largely influence the requirement for parking space for charging.
- The DT and allied equipment may take between 50 and 95 sq. m. of space depending on the required capacity of the DT[32]. Since the infrastructure including the DT(s) would be used exclusively for e-bus charging, the transit agency must arrange for the necessary space.

Space availability for such a set-up could be particularly challenging at intermediate bus stops in the case of en-route charging. **The transit agency should take cognizance of such space requirements while choosing the depot, terminal, or intermediate bus stop for charging. This in turn influences the route selection for electrification.** Moreover, additional land may be required in future to accommodate fleet augmentation, and hence the transit agency should engage and coordinate with municipalities and land-owning agencies to arrange for land on a concessional basis.

Figure 10 highlights the areal requirements for the infrastructure needed to support e-bus operations at a depot, through a reference layout plan. It must be noted that the layout plan is solely for reference purposes, and the insights drawn from it must be applied to real-world cases with necessary context-sensitive adjustments.

Figure 10 | Reference layout plan for an e-bus depot



Source: Analysis by authors

STEP 4.1. UNDERSTAND THE SUITABLE ELECTRICITY DISTRIBUTION NETWORK

To apply for an electricity connection for e-bus charging, a clear understanding of the required sanctioned load is important.

Sanctioned load is the power demand in kW or kVA (kilovolt-ampere) which the serving DISCOM (licensee) agrees to supply as per the applicable supply code regulations. In case of charging infrastructure, it can be estimated by summing the critical loads; that is, the input power ratings of all the EVSEs and other electrical equipment at the site. As a thumb-rule, a 5% buffer for load requirement is also considered — in case unprecedented additional loads appear at the depot level. The total sanctioned load requirement is determined using the following formula:

$$\textit{Total sanctioned load requirement (kW)} = \textit{Input power rating of charger (kW)} \times \frac{\textit{charger}}{\textit{bus}} \times \textit{number of buses} \times 105\%$$

In order to support 80 e-buses using 240 kW chargers, the sanctioned load for charging infrastructure at the depot could be as high as 5.1 MW (megawatt), which is equivalent to the cumulative sanctioned load of about 1,300 apartments.

To support such high-power demand, a High-Tension or High-Voltage electricity connection[33] is a fundamental requirement. Besides, the electrical feeder supplying power to the facility should have sufficient available hosting capacity to meet the sanctioned load. Such an electricity supply provision may not be readily available at every depot or terminal, and hence the serving DISCOM may have to augment the local distribution network to cater to the load (et al. 2019).

Adding capacity to the local distribution network may take considerable time. A new electrical sub-station may need to be built near the charging facility. Finding adequate space to develop new capacity and getting "Right of Way" to extend high-tension electrical cables to the charging infrastructure can be difficult in a densely populated city.

Access to the required distribution network may pose a barrier specially at far-flung route terminals and intermediate halting points where the quality of electricity supply may be unreliable.

It is important for the transit agency to take cognizance of the requirement of electrical infrastructure for bus charging and actively engage with the DISCOM while planning e-bus rollout. Close coordination between the transit agency and the DISCOM — potentially facilitated by the state government — during the planning and implementation phases is imperative for ready and seamless provision of electricity.

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NEXT STOP H

STEP 5. ASSESS THE FINANCIAL SUSTAINABILITY OF E-BUS OPERATION

The economics of an e-bus operation are a critical factor in considering route selection for e-bus deployment, particularly since it involves shifting to a new technology and setting up new infrastructure.

STEP 5.1. ACCOUNT FOR THE UPFRONT COSTS OF E-BUSES AND CHARGING INFRASTRUCTURE

COSTS OF E-BUSES

As directed in the FAME-II scheme, most transit agencies have procured e-buses through the OPEX model, where bids are invited based on the service cost per kilometer. Hence, the actual costs of e-buses are generally not available. In this regard, a committee constituted by the Government of India's Department of Heavy Industry carried out an exercise to benchmark the price for different types of e-buses (Department of Heavy Industry 2018).

In the absence of validated information on the prices of different e-bus models, for the purpose of evaluating the economics of e-bus operation, this research takes into account these benchmarked prices as shown in Table 5.

INVESTMENT IN CHARGING INFRASTRUCTURE

Charging infrastructure is expected to contribute considerably to the CAPEX of e-bus fleet adoption, and the cost primarily depends on the charging technology, number of EVSEs deployed for the fleet, and the cost of upstream electrical infrastructure[36]. There is quite a large variation in the cost of EVSE. Even when the mainstream charging technologies — namely, plug-in charging and pantograph charging — are considered, the cost of the charger or charging station would depend on the type of power output (AC/DC) in the case of plug-in charging, and the power level of the EVSE. Table 6 captures the expected cost estimates for the main three types of EVSEs and the associated upstream electrical infrastructure per EVSE. This gives a fair idea of the investment needed to set up charging infrastructure for an e-bus fleet.

In addition, there would be the cost for installation of the charging infrastructure (approximately, ₹5,28,000 per charger). **It is worthwhile to note that the total cost of ancillary electrical infrastructure would be at the site level; that is, it would be shared across all e-buses charged at the site. On the other hand, an EVSE may or may not be shared by multiple e-buses.** The total cost of charging infrastructure can be estimated as follows.

$$\begin{aligned} &\textit{Total cost of charging infrastructure} \\ &\quad = (\textit{Cost of an EVSE} \\ &\quad + \textit{Cost of ancillary electrical infrastructure per EVSE}) \times \frac{\textit{charger}}{\textit{bus}} \\ &\quad \times \textit{Number of buses} \end{aligned}$$

In the case of a fast-charger (for example, 240 kW DC plug-in), one EVSE may suffice for more than one e-bus with small battery pack[37] (the charger to e-bus ratio can be assumed to be 1:4). That means the total cost of charging infrastructure at the site would be equal to the per-EVSE cost (with addition of the cost of upstream electrical infrastructure per EVSE) times one-fourth of the number of e-buses charged at the site.

For pantograph-based charging, the charger to e-bus ratio could be as low as 1:10 and hence, this type of ultra-fast charging is preferred for en-route opportunity charging. However, the CAPEX including the cost of e-bus[39] and EVSE is very high. A detailed system-level cost estimation is warranted to evaluate the viability of implementing pantograph-based charging. Table 7 explicates the expected costs of adopting different charging strategies for a fleet of 100 e-buses.

Table 5 | Indicative benchmarked prices for e-buses of different configurations

Bus type	Passenger seating capacity	Battery size (kWh)	Driving range[34] (km)	Indicative benchmarked price, incl. taxes (₹ lakhs)
Midi – high floor	31	125	150	75 – 120
Midi – low floor[35]	31	162	200	120 – 140
Standard – high floor	40	125	150	88 – 130
Standard – low floor	40	320	300	145 – 175

Source: Values pertain to the year 2020 and were collected through interviews of e-bus OEMs

Table 6 | Cost estimates for different types of EVSEs and ancillary electrical infrastructure per EVSE

	AC plug-in charger (80 kW)	DC plug-in charger (240 kW)	Pantograph charger (650 kW)
Cost of EVSE (₹)	6,08,000 – 6,72,000	22,80,000 – 25,20,000	1,06,00,000 – 1,18,00,000
Cost of ancillary electrical infrastructure per EVSE[38] (₹)	6,48,000 – 7,16,000	19,40,000 – 21,50,000	52,60,000 – 58,20,000

Note: The estimates pertain to the year 2021 and intend to give a sense of the possible expenditure. Actual costs may vary, based on the additional features of the technology (such as control and communication capability) and the size of the procurement order for EVSEs. The values have been gathered through stakeholder interactions.

Table 7 | Costs of adopting different charging strategies for a fleet of 100 e-buses

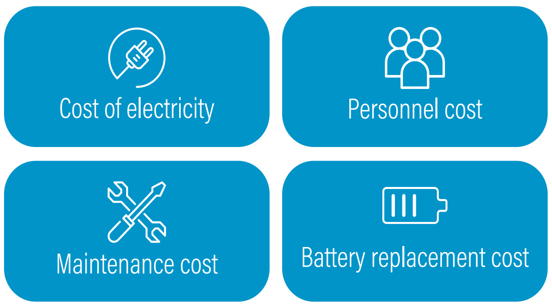
Parameters	Units	Overnight charging at the depot without opportunity charging	Depot-based overnight and opportunity charging	Depot-based overnight charging with opportunity charging enroute	
				For overnight charging	For opportunity charging
Power rating of charger needed	kW	80	240	80	650
A Number of e-buses	-	100			
B Charger:bus ratio	-	1:1[a]	1:4	1:1[a]	1:10
A × B Number of chargers needed	-	**100 × 1.00 = 100**	**100 × 0.25 = 25**	**100 × 1.00 = 100**	**100 × 0.10 = 10**
D Cost of an EVSE	₹	6,40,000	24,00,000	6,40,000	1,12,00,000
E Cost of ancillary infrastructure per EVSE	₹	6,82,000	20,46,000	6,82,000	55,41,400
A × B × (D + E) Total cost of charging infrastructure	₹	100 × (6,40,000 + 6,82,000)	25 × (24,00,000 + 20,46,000)	100 × (6,40,000 + 6,82,000) = 13,22,00,000	10 × (1,12,00,000 + 55,41,400) = 16,74,14,000
		= 13,22,00,000	**= 11,11,50,000**	**= 29,96,14,000**	

[a]Less than one charger per bus may suffice if e-bus operation allows e-bus charging on First In, First Out basis. Accordingly, the required number of chargers will be less.

STEP 5.2. TAKE COGNIZANCE OF THE POSSIBLE OPERATING AND MAINTENANCE COSTS FOR E-BUS OPERATION

The operational cost heads for running an e-bus fleet on a route are captured in Figure 11.

Figure 11 | Different costs involved in e-bus fleet operation



Note: Costs of procuring e-buses, charging infrastructure and upstream electrical infrastructure have been considered to be capital costs

COST OF ELECTRICITY

Electricity is the fuel for an e-bus fleet, and its cost is a major recurring cash outflow for a transit agency. Electricity cost can be estimated as follows.

$$\text{Electricity cost (₹)} = (\text{Electricity consumed (kWh)} \times \text{Energy charge (₹/kWh)}) + (\text{Sanctioned load (kW) or Maximum power demand} \times \text{Demand charge (₹/kW)})$$

The electricity tariff is an important factor which impacts the cost for the electricity consumption. Some important points to note:

- Tariffs (both values and designs) and tariff-related rules vary significantly from state to state.
- Some states have introduced specific tariffs for EV charging, and there is a set of conditions to avail EV-special tariffs. There is no blanket provision that lets all charging facilities for e-buses be eligible for the EV tariff.
- In states where there are separate tariffs for EV charging, one generally has to apply for an exclusive electricity EV-metered connection for a charging facility.
- The tariff has two parts: variable/energy charge (₹/kWh) and fixed/demand charge (₹/kW). Energy charge is applied on the total volume of electricity consumed during a billing period, whereas demand charge is levied on the sanctioned load (kW) for the particular electricity connection or the maximum power demand registered during that period.
- Per unit (kWh) energy charges may have slabs linked with actual electricity consumption levels;that is, the greater the consumption, the higher the rate of energy charge.

Transit agencies can potentially save on the electricity cost by putting a check on the demand charges, since the latter is applied based on the sanctioned load and not on the actual power demand recorded. Also, it applies irrespective of the amount (units) of electricity consumption. To this end, **the transit agency may explore electrifying routes served by different depots, thus distributing the charging load across its depots instead of concentrating on routes served by a common depot.**

PERSONNEL COST

This would depend on the number of staff members involved in operating the e-bus fleet and associated infrastructure, which in turn is largely linked to the e-bus fleet size. Transit agencies in Indian cities task five to six personnel for each bus, which costs approximately ₹ 1,00,000 to ₹ 1,20,000 per month. The need for training the personnel can add to the cost. It must be noted here that personnel costs vary from one transit agency to another by a significant amount, with some agencies having more than 12 personnel per bus, while other staff as low as three personnel for a bus (Ministry of Housing and Urban Affairs 2013).

MAINTENANCE COST

Typically, an e-bus fleet has a lower maintenance cost than a diesel or CNG bus fleet of comparable size, because e-buses have fewer moving parts and need no soot- and grease-related maintenance. **The per kilometer maintenance cost, inclusive of the cost of manpower required for maintenance, is**

expected to be around 10% to 12% of the procurement cost (et al. 2019).

BATTERY REPLACEMENT COST

Based on the battery chemistry and operating conditions, an e-bus may require periodic replacement of its battery pack, possibly once every five to seven years (Moon-Miklaucic, et al. 2019). This is a major cost for the transit agency, and depends on the battery pack size and battery chemistry. It is difficult to specify a value for the battery replacement cost since most e-bus OEMs directly source battery packs from lithium-ion battery manufacturers with whom they have prior partnerships. However, ₹ 20,000/ kWh can be considered as an indicative cost for battery replacement at present[40]. Battery costs may fall in the future, as the global price of lithium-ion batteries is showing a decreasing trend and is projected to fall below $100/kWh (₹7,400/kWh[41]) in the coming years. It is worthwhile to mention here that driving style, duty cycle and ambient weather conditions impact the battery health and consequently, the frequency of battery replacement.

In addition to the above operating costs, in some cases where en-route opportunity charging is necessary, the transit agency may have to bear a recurring cost for land rental for charging infrastructure or to pay for charging at a third-party owned charging facility.

STEP 5.3. TAKE INTO CONSIDERATION THE ECONOMIC BENEFITS OF E-BUS OPERATION

The deployment of e-buses for day-to-day public transit operations is accompanied by a host of benefits including climate change mitigation and reduction in local air pollution. The immense economic value of these benefits should be taken into account while evaluating the financial sustainability of e-bus rollout on a route. This is also to recognize the real purpose of replacing oil-guzzling and polluting ICE buses with e-buses and to reflect the true value of e-bus deployment (Kothari, et al. 2021). An apples-to-apples comparison of costs associated with conventional buses and e-buses is not justified.

To quantify the economic value of the benefits of e-bus adoption, the assessment takes into account the composite damage cost, which is the marginal cost of mitigating potential damage from the release of air pollutants and greenhouse gases. The composite damage cost per bus, a combination of the health damage cost and environmental damage cost, is expressed in ₹/km (Kumar et al. 2018).

Table 8 | Composite damage costs for different types of diesel buses

Bus Type	Fuel economy (km/l)	Composite damage costs (₹/km)
Midi non-AC	4.50	2.245
Midi AC	3.75	2.694
Standard non-AC	3.25	3.108
Standard AC	2.50	4.040

Note: The composite damage costs have been derived from the damage costs for diesel three-wheelers estimated by the study "Green Vehicle Rating for Two- and Three-Wheelers" (Kumar et al. 2018), by comparing the fuel economies of a diesel three-wheeler and the given types of diesel buses.

The composite damage costs for diesel buses are captured in Table 8 and can be used by the transit agency for assessing the overall economic benefits (or cost savings) stemming from the deployment of e-buses. The damage cost savings should be deducted from the actual costs of route electrification to derive the real cost of e-bus rollout on a given route.

STEP 5.4. ASSESS THE IMPACT OF DEPLOYING E-BUSES ON THE FINANCIAL SUSTAINABILITY OF A ROUTE

Once a transit agency is aware of the costs associated with e-bus deployment, it can assess whether the electrification of a route is financially sustainable.

Financial sustainability is quite different from financial viability. The latter is achieved when a service begins to yield positive cash flows, indicating profitability of operations. On the other hand, financial sustainability of a service

is achieved when its sustained provision becomes possible from a financial standpoint. It is generally assessed for public services, wherein profitability and recovery of opportunity costs are not the motives of the service provider, and external support — in the form of subsidies, VGF, rebates, etc. — is available for helping realize a greater good. It is aimed at providing affordable services to all income groups, charging affordable rates as close as possible to cost-recovery levels, and continued service provision. To assess the financial sustainability of deploying e-buses on a route, it is worthwhile to understand the Service Level Benchmarks (SLBs) of public bus transport systems in India. SLBs are standardized indicators used to measure the performance of a service, in order to identify qualitative, quantitative, and managerial gaps and issues in the provided services. SLBs exist for almost all types of infrastructure, ranging from water supply to solid waste management. However, for the scope of this assessment, the relevant SLBs are those used to assess public bus transport systems (Ministry of Housing and Urban Affairs 2013). These SLBs evaluate bus-based public transport systems on two aspects; that is, the quality and expanse of the service and its financial performance.

Aligned with the current scope, to assess the financial performance of a public transport system, there exist three financial SLBs in India:

- **Extent of non-fare revenue:** The percentage contribution from non-fare revenue in the transport authority's total revenue, mainly from advertisements.
- **Staff/bus ratio:** A useful indicator of the staff-related expenses per bus. It indicates the number of members of the staff deployed for the operation of each bus.
- **Operating ratio**: A benchmark is used to assess both system-wide and route-wise financial performance. It is deduced by dividing the cost incurred per kilometer (CPKM) of operation by the earnings per kilometer (EPKM) of operation. Lower operating ratios are better than higher operating ratios, from a financial standpoint, as they imply higher EPKM, relative to CPKM.

The only financial SLB that is relevant to the scope of this research is the operating ratio, as it is the only SLB that explicitly assesses the "financial sustainability" of a route. It can be used to classify a route's operations as financially sustainable or unsustainable. Further, the same SLB can act as an input for route prioritization, as is explicated in the next step in this guidebook.

In order to calculate the operating ratio, one first needs to determine the post-electrification CPKM of a route. For deducing the CPKM for operating e-buses on a route, one can divide the total capital, operating, and maintenance expenditures on route electrification (as explicated in Steps 5.1 and 5.2) over the vehicle holding period by the distance that all e-buses on the route are envisaged to travel over the same period. The pre-electrification EPKM values are expected to be available with the transit agency, as it is a standard practice for them to maintain route-wise records of fare-box revenues and other cash inflows.

$$\text{CPKM} = \frac{\text{(Total capital, operating, and maintenance expenditures for route electrification over the vehicle holding period (₹))}}{\text{(Total distance traveled by all e-buses on the route over the vehicle holding period (km))}}$$

Often, bus agencies aggregate their total costs and earnings and distribute them across all routes on a pro-rata basis, based on number of buses per route/daily running requirement per route/etc. While such practices ease record-keeping, they are inaccurate and not conducive for genuinely assessing the financial sustainability of route electrification. Going forward, to determine the financial sustainability of deploying e-buses on a route, it is critical that the concerned CPKM and EPKM values pertain to the specific route being assessed and are calculated strictly based on that route's electrification requirements and operational characteristics, such as numbers of e-buses and chargers deployed, passenger loading, route-specific fare-box revenue, etc.

For all routes to be assessed, route-specific CPKM and EPKM values should be furnished based on the routes' parameters, and not derived through aggregated system-wide calculations. Also, in order to assess the impact of e-bus deployment on a route's financial sustainability, it is the post-electrification operating ratio that should be determined. Ideally, this should be done only for routes that are technically feasible to electrify.

As a second step for the operating ratio calculation, from the determined CPKM values, the composite damage costs identified in step 5.3 should be deducted, to calculate the true CPKM for route electrification, as:

$$\textit{True CPKM} = \frac{\textit{CPKM}}{\textit{Composite damage cost of identified bus type}}$$

It is the true CPKM value which should be used for calculating the operating ratio of a route after electrification. **For determining the post-electrification operating ratio of a route, the true CPKM of the route is divided by the EPKM of the route (note: EPKM of a route is not expected to change upon electrification, hence the pre- and post-electrification EPKM values are the same).**

The formula for the post-electrification operating ratio is:

Operating ratio (OR)=(True CPKM)/EPKM

Upon determining the post-electrification operating ratios, Table 9 can be referred to for deciding whether a route's electrification is financially sustainable or not. The table lists different ranges of operating ratios against various Levels of Service (LoSs), which are simplified indicators of the route's financial performance. Specifically, an LoS is defined for a particular service (such as public transport, road capacity, non-motorized transport infrastructure, etc.) as a benchmark against which the service's performance can be evaluated. From the lens of performance, service levels are classified across four to six bands, and usually relate to quality, quantity, reliability, responsiveness, environmental acceptability, and cost of the service. **If the operating ratio of a route exceeds 1.5 (within the LoS 4 band), then its operation is deemed financially unsustainable.** Hence, if a route's CPKM and EPKM values — upon deployment of e-buses — are expected to cause its operating ratio to rise beyond 1.5, then it should not be considered for electrification, as it is a financially unsustainable proposition.

CASE-BASED DEMONSTRATION OF THE UNDERSTANDING SO FAR

A bus agency aims to electrify four different routes; namely, R1, R2, R3, and R4. The agency has assessed the parameters of these routes against the characteristics of e-buses and concluded that they are technically feasible to electrify. **As a further step toward that conclusion, the bus agency wishes to gauge the long-term financial consequences of electrifying these technically feasible routes.** In other words, it aims to assess the financial sustainability of deploying e-buses on the identified routes, for which the following tasks should be executed:

- For electrifying the identified routes, **the agency must first determine the route-wise vehicular, infrastructural, and operational requirements.** Two types of cost are associated with the determined requirements:
  1. Upfront costs (capital expenditure)
  2. Operating and maintenance costs

- **The transit agency must account for all the cost heads mentioned in steps 5.1 and 5.2. Then, it must combine these**

Table 9 | Levels of Service for assessing financial sustainability of a route for electrification

LoS	Operating ratio (OR)	Eligibility for electrification
LoS 1	OR ≤ 0.7	Route operations are financially sustainable
LoS 2	0.7 < OR ≤ 1.0	
LoS 3	1.0 < OR ≤ 1.5	
LoS 4	OR > 1.5	Route operations are financially unsustainable

Note: : For financial viability of a proposition, cash inflows must exceed cash outflows. However, for public transport in Indian cities, financial sustainability is measured (not financial viability, as public transport is a public service), wherein cash outflows can exceed cash inflows by a margin of up to 50%, and extra costs of service provision can be met through VGF from the government.
Source: Ministry of Housing and Urban Affairs 2013

Table 10 | Select parameters of routes identified for electrification, to assess CPKM values

Parameters	R1	R2	R3	R4
Type of bus deployed on route pre-electrification	Standard non-AC	Midi AC	Midi non-AC	Standard AC
A Post-electrification CPKM (₹/km)	48.1	58.4	51.9	53.2
B Composite damage costs (₹/km)	3.108	2.694	2.245	4.040
C (= A - B) True CPKM (₹/km)	44.992	55.706	49.655	49.16
D Pre-electrification EPKM (₹/km)	53.5	34.7	47.3	39.1
A/D Operating ratio based on CPKM and EPKM	0.89	1.68	1.09	1.36
C/D Operating ratio based on true CPKM	0.84	1.61	1.05	1.25
Level of Service (based on true CPKM)	2	4	3	3
Conclusion regarding financial sustainability of electrification	Financially sustainable	Financially not sustainable in current circumstances	Financially sustainable	Financially sustainable

cost heads with the determined route electrification requirements, which will be vehicular, infrastructural, and operational. Combining the cost heads with the electrification requirements will largely entail multiplying the envisaged unit costs with the determined route-specific requirements.

- **The next task for the agency is to convert all envisaged costs that are accounted for into CPKM values** using the method specified in step 5.4.

- **To the route electrification costs (or CPKM values), deductions stemming from composite damage costs should be applied,** based on the values provided in step 5.3. This will lead the agency to the true CPKM values for electrifying the routes.

- Finally, the agency must divide the **post-electrification CPKM values of the routes by their pre-electrification EPKM values** to deduce the operating ratios of the various routes under consideration. These ratios will inform the agency whether the electrification of a bus route is financially sustainable.

To better understand the tasks discussed above, certain values for the four routes (R1, R2, R3, and R4) have been assumed in Table 10. The table also highlights the calculations that must be carried out to get the operating ratios.

As is evident from the case-based demonstration summarized in Table 10, routes R1, R3, and R4 are financially sustainable to electrify, whereas R2 is not. The bus agency, therefore, may discard R2 for electrification, and move ahead with the other routes. Further utilization of the deduced levels of service can be done to prioritize the selected routes as well, as explained in step 6.

KEY POINTS:

- There is a large variation in EVSE cost, depending on the charging technology, the type of power output (AC/DC) in the case of plug-in charging, and the power level of the EVSE. Costs may also vary considerably, based on additional features of the technology (like control and communication capability) and the size of the EVSE procurement order.
- The total cost of ancillary electrical infrastructure would be at the site level; i.e., the cost would be shared across all the e-buses charged at the site. An EVSE may or may not be shared by multiple e-buses.
- The main operational cost heads for running an e-bus fleet on a route include electricity, personnel, maintenance, and battery replacement.
- Transit agencies can potentially save on the cost of electricity by putting a check on demand charges, since the latter are applied on the sanctioned load or the recorded maximum power demand.
- The transit agency may explore electrifying routes served by different depots, thus distributing the charging load across depots, instead of concentrating on routes served by a common depot. Effective coordination with serving DISCOM(s) may also help the transit agency to avoid prioritizing the depots for electrification where provision of power is challenging.
- Typically, an e-bus fleet has a lower maintenance cost than a diesel or CNG bus fleet of comparable size, because of the smaller number of moving parts in an e-bus. The per kilometer maintenance cost, inclusive of the cost of manpower required for maintenance, is expected to be around 10% to 12% of the procurement cost.
- An e-bus may require periodic replacement of its battery pack, possibly every five to seven years. This is a major cost to the transit agency and depends on the battery pack size and battery chemistry. However, battery costs are expected to fall as the global prices of lithium-ion batteries show a decreasing trend.
- For a fair assessment of the costs of route electrification, the macroeconomic benefits of deployment of e-buses should be considered in financial terms. Precisely, the economic savings arising out of the health- and environment-related benefits of e-bus deployment (in ₹/km terms) should be deducted from the cost of operating an e-bus per km to estimate the "true CPKM".
- For evaluating the financial sustainability of operating e-buses on a route, a transit agency should calculate its post-electrification Operating Ratio based on the route's true CPKM and EPKM.
- If the post-electrification Operating Ratio of a bus route does not exceed 1.5, then it is financially sustainable to electrify. Otherwise, the route is deemed financially unsustainable to electrify in the present scenario.


HOTEL
AMARVILAS
ibus
ibus Route Map

STEP 6. ADOPT A PRIORITIZATION APPROACH TO CLASSIFY BUS ROUTES

Upon gauging whether individual routes are technically feasible and financially sustainable to electrify, a public transit agency will have identified a set of routes that are ready for e-bus deployment. At that stage, system-wide electrification of all identified routes in one go may not be possible, owing to technical, budgetary, or other constraints. Hence, the transit agency may need to take a calibrated approach, and route prioritization can be used as an effective means for the e-bus rollout.

Considering that financial implications are the overwhelming guiding factor for decision-making on high-investment projects such as e-bus procurement, this guidebook suggests a prioritization pathway linked to the evaluation of financial sustainability.

The financial sustainability assessment for rolling out e-buses on technically feasible routes (as suggested in Step 5.3.) leads to four different Levels of Service (LoSs) based on the estimated Operating Ratio. These LoSs can be considered as the preliminary basis for considering routes for electrification.

The LoSs can be used for prioritizing the routes as well. To further prioritize routes for electrification, it is important to consider the baseline financial performance of the bus operation; that is, the Operating Ratio before the electrification of the route. The reason is that the bus operation legacy on a route may have an overhanging effect on the financial sustainability of electrifying that route. To put this in perspective, the baseline OR of the bus route itself could be greater than 1, which might have resulted in an unattractive OR value in the electrification scenario as well. Then, do such routes merit electrification? Such cases may not be eligible for featuring in the transit agency's list of high-priority routes. However, **it would be worthwhile to assess whether electrification of the route improves the OR of the bus operation, which should be a welcome development from the transit agency's point of view.**

To account in the decision-making for the possible change in route OR, transit agencies should evaluate whether electrification of a route is likely to improve the OR compared to the baseline. Based on the LoS and the possible change in OR of the route after electrification, one can consider six levels of prioritization for routes that are fit for e-bus rollout, as shown in Table 11.

Table 11 | Priority levels to be ascribed to routes for electrification

		Post-electrification Operating Ratio (OR) of the route	
		Improved[42] OR	Unimproved[43] OR
LoS of the route	LoS 1	Priority 1	Priority 2
	LoS 2	Priority 3	Priority 4
	LoS 3	Priority 5	Priority 6
	LoS 4	Route electrification is financially unsustainable	

Thus, the recommended prioritization framework for selecting routes for deployment of e-buses consists of two steps, as highlighted in Figure 12.

At the end of this step, the transit agency would be able to draw a list of routes under each of the priority levels, which would facilitate e-bus deployment.

Figure 12 | Two-step process to prioritize electrification of routes

Step-1

Will OR be attractive?

Check which Level of Service (LoS 1, LoS 2, LoS 3 or LoS 4) the route is likely to fall under based on post-electrification OR

Step-2

Will OR improve?

Check whether the OR of the route is likely to improve after electrification compared to the baseline bus operation

SALIENT ADVANTAGE OF THE APPROACH:

The suggested framework to decide on prioritizing electrification of a route has the advantage of using the existing financial evaluation approach commonly followed by transit agencies in India. The concepts or indicators — namely, “Operating Ratio” and “Level of Service” — are widely understood by stakeholders in the transport sector. They would not require special training or orientation to evaluate the merit of rolling out e-buses on given routes based on this approach.

CASE-BASED DEMONSTRATION OF THE UNDERSTANDING SO FAR

To demonstrate use of the route prioritization approach, as explained in Step 6, the routes in Table 12 must be referred to. These routes have been directly sourced from Table 10 (Step 6), and rely on the LoS classes listed in Table 11 (Step 6).

It can be understood from Table 12 that the priority of R1 is highest for deployment of e-buses, followed by R3 and R4, both of which have same level of priority ascribed to them. R2 is not financially sustainable to electrify; however, its electrification may be explored by the transit agency in the future.

Parameters	R1	R2	R3	R4
Pre-electrification CPKM of the route	0.85	1.44	1.34	1.33
Post-electrification operating ratio based on CPKM and EPKM	0.89	1.68	1.09	1.36
Priority level of route corresponding to CPKM	4	Route not financially sustainable to electrify	5	6
Post-electrification operating ratio based on true CPKM	0.84	1.61	1.05	1.25
Priority level of route corresponding to true CPKM	3	Route not financially sustainable to electrify	5	5


ZERO EMISSION
ZERO EMISSION
ZERO EMISSION
बेस्ट
TATA
Marcopolo
MH-01
DR-0920
MH-01
DR-0907
MH01DR0920

WAY FORWARD

The guidebook charts a detailed path for transit agencies to follow when planning to roll out e-buses and to prioritize routes for electrification. The suggested decision-making process starts from understanding the interplay between e-bus operation and route characteristics along with the technical feasibility of e-bus implementation. The process logically ends with adopting a route prioritization approach for e-bus deployment based on the financial sustainability of rolling out e-buses. From here, the transit agency embarks on two important activities:

- Initiating the procurement of e-buses for the priority routes
- Preparing to expand e-bus service on the remaining routes in future

LINKING WITH THE E-BUS PROCUREMENT PROCESS

Linking the prioritization exercise — that is, the last step in decision-making — to the e-bus procurement process is vital. To this end, this guidebook suggests the following set of next-steps to the transit agency:

- Adopt a phase-wise approach to roll out e-buses and decide on the priority levels that can be targeted for electrification in the initial phase(s) — say, Level 1 to Level 3 based on the number of routes that qualified to these levels
- Create groups of priority routes from the targeted priority levels, according to their serving depots or required driving ranges of e-buses
- Make separate e-bus roll-out plans for each group of priority routes, for ease of implementation:
    - Plan the number of e-buses to be deployed on individual routes keeping in mind the benefit of economies of scale
    - Estimate the corresponding budgetary requirements taking into account all the infrastructure components
    - Plan for sufficient space allocation at the depots/terminals or intermediate bus-stops (in case of long intercity or interstate routes) for setting up charging and ancillary infrastructure
    - Consult with the serving DISCOM(s) regarding the necessary sanctioned load at each charging location, and jointly undertake technical pre-feasibility checks to have a basic understanding of the feasibility of getting electricity connections for the required load at the identified locations
- Hold discussions with e-bus OEMs on the specific requirements — primarily, e-bus range, charging technology, and charger power rating
- Issue tender for e-bus procurement for each group of priority routes

ELECTRIFICATION OF LESS FAVORABLE ROUTES

While the transit agency endeavors to deploy e-buses on current priority routes, those that are at present difficult to electrify should not get ignored. Routes that do not make it to the high-priority list in the present scenario are likely to rise up the priority levels because of technological improvements and reduction in costs. Tomorrow's e-bus models are expected to have more efficient drivetrains, advanced batteries[44], and improved Battery Management Systems (BMS) offering longer driving ranges with the same or lower battery pack sizes. Also, the prices of lithium-ion batteries in the international market continue to decline and may fall below $100/kWh in the near future — a level regarded as an inflection point for the electric mobility sector (BloombergNEF 2020).

On the charging technology front, high-power DC plug-in fast chargers and pantograph super-fast chargers for e-buses are becoming more affordable over time. Innovative charging solutions that are in the trial stage (for example, wireless charging) may also become mature in the meantime. As a result, not only will the economics of route electrification get more attractive, indicating possible improvement in the rankings of currently less favorable routes, but e-bus rollout will also become favorable on routes that are currently considered technically challenging.

Therefore, **transit agencies must periodically reassess the financial sustainability of possible electrification of their unelectrified routes and revise their priority lists. It is important to ensure that the evaluation remains relevant in changing market conditions.** Further, transit agencies should explore ways to reduce CPKM and improve EPKM of the routes through better operation planning — for example, by improving fleet utilization, making demand-responsive changes in routes or service frequencies to increase ridership, etc. Early-stage planning on electricity supply and land arrangement can also help improve the economics of e-bus adoption. Engagement during the conceptualization stage and close coordination throughout the implementation period with the DISCOM and the municipality would, therefore, be critical.

Further, transit agencies should consider employing innovative implementation models (e.g., procuring e-buses based on battery leasing, infrastructure cost sharing with other e-bus operators, etc.) and finding new revenue sources, such as monetizing end-of-first-life batteries by using them to offer ancillary services to the electricity grid.

The government also has a constructive role to play. It should recognize that the economic benefits of e-bus service in terms of mitigating greenhouse gas (GHG) emissions and local air pollution far outweigh the initial high cost of e-bus rollout. Therefore, the central government should continue to offer subsidies for e-bus procurement (as currently available under the FAME scheme) and the sub-national governments should chip in to extend additional financial assistance to transit agencies in the form of VGF and interest subvention on loans. Moreover, state and city authorities' intervention to provide land on concession for building infrastructure for e-buses, and State Electricity Regulatory Commissions' considerate view on tariffs for public e-bus charging would go a long way in making e-bus adoption an attractive proposition for transit agencies.

It is worthwhile to underline here that the transit agencies should not treat bus fleet electrification as a one-time activity. Transitioning to an electric bus format is a journey in itself.

ENDNOTES

1. A little over 1,000 e-buses have been sold in India up to FY20 compared to a total of about 1.87 million passenger buses on the roads

2. Bus-operating transit agencies in India refer to the operational flexibility offered by a bus as its autonomy, which is primarily dependent on its driving range. Greater the autonomy of a bus, wider is the range of routes and duty cycles that it can serve.

3. VGF is a form of non-repayable funding (or grant) provided to support infrastructure projects that are economically justified but fall short of financial viability. Generally, the amount of funding provided in such cases is just enough to bridge the financial gap that makes an unviable project viable. For example, the Gujarat state government has introduced a VGF scheme called Chief Minister Urban Bus Service whereby transport authorities and urban local bodies can avail funding of up to 50% of the operation cost or ₹ 12.50 per km (Anadkat 2019).

4. Compressed Natural Gas

5. Kilowatt-hour

6. A diesel bus with a full tank can cover a distance of anywhere from 400 km to over 1,000 km depending on the fuel tank size.

7. In the case of some routes, there could be additional dead kilometers, depending on the distance between starting point of the journey and the serving depot.

8. One should bear in mind that the cost of the battery accounts for the largest share in the cost of an e-bus – about 40%.

9. Charging stations far from the starting or end point of a bus route increase the dead kilometers of e-bus operation, which may negatively impact the economics of operation.

10. Assuming mileage of 0.8 kWh/km

11. Considering three-hour night-time charging and 97% charger efficiency

12. Internal Combustion Engine buses

13. Dead kilometers are a non-revenue kilometers covered by a bus.

14. Some bus models are yet to receive homologation certificate in India.

15. The names of the e-bus OEMs or the e-bus models can not be revealed due to confidentiality-related reason.

16. As per inputs from OEMs

17. Automotive Research Association of India

18. Phase-II of Faster Adoption and Manufacturing of Electric Vehicles in India (FAME-II) is the flagship scheme introduced by the Government of India to support the adoption of EVs, including e-buses for public transport.

19. To determine the downtime, fuel economy values pertaining to urban conditions have been used.

20. The battery C-rate, which a measure of the rate at which a battery is discharged relative to its maximum capacity, can potentially limit the rate of charging in spite of using a high-power DC charger.

21. From 40% State of Charge (SoC) to 100% SoC

22. Considering fuel economy of 1.04 kWh/ km for midi AC e-bus and 1.3 kWh/km for standard AC e-bus. These fuel economy values are based on inputs received during stakeholder interactions.

23. A battery's DoD indicates the percentage of the battery that has been discharged relative to the overall energy capacity of the battery

24. Headway is the time gap between two consecutive buses on a route, and is the inverse of service frequency.

25. Generally, a shift change gives the maximum break time for a bus.

26. The batteries of the e-buses should be suitable for rapid charging.

27. Range extension can be done by charging at more than one intermediate stop, which could be the requirement on very long routes.

28. Dead kilometers for a bus in a day would be equal to the distance of the starting point from the depot multiplied by the number of times a bus goes back and forth between the depot and terminal in a day. Dead kilometers are added to the total daily trip lengths to estimate the daily running kilometers of a bus on a route.

29. Based on the survey of a sample of e-bus models with non-AC variant

30. Considering an average mileage of about 1.3 kWh/km

31. Compared to a 320-kWh battery pack

32. Highly compact DTs are also available but are more expensive.

33. Minimum voltage level is 11 kV

34. Based on lab testing conditions

35. Low-floor buses are more comfortable than high-floor ones, but generally they are more expensive.

36. In most cases, charging infrastructure is set up at depots or terminals or on the pool of land owned or taken on long-term lease by the transit agency for its bus fleet operation. Hence, the cost of space for charging infrastructure can be ignored. However, in case of en-route charging at intermediate halting points, the bus operator or the transit agency may have to arrange for space on rental or lease for setting up charging stations.

37. The cost includes DT, shed for sub-station yard, earthing, high- and low-tension panel sets, cabling and trenching, and local distribution panels.

38. Depending on the time available for opportunity charging

39. Requires specialized e-bus having a different design and battery chemistry with the ability to absorb charge at high power

40. Based on feedback from e-bus OEMs

41. Conversion rate of $1 = ₹ 74

42. OR decreases in value upon electrification of the route.

43. OR remains unchanged or increases in value upon electrification of the route.

44. Having higher energy densities and higher C-rates

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