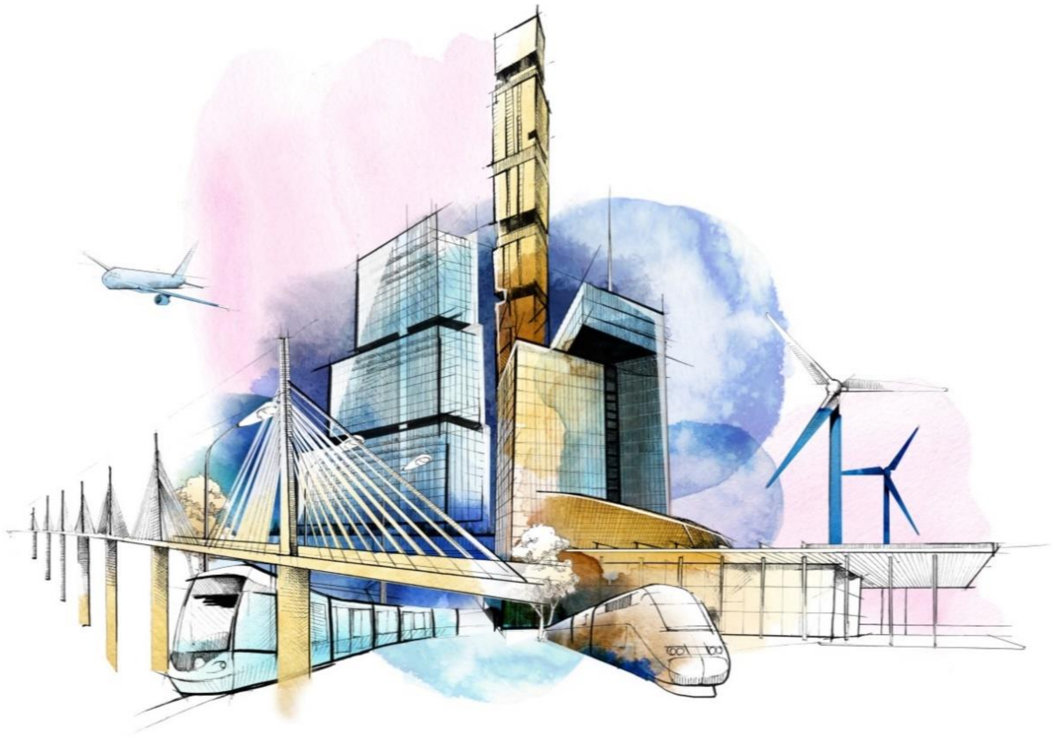

CONSULTANCY SERVICE FOR ELABORATION OF A TRANSITION PLAN FOR MUNICIPAL BUS NETWORK IN NAGPUR

TRANSITION PLAN FOR ELECTRIC BUS FLEET UPGRADE

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EXECUTIVE SUMMARY

The "Transition Plan for Electric Bus Fleet Upgrade" is the Final Report of the study for the transition and development plan of the bus network of the city of Nagpur, awarded by the French Agency of Development (AFD) to SETEC-NODALIS.

The beneficiary of the study is Nagpur Smart and Sustainable City Development Corporation Limited (NSSCDCL), in charge of coordinating for Nagpur Municipal Corporation all Smart City initiatives, including E-Mobility.

This Executive Summary is a compilation of the Executive Summaries of each Task Report of the mission, in order. All the activities, recommendations, and conclusions of the mission are later detailed on the report.

I. INTRODUCTION

Indian Government is promoting the transition of private and shared vehicles towards electrical engines, through the Faster Adoption and Manufacture of Electrical Vehicles (FAME) Program. The transition of the bus fleet towards e-buses may benefit from this incentive. Phase II of FAME Program aims to generate demand for 7,000 E-buses, 500,000 3-wheelers, 55,000 cars, and 1,000,000 2-wheelers.

Within the framework of "Mobilize your City" program for Smart City development in India, the **French Agency for Development (AFD)** is supporting the **Municipal Corporation of Nagpur (NMC)**, for the study of the municipal bus network reorganisation and transition towards electrical buses.

The beneficiary of the study is **Nagpur Smart and Sustainable City Development Corporation Limited (NSSCDCL)**, which is in charge of coordinating for NMC all Smart City initiatives, including E-Mobility.

The study for the transition and development plan of the bus network of the city of Nagpur, awarded by AFD to **SETEC-NODALIS**, consists in:

- The **study of the existing situation and previous studies** performed related to mobility plans in Nagpur (Comprehensive mobility plans, Bus Feeder Services to Metro),
- The **proposal of a plan for the bus network restructuring, transition and development of the urban bus network** plan to accompany the start of revenue service of Nagpur metro (bus routes modifications and implementation of feeder services), and implement overall mobility system in Nagpur also compatible with intermediate para-transit services (Auto, Rickshaws, and Cycle Rickshaws),
- The **study of the transition and evolution of the diesel / CNG bus fleet to electrical buses** (green mobility), with necessary modifications of depots and deployment of charging infrastructure, with technical feasibility studies for the first phases of deployment,
- The corresponding **financial modelling and contractual framework analysis**.

The proposed new bus network shall be compatible and fully integrated with the two metro lines that start revenue service in 2019 and 2020.

II. TASK 1, PART A - NAGPUR INCEPTION MISSION REPORT

Task 1 comprises the collection and organization of all the available mobility and urban planning studies relevant data, through liaising with the project main stakeholders as well the private bus operators. Task 1 main goal is to enable identifying the challenges and potential opportunities as well as highlighting priorities which will form the fundamental elements to elaborate the scenarios of the transition plan. **Part A** describes the organization and main steps and conclusions of the Inception Mission. Meetings, site visits, collected and requested data and main points of discussion are here compiled.

An inception mission has been jointly organized among Nagpur Municipal Corporation (NMC), Nagpur Smart and Sustainable City Development Corporation Limited (NSSCDCL), the *Agence Française de Développement* (AFD) and SETEC-NODALIS teams, and took place between January 16th and 22nd, 2020 in Nagpur.

The following aspects summarize the main topics and conclusions of the inception mission:

INFORMATION REGARDING THE CURRENT SITUATION IN NAGPUR

The inception mission and the meetings with the various stakeholders involved in the urban transport and mobility in Nagpur allowed to gain better knowledge of the situation and challenges faced to implement a comprehensive mobility system. This information is key to the development of relevant studies and advice in the framework of our mission.

Inception mission also highlighted that the studies that have previously been developed (Comprehensive Mobility Plan, Feeder Services studies, etc.) shall be used as the basis of our assignment, as their conclusions are globally shared and accepted among stakeholders.

URBAN TRANSPORT MODERNIZATION FINANCING IS A KEY-ISSUE

The urban mobility two major stakeholders, NMC and MahaMetro, have similar objectives (to provide quality and integrated urban transport system). On major transport axes, as the metro and city bus systems compete for ridership and income, one of the biggest difficulties to overcome is the financing of new projects such as the procurement of new electric buses and subsidies for bus operation.

As E-Buses have higher CAPEX costs than Diesel Buses, and NMC does not have the same possibilities as MahaMetro to obtain "non farebox revenue", the identification of available financing, and specifically of possible concessional support (grants, low or no-interest loans) remains essential.

HOW TO IMPROVE INFORMATION GIVEN ON FUTURE E-BUS TENDERS

In order to reduce the environmental impact of urban transport, the Indian government incentives municipalities to upgrade their bus fleets to electric buses. In parallel to the commissioning of the two Nagpur Metro lines, Nagpur wishes to restructure its bus network and transform part of its diesel bus fleet into electric buses.

The results of the Pre-Feasibility study expected from SETEC-NODALIS could be attached to future E-buses Tenders in order to provide more background information and confidence to Bidders and reduce risks (therefore improving tender attractivity and accuracy of bids technically and cost-wise).

GROSS COST CONTRACT IS THE PREFERRED CONTRACTING FRAMEWORK

It appeared during inception mission that Gross Cost Contracts are the main form currently implemented in India and are well known by all stakeholders (and therefore easier to launch). Also, they helps relieve the burden of CAPEX (by differing it through monthly instalments) for new investments to deploy new buses.

III. TASK 1, PART B AND TASK 2 - INPUT DATA ANALYSIS & MID-TERM VISION FOR NAGPUR PUBLIC TRANSPORT

Task 1 comprises the collection and organization of all the available mobility and urban planning studies relevant data, through liaising with the project main stakeholders as well as the private bus operators. Task 1 main goal is to enable identifying the challenges and potential opportunities and highlighting priorities which will form the fundamental elements to elaborate the scenarios of the transition plan. **Part B** presents a detailed assessment of the collected data through an in-depth review of the existing situation of public transports services in Nagpur, which is a key step in the process as it sets up the basis to understand and complete the current transport strategy. This detailed assessment covers technical elements (routes, fleets, estimated ridership), financial elements (costs, sustainability) and environmental impacts (CO_2 and air pollutants emissions). It is based on urban and transport planning documents and other data collected during and after the Nagpur Inception Mission. **Task 2** focuses on the assessment of the relevance of planning documents conclusions against the current situation, and notably the metro planning progress, and the actual NMC buses ridership (with data provided by DIMTS).

The collected data is described in this section and a detailed analysis of the main bus service planning documents is presented. On the second part of this report, a statistical analysis of the operation data provided by Delhi Integrated Multi-Modal Transit System (DIMTS) is performed. Finally, the report develops our mid-term vision for future public transport services in Nagpur. The following aspects summarize the main topics and conclusions of data analysis:

BUS ROUTES RATIONALIZATION AND BUS FLEET AUGMENTATION

The “Update of Comprehensive Mobility Plan for Nagpur” (2018) and the “Comprehensive Feeder Service Project for Nagpur Metro – Final Report” conclude on bus network optimization and rationalization.

To rationalize the City Bus Service routes in Nagpur, 76 bus routes have been defined. Among these routes, the reports identify 19 trunk routes to be operated along Nagpur’s major transit corridors, serving the main activity centres (designed as “hubs”), as well as 57 feeder routes that would operate from hubs to secondary activity centres.

For the development of this new bus network, the "Update of Comprehensive Mobility Plan for Nagpur" planned a bus fleet size increase by amost 90% in 2018 (820 buses in total) and up to 4,5 times its actual size in 2041 (2,418 buses in total). Among this fleet, 10% is proposed as electric buses.

BUS SCHEDULING, OPERATION, RIDERSHIP, AND MAIN CHARACTERISTICS

The various input data analysed contain information on City Bus Service. In December 2019, the daily ridership estimated was 1.60 Lakh passengers for 345 buses operated per day. In January 2020, after the Nagpur Aqua Metro Line operation began, the average number of passengers was of about 1.71 Lakh passengers for 368 buses operated per day.

Even if a significant increase in ridership is noted from 2017 data, the daily ridership forecasts of the transport planning docments seem higlhy overestimated, despite the increase in bus supply, since daily ridership was expected to be 3.60 Lakh in 2018.

A VISION FOR THE FUTURE OF NAGPUR CITY BUS TRANSPORT SERVICES

As a summary, we propose that the development of City Bus Service network to be based on the 76 "trunk and feeder" routes identified, coupled with a transition plan of the thermal bus fleet (432 buses in 2020) to electrical buses.

Furthermore, we propose that the deployment of the electric bus fleet to consider a development "approach by depot" (bus routes organization and rationalization), as it shall allow to maintain coherent operation and maintenance units. We propose to consider the 9 depots identified in the transport planning documents (3 of which already existing).

IV. TASK 3, PART A - ENGINE, ROLLING STOCK AND INFRASTRUCTURE BENCHMARK

Task 3 consists in studying the possible engine options, the various existing technologies for the rolling stock and the electrical charging infrastructures, as well as the overall impacts on the Nagpur City Bus operation and management strategy. **Part A** assesses the various engine, rolling stock and charging infrastructure options available on the market and that could apply to the Nagpur City Bus System. Its aim is to comfort Nagpur City's decision of a transition towards electric buses, and it provides the key data for the choice of rolling stock and related electrical infrastructure.

MOTORIZATION COMPARATIVE ANALYSIS

Performance criteria	Diesel	Hybrid	CNG	Fuel cell (hydrogen)	Electric
Tail-pipe emissions *(PM, NO_x, HC, CO)*	High ---	Medium --	Very low -	Null +++	Null +++
GHG emissions *(Gco2e/km)*	High ---	Medium --	Low -	Null (1) +	Null (1) +
Passengers' comfort	Standard +	Comfortable ++	Standard +	Very comfortable +++	Very comfortable +++
Noises	High ---	Low to medium --	Low noise -	Very low noise ++	Very low noise ++
Technological maturity	Very good +++	Good ++	Good ++	Low -	Medium +
Autonomy	High +++	High +++	High +++	High +++	Medium ++
Impact on the depot *(Environmental regulations depending on country)*	Not applicable +++	Battery working area ++	Filling station Specific equipment needed, explosive environment -	Filling station Specific equipment needed, explosive environment -	Power supply infrastructures and battery working area -
Maintenance activity	Medium ++ Spare part cost -	Medium ++ Spare part cost (battery) --	Medium ++ Spare part cost (filling station) --	Medium ++ Spare part cost (filling station) --	Low +++ Spare part cost (battery and charging infrastructure) ---
Vehicle cost *(for a 12m bus without AC)* (2)	150 to 250k€ Rs 30 to 50 lakhs +++	250 to 450k€ Rs 1,2 to 1,4 crores +	250 to 450k€ Rs 30 to 50 lakhs ++	600 to 800k€ Rs --	400 to 800k€ Rs 2 to 3 crores -
Fuel cost	0.3 to 0.37 €/km Rs 15 to 23 /km -	0.25 to 0.30 €/km Rs 10 to 17 /km +	0.17 to 0.24 €/km Rs 13 to 19 /km ++	0.8 to 1,2 €/km Rs 60 to 80/km --	0.10 to 0.12 €/km Rs 8 to 10 /km +++
Vehicle maintenance cost in Europe (3)	0.10 to 0.15 €/km +++	0.20 to 0.25 €/km -	0.15 to 0.20 €/km ++	0.4 to 0.5 €/km --	0.18 to 0.22 €/km +
Vehicle maintenance cost in India (3)	Rs 10 to 20 /km -	Rs 15 to 20 /km -	Rs 14 to 18 /km +	No information (4)	Rs 6 to 10 /km +++

(1): Depends on the process of hydrogen and electricity production.

(2): Usual European costs in euros and usual Indian costs (INR) presented for comparative purposes only.

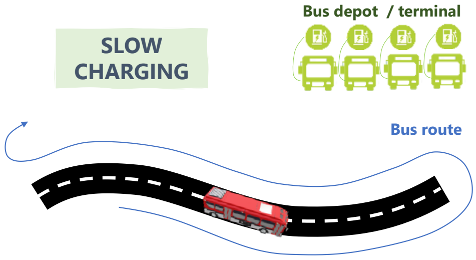
(3): Maintenance costs do not include renovations and renewal costs (battery renewal for example).

(4): Due to lack of data and feedback on this type of motorization for buses and the fact that this technology is not well developed in India.

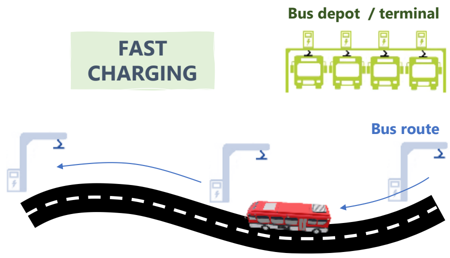
This report focuses on electric vehicles. Different technologies are available for the vehicles and the charging infrastructure, the choice of technology is mainly based on the charging strategy selected. Our **main recommendations** regarding electric vehicles and charging infrastructures are reproduced below.

CHARGING STRATEGY

Different strategies yield to different results regarding the capacities of the storage system in relation to daily travelled distance:



- Slow charging is the process of providing vehicles with enough energy capacity to reach a level of autonomy that allows them to operate for several hours (usually plural round trips). When the reserve is exhausted, the vehicle must return to the depot area (where charging infrastructure is usually installed) to be charged. With slow charging, there is a **strong correlation between the capacity of the storage system and the distance travelled daily** by the vehicle, explained by different specific consumptions according to the context of the networks, and by the depth of discharge at the end of the day: some networks go up to 100% while others limit themselves to 60% in order to extend the life of the batteries and to keep a margin of autonomy.



- Fast charging consists in fitting the vehicles with enough energy capacity to travel a one-way trip or less. The vehicle is charged during dwell times at stations and/or terminals. Charging power is usually large enough to make the charging time fit into the time required for service. In this way, charging has little impact on operation (especially time spent in depot areas). There is **little correlation between the distance travelled daily and the capacity of the storage system**. Indeed, as autonomy is restored at each trip, capacity is rather related to the distance between charging points.
- Mixed charging vehicles can be charged at the terminus at each trip, but their full autonomy is not necessarily restored (i.e., battery is not charged to its total capacity). The vehicles then regain their full autonomy when they are slowly charged at the depot. Depending on the technology, this slow charge also balances battery cells. It should be noted that this type of charge requires the combination of 2 battery technologies (with adapted charge performance) allowing both types of charge. There is some correlation between the capacity of the storage system and the distance travelled daily by the vehicle, depending on whether the system is closer to a slow charging or a fast charging.

Regarding in-line charging technologies (fast charging at a terminal or station), if the strategy partially eliminates the problem of autonomy, it generates specific constraints in terms of necessary charging infrastructure in line or at the terminus, the assigning of the rolling stock to an equipped line (operation and maintenance constraints), shorter lifetime and/or lower battery energy density, implementing of a rolling stock guiding system (for some types of rolling stock), and potential impact on the operating performance (timetables, deadheading, sizing of the vehicle fleet).

For Nagpur, the slow charging strategy (and therefore **depot charging technology**) **is recommended considering the average distance travelled per day**. Indeed, the usual battery storage capacity enables to travel up to 300 km without charging in line. However, it should be noted that the feasibility also depends on the bus depot location.

VEHICLE CHARGING IMPACTS ON REGIONAL ELECTRIC GRID

The number of buses within a bus fleet would to a significant extent determine the charging requirements, which in turn would determine the energy requirement and additional power plants (if necessary). An analysis of load profile can show whether some plants that are not being used during off-peak hours can fuel the electric bus fleet. The bus charging schedule can be controlled since the vehicle travel time is temporally separate from the time of battery charging. Typically, electric vehicles are charged most economically during off-peak hours and preferably using base-load plant supplies (lower electricity costs). Another scenario is if a large electric bus fleet is to be charged during peak-load hours. This configuration shall require the addition of new generators and involve considerable infrastructure investment. A thorough grid supply-and-demand analysis shall be carried on along with electro-voltaic fleet economics to arrive at the optimum plant mix for a particular region. Typically, the practice is to match the electro-voltaic charge demand with base plants.

According to the Approved Tariff Schedule in the Maharashtra State, new underground connections up to 10,000 kVA are allowed. For instance, a depot with 150 electric buses shall require in average 5,000 to 7,000 kVA power connection. **The connection to the existing Maharashtra power distribution grid shall then be possible**.

RECOMMENDATIONS - ELECTRIC MOTOR SYSTEMS

Motor system	Advantages	Disadvantages
Central engine 	• Easy adaptation of existing vehicles • Less equipment	• Cumbersome • Less suitable for low-floored buses • Breakdown = no traction is possible
Drive axle 	• Small size • Independent motorization • Easier maintenance	• Noisier • Heavier maintenance (greater number of equipment)

Most mini and midi buses are equipped with a central motorization. Standard buses can be equipped with either a central motorization or a drive axle. The power of an electric bus traction motor is categorized depending on:

- Peak power (maximum power that the electric motor can deliver during acceleration and braking phases) and
- Continuous power (nominal power supplied in steady state).

The powers usually encountered are very variable, whichever the bus format considered:

- For a minibus and midi bus, it is about 160 kW on average,
- For a standard bus, it is about 200 kW on average.

For mainly urban journeys, it is recommended to choose a **medium power rating** in order to guarantee the best compromise between performance and range: **120 kW for mini, 160 kW for midi, and 200 kW for standard buses**.

RECOMMENDATIONS - AUXILIARY SYSTEMS

A range of evaluation of the auxiliary systems power (mainly lighting and power supply of passenger information media) according to the bus sizes is considered hereafter. These ratings depend directly on the on-board equipment and the inverters responsible for powering them.

Description	Minibus	Midi bus	Standard
Auxiliary system consumption	1.5 to 2 kW	2 to 3 kW	2 to 3 kW
24V Network consumption *	1 kW	1.4 kW	1.4 kW
High Voltage network consumption °	0.5 kW	0.7 kW	0.7 kW

(*) Includes power supply for the ticketing system and the passenger information system.

(°) Includes power supply for the air compressor and the power steering.

RECOMMENDATIONS - THERMAL COMFORT

The power consumption of a bus is divided into traction, air conditioning / heating, and lighting and other auxiliaries (passenger information, public announce…). The distribution between these different items depends greatly on the type of route, commercial speed, and local climatic conditions.

The generally observed distribution for a bus travelling on an urban route (between 15 and 17 km/h commercial speed) in temperate regions is of 63% for traction, 35% for air conditioning / heating and only 2% for lighting, low current and other auxiliaries. Air conditioning is therefore a particularly important consumption item, which can reduce the battery autonomy of vehicles. Furthermore, air conditioning systems require specific maintenance (periodic filter change and refrigerant refilling) that generates additional costs.

Considering the climatic conditions in Nagpur, it is not recommended to equip the vehicles with heating systems. Air conditioning is an option, although it should be noted that this system highly impacts the energy consumption. The recommended solution is either **refrigerated forced mechanical ventilation or glazing openings**.

RECOMMENDATIONS - BATTERY TYPE AND CAPACITY

Each type of battery comprises distinct characteristics. Lithium ion type batteries (Li-Phosphate, Li-Manganese) have good energy densities (available energy of the battery as a function of its mass) and are typically used for transportation applications. Other important aspects, such as life cycle, charging time, and operating temperature are also to be considered when selecting the battery. A certain battery may have high energy density, but shorter span compared to another battery with the same energy density.

Batteries with high power density (ratio between battery available power and its mass) are often used to optimize the performance of brake energy recovery systems. The LI-Titanate battery type developed in recent years also have superior quality in terms of the number of charging cycles.

Some new electric vehicles use two types of battery technologies to increase vehicle performance. A high power density battery is used to recover energy during braking and a high energy density battery is used for the main energy storage unit that is charged by an external power source during refuelling operations (depot charging or in-line charging).

The type of battery will also depend on the chosen charging strategy. Depot charging implies slow charging of the battery and, in this case, for a **Lithium iron phosphate (LFP)** or **Lithium nickel manganese (NMC)** technology battery, the acceptable charge rate is around 1C, meaning that the battery can be charged in 1 hour. The life expectancy is in the order of 3000 cycles.

The **recommended battery types are LFP and NMC**. In view of the climatic conditions in Nagpur and considering the 20-25% margin considered in the event of operational contingencies, vehicles with **medium battery capacity** are recommended. Thus, for a standard bus, the **recommended total capacity is in the range of 300 to 400 kWh**.

RECOMMENDATIONS - CONNECTION SYSTEMS

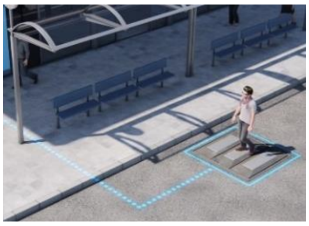
The Bus Up system involves a pantograph located on the bus that meets the rails of the charging station located above the bus. Power ratings can reach up to 600 kW for fast charging. The mobile part is deployed from the roof of the bus. A stem (fixed infrastructure) supports the contact elements allowing the buses to charge. The system guarantees a range of available power that suits any size of bus to be considered (including articulated). On the other hand, it is a system that has not been tested for depot charging. Moreover, it has an impact on operating performance by making the bus heavier and reducing its autonomy.

The inverted pantograph system differs from the Bus Up pantograph system in that it has the moving part of the pantograph on a fixed point. The bus is then only equipped with the contact point, and the moving parts are limited. In this case, there is no longer one pantograph installed per bus, but only at given points. Power ratings can reach up to 600 kW for fast charging. The inverted pantograph imposes high maintenance constraints (requires secure access to the upper parts of the charging infrastructure) and is not more suitable than the pantograph system for the depot charging, even if the constraint on the on-board weight at bus level is lower.

The Combined Charging System (CCS) is used for charging at a depot charging station. These sockets permit rapid DC charging. The connector allows the physical connection with the vehicle. The current trend in the electric vehicle market is the use of type 1 (North and Central America, Korea, Taiwan) and type 2 in India (as well as North and South America, Europe, South Africa, Arabia, Oceania and Australia). For high-power charging, the combined charging system in direct current (DC) variant is used. It should be noted that for powers below 50 kW, the charger can be integrated into the vehicle. Otherwise, the terminal is external. The combined charging system is the most widely deployed system in depots to date. It offers a power range that allows all possible cases to be considered in terms of bus capacities available on the market today.

SAE J1772 plugs (Type 1 plugs) are the most widely used plug in North America for charging passenger vehicles. Unlike the CCS plug, the SAE J1772 plug only allows vehicles to be charged with AC power up to 19.2 kW. The AC / DC converter for charging the batteries is on-board the vehicle. An SAE J3068 plug, also known as a Type 2 plug, is the most widely used plug in Europe for charging passenger cars and it can be used to charge up to 43 kVA. The procurement of minibus type vehicles must be mindful of the type of connection, which in general is poorly adapted to the charging of the battery capacities for urban buses.

For ground-based induction systems, the power supply from the electricity distributor is converted into high frequency alternating current (~20-60 kHz) which feeds the transmitter coils. These are installed under the bus lane. The high-frequency magnetic field produced by the transmitter coils is picked up by a receiver (a circuit resonating with a receiver coil) fitted under the vehicle. The alternating current thus sensed is then converted into direct current on board the vehicle to enable it to charge its batteries.



The ground-based charging system is a proprietary solution developed by Alstom. The bus, on arriving at the charging base, emits a coded signal. Retractable skids under the bus are put in contact with the base on the ground. This signal, received by the ground equipment, allows the protective flap to be raised to ensure that no object can meet the terminal. Water tightness with the environment is then ensured. Based on the installation constraints and the high charging power, the system does not appear to be suitable for depot charging scenarios. Indeed, this system was conceived for fast charging.

	Bus Up	Inversed pantograph	CCS plug	SAE plugs	Induction system	SRS
Depot charging proven	-	-	+++	+++	---	---
Installation	-	-	++	--	--	--
Power adapted	+++	+++	+++	--	+++	+++
Operation and maintenance	-	-	++	++	-	-

Our **recommendation for the connection system for Nagpur is the CCS plug**. This system has proven itself in various depots in Europe and is becoming more and more the standard for a wide range of rolling stock (including smaller vehicles). However, it should be noted that the market for minibuses still features vehicles without CCS plug

RECOMMENDATIONS - HIGH AND MEDIUM VOLTAGE, TRANSFORMERS, AND LOW VOLTAGE SWITCHBOARDS

The high and medium voltage equipment mainly includes switchgears for medium voltage arrivals (distribution network), electricity meter, and switchgears for the transformer's inputs. Transformers allow the electric voltage to be lowered to the chargers input voltage. Usually, this voltage is around 400 V / 50 Hz (three phases). Low voltage switchboards direct electricity from the transformers to chargers.

These equipment' characteristics depend on requested charging power, the number of chargers, the distances between the electric rooms and the charging areas, and the number of buses charging.

RECOMMENDATIONS - CHARGER OPTIONS

Single charging terminals are the most common. A terminal is composed of a power converter and a cable connected to a CCS plug. A single terminal can only supply one bus. The desired voltage and power level are controlled by the vehicle's battery management system within the technical limits of the charging terminal. Variations to the typical model include terminals provided with two fixed or variable power plugs and parallelizable terminals.

A sequential charging terminal allows up to three buses to be charged sequentially from a single charger at a power of 150 kW: the buses connected to the same charger do not charge simultaneously but one after the other. This solution has the advantage of saving space in the depot, as the charging terminal can be installed in a single defined area, and the small remote modules can be installed on the wall or at a height in line with the vehicles. A "first in = first out" principle must be respected and thus the connection of the remote modules to the chargers must ensure that the first vehicles to arrive are connected to separate chargers.

The matrix charging solutions allow a charging station to be connected to several vehicles through charging points. The charging terminal provides the required power for each charging point within the limits imposed by the terminal: the sum of the powers delivered by a charging terminal is limited by its rated power. This solution is more modular, but the space required to implement this solution is greater than in the sequential charging system: in addition to the charging terminal, it is necessary to implement charging points at each location. As the market for matrix charging systems is still immature, the solutions being developed vary from one manufacturer to another.

The **sequential charger is recommended** for Nagpur buses as it optimizes infrastructure and energy consumption.

V. TASK 3, PART B - OPERATION AND MAINTENANCE STRATEGY

Task 3 consists in studying the possible engine options, the various existing technologies for the rolling stock and the electrical charging infrastructures, as well as the overall impacts on the Nagpur City Bus operation and management strategy. **Part B** presents a general assessment of the impacts related to the choice of electrical buses, in terms of depot and charging stations configuration, operational plan and fleet optimization, upgrade of depot infrastructure and bus stops/shelters, as well as requirements regarding specific training for operation and maintenance staff.

This report presents a general assessment of the impacts related to the choice of electrical buses (compared to diesel buses), in terms of depot and charging stations configuration, operational plan and fleet optimization, upgrade of depot infrastructure and bus stops/shelters, as well as requirements regarding specific training for operation and maintenance staff.

ELECTRICAL INFRASTRUCTURE ASSESSMENT

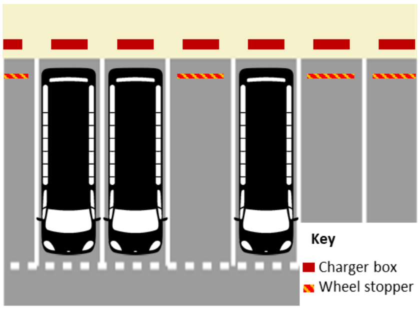
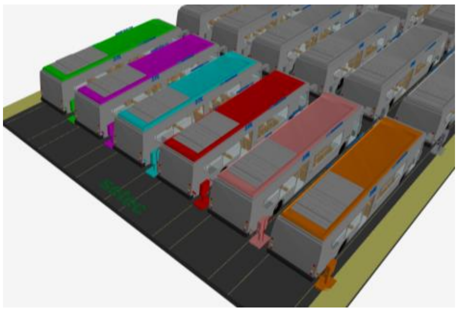
To better adapt to each type of depot present in the Nagpur bus network, **we suggest a modular infrastructure**, which can adapt to varied sizes of depot and quantity of parked buses. The electrical equipment consists of medium voltage equipment (switchgears for medium voltage feeders, electricity meter, general circuit breaker, circuit breakers for the transformer's inputs), redundant transformer substation (transformers, main circuit breakers, secondary circuit breakers, inverter), and chargers' room (electrical switchboards and chargers' terminals).

PARKING LAYOUT

Electric bus parking zones do not require any specific development apart from the installation of the charge boxes. The constraint lies in the temporary immobilization of vehicles in these charging zones for which charging times are directly dependent on the state of the battery of each vehicle. It is therefore necessary that the charging zones allow several charging immobilization times without hampering the maneuvering of other vehicles. This is also dependent on the layout (current or possible) of the bus depot.

Regarding parking layout, 2 configurations are usually applied: individual parking (charger boxes to be installed on the ground, behind the buses) or stacked parking (charger boxes to be installed beside each parking space, if possible, between each space, ensuring that this arrangement does not penalize the movement of vehicles and staff). In some bus networks, when there is no space available to install the charger boxes on the ground, an aerial installation is possible. For this, a load-bearing metal structure is necessary to install the charger boxes and the cable reels. Aerial structure specifications depend on the quantity of buses to charge.

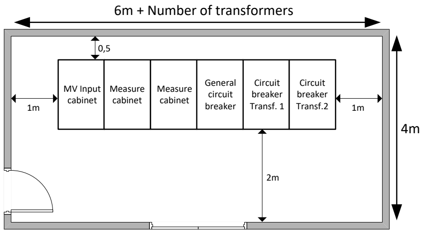
We **recommend for future Nagpur electric bus depots the use of individual parking spaces**, thus allowing easier bus operation, maintenance, and parking.

	Individual parking spaces	Stacked parking spaces
Typical configuration		
Advantages	Easier operation and maintenance scheduling of the buses.	More important ground space is required.
Disadvantages	Space proofing if the depot area is limited.	Operation constraints regarding the use of buses, requirements for a building or metallic overhead structure to install the chargers.

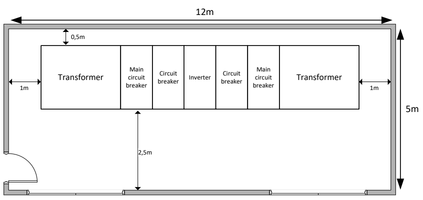
TECHNICAL ROOMS REQUIRED

We recommend a modular infrastructure based on 3 rooms:

Chargers	Electric buses	MV room	Transformer substation	Chargers room
16	48	1 room (32m²)	1 room (60m²)	1 room (65m²)
32	96	1 room (40m²)	2 rooms (2x60m²)	2 rooms (2x65m²)
48	144	1 room (48m²)	3 rooms (3x60m²)	3 rooms (3x65m²)

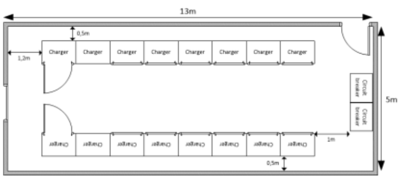


A medium voltage (MV) technical room is typically composed of 1 cabinet for switchgears for medium voltage feeders (Nagpur Power grid network), 2 cabinets for the electricity meter, 1 cabinet for general circuit breaker, and 1 circuit breaker cabinet per transformer. The size of the MV technical room depends on the quantity of transformers (depending on the quantity of chargers to install). The diagram presents the layout of the technical room, including required maintenance spaces. **The MV room shall be air conditioned to keep a constant temperature**.



A transformer substation usually contains: 2 pad-mounted transformers (for redundancy), 2 main switchgears cabinets, 1 cabinet for the inverter, and 2 secondary switchgears cabinets. The diagram presents the layout of this technical room, including required maintenance spaces. **The transformer substation shall be air conditioned to keep a constant temperature. The required minimum area for this room is 60 m²**.

To optimize spaces, some manufacturers propose modular solutions combining the MV room and the transformer substation in a single prefabricated room (container for instance). The room is factory manufactured and upon arrival at the depot wiring and configuration must be done (on-site). The size of the room may depend on manufacturer.



A charger room is composed of the chargers and circuit breakers. To optimize spaces and wiring, **we recommend installing it near the transformer substation**. In this room, the terminals can be placed side by side without space, near a wall with a 100mm space in between, or back to back with a 200mm space in between. The diagram presents the layout including required maintenance spaces. **The required minimum area is 65 m²**. The standard operating temperature of the charging terminals is between -10°C to +50 °C. However, **the technical room shall be air conditioned** to keep a constant temperature.

Bus shelters / stops charging infrastructure

In terms of charging infrastructure, only the opportunity charging technology requires bus shelters / stops upgrades. According to the operation inputs (maximum mileage per day, bus length, etc.), we recommend **depot charging**. However, this report briefly describes the bus stops upgrades requested if an opportunity charging technology was selected.

Maintenance activities – Workshop upgrades

In terms of requirements in the maintenance workshop for the maintenance of electric vehicles compared to current diesel vehicles, there are two categories:

- Vehicles' mechanics and bodywork maintenance: the main body and mechanical elements are identical to the equipment of diesel vehicles. The workstations and tools shall therefore remain essentially the same, or even optimized for certain stations, such as the motorization part or the mechanical braking part.
- Vehicles' electrical and electronic equipment: low voltage electrical / electronic equipment and power electrical equipment become the main equipment requiring workstation adjustments and specific tools for the maintenance, such as an electrical workshop dedicated to the traction chain: engine and traction equipment, or ventilated workshop and storage room dedicated to maintenance and storage of batteries. Furthermore, this equipment requires the installation of an electrical workstation equipped with the tools recommended by the bus manufacturer.

Workshop rooms / stations	Main specifications
Mechanical	It is considered that the overall surface area of the workshops remains identical to that for the maintenance of diesel buses. However, new distributions or redesigns of the mechanical workshop in favor of the high current electrical workshop shall potentially be necessary.
Electrical	
Electromechanical	
Electronic	
Oil storage room and equipment	This room size **can be optimized** (removal of the engine part).
Spare parts storage	The room size is identical to that required for diesel buses maintenance. However, there are more electronic parts, which require specific conditions (constant temperature, for instance).
Battery storage room	The **ventilated battery room**, secure and equipped with a slow charger, shall be sized for the storage of a set of 3 to 5 battery units.

Workshop equipment	Main specifications
Roof access footbridge	Vehicles have more components on the roof, it is **recommended to provide working areas at height**. The footbridge shall have an access height of ~ 3m, a length between 12 to 13m, a track width between 1 to 1,5m, and should be secured by a railing and access by gate.
Overhead crane 2,5 tones	This equipment is **necessary to handle batteries and other traction equipment**, which are located on the bus roof.
Bus washing machine	The height of the machine shall be compatible with electric buses.
Exhaust gas extraction equipment	Gas extraction equipment is not required for electric vehicles.

DEPOT CHARGING MANAGEMENT SYSTEM

A charge management system provides global control of the chargers on a shop floor level and thus enables the automatic distribution of bus charging to limit the maximum power demand. The system therefore controls the chargers sequentially on/off and the bus to be charged, as the chargers can be connected to several buses. It also allows to collect data on the state of charge of the busses, to consider the bus scheduling data and scheduled maintenance tasks, to calculate a bus charge schedule that minimizes the maximum power demand, to adapt scheduling in real time according to operation contingencies, and allows operators to identify ready for operation buses.

SAFETY RELATED TO ELECTRIC BUSES OPERATION AND MAINTENANCE

The **number of bus drivers shall remain constant with the arrival of electric buses**. The driver must therefore be able to connect the charging system. Some additional tasks shall be required, but these tasks are not intended to engage the driver's safety. The main change for the departure and return tasks is to plug or unplug the charger. **Driving habits when driving electric buses are different** from those related to diesel buses as it must be more gradual in terms of acceleration / deceleration to reduce overall battery consumption during service. A risk of electric shock may occur if work is carried out by unqualified personnel in the engine compartment or inside the battery compartment.

Replacement of batteries in electric buses shall be carried out by qualified personnel. It is recommended to set up a battery room in the workshop to make the transition from new and used batteries. It is more advantageous to purchase the batteries when necessary, thus avoiding storing a large quantity of batteries for an extended period. A subcontractor can be responsible for the supply, repair, and disposal of batteries. **Operators shall nevertheless have a procedure to detect damaged or faulty batteries**. Upon detection (at least one battery) and pending its removal, it is recommended to isolate the damaged vehicle on a dedicated area (where storage of oxidizing materials is prohibited).

The nature of the maintenance tasks may expose the worker to electrified bare parts. **A work plan shall be drawn up and suitable protective equipment is required, as well as qualification**. As for batteries, a subcontractor can be responsible of such tasks. Medium voltage and low voltage distribution infrastructure require recurring maintenance, generally entrusted to an external specialized subcontractor which carry out the tests according to a rigorous test plan.

Additional safety recommendations: electric bus depot shall have controlled access, restricted to the operator's personnel and to any third party authorized. Vehicles shall be parked without blocking the access of fire and rescue service equipment from traffic lanes outside the installation. Bus charging areas shall be clearly signed and organized as to allow the access of emergency services and located at least 10m away from flammable or oxidizing materials / facilities. The transformer substation shall be protected against mechanical shock and external aggression, including the mishandle of a vehicle. The bus depot area shall be equipped with suitable automatic fire detection system, firefighting capabilities, and sufficient capacity for retaining fire extinguishing water. Closed rooms housing electric equipment shall be equipped with a mechanical ventilation system or natural smoke and heat evacuation devices.

Human resources and qualifications required

In some cases, the autonomy of an electric bus is not enough for an entire day. In such cases, buses must return to the depot for charging during service, which may increase the total amount of driving hours (and number of drivers). In Nagpur situation, the maximum daily mileage is 200 km (for the current operation contracts) and as such, **no additional driving time shall be necessary**. Nevertheless, this information shall be confirmed during **Task 6**, when we shall assess whether daily mileage can be increased for overall optimization of bus contracts.

For vehicle maintenance, there is a **transfer of 20% of the time** from the “mechanical activities” to “electrical activities”. For the charging and the electrical infrastructure (considering a bus depot hosting up to 50 buses), the **estimated maintenance time is around 140 hours/year and 100 hours/year**, respectively.

Impacts on staff training

Suppliers always offer training after procurement, aimed at allowing staff upgrading on new operation / maintenance tasks. **We recommend NMC and bus operators to capitalize on training offered by suppliers**. Similarly, **we recommend NMC and bus operators to consider a “Train the Trainers” approach**. By taking on new knowledge and skills, bus operators and/or NMC shall be able to shape training modules specifically designed for their staff.

Regarding bus drivers and control centre staff, training must be specific to the procured vehicles and installed electrical equipment. Due to the specificity or parameters of the equipment adapted to the Nagpur bus network as well as the skill level of drivers, training modules must be provided or established on the basis of the documentation from the manufacturers / suppliers as well as local regulation. For maintenance staff, our feedback from different electric bus manufacturers shows that approximately 100 hours of training shall be necessary in Nagpur case to bring a diesel vehicle maintenance employee to an acceptable level of competence to perform maintenance of electric buses.

VI. TASK 4 - FINANCIAL AND CONTRACTUAL FRAMEWORK ANALYSIS

The objectives of **Task 4** are to provide: (i) a financial assessment of the bus transition and development plan as well as a review of the possible financial support mechanisms and sources, and (ii) an analytical review of the current contractual framework of Nagpur City Bus Services and recommendations on the possible optimisation mechanisms.

FINANCIAL ASSESSMENT - OBJECTIVES AND GENERAL APPROACH

A mid-term vision for the future of Nagpur's public transport was developed in **Task 2** of the study based on both replacement of existing diesel buses with electric ones and augmentation of the overall fleet. However, given data availability restrictions (on ridership levels and revenues), we were unable to accurately estimate the overall financial impact of this mid-term vision on the financial sustainability of the system.

Hence, this report focuses on the following:

- Assessment and comparison of the additional costs yielded by the transition and development plan, as developed in **Task 2** and hereafter called "the fleet augmentation scenario", to the current situation, and
- Assessment of the impact of three other possible fleet transition and development scenarios on the financial sustainability of the service, with the following assumptions: an assessment period of 15 years starting 2022, constant ridership levels and commercial revenues over the years (in real terms), and constant bus fleet and supply levels throughout the analysis period.

The suggested scenarios, also called in the report "**fleet replacement scenarios**", are based on a replacement of the existing diesel buses with electric ones considering the end dates of existing contracts as follows:

- **Scenario 1: Replacement of 20% of the network fleet with electric buses**,
- **Scenario 2: Replacement of 50% of the network fleet with electric buses**,
- **A reference scenario: Replacement of diesel buses (with 0% new electric buses) and the same overall fleet**.

For all these scenarios, the new buses (and related charging equipment and infrastructure, when applicable, i.e., electric buses) were assumed to be financed by the operators. Hence, the kilometre charge applied for the new buses includes the investment costs for vehicles and related equipment and infrastructure when applicable.

The financial assessment was conducted using a financial model developed for Nagpur City Bus Services.

FINANCIAL ASSESSMENT - MAIN FINANCIAL MODELLING RESULTS

The comparison of the estimated kilometre charges for electric and diesel standard buses shows that while the operating expenditures are significantly lower for electric buses compared to diesel ones, the investment and renewal costs are considerably higher in the first case. This explains the higher kilometre charge for the electric buses.

The financial modelling of the overall service shows that both fleet replacement scenarios and the fleet augmentation scenario will yield higher service costs compared to the current situation. However, the additional service costs yielded by the fleet augmentation scenario are significantly higher compared to the current situation, reaching more than three times the current service costs (in nominal terms) at the end of the evaluation period.

Fleet replacement scenarios (the reference scenario, scenario 1 and scenario 2) will require around 4%, 16% and 35% more yearly additional resources compared to the current operational subsidies provided by NMC. In 2022, this is equivalent to additional INR 4.33, 17.10 and 36.10 Crores, respectively.

The fleet augmentation scenario shows that while service costs increase remains relatively limited in 2022 (+20% compared to the current situation, which is equivalent to INR 34 Crores of additional service costs), it becomes very significant over the analysis period. In 2037, the service costs of the fleet augmentation scenario exceed three times the service costs of the current situation (equivalent to an additional INR 1043 Crores of service costs compared to the current situation). However, service revenues are unlikely to increase proportionally.

FINANCIAL ASSESSMENT - POSSIBLE LEVERS TO ENHANCE SYSTEM'S FINANCIAL SUSTAINABILITY

A benchmark of Nagpur's urban public transport policies with other comparable agglomerations shows that:

- Priority is given to the service affordability with relatively low tariffs,
- Supply levels are relatively limited, and
- The financial sustainability is very limited with comparatively higher public subsidies.

The conclusions on supply levels are consistent with the current situation and confirm the rationale for Nagpur's bus development plans (fleet augmentation).

However, assuming constant production efficiency, increased supply levels (and thus service costs) will necessary require additional public financial resources (i.e. subsidies: operating or investment subsidies), or increased service revenues. A third solution would be to improve production efficiency.

Therefore, based on these conclusions and the analysis of the operational performance determinants, we identified four action areas that could be explored to support the financial sustainability of the system:

- **Solution 1: Increased cost efficiency**,
- **Solution 2: Increased commercial efficiency**,
- **Solution 3: Investment subsidies**,
- **Solution 4: Increased fare-box revenues**.

While increased fare-box revenues could be achieved through increased tariffs and/or ridership levels, and investment subsidies could be ensured from globally available financial resources (such as the Green Climate Fund and the Clean Technology Fund), optimized cost and commercial efficiency require an optimization of the current contractual framework.

CONTRACTUAL FRAMEWORK ANALYSIS

The analytical review of the current contractual framework identified two main areas that could reduce the potentially increased viability gap in bus electrification scenarios:

- Optimizing contract duration and bus ownership provisions to reduce the annualized CAPEX charge, and
- Providing for contractual incentives in both the NMC-DIMTS and the NMC-Operators contracts for improving commercial efficiency and cost efficiency.

The first area stems directly from the increased share of CAPEX in the annual service charge for electric buses, and the potentially increased service life of electric buses. Current provisions appear somewhat misaligned, with a potential upside to operators that does not benefit NMC nor increases competition for the contract.

The second area stems from the misalignment of current contractual incentives with the objective of reducing the viability gap.

On the cost efficiency side, although bus operators are recruited through competitive bidding processes, the absence or the limited information on the service plan provided at the bidding stage limits the operators' ability to optimize the quoted kilometre charge. Later on, the contractual framework does not allow NMC to benefit from any possible cost-efficiency gains that could be achieved by the operators and DIMTS has no incentive to adjust service plans to allow for such efficiency gains.

On the commercial efficiency side, DIMTS is responsible for the design of service plans without any contractual incentives for optimization. In fact, for DIMTS, the only incentive is related to increasing ridership and exceeding the base monthly passenger count[1].

Therefore, we recommend the following actions to optimize the contractual framework for an enhanced financial performance of the system:

[1] For example, tortuous routes to provide a wider service coverage may maximize ridership levels at the expense of disproportionately higher operating costs through higher km payments to operators.

- Reviewed bus ownership and contract duration clauses,
- More information at the bidding stage on the service plans to be operated by bus operators in order to allow for more optimization of the kilometre charge at the bidding stage,
- Revised contractual provisions to allow NMC to partially benefit from some cost-efficiency gains by operators during the contract period, in particular optimized energy consumption or gains from higher commercial speed,
- Revision of DIMTS' contract in order to introduce contractual incentives for commercial efficiency,
- Revision of payment terms to better reflect the actual costs incurred by bus operators[2].

The above recommendations would need to be refined and confirmed through interviews with key stakeholders (NMC, DIMTS, bus operators, finance providers), based on detailed feasibility analyses.

VII. TASK 6 - PRE-FEASIBILITY STUDY

As agreed between NSSCDCL/NMC, AFD and SETEC-NODALIS and due to COVID-19 situation, **Task 6** is done prior to **Task 5**. It focuses on the upgrade and transition to E-buses of existing thermal Standard buses that shall be replaced by 2022 (as contractually foreseen).

Thus, the pre-feasibility study's goal is to identify the impacts of electrification for all three depots currently operating Standard thermal buses and the related bus routes.

This report's first section (**Report assumptions**) presents the input data and assumptions considered in this report, mainly for the electric simulations and financial model. Two types of simulations were performed: E-buses energy consumption (based on existing bus routes currently operated using Standard thermal buses) and E-buses depot charging (for each one of the three existing depot areas where the corresponding Standard thermal buses are maintained and parked). Macroeconomic and general operational assumptions are equally presented in this section.

The second section (**Simulations results and outputs**) focuses on the simulations purposes, methodology and results. Various scenarios and parameters are here analysed, including different E-buses battery capacities, buses ridership, and considerations on air conditioning system's energy consumption.

[2] These improvements are however expected to be limited as the current contracts and models are already relatively adjusted to the different types of bus and need only minor adjustments/revisions.

After presenting and commenting each simulation's results, the subsequent chapters present the main impacts on each existing depot configuration (electric infrastructure, charging management system, workshop upgrades), as well as on the required resources and qualifications (safety, drivers, maintenance activities, charging activities).

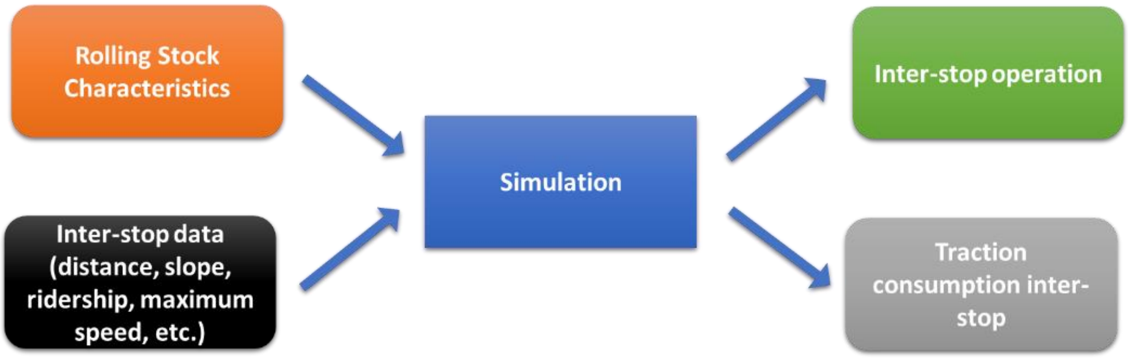
The third and last section (**Financial and contractual assessment**) presents an update of the financial and contractual assessment previously and more generally done in *Task 4 Report*. The financial model initiated during Task 4 is here used again to analyse the impacts of buses electrification for each bus depot, considering various parameters, for investment and operation and maintenance expenses. The impacts on the viability gap for Nagpur City Bus Service are also presented, as well as considerations on contractual matters regarding the existing and future bus providers-operators-maintainers.

ENERGY CONSUMPTION SIMULATION ASSUMPTIONS

An analysis of the network operation on the selected routes is performed, in order to **determine the electrical consumption profiles on each route**. The simulation software developed by setec, **Volt@bus**, allows to calculate traction power consumption, based on detailed electrical simulations considering the various parameter of the route, the rolling stock, and the ridership, and auxiliary's consumption, and particularly the HVAC when applicable (which is a main consumer), based on an environmental and thermal model.

The traction consumption corresponds to the electrical energy necessary for a vehicle to move over a given distance. **Volt@bus** simulates a simplified operation of a bus on a given route. It estimates traction consumption for each section between bus stops and its value is given in kWh / km.

The "running profile" of a bus describes the speed and the traction or braking power used by the vehicle at any point on its route. In order to integrate the impact of congestion, unplanned bus stops and regular circulation (especially in urban areas), this "regular running speed" is usually lower than the actual maximum road speed limitation. The simulation of the running profile and traction power consumption is done for each section between bus stops Traction power electric consumption is likely to vary depending on the period of time considered (peak / off-peak variations in terms of speed profile depending on general circulation, external temperature, number of passengers, etc.).

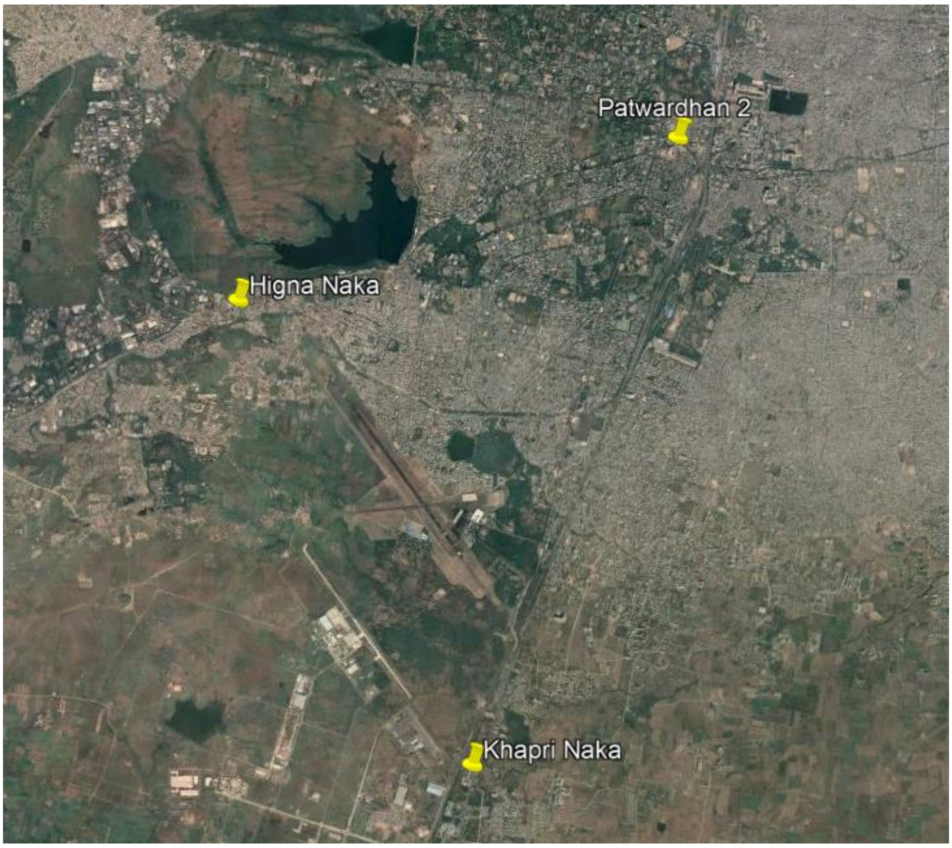


The consumption of the vehicle's auxiliary systems (i.e., HVAC, on-board ticketing equipment, on-board passenger information equipment, etc.) is calculated on the basis of the estimated capacity and power consumption of each system / equipment and the average distance and speed of the vehicle on a given section between bus stops. **Volt@bus** simulations estimate for each section between bus stops ("inter-stop") the energy consumption for the auxiliaries in kWh / km.

As agreed with NSSCDCL and NMC (with consent of AFD), this pre-feasibility study focuses on existing routes currently being operated with standard buses (including CNG buses) which are set to be replaced by 2022 as per current bus operator's contracts. **A total of 45 routes is included in the Volt@bus model and their corresponding mileage energy consumption estimated**. The mileage consumption for the routes that cannot be modelled is estimated considering the average consumption of the other routes (representative enough for this level of study).

Due to the exceptional worldwide COVID-19 situation, only one site visit to Nagpur City has been possible during the inception of the mission, but only Patwardhan 2 depot was visited. As such, **the depot layouts considered and proposed in this pre-feasibility study are based information provided by DIMTS and aerial views**. Regarding the available surfaces, it is assumed that, for each depot, there is enough space to park all E-buses, their chargers and the associated electrical infrastructure corresponding to the power required to supply the whole fleet.

Moreover, the connection to the external city power supply is deemed possible (details shall be confirmed at further design stage). Finally, maintenance and cleaning operations are considered possible for both thermal and electric buses.

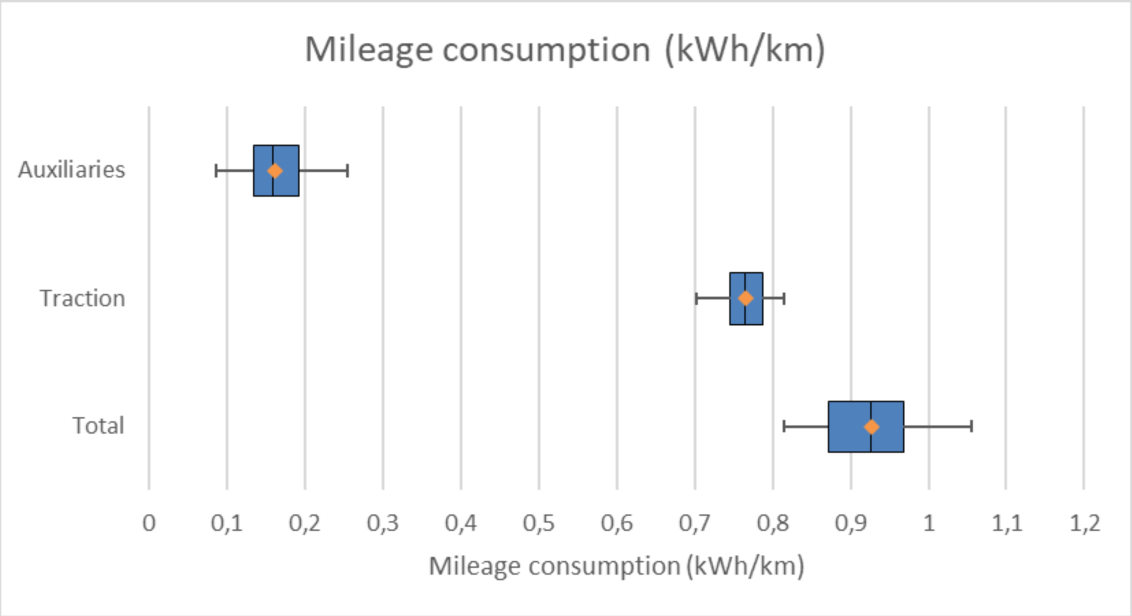


For each bus route, the following simulation parameters shall be considered: inter-stop slope, inter-stop distance, inter-stop passenger load, inter-stop maximum speed, and inter-stop average speed. As the passenger load (bus ridership) data was unavailable for each inter-stop, a conservative assumption of **20 passengers at all times and throughout each bus run is considered**. Regarding the “inter-stop maximum speed”, taking into account both Nagpur inner-city speed limitations for buses (50 km/h) and actual traffic congestion, **a single value of 40 km/h is considered**. The “inter-stop average speed” is calculated from the service schedule provided by DIMTS as “total distance of the daily task divided by total driving time”. **Average speed is considered uniform throughout each daily task**.

The modelling parameters for the rolling stock considered in this pre-feasibility study are the result of our **experience and feedback from main international electric buses suppliers**.

ENERGY CONSUMPTION SIMULATION RESULTS

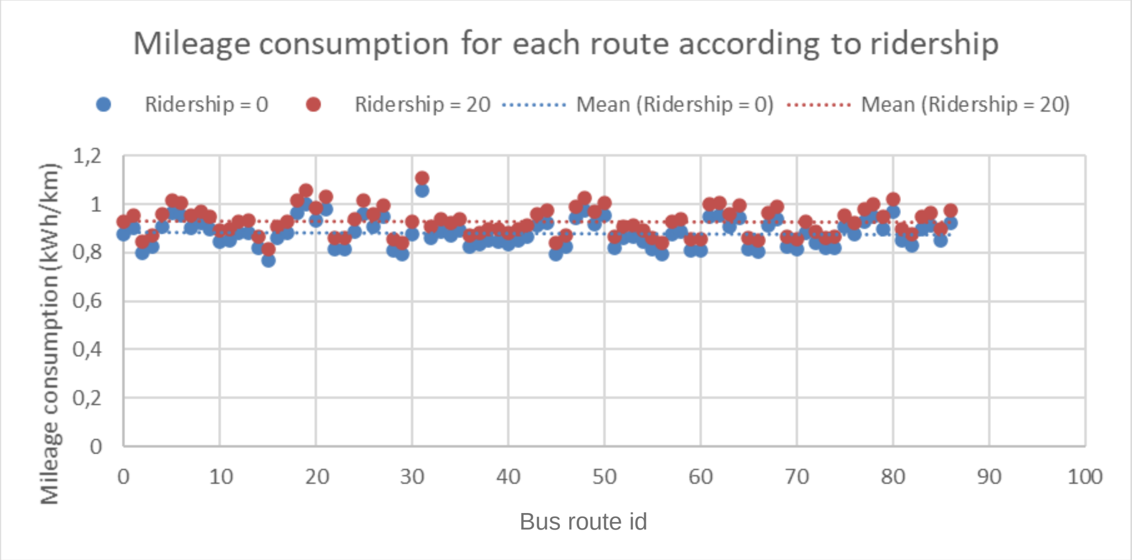
Energy consumption simulations have been carried out for the 45 routes identified through **Volt@bus** software. **On average the mileage consumption is 0.93 kWh/km and is essentially due to the traction power**. It does not exceed 1.1 kWh/km whereas the minimum mileage consumption is slightly higher than 0.8 kWh/km. Thus, the statistical dispersion of mileage consumption estimations is quite low. The share of energy consumption related to auxiliaries is low since no HVAC system is considered in the electric simulations. Indeed, traction power represents over 83% of the total mileage energy consumption.



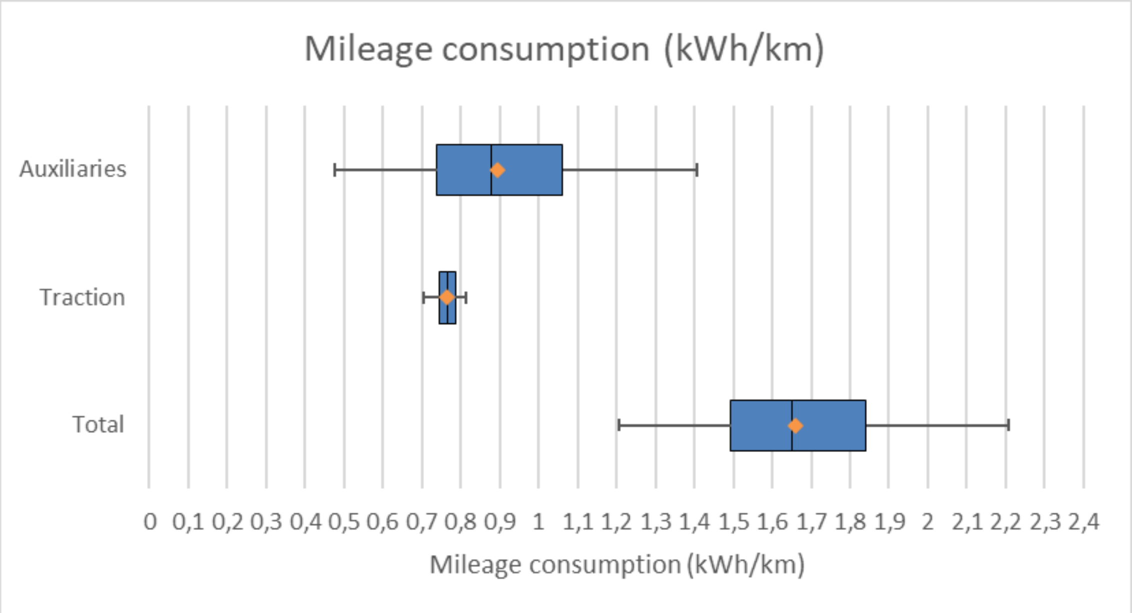
It should be noted that **the average consumption on Nagpur City is quite low compared to other networks, mainly due to a relatively flat city topography**. Finally, the estimated electricity consumption for Nagpur City corroborates Kolkata City's feedback highlighted in the IEA report “Global EV Outlook 2020”. Indeed, the report presents an average electricity consumption for 12-m electric buses of 0.94 kWh/km. In Kolkata case, buses are air conditioned (which increases the consumption related to auxiliaries) but are equipped with 188 kWh batteries (which decreases the consumption related to traction due to batteries weight).

To assess the impact of some simulation assumptions and parameters on the results, two sensitivity analysis have been carried out: impact of bus ridership, and Impact of the air-conditioning system on electric consumption.

For bus ridership, the **average difference between the two scenarios considered (0 or 20 passengers) is close to 5%**. In comparison to the mass of an empty standard vehicle (13.5 tons), the impact of the ridership **is considered low and thus within this prefeasibility study’s margin of error**.



When considering an air-conditioning system, the mileage average consumption dispersion is rather important. The air-conditioning system consumption alone ranges from 0.5 to 1.4 kWh/km. On the other hand, traction consumption remains constant compared to the scenarios without air-conditioning. As a result, in this case, the auxiliaries represents over 54% of the total energy consumption. Finally, the resulting **average mileage consumption is estimated to be 70% greater when considering an air-conditioning system (compared to the base scenario without air-conditioning)**.



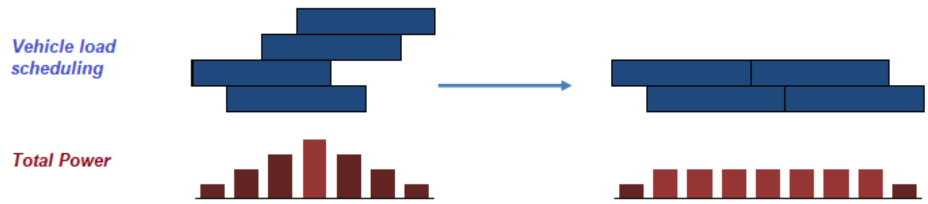
Depot Charging Simulation Assumptions

The objective of the charging simulations is to estimate all the electrical quantities (power and energy) that shall be necessary for charging buses, using input data from the bus service planning data. This includes planning the electric vehicles charge in its depot and thus optimizing the power required to charge the buses. In addition, data on the state of charge of bus batteries throughout the day are provided in the charging simulations, confirming the assumptions taken to carry out Nagpur City bus service planning. Thus, the electric simulations aim at **sizing the fleet of the electric buses needed to operate the network** (i.e., confirm the total required E-buses fleet in comparison to the existing fleet), and **sizing the necessary electrical infrastructures in the depot**.

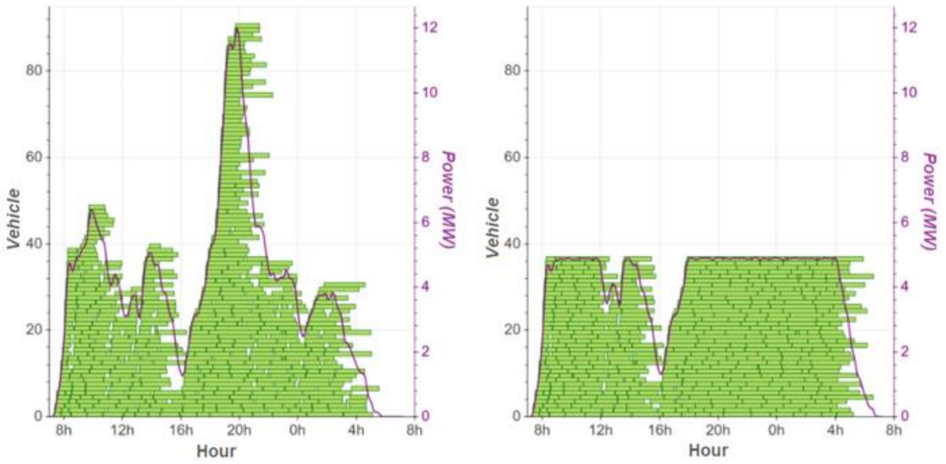
The bus consumption per kilometre and the route planning provided make it possible to assign each bus to a task and to determine the **minimum number of electric buses required to carry out all the daily tasks**. Depending on the time spent at the depot by the vehicles, a bus charging planning is set up as to guarantee the correct charging of the vehicles while optimizing the maximum power necessary for the electric power supply of the depot.

Based on the results of the energy consumption simulations, the objective of this step is to perform a **simulation of the required charging infrastructure for the selected routes and bus fleet**. The following aspects are determined: charging status of vehicles, organization of electrical buses charge, and evolution of the power demand for the corresponding depot. Based on the operation input data and selected engine options, we can identify and pre-size the electrical infrastructure required to fulfil the performance objectives of the simulated case, and in particular the degraded modes (operational defaults, maintenance activities) and the corresponding redundancy level required.

Two scenarios are identified: one **scenario without optimization** (without smoothing or load shifting) of the electrical power demand, one scenario **with optimization** (with smoothing or load shifting of electrical power demand), based on a reorganization of the bus operation and timetables programming. For each predefined scenario, we can perform the simulations with **Volt@bus**. The software includes an algorithm that optimizes the charge patterns to limit the power demand peaks.



Volt@bus principle of electrical charging planning reorganization (in blue) to optimize the required electrical power (in red)



Charging power required without (left graph) and with (right graph) optimization of operation and charging schedule using **Volt@bus** software simulations

The principle is to reorganize the programming of the vehicles charging to benefit from the lowest cost for kWh (by limiting the need for a high-power subscription which is costly in OPEX). The reorganization is done by minimizing the simultaneous charge of buses and simultaneously ensuring the commercial service planned with sufficient remaining power capacity for the planned trip from and to the depot. The process is iterative and based upon several simulations. For each simulation we set the maximum power deliverable by the bus depot. Finally, **the chosen solution is the one that allows all buses to be charged in time, but with the lowest installed power**.

The bus charging simulations are carried out considering the mileage consumption for each route. The current operational data allows a fine estimate of the load planning, considering the entry and exit constraints of vehicles at each depot. We understand from the service planning data that, depending on the bus route, some buses are performing a morning shift and later an evening shift without going back to the depot. Other buses carry out a single run during the day.

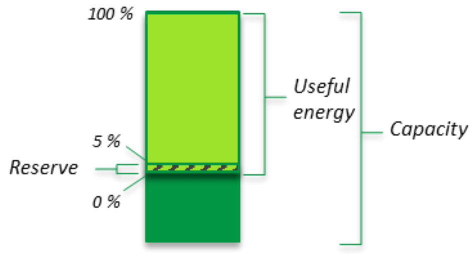
In order to limit as far as possible impacts on operation, **the same operating pattern are considered in the simulations**. Nonetheless, it is possible that some buses will not be able to carry out both morning and evening shifts without being charged (at least partially) due to lack of energy (battery capacity). To address this, and only when necessary, the specific vehicle shall return to the depot at the end of its morning shift. In order to achieve this, a trip between the last stop of the morning shift and the depot is added to the original bus service schedule, and another bus takes over from the first one to carry out the evening shift. A trip between the bus depot and the first stop of the evening shift is added to the bus service schedule.

It should be noticed that **this adaptation of the bus schedule can increase the total bus fleet**. In this pre-feasibility study, we have considered different options as to **minimize this impact**.

The choice of the battery capacity is important to determine the number of buses required to perform the tasks of the service planning. If the capacity is too low, some runs, which require more energy than that stored in the battery, could not be carried out by a single bus (another bus will have to take over from the bus that runs out of energy), thus having an impact on total bus fleet. On the contrary, it is not recommended to oversize the battery as this increases the investment cost of the vehicles while it is only useful for a small part of the fleet. Therefore, given the current bus schedule trips distances, a battery capacity of 400 kWh seems to be a good compromise for the pre-feasibility study.

This recommended battery capacity is considered an input data for the electric simulations, and it is optimized when possible (for instance to a battery capacity of 350 kWh). It should be noted that this potential optimization can only be possible if it does not impact the bus service schedule and shall only be indicative at this stage of pre-feasibility studies.

Finally, the usable energy of a battery is considered to be 80% of the total capacity. It is commonly considered that below 80% residual capacity, the battery is at the end of its life for mobility purposes. Considering 80% of the total capacity as usable energy ensures the proper functioning of the transport system during the entire life of the battery. According to usual practices, the battery reserve required by a bus to return to the depot is set at 5% of the usable energy.



DEPOT CHARGING SIMULATION RESULTS

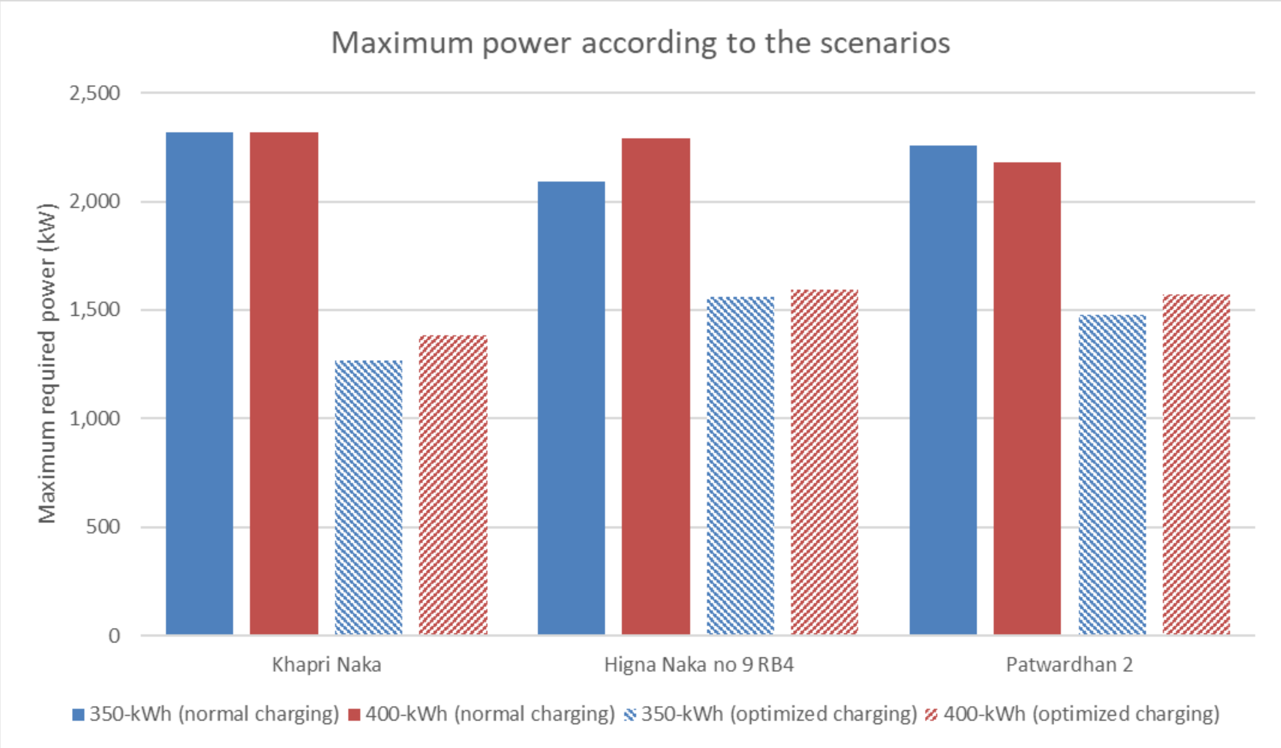
For each simulated Nagpur City bus, a mileage consumption has been estimated and an energy consumption profile has been estimated. These consumption profiles are an input data for depot charging simulations.

Battery capacity is a core element for the conversion of thermal to electric buses. **To minimize impact on operation, batteries with a large capacity should be preferred**. Nonetheless, battery prices are proportional to their capacity, as are the related environmental impacts. Finally, the more important a battery capacity, the higher the related capital expenditure. As of a consequence, the key challenge shall be to **optimize the size of the batteries** between lower capacities (lower CAPEX, lower environmental impacts, higher impacts on O&M) and higher ones (higher CAPEX, higher environmental impacts, lower impacts on O&M). **Three battery capacity scenarios are considered as to assess the impacts on buses operation and depot charging: 400 kWh, 350 kWh, and 300 kWh batteries**.

The reduction of the battery capacity from 400 kWh to 350 kWh results in an increase on the number of buses required to perform the theoretical daily service schedule. In total, 5 additional buses should be needed in the 350 kWh scenario: 1 at Patwardhan depot, 1 at Khapri Naka depot and 3 at Higna Naka depot. In addition, 1 additional charger should be installed in each depot. From an energy point of view, increasing the number of buses in operation would also increase the daily energy consumption, but to a very limited extent.

Bus depot	Battery capacity scenario	Number of vehicles	Number of chargers	Energy consumption for bus operation (kWh/day)	Charging option	Maximum required power (kW)
Khapri Naka	**350-kWh**	68	23	15,775	normal	2,319
					optimized	**1,265**
	400-kWh	**67**	**22**	**15,588**	normal	2,318
					optimized	1,381
Higna Naka	**350-kWh**	70	23	15,570	normal	2,092
					optimized	**1,559**
	400-kWh	**67**	**22**	**15,536**	normal	2,291
					optimized	1,594
Patwardhan 2	**350-kWh**	53	18	13,794	normal	2,256
					optimized	**1,475**
	400-kWh	**52**	**17**	**13,778**	normal	2,182
					optimized	1,572

As a conclusion and from a purely technical point of view, the option of using 350 kWh batteries would not have an important number of impacts on buses operation and maintenance (activities and costs) but could reduce investment costs. Furthermore, the same electrical infrastructure (in terms of number of equipment, sizing of the systems, etc.) could be used given the close number of chargers required in both scenarios.



IMPACTS ON DEPOT CONFIGURATIONS

Given the charging simulation results, **with either 350 or 400 kWh batteries, the same electrical infrastructure can be implemented**.

The dimensioning elements of the electrical infrastructure (for E-buses charging) are the number of chargers and their power. As developed in *Task 3B Report*, a modular architecture is recommended (adaptable to bus fleet increases). Dimensioning is done based on the maximum number of chargers potentially connected to the infrastructure.

At this stage, **the optimization allowed by the "optimized charging" option does not modify the infrastructure**. Indeed, to ensure a high level of flexibility, it is recommended that the infrastructure is sized for the maximum possible power (including for example an unscheduled need to simultaneously charge more buses than in normal conditions due to operational constraints) and not for the maximum power observed on a typical operating day.

Since Khapri Naka and Higna Naka could have the same infrastructure (in terms of equipment and system dimensioning), two levels of redundancy are analysed to illustrate two possible options for the electric infrastructure:

- Khapri Naka is designed with a partial redundancy, and
- Higna Naka is design with full redundancy.

Comparing both options allows to quantify the cost difference between the two possible levels of redundancy.

INVESTMENT COSTS

Two types of investment costs for operators are here considered:

- Vehicles and batteries costs, and
- Investments costs for electric infrastructure and systems (only those related to electric buses) that could be borne by the operator[3].

For the 400 kWh batteries scenario, the capital expenditures are estimated at:

- **Khapri Naka** depot = **155.9 Crores INR**,
- **Higna Naka** depot = **157.5 Crores INR**, and
- **Patwardhan 2** depot = **122.7 Crores INR**.

When comparing Khapri Naka (partial redundancy) and Higna Naka (full redundancy) depots, the **full redundancy** of the electrical infrastructure costs approximately **1.6 Crores INR** but allows a normal operation of the charging planning even if a transformer breaks down.

For the 350 kWh batteries scenario, the capital expenditures are estimated at:

- **Khapri Naka** depot = **156.7 Crores INR** (+0.5%),
- **Higna Naka** depot = **155.0 Crores INR** (-1.6%), and
- **Patwardhan 2** depot = **121.3 Crores INR** (-1.1%).

When comparing Khapri Naka (partial redundancy) and Higna Naka (full redundancy) depots, the **full redundancy** of the electrical infrastructure equally costs approximately **1.7 Crores INR** but allows a normal operation of the charging planning even if a transformer breaks down.

Compared to the 400 kWh scenario, the electrical infrastructure remains almost identical. In terms of CAPEX costs, the lower battery capacity respectively **saves 2.5 Crores and 1.4 Crores** for Higna Naka and Patwardhan 2 depots. On the contrary, in the case of Khapri Naka depot, the **total cost is 0.9 Crores higher** than with 400 kWh batteries due to a significant increase in the number of buses required (+3). Thus, there is a real interest in limiting the capacity of the batteries, provided that this does not lead to a substantial increase in the number of buses in operation.

The purchase of electric buses and their batteries accounts for about 80% of the total capital expenditures for each depot. The share of capital expenditure allocated to the purchase of charging systems is estimated at about 15% whereas the last 5% are divided between the electrical infrastructure at the depot and the charging management system.

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[3] The investment cost related to electric infrastructure and systems can be bored by NMC if the expected service is well defined in advance (since service impacts E-buses energy consumption and charging infrastructure needs). It should be noted that if cost is bored by operator, this shall be included in its cost by km (thus not having a tangible impact in the viability gap).

Operational and Maintenance Costs

For standard E-buses, energy costs are calculated according to the electrical consumption of each bus depot as well as the maximum power required. The electrical consumption composes the variable part of the energy costs. On the contrary, the maximum power required for a depot determines the power to be subscribed and therefore the fixed charge of the energy costs. Thus, limiting the subscribed power reduces the fixed charge (due the interest of optimizing bus depot charging).

The OPEX analysis is declined in different aspects. Two variables are considered:

- Battery capacity: 350 kWh or 400 kWh,
- The use of an advanced charging management system (i.e., “optimized charging”) or a regular charging management system (i.e., “normal charging”).

Finally, for each depot, two reference electricity tariffs are considered:

- The reference tariff applicable for Electric Vehicle Charging Stations:
  - In this case, regardless of the scenario, **electric buses’ operational costs per km are approximately half the operational costs of diesel buses**. Energy/Fuel costs in particular are almost five times lower for electric buses than for diesel.
  - In addition, **increasing the size of the batteries capacity slightly decreases the operational costs** (lower insurance costs due to the lower number of buses + lower number of kilometres with 400 kWh batteries). Besides, it is noted that charging optimization allows to reduce to a very limited extent the energy cost.
  - Nonetheless, the advanced charging management system maintenance costs cancel the positive effect on energy costs due to the incentive EV tariff.
- The tariff category applicable for electricity supply at High Voltage for public service such as State or Local Authority Transport establishments:
  - Increasing the cost of electricity decreases the gap between electric and diesel buses. The **operational costs per kilometre of electric vehicles are 25 to 33% lower than those of diesel vehicles**.
  - On the other hand, with either 350 kWh or 400 kWh batteries, the operational costs are similar. However, the advanced charging management system reduces the global ratio per km by 1 Rs.

Annual operation and maintenance cost analysis considering incentive tariff (all three depots)

Global ratio (operational cost) per km	Electric buses				Diesel buses
	350 kWh batteries		400 kWh batteries		
	Optimized	Normal	Optimized	Normal	
Khapri Naka depot	26 Rs/km	26 Rs/km	25 Rs/km	25 Rs/km	44 Rs/km
Higna Naka depot	26 Rs/km	26 Rs/km	25 Rs/km	25 Rs/km	45 Rs/km
Patwardhan 2 depot	23 Rs/km	23 Rs/km	22 Rs/km	22 Rs/km	43 Rs/km
Average for the three depots	**25 Rs/km**	**25 Rs/km**	**24 Rs/km**	**24 Rs/km**	**44 Rs/km**

Annual operation and maintenance cost analysis considering public service tariff (all three depots)

Global ratio (operational cost) per km	Electric buses				Diesel buses
	350 kWh batteries		400 kWh batteries		
	Optimized	Normal	Optimized	Normal	
Khapri Naka depot	32 Rs/km	33 Rs/km	31 Rs/km	32 Rs/km	44 Rs/km
Higna Naka depot	32 Rs/km	33 Rs/km	32 Rs/km	33 Rs/km	45 Rs/km
Patwardhan 2 depot	29 Rs/km	30 Rs/km	29 Rs/km	29 Rs/km	43 Rs/km
Average for the three depots	**31 Rs/km**	**32 Rs/km**	**31 Rs/km**	**31 Rs/km**	**44 Rs/km**

Conclusions on CAPEX and OPEX Analysis

The CAPEX and OPEX cost analysis show that the electrification option considering buses with 350 kWh battery capacity is generally cheaper than the option using 400 kWh batteries. Nonetheless, for Khapri Naka depot, the number of additional buses caused by the reduction in battery capacity induces a significant increase in CAPEX. This CAPEX increase is not compensated by the reduced-capacity-batteries (lower unitary prices).

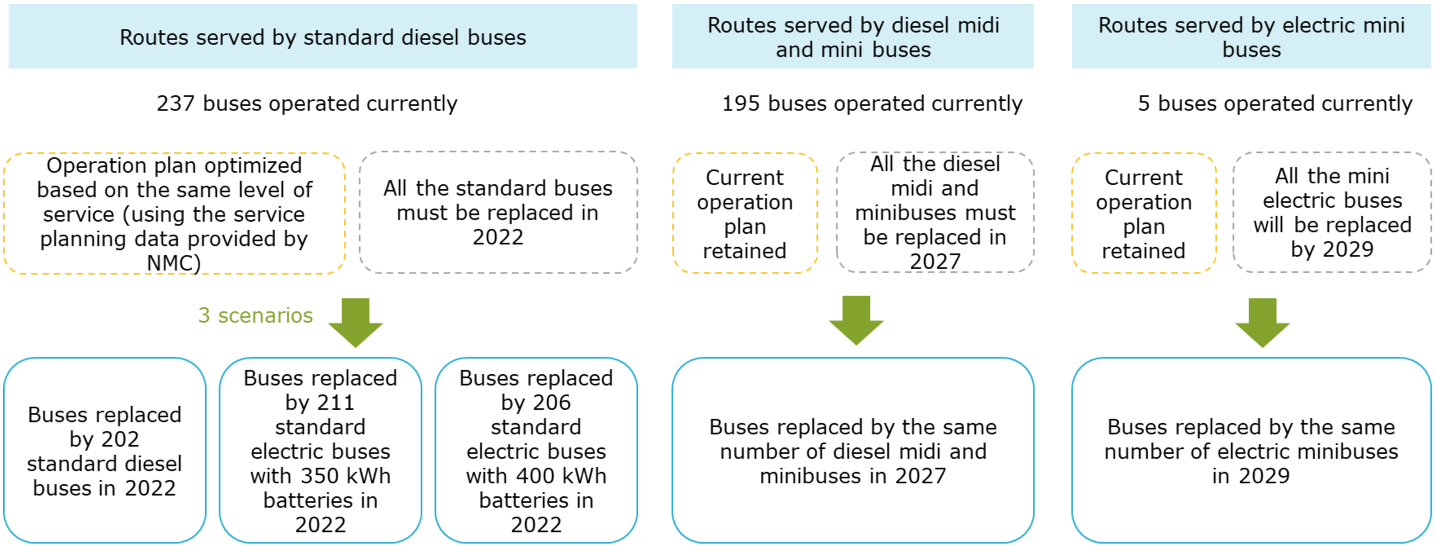
Regarding OPEX, due to the highly subsidised incentive tariff, operating electric buses is significantly cheaper than operating diesel buses. The impact of battery capacity is almost negligible, as well as the potential savings allowed by charging optimization. However, it is to be noted that **a charging management system is very beneficial to operations and thus highly recommended for Nagpur City Service E-buses**. Charging management systems increase the flexibility of depot bus charging and allow a precise follow-up of the state of charge of the vehicles in real time. In a case of energy supply failure or electrical infrastructure malfunction, for instance, the charging schedule can be automatically adapted by the charging management system to limit the impacts on bus operation.

Update of the Financial Assessment

The operational simulations found that the current operation plan of standard buses could be further optimised. As such, a **reduced number of diesel buses (202 standard diesel buses compared to 237 currently) would be necessary for the same level of service**. It was consequently assumed on the update of the financial assessment that the replacement of the existing 237 standard buses in 2022 will also be the opportunity to optimise the operation plan on routes operated by these buses, and hence only 202 new standard diesel buses would be necessary if no electrification was envisaged. The number of the necessary standard electric buses (if all of these routes was to be electrified) was then estimated based on the technical characteristics of batteries in each electrification scenario. This number is higher than the necessary 202 standard diesel buses, given the considerations of the battery autonomy and the resulting changes in the operation plan.

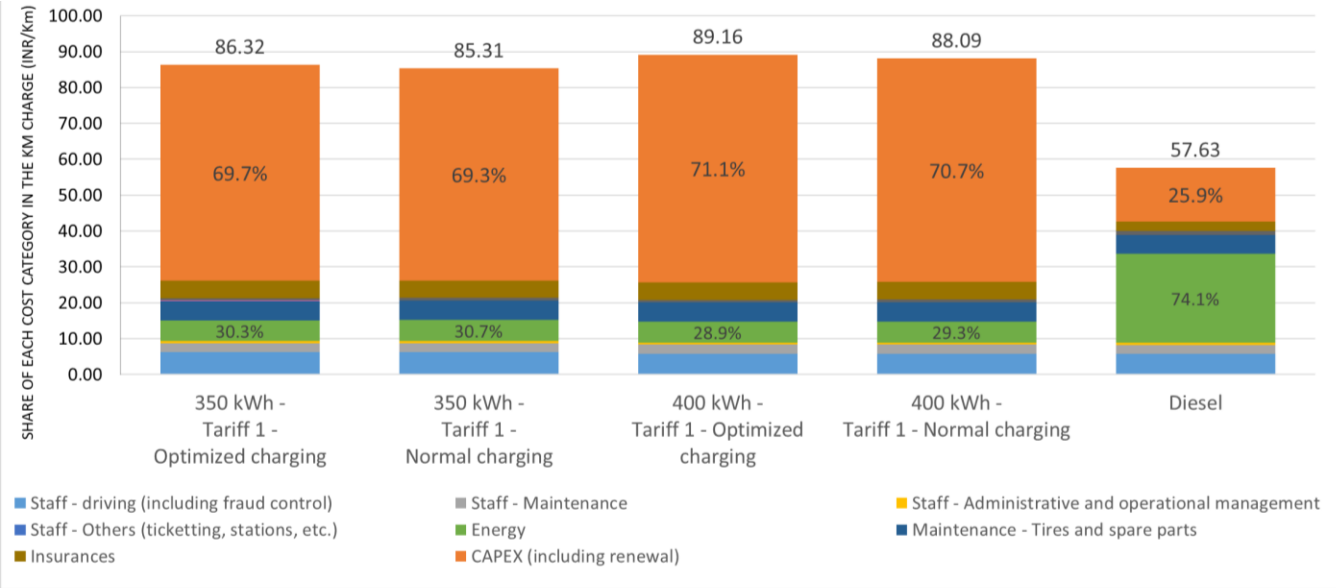
The following replacement scenarios were considered:

- **Reference scenario:** Replacement of standard diesel buses with new ones, with no new electric buses (replacement of the existing 237 standard diesel buses with 202 new standard diesel buses).
- **Scenario 1:** Replacement of standard diesel buses with new electric buses of 350 kWh of battery capacity (replacement of the existing 237 standard diesel buses with 211 new standard electric buses of 350 kWh battery capacity).
- **Scenario 2:** Replacement of standard diesel buses with new electric buses of 400 kWh of battery capacity (replacement of the existing 237 standard diesel buses with 206 new standard electric buses of 400 kWh battery capacity).

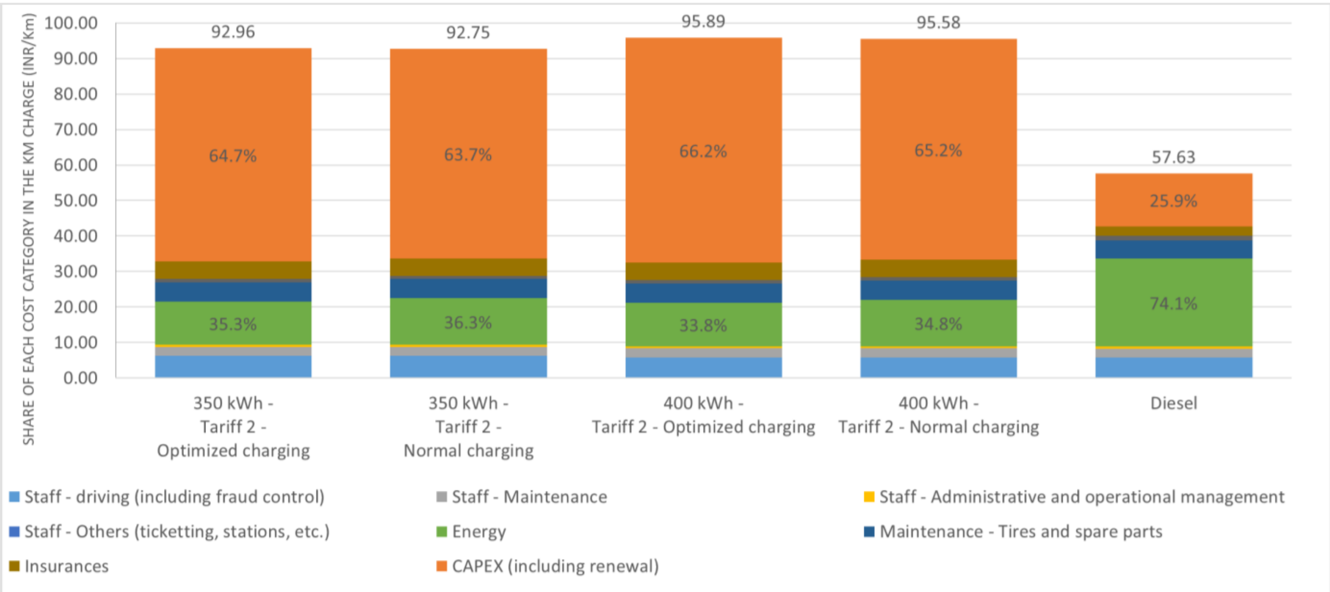


Characteristics of the Nagpur City Bus network considered for the financial analysis

The figures below provide a summary of the estimated kilometre charges for the new standard electric buses for each battery capacity, considering “optimized charging” and “normal charging”, and a comparison to the estimated kilometre charge for the new standard diesel buses. Estimates were conducted using both the EV charging stations electricity cost (Tariff 1) and the Public Service electricity cost (Tariff 2) in Maharashtra state.



Comparison of the km charge for electric and diesel standard buses - Tariff 1 (incentive tariff)



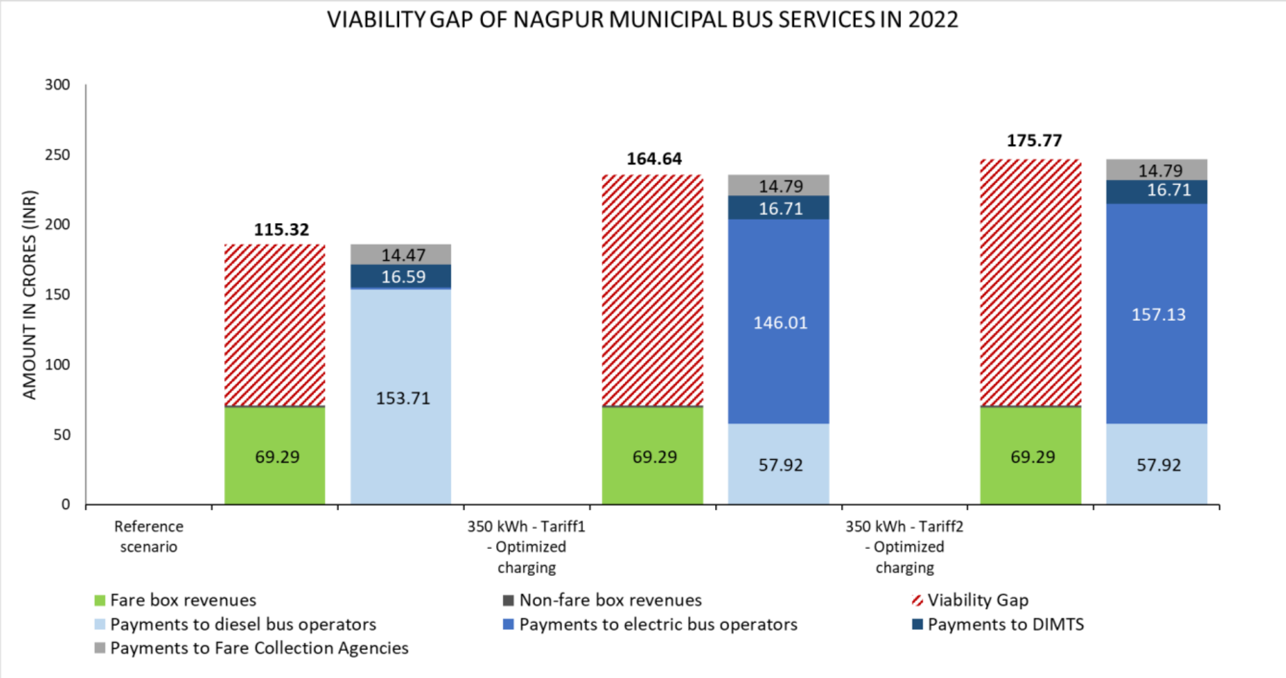
Comparison of the km charge for electric and diesel standard buses - Tariff 2 (regular tariff)

The main conclusions are the following:

- Even though buses with a 400 kWh battery capacity allow for an optimisation of the OPEX (due to less energy costs and shifts) compared to buses with a 350 kWh battery capacity (between 1 and 1.7% less depending on the scenarios), **the higher investment costs (around 3%) result in a higher kilometre charge in all the analysed scenarios**.
- If the incentive tariffs (Tariff 1) are applied to the new electric buses, this will result in a relatively **significant decrease in the energy consumption costs and hence in the total kilometre charge of the operators**. Depending on the scenarios the decrease can vary between around 8 and 9%.
- The energy economies allowed by the advanced depot charging management system ("optimized charging") are offset by the additional investment and maintenance costs. Hence, the installation of an advanced charging management system results in a higher kilometre charge in all the analysed scenarios. The increases are however very limited (to a maximum of +0.3%) when using a public service electricity tariff (Tariff 2) instead of an EV charging stations tariff (Tariff 1). Nonetheless, having a charging management system (in its regular configuration at least) is very beneficial from an operational point of view.

The results of the viability gap analysis show that **coverage of the service costs (including investment and financing costs in vehicles and related equipment, infrastructure, assumed to be borne by the operators and hence included in their kilometer charge) by the operating revenues (around 38% in the reference scenario) is reduced in the electrification scenarios (around 28 to 30%)**. The EV charging stations electricity tariff (tariff 1) allows to reduce the viability gap by around 7% compared to a standard public service electricity tariff (tariff 2).

It must be noted that the results for the reference scenario (replacement with standard diesel buses) are slightly different compared to the findings presented in *Task 4 Report* given the updated operational data received at the beginning of the prefeasibility study, which allowed to estimate a new yearly average annual kilometre per standard diesel bus, the proposed optimisations of the operational plan for the simulated routes, and the different number of operated buses, all resulting in higher annual operated kilometres per bus, and hence higher payments to the operators.



Viability gap of Nagpur City Bus Services in 2022

The comparison of these results with the current viability gap of Nagpur City Bus Services (adjusted to inflation) shows that all the replacement scenarios (with diesel or electric buses) will require additional resources to cover the operating expenses. While the reference scenario would require around 10% more resources compared to the current situation, the introduction of buses with 350 kWh battery capacity would require much more. This is equivalent to **an increase of 58% with tariff 1 and 68% with tariff 2 compared to the current situation**.

The additional resources needed for the reference scenario compared to the current situation are explained by the fact that the new diesel buses are assumed to be purchased by the operator and thus, would yield a higher kilometre charge.

The following graph presents the additional viability gap that will need to be covered in each electrification scenario (represented in red and estimated for example at + INR 10.91 Crores for the reference scenario in 2022) in comparison to the current viability gap that is now covered by NMC (represented in pink, adjusted to inflation).

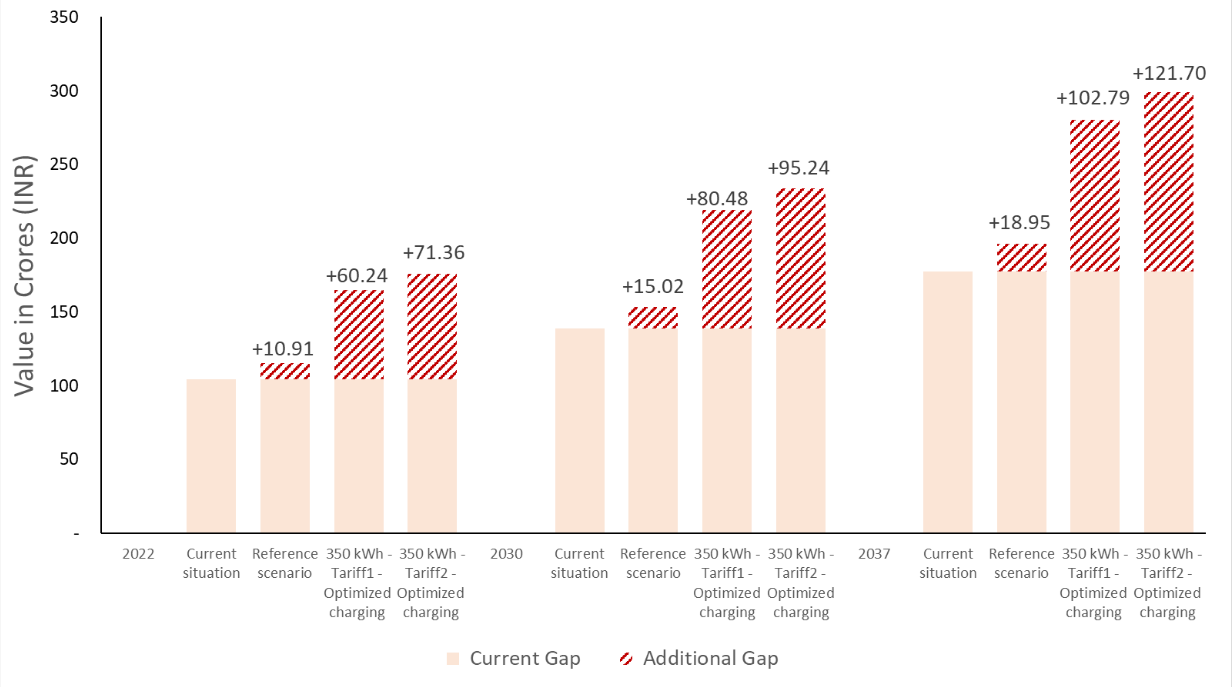


Figure 1. Comparison of the additional annual gap to the current one

Conclusions on Updated Financial Assessment

The financial modelling results show that the electrification of the standard buses will require additional resources compared to the reference scenario (replacement with standard diesel buses). However, the electrification of the bus fleet will yield positive externalities that are not captured by the financial analysis, such as local air pollution reduction (see hereafter).

Buses with a 350 kWh battery capacity seem more financially viable to NMC given the limited investment and operation costs compared to buses with a 400 kWh battery capacity. In fact, even though the first replacement scenario requires additional buses compared to the second one, the overall cost of service in the first case remains lower than the second one.

In addition, although the installation of an advanced charging management system would result in slightly higher kilometre charges and hence increased service costs (due to the additional investment and maintenance costs), such system is very beneficial to operations and should be considered.

Based on the chosen scenario, **it is thus necessary for NMC to find additional financial resources to cover cost increases and maintain the financial sustainability of the system.**

Levers to enhance the system's financial sustainability include possible international financing sources (investment subsidies), a possible increase in farebox revenues, and a possible increase in cost and commercial efficiency through an optimized contractual framework. For the non-fare box revenues, they are currently limited to advertisements on bus stops and estimated at less than 5% of the total service revenues.

Other non-fare box revenues (land valorisation and other secondary resources) could be mobilised, however there are no studies or analyses that provide an estimation of the possible revenue streams from these resources. Hence, these resources were not included in the financial analysis.

CONTRACTUAL ASPECTS AND RECOMMENDATIONS

Contracts with the existing operators for diesel buses were signed in 2017 for:

- A five-year duration for standard buses owned by NMC (expiration in 2022), with a possible extension of up to 10 years, and
- A 10-year duration for midi and minibuses provided by the operator (expiration in 2027).

If one of the electrification scenarios proposed as part of this task (replacement of all the existing 237 diesel standard buses by electric ones in 2022) is retained by NMC, two options could be envisaged:

- Renegotiate contracts with the existing operators to include the electric buses and hence extend the duration by an additional 10 years for standard buses, or
- Launch a new competitive call for tenders to recruit one or several operator(s) for the operation of the new electric standard buses.

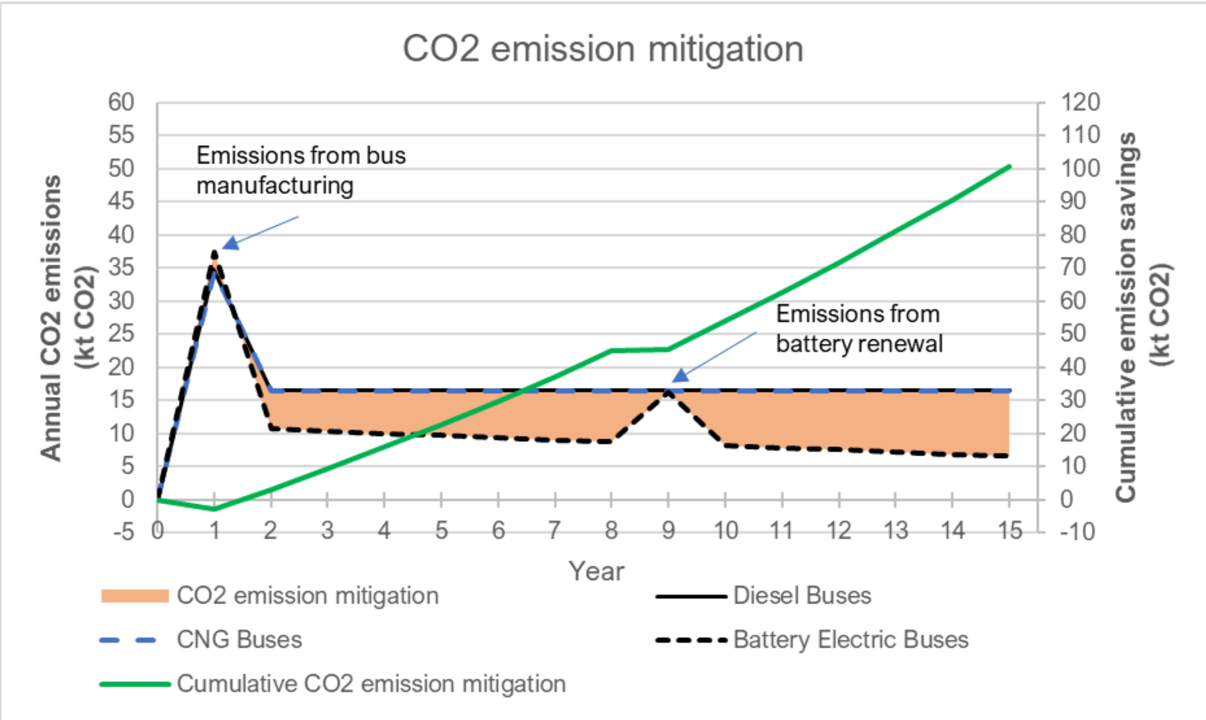
However, given (i) the close expiration date of the existing contracts and the generally long time necessary for renegotiations, and (ii) the change in the technology and in the bus ownership which requires a different set of operation and maintenance skills as well as significantly higher investments from the operators, **it is highly recommended for NMC to launch a new call for tenders for the new electric buses**. This will allow to select the operator(s) with the most adequate set of skills for the operation and maintenance of electric buses and the financial capacities to bear the significantly higher investment costs (which might not be ensured by the existing operators), as well as to optimise the operators' kilometre charge through the competitive process.

In addition, **NMC should seize the opportunity of this replacement to improve the tender processes and contracts** namely by: (i) providing more information on the operation plans at the bidding stage to allow the bidders to optimise their kilometre charge, (ii) verifying that the remuneration formula for an increase or decrease in the annual number of km matches the operation cost structure, and (iii) including an objective contractual mechanism to allow for an adjustment of the km charge in case the service plan specified in the tender documents is changed in such a way that it results in a significant increase or decrease of the km charge (for instance, as a result of the construction of priority lanes that would improve the commercial speed).

GENERAL ENVIRONMENTAL IMPACTS ASSESSMENT

The estimation of emissions presented is based on the "400 kWh batteries" scenario results. The scenarios presented below compare the overall emissions of a fully Electric fleet and of a fully CNG/Diesel fleet. Greenhouse gases emissions for CNG buses are presented in the graphs but the comparison ("emission mitigation") is done between the 100% diesel and 100% electric scenarios.

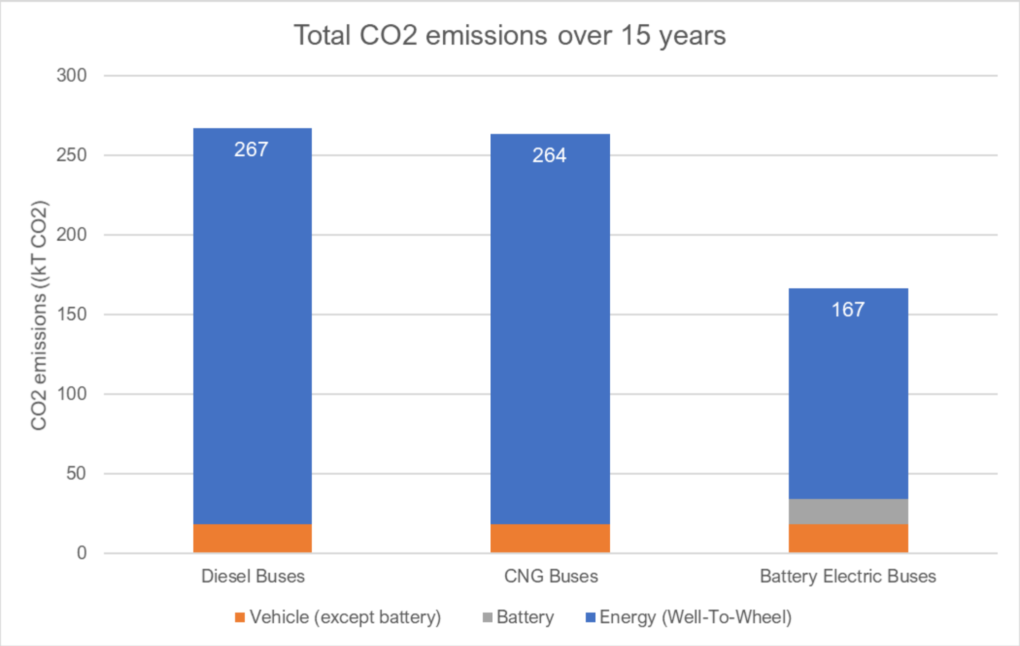
The following figure shows the CO_2 emission mitigation during the lifetime of vehicles depending on whether they are diesel, CNG or electric vehicles. Regarding battery electric buses, emissions are generally lower than diesel buses. Even with a grid emission factor of approximately 700 gCO_2/kWh, **battery electric buses emit over 30% less CO_2 than diesel buses**. Electric vehicles achieve their maximum potential (regarding reducing emissions) as the electricity mix decarbonizes but, in any case, reduce greenhouse gas emissions compared to diesel vehicles.



CO_2 emission mitigation estimations for Nagpur City Bus Service fleet

Regarding electric bus emissions, two "emission peaks" exist, corresponding to bus and battery manufacturing, as battery electric buses manufacturing is greater than diesel buses production. Thus, if the emissions related to the production of vehicles and batteries are included in the year of purchase of the vehicles, the total emissions in the first year are higher for electric vehicles than for diesel vehicles. In the ninth year, the batteries must be renewed, inducing an increase of CO_2 emissions for electric buses.

In total, for the whole fleet and for a time span of 15 years, **battery electric buses would save approximately 100 ktCO_2, or 38% of diesel buses total emissions**.



Estimation of total CO_2 emissions for 15 years for Nagpur City Bus Service fleet

On the other hand, it can be noted a low share of “vehicle (+ battery)” manufacturing emissions on the overall life cycle, even for battery electric buses (20% for electric buses and 7% for diesel buses).

CNG and diesel buses emit almost the same amount CO, HC and NOx whereas battery electric buses do not release this kind of pollutants during operation (tailpipe emissions). Since the volume of air pollutants emitted depends primarily on engine generation, it should remain approximately constant from year to year. For internal combustion engines, a next step on lowering air pollutants’ emissions shall come when new emission standards are introduced.

Each year, approximately 90 tons of carbon monoxide, 10 tons of hydrocarbon and 25 tons of nitrogen oxides would be saved thanks to the conversion from thermal to battery electric buses. Regarding particulate matter, CNG buses already allow a great reduction of emissions compared to diesel buses. In the estimations, diesel buses would emit approximately 600 kg of PM each year, while CNG buses would emit around 60 kg of PM / year.

ELECTRIC BATTERIES “END-OF-LIFE”

Batteries are the core technology of electric vehicles. Due to a substantial need for rare metals, the mining of which has proven negative environmental consequences, the advent of batteries is the subject of intense deliberations. In particular, the issue on how to recycle used batteries that will flood the market by the end of the decade is constantly in debate.

The end-of-life issue is a real opportunity to reduce the environmental impact of batteries over their entire life cycle. It is also a lever for certain countries that have little or no underground resources to acquire a very relative energy independence from the main producing countries.

For uses in urban mobility, a battery is considered to be at the end of its life when the amount of energy it can store reaches 80% of its initial capacity (or up to 70% depending on the case). Two strategies are then available: **recycling of the battery** to recover critical and non-critical materials from it, or **re-use of the battery** for stationary uses which can increase the life of the battery from 5 to 15 years depending on its condition and the characteristics of the second life application. Either perspective has advantages and disadvantages, but **both can reduce the environmental impact related to a battery's life cycle**. It is to be noted that in general, once the battery is no longer usable in its second life application, it can still be recycled.

The recycling of critical metals through a robust recycling system is a means to reduce demand for raw materials, reduce GHG emissions, reduce local pollution from mining and refining of these metals, and reduce countries' dependence on imports. Nevertheless, there are currently obstacles to the development of the sector. For instance, the low volumes of batteries at the end of their life cycle, due to the very recent emergence of electric vehicles worldwide, do not allow recycling channels to benefit from significant economies of scale. The increase in battery production volumes should soon increase the pressure on critical metals and drive up their prices, while **the increase in end-of-life battery volumes should drive down recycling costs**. The technology for high efficiency recycling is already mature, but still needing to be industrially scaled.

URBAN PLANNING AND STREET UPGRADES

The success of a public transport system and its efficiency is not only due to its own technical characteristics. Urban insertion, integration with other modes, street upgrading and furniture, interoperability… These concepts shall help **making a bus system more reliable, easier-of-access and visible, thus guaranteeing a better efficiency for operators and attractivity for users**.

The performance of a City Bus line is essentially analysed in terms of commercial speed (or journey time) and regularity. It is considered that in an urban area, **a bus system using exclusive bus corridors (such as BRT systems) can reach a commercial speed of around 20 km/h** (25 km / h in the suburban sector, depending on the number of stations along the route). In areas particularly subject to automobile pressure, **the bus corridor should be protected with an impassable curb** (or other device: green space, etc.), provided that this does not create greater difficulties with other uses (operation of driveways and deliveries in particular).

In order to guarantee a good performance of a City Bus system, it is recommended to adopt "bus priority" strategies when dealing with traffic-lights-managed intersections. Indeed, **the efficiency of exclusive right-of-way facilities is optimal with a priority system at intersections**.

Bus stop equipment must help to make users' waiting time less disturbing: by protecting them from bad weather, by providing them with information about their journey, by allowing them to make their journey independently. When passengers get off a bus at a bus stop, they must find information to help them find their way around, to their destination or to their connection. The complete equipment (furniture, signage, static and dynamic information displays, lighting systems, and specific equipment) of a bus stop shall thus **facilitate the journey**.

In order to better integrate a City Bus System with other modes, it is often possible to have bicycle-bus cohabitation in a reserved area. **However, this should not be at the expense of the desired level of service for the public transport concerned.** If the facilities and operating conditions are not in place to implement this cohabitation in a satisfactory manner for the efficiency of public transport and the safety of all users, facilities appropriate for cyclists shall be provided in parallel with those allocated to public transport. If traffic constraints dictate, there is no reason why an **impassable physical divider** should not be used.

Finally, to improve integration between different transport modes, the MaaS (Mobility-as-a-Service) model can be adopted. The MaaS is a rather recent model that aims at **integrating (from journey planning to payment) all transport modes of a city or region (public and private)** as a means of facilitating the access of citizens to transport solutions. For the user, a MaaS application ads value by using a single mobility application with a single payment channel. A MaaS service also yields new business models with advantages for transport operators, such as access to improved user and demand information and new opportunities to serve unmet demand. Finally, the overall goal of a MaaS model is to **provide reliable and easy-of-access alternative to the use of private transport**.

PREAMBLE

Introductory section.

1. Introduction

1.1 Project presentation and context


Nagpur City – Urban transit


Nagpur City – Zero Mile


Nagpur City – Cotton Market

The Indian Government is promoting the transition of private and shared vehicles towards electrical engines, through the Faster Adoption and Manufacture of Electrical Vehicles (FAME) Program. The transition of the bus fleet towards e-buses may benefit from this incentive. Phase II of the FAME Program aims to generate demand for 7,000 E-buses, 500,000 3-wheelers, 55,000 cars, and 10,00,000 2-wheelers.

Within the framework of the “Mobilize your City” program for Smart City development in India, the French Agency for Development (AFD) is supporting the Municipal Corporation of Nagpur (NMC), for the study of the municipal bus network reorganisation and transition towards electrical buses.

The beneficiary of the study is Nagpur Smart and Sustainable City Development Corporation Limited (NSSCDCL), which is in charge of coordinating for NMC all Smart City initiatives, including E-Mobility.

The study for the transition and development plan of the bus network of the city of Nagpur, awarded by AFD to SETEC-NODALIS, consists in:

- The study of the existing situation and previous studies performed related to mobility plans in Nagpur (Comprehensive mobility plans, Bus Feeder Services to Metro),
- The proposal of a plan for the bus network restructuring, transition and development of the urban bus network plan to accompany the start of revenue service of Nagpur metro (bus routes modifications and implementation of feeder services), and implement overall mobility system in Nagpur also compatible with intermediate para-transit services (Auto, Rickshaws, and Cycle Rickshaws),
- The study of the transition and evolution of the diesel / CNG bus fleet to electrical buses (green mobility), with necessary modifications of depots and deployment of charging infrastructure, with technical feasibility studies for the first phases of deployment,
- The corresponding financial modelling and contractual framework analysis.

The proposed new bus network shall be compatible and fully integrated with the two metro lines that start revenue service in 2019 and 2020.

1.2 Report objective and content


Nagpur City – Train station


Nagpur City – Train station


Nagpur City – Train station


Nagpur City – Train station

As agreed between NSSCDCL/NMC, AFD and SETEC-NODALIS and due to COVID-19 situation, Task 6 was done prior to Task 5 and presented the Prefeasibility Study of the Deployment of Buses in Nagpur City.

This report consists the main deliverable for **Task 5 – Transition Plan for Electric Bus Fleet Upgrade** and is the **Final Report** of the SETEC-NODALIS mission of "*Consultancy service for elaboration of a transition plan for municipal bus network in Nagpur*". This document is structured to be a standalone report that presents a **thorough and concise summary of all tasks and activities of the mission**. Detailed information on each Task is addressed in each respective Task Report.

This report is structured in seven sections:

- **Nagpur public transport diagnostic (chapters 2 to 5):** This section presents the main information and input data used during the mission. Information is related to urban and transport planning including Nagpur City Bus Service, Nagpur metro system's planned feeder service, as well as up-to-date operational data gathered from bus operators and DIMTS,
- **City Bus Service upgrade and rationalization (chapters 6 to 8)**: this section presents an analysis of the current situation and forecast scenarios for Nagpur City public transport system, in particular the City Bus Service. A mid-term vision for the future of public transport services (rationalization and upgrade) and for the electrification of the bus fleet are also presented,
- **City Bus Service fleet electrification (chapters 9 to 16):** this section presents the context of the study and the technical and technological options and recommendations. Motorization, charge strategy, infrastructure, systems, and equipment are here presented, and recommendations drawn as to best fit the needs for the electrification of Nagpur City Bus Service,
- **Case study: replacement of standard buses in 2022 (chapters 17 to 23):** this section presents the assumptions and results of E-buses energy consumption and depot charging simulations, as well as the identification of impacts on depots' designs, the pre-dimensioning of the required infrastructure, impacts on operation and maintenance activities, and an overall assessment of CAPEX and OPEX and environmental impacts,
- **City Bus Service financial assessment (chapters 24 to 26):** this section presents a financial assessment of the Nagpur City Bus Service (revenues, expenses, viability). It firstly presents an overview of the current situation then provides a financial assessment of possible scenarios for bus fleet upgrade (electrification) and augmentation, as well as a review of the possible levers to enhance the financial sustainability of the system,
- **City Bus Service contractual framework analysis (chapters 27 to 29):** this section presents an analytical review of the current contractual framework of Nagpur bus services and possible evolutions, and
- **Conclusions and recommendations (chapter 30):** This section summarizes the main element of this report and its main recommendations.

1.3 Reference documents

Documents listed in the table below are used as a reference in this report.

Table 1. Report reference documents

	Document title / description	Document Reference	Issue	Date
[R1]	Inception Report - Part A *Nagpur Inception Mission Report*	MOB-AC2-09-NAGPUR-RPT-101	A	28-02-2020
[R2]	Inception Report - Part B *Data Analysis & Mid-Term Vision for Nagpur Public Transport*	MOB-AC2-09-NAGPUR-RPT-201	B	16-06-2020
[R3]	Engine and O&M Strategy Report - Part A *Rolling Stock & Infrastructure Benchmark*	MOB-AC2-09-NAGPUR-RPT-301	C	11-05-2020
[R4]	Engine and O&M Strategy Report - Part B *Operation and Maintenance Strategy*	MOB-AC2-09-NAGPUR-RPT-302	B	07-05-2020
[R5]	Financial and Contractual Framework Analysis Report	MOB-AC2-09-NAGPUR-RPT-401	C	27-11-2020
[R6]	Pre-Feasibility Study Report	MOB-AC2-09-NAGPUR-RPT-601	B	14-06-2021

1.4 List of acronyms and abbreviations

Acronyms and abbreviations used in this report are listed in Table 2.

Table 2. Acronyms and abbreviations

(N/A)	information Not Available
A	Ampère (unit)
A.M. / P.M.	ante meridiem / post meridiem
AC / DC	Alternate Current / Direct Current
AC / Non-AC	Air-Conditioning system / no Air-Conditioning system
ADB	Asian Development Bank
ADEME	*Agence De l'Environnement et de la Maîtrise de l'Énergie* French Agency for the Environment and Energy Management
AFD	*Agence Française de Développement* French Development Agency
AFDB	AFrican Development Bank
ATEX	*Appareils destinés à être utilisés en ATmosphères Explosives* Equipment used in Explosive Atmospheres (EU regulation)
AVLS	Automatic Vehicle Location System
BIM	Building Information Modelling
BMS	Battery Management System

BOT	Build Operate Transfer
BOV	Battery Operated Vehicle
BRT / BRTS	Bus Rapid Transit (System)
BS	Bharat Stage
BSES	Bharat Stage Emission Standards
C/K	Cost Efficiency
CAPEX	CAPital EXpenditures
CCS	Combined Charging System
CDP	City Development Plan
CIF	Climate Investment Fund
CMP	Comprehensive Mobility Plan
CNG	Compressed Natural Gas
CPIIW	Consumer Price Index for Industrial Workers
CTF	Clean Technology Fund
DIMTS	Delhi Integrated Multi-Modal Transit System
ELV	Extra Low Voltage
ETVM	Electronic Ticketing Vending Machine
EV	Electric Vehicles
FAME	Faster Adoption and Manufacture of Electrical Vehicles
FBS	(Nagpur Metro) Feeder Bus Service
FSI	Floor Space Index
GCC	Gross Cost Contract
GCF	Green Climate Fund
GDP	Gross Domestic Product
GGGI	Global Green Growth Institute and Center for Study of Science, Technology and Policy
GHG	GreenHouse Gases
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit* German Corporation for International Cooperation
GPS	Global Positioning System
GSDP	GrosS Domestic Product
GST	Goods and Services Tax
HV	High Voltage
HVAC	Heating, Ventilation and Air-Conditioning
IBRD	International Bank for Reconstruction and Development
IBTM	Integrated Bus Transport Management
ICCT	International Council on Clean Transportation

IMF	International Monetary Fund
INR / Rs	Indian Rupees
IPT	Intermediate Public Transport
ITS	Intelligent Transport Systems
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KfW	*Kreditanstalt für Wiederaufbau* German Development Bank
kVA	kilo-Volt-Ampère (unit)
kW / kWh	kilowatt (unit) / kilowatt-hour (unit)
LAN / VLAN	Local Area Network / Virtual Local Area Network
LFP	Lithium iron phosphate
LoS	Level of Service
LRT / LRTS	Light Rail Transit (System)
LV	Low Voltage
MahaMetro	Maharashtra Metro Rail Corporation Limited
MBOA	Model Bus Operator Agreement
MDB	Multilateral Development Bank
MIDC	Maharashtra Industrial Development Corporation
MIHAN	Multi-modal International cargo Hub and Airport, Nagpur
MMI	Multimodal Integration Initiative
MoHI&PE	Ministry of Heavy Industries & Public Enterprises
MoHUA	Ministry of Housing and Urban Affairs
MoU	Memorandum of Understanding
MoUD	Ministry of Urban Development
MRTS	Metro (or Mass) Rail Transit System
MS	*Marché Subséquent*
MSRTC	Maharashtra State Road Transport Corporation
MV	Medium Voltage
NGV	Natural Gas Vehicle
NIT	Nagpur Improvement Trust
NMC	Nagpur Municipal Corporation (institution)
NMC	Lithium nickel manganese (type of battery)
NMPL	Nagpur Mahanagar Parivahan Private Limited
NMT	Non-Motorized Transport
NSSCDCL	Nagpur Smart and Sustainable City Development Corp. Ltd.
O&M	Operation and Maintenance
OCC	Operations Control Centre

OD	Origin and Destination
OPEX	OPerational EXpenses
P/K	Commercial Efficiency
PDF	Portable Document File
PEM	Proton Exchange Membrane
PHPDT	Passenger per Hour Per Direction Traffic
PIS	Passenger Information System
PLC	Programmable Logic Controllers
PMU	Program Management Unit
PPP	Public-Private Partnerships
PT	Public Transport
PV2EV	PhotoVoltaic to Electric Vehicle (project)
PWD	Public Works Division
RFMV	Refrigerated Forced Mechanical Ventilation
RFP	Request For Proposal
RITES	Formerly “Rail India Technical and Economic Service Limited”
RTA	Resistance to Forward Motion
SCADA	Supervisory Control And Data Acquisition
SEZ	Special Economic Zone
SPV	Special Purpose Vehicle
TDS	Tax Deducted at Source
TOD	Transit Oriented Development
TOR	Terms of Reference
TTMC	Traffic and Transport Management Centre
TUMI	Transformative Urban Mobility Initiative
TW	Two-Wheelers
UITP	*Union Internationale des Transports Publics* International Association of Public Transport
UMTA	Unified Metropolitan Transport Authority
UMTC	Urban Mass Transit Company Limited
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
V	Volt (unit)
VNIL	Vansh Nimay Infraprojects Private Limited
WACC	Weighted Average Cost of Capital
WPI	Wholesale Price Index

NAGPUR PUBLIC TRASPORT DIAGNOSTIC

This section presents the main information and input data used during the mission. Information is related to urban and transport planning including Nagpur City Bus Service, Nagpur metro system's planned feeder service, as well as up-to-date operational data gathered from bus operators and DIMTS.

- Nagpur Inception Mission
- Nagpur City's urban and transport planning documents
- Nagpur City's Metro Feeder Bus System planning documents
- City Bus Service operational data
- Nagpur's public transport analysis

2. Nagpur Inception Mission

2.1 Inception Mission organization

The beginning of the "Elaboration of a transition plan for municipal bus network in Nagpur" study between AFD and SETEC-NODALIS teams took place on January 6th, 2020.

During a preparation and kick-off meeting on December 17th, 2019, the need of an Inception Meeting in Nagpur has been confirmed in order to meet with local project stakeholders and gather available input data.

The Inception Mission has been jointly prepared by AFD France, AFD India and SETEC-NODALIS teams between the 6th and the 15th of January.

Attended meetings and site visits during Nagpur Inception Mission are listed in Table 3, as well as meeting's agenda and attendees.

Table 3. Nagpur Inception Mission meetings and site visits

Date	Object	Main subjects	Attendees (other than AFD and SETEC-NODALIS)
16-01	Visit of Smart City Operation Control Centre / NSSCDCL		
16-01	Kick-off Meeting with Dr. Sonawane (NSSCDCL) and NSSCDCL and UMTC Teams	• Global study targets, tasks, and deliverables • SETEC and NODALIS main references in urban transport and team organization • Identified relevant stakeholders for the study • Focus on the Electric Bus Tender • List of received and requested input data • Inception mission planning	• Dr. Ramnath SONAWANE (NMC-NSSCDCL) • Rajesh DUFARE (NMC-NSSCDCL) • Tarun CHOUDHARY (UMTC) • Nivesh MODI (UMTC) • Aditya GHATATE (UMTC)
16-01	Meeting with Mr. Page (NMC - Transport Undertaking) and Mr. Sadabarty (DIMTS)	• Global study targets, tasks, and deliverables • City bus operation organization and main operation data • Contracts with bus operators and DIMTS • Focus on the Electric Bus Tender • List of received and requested input data	• Ravindra PAGE (NMC - Transport Undertaking) • Satish SADAWARTE (DIMTS) • Nivesh MODI (UMTC) • Aditya GHATATE (UMTC)
17-01	Meeting with Mr. Gupta (MahaMetro)	• Global study targets, tasks, and deliverables • Focus on the Multimodal Integration Initiative from MahaMetro	• Mahesh GUPTA (MahaMetro) • Nivesh MODI (UMTC) • Aditya GHATATE (UMTC)
17-01	Visit of Olectra-BYD Electric Bus depot at Matrushakti		
17-01	Visit of R.K. City Bus Operations depot at Patwardhan		

Date	Object	Main subjects	Attendees (other than AFD and SETEC-NODALIS)
20-01	Sitabuldi and City Centre site visits		
	Meeting with city bus operators R.K. City Bus Operations and Travel Time City Bus Services	• Global study targets, tasks, and deliverables • City bus operation organization and main operation data • Relations with NMC and DIMTS • Focus on the Electric Bus Tender • ITS Systems and Smart City	• Neelmanu GUPTA (R. K. City Bus Operations) • Sadanand KALKAR (Travel Time Car Rental Pvt. Ltd.) • Ravindra PAGE (NMC - Transport Undertaking) • Nivesh MODI (UMTC) • Aditya GHATATE (UMTC)
21-01	Visit of Nagpur Metro Network and multimodal hubs, Airport and Mihan areas		
	Meeting with Nagpur City Mayor *This meeting could not take place due to external reasons*		
22-01	Meeting with Nagpur City Commissioner *This meeting could not take place due to external reasons*		
	Meeting with NMC - Transport Undertaking and DIMTS	• Financial and contractual data from NMC - Transport Undertaking and DIMTS • Operational data gathered by DIMTS	• Ravindra PAGE (NMC - Transport Undertaking) • Satish SADAWARTE (DIMTS) • Aditya GHATATE (UMTC)
	Inception Mission Wrap-Up Meeting with Dr. Sonawane and NSSCDCL Teams	• Inception mission meetings and site visits • List of input data collected and requested • Main learnings from inception mission • Way forward and next steps	• Dr. Ramnath SONAWANE (NMC-NSSCDCL) • Rajesh DUFARE (NMC-NSSCDCL) • Devendra MAHAJAN (NMC-NSSCDCL) • Aditya GHATATE (UMTC)

2.2 Inception Mission’s main learnings

2.2.1 Urban transport organization in Nagpur

“Go Green” private bus parked at Olectra Greentech – BYD Depot

In Nagpur City, **two major stakeholders** act together in order to provide quality and integrated urban transport:

- **NMC - Transport Undertaking**, a department under NMC and its municipal budget. Its only income source is the municipal budget (that includes fare revenue collected from city bus users). NMC - Transport Undertaking has contracted with DIMTS for assistance in managing city bus operation performance and the contracts with the four current bus operators: R. K. City Bus Operations, Hansa Travels, Travel Time, and Olectra Greentech – BYD.

Platform at Orange Line Jaiprakash Nagar Station

CNG bus at R. K. City Bus Operations Depot

- **MahaMetro**, a Maharashtra state owned company under state budget. Their main income sources are fare revenue, advertising in metro stations, and rent of commercial slots in metro station buildings. Another important source of income is the TOD initiative related to the metro project: landowners within 500m from track alignment can ask to increase their FSI, up to 4 times current index for areas above 4,000m². This FSI increase is sold at 30% of land value, and the revenues is split 50% for NMC and 50% for MahaMetro. Up to now, this has generated a revenue of more than 50 Crores.

Income sources differ between these two stakeholders, and in some major urban transport axes the **city bus and metro systems compete for ridership** (and thus income).

There is currently no structure similar to Hyderabad's *Unified Metropolitan Transportation Authority* (an urban transportation planning agency) for the general organization of urban transport in the city of Nagpur.

2.2.2 On-going contracts regarding city buses

Electric bus chargers at Olectra Greentech – BYD Depot

Current city bus operators (other than Olectra - BYD) have signed a 5-year contract with NMC (ending 2022) for the **operation and maintenance of NMC-owned buses** (79 for each operator). **The 237 NMC-owned buses fleet shall be rolled-out at the end of these contracts (2022)**.

In parallel, a 10-year contract has been signed with NMC (ending 2027) for the **operation and maintenance of operator's owned buses** (65 for each operator).

Bus shelters have been designed by NMC and NSSCDCL. A 10-year contract for **supply, operation and maintenance of bus shelters** (with royalties paid to NMC) has been signed with Sign Post (ending 2029).

2.2.3 E-buses Tender

Bus washing machine at R. K. City Bus Operations Depot

As per during the inception mission, **only one Bidder has provided a reply**, the deadline for Bidder has then been extended, as in India there should be at least three different Bidders in order not to invalidate a Tender.

Attractiveness of the Nagpur E-Buses Tender (provision of 40 electric buses) is low for current Nagpur city bus operators, as other major tenders are on-going at the same time in India in other states / municipalities.

Bus operators also mentioned that they do not really understand how to establish the costs in order to reply to these tenders, as **few input data is given in Tender** regarding depot configuration and requirements, routes to be operated, and operation and maintenance requirements.

2.2.4 Nagpur metro operation and urban integration

Aqua Line works

During the inception mission, MahaMetro was awaiting approval to start **revenue service on Aqua Line** (East/West) with same principles as Orange Line (North/South) – few stations for the start of commercial service. As per further information gathered after the inception mission, revenue service has started on Aqua Line on January 28th, 2020 (6 stations).

Site visit showed that **ridership was low at that stage** (only 6 stations open on Orange Line during inception mission). Furthermore, it has been noted that the electric vehicle's charging station installed at Orange Line's Airport Station was not operational (according to information from NSSCDCL, charging stations should be operational).

Orange Line Jaiprakash Nagar Station

MahaMetro proposes **Multimodal Integration** in various metro station / urban transport hubs, and promotes **transport integration** with rickshaws, autos, 2-wheelers, scooters, cycles, cars, feeder buses, and city buses. Bike sharing and E-Rickshaws services are under MahaMetro management, which signed different MoU with interested companies (e.g., "BOUNCE" for bike sharing system).

As to improve integration and increase metro ridership, MahaMetro was planning to develop a "Green Journey Transportation App" (**Mobility as a Service app**), with integration of city buses and feeder buses. Likewise, MahaMetro would implement the State Bank Nagpur Metro MAHA Card (prepaid contactless and chip bank card), that shall allow metro users to avoid queuing for the acquisition of metro tickets.

MahaMetro was planning to redesign the **Sitabuldi area road arrangement** (using one-way roads). The general plan had been approved by NMC and would act as an improvement of city bus service and non-motorized transport.

2.2.5 Bus routes rationalization and feeder buses routes

Banner for MAHA card at Orange Line New Airport Station

Previous studies of Nagpur city bus network (CMP, 2018 update and Feeder Routes studies conducted by MahaMetro in 2018) have concluded on **bus network optimization and rationalization** that should be the base of this study.

Regarding the **coordination of bus routes rationalization**, it should be noted that bus routes along metro line's alignment cannot be removed prior to the complete (or almost) revenue service on each metro line, as current bus routes serve the territory better than metro stations (bus and metro ticket fare is the same). Moreover, new feeder services cannot be implemented before metro stations are in service.

2.2.6 Miscellaneous relevant information

General view of Olectra – BYD Depot

Feeder buses docking bay at Orange Line Jaiprakash Nagar Station

Maintenance area at R. K. City Bus Op. Depot

Other valuable information collected during the inception mission is listed hereafter:

- The **construction of footpaths and bicycle paths** is performed by MahaMetro along the Orange and Aqua metro lines alignment and around metro stations, and by NMC - Public Works Department outside of metro station areas. A masterplan, typical design and block costs have been provided by MahaMetro to NMC to implement these footpaths and bicycle paths.
- **Gross Cost Contract is the preferred type of contract**, as it helps to relieve the burden of CAPEX (by differing it through monthly instalments) for new investments to deploy new buses.
- **The Smart City OCC is operational**, with various equipment deployed across the city, including bus shelter “Smart City Kiosks”.
- From the AVLS (GPS Tracking) and the city bus ticketing database, **valuable operation and revenue data is available for the city buses operation**.

3. Nagpur City's urban and transport planning documents

The main available urban and transport planning documents for Nagpur are analysed in this chapter. This analysis covers technical elements on general urban planning and public transport planning for the city of Nagpur.

3.1 Overview of collected input data

The main transport planning documents are summarized below: the context and the objectives are explained for the City Development Plan for Nagpur, the Comprehensive Mobility Plan for Nagpur and the update version of the later.

3.1.1 City Development Plan for Nagpur, 2041 – Final Report (2008-2012)

The "City Development Plan for Nagpur, 2041 – Final Report" (hereafter refered as [CDP]) document presents NMC's strategy and vision "*of a desired future perspective for the city and mission statements on how the Corporation, together with other stakeholders, intends to work towards achieving the vision in the next five years*" ([CDP], p. 1).

The document initial statement is that despite Nagpur's recent development (infrastructure, urban environment, facilities, industrial activities) and potential (tourism industries), the city's growth does not follow the pace of other important cities in Maharashtra state (Pune, Nashik…). The development of large-scale industries and service delivery are appointed as the two main barriers to overcome. Urban and environmental aspects are nonetheless also to be considered in the city's development. As a result, the [CDP] vision for Nagpur has been formulated as "*Growth nucleus of Central India; An eco-city that provides adequate, equitable, sustainable access to urban services for all citizens; A city that is safe, livable and promotes growth of its citizens*" ([CDP], p. 3).

For developing this vision, twelve major sectors are analysed in the [CDP] in order to propose development projects: Water supply, Sewerage and sanitation, Solid waste management, Storm water drainage, Urban roads, traffic and transportation, Urban poor and access to basic services, Social infrastructure, Heritage development, Tourism development, Urban governance, and Disaster management. According to the [CDP], the goals and projects presented were envisaged to be implemented by the year 2021 and were already identified as immediate priorities.

Chapter 8.2 of the [CDP] assesses Nagpur's existing traffic and transportation systems, while chapter 8.3 presents the TOD concept and opportunity at Nagpur. Further on, chapter 17.6 lists and details the strategies, projects and investment plan for the Urban Roads, Traffic and Transportation Sector. The final chapter of the [CDP] deals with financial analysis of the city's investment capacity, the development of a financial operational plan for implementing the identified projects, and the supporting review and monitoring framework.

3.1.2 Comprehensive Mobility Plan for Nagpur – Final Report (2013)

The "Comprehensive Mobility Plan for Nagpur – Final Report" (hereafter referred as [CMP13]) document was prepared by UMTC (Urban Mass Transit Company Limited) under NIT (Nagpur Improvement Trust) assignment. It presents Nagpur City's plan to integrate land use and transport "*for the safe and sustainable mobility needs of the people of Nagpur*" ([CMP13], p. i).

The [CMP13] study objectives were to "*provide long-term vision(s) and goals for desirable urban development in Nagpur Metropolitan Region, to illustrate a basic plan for urban development and include a list of proposed urban land use and transport measures to be implemented within a time span of 20 years or more, and to ensure that the most appropriate, sustainable and cost-effective implementation program is undertaken in the urban transport sector*" ([CMP13], p. ii).

The document is divided into several chapters covering general assessment of mobility and transport in Nagpur Metropolitan Region, primary data collection and data analysis, travel demand estimations, establishment of the vision and goals for Nagpur's mobility as well as the associated projects, and an implementation plan and institutional framework.

The [CMP13] follows guidelines established by MoUD (National Urban Transport Policy Guidelines) focusing on the optimization of the mobility of people and goods, the improvement of public transport, non-motorized vehicles and pedestrians, and the integration of land use and transport systems. Its main data sources were "1st Generation" City Development Plan (2007), Master Plan / Perspective Plan for Transportation System of Nagpur City 2031 (2007-2008), environmental and legal framework and standards, as well as primary surveys and data collection and stakeholders' secondary data collection.

Primary surveys included road network inventory, screen-line traffic volume counts, intersection turning volume counts, speed and delay, roadside motor vehicle OD, parking, non-motorized transport, household interview, public transport and intermediate public transport passengers, commuter intercity bus and rail passenger, goods transportation.

3.1.3 Update of Comprehensive Mobility Plan for Nagpur (2018)

The "Update of Comprehensive Mobility Plan for Nagpur" (hereafter refered as [CMP18]) document was prepared by UMTC under an agreement with MahaMetro. It revises the [CMP13] by updating the traffic data, the transport model built as well as the resulting proposals for a 20-year horizon period.

The main goals defined in the [CMP18] are as follows:

- "*Develop public transit system in conformity with the land use that is accessible, efficient, and effective.*
- *Ensure safety and mobility of pedestrians and cyclists by designing streets and areas that provide a more desirable, livable city for residents and visitors and support the public transport system.*
- *Develop traffic and transport solutions that are economically and financially viable and environmentally sustainable for efficient and effective movement of people and goods.*
- *Develop a Parking System that reduces the demand for parking and need for private mode of transport and also facilitate organized parking for various types of vehicles*" ([CMP18], p. 42).

The need of an updated CMP is defined in the [CMP18] as to "*track and evaluate the changes after last CMP, coherence with ongoing Projects, Metro Rail Policy mandates an updated CMP for approval of Metro's next phase, update the earlier CMP with additional projects (if any)*" ([CMP18], p. 41).

The document is divided into several chapters covering general assessment of mobility and transport in Nagpur Metropolitan Region, primary and secondary data collection and data analysis, travel demand estimations, establishment of the vision and goals for Nagpur's mobility as well as the associated projects, and an implementation plan and institutional framework.

The [CMP18] was prepared based on the Revised CMP Toolkit published by the MoHUA. Its main secondary data sources were:

- "*Detailed Project Report for Rail Based Mass Transit System in Nagpur (Traffic and system selection report, 2017),*
- *Comprehensive Mobility plan (2013),*
- *Detailed Project Report for Feeder System for Nagpur Metro (2017),*
- *Nagpur Parking Policy and Parking Master Plan (2016/7),*
- *City Development Plan for Nagpur City for 2041,*
- *District Census Handbook Nagpur Nagar,*
- *Smart City Mission report (2016),*
- *Environmental status report 2013-14 of Nagpur City*" ([CMP18], p. 7).

3.2 Assessment of Nagpur's public transport

3.2.1 General transport assessment

According to the [CDP] and based on the Traffic and Transportation Master Plan for Nagpur (prepared in 2008), public transport ("Star bus") represented about 8% of the trips in Nagpur, while other non-private transport (auto rickshaws, cycle, walk) represented about 27% of the modal split. Two-wheelers and private cars were the major transport options, representing over 65% of trips (see Figure 2).

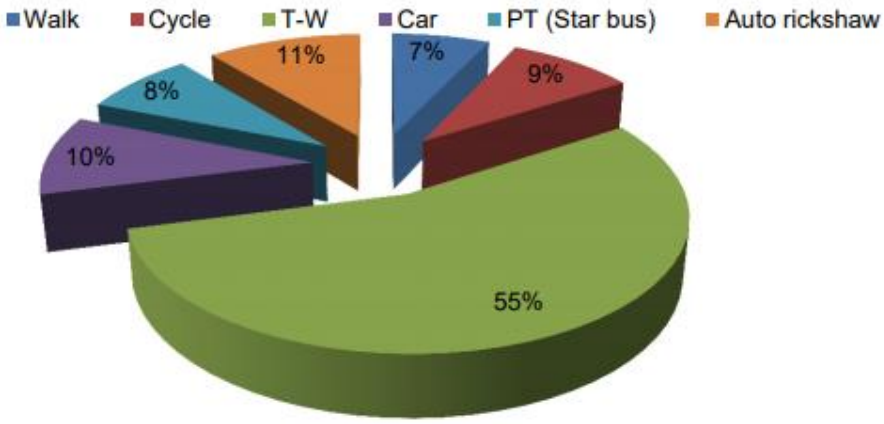


Figure 2. Modal split of trips in Nagpur in 2008 (source: [CDP], p. 123)

The existing city bus fleet system was composed of 470 buses. It was managed and operated until 2007 by Maharashtra State Road Transport Corporation (MSRTC) in Nagpur, and then taken over by NMC. New buses were procured in 2010 under Jawaharlal Nehru National Urban Renewal Mission (JNNURM) funding and handed over to Vansh Nimay Infraprojects Private Limited (VNIL) for operation and maintenance for 10 years.

A Special Purpose Vehicle (SPV) was established then by NMC (the Nagpur Mahanagar Parivahan Private Limited – NMPL) for outsourcing operation and maintenance tasks related to public transport. VNIL's activities included the operation and maintenance of city buses, route planning, fare card system and fare collection, as well as route rationalization (NMPL participation was possible in terms of rationalization of fares).

Amongst the main issues and key challenges identified in the [CDP], the following are related to public transport:

- "*Lack of efficient public transportation system,*
- *(…) role of NMC is negligible in planning and implementation of METRO project,*
- *No initiative for formation of Unified Metropolitan Transport Authority (UMTA),*
- *Implementation master plan prepared by NMC and CMP prepared by NIT are yet to be taken up (…)*" ([CDP], pp. 130-131).

General information presented in [CMP13] regarding public transportation corresponds to the one given in [CDP]. Specific information is the result of primary and secondary data collection and computation of the Levels of Service (LoS), according to the calculation methodology established by MoUD.

The overall LoS of public transportation was considered as below expectations. Indeed, the [CMP13] concludes on the general index “Overall LoS of Public Transport Facilities” with the following: “*The city has very poor Transport System which need considerable improvements in terms of supply of buses/ coaches and coverage, system quality. The system may require route rationalization and bus augmentation to improve the performance*” ([CMP13], p. 99).

The [CMP18] briefly describes the air, rail, city bus, metro, and intermediate public transport (IPT) characteristics. Regarding Nagpur Metro Rail, in order to meet growing transport demand, two major corridors were identified to be part of the Mass Rapid Transit System (see Figure 3):

- **Alignment 1: North-South Corridor**: The total length of this corridor is 19.6 km, a part is underground. There are 20 stations on this corridor (15 stations elevated and 5 at Grade). Sitabuldi Station is an inter-change station.
- **Alignment 2: East-West Corridor**: The total length of the corridor is 18.6 km. There are 20 stations on this corridor.

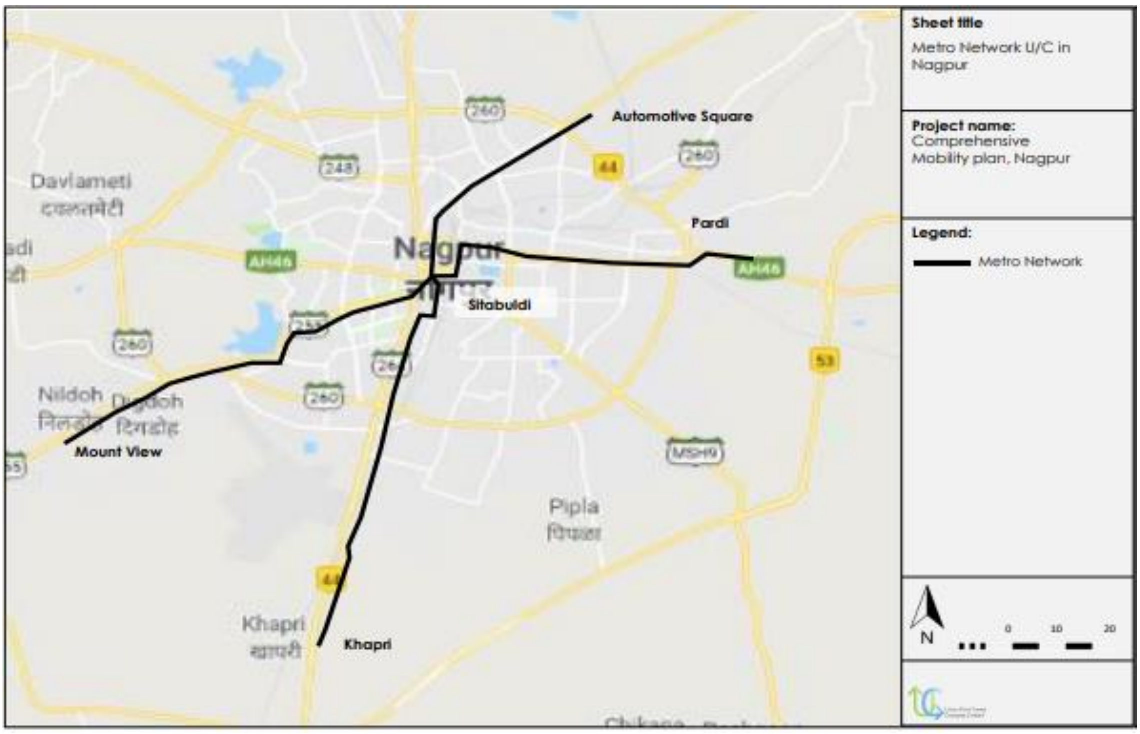


Figure 3. Mass Raid Transit System - Nagpur Metro - Corridors alignment (source: [CMP18], p. 58)

The intermediate public transport (IPT) which includes auto rickshaws, shared autos, and taxis (see Figure 4), offers high flexibility and almost door to door services with low fares. They also play the role of feeder service to the main mass transport system (both rail and road based). Battery operated vehicles (e-rickshaws) also operate within Nagpur City. The [CMP18] states that approximately 1,000 battery operated e-rickshaws were operating within Nagpur City in 2016. These vehicles are exempt from certain taxes.

Figure 4. 3-wheelers IPT in Nagpur (source: [CMP18], p. 59)

Information on the calculation of the Levels of Service (LoS) is given in [CMP18]. The overall LoS of public transportation was considered as slightly better than in 2013 (for "Pedestrian infrastructure facilities" and "Travel speed along major corridors") but still needing improvements. Indeed, the [CMP18] concludes on the general index "Overall LoS of Public Transport Facilities" with the following: "*The city has a public transport system which may need considerable improvements in terms of supply of buses/coaches. The network coverage is good but frequency of services available may need improvements*" ([CMP18], p. 74). In particular, the LoS of the index "Sustainability of public transport (from an economical point of view)" has even decreased between the evaluations done in 2013 and 2018.

3.2.2 Traffic and transport modelling

The dataset used in the [CMP18] are planning variables (demographic data, employment), transport network (road and public transport), as well as travel demand and characteristics. Planning variables are obtained from the Census database (it has been informed by NSSCDCL during the Inception Mission performed in Nagpur in January 2020 that the household surveys and data for the [CMP18] is dated from 2011). Unfortunately, the [CMP18] report does not include a demographic map that would assist in understanding urban displacement issues and the dynamics likely to occur over the next 20 years.

The travel demand forecasts are presented for the years 2021, 2031 and 2041 and year 2018 is considered as the base year. The Nagpur transport model is developed using CUBE software. The model (not available as input data) is based on a conventional 4-stage transport modelling approach (trip generation > trip distribution > modal choice > assignment).

Two modelling scenarios are defined in the [CMP18]:

- **Scenario 1: Business as Usual**/Do nothing scenario with minimum investments done on public transportation sector and projected population and employment,
- **Scenario 2: Sustainable Urban Transport Scenario** with a compact high-density mixed-use development that is planned along public transit stations (or corridors) which provide housing, employment, entertainment, and civic functions within the walking distance.

3.2.2.1 Scenario 1 – Horizon 2041

The modal share has been calculated for various trip purposes: Home based Work, Home based Education, Home based Others. Modal split aggregates are presented in Table 4.

Table 4. Mode split – Scenario 1 – Do Nothing (data source: [CMP18], p. 84)

Mode split	2021	2031	2041
Public transport (city buses, metro, rail)	24%	24%	24%
IPT (auto, rickshaws, taxis)	19%	19%	19%
Private modes (cars and 2-wheelers)	57%	57%	57%

3.2.2.2 Scenario 2 – Horizon 2041

The hypothesis of Scenario 2 comprises the proposed projects presented in the [CMP18] and population density of 400 people per hectare in the zones along transit corridors, in the year 2041. Expected mode split aggregates are presented in Table 5.

Table 5. Mode split – Scenario 2 – Sustainable urban transport (data source: [CMP18], p. 85)

Mode split	2021	2031	2041
Public transport (city buses, metro, rail)	43%	46%	50%
IPT (auto, rickshaws, taxis)	13%	13%	12%
Private modes (cars and 2-wheelers)	44%	41%	38%

3.3 Public transport strategy for Nagpur

3.3.1 Nagpur City mobility goals

The [CMP18] formulates four main goals for the future of Nagpur's mobility:

- "*Goal 1: Develop public transit system in conformity with the land use that is accessible, efficient and effective.*

- *Goal 2: Ensure safety and mobility of pedestrians and cyclists by designing streets and areas that make a more desirable, liveable city for residents and visitors and support the public transport system.*
- *Goal 3: Develop traffic and transport solutions that are economically and financially viable and environmentally sustainable for efficient and effective movement of people and goods*" ([CMP18], p. 88), and
- "*Goal 4: Develop a Parking Policy that discourage the demand for parking and need for private mode of transport and also facilitate organized parking for various types of vehicles*" ([CMP18], p. 91).

3.3.2 Transit-Oriented Development opportunity at Nagpur

The [CDP] presents and develops the TOD concept applied to Nagpur development of traffic and public transportation. Indeed, some main roads are identified for mass transit: "*As a part of this strategy, all important radial roads comprising Amravati Road, Higna Road, Wardha Road, Sadar Road, CA Road, Kamptee Road, Inner Ring Road are recommended as mobility corridors which will maximize throughput of people, focusing on mass transport and non-motorized traffic, rather than personal automobile traffic. In the first phase, 87.2km of corridors can be developed as mobility corridors up to inner ring road. The corridors can then be extended up to outer ring road as part of the 2nd phase (58.7km)*". The "mobility corridors" are shown in Figure 5.

The TOD concept and generalities on its application to Nagpur are presented in the [CMP13] mostly as they are presented in the [CDP].

Figure 5. Identification of potential Nagpur's "mobility corridors" (source: [CDP], p. 136)

3.3.3 Mobility Corridor Strategy

The [CMP13] details a **Mobility Corridor Strategy**, identifying two stages for the establishment of "mobility corridors", as seen in Figure 6. The total length is approximately 87.2 km for Phase I (expected to be developed up to 2022) and additional 58.7km for Phase II (expected to be developed up to 2032).

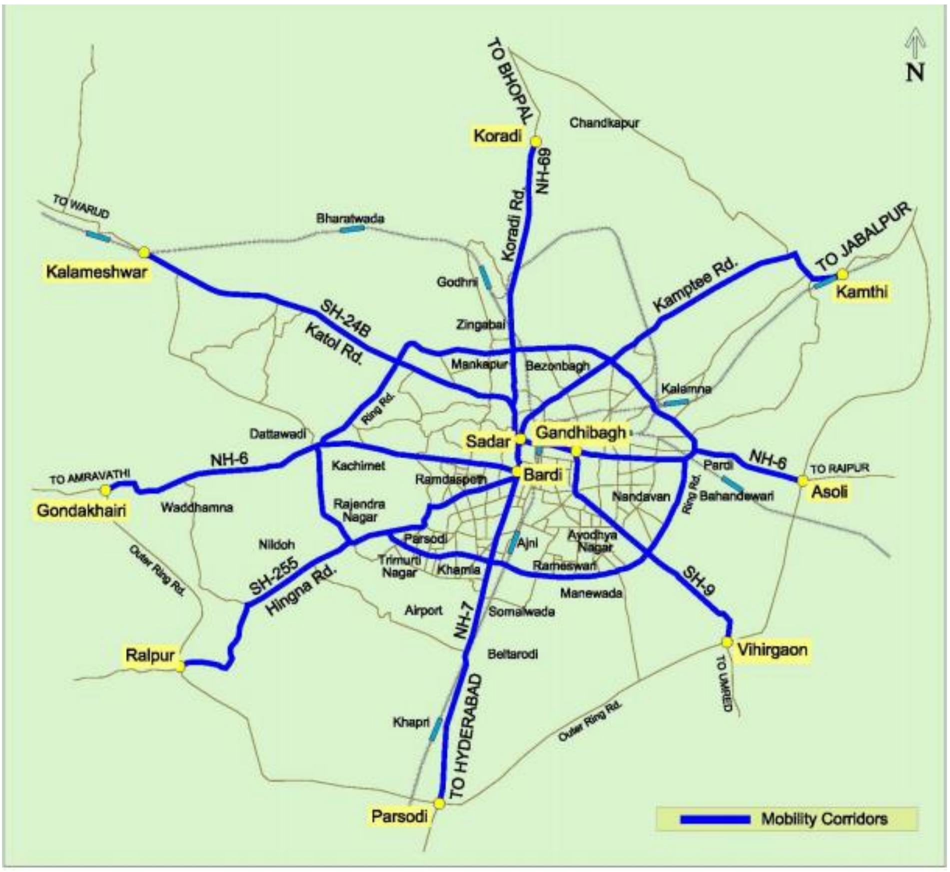


Figure 6. Mobility corridors identified for Phase I (from central Nagpur to Inner Ring Road) and Phase II (from Inner Ring Road to adjoining cities) in 2012 (source: [CMP13], p. 135)

3.3.4 Public Transit Strategy

The [CMP13] also develops a **Public Transit Strategy**, which aims at achieving 30% of modal share for public transportation in 2032. The strategy is based in three main actions:

- **The rationalization of bus routes**: some areas in the southeast side of Nagpur City were identified as being weakly connected by bus routes (see Figure 7), even though these areas were "*growing with rapid developments happening beyond inner ring road*" and, as such needed "*improved connectivity to bus routes with easy accessibility*" ([CMP13], p. 142).

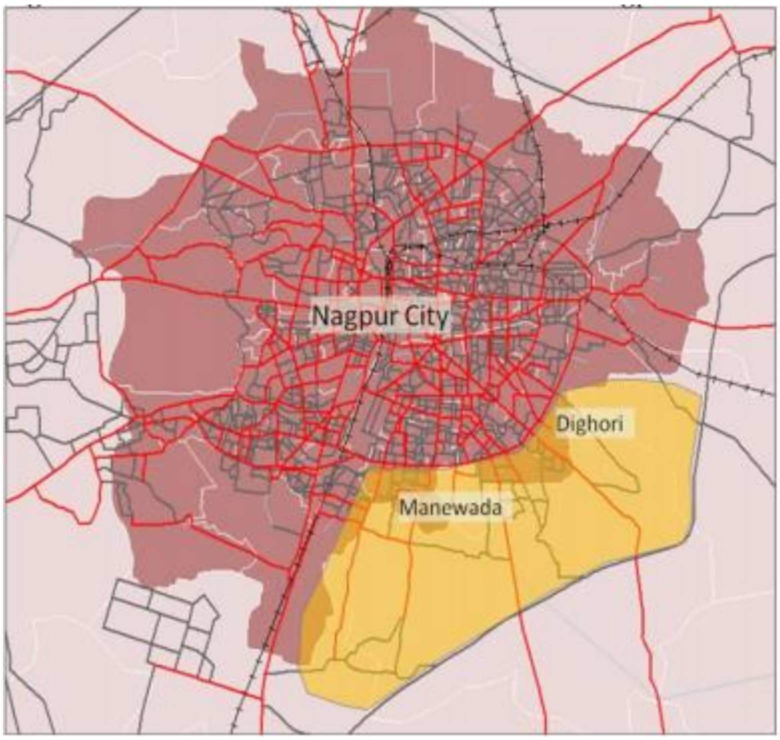


Figure 7. Bus routes rationalization identified in 2012 (source: [CMP13], p. 143)

- **The augmentation of City Bus fleet**: a "rule of thumb" of 50 buses per lakh of population was to be considered, as well as travel demand (estimated ridership considering modal shift). Considering the abovementioned "rule of thumb", the [CMP13] estimates a fleet of respectively 1,250, 1,600, and 2,000 buses for 2012, 2020, and 2032. The bus types recommended are "*AC low floor, semi low floor on trunk routes, standard buses on main routes other than trunk routes and mini buses for feeder routes*" ([CMP13], p. 144). Parallelly, the [CMP13] estimates the needed bus fleet considering operational parameters and travel demand – the main assumptions and results are presented in Table 6.

Table 6. City Bus fleet augmentation estimations using travel demand data (data source: [CMP13], pp. 144 to 146 and p. 176 on "daily emissions")

Assumptions / Results	Values for 2012 (base year estimation)	Values for 2032 (horizon scenario)
Daily running km	200 km / bus / day	250 km / bus / day
Average bus trip distance	17 km / bus / day	21 km / bus / day
Daily passengers	567 pax / bus / day	780 pax / bus / day
Ideal existing situation	10% bus modal share 599 buses required *30 tons/day in emissions*	-

Assumptions / Results	Values for 2012 (base year estimation)	Values for 2032 (horizon scenario)
Do-nothing situation	-	5.5% bus modal share 443 buses required *69 tons/day in emissions*
Scenario with construction of an LRT system	-	10% bus modal share 841 buses required *67 tons/day in emissions*
Scenario with LRT + bus routes rationalization	-	10.5% bus modal share 832 buses required *63 tons/day in emissions*
Scenario with LRT + bus routes rationalization + TOD projects	-	13.5% bus modal share 1,132 buses required *62 tons/day in emissions*
Scenario with LRT + bus routes rationalization + TOD projects + banning of shares autos	-	17.5% bus modal share 1,480 buses required

- **The adoption of a Higher Order Public Transport Strategy**: comprises the development of the “mobility corridors” (see Figure 8).

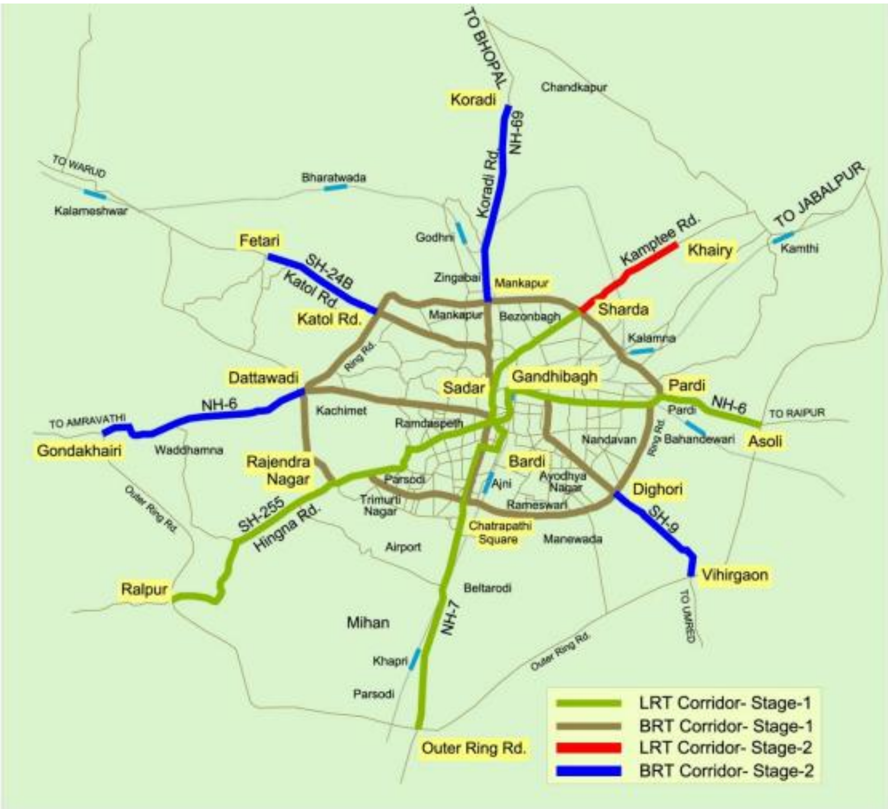


Figure 8. Proposed "Higher Order Public Transport System" for Nagpur, initial stage and extensions (source: [CMP13], p. 160)

3.4 The Unified Metropolitan Transport Authority

Both the [CDP] and the [CMP13] emphasize the **need of an Urban Transport Fund and a City Level UMTA (or equivalent)**. In its "Institutional Framework" analysis chapter, the [CMP13] lists and defines the issues, functions and legal backing of a City Level UMTA, and proposes a recommended structure for its setup, as shown in Figure 9. It should be noted that, up to date, the authority has not yet been set up by the Government of Maharashtra.

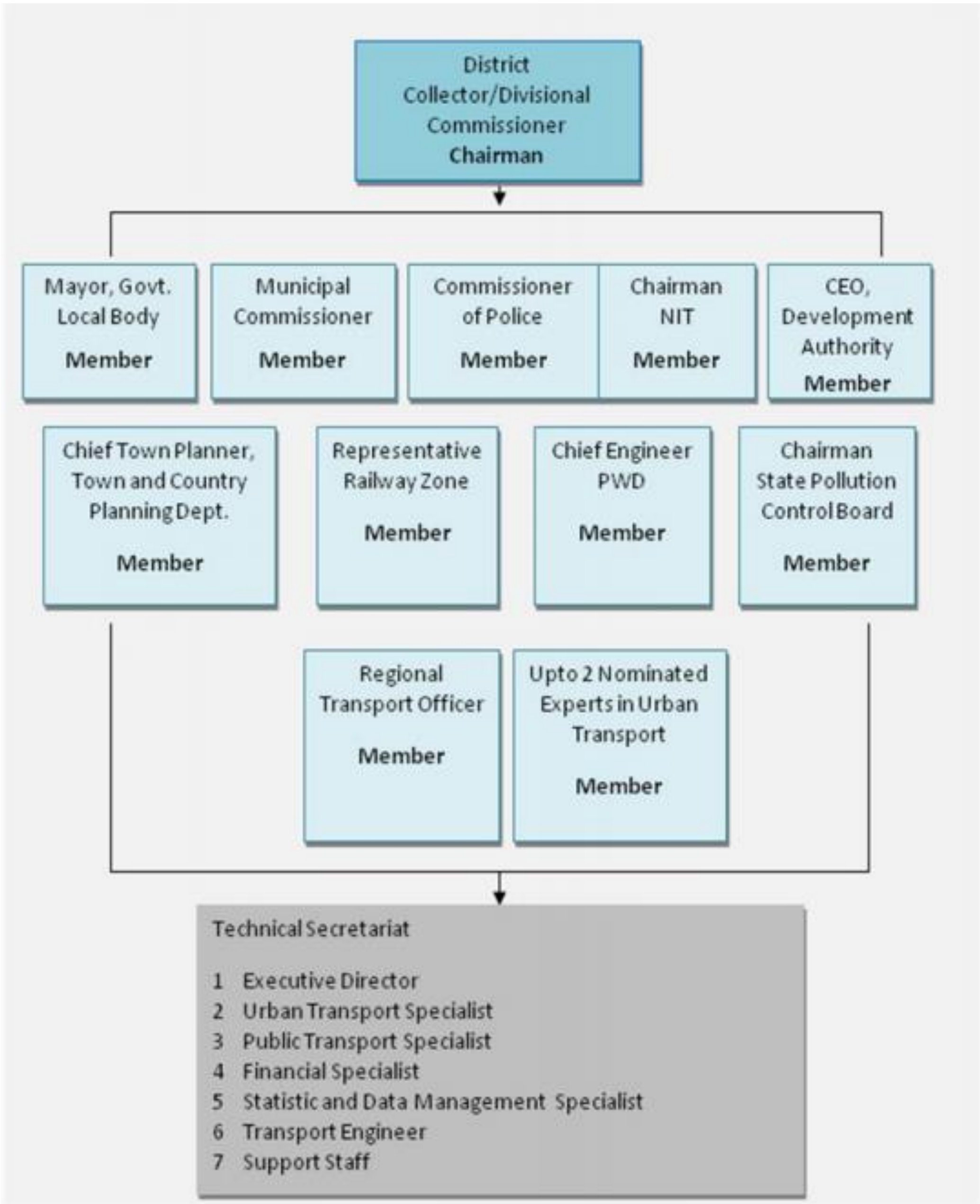


Figure 9. Recommended structure for UMTA setup (source: [CMP13], p. 193)

3.5 Improvement measures recommended

The [CMP18] recommends a series of improvements and proposals regarding "*land use and transport strategy, road network development strategy, public transit improvement strategy, non-motorized transport strategy, freight management strategy, traffic engineering measures,* [and] *travel demand management strategy*" ([CMP18], p. 99). The following paragraphs present the proposed improvements regarding the public transport strategy.

3.5.1 Mass Rapid Transit Corridors

TOD corridors for Mass Rapid Transit Systems are identified in the [CMP18] based on mobility demand and on the future transit demands estimated through 4-stage model (in our analysis, we assume this demand estimation is based on Scenario 2). Seven high capacity (rail based) corridors are identified as well as five medium capacity (bus based) corridors. They are identified in Table 7 and in Figure 10.

Table 7. Proposed transit corridors and estimated daily trips (data source: [CMP18], p. 99 and 100)

Mass Transit Corridor	Length (km)	Type	Daily trips 2021	Daily trips 2031	Daily trips 2041
Automotive Square to Khapri Station	19.7	High capacity (phase 1)	5.01 Lakhs	6.33 Lakhs	7.74 Lakhs
Pardi to Mount View (Hingna)	20.1				
Automotive Square to Kanhan River	13.0	High capacity (phase 2)			
Prajapati Nagar to Transport Nagar	5.6				
MIHAN to MIDC ESR	18.5				
Lokmanya Nagar to Hingna	6.7				
Vasudev Nagar to Dattawadi	4.5				
Katol Road	5.8	Medium capacity	0.64 Lakhs	0.81 Lakhs	0.99 Lakhs
Koradi Road	2.6				
Umred Road	5.5				
Amaravathi Road	8.2				
Vasudev Nagar to Dattawadi on Inner Ring Road	34.0				
TOTALS	**144.2**	**-**	**5.64 Lakhs**	**7.14 Lakhs**	**8.73 Lakhs**

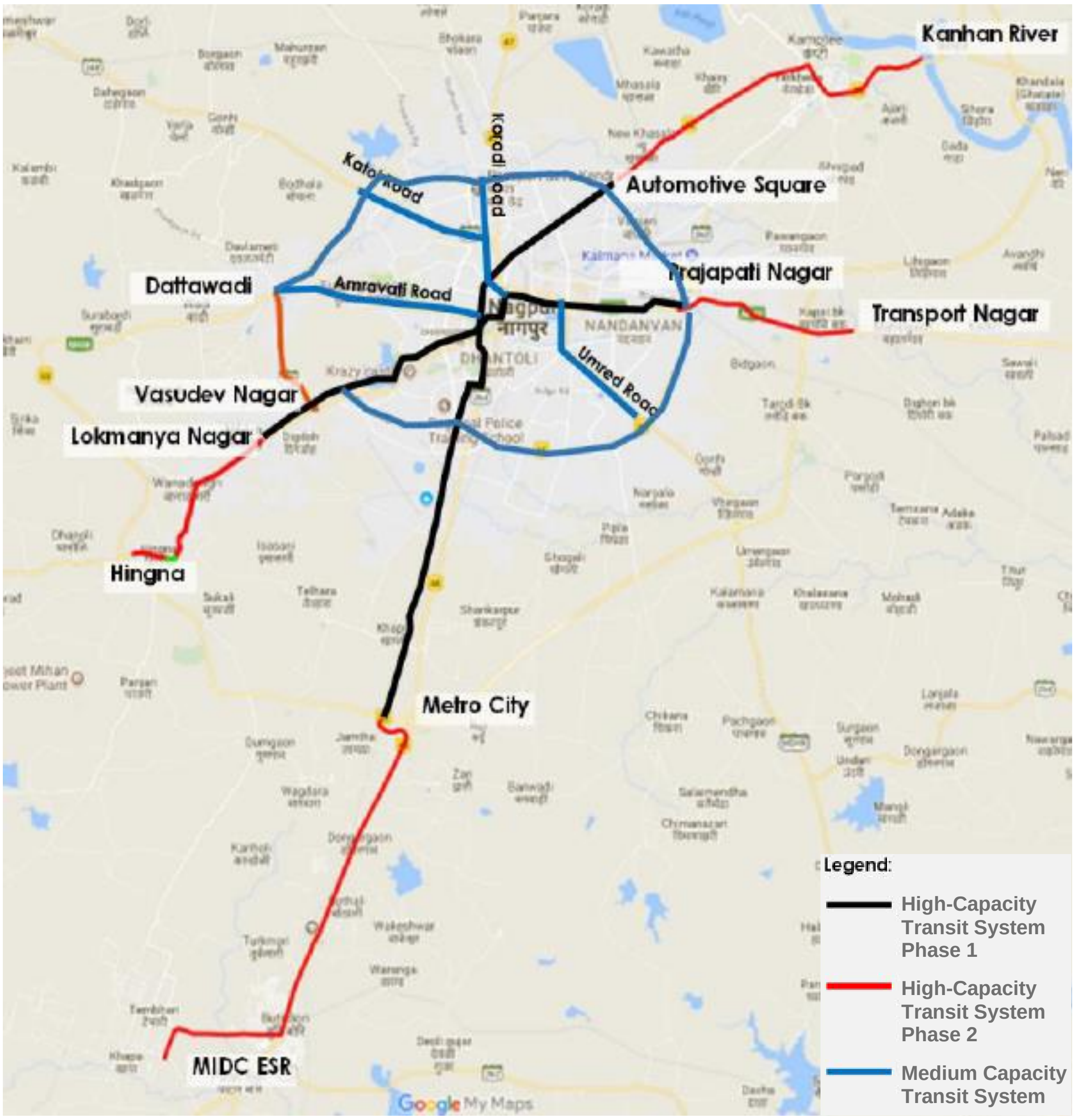


Figure 10. Proposed Mass Transit Corridors (base map source: [CMP18], p. 100)

3.5.2 City Bus System

The strategy for Nagpur's City Bus System is based on (and further developed in) the [FBS18] document (see chapter 4.1.3), including city bus routes rationalization, city bus fleet augmentation, and city bus depots and infrastructure development.

Nonetheless, the [CMP18] presents a different proposition for the augmentation of City Bus fleet from that presented in the [FBS18], as it can be seen in Table 8.

The fleet augmentation is based on the LoS-1 benchmark requirement of SLB Handbook. The [CMP18] also recommends that **10% of the fleet to be composed of electric buses**, as the Government of India promotes the National Mobility Mission Plan 2020.

Table 8. Phasing of required city bus service fleet (data source: [CMP18], p. 106)

Information	2018	2021	2031	2041
Ridership	3,60,363	4,87,098	9,55,394	12,13,677
Total bus fleet *	607	820	1,904	2,418
Number of recommended electric buses (from total fleet)	54	74	171	215

** Total includes spare vehicles as per [CMP18].*

3.5.3 Other city transport improvements

Multimodal hubs are identified in the [CMP18] to ensure efficient coordination across feeder services and other various transport modes. They are presented in Table 9. Some multimodal hubs are already in service like the hub of Sitabuldi.

Table 9. List of proposed multi-modal hub locations (source: [CMP18], pp. 108 and 109)

Multi-modal hub type	Location	Integrated modes
Level 1 City Transport Modes only	Mor Bhawan Bus Terminal	High Capacity Mass Rapid Transit System + IPT connectors + City Bus Service
	Sitabardi Bus Terminal	High Capacity Mass Rapid Transit System + IPT connectors + City Bus Service
Level 2 Regional + City Transport Modes	Ganesh Peth Bus Terminal	Regional Bus Service + IPT connectors + City Bus Service
	Chhatrapati Bus Terminal	Regional Rail + City Bus Service
	Ravi Nagar Bus Stop	Regional Rail + City Bus Service
	Nagpur Railway Station	Regional Rail + High Capacity Mass Rapid Transit System + IPT system + City Bus Service
	Ajni Railway Station	Regional Rail + IPT system + City Bus Service
	Kamptee Railway Station	Regional Rail + High Capacity Mass Rapid Transit System + IPT system + City Bus Service
	Nagpur Airport	High Capacity Mass Rapid Transit System + IPT and Airport connectors + City Bus Service

The [CMP18] also develops recommendations in terms of Intelligent Transportation System (ITS), road network, non-motorized transport (footpath, cycle ride, public bike sharing, pedestrian zone), freight and parking management, traffic engineering and management. The environmental and social impacts of the projects have been evaluated.

3.5.4 Estimated investment costs

The [CMP18] presents the projects imagined (among others) for the development of Nagpur's public transportation. Table 10 summarizes the information.

Table 10. Nagpur's public transportation development projects (data source: [CMP18], pp. 124 to 128, cxlviii and cl)

Project description	Phasing	Estimated cost (Rs. Crores)
Traffic and Pedestrian Management measures (664 km)	Short to Medium-term (~ 2018-2027)	33.2
Construction of footpaths (664 km)	Short to Medium-term (~ 2018-2027)	132.8
Provision of cycle track (146 km)	Short to Medium-term (~ 2018-2027)	73.0
Provision of Pedestrian Zones and Pedestrian Infrastructure (4 pedestrian zones)	Short-term (~ 2018-2022)	8.0
Bus Augmentation (1,904 new buses), including 10% electric bus fleet	Short to Long-term (2018-2035)	1,359.0
Bus Q Shelters (710 units)	Short to Long-term (2021-2031)	45.0
ITS (Control room / Passenger Information System and Traffic Information System)	Short-term (~ 2018-2022)	25.0
Redevelopment of City Bus Terminal – Multi Mobility Hub at Mor Bhawan	Medium-term (~ 2023-2027)	100.0
Bike Sharing Plan: Main Docking Stations (9 units) + Substations (75 units)	Short to Medium-term (~ 2018-2027)	12.0
Medium Capacity Mass Transit System (56.5 km)	Short to Medium-term (~ 2018-2027)	1,130.0
High Capacity Mass Transit System (88.1 km)	Short to Medium-term (~ 2018-2027)	27,920.0
Development of New Bus Terminals (9 units)	Short to Medium-term (~ 2018-2027)	90.0

4. Nagpur Metro Feeder Bus System

The main available Nagpur Metro Feeder Bus System (FBS) planning documents are analysed in this chapter.

4.1 Overview of collected input data

The main transport planning documents are summarized below: the context and the objectives are explained for the Detailed Project Report for Feeder System for Nagpur Metro, the Operation and Implementation Plan for Feeder Bus Service, and the Comprehensive Feeder Service Project for Nagpur Metro.

4.1.1 Detailed Project Report for Feeder System for Nagpur Metro – Final Report (2014)

The "Detailed Project Report for Feeder System for Nagpur Metro – Final Report" (hereafter reffered as [FBS14]) document was prepared by UMTC under an agreement with Nagpur Improvement Trust (NIT). The main goals defined in the [FBS14] report are as follows:

- "*Establish an efficient and cost effective "Feeder Service" for the proposed Metro Rail*
- *Providing connectivity from various zones to the Metro Stations*
- *To complement the metro system without denunciating the other public transit systems*
- *To provide a Comprehensive accessibility option to all the commuters*" ([FBS14], p. 15).

The [FBS14] is divided into chapters covering a general assessment of Nagpur's population growth and socio-economic aspects, the presentation of transport measures and projects, the design of the Nagpur Metro Feeder Bus System and its operational and block cost estimates, a non-motorized transport and ITS strategies, and an implementation plan.

The study is based on the results and projects presented on the [CMP13]. The [FBS14] document assumes that the Nagpur Metro starts its operation in 2018. The area of study of the document is shown in Figure 11.

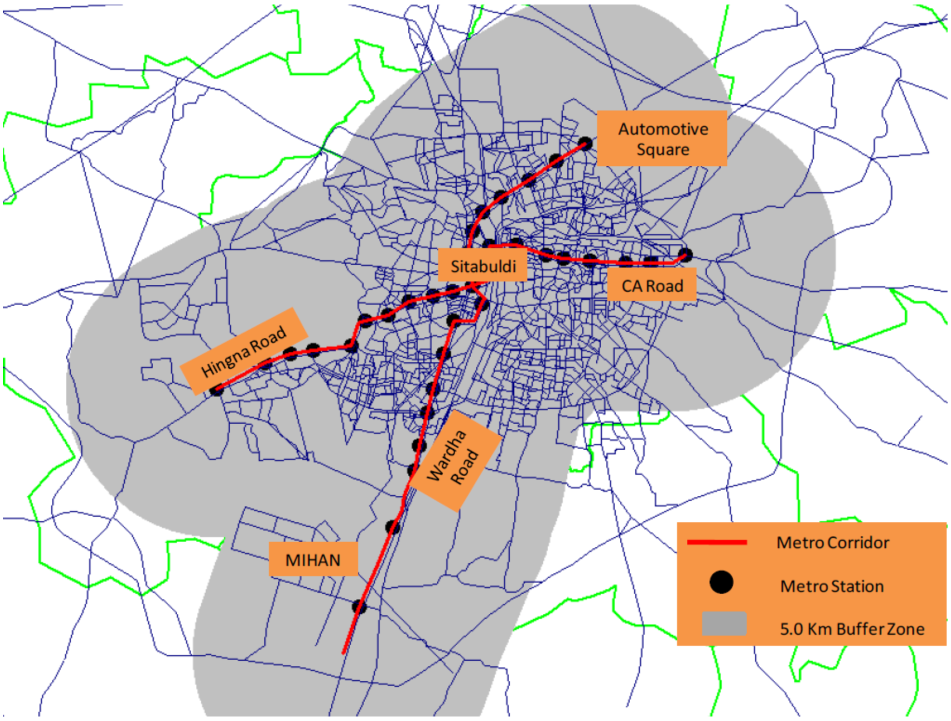


Figure 11. Project Influence Area (source: [FBS14], p. 17)

4.1.2 Operation and Implementation Plan for Feeder Bus Service – Operation Plan Report + Infrastructure Development Plan for Feeder Bus Service (2018)

The "Operation and Implementation Plan for Feeder Bus Service – Operation Plan Report" (hereafter reffered as [FBSOP]) and the "Infrastructure Development Plan for Feeder Bus Service" (hereafter reffered as [FBSID]) documents were prepared by UMTC under an agreement with MahaMetro.

Although largely based on the results of the [FBS14] document, the [FBSOP] and the [FBSID] differ from the [FBS14] report on that:

- They assume that the Nagpur Metro starts its operation in 2017,
- They consider alternate vehicle technologies,
- The routes have been designed considering a **buffer zone of 2.5 km** around the metro stations, compared to the **5 km considered in the previous study**,
- They focus on having greater frequency with shorter route lengths.

The area of study is shown in Figure 12.

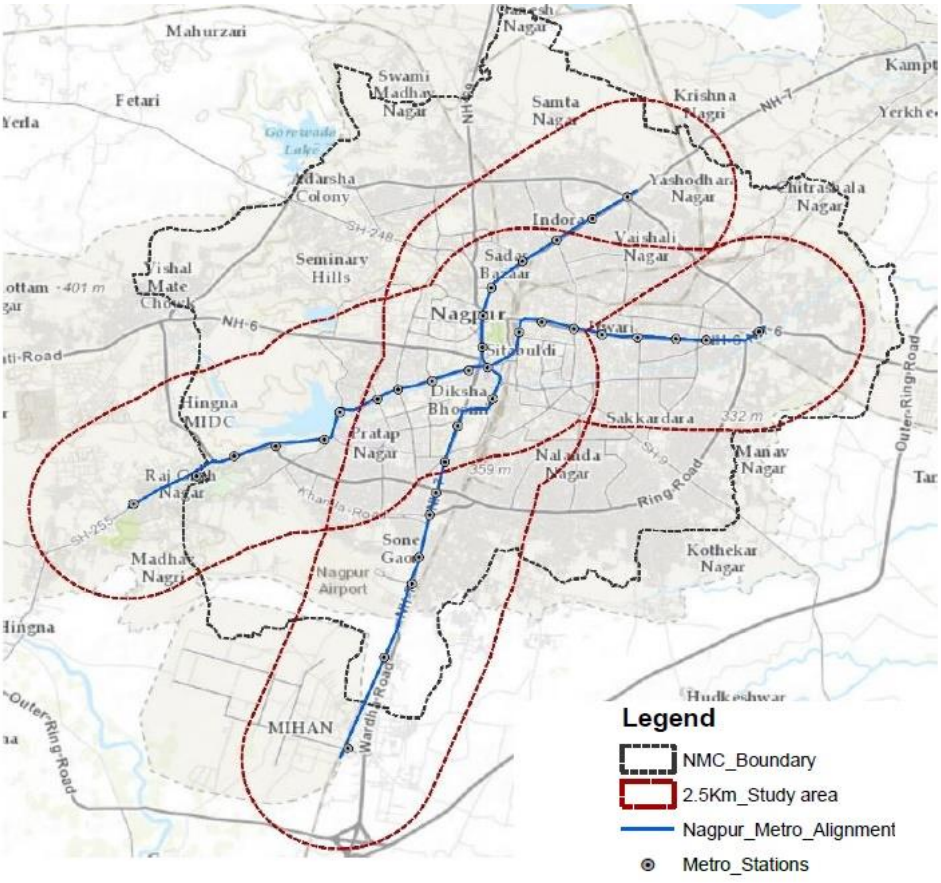


Figure 12. Study area (source: [FBSOP], p. 38)

4.1.3 Comprehensive Feeder Service Project for Nagpur Metro – Final Report (2018)

The "Comprehensive Feeder Service Project for Nagpur Metro – Final Report" (hereafter refferd as [FBS18]) document was prepared by UMTC under an agreement with MahaMetro and German Development Bank (KfW). It analyses Nagpur City's transport situation regarding City Bus Services and Non-Motorized Transport (NMT) as well as (future) Nagpur Metro system and its Feeder Bus Service. It's main goal is to propose an cohesive plan to achieve "*seamless integration of all modes of public transport systems (existing & planned) and the Non-Motorized modes as a means of enhancing the ridership along the transit corridors*" ([FBS18], p. 1-1).

The [FBS18] report is part of a larger study which scope comprehends:

- The study of opportunity, the planning and the implementation options for the Nagpur Metro Feeder Bus Service, comprising a "*buffer zone area with a radius of 2.5 km on either side of the metro alignment*" ([FBS18], p. 1-3),
- The analysis of current Nagpur City Bus Services, the review of all bus routes operating, and the preparation of a Route Rationalization Plan for City Bs Services that considers the NMC's jurisdiction area ([FBS18], p. 1-3),

- The analysis of current Nagpur NMT, the drawing of a NMT Master Plan, a Public Bike Sharing Scheme and the Concept Designs for Urban Place Making, contemplating a "*buffer zone area with a radius of 500 m on either side of the metro alignment*" ([FBS18], p. 1-3), and
- The proposition of an Implementation Options Report for the above-mentioned plans, scheme, and designs.

The document presents a general assessment of Nagpur City's profile and public transport characteristics, non-motorized transport characteristics, a demand assessment (for metro feeder bus services), and the evaluation of routes, services, infrastructure and systems needed, as well as impacts and costs.

The [FBS18] is based on secondary data gathered from previous studies and documents, such as the [CDP], the [CMP13], and the [FBSOP]. Additional data was obtained through primary surveys carried out by UMTC, such as "*Public Transport Occupancy Surveys, Public Transport Speed and Delay Surveys, On Board Boarding and Alighting Surveys, Bus Passenger OD Surveys along with Revealed Preference Surveys, Vehicle Operator Survey*" ([FBS18], p. 1-4).

For the Public Transport part of the study, following the stage of data collection and analysis, base-year and horizon-year demand were modelled, and major public transport corridors identified. The selected routes were then classified as Metro Feeder Routes and City Bus Routes, and an Operational Plan (containing information on service, fleet, technology, procurement plan and block cost estimates) and an Infrastructure Plan (comprising bus stops, bus terminals, bus depots and ITS systems) were drafted. An impact analysis and an Implementation Strategy Plan complete the study.

4.2 Assessment of Nagpur's public transport

The [FBS18] report presents an analysis of Nagpur City's transport system (using data from 2014 to 2017). Table 11 presents a summary of general traffic data.

Table 11. Nagpur City general traffic data in 2017 (data source: [FBS18], pp. 2-22 and 3-15)

Indicators	Values (2017)
Average trip length (km)	8.60 for two-wheelers 10.80 for private cars 5.80 for autos 11.60 for bus + IPT 2.90 for cycles
Modal shares	42.6% two-wheelers 5.7% private cars 19.8% autos 15.6% bus + IPT 6.4% cycles
Nagpur City buses supply (in bus per 1,00,000 population)	9 buses

The [FBS18] report has been produced during an important change in city bus services management. Through a contract with DIMTS, NMC engaged the services of integrated bus transport management. DIMTS "*shall be managing the day to day coordination of bus services on behalf of NMC, who shall also provide technology based solutions to integrate all the domain elements of City Bus Services for a modern and efficient city bus services to the commuters of the city*" ([FBS18], p. 3-7). Furthermore, "*NMC has allotted the operations of CBS to four operators (3 Diesel & 1 Ethanol) under a Gross Cost Contract to operate 487 buses*" ([FBS18], p. 3-7), those being **432 diesel buses** (144 buses per operator) and **55 ethanol buses**.

Key indicators of the city bus service for 2014-2017 are presented in Table 12. Information on existing and operating city bus routes in Nagpur (in 2017) and on the intensity of bus routes on major corridors are presented respectively in Figure 13 and Figure 14. Finally, the manpower distribution pre job description for pre-March 2017 operation of Nagpur City Buses is presented in Figure 15.

Table 12. City bus transport system indicators in 2014-2017 (data source: [FBS18], pp. 3-7, 3-12, 3-13, 3-30, 3-31)

Indicators	2014	2015	2016	2017 (pre-March)	2017 (post March)
Total bus fleet	470 buses	470 buses	470 buses	470 buses	487 buses
On-road (operational) fleet	205 buses (44%)	209 buses (45%)	217 buses (46%)	222 buses (47%)	263 buses (54%)
Operational routes	-	-	-	36 out of 183 (20%)	38 out of 183 (21%)
Dead km (% of total operated km)	5.60%	5.38%	4.89%	-	-
Missed or cancelled trips (% of total trips)	-	-	-	5.16%	2.74%
Average daily km	219 km / bus	216 km / bus	220 km / bus	208 km / bus	228 km / bus
Average load factor in buses	39%	36%	44%	48%	61%
Total daily number of passengers	1.38 lakh*	1.26 lakh*	1.25 lakh*	0.92 lakh	0.99 lakh
Number of depots	-	-	4 depots	-	4 depots °
Number of bus stops or shelters	-	-	190 units	-	190 units

** Although it is not clear on the report, these figures seem to include IPT passengers.*

° 4 depots were in operation in 2017 out of the 7 available depot areas.

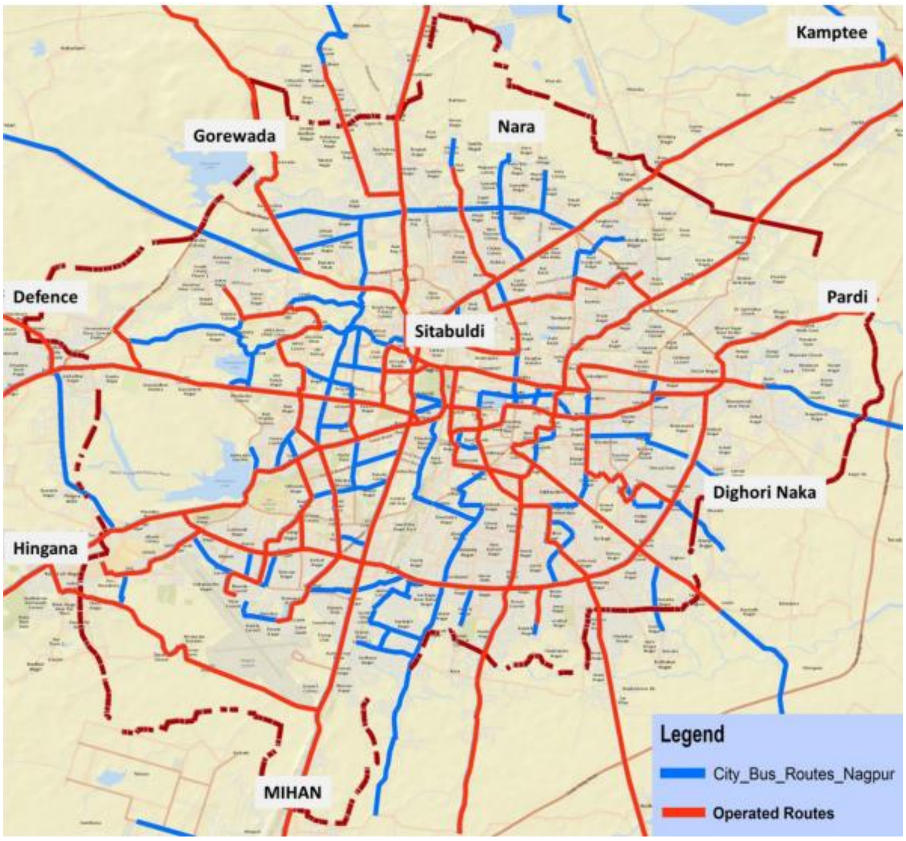


Figure 13. Existing and operating city bus routes in 2017 (source: [FBS18], p. 3-10)

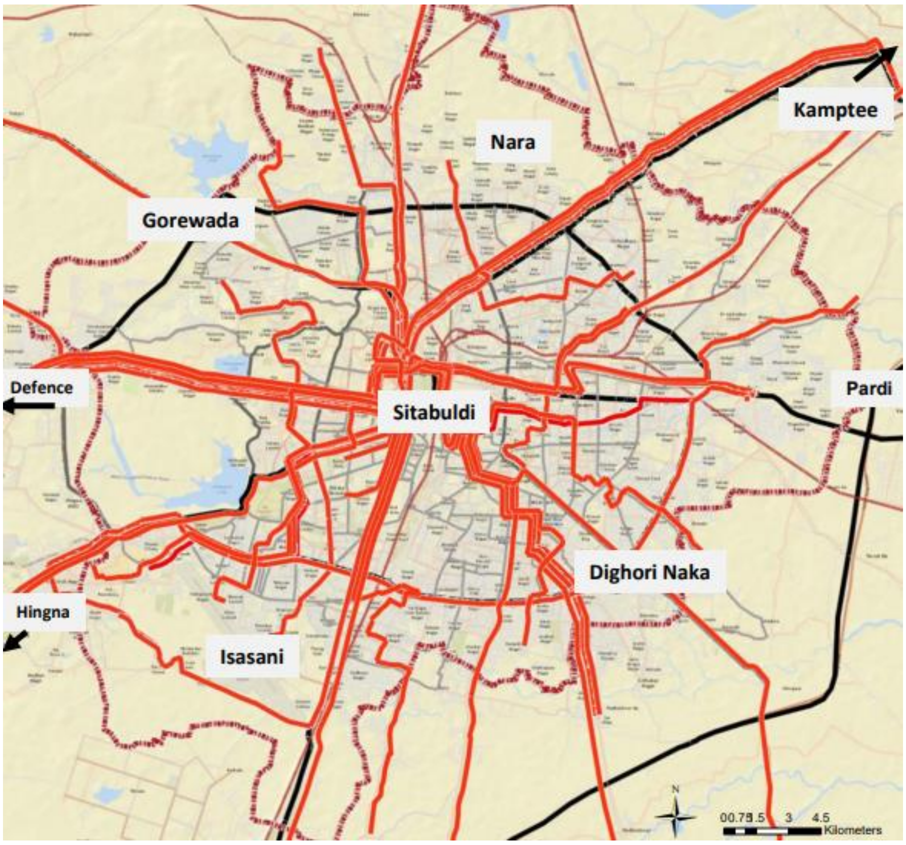


Figure 14. Intensity of city bus routes on major corridors (source: [FBS18], p. 3-11)

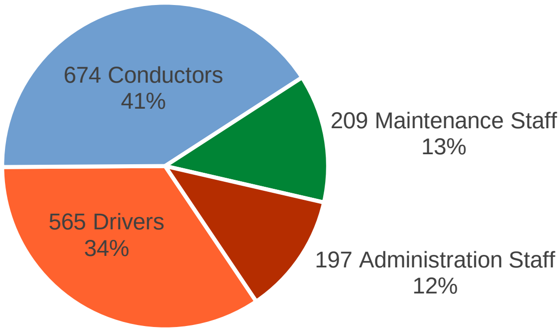


Figure 15. Manpower distribution for the operation and maintenance of city buses pre-March 2017 (data source: [FBS18], pp. 3-13 and 3-14)

The main conclusions of the [FBS18] document regarding the assessment of Nagpur City public transportation (pre-March 2017) are:

- Low quality and efficacity of bus operation, as well as lack of bus maintenance,
- Due to the city's radial route structure and Sitabuldi strong central area, a majority of existing bus routes overlap with each other. Indeed, "*of the 183 notified city bus routes, **80 originate from Sitabuldi***" ([FBS18], p. 3-15),

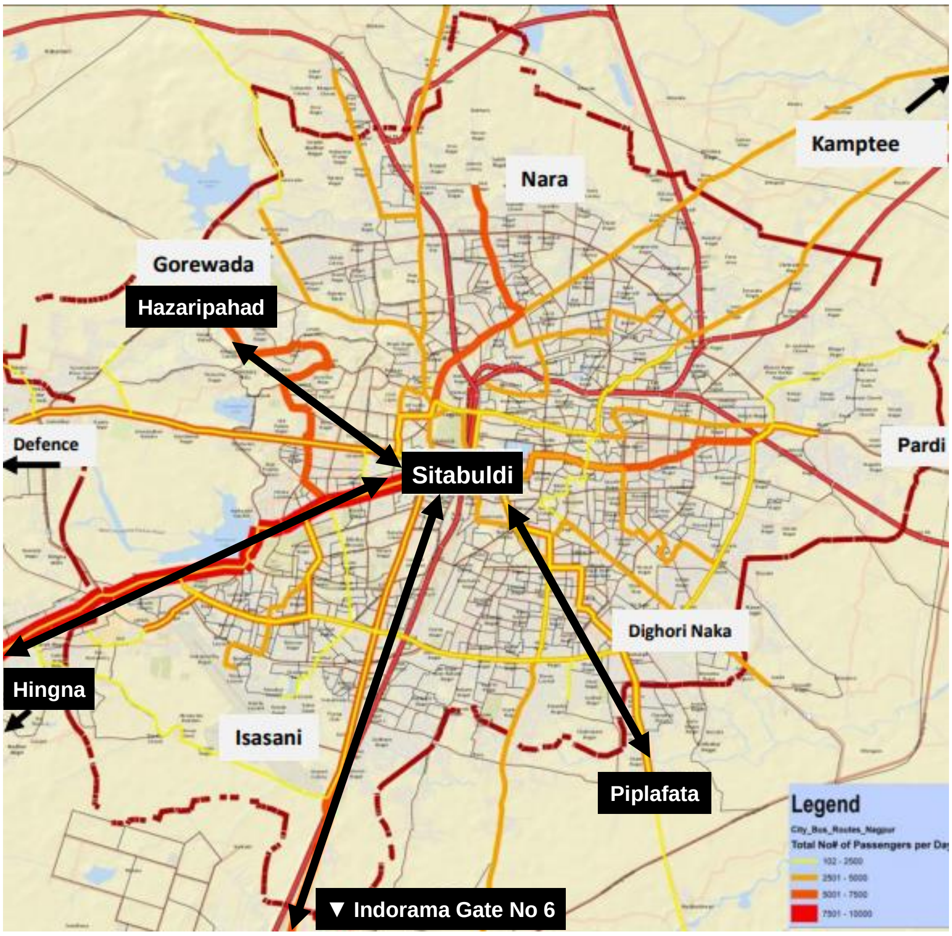


Figure 16. Distribution of daily city bus ridership per bus route (base map source: [FBS18], p. 3-17. Addition data from Google Maps, 2020)

- With regards to daily ridership (about 98,611 passengers in 2017), **almost 30% of the passengers are concentrated on only 3 out of the 38 routes in operation**. These routes are Sitabuldi – Hingna Gramin Hospital (9,855 pax/day and 3.5 min headway), Sitabuldi – Indoram Gate No 6 (9,804 pax/day and 4.5 min headway) and Piplafata – Hazaripahad (9,154 pax/day and 4.2 min headway) – see Figure 16. All other bus routes present a daily ridership of less than 6,200 pax/day and average headway varies from 3.5 to 108 minutes,
- Regarding the socioeconomic characteristics of bus passengers, the [FBS18] document concludes that the majority of travellers are 22-40 years old (74%) and male (79%), employees (57%) or students (21%), with an average household monthly income of Rs 5-15,000 (62%), and spending Rs 501-1,000 monthly on transport (51%). With regards to trip characteristics of bus passengers, the report concludes that most trips are related to work / business (51%) and usually include 2 transfer modes (73%) while travelling within the city,
- The [FBS18] document identifies seven available depot areas, which are shown in Figure 17 – information on the four bus depots under operation in pre-March 2017 is given in Table 13,

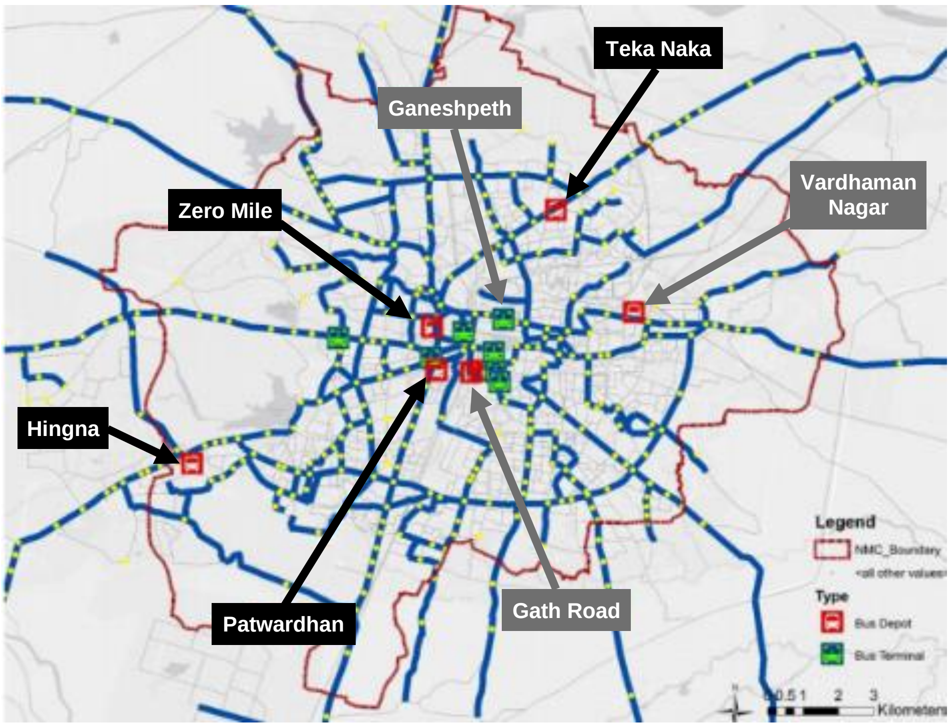


Figure 17. Location of the available bus depot areas in 2017 (base map source: [FBS18], p. 3-30. Additional data from Google Maps, 2020)

Table 13. Information on bus depots in pre-March 2017 (data source: [FBS18], pp. 3-33 and 3-34)

Bus Depot	Available area	Used for maintenance?	Bus washing activities?	Other comments
Teka Naka	1.45 acres	Small maintenance only	15-20 buses per day	No proper paving / shades for buses
Zero Mile	0.50 acres	Small maintenance only	20-25 buses per day	No proper shelter for buses
Patwardhan	3.50 acres	Small and major* maintenance activities	*(no data)*	No proper shade for buses
Hingna	5.00 acres	Small and major* maintenance activities	*(no data)*	-

** Inspection Pits, Washing Bays, Repair Bays and Spare Parts Store available.*

4.3 Proposed Nagpur Metro Feeder Bus System

The [FBS14] proposes a total of **31 routes** for the Nagpur Metro FBS, including 10 Battery Operated Vehicle (BOV) routes, as seen in Figure 18. BOV (e-rickshaws) are proposed when the roads are not sized for Midi or Mini-size buses.

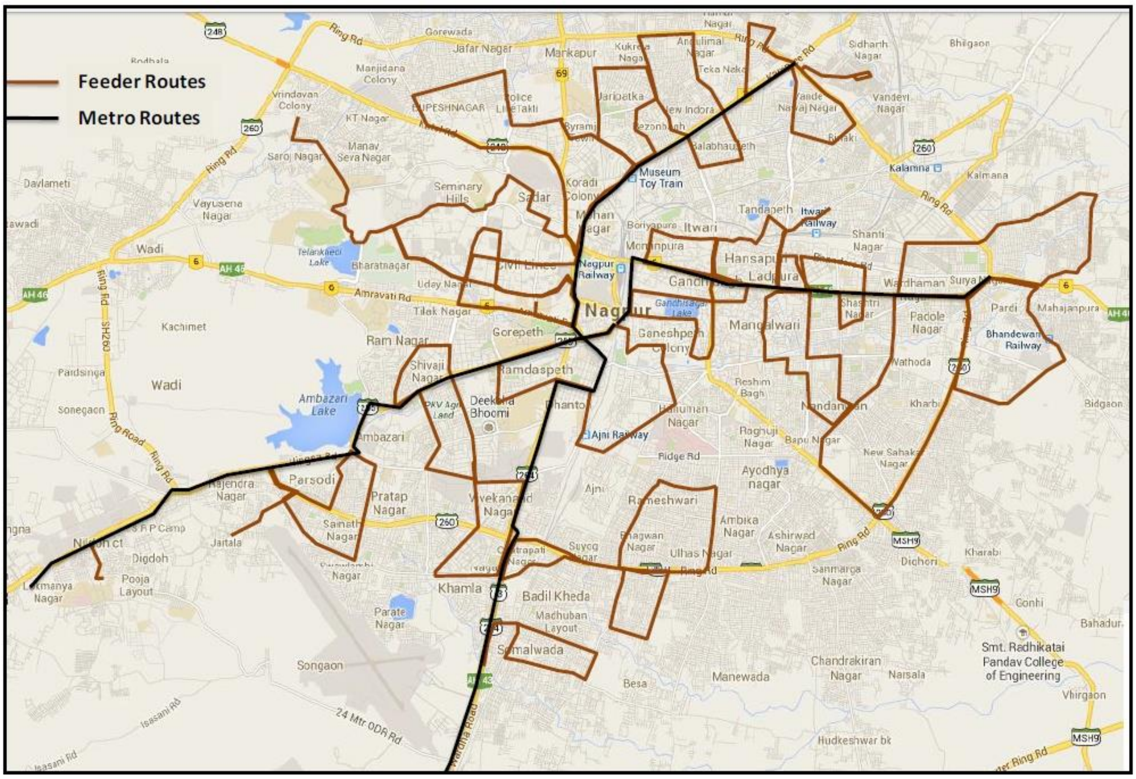


Figure 18. Feeder routes and Nagpur Metro corridors (source: [FBS14], p. 65)

The potential catchment for each of the route was estimated, as presented in Figure 19. The [FBS14] document presents no forecasts for the year 2041.

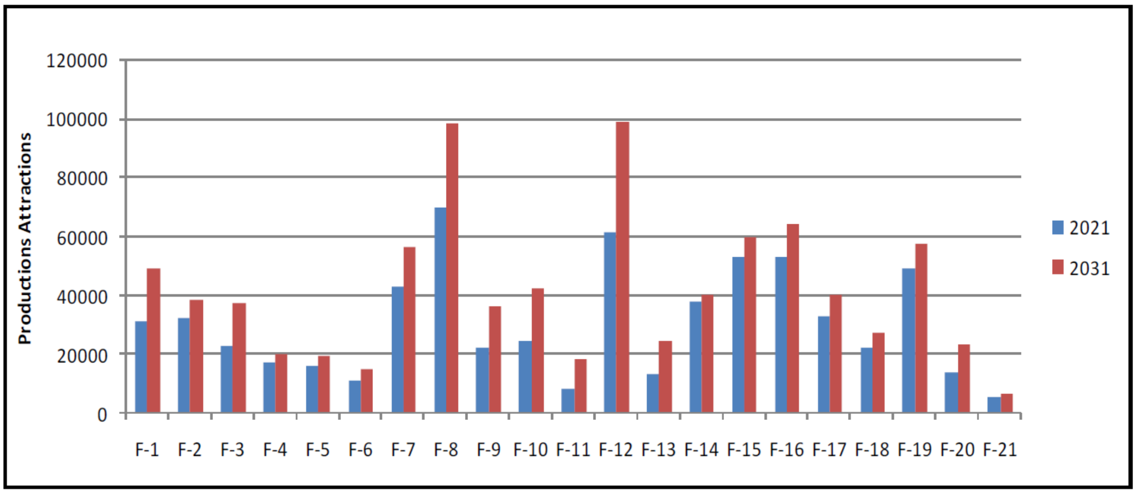


Figure 19. Potential catchment served by the Feeder Routes (source: [FBS14], p. 23)

In terms of ITS strategy, the [FBS14] document proposes the following:

- The FBS fleet shall be equipped with Passenger Information System on board (current/next stop and route map/location via digital displays and audio system), Automatic Vehicle Location System (including bus mounted GPS based driver console and GIS based fleet monitoring and control system), and Bus Driver Console,
- The FBS stations and stops shall be equipped with Electronic Display Boards, presenting off-board passenger information system,
- The FBS fare and collection system shall be composed of Handheld Ticketing Devices and a Smart Card, integrated to the Nagpur Metro System,
- The FBS is also composed of a Central Control Centre, a Bus Terminal Management System, and a Security Camera Network System.

The [FBSOP] proposes a total of **38 routes** for the Nagpur Metro FBS – 20 routes along the East-West metro corridor and 18 routes along the North-South metro corridor. The average length is 5.53 Km. 27 routes are circular routes and 11 are point to point routes.

Being part of the same overall studies, the [FBS18] presents the same conclusions and proposals as the ones presented in the [FBS14] and in the [FBSOP].

4.4 Recommended rationalization of Nagpur City Bus Service routes

According to the [FBS18] document, "*with the metro operations, some portion of the existing public transport demand shall shift to metro. As a method to mitigate the impact of the Metro operations on City Bus Services, Route Rationalization of City Bus Services is recommended considering the base year and future year demand for Bus Services*" ([FBS18], p. 3-37). Indeed, the report states that "***29 routes overlap over the proposed metro corridor** which accounts for the 66% of the total city bus services operating withing Nagpur city*" ([FBS18], p. 3-36), as it can be seen in Figure 20.

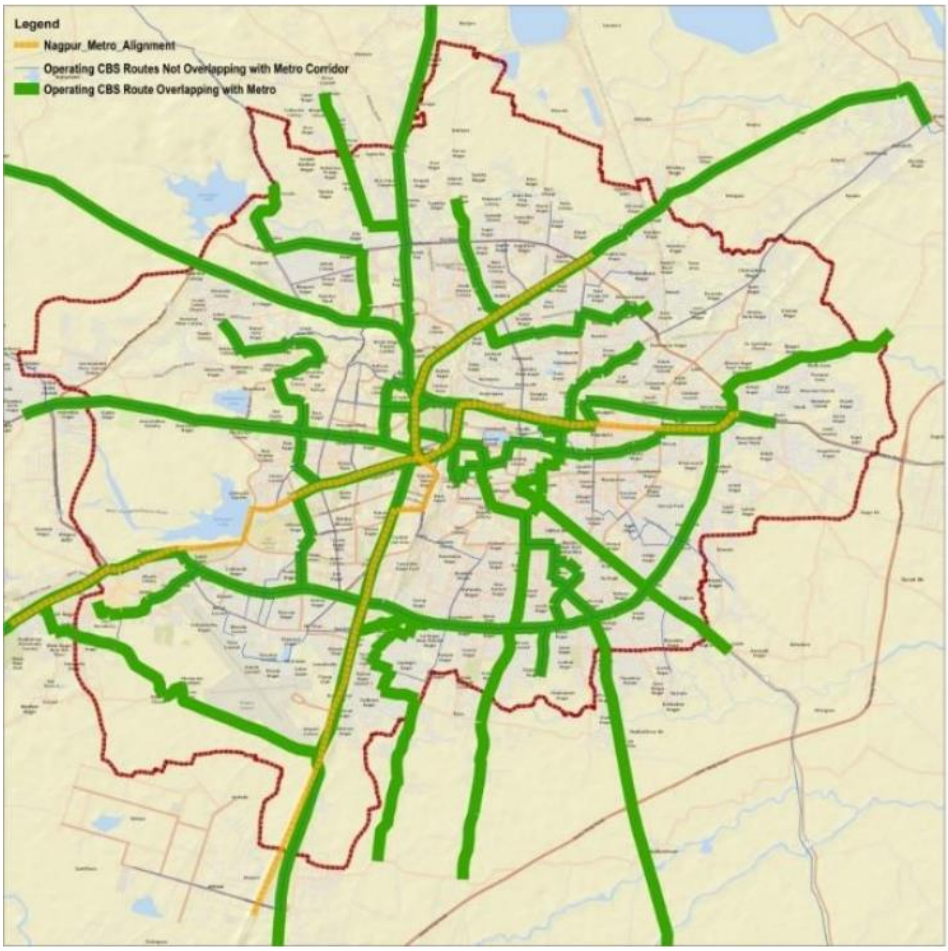


Figure 20. Overlap of operational City Bus routes (pre-March 2017) with metro corridors (source: [FBS18], p. 3-35)

Considering the radial structure of Nagpur city and the strong central area of Sitabuldi, the [FBS18] document proposes a bus routes rationalization based on the "Hub & Spoke Model", illustrated in Figure 21. This model divides corridors in "trunk routes", connecting major activity centres within the city, and "feeder routes" operating from hubs (important connection and transfer points) to minor activity centres.

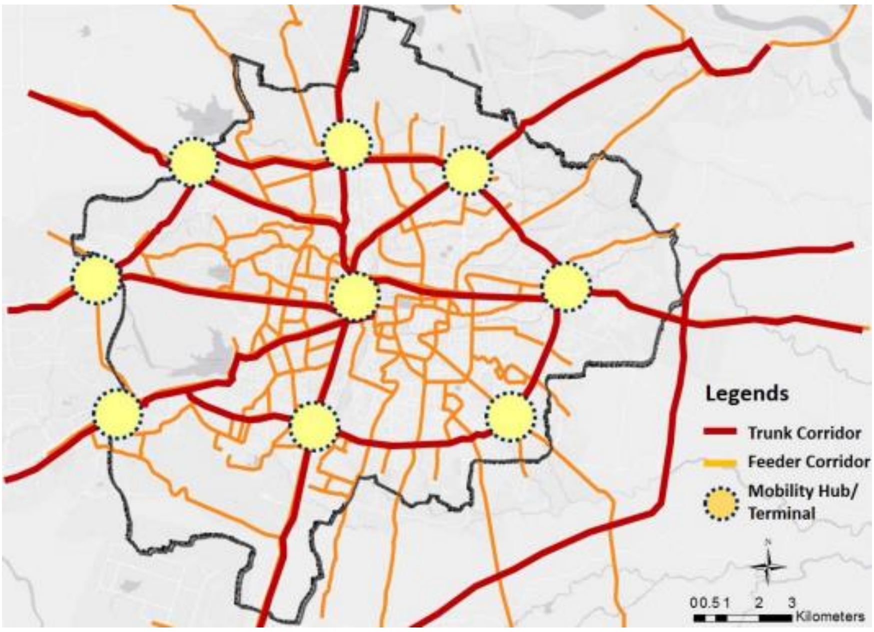


Figure 21. Proposed "Hub & Spoke Model" for Nagpur (source: [FBS18], p. 6-5)

After a 3-stage process (listing of total existing routes, removal of overlaps with metro lines, evaluation of the PHPDT and revenue generation capacity of routes), **a list of 76 rationalized city bus routes is proposed**, as seen in Figure 22.

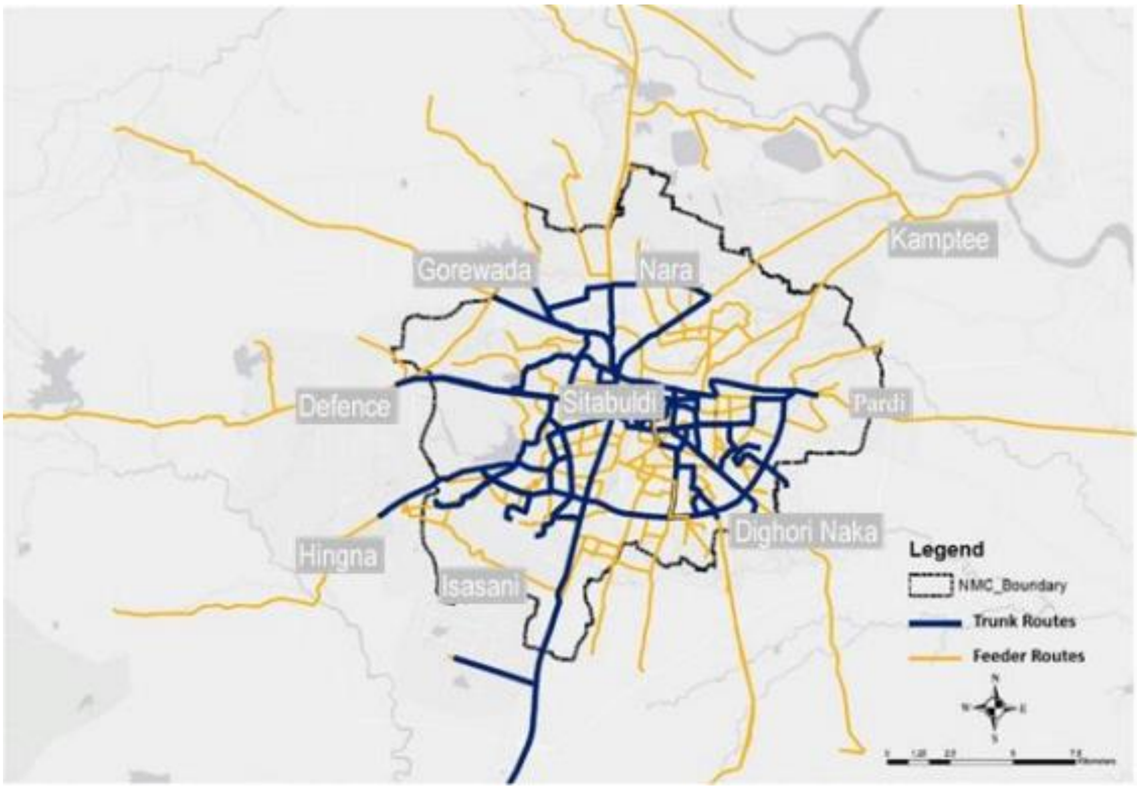


Figure 22. The proposed 76 "trunk" and "feeder" City Bus routes (source: [FBS18], p. 6-12)

The report estimates the fleet evolution for city bus services and proposes a phasing for bus deployment, including a detail by motorization type, as seen in Table 14. The estimations consider (among others) the following parameters:

- "*Hours of Operations – 16 hours*
- *Average Running Speed – 25 kmph*
- *Distance between bus stops – 500 m*
- *Dwell Time at the Bus stops – 30 seconds per stop*" ([FBS18], p. 6-19).

Table 14. Phasing of required city bus service fleet (data source: [FBS18], pp. 6-19 and 6-20)

Bus type	2018	2023	2028
Midi buses	16	73	172
Standard – B (electric battery)	114	156	196
Standard – D (diesel fuel)	396	724	1,034
Standard – E (ethanol fuel)	51	88	117
TOTAL FLEET *	**607**	**1,093**	**1,596**
Operated routes	**46**	**64**	**76**

* *Total includes +5% contingency of spare vehicles suggested in* [FBS18].

4.5 Improvement measures recommended

4.5.1 Recommended vehicle types for City Bus Services

The [FBS18] report proposes an evolution of city bus fleet based on different propulsion technologies (diesel, electric battery-operated, and ethanol fuel) and bus sizes (mini buses, midi buses, and standard buses). Main characteristics and specifications are also presented in the report, as shown in Table 18.

Table 15. Proposed specifications for city bus service buses (data source: [FBS18], pp. 6-23, 6-24, and 6-25)

Characteristics	Standard Urban Bus (AC or Non-AC)	Midi Buses (AC or Non-AC)	Minibus
Emissions	BS III or BS IV or latest as applicable *	BS III or BS IV or latest as applicable *	BS III or BS IV or latest as applicable *
Seating capacity	32 to 34	23 to 28	13 to 22
Wheelbase	-	≤ 5,000 mm	3,000 mm
Overall length	≤ 12,000 mm	≤ 9,400 mm	≤ 7,000 mm
Overall width	≤ 2,600 mm	≤ 2,500 mm	≤ 2,200 mm
Overall height	≤ 3,800 mm	-	-
Maximum floor height	900 / 650 / 400 mm	900 / 650 / 400 mm	900 / 650 / 400 mm
Life cycle	12 years or 10,00,000 km	12 years or 10,00,000 km	12 years or 10,00,000 km

* *Bharat Stage 6 (BS VI) is applicable since April 1st, 2020.*

4.5.2 Recommended City Bus infrastructure development

With regards to the upgrading of City Bus Service infrastructure (bus shelters, bus depots, ITS systems…), the [FBS18] document recommends the following:

- The installation of **additional 710 Bus Q Shelters** (see Figure 23) along the proposed "trunk" and "feeder" city bus routes,

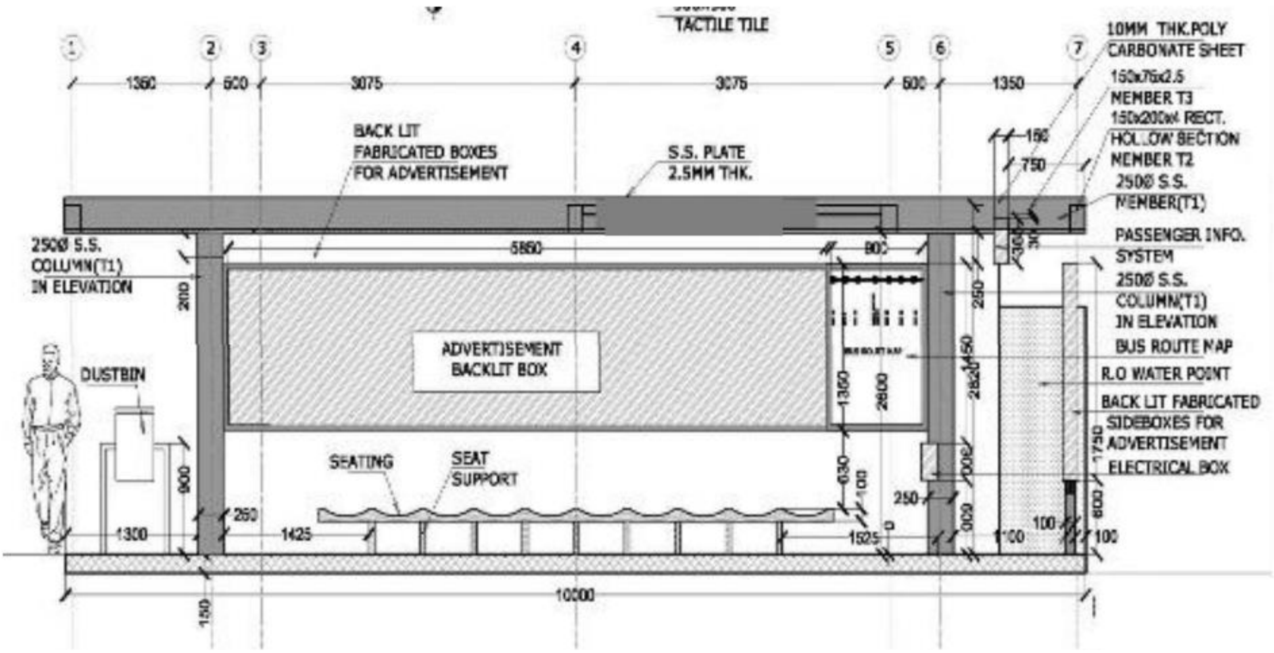


Figure 23. Suggested Bus Q Shelter's layout for city buses (source: [FBS18], p. 7-8)

- The **upgrade of the 4 existing bus depots** (Teka Naka, Hingna, Zero Mile, and Patwardhan) and the **development of 6 new bus depots** (see Figure 24). The proposed operational use (routes, bus fleet) and required area for each existing and proposed depot is presented in Table 16.

  Finally, it should be noted that "*considering the activities undertaken in the depots, during the day and night, the depot shall create disturbance/noise pollution for the surrounding areas. Since the* [Zero Mile depot] *area is only 0.5 acres, depot doesn't have adequate space to accommodate enough no. of buses. Under the mentioned circumstances, it is recommended to shut down the depot at the aforementioned location and requisite land space be utilized for the other services of City Buses*" ([FBS18], p. 7-13).

Table 16. Proposed bus depots for city bus service (data source: [FBS18], pp. 7-14 and 7-15)

Depot name / location	Status	No. of routes operated	2018 bus fleet	2023 bus fleet	2028 bus fleet	Area required (acres)	Area available (acres)	
Zero Mile	Existing	0	-	-	-	-	0.5	-
Hingna	Existing	9	113	231	297	11.3	10.4	😐

Depot name / location	Status	No. of routes operated	2018 bus fleet	2023 bus fleet	2028 bus fleet	Area required (acres)	Area available (acres)	
Patwardhan	Existing	16	45	125	184	8.2	8.2	☺
Teka Naka	Existing	12	81	160	220	10.65	10.65	☺
Dattawadi	Proposed	9	31	108	155	6.8	7.4	☺
Babulkheda	Proposed	8	80	104	172	8.6	7.82	😐
Katol Naka	Proposed	3	10	8	13	0.65	0.65	☺
Takli	Proposed	7	21	47	96	4.8	10.56	☺
Octroi Naka	Proposed	5	117	187	257	12.85	12.85	☺
Wathoda	Proposed	7	108	71	125	12.1	4.18	☹

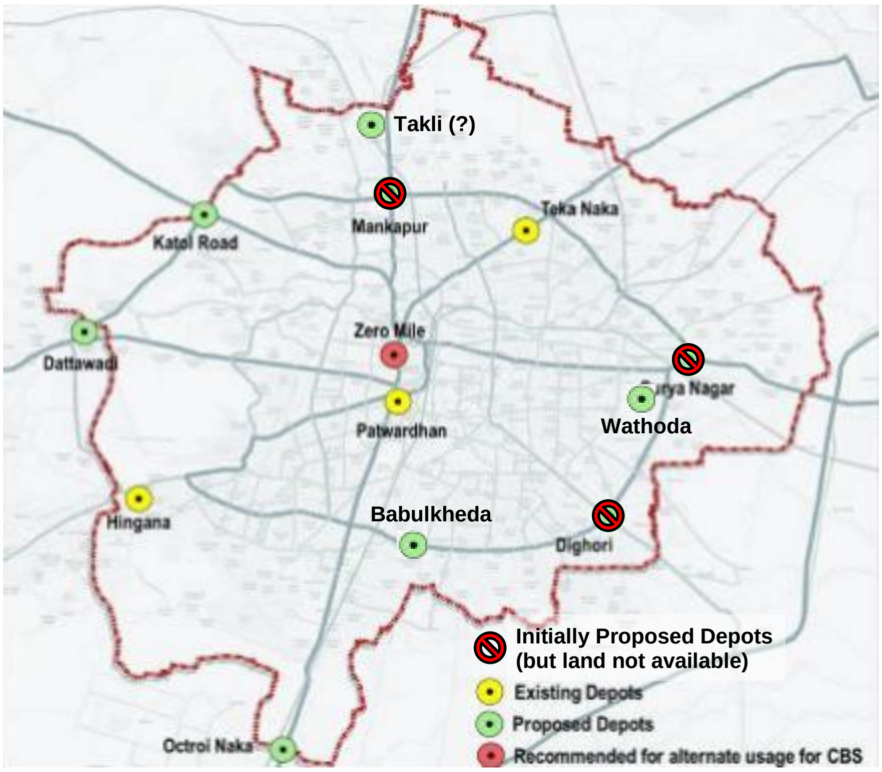


Figure 24. Location of under operation (pre-March 2017) and proposed bus depots (base map source: [FBS18], p. 7-13. Additional data from Google Maps, 2020)

- The **development of ITS** for bus fleet monitoring and tracking (GPS and GPRS based vehicle tracking units, automatic vehicle location system software), passenger information (on bus stations, terminals and inside buses), financial management (central accounting system, receipts accounting module, payment accounting module, daily receipts and payments cross-tally), automated fare collection (station ticket terminals, smart cards, bus card validators and bulk initialization machine), vehicle real-time scheduling (including dynamic planning software) and for depot management (general, storage, inventory, and personal information).

4.5.3 Estimated investment costs

A project cost estimation for the proposed projects is presented in the [FBS18] report. With regards to City Bus Service, the main CAPEX data related to necessary "immediate" investment is summarized in Table 17.

Table 17. CAPEX estimates for City Bus Service (data source: [FBS18], pp. 10-2 to 10-5)

Investment component	Number of items	Unitary price	Total CAPEX
Standard AC / Non-AC Diesel buses	75	Rs 62,50,000	Rs 47.00 Crores
Midi AC / Non-AC Diesel buses	1	Rs 45,00,000	Rs 0.45 Crores
Standard Electric buses	89	Rs 1,15,00,000	Rs 103.00 Crores
Bus Q Shelters	710	Rs 6,38,000	Rs 45.30 Crores
Upgrade of existing depots	*overall cost*		Rs 18.25 Crores
Development of proposed depots	*overall cost*		Rs 48.16 Crores
Depot equipment (all depot areas)	*overall cost*		Rs 195.00 Crores
Mobility Hub at More Bhawan	1	Rs 1,00,00,00,000	Rs 100.00 Crores
Development of bus terminals	11	Rs 8,60,00,000	Rs 95.00 Crores
Development of ITS for bus service	*overall cost*		Rs 6.26 Crores
TOTAL COST FOR CITY BUS SERVICE			**Rs 496.55 Crores**

4.6 Energy consumption and emissions assessment

An environmental and socio-economic impact assessment of the proposed developments and investments is presented in the [FBS18] document. Regarding City Bus Services, an energy consumption and CO_2 emission modelling is done in order to evaluate potential savings related to two distinct methods:

- <u>Change of fuel type for NMC buses within Nagpur:</u> the report considers a shift of a 100% Diesel bus fleet (2015, base year) to a 70% Diesel – 10% Ethanol – 20% Electric bus fleet (2028, horizon year). This scenario leads to **potential savings of 56% in fuel consumption and 58% in CO_2 emissions**,
- <u>Modal shift from other modes of transport to bus and metro systems:</u> the report considers a shift of 3.9% of private modes towards metro system and of 4.9% towards bus (city bus and feeder bus) system. This scenario leads to **potential savings of 14% in fuel consumption and 4% in CO_2 emissions**.

5. City Bus Service operational data

The operational data used in this chapter was provided by DIMTS. The various databases contain information on city bus scheduling, operation, and ridership. In particular, the data analysed here comprises:

- Route-wise operational parameters,
- Bus scheduling information,
- Monthly mileage production of 4 bus operators from April 2017 to January 2020,
- Scheduled and actual trips and kilometres per bus route and ridership for the month of January 2020,
- Viability Gap Statement – payments to operators, fare collection agencies and DIMTS,
- Kilometres, total ticket revenue collection, and pass passenger details during the month of December 2019 of 4 bus operators,
- Kilometres, total ticket revenue collection, and pass passenger details during the month of March 2020 of 4 bus operators.

5.1 Analysis of bus operation and ridership

The available and comparable data available is summarized in Table 18, where we compare the number of operational bus routes, the average daily operated buses, the maximum daily operated buses and the total fleet sizes between several dates.

Table 18. Operational data synthesis (data sources: see details in reference document [R2])

Item	March 2017	Forecast for 2018	December 2019	January 2020	March 2020 *1st to 21st*
Number of operational bus routes	36	76	115	118	106
Average daily operated buses	*(N/A)*	*(N/A)*	345	*(N/A)*	300
Maximum daily operated buses	*(N/A)*	*(N/A)*	370	368	361
Total fleet size	248	607	437	437	437
Average daily number of passengers	**1.25 Lakh**	**3.60 Lakh**	**1.60 Lakh**	**1.71 Lakh**	**1.50 Lakh**
Ticket passenger per month	*(N/A)*	*(N/A)*	34,01,403	35,23,039	21,09,629
Pass passenger per month	*(N/A)*	*(N/A)*	15,73,964	17,90,152	10,42,188
Total passenger per month	*(N/A)*	*(N/A)*	49,71,271	53,13,191	31,51,817
Average price per trip (ticket)	*(N/A)*	*(N/A)*	12.0 Rps	12.0 Rps	12.2 Rps
Average price per trip (pass)	*(N/A)*	*(N/A)*	5.9 Rps	5.9 Rps	6.1 Rps

An important increase on the number of operated bus routes can be noted between 2017 and 2020, with an increase of ~77 routes, as well as an increase in the number of operated buses. Moreover, it is noted that **the average daily number of passengers has increased by over 30% between 2017 and 2020**.

Regarding the CMP forecasts for 2018, the average daily ridership was estimated at 3.60 Lakh passengers for a fleet of 607 buses. In December 2019, the daily ridership was of 1.61 Lakh passenger for a fleet of 437 buses. **City Bus Service ridership forecasts appear to be very high despite the significant increased bus fleet**.

5.2 Analysis of City Bus quality of service

The quality of service offered by the various bus operators is assessed in this section. Table 19 presents the missed kilometres and the justifications for each of the 3 thermal bus operators. Data is available from April 2017 to January 2020.

Table 19. Miss kilometres from April 2017 and January 2020 (source: see details in reference document [R2])

Operator	Period	Accident	Breakdown	No Bus	No Driver	Trip Not Completed	No Driver & No	No Conductor
Traveltime City Bus Services	apr-17 / mar-18	0%	35%	10%	3%	1%	2%	12%
	apr-18 / mar-19	1%	19%	32%	5%	1%	1%	29%
	apr-19 / jan-20	0%	13%	2%	2%	1%	0%	55%
R.K. City Bus Operations	apr-17 / mar-18	1%	13%	6%	6%	12%	2%	16%
	apr-18 / mar-19	1%	12%	35%	10%	7%	0%	9%
	apr-19 / jan-20	1%	20%	5%	3%	0%	2%	50%
Hansa City Bus Services	apr-17 / mar-18	0%	32%	3%	2%	1%	2%	19%
	apr-18 / mar-19	0%	14%	18%	4%	1%	1%	56%
	apr-19 / jan-20	1%	32%	11%	7%	4%	1%	27%

Operator	Period	Planned Curtalment	Software Issue	Traffic Jam	Agitation	In House	Total miss KM	Total KM
Traveltime City Bus Services	apr-17 / mar-18	11%	0%	9%	1%	16%	6%	7994309
	apr-18 / mar-19	8%	0%	4%	0%	0%	8%	8302929
	apr-19 / jan-20	16%	0%	9%	0%	0%	6%	7340228
R.K. City Bus Operations	apr-17 / mar-18	8%	1%	8%	2%	23%	6%	8123109
	apr-18 / mar-19	17%	0%	7%	1%	0%	5%	8136774
	apr-19 / jan-20	7%	0%	12%	0%	0%	4%	7310524
Hansa City Bus Services	apr-17 / mar-18	12%	1%	5%	2%	20%	5%	7933109
	apr-18 / mar-19	4%	0%	2%	0%	0%	11%	8201427
	apr-19 / jan-20	14%	0%	3%	0%	0%	8%	7448303

The average of scheduled kilometres is 78.8 Lakh km for Travel Time City Bus Services operator, 78.6 Lakh km for R.K. City Bus Operations operator, and 78.6 Lakh km for Hansa City Bus Services operator. **The higher average share of miss kilometres concerns Hansa City Bus Services with 8%**. Nevertheless, we note that the proportion of operated kilometres in relation to schedule kilometres is stable overall and that this proportion is consistent.

The main factors impacting the bus services are “breakdown”, “no bus” and “no conductor”. The secondary factors are “no driver”, “planned curtailment” and “traffic jam”.

Figure 25 shows the scheduled and operated kilometres from April 2017 and January 2020 for the example of Travel Time City Bus Services (similar patterns for R.K. City Bus Operations and for Hansa City Bus Services). Three phases stand out: a first phase of growth between April 2017 and January 2018, following by a drop in scheduled kilometres in February 2018 and September 2018. Then, after November 2018, the scheduled kilometres increased steadily.

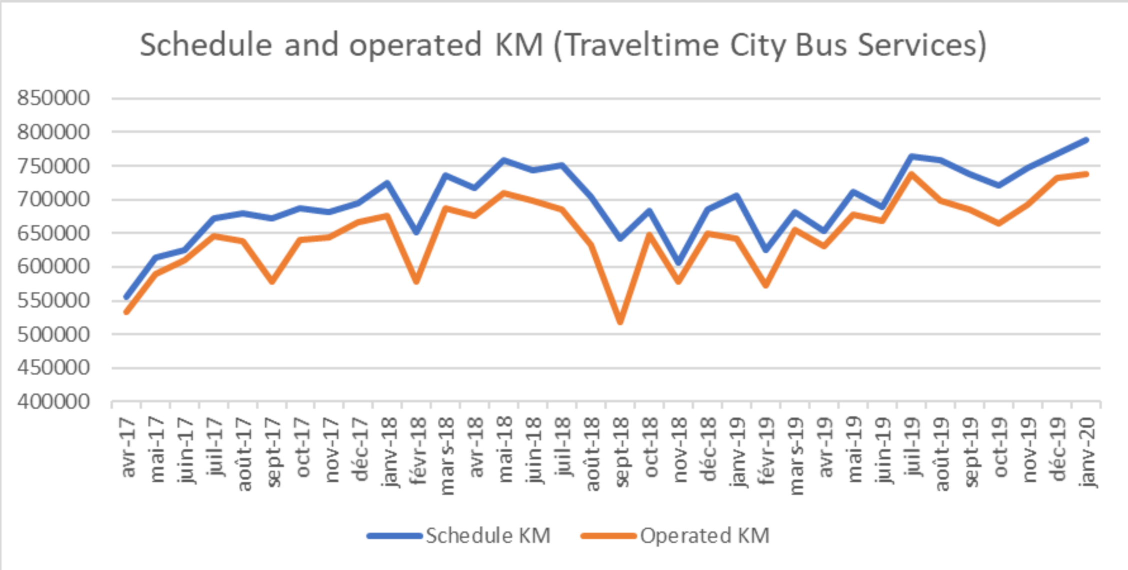


Figure 25. Scheduled and operated kilometres (source: see details in reference document [R2])

6. Nagpur's public transport analysis

6.1 Urban, traffic, and organizational aspects

Regarding general traffic aspects and as summarized in Table 20, it is noted an increase in transport time for Nagpur citizens (average trip lengths) for all modes, and a **slow but important evolution in the modal share from 2-wheelers and private cars to public transportation (buses and IPT)**.

Table 20. Nagpur City general traffic data (data source: [CDP], [CMP13], [FBS18], and [CMP18])

Indicators	Values (2008) [CDP]	Values (2011-2012) [CMP13]	Values (2017) [FBS18]	Values (2017-2018) [CMP18]
Average trip length (km)	*(N/A)*	5.5 two-wheelers 6.9 private cars 4.5 autos / taxis 9.4 public transport 3.9 cycles	8.6 for two-wheelers 10.8 for private cars 5.8 for autos 11.6 for bus + IPT 2.9 for cycles	8.6 two-wheelers 10.8 private cars 5.8 autos / taxis 13.1 buses 3.3 cycles
Modal shares	55% two-wheelers 10% private cars 11% autos /rickshaws 8% buses (Star bus) 9% cycles	65% two-wheelers 13% private cars 12% autos / taxis 10% public transport *(N/A) cycles*	43% two-wheelers 6% private cars 20% autos 16% buses + IPT 6% cycles	43% two-wheelers 6% private cars 20% autos / taxis 16% buses + IPT 6% cycles
Nagpur City buses supply	*(N/A)*	8 per Lakh population	*(N/A)*	9 per Lakh population

From an organizational point of view, we note that the need for a Unified Metropolitan Transport Authority (UMTA) is repeatedly included in transport planning documents, from the [CDP] to earlier documents. However, up to date, there have been little progress on the matter, and **a UMTA is still not operational** in Nagpur City nor in Maharashtra state. The same is noted for the formation of the Nagpur Transport Fund.

On the other hand, **substantial development has been verified regarding ITS and the setting up of a traffic information management control centre**. As seen during the Nagpur Inception Mission, the creation of the Smart City Mission Control Centre is vital for the traffic management in Nagpur.

The planning documents (especially the [CDP]) have identified **a TOD opportunity, and it is verified that this principle has been applied to the recent urban and transport development in Nagpur**. An important example is the development of the Nagpur Metro corridors, as seen during the Nagpur Inception Mission, and the planning for a Medium-Capacity Mass Transit System composed of five structural corridors.

6.2 Nagpur's current public transportation

6.2.1 Nagpur's transports main challenges

According to data gathered during the Nagpur Inception Mission Report and the other input data, the following problems summarize the current public transport situation in Nagpur:

- There is a **lack of efficiency** in the public transportation system, both in operational and financial terms, for instance:
  - A majority of existing bus routes overlap with each other ("*of the 183 notified city bus routes,* ***80 routes originate from Sitabuldi***" ([FBS18], p. 3-15), and
  - **Almost 30% of the passengers are concentrated on only 3 out of the 38 routes in operation** [Sitabuldi – Hingna Gramin Hospital (9,855 pax/day and 3.5 min headway), Sitabuldi – Indoram Gate No 6 (9,804 pax/day and 4.5 min headway) and Piplafata – Hazaripahad (9,154 pax/day and 4.2 min headway)].
- The **role of NMC is negligible in planning and implementation of the Nagpur Metro** projects, even if they have a significant role in reshaping urban public transport (structural axes, multimodal integration, coherence of services…),
- To date, **there has not yet been an initiative to create a Unified Metropolitan Transport Authority** (UMTA) or equivalent, thus hindering the possibility of having an overall and coherent view of the public transport system (metro, city buses, metro feeder buses, rickshaws, taxis, scooters…) in Nagpur's metropolitan region,
- The **implementation of the Transport and City Master Plans** ([CDP], [CMP18]) are delayed.

6.2.2 Improvement of the overall quality of service of Nagpur's public transportation

There seems to be **an improvement in the overall quality of service of public transportation in Nagpur**. This is translated by an increase in LoS especially with regards to the organization of public transport system, the service coverage in Nagpur City, and the percentage of fleet as per urban bus specifications.

Moreover, we noticed that the **number of operational City Bus Service buses and routes have significantly increased**, as seen in Table 21. Nonetheless, and according to information gathered during the Nagpur Inception Mission, **the 118 operated City Bus routes do not correspond to the 76 rationalized routes** identified in the [CMP18], and **only 2 out of the 38 proposed Feeder Bus Service routes had been implemented** by NMC (in January 2020).

Table 21. City bus transport system indicators (data source: [CDP], [CMP13], [FBS18] and input operation data received during the mission - see details in reference document [R2])

Indicators	2011-2012 [CDP] & [CMP13]	2014 [FBS18]	2015 [FBS18]	2016 [FBS18]	2017 (pre-March) [FBS18]	2017 (post March) [FBS18]	2019-2020
Total bus fleet	470 buses	470 buses	470 buses	470 buses	470 buses	487 buses	437 buses
On-road (operational) fleet	254 buses (54%)	205 buses (44%)	209 buses (45%)	217 buses (46%)	222 buses (47%)	263 buses (54%)	~370 buses (85%)
Operational routes (% of total routes)	66 routes (38%)	-	-	-	36 routes (20%)	38 routes (21%)	~118 routes *(% N/A)*
Average daily km	200 km/bus	219 km/bus	216 km/bus	220 km/bus	208 km/bus	228 km/bus	185 km/bus
Average load factor in buses	-	39%	36%	44%	48%	61%	-
Total daily number of passengers	1.25 lakh*	1.38 lakh*	1.26 lakh*	1.25 lakh*	0.92 lakh	0.99 lakh	1.60 lakh to 1.71 lakh
Number of depots	4 depots	-	-	4 depots	-	4 depots	4 depots °
Number of bus stops or shelters	190 units	-	-	190 units	-	190 units	-

** Although it is not clear on the documents, these figures seem to include City Bus and IPT passengers.*

° A 5th depot under construction has been identified during the Nagpur Inception Mission.

However, through a comparison between expected traffic on public transportation from previous studies (such as [CDP], [CMP13], and [CMP18]) and recent operational statements, it shall be noted that a **significant gap between forecast and actual ridership** is verified. Indeed, daily ridership in 2019/2020 seems to be **less than half** the daily ridership forecasted for 2018 by the [CMP18].

6.3 Traffic and transport forecast

The planning documents (mainly the most recent [CMP18] and [FBS18]) present forecasts of population, traffic, and public transportation users growth for the next years up to 2031. These forecast results are used to estimate the fleet augmentation that shall be needed for both the City Bus Service and the Nagpur Metro Feeder Bus Service (as seen in the [FBS14] and [FBSOP] documents).

We notice however that **some forecast results could possibly be challenged**. Regarding the [CMP18] projections, as early as for the horizon year of 2021, the difference between the modal shares of the two simulated scenarios is of 19% (in the “sustainable urban transport” scenario).

Nevertheless, no detailed explanation is given as to justify this important augmentation and the commissioning of the metro lines cannot be sufficient to justify such a substantial increase in the modal share. Indeed, and as verified during the Nagpur Inception Mission, **current metro ridership seems to be very low** (partially because metro coverage is still very limited, with few open stations), **and ridership on the City Bus Service does not seem to have increased significantly as to justify the simulated modal shift**.

Regarding the Feeder Bus Service, the projected bus fleet has been estimated based on total ridership of the feeder, this being estimated based on the ridership of the metro system. The part of metro users willing to use Metro Feeder Bus Services was considered at 20% based on case studies of other cities (reference: [FBS14] report). This assumption could also be challenged. **The estimation of Feeder Bus Service shall require a territorial approach to consider the different existing contexts particular to Nagpur**.

The primary data collected for the transport planning documents is not available for consultation, and neither is the transport model used. Therefore, and being unable to execute a thorough and reliable forecast study to determine a more precise public transport users augmentation, **the study has relied on the data analysis and conclusions set out by planning documents**, especially the [CMP18], the [FBS18], and the [FBSOP] reports.

While the [CMP18] and the [FBS18] present a more global analysis in terms of mobility at the level of Nagpur City (high and medium MRTS, trunk bus routes, feeder bus routes), the [FBSOP] focuses on providing connectivity from various zones to metro stations (on a 2,5 km buffer zone). **As such, the study has considered the transport planning principles detailed in the [CMP18], as well as the public transport evolutions and projects foreseen in the [FBS18] for City Bus Service**.

It should be noted that, during later studies, **an update of the primary data / transport model shall be necessary in order to better assess travel demand and service (offer) needs for Nagpur City Bus Service**.

CITY BUS SERVICE UPGRADE AND RATIONALIZATION

This section presents an analysis of the current situation and forecast scenarios for Nagpur City public transport system, in particular the City Bus Service. A mid-term vision for the future of public transport services (rationalization and upgrade) and for the electrification of the bus fleet are also presented.

> Mid-term vision for City Bus and Nagpur Metro Feeder Bus services
> General urban planning and street upgrades recommendations

7. Mid-term vision for City Bus and Nagpur Metro Feeder Bus services

To rationalize the city bus routes in Nagpur, the [FBS18] report identifies **19 trunk routes** that would operate along the major transit corridors, serving main activity centres (designed as hubs), as well as **57 feeder routes** that would operate from hubs to secondary activity centres. Table 22 presents the expected daily ridership forecast for 2021 and the length for the 19 identified trunk routes.

It shall be noted that the "trunk and feeder" routes proposed in the [CMP18] and [FBS18] reports are mainly coherent with the previously identified "mobility corridors" and TOD opportunity in the [CDP] and the [CMP13] documents (see Figure 26). For this reason, **the study of the development of City Bus Service network should be focused on the implementation of the 76 rationalized bus routes, specially the 19 trunk routes**.

Table 22. Trunk routes daily ridership for 2021 and route length (data source: [CMP18])

Route description	Daily Ridership 2021	Route Length (km)
Pardi to Vaishali Nagar	14 417	21
Kharbi to Pannasay Layout	21 697	23
Sitabuldi to Katol Naka	4 008	10
Dighori to Dattawadi	8 068	19
Ashirwad Naar to Gandhibagh	6 549	6
Sitabuldi to Surya nagar	20 009	12
Pardi to Mahindra & Mahindra	48 088	26
Sitabuldi to Defence	16 873	13
Sitabuldi to Tekanada	14 091	7
Sitabuldi to Mankapur	9 510	6
Sitabuldi to Gorewada	10 196	9
sitabuldi to Morarji	22 351	34
Sitabuldi to Hingna	5 485	8
Tekanaka to Mahindra & Mahindra	3 309	21
Gandhibagh to Kamptee	27 762	11
sitabuldi to Narsala	13 190	14
Sitabuldi to MIHAN	45 484	15
Wardhaman Nagar to Dahegaon	8 763	23
Shakti mata mandir to Jaitala	1 855	15

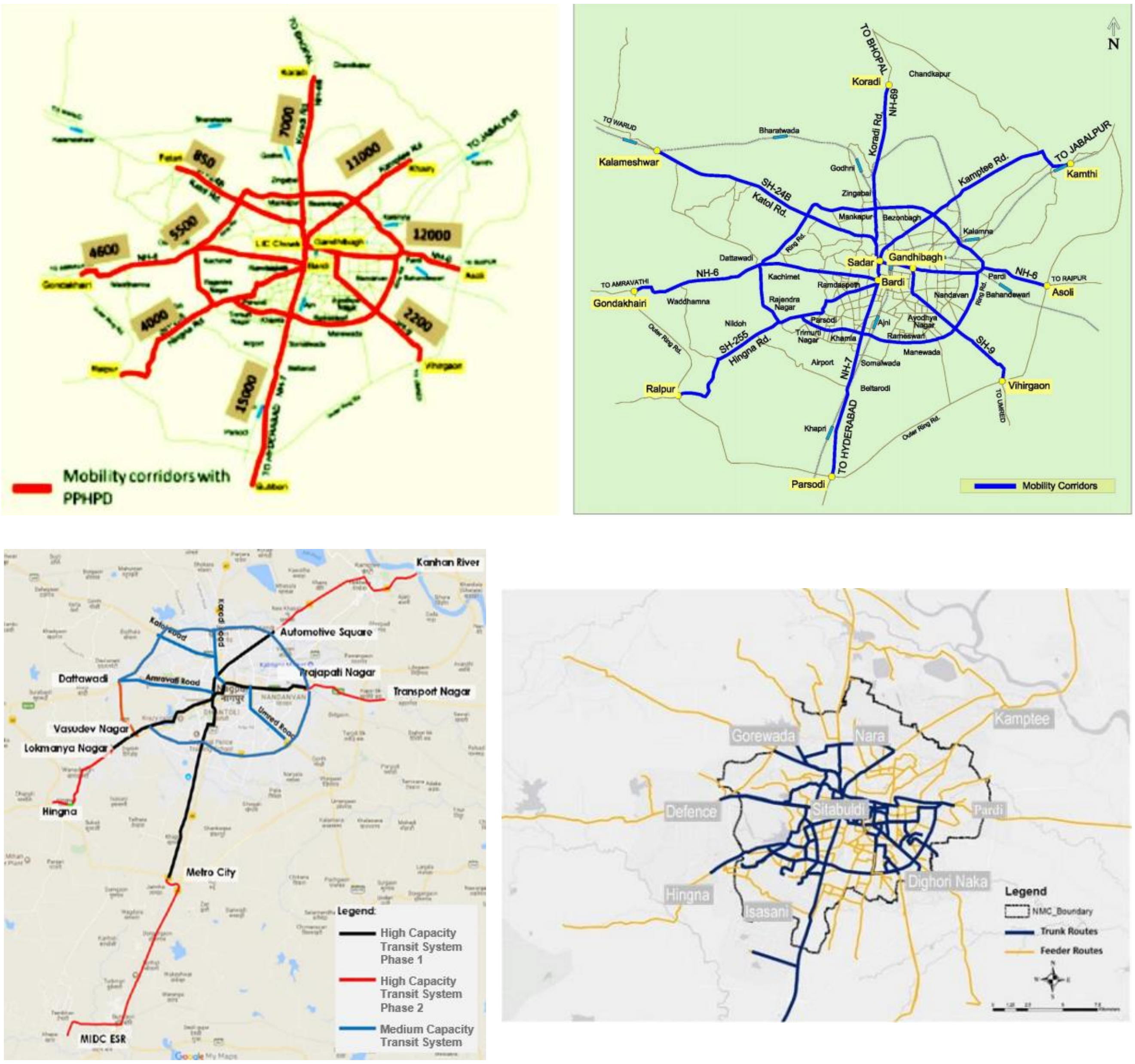


Figure 26. Representation of the "mobility corridors" and "trunk and feeder routes" identified on Nagpur's urban and transport planning documents (sources: top-left: [CDP], top-right:[CMP13], bottom-left:[CMP18], and bottom-right: [FBS18])

Furthermore, we propose that the development of the rationalized City Bus Service routes using an “approach by depot location”, as it shall allow to maintain coherent operation and maintenance units. For this, **we recommend that the 3 existing depot locations and the 6 new depot locations identified on the [CMP18] and the [FBS18] reports shall be used for the organization of the “feeder and trunk” bus routes** (see Figure 27).

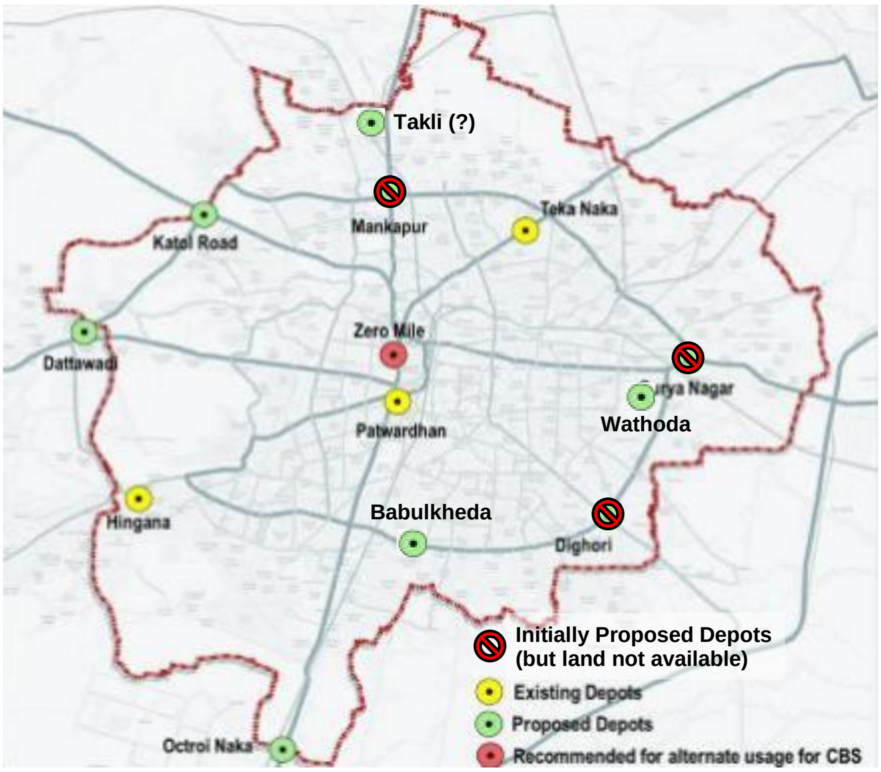


Figure 27. Location of proposed bus depots (base map source: [FBS18])

Finally, regarding the Nagpur Metro Feeder Bus Service the [FBSOP] and the [FBSID] documents propose a fleet, infrastructure and service development in order to enhance metro ridership. The documents recommend **38 metro feeder bus routes** (as seen in Figure 28) that shall be implemented complementarily to the “trunk and feeder” City Bus Service routes planned by the [CMP18].

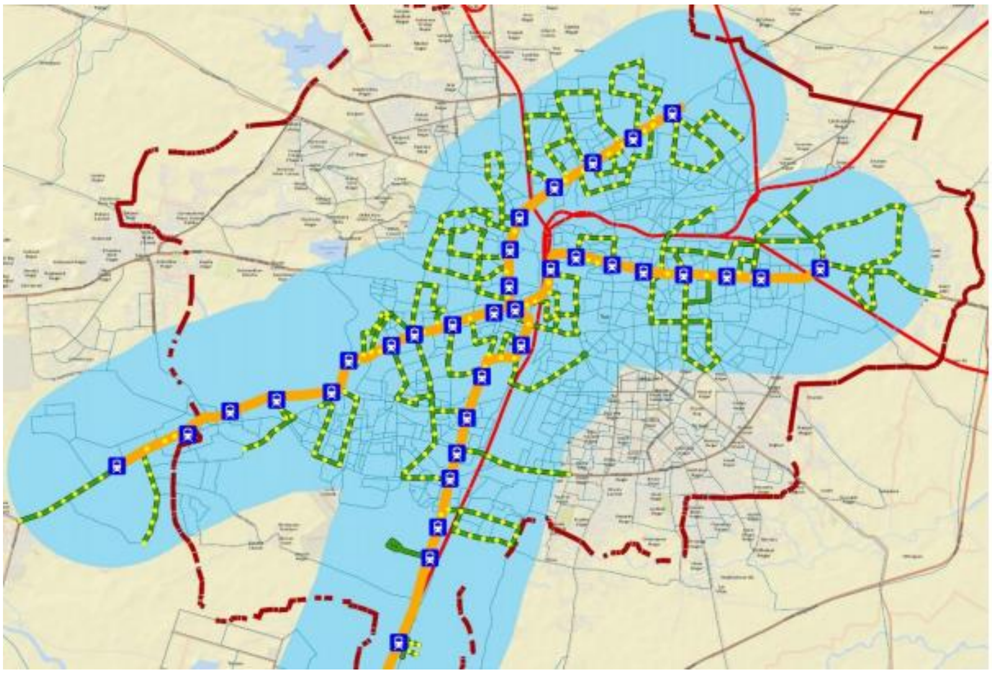


Figure 28. Feeder Bus Service routes and Nagpur Metro corridors (source: [FBS18], p. 6-3)

Indeed, the recent opening of the Orange and Aqua Metro Lines shall contribute to a fast-paced and sustainable development of public transport in Nagpur City, and **the metro Feeder Bus Service shall be an essential backbone**. It is to be noted that **the metro feeder buses shall equally have a positive impact on the City Bus Service (as of increase in ridership), provided that both systems are complementary** (and not concurrent, as it is mainly the current case in Nagpur).

To conclude, and provided that the Feeder Bus Service is essentially a "metro feeder service" (with limited ridership and bus frequency compared to the City Bus Service), **the later steps of bus service rationalization shall be focused on the 76 "trunk and feeder" routes identified for the City Bus Service**.

8. General urban planning and street upgrades recommendations

The success of a public transport system and its efficiency is not only due to its own technical characteristics. Urban insertion, integration with other modes, street upgrading and furniture, interoperability… These concepts shall help **making a bus system more reliable, easier-of-access and visible, thus guaranteeing a better efficiency for operators and attractivity for users**.

This chapter presents general recommendations that could help improve Nagpur City Bus Service efficiency and attractivity and shall be part of further developments regarding E-Buses studies and implementation.

8.1 Improving performance

8.1.1 Exclusive bus corridors

The performance of a City Bus line is essentially analysed in terms of commercial speed (or journey time) and regularity. It is considered that in an urban area, **a bus system using exclusive bus corridors (such as BRT systems) can reach a commercial speed of around 20 km/h** (25 km/h in the suburban sector, depending on the number of stations along the route). Journey times must be reliable (the announced time is respected) and be as equivalent as possible throughout the day, the week or the year.

In areas particularly subject to automobile pressure, **the bus corridor should be protected with an impassable curb** (or other device: green space, etc.), provided that this does not create greater difficulties with other uses (operation of driveways and deliveries in particular). The optimal solution is to raise the whole of the dedicated site (see Figure 29): this configuration makes it easier to identify the platform, to evacuate rainwater easily and to ensure that the edge of the platform remains in place over time but requires fine work on the levelling at the crossings. It does not pose a safety problem if its shape is architecturally designed or simply chamfered.

Figure 29. Elevated exclusive bus corridor in Nantes, France

8.1.2 Bus priority at intersections

In order to guarantee a good performance of a City Bus system, it is recommended to adopt “bus priority” strategies when dealing with traffic-lights-managed intersections. Indeed, the efficiency of exclusive right-of-way facilities is optimal with a **priority system at intersections**: the aim is to prepare the junction for the arrival of each bus, so that it passes through without stopping.

Figure 30. Traffic light priority system in Paris, France - left: bus priority signal / rigth: pedestrian no-crossing signal (source: Wikimedia Commons)

All **traffic light priority systems** are based on (a) detection of the vehicle at a given point and time (or several depending on the technology used), (b) determination of its approach speed to the intersection, and (c) an "acknowledgement" signal after the bus passes the intersection. At present, two technologies are used to install priority at intersections for public transport systems: detection by **ground loops** linked to the intersection controller or **radio communication** between the vehicle and the intersection controller.

Historically, the radio communication system was developed for bus networks running on the road. Thanks to very frequent communication between the vehicle and the controller (approximately every 2 seconds), it allows the traffic light diagram to be adapted in almost real time to take better account of the hazards of the bus route. **Unlike the loop system, this system does not require roadworks.**

Loop systems have been developed mainly on tramway projects, since on the one hand this technology is perfectly adapted to guided modes (as the vehicle always runs by the same lane), and on the other hand the design of tramway and BRT projects seeks, by definition, to eliminate hazards (exclusive right-of-way, systematic stops, etc.).

The day-to-day operation of a City Bus service using traffic light priority often requires a revision of the traffic light settings developed in the studies (recalibration of the parameters and durations of the sub-phases of the traffic light cycle). **These modifications are simpler to make with the radio system** (action on the vehicle's on-board computer, therefore the responsibility of the operator) than with the loop system (action by the traffic light manager, with an interface to be managed by the operator).

8.2 Improving quality of service

8.2.1 Urban street furniture: bus stops

Bus stop equipment must help to make users' waiting time less disturbing: by protecting them from bad weather, by providing them with information about their journey, by allowing them to make their journey independently. When passengers get off a bus at a bus stop, they must find information to help them find their way around, to their destination or to their connection. The complete equipment of a bus stop shall thus **facilitate the journey**.

The **furniture** should be designed to protect passengers from rain, wind and sun, while providing optimum natural light. Translucent surfaces should be used wherever possible, with particular attention to possible exposure to vandalism. The furniture should have a sufficient number of suitable seats and supports (particularly ischiatic). The material used should not be susceptible to damage (scratches, graffiti) in order to preserve its durability.

Furthermore, bus stops shall be equipped with:

- **Clear signage:** identification of the City Bus Service transport mode),
- **Static information displays:** City Bus network plan, regular bus lines and service specific to the bus stop, neighbouring urban map showing points of interest and connection to other transport modes, and
- **Dynamic information displays:** City Bus Service current state, approaching buses and awaiting times, general and alert information (linked to the City Public Information services).

The **lighting systems** to be provided at bus stops must contribute to two main objectives: contribute to passengers' sense of security and make the station atmosphere more welcoming (particularly in long waits) and make passenger information as accessible, legible and hierarchical as possible (maps, customer information, signage) and facilitate the use of station equipment.

The equipment can be different for each station, depending on their urban context and specific issues. **Specific equipment** shall include for instance: Smart City Kiosk providing access to various online services (as already installed in several bus stops, see Figure 31), water fountains, vending machines…

Figure 31. New Nagpur City Bus stop and Smart City Kiosk

8.2.2 Bus corridors and cycling[4]

It is often possible to have bicycle-bus cohabitation in a reserved area. **However, this should not be at the expense of the desired level of service for the public transport concerned.** If the facilities and operating conditions are not in place to implement this cohabitation in a satisfactory manner for the efficiency of public transport and the safety of all users, facilities appropriate for cyclists shall be provided in parallel with those allocated to public transport.

For **unidirectional bus-bike shared lanes**, a normal bus lane width (3 m to 3.50 m) is usually sufficient. It may be preferable to widen a bus-bike lane to around 4.50 m in the following situations: high bus frequency, busy cycle route, commercial speeds above 30 km/h, presence of light vehicles.

If traffic constraints dictate, there is no reason why an **impassable physical divider** should not be used in a closed lane of at least 4.5m. Below this width, an open lane with a crossable divider is preferred to allow bus drivers and cyclists to pass each other easily.

Bi-directional bus lanes are often built to provide high service level bus lines; in this case, opening up the bus site to cycles leads to a deterioration in service and is generally not recommended. In this case, parallel cycle routes should be provided.

[4] The content of this chapter has been adapted from the French Centre for Studies and expertise on Risks, Environment, Mobility and Development (CEREMA) guide “Bicycles and public transport: sharing the road”, published in August 2010 (https://www.cerema.fr/fr).

8.2.3 Integration with other public transport modes: the "Mobility as a Service" model

Buses, metros, BRTs, tramways, trains, bike-sharing, rental services, taxis, rickshaws, shared vehicles, on-demand transport, scooters, park-and-ride car parks… Using different mobility solutions usually means coping with multiple information sources and applications, whether for service information, calculating journey times or for payment. As a result, combining several modes of transport for a journey is rarely an easy task.

MaaS, or *Mobility-as-a-Service*, is a rather recent model that aims at **integrating (from journey planning to payment) all transport modes of a city or region (public and private)** as a means of facilitating the access of citizens to transport solutions.

For the user, a MaaS application ads value by using a single mobility application with a single payment channel. A MaaS service also yields new business models with advantages for transport operators, such as access to improved user and demand information and new opportunities to serve unmet demand. Finally, the overall goal of a MaaS model is to **provide reliable and easy-of-access alternative to the use of private transport**.

CITY BUS SERVICE FLEET ELECTRIFICATION

This section presents the context of the study and the technical and technological options and recommendations. Motorization, charge strategy, infrastructure, systems, and equipment are here presented, and recommendations drawn as to best fit the needs for the electrification of Nagpur City Bus Service.

> Assessment of engine options
> Electric vehicles charging strategy
> Focus on the regional electric grid
> Assessment of rolling stock and battery options
> Assessment of charger options
> Assessment of connection systems
> Workshop upgrades
> Required resources and qualifications

9. Assessment of engine options

9.1 Diesel thermal engines

9.1.1 General and regulatory background

Diesel is the dominant energy in the quantity of bus vehicles sold. Seeking a reduction in polluting emissions, European standards have been imposed on bus vehicle manufacturers since 1990 and introduced similarly in India since 2000 via the Bharat Stage Emission Standards (BSES), based on European regulations. As emission restriction thresholds have been lowered, the technical performance of thermal engines has been greatly improved.

Currently the most recent European standard for buses is the Euro VI standard. Its equivalent in India, Bharat Stage VI (BS-VI), was to be applied nationwide from April 2020 (although current COVID-19 lockdown situation in India and ongoing negotiations with industry players have an important impact on the effective date). The standard imposes very low emission thresholds compared to older regulations, as seen in Table 23.

Table 23. Evolution of European and Bharat Stage Emission standards for buses
(data sources: European Commission and Ministry of Road Transport and Highways of India)

Indian standard		India 2000 (BS-I)	Bharat Stage II (BS-II)	Bharat Stage III (BS-III)	Bharat Stage IV (BS-IV)	Bharat Stage VI (BS-VI)
Implementation date nationwide		2000	2005	2010	2017	2020
Euro standard (since)		Euro I (1993)	Euro II (1996)	Euro III (2001)	Euro IV (2006)	Euro VI (2014)
Emissions (g/kWh)	Nitrogen oxides (NO_x)	9.0	7.0	5.0	3.5	0.4
	Carbon monoxides (CO)	4.5	4.0	2.1	1.5	1.5
	Hydrocarbon (HC)	1.23	1.10	0.66	0.46	0.13
	Particulate matter (PM)	0.36	0.15	0.13	0.02	0.01

Note: Bharat Stage V (Euro V equivalent) to be skipped to accelerate lowering of polluting emissions in India.

In addition to its environmental benefits, linked to the substantial reduction in NO_x and hydrocarbons emissions between BS-IV and BS-VI, this standard shall allow manufacturers to develop engines that are more efficient, and consume less fuel.

9.1.2 Reliability and technological risks

The classic diesel engine does not present any major technological risk since it is widely proven on several networks / countries.

9.2 Hybrid motorization

9.2.1 General and regulatory background

Hybrid power is the technology to overcome battery performance gaps by implementing a controlled internal power generation (internal combustion engine) associated with electric propulsion and allows a reduction of 10 to 20% in fuel consumption compared to 100% internal combustion engines. This technology has limited performance in terms of GHG (greenhouse gases) emission and local pollutions.

Several combinations exist (NGV/Electric, Diesel/Electric), currently the most developed being the Diesel/Electric combination. This motorization is subject to the same regulations as conventional diesel equipment. However, maintenance works on the rolling stock close to the electrical power feeders (for charge) require specific training and electrical authorization for the maintenance staff.

The depot shall also comply with relevant regulations (generally related to environmental protection) for batteries storage areas.

9.2.2 Performance and O&M costs

In terms of maintenance, the series-hybrid technology reduces maintenance interventions related to the use of a gearbox. A reduction in the use of mechanical braking also limits this maintenance item. In addition, the wear of the engine is limited by its operation at optimized speeds. Finally, electric motors need less maintenance. However, the “stop and start” type of functionality implies a reduction of the internal combustion engine oil drain maintenance steps.

Parallel hybridization technology is heavier from the maintenance point of view, in particular because of the presence of the gearbox and the mechanical distribution organ.

However, feedback and field experience are still insufficient to reliably estimate the maintenance volume over the life of the rolling stock. The main maintenance expense item is the replacement of electrical energy storage systems, which will be likely be replaced once over the life of a vehicle.

Finally, energy efficiency allows savings on fuels of about 10 to 20 %.

9.2.3 Greenhouse gases and local pollution emissions

Hybrid technology has an average performance in terms of GHG emissions and local pollution. Indeed, the electric motorization allows savings of almost 25% of fuel consumption and the reduction by the same amount the greenhouse gases and local pollution emissions.

9.2.4 Marketing

The marketing of hybrid vehicles is currently expanding, and most manufacturers offer nowadays hybrid vehicles in their catalogues. Most manufacturers have chosen to move towards series-hybrid technology.

9.2.5 Reliability and technological risks

The hybrid engine (Diesel/Electric) presents in average good feedback on operation in terms of reliability, availability, user comfort and noise comfort.

9.2.6 Feeding mode constraints for the depot

In terms of infrastructure and equipment, hybrid technology has no specific needs on depots. However, it is preferable to equip the depot with a dedicated area for battery storage (spare part or storage of battery packs before recycling).

9.3 Compressed Natural Gas engines

9.3.1 General and regulatory background

Dynetek storage system (source: MAN gas technology manual)

Natural gas is currently the most common non-derived alternative fuel to diesel for bus propulsion. It is used in its compressed form (CNG). Natural gas is made of more than 95% methane or biomethane, commonly known as "city gas", as well as other very light hydrocarbons. Compressed natural gas corresponds to methane compressed between 200 and 300 bars in gaseous form. It can be stored at room temperature, facilitating its daily use.

CNG is 30-50% cheaper than diesel. The autonomies announced by the manufacturers and verified by the operators offer optimal bus operating conditions. The combustion conditions of CNG allow for smoother driving.

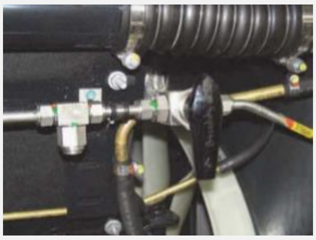
It should be noted that Euro standards and BSES also apply to CNG engines.

9.3.2 Greenhouse gases and local pollutants emissions

The most important benefit from CNG motorization is a 95% reduction of fine particulate emissions 50% reduction in nitrogen oxides compared to the BS-VI threshold. Of all hydrocarbons, natural gas gives off the least amount of carbon monoxide when burned and thereby reduces by 37% CO_2 emissions compared to diesel motorization. It does not emit black smoke or odours.

9.3.3 Reliability and technological risks

The natural gas bus has undergone numerous tests that guarantee upmost safety.



Shut-off piston and high-pressure filter engine compartment (source: MAN gas technology manual)

- Risk of explosion: Contrary to popular belief, the explosivity ranges of the gas are very low. Indeed, several elements are necessary to constitute an explosion risk: the presence of air, a source of ignition and a certain concentration of gas in the atmosphere (from 5 to 15 %). It is highly unlikely that all these conditions are met.
- Pressure risk: The gas is kept in the tanks at a pressure of 200 to 300 bar, and this pressure is reduced to 10 bar before injection. However, an unqualified manoeuvre on the gas circuit may under critical conditions cause gas and/or certain parts of the circuit to be projected with an energy comparable to that of a rifle bullet (500 m/s). Therefore, the operator shall ensure that the circuit on which he intervenes is properly isolated from the pressure source and that it has been previously depressurized to a pressure close to atmospheric pressure.
- Gas flammability: The temperature required to ignite a natural gas mixture is 550°C. The risk of ignition following a leak is conceivably very low.

9.3.4 Feeding mode constraints for the depot

CNG plant in Poitiers, France (source: Transbus)

The installation of CNG buses in a network requires facilities for the supply and maintenance of these buses. Other constraints may apply: the covered depot areas and workshops should be equipped with efficient ventilation and gas detectors located in the upper part / a compressor station should be built to ensure that the CNG buses are filled with fuel (the station ensures that the buses can be filled slowly or quickly and, in the case of slow filling – usually at night –, each parking space has a gas supply). For illustration, these constraints are mandatory according to ATEX regulations applicable for European projects.

9.4 Ethanol motorization

Scania Ethanol City Bus (source: Scania)

Ethanol is mainly used as a biofuel additive for gasoline in proportions ranging from 0 to 100%. ED95 contains 95% bioethanol and 5% additive. It is intended for specific engines running only on this fuel and reduces net CO_2 emissions by 50% to 90% and particle emissions by more than 70%.

The technology is now being marketed by the manufacturer Scania, and is most developed in Sweden, including the city of Stockholm, which has been running its buses on bioethanol for more than 20 years.

As seen during the Nagpur Inception Mission, Scania had a contract to operate Ethanol buses in Nagpur but withdrew from the market.

Due to lack of data and feedback on this type of motorization for buses and the fact that this technology is not well developed in India, this technology does not seem to be a desirable solution in the case of Nagpur.

9.5 Hydrogen motorization

9.5.1 General and regulatory background

Solaris Urbino Hydrogen bus (source: Solaris)

Hydrogen (or dihydrogen, H2) presents itself as an invisible and odourless gas. Of all the chemical elements, it is the lightest. It is also the most abundant chemical element in the universe. On Earth, it is rarely present in its pure state, but it is used in the composition of water and hydrocarbons.

Hydrogen is not a source of energy *per se* but "an energy carrier". It must be produced and then stored before being used.

This gas molecule that stores energy can restore it in several ways:

- By burning it: the combustion of a kilogram of hydrogen releases three times more energy than that of a kilogram of gasoline and only produces water,
- By a fuel cell: hydrogen coupled with a supply of air introduced into a fuel cell allows to produce electricity by only discharging water.

9.5.2 Greenhouse gases and local pollutants emissions

Starbus Fuel Cell (source: TATA motors)

Hydrogen is currently an important industrial gas: 75 million tonnes are supplied annually to the chemical industry, almost 45% for petroleum refining (desulfurization), almost as much for the production of ammonia and nitrogen fertilizers, approximately 10% for the food, electronic and metallurgical industries and finally almost 1% for the space propulsion of rockets by combustion of liquid hydrogen and oxygen [5].

Dominated by a process where the necessary thermal energy is provided by the partial combustion of methane (steam methane reforming), global hydrogen production is accompanied annually by nearly a billion tons of CO_2 emissions in the atmosphere.

In the context of an intensifying global energy transition and increasing production of carbon-free hydrogen, it seems likely that the reforming of methane will gradually disappear.

Three alternative pathways, which can be combined, are now actively explored: electrolysis, biomass, and thermochemistry.

9.5.3 Reliability and technological risks

As natural gas buses, fuel cell buses have undergone numerous tests that guarantee upmost safety.

The risks are mostly the same as natural gas propelled buses:

[5] Source: American Energy.gov

- Risk of explosion: The explosivity ranges of the hydrogen are more important than those of natural gas (from 4 to 75% vs 5 to 15% for natural gas). However, several elements are necessary to constitute an explosion risk: the presence of air, a source of ignition and a certain concentration of gas in the atmosphere. It is highly unlikely that all these conditions are met.
- Pressure risk: On a bus system, the gas is kept in tanks at a pressure from 300 to 700 bars. However, an unqualified manoeuvre on the gas circuit may under critical conditions cause gas leak and/or certain parts of the circuit to be projected with an energy comparable to that of a rifle bullet (500 m/s). Therefore, the operator shall ensure that the circuit on which he intervenes is properly isolated from the pressure source and that it has been previously depressurized to a pressure close to the atmospheric one.
- Gas flammability: The temperature required to ignite a natural gas mixture is 500°C. The risk of ignition following a leak is conceivably very low.

9.5.4 Feeding mode constraints for the depot

Hydrogen station filling (source: McPhy)

As the natural gas, the installation of fuel cell buses in a network requires facilities for the supply and maintenance of these buses. Other constraints may apply: the covered depot areas and workshops should be equipped with efficient ventilation and gas detectors located in the upper parts.

In addition, a hydrogen station should be built to ensure that the fuel cell buses are filled with fuel. Most of the time, hydrogen is not produced in that station: As with diesel, hydrogen is transported and stored in tanks to the station.

More rarely, hydrogen can be produced in the station by electrolysis. However, this process requires a large space and is, at present, very expensive.

9.6 Electric motorization

The electric motorization is divided into two distinct families:

- The 1st family requires a continuous supply of energy to the rolling stock. This is the case of trolleybus rolling stock types,
- The 2nd family presents energy storage in the vehicle allowing its circulation with a variable autonomy depending on used materials, technologies, and network profiles.

These recent years, the enthusiasm for electric buses encourages manufacturers to propose different strategies of energy accumulation and battery charging.

The environmental advantages of this technology are proven:

- Zero tail-pipe emissions,
- Very low emission of greenhouse gases.

9.6.1 General and regulatory background

Electric engine technology presents few regulatory constraints except for outdoor infrastructures (electrical interface point). Buses must also usually comply with environmental regulations for battery storage areas.

The charging interface for the electric buses is subject to multi-level standards:

- Type of connector used,
- Communication protocol,
- System security,
- Charging typology.

9.6.2 Environmental impact

If GHG emissions are reduced during their use, electric vehicles are not without impact on the environment, as shown in Figure 32.

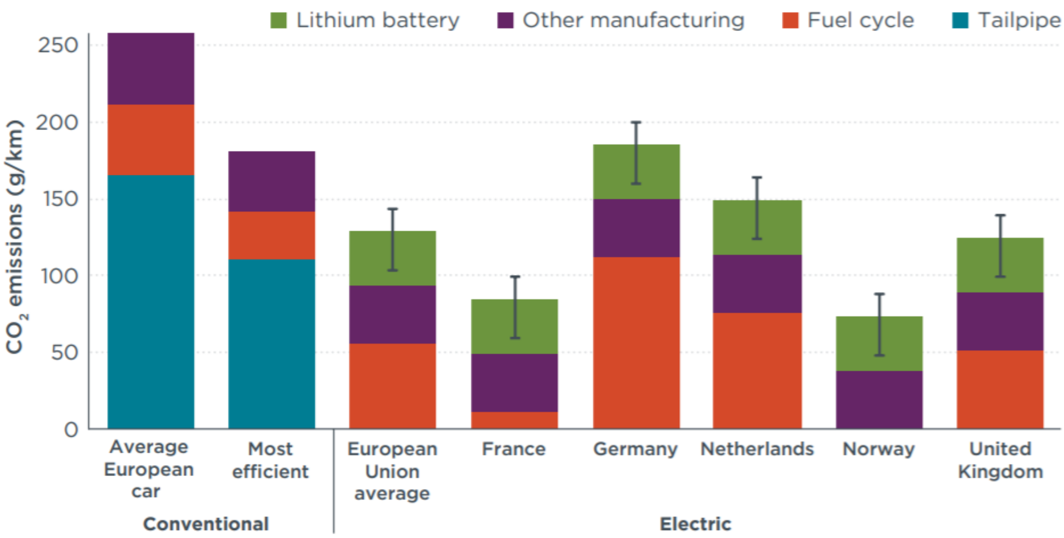


Figure 32. Life-cycle emissions (over 150,000 km) of electric and conventional vehicles in Europe in 2015 (source: ICCT report [6])

As shown in Figure 32, the life-cycle impact of a vehicle is the sum of the emissions impacts from all the associated vehicle's activities: manufacturing, fuel cycle, and use. Electric vehicle manufacturing requires more energy and produces more emissions than manufacturing a conventional car because of the electric vehicles' batteries. Lithium-ion battery production requires extracting and refining rare earth metals and is energy intensive because of the high heat and sterile conditions involved. Most lithium-ion batteries in electric vehicles in Europe in 2016 were produced in Japan and South Korea, where approximately 25%–40% of electricity generation is from coal.

[6] https://theicct.org/sites/default/files/publications/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf

Moreover, the reduction of emissions varies greatly depending on the mode of energy production. While solar or wind power has a very moderate carbon footprint (78g and 22g CO_2 per km respectively), it is otherwise for gas (430g CO_2 per km) or coal (1000g CO_2 per km). Thus, as shown in Figure 32, the manufacture of the battery alone accounts for around 40% of the environmental footprint of an electric vehicle in France and around 20% in Germany where the fuel cycle is more important. Also, the battery recycling is currently underdeveloped.

Heating, ventilation, and air-conditioning (HVAC) systems also have a significant environmental impact. An air conditioning system consists in a heat pump that takes hot air from the inside and expels it to the outside contributing to the formation of urban heat islands. Moreover, air-conditioners contain refrigerants that are powerful greenhouse gases. Finally, these systems drastically increase the energy consumption of a vehicle.

9.7 Comparative analysis of engine options

Table 24 and Table 25 present a comparison between diesel, hybrid, CNG and electric engine technologies.

Table 24. Comparative analysis of motorization technologies

Performance criteria	Diesel	Hybrid	CNG	Fuel cell (hydrogen)	Electric
Tail-pipe emissions *(PM, NO_x, HC, CO)*	High ---	Medium --	Very low -	Null +++	Null +++
GHG emissions *(Gco2e/km)*	High ---	Medium --	Low -	Null (1) +	Null (1) +
Passengers' comfort	Standard +	Comfortable ++	Standard +	Very comfortable +++	Very comfortable +++
Noises	High ---	Low to medium --	Low noise -	Very low noise ++	Very low noise ++
Technological maturity	Very good +++	Good ++	Good ++	Low -	Medium +
Autonomy	High +++	High +++	High +++	High +++	Medium ++
Impact on the depot *(Environmental regulations depending on country)*	Not applicable +++	Battery working area ++	Filling station Specific equipment needed, explosive environment -	Filling station Specific equipment needed, explosive environment -	Power supply infrastructures and battery working area -

Performance criteria	Diesel	Hybrid	CNG	Fuel cell (hydrogen)	Electric
Maintenance activity	Medium ++ Spare part cost -	Medium ++ Spare part cost (battery) --	Medium ++ Spare part cost (filling station) --	Medium ++ Spare part cost (filling station) --	Low +++ Spare part cost (battery and charging infrastructure) ---

Note (1): Depends on the process of hydrogen and electricity production.

Table 25. Comparative costs analysis of motorization technologies

Performance criteria	Diesel	Hybrid	CNG	Fuel cell (hydrogen)	Electric
Vehicle cost *(for a 12m bus without AC)* **(1)**	150 to 250k€ Rs 30 to 50 lakhs +++	250 to 450k€ Rs 1,2 to 1,4 crores +	250 to 450k€ Rs 30 to 50 lakhs ++	600 to 800k€ Rs --	400 to 800k€ Rs 2 to 3 crores -
Fuel cost	0.3 to 0.37 €/km Rs 15 to 23 /km -	0.25 to 0.30 €/km Rs 10 to 17 /km +	0.17 to 0.24 €/km Rs 13 to 19 /km ++	0.8 to 1,2 €/km Rs 60 to 80/km --	0.10 to 0.12 €/km Rs 8 to 10 /km +++
Vehicle maintenance cost in Europe (2)	0.10 to 0.15 €/km +++	0.20 to 0.25 €/km -	0.15 to 0.20 €/km ++	0.4 to 0.5 €/km --	0.18 to 0.22 €/km +
Vehicle maintenance cost in India (2)	Rs 10 to 20 /km -	Rs 15 to 20 /km -	Rs 14 to 18 /km +	No information **(3)**	Rs 6 to 10 /km +++

Notes:

(1): Usual European costs in euros and usual Indian costs (INR) presented for comparative purposes only.

(2): Maintenance cost does not include renovations and renewal costs (battery renewal for example). The difference between European and Indian costs is due to the cost of labour, most important in Europe.

(3): Due to lack of data and feedback on this type of motorization for buses and the fact that this technology is not well developed in India.

As we can see, the **electric motorisation presents significant advantages over other engine options**, that is why we retained this one for the next of this study.

10. Electric vehicles charging strategy

Vehicle charging strategy is an essential aspect in the dimensioning of depot areas, workshop facilities and terminus infrastructure, as well as in the choice of energy subscription grade.

The dimensioning of infrastructure depends on the charging strategy and particularly on the following elements:

- Operating hours (split or continuous),
- Number of vehicles to charge,
- Number of vehicles charged simultaneously,
- Energy consumption of vehicles (this item depending on city/route profile, presence of auxiliary equipment, battery type, vehicle capacity, and vehicle commercial speed).

Below is presented a common definition of the different charging strategies:

- Fast charging consists in fitting the vehicles with enough energy capacity to travel a one-way trip or less. The **vehicle is charged during dwell times at stations and/or terminals**. Charging power is usually large enough to make the charging time fit into the time required for service. In this way, charging has little impact on operation (especially time spent in depot areas).
- Slow charging is the process of providing vehicles with enough energy capacity to reach a level of autonomy that allows them to operate for several hours (usually plural round trips). When the reserve is exhausted, the **vehicle must return to the depot area** (where charging infrastructure is usually installed) **to be charged**.
- Mixed charging vehicles can be charged at the terminus at each trip, but **their full autonomy is not necessarily restored** (i.e., battery is not charged to its total capacity). The vehicles then regain their full autonomy when they are slowly charged at the depot. Depending on the technology, this slow charge also balances battery cells. It should be noted that this type of charge requires the combination of 2 battery technologies (with adapted charge performance) allowing both types of charge.

In addition, the term "**in-line charging**" is used to qualify the charging technology at a terminal or station. Fast and mixed charging strategies use in-line charging.

10.1 In-line charging technologies

Innovative charging technologies are currently being developed, experimented, and marketed. The principle is to split and increase the frequency of charging, by relying on charging at terminus or at stations.

Regarding the in-line charging, the equipment to be installed depends on the power demand. In the case where the power exceeds 250 kW, a connection to the local high voltage network is necessary. The equipment to be installed is therefore the same as for the charging in the depot.

Inverted pantograph (source: ABB)

Bus um pantograph (source: Heliox)

Geneve Trolleybus (source: Van Hool)

Induction charging (source: Bombardier PRIMOVE)

When the power demand is less than 250 kW, a connection to the low voltage network is usually enough.

Regarding the in-line charging, the main technologies are as follows:

- Charge by Bus up pantograph with a pantograph located on the bus that meets the rails of the charging station located above the bus,
- Charge by inverted pantograph with pantograph installed at giver points, and no longer one on the bus, which is just equipped with the contact points,
- Charge by induction which allow to charge the battery by setting the bus above a coil fed by an electric courant, but this technology is not yet very developed,
- Manual connection via a charging plug, and
- Ground-based charging system with retractable skids under the bus put in contact with the base on the ground when he arrives at the charging base.

The graph in Figure 33 gives the distribution of the type of connection for fast charging among worldwide projects.

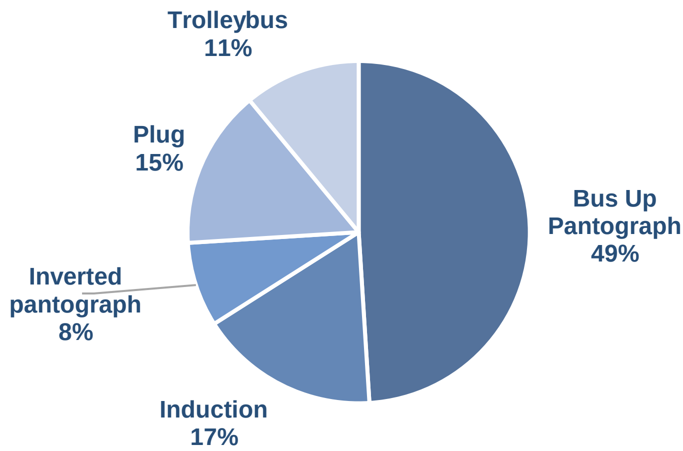


Figure 33. Connection type for fast charging (data source: UITP and manufacturers data)

Although the state of the market shows a majority for the "Pantograph" technology, the trend in recent years has been towards the "Articulated arm" one.

10.2 Depot charging technologies

10.2.1 General description

Bus Up charging Schipol Catergingweg depot (source: Ville Rail & Transport)

Regarding charging at the depot, in most cases vehicles are connected to charging stations via a plug. For buses, these are usually DC (direct current) stations. These allow a greater transfer of power and are often referred to as "quick charging stations". They reduce on-board equipment by using a charger external to the vehicle to convert from AC (alternate current) to DC.

Plug charging
(source: RATP depot – Paris)

The terminal replaces part or all the on-board charger. As a result, the terminal is larger in size, but the on-board equipment on the vehicle is reduced (impacts on equipment size and weight).

The terminal performs the charger function by adapting its output voltage and current to the vehicle and the state of charge of the batteries. The charging power offered by this system varies between 30 and 150 kW, or even 200 kW.

In a few cases where the mixed charging strategy is applied, the technology used for in-line charging (mainly pantograph or articulate arm) is also used in depots. In this case the power and charging time in the depot is comparable to that of a manual charging station.

10.2.2 Depot charging management system

A charge management system provides global control of the chargers on a shop floor level and thus enables the automatic distribution of bus charging in order to limit the maximum power demand.

The system therefore controls the chargers sequentially on/off and the bus to be charged, as the chargers can be connected to several buses.

10.2.2.1 Required system infrastructure

The equipment required for the charging management system is as follows:

- Chargers capable of being remotely controlled and supervised,
- A communication infrastructure at the depot level, allowing communication between the chargers, the Programmable Logic Controllers (PLC) and the supervision equipment: for example, a multiservice Ethernet LAN on which a VLAN is dedicated to the charging management system,
- Industrial PLC in redundancy for centralized management of chargers,
- A Battery Management System (BMS) server for data acquisition and supervision.

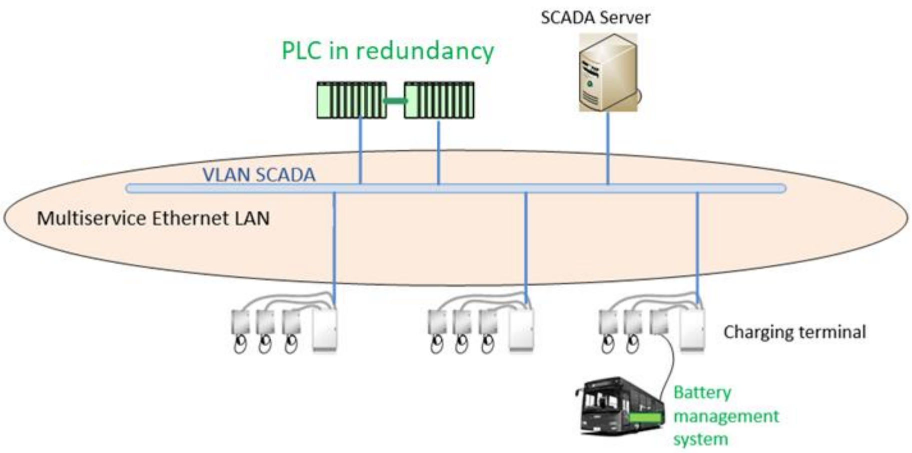


Figure 34. Schematic diagram of the charge management system

10.2.2.2 Functionalities

The charging management system makes it possible to:

- Collect data on the state of charge of the busses by dialoguing with the chargers,
- Consider the planning data (service end time / service start time) and scheduled maintenance tasks,
- Calculate a bus charge schedule that minimizes the maximum power demand,
- Start and stop the bus charge according to this schedule,
- Adapt scheduling in real time according to operating contingencies (bus late in arriving at the depot, battery charge at the end of service lower than expected, etc.),
- Allow operators to easily identify buses ready for operation (charge complete).

Among the solutions proposed by manufacturers, some go even further in the optimization by relying on real-time data of the battery status communicated by the buses. Such solutions are not considered here because they require a real-time communication infrastructure with the buses and are still experimental.

In order to collect data on the state of charge of the buses, the solution studied in this report is based solely on communication between the BMS and the chargers, which are themselves capable of communicating with the bus battery management system.

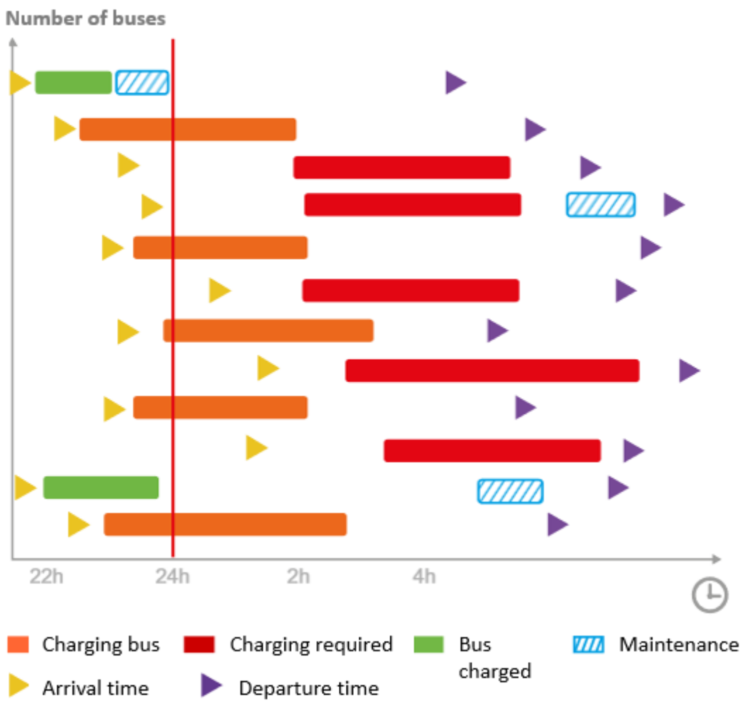


Figure 35. Example of charge management system (source: C-Way)

10.3 Recommendations

The graph in Figure 36 shows the usual capacities of the storage system in relation to the daily distance travelled electrically by the buses according to the charging strategy.

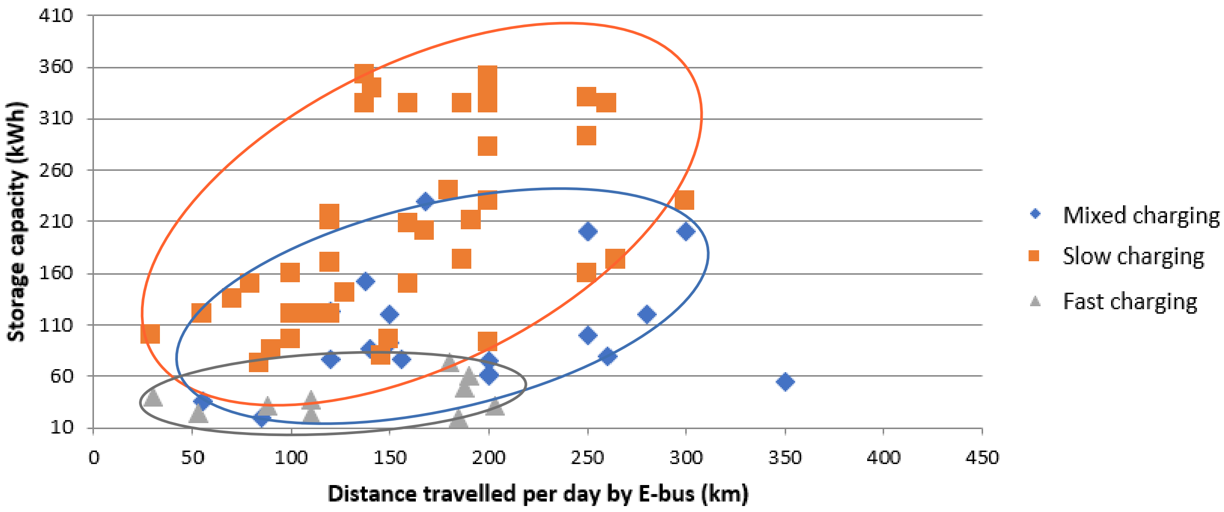


Figure 36. Usual capacities in relation to the daily distance travelled (data source: UITP and manufacturers)

Differences can be observed in strategy between slow and fast charging.

Indeed, for slow charging, there is a strong correlation between the capacity of the storage system and the distance travelled daily by the vehicle. The differences around this correlation can be explained by different specific consumptions according to the context of the networks, and by the depth of discharge at the end of the day: some networks go up to 100% while others limit themselves to 60% in order to extend the life of the batteries and to keep a margin of autonomy.

Regarding fast charging, there is little correlation between the distance travelled daily and the capacity of the storage system. Indeed, as autonomy is restored at each trip, capacity is rather related to the distance between charging points.

Finally, for mixed charging, there is some correlation between the capacity of the storage system and the distance travelled daily by the vehicle, depending on whether the system is closer to a slow charging or a fast charging.

Regarding in-line charging technologies, if this system eliminates partially the problem of autonomy, it generates specific constraints in terms of:

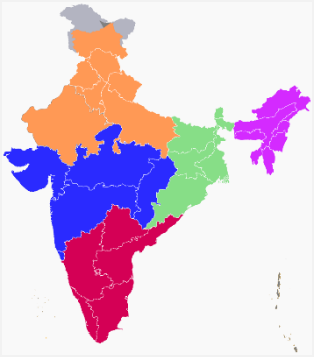
- Necessary infrastructures for charging in line or at the terminus that generates additional costs,
- For some technologies, there is the need to implement a rolling stock guiding system (Siemens or ABB systems for instance), to ensure the precise positioning of the bus on the charging system,

- There is a need to assign the rolling stock to an equipped line (operation and maintenance constraints),
- Some problems related to the fast charging of batteries: shorter lifetime and/or lower battery energy density, and
- Potential interaction on the operating performance (timetables, deadheading, sizing of the vehicle fleet).

In the case of Nagpur city bus network, the **slow charging strategy** (and therefore **depot charging technology**) is recommended considering the average distance travelled per day. Indeed, the usual battery storage capacity enables to travel up to 300 km without charging in line.

11. Focus on the regional electric grid

11.1 India and Maharashtra network



Regional power grids (source: Power Grid Corporation of India)

Indian National Grid is the high-voltage electricity transmission network in mainland India, connecting power stations and major substations and ensuring that electricity generated anywhere in mainland India can be used to satisfy demand elsewhere. The National Grid is owned, operated, and maintained by state-owned Power Grid Corporation of India. It is one of the largest operational synchronous grids in the world with 360.78 GW of installed power generation capacity in 2019.

Individual State grids were interconnected to form 5 regional grids covering mainland India. The grids are Northern, Eastern, Western, North Eastern and Southern. The state of Maharashtra is comprised in the Western Grid. Today, each regional grid is interconnected.

India's grid is connected as a wide area synchronous grid nominally running at 50 Hz. The general layout of electricity networks applicable for the transmission and distribution grid in India is shown in Figure 37.

According to the Approved Tariff Schedule in the Maharashtra State of 2019 (https://www.mahadiscom.in/consumer/wp-content/uploads/2020/03/Order-322-of-2019.pdf), new underground connections up to 10,000 kVA are allowed.

For instance, a depot with 150 electric buses shall require in average 5,000 to 7,000 kVA power connection.

The connection of new charging infrastructure on Nagpur bus depots shall then be possible.

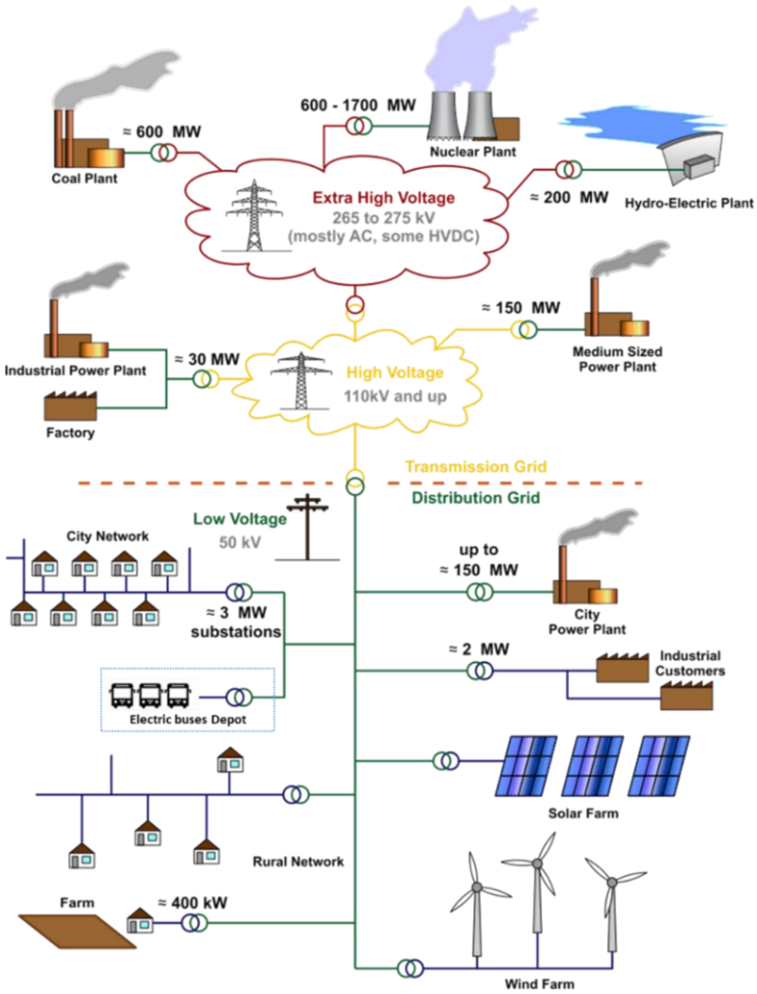


Figure 37. Typical electricity grid schematic

11.2 Electric vehicle charging impacts on regional electric grid

How does an electric grid work?

An electricity grid consists of a mix of several types of power plants along with the transmission and distribution network. The power plants are the generating elements of the grid and operate to meet the base load and peak demand of a region. The base-load power plants, like coal plants, operate continuously to meet the minimum load and are cost-effective. Peaking plants, like hydro and gas-based plants, on the other hand, are operated during peak-demand hours and, hence, are costly. Unlike the baseload power plants, the peaking plants present the advantage of having a quick response time and can be turned on and off at short notice. The peak-load profile of a region determines the total installed capacity required to serve that area, whereas the hourly load is met with the most optimal mix of power plants (it could be just the base-load plants or these along with a few peaking generators).

What are the impacts of electric bus charging on Grid infrastructure?

The number of buses within a bus fleet would to a significant extent determine the charging requirements, which in turn would determine the energy requirement and additional power plants (if necessary). An analysis of load profile can show whether some plants that are not being used during off-peak hours can fuel the electric bus fleet. Some loads like consumer (residential and office) electricity demands are instantaneous and need to be met in real-time. However, the bus charging schedule can be controlled since the vehicle travel time is temporally separate from the time of battery charging. Typically, electric vehicles are charged most economically during off-peak hours and preferably using base-load plant supplies. This configuration shall mean lower electricity costs.

The other scenario could be if a large electric bus fleet is to be charged during peak-load hours. This configuration shall require the addition of new generators and involve considerable infrastructure investment. A thorough grid supply-and-demand analysis shall be carried on along with electro-voltaic fleet economics to arrive at the optimum plant mix for a particular region. Typically, the practice is to match the electro-voltaic charge demand with base plants.

To summarize, before an electric bus fleet is added to an area, a detailed sub-station and feeder-level study should be done to assess the local distribution network capacity and congestion probability due to charging needs and patterns. The benefits provided by the adoption of electro-voltaic energy need to be determined keeping in mind the overall regional grid profile and electric transport policy landscape.

12. Assessment of rolling stock and battery options

12.1 General aspects

The statistical data presented in this chapter are taken from the reference report "An overview of electric buses in Europe - ZeEUS eBus report - October 2017" coordinated by UITP (International Association of Public Transport).

According to the review of the input data, a benchmark report has been prepared (for details, see reference [R3]) and is based on the following data:

- Bus sizes: Standard (44 seats), Midi (32 seats) and Mini (21 seats) buses,
- Travelled distance: 200 km per day per bus (in average, minimum guaranteed per gross cost contract),
- Number of depots: 3 (+1 under construction).

The following constraints have been identified during the Inception Mission:

- Although Nagpur is situated on a plateau, some areas are elevated,
- The curve radius of certain roads and the depots capacities do not allow the circulation of articulated buses
- The city core area is very congested,
- Operating conditions include a relatively large temperature range, reaching up to 45°C in Summer and down to 10°C in Winter.

Three operators are currently operating diesel buses ("Red buses") in Nagpur (Hansa Travels, R. K. City Bus Operations and Travel Time Car Rental) each operating 144 buses, distributed as shown in Figure 38. A fourth operator, Olectra Greentech – BYD is operating 5 electric midi-buses ("Pink buses").

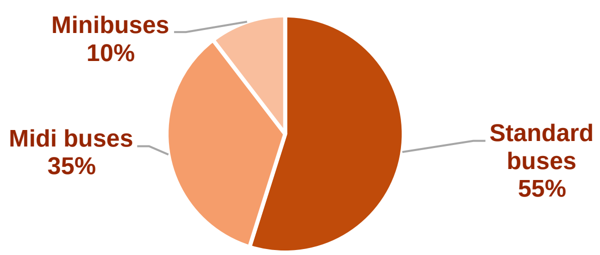


Figure 38. Size of the diesel buses operated on the bus Network of Nagpur (data source: NSSCDCL / DIMTS)

12.2 Passenger capacity

The study has focused on standard buses, midi-buses, and minibuses since there are no articulated buses in the Nagpur bus network and the current market mainly offers articulated buses for opportunity charging.

12.2.1 Minibus

Minibus LDV E80 (source: LDV Group)

Minibuses are a niche market in the electric bus range. They are not part of the catalogue of the main manufacturers of standard or articulated buses and are only offered by smaller manufacturers.

Minibuses are characterised by their reduced length of less than **8 metres** and their passenger capacity generally limited **to 21-22 seats**.

Minibuses usually have only one passenger access door.

12.2.2 Midi-bus

Midibus Safra Businova (source: Businova)

Unlike minibuses, midi buses are more widespread and are offered by several manufacturers who also produce standard-size buses.

The midi bus format is characterized by its high variability in terms of size: the length varies from **8 to 11 meters**. This has a direct influence on passenger capacity, generally between **60 and 70 passengers**.

Most midi buses have 2 doors, one at the front and in the middle / at the tail of the vehicle, usually one being for passenger access only and the other for exit only. Adapted to urban journeys, midi bus vehicles are usually all adapted for people with reduced mobility in order to comply with the international regulations.

12.2.3 Standard bus

Standard bus Solaris Urbino 12 (source: Solaris)

Standard size buses account for two thirds of current electric bus fleets. They are therefore the bus format specially developed by manufacturers. Standard buses are characterized by their length of **12 meters**.

The total passenger capacity (seated and standing) of standard buses averages between **80 and 90 passengers** per bus.

Standard buses can have 2 or 3 doors depending on the chosen configuration. They are all usually adapted for people with reduced mobility in order to comply with the international regulations.

12.2.4 Articulated bus

Articulated bus Volvo 7900 (source: Volvo)

Articulated buses are characterized by their length of **18 meters** (articulated) to **24 meters** (bi-articulated). The total passenger capacity (seated and standing) of articulated buses averages between **80 and 155 passengers** per bus. The articulated buses can have up to 4 doors depending on the chosen configuration.

Articulated electric buses are, most often, offered for opportunity charging because their consumption (higher than standards buses) does not allow long distances per day.

12.3 Thermal comfort systems

Thermal comfort management is the main problem encountered in the case of electrically driven vehicles. Indeed, if this element is necessary for the comfort of both passengers and driver, it is also a major source of energy consumption.

In view of the climatic conditions in Nagpur, heating systems are not necessary. Air conditioning and ventilation systems are an option, although the choice of technology must be made in awareness of the environmental impacts and additional costs.

Furthermore, the air conditioning system requires specific maintenance (periodic filter change and refrigerant refilling) that also generates additional costs.

12.3.1 Air conditioning system

Air suction system inside bus (source: Transbus)

The operating conditions of city buses make it difficult for the air conditioning to work properly due to frequent stops with the doors open. For more efficient air conditioning, the vehicles are equipped with lockable windows and roof hatches that can be electrically operated by the driver.

Some networks opt only for air conditioning in the driver's cab, given that drivers spend more time on buses than passengers. This system is less expensive than integral air conditioning.

12.3.2 Refrigerated forced mechanical ventilation

RFMV on Agora bus (source: RATP, Paris)

Refrigerated forced mechanical ventilation (RFMV) uses only outside air and produces a temperature difference of a few degrees from the outside to give passengers a feeling of freshness.

Much less efficient than air conditioning, RFMV is however energy efficient and more economical. For the ventilation of a minibus, the power of such a system is 400W. The RFMV is particularly useful in hot and dry climates, but less efficient in humid climates.

12.3.3 Glazing opening

Glazing openings are the least onerous solution and naturally require zero energy consumption but provide low efficiency in decreasing the atmosphere temperature inside a bus.

Sliding glass panes allow a greater flow of air to enter than tiltable glass panes.

12.3.4 Impact on the energy consumption

The power consumption of a bus is divided into traction, air conditioning / heating, and lighting and weak currents. The distribution between these different substations depends greatly on the type of line, commercial speed and climatic conditions.

The following graph shows the distribution generally observed for a bus travelling on an urban route (between 15 and 17 km/h commercial speed) in temperate regions.

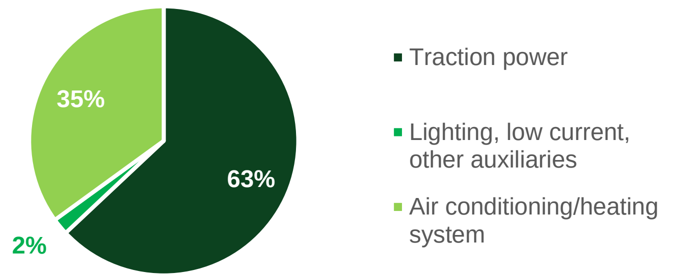


Figure 39. Consumption distribution (data source: UITP and manufacturers)

Air conditioning is therefore a very important consumption item, which can reduce the battery autonomy of vehicles.

Furthermore, the air conditioning system requires specific maintenance (periodic filter change and refrigerant refilling) that generates additional costs.

12.3.5 Recommendations

In terms of thermal comfort, **RFMV and glazing openings** are recommended. Although these systems are less efficient than air conditioning, they are more energy efficient and adapted to Nagpur City.

12.4 Auxiliary systems

A range of evaluation of the auxiliary systems power (mainly lighting and power supply of passenger information media) according to the bus sizes is considered on Table 26. These ratings depend directly on the on-board equipment and the inverters responsible for powering them.

Table 26. Average auxiliary systems power (data source: manufacturers)

Description	Minibus	Midi bus	Standard
Auxiliary system consumption	1.5 to 2 kW	2 to 3 kW	2 to 3 kW
24V Network consumption *	1 kW	1.4 kW	1.4 kW
High Voltage network consumption °	0.5 kW	0.7 kW	0.7 kW

Notes: (*) Includes power supply for the ticketing system and the passenger information system. (°) Includes power supply for the air compressor and the power steering.

12.5 Electric motor systems

12.5.1 Central engine

The central engine provides the propulsion of the vehicle. It connects directly to a transmission and to the rear axle, thus providing the propulsion power. This engine can be installed in both transverse and longitudinal configurations.

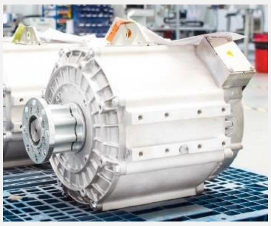
Central engines present the advantage of allowing easy adaptation of existing vehicles. Nevertheless, they present the disadvantage of being rather cumbersome and is not the most suitable for low-floored buses.

12.5.2 Drive axle

The engine is directly connected to the drive axle. This type of motorization has two independent electric motors of equal unit power, placed on the drive axle and on each side of the vehicle.

This type of motorization is better suited to low-floored buses due to its small size. However, this technology is noisier than others due to the presence of high-pitched sounds.

12.5.3 Comparison: Central engine *versus* Drive axle



TM4 Central engine (source: DANA)

Drive axle: ZF AVE 130 (source: ZF)

Table 27 shows a comparison between central engine and drive axle.

Table 27: Comparison: Central engine versus Drive axle

Motor system	Advantages	Disadvantages
Central engine	• Easy adaptation of existing vehicles • Less equipment	• Cumbersome • Not the most suitable for low-floored buses • In the event of a breakdown, all means of traction is lost
Drive axle	• Small size • Independent motorization • Maintenance: equipment less heavy and smaller to repair	• Noise • Maintenance aspect: More equipment to repair

12.5.4 Usual powers

The vast majority of mini and midi buses are equipped with a central motorization. Standard buses can be equipped with either a central motorization or a drive axle.

The power of an electric bus traction motor is categorized depending on:

- Peak power: this is the maximum power that the electric motor can deliver. It can only be supplied for a short period of time (acceleration and braking phases),
- Continuous power: this is the nominal power of the motor. It can be supplied in steady state without any time constraint.

The powers usually encountered are very variable, whichever the bus format considered:

- For a minibus and midi bus, it is about 160 kW on average,
- For a standard bus, it is about 200 kW on average.

The peak powers of the main existing traction engines applied to buses are given on Figure 40.

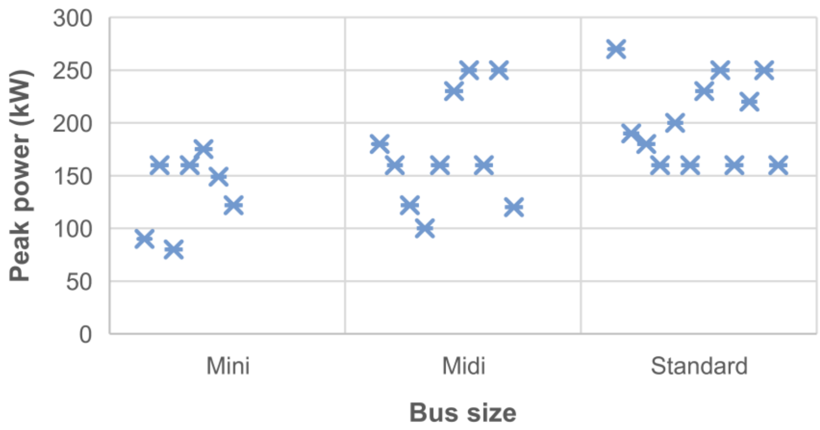


Figure 40. Usual peak powers (data source: UITP and manufacturers)

12.5.5 Recommendations

The power of an electric motor characterizes the ability to maintain its maximum torque at a given speed. The higher the power, the more the motor will be able to exceed the maximum torque at a high speed.

For mainly urban journeys such as the majority of Nagpur city buses routes, where the actual maximum speeds reached by the buses are between 40 and 50 km/h (depending on the route), it is recommended to choose a **medium power rating** in order to guarantee the best compromise between performance and range:

- **120 kW for a minibus**,
- **160 kW for a midi bus**,
- **200 kW for a standard bus**.

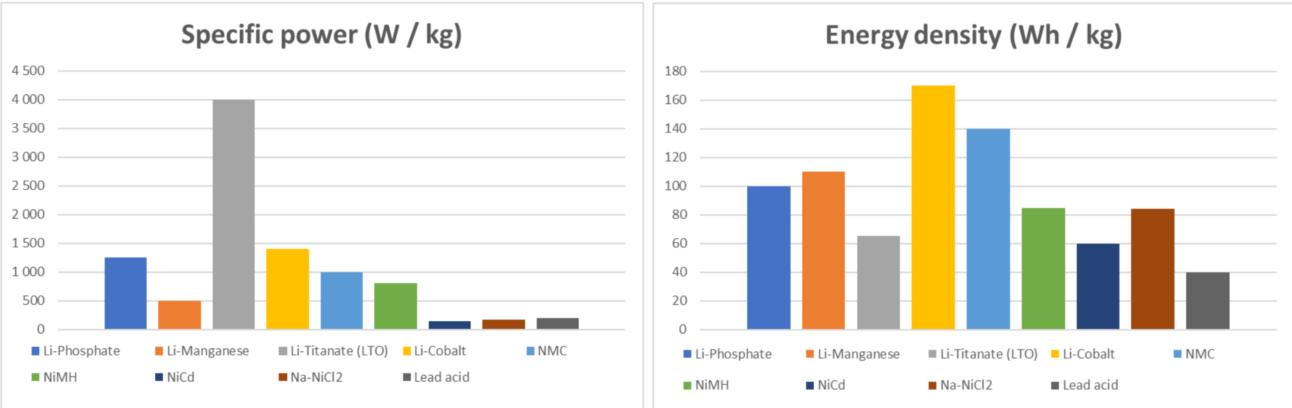
For journeys on expressways where maximum speed can reach 90 km/h, it is recommended to opt for the most powerful engine on the market (250 kW on the market). This is hardly the case of buses running in Nagpur city, even if some routes include peri and extra-urban sections.

12.6 Battery options

12.6.1 General data

Each type of battery comprises distinct characteristics. One of the first aspects to be considered when analysing battery performance is energy density. This ratio is defined as the available energy of the battery (Wh) as a function of its mass (kg). Power density is the ratio between battery available power (W) and its mass (kg). Graphs in Figure 41 show the energy and power density of the main types of batteries respectively.

Figure 41. Energy density (left) & Power density (right) *vs.* battery type (data source: Global Green Growth Institute)



Lithium-ion type batteries (Li-Phosphate, Li-Manganese) have good energy densities and are typically used for transportation applications. Other important aspects, such as life cycle, charging time, and operating temperature are also to be considered when selecting the battery.

A high power density battery is used to recover energy during braking and a high energy density battery is used for the main energy storage unit that is charged by an external power source during refuelling operations (depot charging or in-line charging).

12.6.2 Charging strategy

The type of battery will also depend on the chosen charging strategy. Depot charging implies slow charging of the battery.

The duration of the charge depends on the following parameters:

- Maximum charger capacity (kW),
- Battery capacity (kWh),
- Maximum charge rate as a function of service life.

This last point is a characteristic linked to the type of battery used, and it is not enough to have a high-power charger to carry out a quick charge. If charging is too fast compared to the acceptable charging rate, battery lifespan is greatly reduced.

This battery capacity is expressed in C-rate. A charge at a rate of 1 C corresponds to a power in Watts equal to 1 times battery capacity in Wh. This means that the battery can be charged in 1 hour. For a 1 kWh battery charged at 2 kW, the charge rate is said to be 2 C.

Regarding slow charging, for a Lithium iron phosphate (LFP) or Lithium nickel manganese (NMC) technology battery, the acceptable charge rate is around 1C, which means that the battery can be charged in 1 hour. The life expectancy is in the order of 3000 cycles.

12.6.3 Battery lifespan

Battery lifespan is given as the time the battery is at a capacity of ~80% or higher compared to its initial capacity. For a capacity below ~80% it is considered that the performance of the battery no longer allows it to be in a nominal operating and performance mode.

Battery lifespan also considers the average number of charging / discharging cycles and the average depth of discharge. The graph in Figure 42 shows the cycle life of a typical Li-ion battery as a function of the depth of discharge.

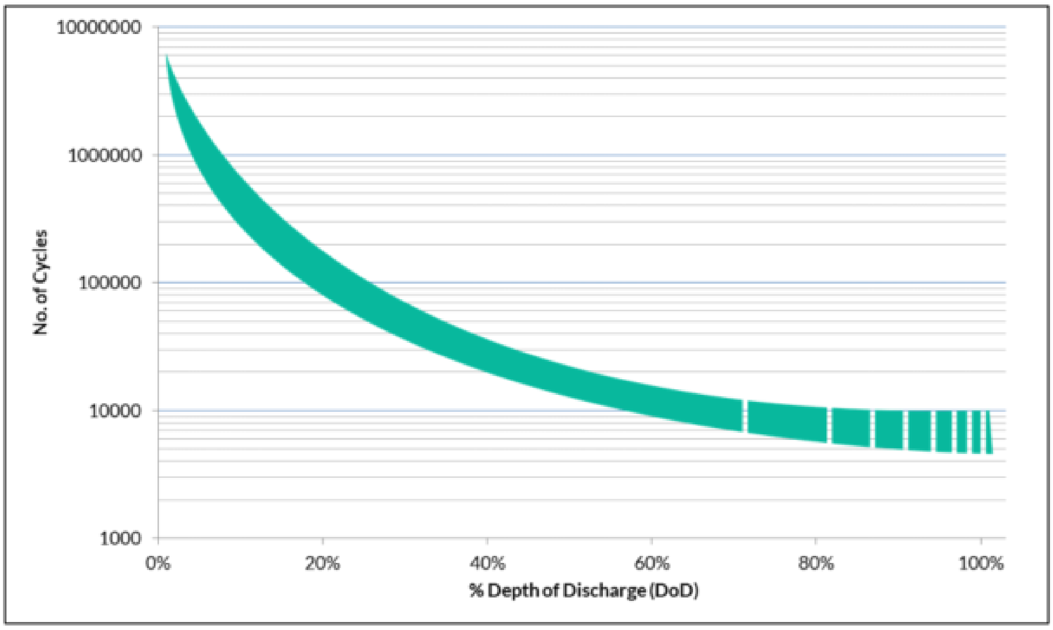


Figure 42. Cycle life of a typical Li-ion battery as a function of DoD at 25°C (data source: Global Green Growth Institute)

12.6.4 Battery Management System

Batteries consist of individual cells connected in series (to achieve the desired voltage) and in parallel (to achieve the required energy level). To protect the individual cells from aging, lack of balance, adverse effects of overcharging, and overheating, it is required to equip battery banks with a Battery Management System (BMS). The most important function of the BMS is to ensure safety so that the battery system is not used below its capacity in terms of operating temperature, voltage, and current.

In general, the BMS is a device that insures Data acquisition, Data management, Electrical management, Temperature management, and Security management.

In practice, a BMS will give the complete status of each battery bank and help manage charging to maximize the life cycle of the bank. One of the selection criteria for the electric bus manufacturer shall be the technical quality of the proposed BMS.

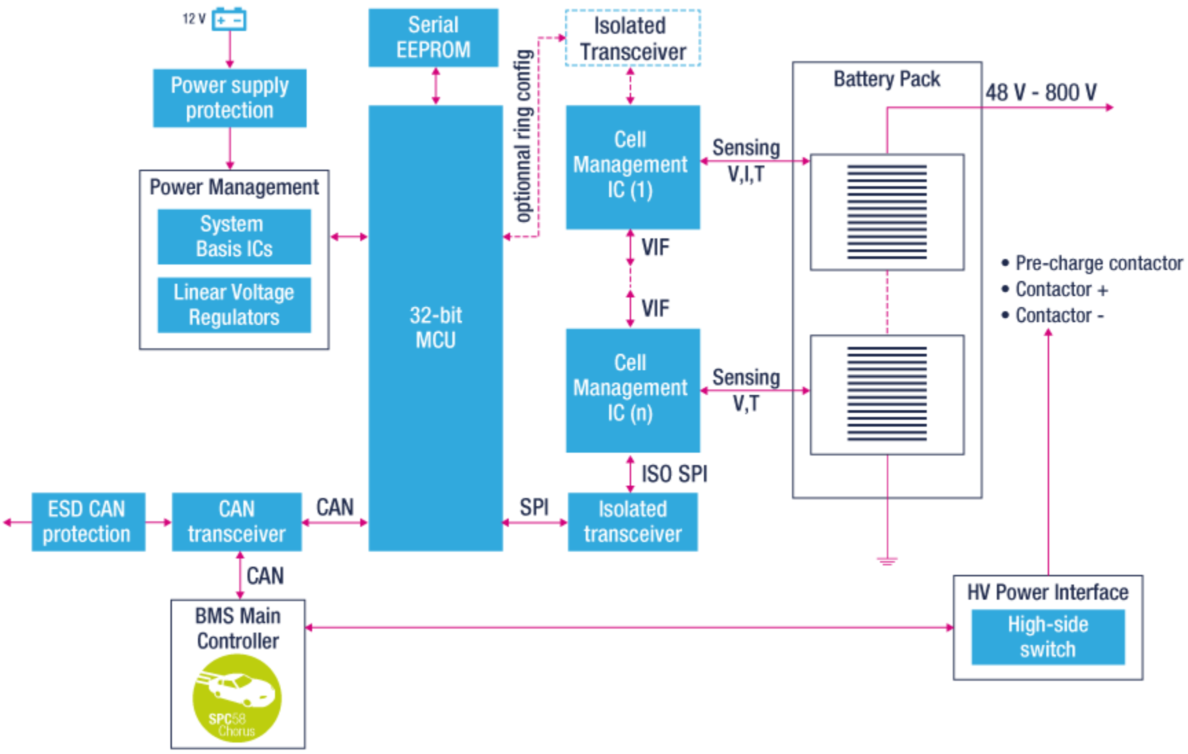


Figure 43: Example of diagram of Battery Management System (source: STMicroelectronics)

12.6.5 Summary of battery parameters

The representative parameters of the electric buses batteries for a depot charging are presented in Table 28.

Table 28. Representative parameters of electric bus batteries (data source: manufacturers)

Battery type	Energy density	Charging rate	Lifespan
LFP (Lithium iron phosphate)	100 Wh / kg	1 C	3000 cycles
NMC (Lithium nickel manganese)	120 Wh / kg	1 C	3000 cycles

12.6.6 Batteries usual capacities

Batteries usual capacities encountered in the market are highly variable, whichever the bus size considered:

- For a minibus it varies from 43 to 160 kWh,
- For a midi bus it varies from 86 to 240 kWh,
- For a standard bus, it varies from 150 to 660 kWh.

12.6.7 Recommendations

In view of the climatic conditions in Nagpur and considering a 20-25% margin considered in the event of operational contingencies, vehicles with **medium battery capacity** are recommended. Thus, for a standard bus, the recommended total capacity is in the range of 300 to 400 kWh.

Simulations of the charge illustrate the selection of a battery capacity.

12.7 Focus on electric batteries "end-of-life"

Batteries are the core technology of electric vehicles. Due to a substantial need for rare metals, the mining of which has proven negative environmental consequences, the advent of batteries is the subject of intense deliberations. In particular, the issue on how to recycle used batteries that will flood the market by the end of the decade is constantly in debate.

Nevertheless, battery electric vehicles are significantly more resource-efficient. Even if a thermal engine vehicle requires relatively few critical resources for is production, it consumes a large amount of raw materials during operation. In contrast, an electric vehicle requires approximately 300 to 400 times less raw materials over its entire life cycle compared to a thermal one[7].

Among the raw materials required for battery electric vehicles, the production of batteries requires highly critical metals such as cobalt and lithium. The mining of these metals has serious environmental and health consequences: destruction of ecosystems during the creation of the mine, massive use of fossil fuels to extract and refine the ore, use of chemicals and water to separate the metal from the ore, toxic effluents, etc. However, these negative externalities are not exclusive to battery production, but are specific to all types of mining (coal, metals such as aluminium or copper, rare earths, etc.). Nevertheless, reducing the environmental impact of these mines, which are often open-pit mines, is essential. The mining industry must continue its efforts to improve its practices.

Furthermore, a large part of the resources that make up batteries can be recycled or reallocated. This is an important advantage over fossil fuels (gas, oil, coal), which cannot be recovered and reused after combustion.

The end-of-life issue is thus a real opportunity to reduce the environmental impact of batteries over their entire life cycle. It is also a lever for certain countries that have little or no underground resources to acquire a very relative energy independence from the main producing countries (Congo for cobalt, Australia, Chile or China for lithium, Indonesia, Philippines, Russia for nickel, China for graphite, etc.).

For uses in urban mobility, a battery is considered to be at the end of its life when the amount of energy it can store reaches 80% of its initial capacity (or up to 70% depending on the case). Two strategies are then available:

- Recycling of the battery to recover critical and non-critical materials from it, or
- Re-use of the battery for stationary uses which can increase the life of the battery from 5 to 15 years depending on its condition and the characteristics of the second life application.

Either perspective has advantages and disadvantages, but both can reduce the environmental impact related to a battery's life cycle. It is to be noted that in general, once the battery is no longer usable in its second life application, it can still be recycled.

[7] Transport & Environment, « From dirty oil to clean batteries », 2021, https://www.transportenvironment.org/sites/te/files/publications/2021_02_Battery_raw_materials_report_final.pdf.

12.7.1 Second life of batteries

As part of the global transformation of the electricity mix, the share of renewable energies is set to increase drastically. As an example, the Indian Government has established a target of 175 GW (>40% of the total energy generation in 2019) to be generated by renewable sources by 2022[8].

The increase in the share of non-controllable energy sources is accompanied by numerous disadvantages, including the balancing of supply and demand. The use of batteries is one of the solutions available to grid operators to:

- Compensate the intermittency of these sources of electricity production by reallocating the energy stored in the batteries when demand is greater than supply,
- Integrate renewable sources in a territory,
- Reduce / smooth power peaks,
- Regulate the frequency of the electrical network.

An increased number of projects are emerging around the world. Thus, demand for stationary use should grow significantly in the coming years. However, there are still obstacles that need to be surmounted quickly to unlock the potential of batteries for these types of use:

- The competitiveness of end-of-life batteries against new batteries is being questioned due to the decreasing costs of new batteries on the market (-85% since 2010) and improving performance,
- Battery repurposing is the result of a multi-step process that consists of dismantling the battery followed by a test to verify its “State of Health” (SoH), a reconfiguration and finally the installation of a new Battery Management System (BMS) and cooling system before repackaging. The cost of these operations is estimated by the IEA to be between 25 to 49 US$/kWh[9],
- The rapid evolution of battery technology makes it difficult to identify exactly which batteries need to be repurposed. As batteries are not yet labelled and given the lack of transparency on certain data such as the SoH of batteries, it may be difficult for a third party reconditioner to recognise the characteristics and even more so the exact status of the batteries (storage, SoH, safety, etc.),
- The transport of batteries is considered dangerous in a large number of countries, including in India. This leads to high transport costs and potential difficulties in crossing borders.

[8] International Energy Agency, « India 2020 - Energy Policy Review », 2020, https://www.iea.org/reports/india-2020.

[9] International Energy Agency, « Global EV Outlook 2020 », 2020, https://www.iea.org/reports/global-ev-outlook-2020.

12.7.2 Battery recycling

The recycling of critical metals through a robust recycling system is a means to:

- Reduce demand for raw materials,
- Reduce GHG emissions,
- Reduce local pollution from mining and refining of these metals,
- Reduce countries' dependence on imports.

Nevertheless, there are currently obstacles to the development of the sector. On the one hand, even if the price of certain metals such as cobalt fluctuates ($90/kg in 2018, $30/kg in 2019-2020, $50/kg in 2021), the cost of raw materials is still too low for recycling options to be economically viable. In addition, the low volumes of batteries at the end of their life cycle, due to the very recent emergence of electric vehicles worldwide, do not allow recycling channels to benefit from significant economies of scale.

The increase in battery production volumes should soon increase the pressure on critical metals and drive up their prices, while the increase in end-of-life battery volumes should drive down recycling costs.

12.7.2.1 Legislation and market overview

The recycling market is still limited due to the small volumes of batteries to be recycled and legislation that has yet to be defined in most countries.

In particular, India does not currently have a specific policy on lithium-ion battery recycling. As of October 2019, the outline of a recycling policy has been proposed by the EU government, but no comprehensive legislation is yet in place. This proposal suggests that **India should focus, at least initially, on extended battery manufacturer responsibility. This means that the collection and management of used batteries should be organised by the manufacturer.** Manufacturer responsibility is also an integral part of the policies pursued by other countries/regions that are more advanced in this area, such as China and Europe.

The European case is particularly well documented. As such, we propose a brief case study of this region on the following paragraphs.

European regulations

Batteries are currently regulated in Europe through Directive 2006/66/EC. Recognising the obsolescence of this Directive considering new battery technologies, new uses, and the strategic importance of the battery market, the European Commission proposed a new regulation in December 2020. This regulation establishes a precise and harmonised framework at EU level, covering the entire life cycle of batteries, from their production process to their second life or recycling.

The primary objective of this regulation is to control and limit as much as possible the environmental impact of batteries, by making them efficient, sustainable, safe, and compatible with a circular economy.

To achieve this, the proposed new regulation focuses on structural elements, such as:

- Sustainability and safety of batteries (including rules on carbon footprint, minimum recycled content in new batteries, performance and lifespan criteria and safety parameters),
- Monitoring of batteries through marking or provision of information (including storage of information on technology as well as data on health status, battery capacity, battery remaining life…), and
- End-of-life management (including extended manufacturer responsibility, collection targets and obligations, recycling efficiencies and recovered material rates).

In concrete terms, this will mean that from July 2024 onwards, the carbon footprint of batteries used in electric vehicles placed on the European market must be clearly stated.

In July 2027, only batteries with a footprint below a maximum threshold may be put into service. The thresholds for the incorporation of recycled materials in new batteries for 2030 and 2035 are as shown in Table 29.

Table 29. Thresholds for incorporation of recycled materials in new batteries according to European regulations

Incorporation rate of	2030	2035
Co (cobalt)	12%	20%
Li (lithium)	4%	10%
Ni (nickel)	4%	12%

With regards to recycling, minimum recycling thresholds for the different battery materials will be set for 2025 and 2030, as seen in Table 30.

Table 30. Thresholds for minimum recycling of materials for new batteries according to European regulations

Recovery rate of	2025	2030
Co (cobalt) Ni (nickel) Cu (copper)	90%	95%
Li (lithium)	35%	70%

The European Commission also encourages manufacturers to perform eco-design and "Design for Recycling" (DfR). These practices consist of identifying, at the design stage, features that could improve the economic viability and safety of second life applications and/or recycling.

Furthermore, the new regulation will cover all batteries placed on the European market, including batteries imported into the EU.

European recycling market

In 2019, the recycling capacity in Europe was only 33 kilotons per year through around 15 recycling companies. Nearly 18 kt were recycled (59% of capacity), but as much was exported outside the EU due to cost or complexity of recycling. According to the European Commission, 8,00,000 tons of batteries enter the European market for mobility purposes alone. This is the volume of batteries that will have to be disposed of each year in Europe within the next 10 years.

Recycling capacities in Europe shall therefore be scaled up promptly. New companies are taking a stand and investing in battery recycling. According to the consultancy firm Circular Energy Storage[10], more than 10 companies have a concrete plan and could recycle more than 15 kt of additional batteries in the very short term.

12.7.2.2 Battery recycling technologies

The recycling of lithium-ion batteries generally involves physical and chemical processes. Since the residual economic value of the battery lies mainly in the cathode (~40%[11]), the recycling of the battery primarily involves recycling the cathode materials. However, the dismantling of batteries and other processes also allows for the recovery of some of the lithium, aluminium, or graphite anode.

There are currently three methods for recycling battery materials:

- Pyrometallurgy,
- Hydrometallurgy, and
- Direct cathode recycling.

The first two methods are now well proven and mature and at the stage of industrialisation, while the latter is at a stage of industrial pilot.

Due to the presence of many materials and the complexity of batteries, recycling is a risky operation (thermal runaway and explosion, toxic gases, etc.). Therefore, in order to limit the risk of short-circuits, the batteries are completely discharged before any handling (this is called a “stabilisation process”).

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[10] https://circularenergystorage.com/

[11] Mengyuan Chen et al., « Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries », *Joule* 3, nº 11 (novembre 2019): 2622-46, https://doi.org/10.1016/j.joule.2019.09.014.

Next, most processes require pre-treatment of the battery (optional for pyrometallurgy). The battery pack is dismantled to isolate the different modules (BMS, casing, cells...). Some modules are then crushed under an inert atmosphere to physically separate different materials. A mechanical separation (magnetic sorting, sieving, densiometric sorting) allows the recovery of a large part of the copper and steel. The rest is agglutinated in a black powder containing metals such as nickel, cobalt, lithium, and manganese. This powder must undergo various hydrometallurgical or pyrometallurgical treatments to separate the different materials.

Pyrometallurgy

Pyrometallurgy is a process of melting different metals at high temperature (about 1,500°C). This process produces an alloy of cobalt, copper, iron, and nickel. The metals in this alloy can then be separated via a hydrometallurgical process. The anode, plastics, aluminium, and electrolyte are usually burnt to provide energy for the process.

This process is mature and relatively simple to implement but requires a significant input of energy. In addition, some of the battery materials cannot be recovered (graphite, plastics, lithium, manganese, or aluminium) as they help the melting process.

Hydrometallurgy

Hydrometallurgical treatments consist in dissolving the different materials by leaching with an acid. The solid/liquid phases are then separated, concentrated, and purified. The ions in solution are then recovered through various chemical processes (precipitation, electrolysis, solvent extraction…).

This process has the advantage of allowing the recovery of most materials (including lithium) with a high level of purity. In addition, the energy input required is relatively low. The carbon footprint of this process is therefore better than pyrometallurgy. On the other hand, the process is complex and requires good management of effluents (especially water and solvents).

Direct recycling of the cathode

A direct cathode recycling process is currently being developed[12]. With direct recycling, the cathode materials are synthesized by various chemical processes. This results in a powder with similar or even identical properties to those of a virgin cathode. There is therefore no need to extract the various materials as they can be reused directly. This saves energy, but these cathodes can only be used in the manufacture of batteries of the same type, which can be a barrier for the development of this technology.

[12] https://recellcenter.org/

12.7.2.3 Recycling efficiency

An impact assessment commissioned by the European Commission in 2020 shows that it is already possible to achieve the recyclability rates set by the new European regulation for 2025. Regarding lithium, the recycling of telephone batteries is currently carried out with a recovery rate of between 76% and 95% (in general above 90%), and there is significant room for improvement. For cobalt, extraction efficiency exceeds 97%. Furthermore, in China, official guidelines for companies to qualify for government funding or assistance require companies to recover 98% of cobalt and nickel and 85% of lithium. Although this is not (yet) binding legislation, companies that do not meet the requirements cannot receive any public support.

However, according to expert Hans Eric Melin[13], most recycling companies are already complying. In the United States, companies such as Redwood Materials claim to be able to collect metals such as cobalt, nickel, aluminium, and graphite at rates of over 95% and lithium at over 80%.

The technology for high efficiency recycling is therefore already mature, but still needing to be industrially scaled.

[13] https://circularenergystorage.com/about

13. Assessment of charger options

13.1 Single charging terminal

13.1.1 Typical model description

Charging terminal: IES Synergy (source: IES)

Single charging terminals are the most common terminals on the market for charging infrastructure for electric buses. The typology is simple: a terminal is composed of a power converter and a cable connected to a CCS plug. A single terminal can only supply one bus.

The terminals are supplied with a low AC input voltage, which is converted to a DC output voltage. The desired voltage and power level are controlled by the vehicle's BMS within the technical limits of the charging terminal.

Usual characteristics of the single charging terminals are described in Table 31.

Table 31. Single charging terminals usual characteristics (data source: manufacturers)

Characteristics	Typical values		
Nominal power	50 kW	100 kW	150 kW
Maximal current output	100 A	200 A	200 - 250 A
Voltage output		500-850 Vcc	
Power factor		0,99	
Performance		94%	
Dimensions (out of maintenance size)	800x600x2000 mm	1000x800x2000 mm	1200x800x2000 mm

13.1.2 Variations of typical model

13.1.2.1 Terminal provided with two fixed power plugs

Charging terminal: two fixed power plugs (source: ABB)

One of the variants proposed is charging two electric buses from a single terminal. The same terminal is then equipped with two cables and CCS plugs. In this variant, each plug provides a fixed power (usually 50 kW) independently of the other. The possible operating configurations are:

- Neither plug provides power,
- One plug provides 50 kW, the other plug provides no power,
- Both plugs provide each 50 kW.

Although the ground space is reduced by the presence of a single terminal, this variation presents the disadvantage of not benefiting from the total installed power when only one bus is connected.

13.1.2.2 Terminal provided with two variable power plugs

Charging terminal: two variable power plugs (source: ABB)

With this variant it is still possible to connect two buses to the same charging terminal, but the operating principles of this configuration are as follows:

- One outlet can operate alone, or both can operate simultaneously,
- Each plug can supply power up to the power of the charging terminal,
- The sum of the power delivered by the two plugs at a time may not be greater than the total power of the charging terminal.

A significant advantage from the variation presented earlier, in this variation charging a single bus uses all available power.

13.1.2.3 Parallelizable terminal

Charging terminal: IES Synergy (source: IES)

In this variation, each 50 kW charging terminal has only one plug, but the terminals can be parallelized two by two via a power link. Manufacturers impose a maximum distance of 10 meters between two parallelized terminals.

The operation of the terminals then follows the principles below:

- Either each terminal supplies its nominal power (50kW),
- Or one of the two terminals supply the power of the two terminals (100 kW) to a vehicle. The other terminal then does not supply current to a second vehicle.

13.2 Sequential chargers

13.2.1 Sequential charger

13.2.1.1 General description

The sequential charging terminal allows up to 3 buses to be charged sequentially from a single charger at a power of 150 kW: the buses connected to the same charger do not charge simultaneously but one after the other. The sequential solution is today mainly developed by the manufacturer ABB (see Figure 44).

Figure 44. Sequential charging system (source: ABB)

The following configuration is given as an example, but it should be noted that the configuration is specific to each solution.

For a group of 3 spots, the charging system consists of the following elements:

- 1 charging terminal of 150 kW, at a maximum distance of 150 meters from the first remote module,
- 3 charger boxes connected in series, distant between them of 30 meters maximum,
- Power and communication cables between the charger and the remote modules,
- 1 charging cable including the CCS plug, on reel, with a maximum length of 10 meters (optimal length: 7 meters).

This connection principle is illustrated below.

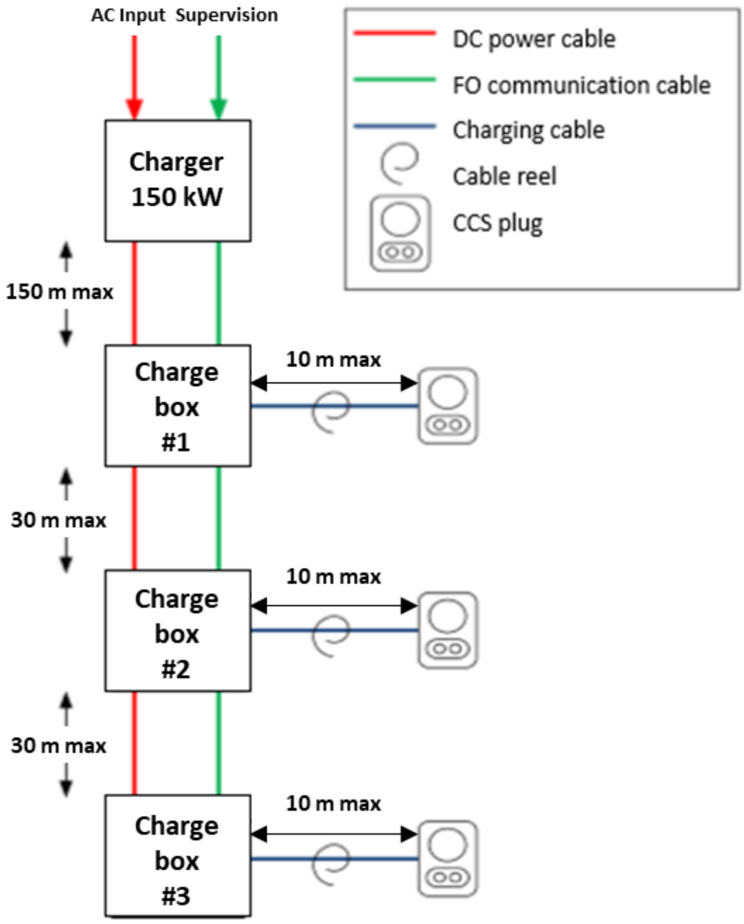


Figure 45. ABB connection principle

The specifications of the individual elements are presented in Table 32.

Table 32. Equipment specifications

Equipment	Weight	Size (D x W x H)
Charging terminal	1500 kg	800 x 1200 x 2000 mm
Charger box	50 kg	220 x 600 x 800 mm

This solution has the advantage of saving space in the depot:

- The charging terminal can be installed in a single defined area,
- The remote modules have a small volume and can be installed on the wall or at a height in line with the vehicles.

In the case of remote modules installed at a height, the use of a reel allows the plug to be lowered and raised by remote control.

13.2.1.2 Wiring principle

The wiring principle must respect the "first in = first out" logic and thus allow the sequencing of the charging without any constraint on the bus flow.

Thus, the connection of the remote modules to the chargers must ensure that the first vehicles to arrive are connected to separate chargers.

Filling the bus storage at the depot prioritizes rows rather than columns. In conjunction with the parking software, this storage principle makes it possible to facilitate operation with traffic lights at the beginning of the line: when a line is full, the traffic light turns red and the light on the next line turns green (as illustrated in Figure 46) and limit cable lengths.

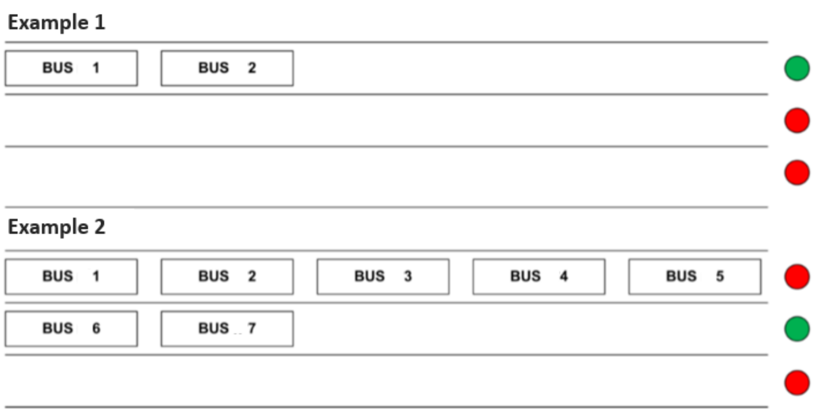


Figure 46. Wiring principle

13.3 Recommendations

Regarding Nagpur City Electric Buses, the **sequential charger** is recommended as it optimizes infrastructure and energy consumption.

14. Assessment of connection systems

14.1 Bus Up pantograph

14.1.1 System principle

Bus Up system (source: Heliox)

The Bus Up system involves a pantograph located on the bus that meets the rails of the charging station located above the bus. Power ratings can reach up to 600 kW for fast charging. In some cases, the information exchanged can also be exchanged via Wi-Fi, as for the manufacturer Heliox for example, for the system set up in the city of Differdange in Luxembourg.

The mobile part is deployed from the roof of the bus. A stem (fixed infrastructure) supports the contact elements allowing the buses to charge. For the installation of the power and communication cables, a path between each stem and the charging station is necessary.

There are different contact profiles at the top level depending on the number of contacts. The most common are 4- and 5-pole.

14.1.2 Strengths and constraints

Bus Up charging Schipol Catergingweg depot (source: Ville Rail & Transport)

The Bus Up pantograph system is a system that guarantees a range of available power that suits any size of bus to be considered (including articulated). On the other hand, it is a system that has not been tested for depot charging. Moreover, it has an impact on operating performance by making the bus heavier and reducing its autonomy.

It implies installation constraints, particularly in terms of ceiling height and floor space in the depot: in addition to the installation of the structural columns, there is also the installation of the charging terminal.

In addition, the operation and maintenance of a fleet with such a system presents certain additional constraints:

- The operation concerning the positioning of buses must be accurate,
- Maintenance of both the inverted pantograph and the fixed connection systems must be carried out at height (security working conditions).

14.2 Inverted pantograph

14.2.1 System principle

Contact with inverted pantograph (source: ABB)

The inverted pantograph system differs from the Bus Up pantograph system in that it has the moving part of the pantograph on a fixed point. The bus is then only equipped with the contact point, and the moving parts are limited. In this case, there is no longer one pantograph installed per bus, but only at given points. Power ratings can reach up to 600 kW for fast charging.

14.2.2 Strengths and constraints

Detail of the inverted pantograph: mobile part and current rail (source: busworld.org)

The inverted pantograph imposes high maintenance constraints and is no more suitable than the pantograph system for the depot charging, even if the constraint on the on-board weight at bus level is lower.

Maintenance constraints are more complex in the case of the inverted pantograph, as the maintenance of the pantograph (which may require its dismantling) requires secure access to the upper parts of the charging infrastructure (e.g. by nacelle).

Indeed, within the framework of the Bus Up pantograph, the roof access gangways are elements already present in the maintenance workshops.

Based on these criteria, this system does not appear to be suitable for the depot charging.

14.3 SAE Plugs (J plugs)

14.3.1 System principle

Connector SAE J1772 (source: EDN)

The SAE J1772 plug, also known as the Type 1 plug, is the most widely used plug in North America for charging passenger vehicles. Unlike the CCS plug, the SAE J1772 plug only allows vehicles to be charged with AC power up to 19.2 kW. In this case, the AC / DC converter for charging the batteries is on-board the vehicle.

The SAE J3068 plug, also known as a type 2 plug (according to IEC 62196-2), is the most widely used plug in Europe for charging passenger cars. It can be used to charge up to 43 kVA.

14.3.2 Strengths and constraints

Connector SAE J3068 Mennekes (source: sdey.fr)

The acquisition of minibus type vehicles must be mindful of the type of connection. Indeed, these vehicles are offered as standard equipped with SAE J1772 connectors, which are poorly adapted to the charging of the announced battery capacities.

Proposed on most models by manufacturers, the option of the type 1 plug must be preferred when acquiring vehicles. However, certain sizes of midi buses with low on-board battery capacity and some school bus manufacturers do not yet offer this option.

14.4 Combined Charging System (CCS)

14.4.1 System principle

Terminal charging: Connector SAEJ1772 CCS (source: MIDA)

The combined charging system is used for charging at a depot charging station. These sockets permit rapid DC charging. The connector allows the physical connection with the vehicle. The current trend in the electric vehicle market is the use of type 1 (North and Central America, Korea, Taiwan) and type 2 in India (as well as North and South America, Europe, South Africa, Arabia, Oceania and Australia). For high-power charging, the combined charging system in direct current (DC) variant is used. Table 33 shows a comparation between the different plugs.

Table 33. Comparation of different plugs and standards (data source: Website "The Driven")

Current type	Plugs	
AC		
	J1772 (or type 1)	J3068 (or type 2)
DC		
	CC1	CCS2

It should be noted that for powers below 50 kW, the charger can be integrated into the vehicle. Otherwise, the terminal is external.

14.4.2 Strengths and constraints

The combined charging system is the most widely deployed and most widely used system in depots to date. It is proven for depot charging. It offers a power range that allows all possible cases to be considered in terms of bus capacities available on the market today.

The installation of the charging stations (on public spaces) requires a study to ensure the safety of the installation for pedestrian flows and gyrations, but these are elements that are easy to anticipate. However, special provisions must be made for the protection of the charging terminal. These protections are not complex to implement (wheel chocks) or even use elements specific to the traffic already potentially existing (sidewalks for example).

It is a system perfectly adapted to depot charging.

14.5 Induction systems

Roof induction systems are not developed today. Indeed, the information collected is not sufficiently well founded to be considered in the present benchmark study. Ground-based induction system is presented.

14.5.1 System principle

The power supply from the electricity distributor is converted into high frequency alternating current (~20-60 kHz) which feeds the transmitter coils. The transmitter coils are installed under the bus lane. The high-frequency magnetic field produced by the transmitter coils is picked up by a receiver (a circuit resonating with a receiver coil) fitted under the vehicle. The alternating current thus sensed is then converted into direct current on board the vehicle to enable it to charge its batteries.

14.5.2 Strengths and constraints

Primove Ground-based induction system (source: Bombardier)

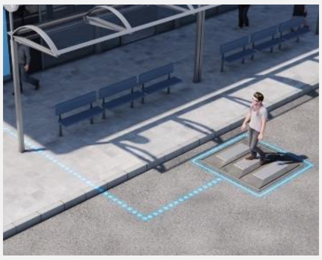
If in pure operating terms the system may seem suitable, the available capacities, the impacts in terms of installation and the precautions to be taken regarding massive installation in depots confirm the incompatibility of the induction system with depot charging. Moreover, the technology is now proprietary and captive to a single supplier. This is the reason that disqualifies the system outside the limitations and constraints stated above.

14.6 Ground-based charging system

14.6.1 System principle

The ground-based charging system is a proprietary solution developed by Alstom. The bus, on arriving at the charging base, emits a coded signal. Retractable skids under the bus are put in contact with the base on the ground. This signal, received by the ground equipment, allows the protective flap to be raised to ensure that no object can meet the terminal. Water tightness with the environment is then ensured.

14.6.2 Strengths and constraints



In-line Alstom SRS (source: Alstom)

Based on the installation constraints and the high charging power, the system does not appear to be suitable for depot charging scenarios. Indeed, this system was conceived for fast charging.

While some advanced aspects specific to Alstom's design may have, according to the manufacturer, advantages for predictive maintenance, the depot scale equipment and related constraints put this scenario on the same level as the induction charging one. Moreover, the technology is now proprietary and captive to a single supplier. This is the reason that disqualifies the system outside the limitations and constraints outlined above.

14.7 Recommendations

Table 34 presents a comparative summary of connection systems.

Table 34. Comparative analysis of connection systems

	Bus Up	Inversed pantograph	CCS plug	SAE plugs	Induction system	SRS
Depot charging proven	-	-	+++	+++	---	---
Installation	-	-	++	--	--	--
Power adapted	+++	+++	+++	--	+++	+++
Operation and maintenance	-	-	++	++	-	-

The **CCS plug** is recommended for Nagpur City Electric Buses charging stations in depots. This system has proven itself in various depots in Europe.

The market for atypical vehicle formats such as minibuses still features vehicles without CCS plug. This criterion will have to be taken into account when acquiring this type of vehicle, as the interoperability of the charging points with all the vehicles in a transport network is an important criterion in the choice of vehicles.

15. Workshop upgrades

This chapter's goal is to define the new requirements in the maintenance workshop for the maintenance of electric vehicles compared to current diesel vehicles.

15.1 Vehicles' maintenance

15.1.1 Mechanics and bodywork

The main body and mechanical elements are identical to the equipment of diesel vehicles, such as the following parts:

- The structure of the mechanically welded mechanical chassis,
- The bodywork (exterior trim, windows, windshield, etc.),
- Interior fittings (grip bar, seats, signage, etc.),
- Bumpers and suspension system,
- Transmission, although simplified to a gearbox stage, will require maintenance identical to that of a diesel or hybrid vehicle,
- Tires,
- Mechanical brakes,
- Door mechanisms,
- The other mechanical elements and / or electronic systems: management, ventilation, lighting, passenger information, video surveillance and air conditioning equipment (if existing) shall also be maintained in the same way.

The workstations and tools shall therefore remain essentially the same, or even optimized for certain stations, such as:

- The motorization part: the traction chain being simplified on the electric vehicle with a single reduction stage, no gearbox or associated clutch,
- The mechanical braking part: the braking energy recovery system for brakes directly reduces wear on the pneumatic brake discs and cylinder.

15.1.2 Electrical and electronic equipment

Low voltage electrical / electronic equipment (engine control, dashboard, on-board equipment, etc.) and power electrical equipment (battery, traction motor, etc.) become the main equipment requiring workstation adjustments and specific tools for the maintenance, such as:

- An electrical workshop dedicated to the traction chain: engine and traction equipment (inverter, energy recovery system under braking, etc.),
- Ventilated workshop and storage room dedicated to maintenance and storage of batteries.

Furthermore, this equipment requires the installation of an electrical workstation equipped with all the tools recommended by the bus manufacturer (mobile diagnostic system, electrical controller, hot spot detector, etc.).

15.1.3 Summary of workshop upgrade items required

Table 35 summarizes the different workshops and their needs.

Table 35. Summary of workshops upgrade items required

Workshop item	Main specifications
Mechanical	It is considered that the overall surface area of the workshops remains identical to that for the maintenance of diesel buses. However, new distributions or redesigns of the mechanical workshop in favor of the high current electrical workshop shall potentially be necessary.
Electrical	
Electromechanical	
Electronic	
Oil storage room and equipment	This room size can be optimized regarding the removal of the engine part.
Spare parts storage	The room size is identical to that required for diesel buses maintenance. However, there are more electronic parts, which require specific conditions (constant temperature, for instance).
Battery storage room	The ventilated battery room, secure and equipped with a slow charger, shall be sized for the storage of a set of 3 to 5 battery units.

15.2 Specific equipment required

Regarding required workshop equipment, the recommendations are presented in Table 36.

Table 36. Workshop specific equipment evolution

Workshop equipment	Main specifications
Roof access footbridge	Vehicles have more and more components on the roof, it is recommended to provide working areas at height. The main specifications are: • Access height: ~ 3m • Length: 12 to 13m • Track width: 1 to 1,5m • Secured by a railing and access by gate
Overhead crane 2,5 tones	This equipment is necessary to handle batteries and other traction equipment, which are located on the bus roof.
Bus washing machine	The height of the machine shall be compatible with electric buses.
Exhaust gas extraction equipment	Gas extraction equipment is not required for electric vehicles.
Workshop compressor	The need is identical to that of diesel buses
Bus lifting equipment	
Washing machine for parts with vapor extraction	
Extractor hood for electromechanical workshop	

Figure 47 presents an example of roof access footbridge to access an electric bus rooftop.

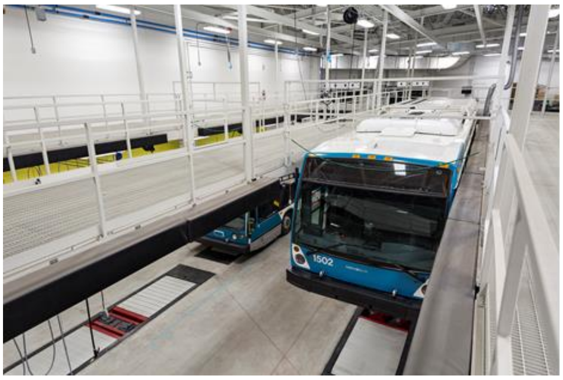


Figure 47. Example of roof access footbridge – STO Workshop, Canada (source: architecture office Cobalt 27)

16. Required resources and qualifications

16.1 Safety related to electric buses operation and maintenance

This section presents the precautions suggested to guarantee an elevated level of safety in the operation and maintenance of electric buses.

16.1.1 Safety during vehicle operation

16.1.1.1 Driving electric buses

In general, the driving habits to be adopted when driving electric buses are different from those related to diesel buses (this is also true for maintenance staff when necessary). Indeed, driving must be more gradual in terms of acceleration to reduce overall battery consumption during service, as well as to avoid sudden acceleration (or deceleration, for that matter).

Electric buses are electric-shock-safe for passengers and drivers as there is no direct contact possible between a person and energized equipment or parts. In addition, electric buses are designed to emit minimal noise to guarantee the safety of people around.

However, a risk of electric shock, which can cause electrocution and severe injury, may occur if work is carried out by unqualified or untrained personnel in the engine compartment or inside the battery compartment.

In the event of an accident or failure to immobilize an electric bus, it must be towed. Additional constraints related to the towing of a damaged electric bus (compared to diesel buses) may apply. Furthermore, the mileage while towing is limited. Most electric buses have axles that must be decoupled. Otherwise, the engine can turn into a generator and directly charge batteries. As such, one of the limits imposed by electric bus manufacturers is the towing distance – 30 to 40 kilometres at its maximum. Beyond this distance, it is recommended to perform towing using a trailer.

Therefore, necessary training of bus drivers (and maintenance staff that may drive a bus) is required. This is generally part of the services offered by manufacturers when purchasing new vehicles.

16.1.1.2 Vehicle monitoring

During commercial service, the on-board systems on an electric bus operate relatively the same as on diesel buses. Real-time vehicle data may be communicated to the control centre to monitor the condition of the bus and perform performance studies (depending on installed on-board systems).

During battery charging phase, a centralized monitoring (at depot) shall allow real-time supervision. The electrical charging infrastructure may also be supervised in real-time to detect any failures and ensure that the necessary operations are made to return to nominal service as quickly as possible.

Indeed, the interest is specially to detect the situation “Bus present on parking space and connected to charging infrastructure but not charging”. To avoid this malfunction, many solutions for detecting the presence of vehicles already exist in the market and may be installed in electric bus depots (parking space occupied or not). Sensors are usually based on laser or ultrasound technology.

16.1.2 Safety during vehicle maintenance

Generally, maintenance processes are composed of three distinct aspects:

- Departure and return maintenance check, performed by the driver at the beginning and at the end of his/her service,
- Preventive maintenance,
- Corrective maintenance.

16.1.2.1 Departure and return maintenance check

A driver's general routine includes vehicle state check and verifications allowing:

- To detect deficiencies and malfunctions as soon as possible,
- To promptly inform the bus operator,
- To prevent the operation of a vehicle when its condition may cause an accident or a breakdown.

Table 37 describes the additional check tasks related to electric buses.

Table 37. General driver’s checklist (departure and return maintenance check)

Part of vehicle	General task items	Additional task (electric bus)
Outside vehicle	• Headlights, position lights, rear lights, • Mirrors, • Front and rear tires and wheels.	• Plug or unplug battery charger, • Check the charger plug.
Inside vehicle	• Windshield wipers and washer, • Hazard warning lights, • Direction, • Manometer, • Honk.	• Battery charge level check.

These new tasks are not intended to engage the driver’s safety, from an electrical or mechanical point of view. The main change for the departure and return tasks is to plug or unplug the charger. These tasks duration is estimated at maximum:

- 1 minute to unplug,
- 5 minutes to check and plug the battery charger.

For any user and for the driver, electric buses design prevents contact with bare parts under voltage.

There is no actual safety impact from the bus driver's viewpoint with the introduction of electric buses. Finally, the number of bus drivers shall remain constant with the arrival of electric buses. The driver must therefore be able to connect the charging system.

16.1.2.2 Preventive and corrective maintenance

BATTERY REPLACEMENT

Battery pack – Martinique 24m BRT (source: setec)

Li-Ion module example (source: SAFT)

Lithium-ion batteries present many non-negligible risks. The most important is the thermal run-away of a cell, the basic unit of a battery. This risk may be due to assembly problems, shocks, a short-circuit or a sudden/sharp increase in temperature. The battery can ignite violently, which releases a quantity of polluting gases supposed to be far below standards. However, cases of cell assembly problems are uncommon, since only 1 cell in 10,000 is faulty (feedback from battery manufacturers).

Replacement of batteries in electric buses shall be carried out by qualified personnel.

It is recommended to set up a battery room in the workshop to make the transition from new and used batteries. Indeed, it is more advantageous to purchase the batteries when necessary, thus avoiding storing a large quantity of batteries in the workshop for an extended period. Also, a subcontractor can be responsible for the supply, repair, and disposal of batteries.

The battery room shall ideally be conceived with a 2-hours fire resistance and a fire detection system in accordance with the local building standards. It is suggested to set up this room with at least two accesses, including direct access to the outside for receiving and shipping batteries. The minimum room area is about 40m². In addition, access to the battery room should be limited to qualified personnel.

ISOLATION OF A DAMAGED OR ACCIDENTED VEHICLE

A bus system operator shall have a procedure to detect damaged or faulty batteries in vehicles. Upon detection of damage or a malfunction of at least one battery on a vehicle, pending its removal, it is recommended to isolate the damaged vehicle from other vehicles on a dedicated area allowing its isolation from the vehicle fleet. Any storage of oxidizing materials is prohibited in this area.

16.1.3 Safety during charging infrastructure maintenance

16.1.3.1 Chargers and power converters

Power converters are common to all charging systems. These are AC/DC conversion modules allowing the use of distributed power at 400V from the main input to charge the buses. It should be noted that the operations and safety issues here considered are independent from the charging system (i.e. the technical means chosen to connect the bus to the charging infrastructure).

Power modules are calibrated for approximately 20,000 hours of effective use. Their replacement takes half a day per terminal charger and requires one worker.

The fans are usually renewed every 10,000 hours of use and about an hour is necessary for its replacement.

In addition, there are two types of continuous maintenance:

Example of electrical measurement (source: Novabus)

- Off-power operations: cleaning, switchgears tests, parameters control, etc. In general, these operations shall be performed every 6 months,
- Under-voltage operations: fans check, voltage and current measurements, etc. In general, these operations must be performed every year.

During the performance of the aforementioned operations, all aspects related to safety present electrification risks. The nature of the work may expose the worker to electrified bare parts. Under these conditions, a work plan shall be drawn up before carrying out the task.

Suitable protective equipment is required, and the operations must be carried out by qualified personnel. Also, as for batteries, a subcontractor can be responsible for the performance of such tasks.

16.1.3.2 Charger plugs

In addition to chargers and power converters operations, the charger plugs shall be maintained through visual inspection operations and light cleaning operations.

For any user and for the driver, the plug's design prevents contact with electrified bare parts.

Awareness of electrical risks is nevertheless to be expected, in order to guarantee a homogeneous level of knowledge of the risk and to be sure of the knowledge of good practices in the event of an accident or possible incident.

16.1.3.3 Medium voltage and low voltage infrastructure

Example of thermographic inspection (source: Veritas Technologies Ltd.)

The medium voltage (MV) and low voltage (LV) distribution infrastructure supplying vehicle charging and auxiliary building loads require recurring maintenance.

The medium and low voltage switchgears in the MV room, transformer substation and chargers room require annual infrared thermographic inspection. An immediate intervention may be required depending on inspection's results.

In general, it is recommended to perform preventive maintenance of the MV/LV infrastructure every three years. Switching off enables electrical and visual inspection of the equipment to detect possible deterioration, which cannot be detected by infrared.

These operations are generally entrusted to an external specialized subcontractor which shall carry out the tests according to a rigorous test plan.

16.1.4 Other general safety aspects

This chapter presents the general safety recommendations for charging vehicles in parking areas. Recommendations include:

- Accessibility aspects,

- Management of damaged batteries and vehicles,
- Additional facilities to be provided for the arrival of electric buses (compared to diesel), such as sprinkler system fire or special instructions.

These recommendations are based on European regulations that set the general requirements applicable to electric bus depots. European regulations are established using feedback from electric vehicles operation as well as from incidents in depots and parking areas.

The recommendations presented hereafter shall be adapted to India and Nagpur's regulations and requirements.

16.1.4.1 Accessibility

ACCESS CONTROL

As for diesel vehicles, an electric bus depot shall have controlled access. This access shall be restricted to members of the bus system operator's personnel and to any third party authorized by that operator.

FIRE AND RESCUE SERVICES

Vehicles shall be parked without blocking the access of fire and rescue service equipment from traffic lanes outside the installation, even outside the operation and opening hours of the depot.

In addition, the access system of the depot area shall be designed as to allow immediate access (on request) to fire and rescue services.

CHARGING AREAS

Bus charging areas shall be clearly signed, for example by a paint marking on the ground, and shall be organized as to allow the access of emergency services if required. These areas shall be located at a minimum distance of 10 m from any flammable or oxidizing materials filling / distribution facilities.

Also, the transformer substation shall be protected against mechanical shock and external aggression, including in the event of mishandle of a vehicle.

16.1.4.2 Emergency and security systems

FIRE DETECTION SYSTEM

The bus depot area shall be equipped with a suitable automatic fire detection system. This detection activates an alarm audible at any point in the depot, ensuring early warning of the people present on the site. The system can only be put back into service after the operator has acknowledged that there is no risk.

FIREFIGHTING CAPABILITIES

The depot shall be equipped with the following firefighting capabilities:

- A hydrant located less than 100 m away,

- Fire extinguishers distributed inside the workshop, on charging areas and locations presenting specific risks. The equipment shall be appropriate for the risk of electric fire, and compatible with other products stored,
- Depot plans facilitating the intervention of the fire and rescue services with a description of the dangers for each area.

This equipment shall be kept in good condition and checked at least once a year.

RETENTION AND ISOLATION OF THE COLLECTION NETWORK

The depot shall have sufficient capacity for retaining fire extinguishing water.

SMOKE EXTRACTION

The closed rooms housing charging or electric equipment shall be equipped at the top with a mechanical ventilation system or natural smoke and heat evacuation devices allowing the evacuation of smoke and combustion gases in case of fire.

16.2 Human resources and qualifications required for operation and maintenance

This section presents a qualitative and quantitative estimate of the additional durations necessary for the operation of electric buses, in terms of:

- Driving time,
- Electric vehicle maintenance,
- Charging equipment maintenance,
- Electrical infrastructure maintenance.

16.2.1 Additional driving time

As discussed in chapters 20.1.1 and 20.2.1, in some cases, the autonomy of an electric bus is not enough to carry out the same level of service compared to thermal buses. In such cases, buses must return to the depot for charging during service. This results in an increase in mileage and thus also in driving time.

For respectively 350 and 400 kWh battery capacities, the additional driving time is estimated at 15 and 5 hours per day as a consequence of the electrification of the bus fleet, which is an almost negligible increase.

16.2.2 Electric vehicle maintenance

In general, electric bus manufacturers indicate a lower overall hourly maintenance volume for an electric bus compared to a diesel bus. Indeed, feedback from experience on several international networks and the elements of maintenance plans of the various manufacturers show a decrease of 8% to 10% in total maintenance hours. However, we consider that this (low) margin does not imply necessarily a change in the overall number of maintenance hours.

These same experience feedback used to assign approximately 20% of the volume of vehicle maintenance hours to the specificity of electric propulsion.

If the overall hourly volume of maintenance tasks does not vary for each vehicle, there is a transfer of about 20% of the time from "Mechanical activities" to "Electrical and Electronical activities" (thus requiring specific training but not necessarily an increase in maintenance staff).

16.2.3 Charging equipment maintenance

Traction inverter (source: ELFA II Traction inverter – Siemens)

Charging equipment maintenance includes the off-power and under-voltage operations. The maintenance hours associated to these tasks depend on the quantity of charges (and thus, the number of electric buses). For instance, for 16 charges (up to 48 electric buses), the estimated maintenance time is around **140 hours per year in average**.

Since maintenance operations require a qualified staff and specific tools, the "Charging equipment maintenance" activities are usually subcontracted by bus service operators.

16.2.4 Electrical infrastructure maintenance

For a bus depot of up to 50 electric buses, the estimated number of hours allocated for the maintenance of the electrical infrastructure is around **100 hours per year in average**. This amount includes visual inspection of electrical rooms.

Usually, all annual inspections and general preventive maintenance operations (every 3 years) are subcontracted by bus service operators. Indeed, these operations require a high level of specific skills and tools which would be very expensive to develop by a bus service operator (training, tools, ...).

16.3 Impacts on staff training

There are two main types of impacts on staff training for the operation and maintenance of electric vehicles and infrastructure (compared to diesel vehicles specific training):

- Bus drivers and control centre staff training,
- Maintenance staff training.

The current chapter considers a scenario of upgrading existing operation and maintenance staff from diesel vehicle-related tasks to electric vehicles ones.

16.3.1 Staff training strategy

Electric bus and electric charger suppliers always offer training after procurement of new vehicles or equipment. This training is aimed at allowing staff upgrading on new operation and/or maintenance tasks. Whenever possible and applicable, we recommend NMC and bus operators to capitalize on training offered by suppliers as a way of promoting reclassification and mobility of existing staff.

Similarly, and as a mean to maximize investment in training and ensure its capacity to deploy new knowledge based on current and future needs of City Bus Services, we recommend NMC and bus operators to consider a "Train the Trainers" approach. By taking on new knowledge and skills, bus operators and/or NMC shall then be able to shape training modules specifically designed for their operation and maintenance staff.

16.3.2 Bus drivers and control centre staff training

Although driving activities are not essentially different between diesel and electric buses, staff must be trained specifically on the following aspects:

- Connection and disconnection of electric buses at the charging station (drivers and maintenance staff),
- Driving habits with electric buses (drivers and maintenance staff): change in the driving mode and in the reactivity of an electric bus at start-up. Driving should be more gradual in terms of acceleration,
- Update on eco-driving (ecological driving) specific to electric vehicles,
- Charging management system software training (operating and control centre staff), commonly provided by system manufacturer following procurement,
- Information session on safety procedures (fire, consignment, etc.),
- Electrical accreditation to raise awareness of electrical risks and to guarantee a good understanding of the directives to be followed and best practices to adopt.

Training must be specific to the procured vehicles and electrical equipment that shall be installed. In fact, due to the specificity or parameters of the equipment adapted to the Nagpur bus network as well as the skill level of drivers, training modules must be provided or established on the basis of the documentation from the manufacturers and / or suppliers of equipment, as well as local regulation.

16.3.3 Maintenance staff training

Maintenance positions are the ones that usually undergo the biggest changes in terms of knowledge and skill requirements, when switching from diesel to electric buses. Indeed, a traditional mechanic worker is not necessarily trained and skilled for electromechanics.

Our feedback from different electric bus manufacturers shows that approximately **80 hours of training** are necessary to bring a conventional maintenance employee (diesel vehicle mechanic) to an acceptable level of competence to perform maintenance of electric buses. This statement is based on certain assumptions such as the employee's desire to learn, that the employee is already familiar with conventional maintenance technics (on his current position) and that the employee demonstrates basic electrical skills.

Given the disparity of experience and the level of aptitude of the resources to be trained, we recommend considering a fixed hourly volume of **100 hours of training**.

As part of any training that shall be deployed, two important aspects shall be considered to maximize the outcomes of training:

Development of new skills just-in-time: when staff is trained too early, they are exposed to the risk of obsolescence of new skills. Indeed, an employee learns new skills but does not have the opportunity to put them into practice,

Development of good practices to allow faster learning: application in the workplace of the knowledge and skills acquired through training and the maintenance over time of the knowledge and skills learned. Failing to ensure a good learning transfer, knowledge could become obsolete and resistance to change could increase.

CASE STUDY: REPLACEMENT OF STANDARD BUSES BY 2022

This section presents the assumptions and results of E-buses energy consumption and depot charging simulations, as well as the identification of impacts on depots' designs, the pre-dimensioning of the required infrastructure, impacts on operation and maintenance activities, as well as an overall assessment CAPEX and OPEX and of environmental impacts.

> Mid-term vision for the diesel to electric bus fleet transition
> General aspects and simulation assumptions
> E-buses energy consumption simulation results
> E-buses depot charging simulation results
> Impacts on depot configuration
> CAPEX and OPEX analysis
> Environmental issues and overall assessment of impacts

17. Mid-term vision for the diesel to electric bus fleet transition

The transport planning documents recommend an augmentation of the bus fleet for the City Bus Service as per the [FBS18]. One of the forecast assumptions being the beginning of Nagpur Metro revenue service in 2018 (and current operation being limited by a few number of open stations), it has been considered a +4 years for the forecast fleet augmentation (i.e., the fleet proposed for 2021 → considered for 2025, etc.).

Moreover, the [CMP18] recommends that 10% of the fleet to be composed of electric buses, as the Government of India promotes the National Mobility Mission Plan 2020. Finally, bus fleet replacement and possible augmentation shall take place at specific dates according to current and to-come contracts for bus procurement and O&M.

Based on the input data, the preliminary assumptions presented in Table 38 were made. The **main horizon-year (indicated in light blue on the table) was 2022** as a very short-term replacement of 144 buses is to be prepared by NMC.

Table 38. Preliminary assumptions for City Bus Service fleet evolution

Horizon year	Fleet in operation	Assumptions
2022	195 existing + 212 new thermal buses 5 existing + 65 new electric buses **Total fleet: 477 buses**	• **By 2022, replacement of the NMC Standard diesel buses** • 10% of new bus fleet to be electric • RFP for the procurement and O&M of 40 new electric Midi buses
2025	407 existing* + 308 new thermal buses* 70 existing* + 35 new electric buses* **Total fleet: 820 buses**	• 820 buses recommended for 2021 + 4 • 10% of new bus fleet to be electric °
2030	520 existing* + 667 new thermal buses* 100 existing* + 75 new electric buses* **Total fleet: 1,362 buses**	• 1,904 buses recommended for 2031 + 4 • **By 2027, end of the current procurement and O&M contracts** • 10% of new bus fleet to be electric° • **By 2029, end of the 10-year 5 E-buses O&M contract**
2035	1,187 existing* + 487 new thermal buses* 175 existing* + 55 new electric buses* **Total fleet: 1,904 buses**	• 1,904 buses recommended for 2031 + 4 • 10% of new bus fleet to be electric °
2040	1,674 existing* + 227 new thermal buses* 230 existing* + 30 new electric buses* **Total fleet: 2,161 buses**	• 2,418 buses recommended for 2041 + 4 • 10% of new bus fleet to be electric °
2045	1,901 existing* + 227 new thermal buses* 260 existing* + 30 new electric buses* **Total fleet: 2,418 buses**	• 2,418 buses recommended for 2041 + 4 • 10% of new bus fleet to be electric °

** The bus fleet augmentation and replacement for further years depend strongly on future RFPs and "Procurement and O&M" Contracts.*

° The ratio of electric buses shall very probably be greater than 10% on the upcoming years.

18. General aspects and simulation assumptions

18.1 Energy consumptions simulations

An analysis of the network operation on the selected routes is performed, in order to determine the electrical consumption profiles on each route.

The simulation software developed by **setec**, **Volt@bus**, allows to calculate:

- Traction power consumption (in kWh/km) which corresponds to the electrical energy necessary for a vehicle to move over a given distance, based on detailed electrical simulations considering the various parameter of the route, the rolling stock, and the ridership,
- Auxiliary's consumption, and particularly the HVAC when applicable (which is a main consumer), based on an environmental and thermal model.

18.1.1 Traction power consumption

The traction consumption corresponds to the electrical energy necessary for a vehicle to move over a given distance. **Volt@bus** simulates a simplified operation of a bus on a given route. It estimates traction consumption for each section between bus stops and its value is given in kWh / km.

The "running profile" of a bus (see Figure 48) describes the speed and the traction or braking power used by the vehicle at any point on its route. There are typically two running profiles possible: "ordinary" (the bus standard speed and energy consumption in regular operation) and "strained" (meaning that the bus reaches as often as possible its maximum speed, applying maximum acceleration and deceleration power). In **Volt@bus** simulations, the "strained" running profile is considered: during the acceleration and braking phases, the accelerations and decelerations are maximum (1.3m/s²) from 0 km/h up to the set maximum speed and within the limits of the vehicle motorization capacities.

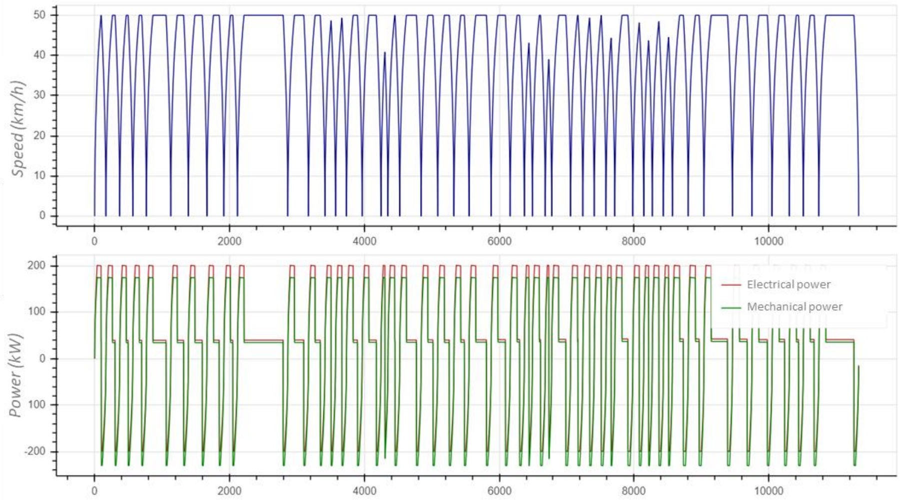


Figure 48. Typical electric bus trip (example from a Canadian study)

The “strained” running profile considers that the vehicle does not make any additional stop (due to traffic congestion, traffic lights, etc.) other than those necessary to serve the stops of the line, the bus running at a regular speed (it is one of the simulation’s input parameter). In order to integrate the impact of congestion, unplanned bus stops and regular circulation (especially in urban areas), this “regular running speed” is usually lower than the actual maximum road speed limitation.

The simulation of the running profile and traction power consumption is done for each section between bus stops and depends on the following main variables:

- Rolling stock: general characteristics (mass), kinematic characteristics (maximum acceleration/deceleration, forward-movement resistance), and electrical characteristics (power, efficiency).
- Operating data: distance between bus stops (“inter-stop”), maximum speed on the inter-stop section, slope of the inter-stop section, direction considered (outward or return), and average ridership of the inter-stop section.

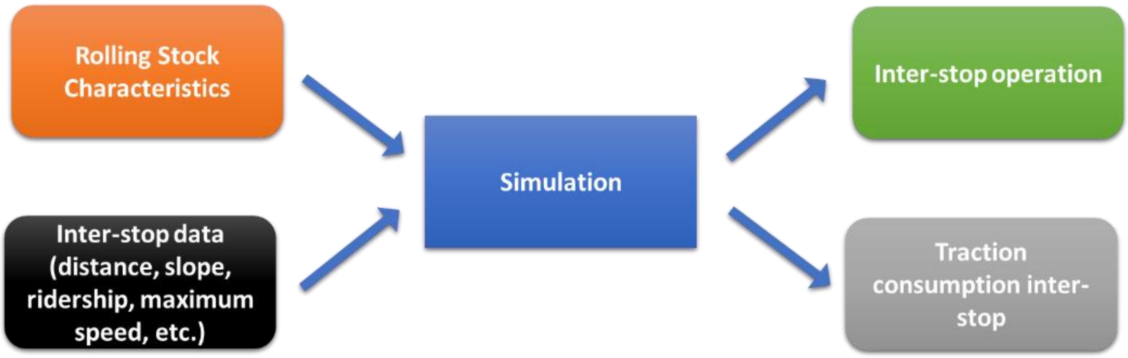


Figure 49. Traction consumption calculation for each inter-stop

Traction power electric consumption is likely to vary depending on the period of time considered (peak / off-peak variations in terms of speed profile depending on general circulation, external temperature, number of passengers, etc.).

18.1.2 Auxiliaries power consumption

The consumption of the vehicle’s auxiliary systems (i.e., HVAC, on-board ticketing equipment, on-board passenger information equipment, etc.) is calculated on the basis of:

- The estimated capacity and power consumption of each system / equipment,
- The average distance and speed of the vehicle on a given section between bus stops.

Volt@bus simulations estimate for each section between bus stops (“inter-stop”) the energy consumption for the auxiliaries in kWh / km.

18.1.3 Nagpur City Service parameters

18.1.3.1 Bus routes simulated

As agreed with NSSCDCL and NMC (with consent of AFD), this pre-feasibility study focuses on **existing routes** currently being operated with **standard buses** (including CNG buses) which are set to be replaced by 2022 as per current bus operator's contracts. According to input data shared by DIMTS on 28-12-2020 and on 21-01-2020, the corresponding routes are presented in Table 39.

Table 39. Main Nagpur City Service bus routes simulated (source: see details in reference document [R6])

Bus route number / Bus route operated by		
Traveltime City Bus Services	R.K. City Bus Operations	Hansa City Bus Services
4, 13, 35, 47, 48, 49, 107, 108, 155, 232, 239, 245, 246, 253	3, 7, 20, 26, 38, 54, 68, 79, 111, 210, 231, 250	23, 28, 32, 35, 40, 42, 52, 54, 86, 106, 134, 135, 174, 188, 222, 228 / 228 A, 244, 249, 250, 263, 277

A total of 45 routes is included in the Volt@bus model and their corresponding **mileage energy consumption estimated**.

The mileage consumption for the routes that could be modelled was estimated considering the **average consumption** of the other routes (representative enough for this level of study).

18.1.3.2 Bus depots' locations and configuration

Due to the exceptional worldwide COVID-19 situation, only one site visit to Nagpur City has been possible during the inception of the mission, and only Patwardhan 2 depot was visited. As such, the depot layouts considered and proposed in this study are based information provided by DIMTS and aerial views.

Regarding the available surfaces, it is assumed that, for each depot, there is enough space to park all E-buses, their chargers and the associated electrical infrastructure corresponding to the power required to supply the whole fleet. Moreover, the connection to the external city power supply is deemed possible (details shall be confirmed at further design stage). Finally, maintenance and cleaning operations are considered possible for both thermal and electric buses.

18.1.3.3 Bus routes parameters

For each bus route, the following simulation parameters were considered: inter-stop slope, inter-stop distance, inter-stop passenger load, inter-stop maximum speed, and inter-stop average speed.

The "inter-stop distance" parameter is determined from the distances indicated in the description sheet of the Nagpur City Service bus routes.

The “inter-stop slope” parameter considers bus stops’ X and Y GPS Coordinates indicated in DIMTS input data and the Z coordinate is extracted using Google Earth® specific tools. Additionally, and considering the level of pre-feasibility study and the general uniform topography of Nagpur City, the slope is considered uniform between two bus stops.

As the passenger load (bus ridership) data was unavailable for each inter-stop, a conservative assumption of **20 passengers at all times and throughout each bus run** is considered. This parameter may be overestimated but a more conservative approach is to be favoured in the absence of data. In any case, the impact on energy consumption of the “inter-stop passenger load” parameter is limited, as the mass of the passengers represents approximately 10% of the total mass of the vehicle. A brief sensitivity analysis to this parameter is proposed in this report. Further analysis should be conducted with actual inter-stop ridership data in the future development of the studies (i.e., preliminary design, for instance).

Regarding the “inter-stop maximum speed”, taking into account both Nagpur inner-city speed limitations for buses (50 km/h) and actual traffic congestion, a single value of **40 km/h** is considered.

The “inter-stop average speed” is calculated from the service schedule provided by DIMTS as “total distance of the daily task divided by total driving time”. Average speed is considered **uniform throughout each daily task**.

18.1.3.4 Rolling stock parameters

The modelling parameters for the rolling stock considered in this pre-feasibility study are the result of our experience and feedback from main international electric buses suppliers.

Details can be found in the related **Task 6 Report** (see reference document [R6]).

18.1.3.5 Energy consumption related to auxiliary systems

A choice has been made not to consider HVAC systems for electric buses in Nagpur (similarly to the Tenders initiated by NMC Transport Department). It was rather recommended to equip buses with RFMV (Refrigerated Forced Mechanical Ventilation) systems and glazing openings. Thus, the average power of RFMV devices is estimated at **1 kW**.

The High Voltage (HV) system is responsible for a small part of the overall electric consumption of the bus. The average power n of these equipment combined is approximately **0.7 kW**.

The Extra Low Voltage (ELV) system is composed of on-board auxiliary and control devices. The average power dissipated by this equipment is approximately **1.4 kW**.

18.2 Depot charging simulations

The objective of the charging simulations is to estimate all the electrical quantities (power and energy) that shall be necessary for charging buses, using input data from the bus service planning data. This includes planning the electric vehicles charge in its depot and thus optimizing the power required to charge the buses.

In addition, data on the state of charge of bus batteries throughout the day are provided in the charging simulations, confirming the assumptions taken to carry out Nagpur City bus service planning.

Thus, the electric simulations aim at **sizing the fleet of the electric buses needed to operate the network** (i.e., confirm the total required E-buses fleet in comparison to the existing fleet), as well as **sizing the necessary electrical infrastructures in the depot**.

The bus consumption per kilometre and the route planning provided by DIMTS made it possible to assign each bus to a task and to determine the minimum number of electric buses required to carry out all the daily tasks. Depending on the time spent at the depot by the vehicles, a bus charging planning was set up as to guarantee the correct charging of the vehicles while optimizing the maximum power necessary for the electric power supply of the depot.

Two scenarios are identified:

- One **scenario without optimization** (without smoothing or load shifting) of the electrical power demand,
- One **scenario with optimization** (with smoothing or load shifting of electrical power demand), based on a reorganization of the bus operation and timetables programming.

For each predefined scenario, simulations are performed with **Volt@bus**.

The software includes an algorithm that **optimizes the charge patterns to limit the power demand peaks**. The principle is to reorganize the programming of the vehicles charging to benefit from the lowest cost for kWh (by limiting the need for a high-power subscription which is costly in OPEX). The reorganization is done by minimizing the simultaneous charge of buses and simultaneously ensuring the commercial service planned with sufficient remaining power capacity for the planned trip from and to the depot. The process is iterative and based upon several simulations. For each simulation we set the maximum power deliverable by the bus depot. Finally, the chosen solution is the one that allows all buses to be charged in time, but with the lowest installed power.

Figure 50 and Figure 51 illustrate some of the principles of the methodology and outputs from **Volt@bus** software.

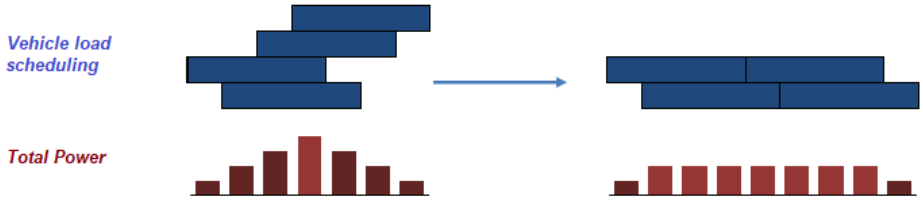


Figure 50. **Volt@bus** principle of electrical charging planning reorganization (in blue) to optimize the required electrical power (in red)

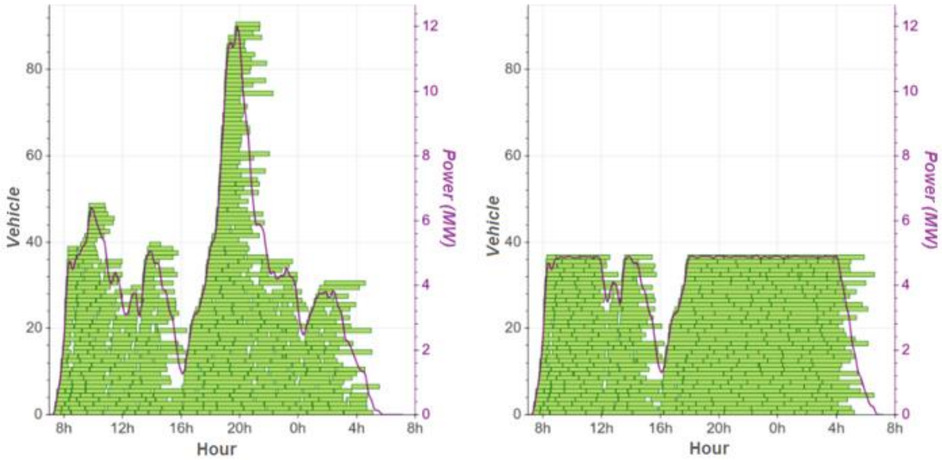


Figure 51. Charging power required without (left graph) and with (right graph) optimization of operation and charging schedule using **Volt@bus** software simulations

Horizontal bars (blue in Figure 50 and green in Figure 51) represent the charging time for a particular bus (the horizontal axis in Figure 51 graphs represent the hours of a day). Stacked horizontal bars represent buses that are charged at the same time (left vertical axis of Figure 51 graphs), assuming the number of available chargers at the depot is compatible. The bigger the stack, the higher is the peak required power (right vertical axis of Figure 51 graphs) for the depot (regarding bus charging).

Figure 51 shows an example of peak required power in two cases:

- In the first case (left graph), the buses are charged upon their arrival at the depot area. The operation settings and inputs (battery status, arrival and departure times, etc.) are not considered to optimize charging. In this configuration, the peak required power is around 12 MW.
- In the second case (right graph), the buses are charged according to operation settings and inputs (minimizing the simultaneous charge of buses and simultaneously ensuring the commercial service planned with sufficient remaining power capacity for the planned trip from and to the depot). The peak required power is around 5 MW.

18.2.1 Simulation input data

The bus charging simulations are carried out considering the mileage consumption for each route estimated in the previous step. The current operational data allowed a fine estimate of the load planning, considering the entry and exit constraints of vehicles at each depot. The inputs described in the following chapters are the prerequisite for any electrical simulation for a given transport system.

18.2.1.1 Bus service schedule

Operational data has been provided by NMC (through DIMTS). The simulations are based upon the service schedule provided for each current depot. The operational data for the E-buses charging simulations for each depot comprises:

- Identification of the task = sequence of bus routes comprising “exit from the depot” trip (deadhead mileage) + one or more service trips (commercial mileage) + “return to the depot” trip (deadhead mileage),
- Start time of each trip,
- End time of each trip,
- Distances travelled for each trip,
- Initial and final bus stops / locations for each trip.

We understood from the service planning data that, depending on the bus route, some buses are performing a morning shift and later an evening shift without going back to the depot (for instance, bus routes 135/02 and 135/02A). Other buses carry out a single run during the day (for instance, the bus route 107/23G).

In order to limit as far as possible impacts on operation, **the same operating pattern were considered in the simulations**. Nonetheless, it is possible that some buses would not be able to carry out both morning and evening shifts without being charged (at least partially) due to lack of energy (battery capacity).

To address this, **and only when necessary**:

- The specific vehicle shall return to the depot at the end of its morning shift. In order to achieve this, a trip between the last stop of the morning shift and the depot is added to the original bus service schedule,
- Another bus takes over from the first one to carry out the evening shift. A trip between the bus depot and the first stop of the evening shift is added to the bus service schedule.

It should be noticed that this adaptation of the bus schedule **can increase the total bus fleet**. In this pre-feasibility study, we have considered different options as to minimize this impact.

18.2.1.2 Electric battery capacity

The choice of the battery capacity is important to determine the number of buses required to perform the tasks of the service planning. If the capacity is too low, some runs, which require more energy than that stored in the battery, could not be carried out by a single bus (another bus will have to take over from the bus that runs out of energy), thus having an impact on total bus fleet.

On the contrary, it is not recommended to oversize the battery as this increases the investment cost of the vehicles while it is only useful for a small part of the fleet.

Therefore, given the current bus schedule trips distances, a battery capacity of 400 kWh seems to be a good compromise for the pre-feasibility study.

This recommended battery capacity is considered an input data for the electric simulations, and it was optimized when possible (for instance to a battery capacity of 350 kWh). It should be noted that this potential optimization can only be possible if it does not impact the bus service schedule and shall only be indicative at this stage of pre-feasibility studies.

Finally, the usable energy of a battery is considered to be 80% of the total capacity. It is commonly considered that below 80% residual capacity, the battery is at the end of its life for mobility purposes. Considering 80% of the total capacity as usable energy ensures the proper functioning of the transport system during the entire life of the battery. According to usual practices, the battery reserve required by a bus to return to the depot is set at 5% of the usable energy. Table 40 and Figure 52 summarize these parameters.

Table 40. Bus battery parameters considered for the electric simulations (data source: SETEC-NODALIS experience and feedback from international electric buses suppliers)

Bus type	Battery capacity (kWh)	Battery usable energy (kWh)	Battery reserve (kWh)
Standard (12 m)	400	320	16
	350	280	14
	300	240	12

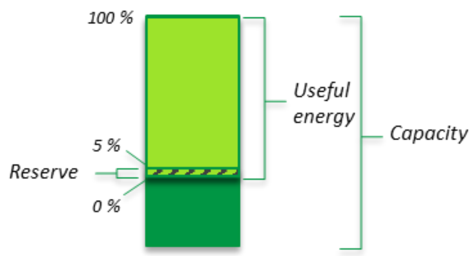


Figure 52. Visual explanation of bus battery parameters and assumptions

18.2.1.3 Bus charging infrastructure

According to SETEC-NODALIS recommendations, the considered typology of bus depot chargers is the following:

- The charging mode is sequential charging at the depot, from “null” to the “maximum” charge rate,
- Each bus charger has three connection points (i.e., one charger can be connected to one, two, or three buses at the same time),
- Vehicles connected to the same charger are charged sequentially (i.e., one after the other, in a “first-in, first-out” basis),
- A smart charging control system is implemented for managing the placement and charging of buses.

The parameters for the chargers considered in the simulations are presented in Table 41.

Table 41. Bus chargers’ parameters considered in the simulations

Parameter	Charger characteristics
Charging power	• 150 kW for charging up to 85% of battery capacity • Power decreasing exponentially for the 15% remaining battery capacity
Overall electrical efficiency	• 90% (including a 94% efficiency ratio of chargers)

18.2.2 Additional assumptions for depot charging simulations

The following additional assumptions are considered for the simulations:

- The everyday assignment of tours to vehicles (1 tour = sequence of trips including “exit from depot” and “return to depot”) is done according to a "first in = first out" practice (i.e., the first bus returning to the depot shall be the first one exiting it for the following tour),
- A 3-minute “bus manoeuvring and positioning” time is added on arrival at the depot and before departure, for a total of 6 minutes. This time is established based on SETEC-NODALIS experience and feedback from bus operators[14],

[14] The 3 minutes bus manoeuvring and positioning time is based on the Canadian experience. This value depends on the operator and the parking management but may not have a significant impact as this latency time is very low compared to the charging time (several minutes versus several hours).

- It is possible to reassign bus runs to optimize the electrical charge (i.e., there is no need for strict correspondence 1 vehicle = 1 scheduled tour only). This assumption has no impact whatsoever on operational procedures,
- In the middle of the day, bus battery charge can be partial: a bus must simply have sufficient battery energy to carry out its following tour (including “return to depot”),
- After night charging, the state of charge must exceed 95% of the battery capacity,
- For their first start, each bus is fully charged (i.e., > 95% of battery capacity),
- At the end of their last trip of the day, each bus must be immobilized at the depot (before charging) for 30 minutes for cleaning and maintenance tasks. This time is established based on SETEC-NODALIS experience and feedback from bus operators. This assumption in particular has the consequence of reducing the available charging time and is equivalent to considering that the buses are in service for an extra half hour.

Finally, this report considers the contract between NMC and DIMTS, through which NMC engaged the services of integrated bus transport management, including the establishment of the daily scheduled service (theoretical daily bus.km) to the bus operators. DIMTS is responsible for “*managing the day to day coordination of bus services on behalf of NMC, who shall also provide technology based solutions to integrate all the domain elements of City Bus Services for a modern and efficient city bus services to the commuters of the city*”.

Additionally, each bus operator is contractually responsible for achieving the operational performance required and for respecting the daily service established by DIMTS. Bus operators’ revenues are based on the respect of the daily service (real daily bus.km). Bus drivers are normally trained by bus operators in that matter.

18.3 Macroeconomic assumptions

The main macroeconomic parameters used in the financial model are summarized in Table 42.

Table 42. General macroeconomic parameters (data source: IMF historical data and projections up to 2021 and assumptions for “After 2021”)

Year	Inflation*
2016	4.50%
2017	3.60%
2018	3.40%
2019	4.50%
2020	3.30%
After 2021	3.60%

18.4 Operational assumptions

A ratio of 340 days is considered to convert annual figures of operational data to daily figures. This corresponds to the conversion ratio used in the existing contracts with Hansa City Bus Services and Olectra BYD Greentech to convert the daily operated kilometres per bus to annual kilometres.

Table 43, Table 44, and Table 45 show the annual mileage production of standard buses according to their motorization. It is to be noted that the total number of buses shown does not consider a 10% reserve for operation and maintenance.

Based on input data received, an estimation of the number of buses needed for the theoretical scheduled service was performed, in order to assess the actual required number of standard diesel buses (Table 43). We observed that the total number of buses (182 standard diesel buses, or 202 when considering a +10% reserve) is inferior to the current standard diesel fleet of the three operators (3 x 79 = 237 standard diesel vehicles). This potential optimization of the current fleet is a possibility based on received input data.

Table 43. Operation assumptions for standard diesel buses

Bus depot	Number of buses	Number of tours	Daily Mileage (km/day)	Yearly Mileage (km/year)	Average mileage per bus per year
Khapri Naka	63	63	15,318	52,08,120	82,669
Higna Naka	67	67	14,870	50,55,800	75,460
Patwardhan 2	52	52	13,909	47,29,060	90,943

Table 44. Operation assumptions for standard electric buses - 400 kWh batteries (data source: **Volt@bus** simulations)

Bus depot	Number of buses	Number of tours	Daily Mileage (km/day)	Yearly Mileage (km/year)	Average mileage per bus per year
Khapri Naka	67	70	15,456	52,55,040	78,433
Higna Naka	67	67	14,870	50,55,800	75,460
Patwardhan 2	52	52	13,909	47,29,060	90,943

Table 45. Operation assumptions for standard electric buses - 350 kWh batteries (data source: **Volt@bus** simulations)

Bus depot	Number of buses	Number of tours	Daily Mileage (km/day)	Yearly Mileage (km/year)	Average mileage per bus per year
Khapri Naka	70	79	15,637	53,16,580	75,951
Higna Naka	68	69	14,903	50,67,020	74,515
Patwardhan 2	53	59	13,926	47,34,840	89,337

19. E-buses energy consumption simulation results

19.1 Network mileage consumption

Energy consumption simulations have been carried out for the 45 routes identified through **Volt@bus** software. The box-and-whisker plot shown in Figure 53 is used to characterize the distribution of consumption values on a single graph:

- The left vertical bar indicates the minimal consumption,
- The right vertical bar indicates the maximal consumption,
- The blue rectangle contains 50% of the consumption values (values between the first and the third quartile),
- The vertical bar in the middle of the rectangle corresponds to the median,
- The orange dot represents the mean consumption.

Figure 53 presents the distribution of mileage consumption on the network for the 45 simulated bus routes.

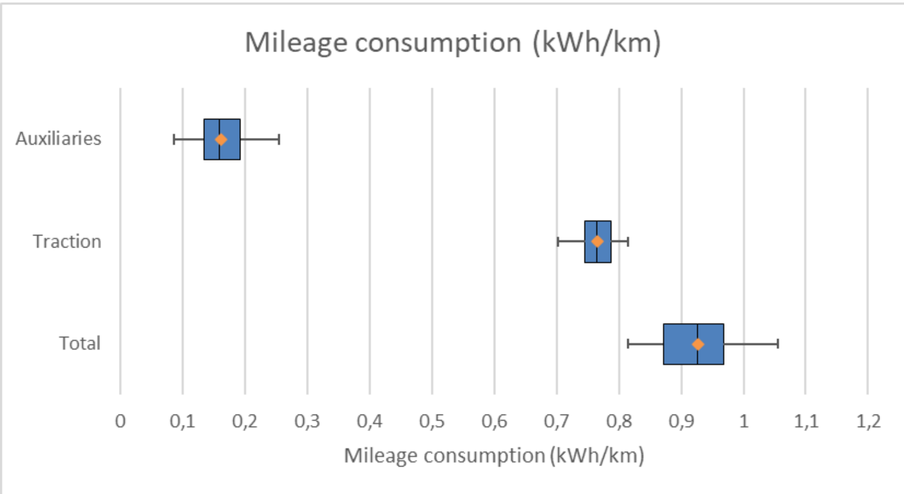


Figure 53. Distribution of mileage consumption on the network

On average the mileage consumption is 0.93 kWh/km and is essentially due to the traction power. It does not exceed 1.1 kWh/km whereas the minimum mileage consumption is slightly higher than 0.8 kWh/km. Thus, the statistical dispersion of mileage consumption estimations is quite low.

The share of energy consumption related to auxiliaries is low since no HVAC system is considered in the electric simulations. Indeed, traction power represents over 83% of the total mileage energy consumption, as shown in Figure 54.

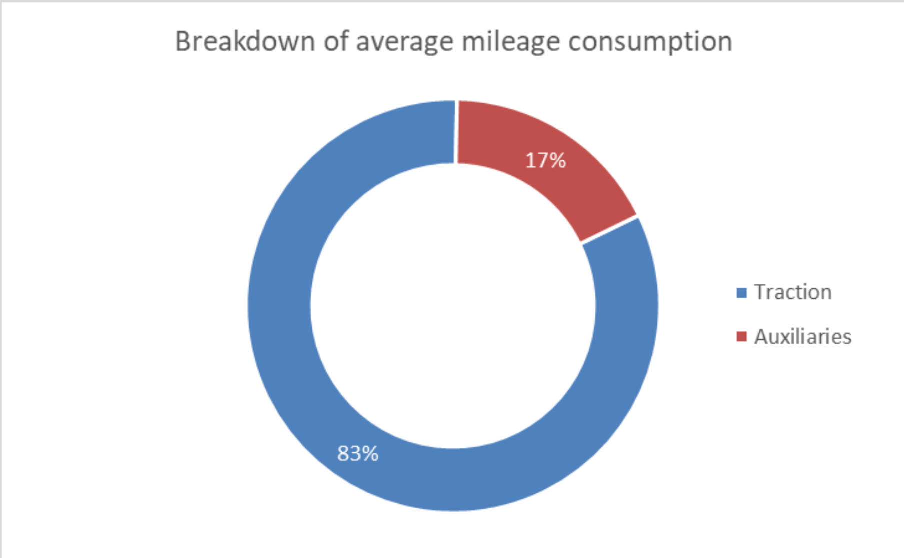


Figure 54. Breakdown of the average mileage consumption

It should be noted that the average consumption on Nagpur City is quite low compared to other networks, mainly due to a relatively **flat city topography**.

Finally, the estimated electricity consumption for Nagpur City corroborates Kolkata City's feedback highlighted in the IEA report "Global EV Outlook 2020" [15, 16]. Indeed, the report presents an average electricity consumption for 12-m electric buses of 0.94 kWh/km. In Kolkata case, buses are air conditioned (which increases the consumption related to auxiliaries) but are equipped with 188 kWh batteries (which decreases the consumption related to traction due to batteries weight).

19.2 Focus on selected bus routes

To better understand the previous results, in this chapter we focus on two Nagpur City Bus routes:

- Route n°4, for which the mileage consumption is near the network's average,
- Route n°48, which presents the highest mileage consumption of the simulated network.

For route n°4, in the direction Hazarpahad-Pipla Fata, the average mileage consumption is 0.95 kWh/km (see Figure 55 and Figure 56).

[15] IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020.

[16] TERI. 2020 Successful Operation of Electric Bus Fleet – "A Case Study of Kolkata" New Delhi: The Energy and Resources Institute, https://iea.blob.core.windows.net/assets/db408b53-276c-47d6-8b05-52e53b1208e1/e-bus-case-study-TERI-Kolkata.pdf

For this route, approximately 81.2% of the consumption corresponds to the traction of the vehicle, while auxiliaries represent about 18.8%. The shorter the inter-stop distances, the higher the energy consumption because electric buses need a lot of power during acceleration phases.

It should be noted that consumption is strongly linked to the speed of the vehicle: the higher the maximum speed allowed, the higher the proportion of consumption due to traction. Furthermore, the higher the average speed, the lower the auxiliary consumption (in terms of energy dissipated related to auxiliaries' use).

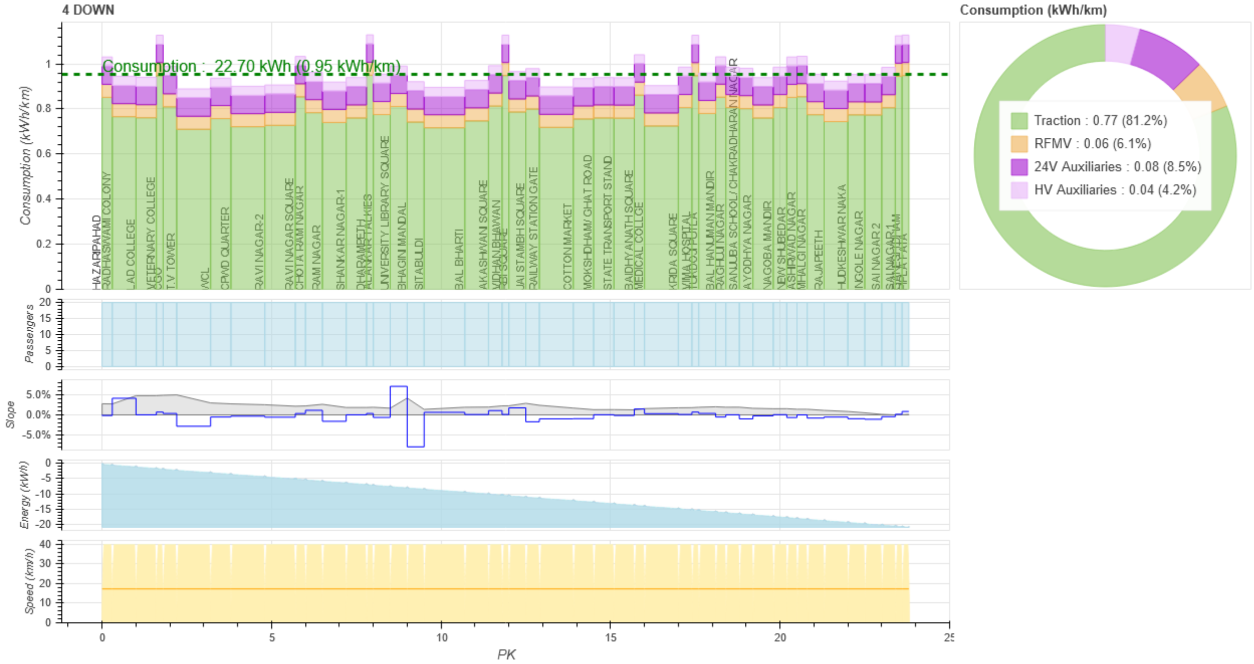


Figure 55. Estimated energy consumption for bus route n° 4 Down

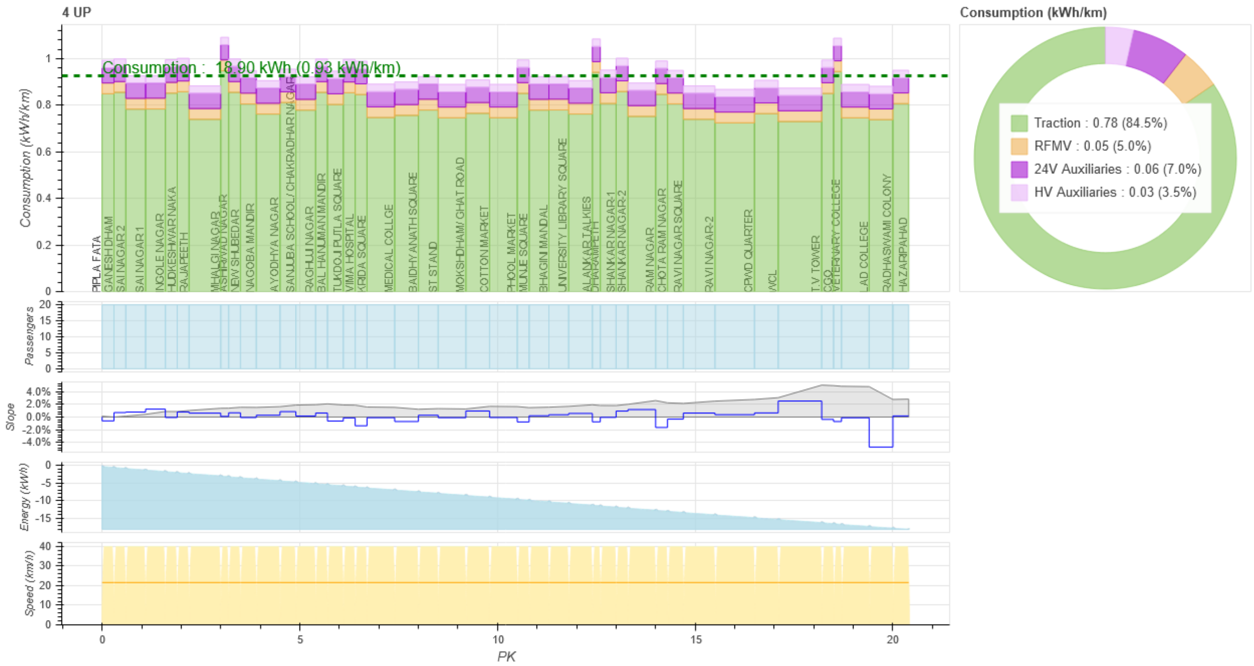


Figure 56. Estimated energy consumption for bus route n° 4 Up

Regarding route n°48 (see Figure 57 and Figure 58), the share of auxiliaries is greater due to a low average speed. Auxiliaries represent 24.2% of the total energy consumption whereas the traction chain represents about 75.8%.

It should be noted that, as detailed speed-specific information was not available (although not necessary for this level of study), the average speed has been estimated using data from bus scheduling by dividing trips distance by their duration.

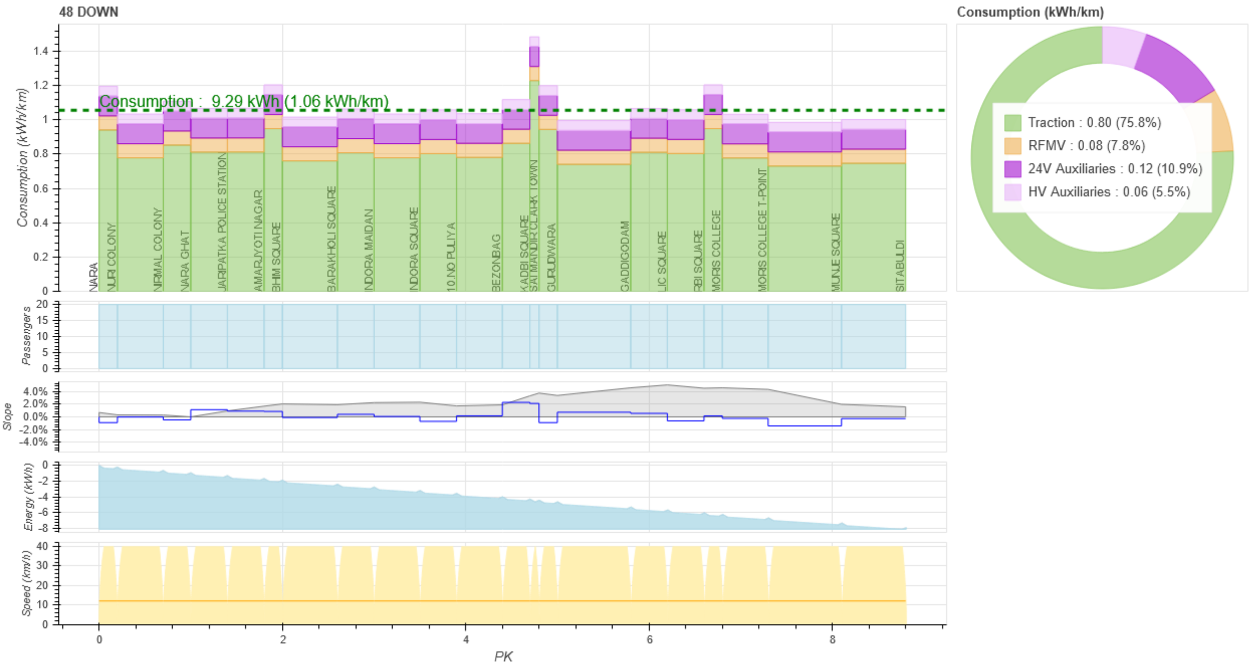


Figure 57. Estimated energy consumption for bus route n° 48 Down

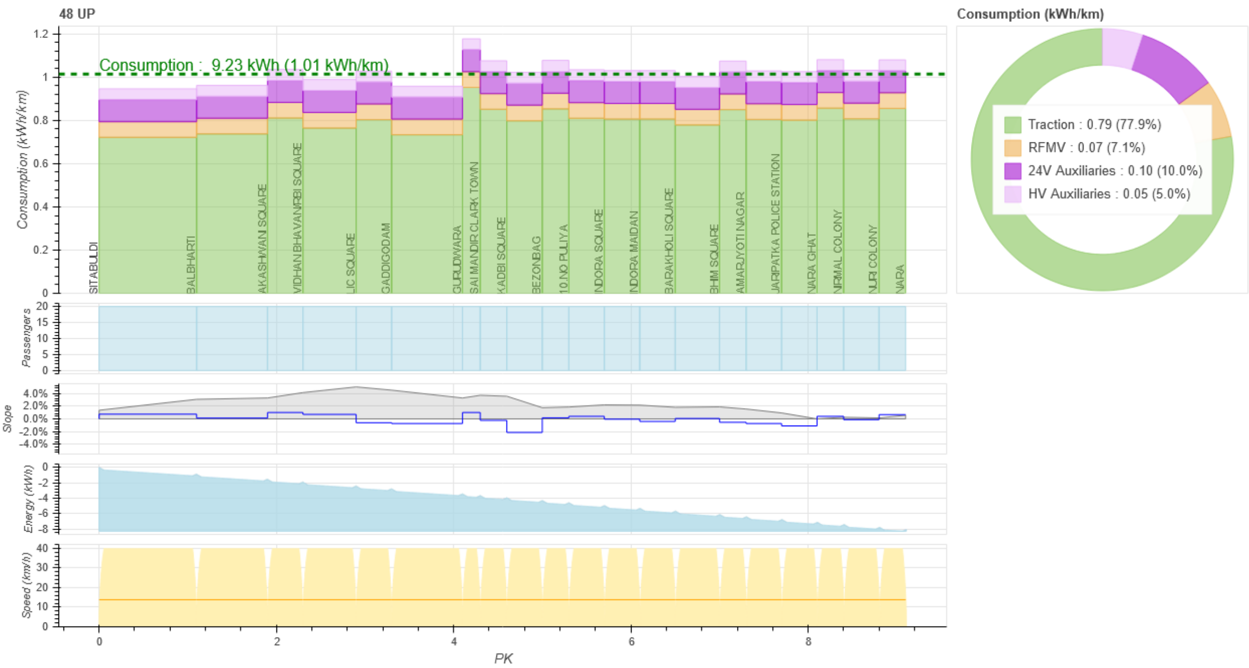


Figure 58. Estimated energy consumption for bus route n° 48 Up

19.3 Sensitivity analysis

To assess the impact of some simulation assumptions and parameters on the results, two sensitivity analysis have been carried out:

- Impact of bus ridership, and
- Impact of the air-conditioning system on electric consumption.

19.3.1 Bus ridership

Little information on bus ridership was available for simulations. Therefore, **Volt@bus** simulations considered a constant ridership of either 0 or 20 passengers. A ridership of 0 corresponds to an empty bus, whereas a constant ridership of 20 passengers is rather ambitious.

Figure 59 illustrates the mileage consumption for each route according to the ridership. As shown, the average difference between the two scenarios is **close to 5%**. In comparison to the mass of an empty standard vehicle (13.5 tons), the impact of the ridership is considered low and thus **within this prefeasibility study's margin of error**.

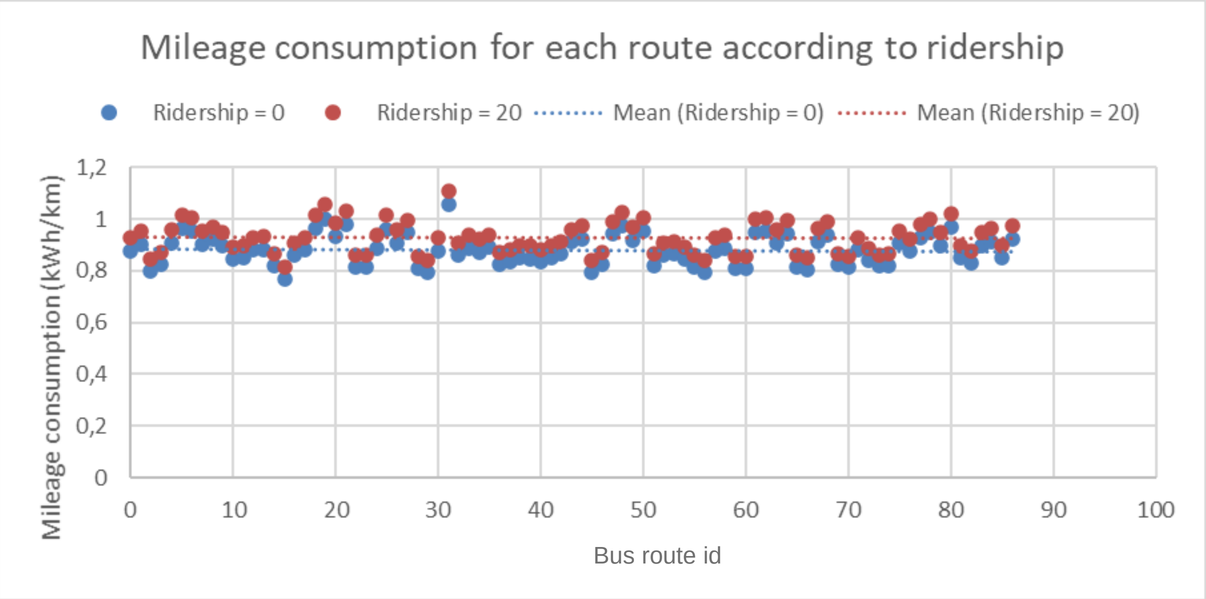


Figure 59. Average mileage consumption per bus route according to ridership

More detailed simulations could be performed at further stage of study (if deemed necessary) with additional input data from DIMTS regarding the bus routes ridership patterns (i.e., estimation of the quantity of passengers between each stop through the various trips of the day).

19.3.2 Air conditioning

According to the theorical model considered in **Volt@bus** (issued from our experience and feedback from bus manufacturers), for an outdoor temperature of 40°C, the air conditioning power must equal 15 kW to ensure that the indoor temperature remains below 30°C (see Figure 60).

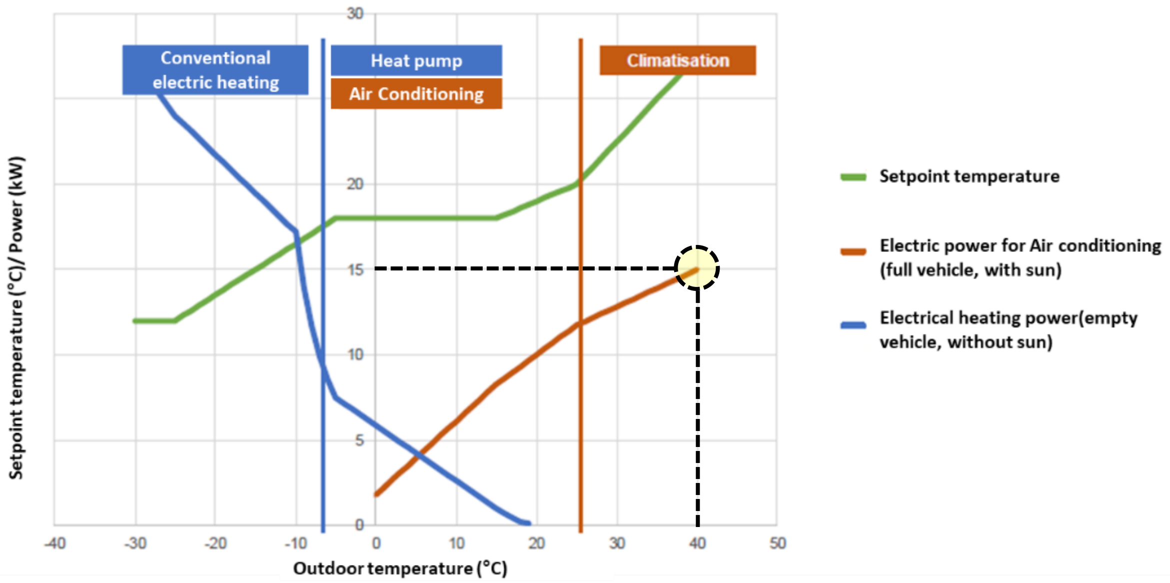


Figure 60. Relation between air conditioning / heating power and outdoor temperature considered in **Volt@bus**

Figure 61 presents the dispersion of average electricity consumption per km resulting from **Volt@bus** simulations (with an air-conditioning system) for the same 45 Nagpur City bus routes. As shown, when considering an air-conditioning system, the mileage average consumption dispersion is rather important (compared to results shown in Figure 53).

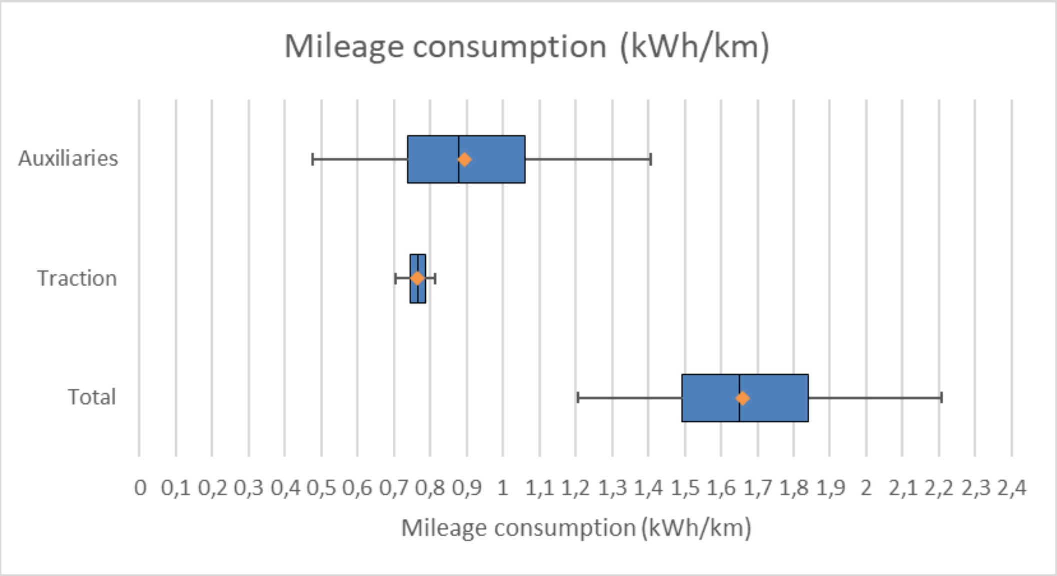


Figure 61. Distribution of mileage consumption on the network (with air-conditioning)

The air-conditioning system consumption alone ranges from 0.5 to 1.4 kWh/km. On the other hand, traction consumption remains constant compared to the scenarios without air-conditioning. As a result, in this case, the auxiliaries represents over 54% of the total energy consumption (see Figure 62).

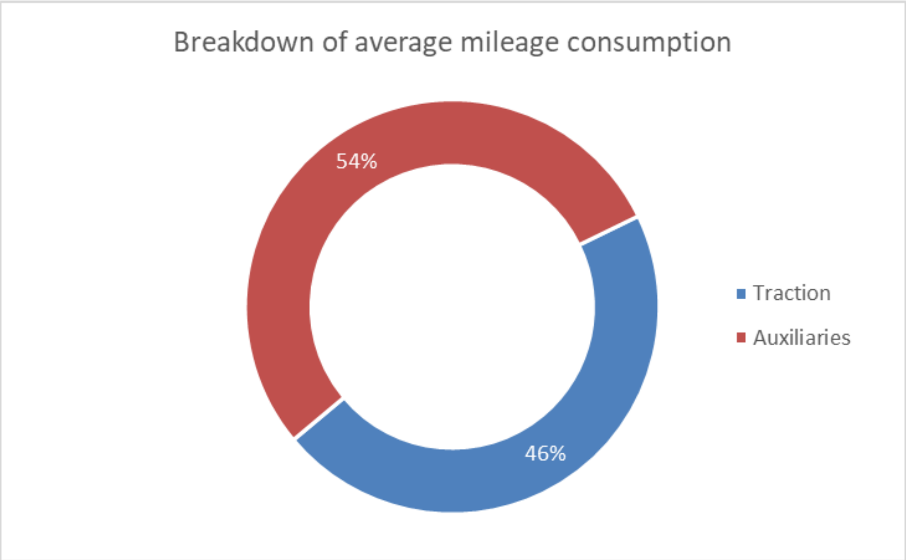


Figure 62. Breakdown of the average mileage consumption (with air-conditioning)

Finally, the graph in Figure 63 shows that resulting **average mileage consumption is estimated to be 70% greater when considering an air-conditioning system** (compared to the base scenario without air-conditioning).

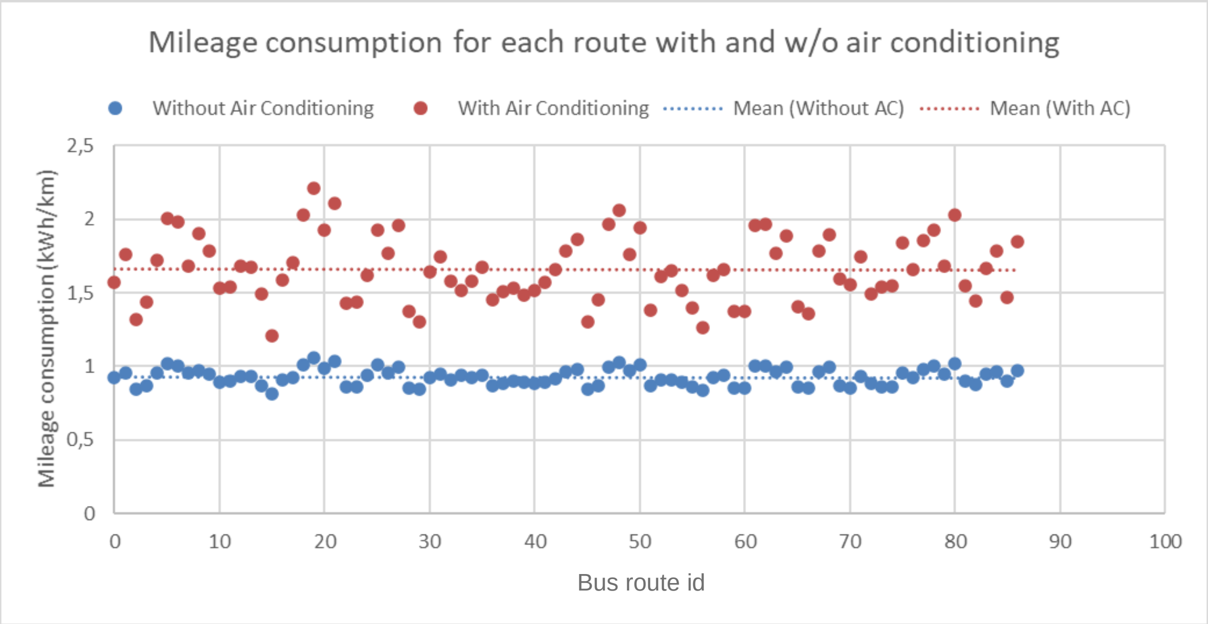


Figure 63. Average mileage consumption per bus route with / without air-conditioning

Important note: the results shown here are to be taken with precaution since they depend largely on the average speed of each vehicle (for which few reliable data was available at the time of the study). For this prefeasibility study, the **Volt@bus** model did not consider real traffic conditions. In order to more accurately estimate the impact of air-conditioning on E-buses energy consumption, more detailed data on the speed profile of vehicles and traffic on each route shall be needed.

20. E-buses depot charging simulation results

For each simulated Nagpur City bus, a mileage consumption has been estimated and an energy consumption profile has been estimated. As explained earlier, these consumption profiles are an input data for depot charging simulations.

Battery capacity is a core element for the conversion of thermal to electric buses. **To minimize impact on operation, batteries with a large capacity should be preferred**. Nonetheless, battery prices are proportional to their capacity, as are the related environmental impacts. Finally, the more important a battery capacity, the higher the related capital expenditure. As of a consequence, the key challenge shall be to **optimize the size of the batteries** between lower capacities (lower CAPEX, lower environmental impacts, higher impacts on O&M) and higher ones (higher CAPEX, higher environmental impacts, lower impacts on O&M).

In the section, three battery capacity scenarios are considered as to assess the impacts on buses operation and depot charging:

- 400 kWh batteries, as initially recommended by SETEC-NODALIS,
- 350 kWh batteries, and
- 300 kWh batteries.

Terminology definition

The terminology used in this chapter is as follows (see also Figure 64):

- Entrance: Bus route from a terminus to its depot,
- Exit: Bus route from depot to a terminus,
- Trip: Bus route from a terminus to another (revenue service or deadhead),
- Tour: Bus route consisting of a sequence of trips that start with an exit (from a bus depot) and ends with an entrance (at a bus depot),
- Task: Sequence of tours assigned to a single bus for a day (daily service schedule).

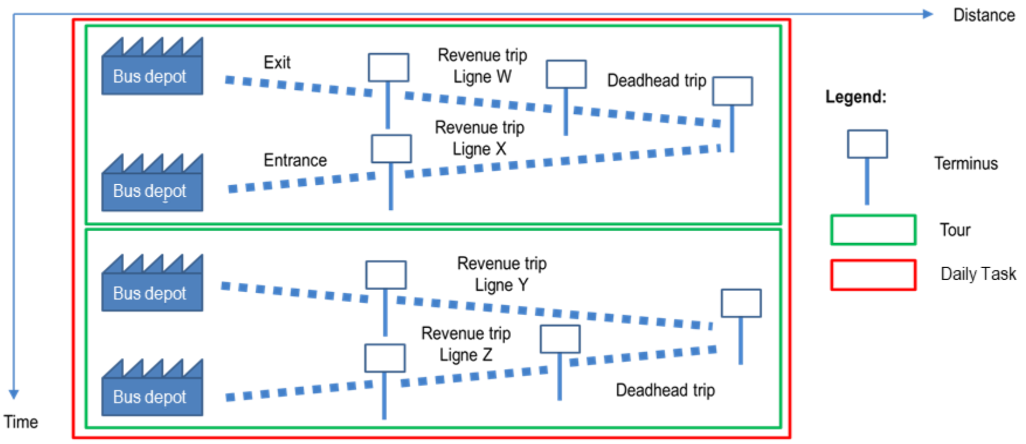


Figure 64. Definition of the terminology used in this report

We understand from the service planning data that daily tasks are either composed of a morning tour and an evening tour without going back to the depot, or a single tour during the day.

In any case, and so as not to impact existing operation conditions with the transition to E-buses, we considered that there shall be no opportunity to charge buses between trips. As such, **each bus shall leave its depot with sufficient (battery) energy to perform its complete daily task**.

For diesel buses, this usually does not represent an operational issue (even if buses are only fuelled up at the depot). On the contrary, for electric buses (with the current technologies and capacities), depending on the maximum energy that can be stored in a battery and the average mileage consumption, this constraint can lead to certain impacts on bus operation (split of a task in two or more, i.e., additional buses may be necessary to complete the task as scheduled). This issue is detailed hereafter.

20.1 Scenario “400 kWh batteries”

When considered battery capacities of 400 kWh for all Nagpur City E-buses (for the 45 simulated bus routes), all tasks whose consumption does not exceed the useful capacity can be performed. Figure 65 presents the energy consumption of each scheduled task.

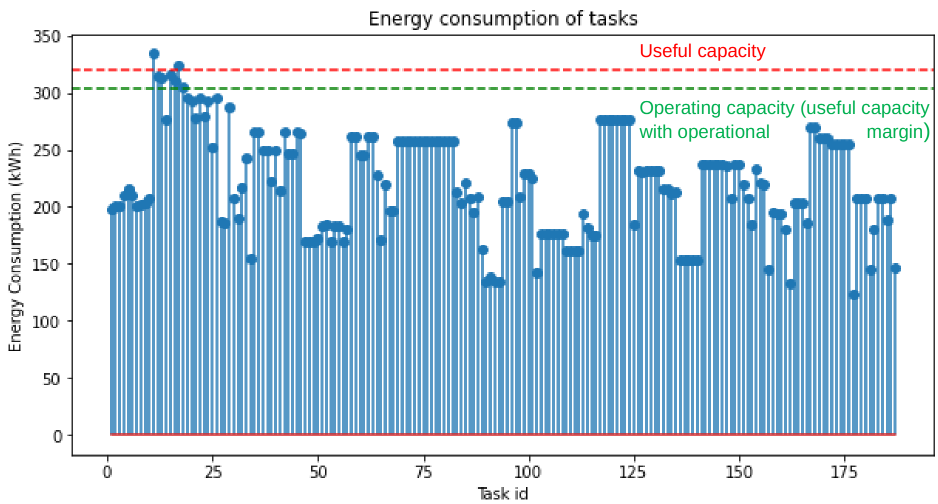


Figure 65. Energy consumption of each scheduled daily task (400 kWh scenario)

It is noted that 7 daily tasks shall require more energy than the batteries operating capacity (= useful capacity - operational margin), including 2 tasks that would need more than the total battery capacity (400 kWh).

As such, these seven tasks must be split and assigned to other vehicles (i.e., another bus takes over from a bus that is running out of energy to finish an overconsuming task).

In order to achieve this, the specific vehicle (running out of energy) shall return to the depot at the end of its morning tour. For this, a trip (between the last stop of the morning tour and the depot) is added to this first bus daily service schedule,

Another bus (with sufficient battery charge) takes over from the first one to carry out the evening tour. A trip (between the bus depot and the first stop of the evening tour) is thus added to this second bus daily service schedule.

20.1.1 Impacts on bus fleet

The resulting daily service schedule for each bus depot is shown in Figure 66 (Khapri Naka), Figure 67 (Higna Naka) and Figure 68 (Patwardhan 2). Each graph represents the number of buses operating simultaneously during the day. The maximum number on each graph (maximum theoretical buses operating simultaneously) correspond to the minimum number of required buses to perform the daily service schedule. In each graph, the **grey curve** represents the "initial schedule" (the theoretical number of required buses), and the **blue curve** represents the "final schedule" (the actual required number of buses).

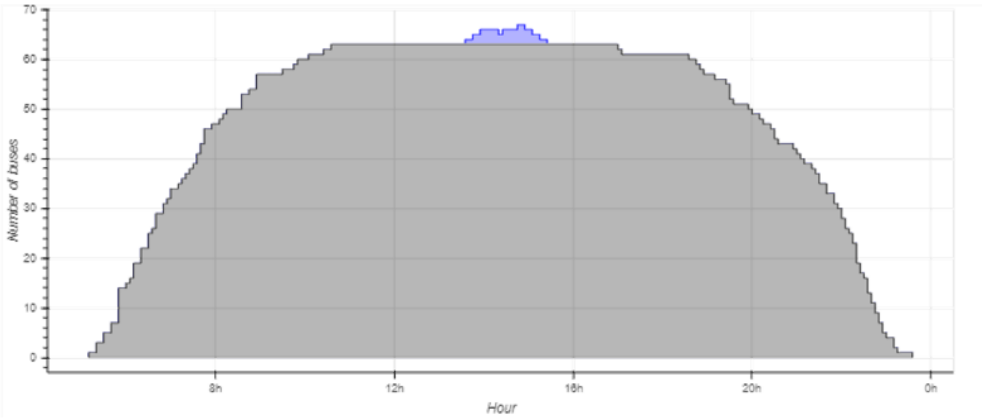


Figure 66. Number of buses simultaneously in operation - Khapri Naka depot (400 kWh scenario)

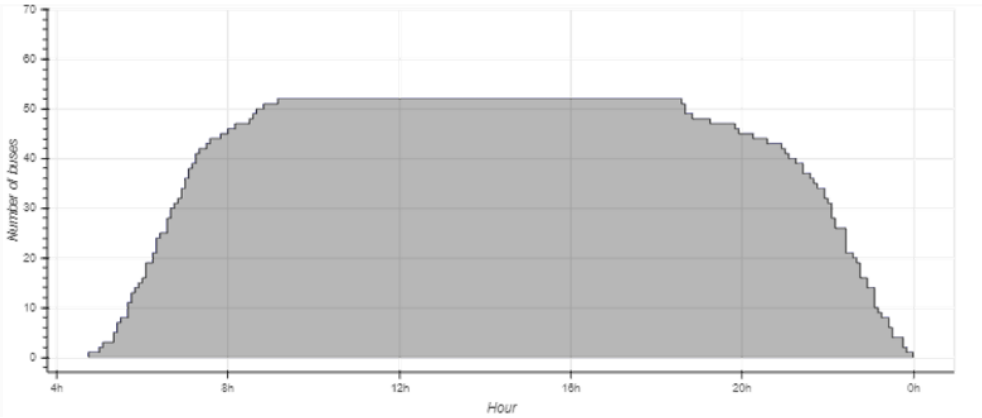


Figure 67. Number of buses simultaneously in operation - Higna Naka depot (400 kWh scenario)

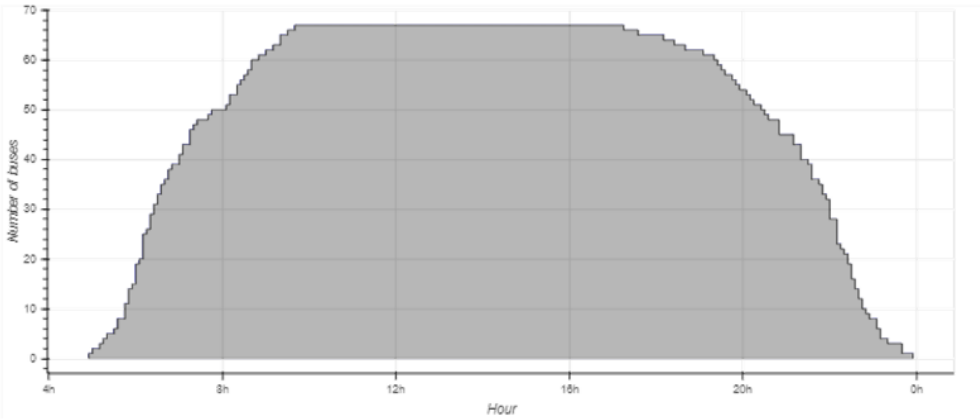


Figure 68. Number of buses simultaneously in operation - Patwardhan 2 depot (400 kWh scenario)

We notice that, when considering the battery capacity limitation of 400 kWh, the service schedule for buses at Higna Naka and Patwardhan 2 depots remain unchanged. The battery capacity shall be sufficient to carry out all the scheduled tasks without modification. On the other hand, the theoretical planning for Khapri Naka depot requires at least 4 additional buses in order to be viable (i.e., at least 4 buses will not be able to complete their daily task, those tasks needing to be split and additional being buses required). This information is summarized in Table 46 hereafter.

Table 46. Minimum required number of vehicles for each bus depot (400 kWh scenario)

Bus depot	Khapri Naka	Higna Naka	Patwardhan 2
Theoretical number of buses	63	67	52
Number of buses operating simultaneously (result from simulations)	67	67	52
Minimum number of buses required (see ***note*** below)	67	67	52

Note: the actual total number of buses required is not systematically equal to the number of buses operating simultaneously. Indeed, depending on the service schedule, some buses must go on a new tour after a previous one (i.e., the bus goes back to the depot at the end of a first tour, but is needed later for a new tour). If the layover time between these tours is sufficient to restore enough energy to the battery (i.e., sufficiently for the next complete tour), the bus can leave the depot. Otherwise, another bus (sufficiently charged for the tour) must be deployed, increasing the total number of buses required by one unit (since all other vehicles are already in operation).

In the 400 kWh scenario, the charging simulations demonstrate that the total number of buses required is equal to the number of buses operating simultaneously (no additional bus required).

The increase on the number of required buses (compared to the theoretical number) leads to a slight increase of the mileage due to deadhead trips between the depot and a terminal (and vice versa). The resulting mileage for each depot, considering the data presented above, is shown in Table 47.

Table 47. Additional mileage due to deadhead (400 kWh scenario)

Bus depot	Khapri Naka	Higna Naka	Patwardhan 2
Initial mileage (km)	15,317.6	14,870.3	13,909.5
Additional mileage (km)	138.6	0	0
Proportion	0.9%	0%	0%
Final mileage (km)	15,456.2	14,870.3	13,909.5

Since the only modified planning is that of Khapri Naka depot, the additional 139 kilometres shall be covered by buses parked in this depot. Note that this only represents less than 1% of the total mileage, thus impacting very little bus operation and maintenance.

20.1.2 Impacts on depot charging activities

Depot charging activities for a typical day are illustrated in the following chapters. In each graph (Figure 69, Figure 71, and Figure 73), vehicles are represented by horizontal bars. The colour code indicates whether a vehicle is:

- In operation / Waiting for or under cleaning/maintenance (**grey bars**),
- At depot and charging (**green bars**),
- At depot or terminus and idle: not in operation and not under cleaning, maintenance, or charging activities (**blank spaces**).
- Fully charged when a **blank space** follows a charging activity,
- Partially charged (< 100% state of charge) when an operating activity (**grey bar**) directly follows a charging activity (**green bar**).

As explained earlier, the charging principle is based on a "first in = first out" practice. It should also be noted that two charging options are considered:

- **Normal charging (without peak power smoothing):** buses are charged as soon as they enter the depot (after required preliminary maintenance activities) or as soon as a charger is available. This option often results in a larger simultaneous charging rate (and thus more important peak required power).
- **Optimized charging (with peak power smoothing):** not all buses are charged when they enter the depot (after required preliminary maintenance activities) or as soon as a charger is available. Some vehicles (even if connected to the charging equipment) shall only begin charging when another bus finishes charging, provided the total power required does not exceed a set limit (thus limiting peak required power). Requirements for “optimized charging” are further presented in chapter 21.

20.1.2.1 Khapri Naka depot

Figure 69 illustrates the charging activities for the Khapri Naka depot. The graphs on the left show the operating and charge cycles for each of the 67 buses. The graphs on the right illustrate the charging activities of each charger. One green rectangle corresponds to the charging of one vehicle.

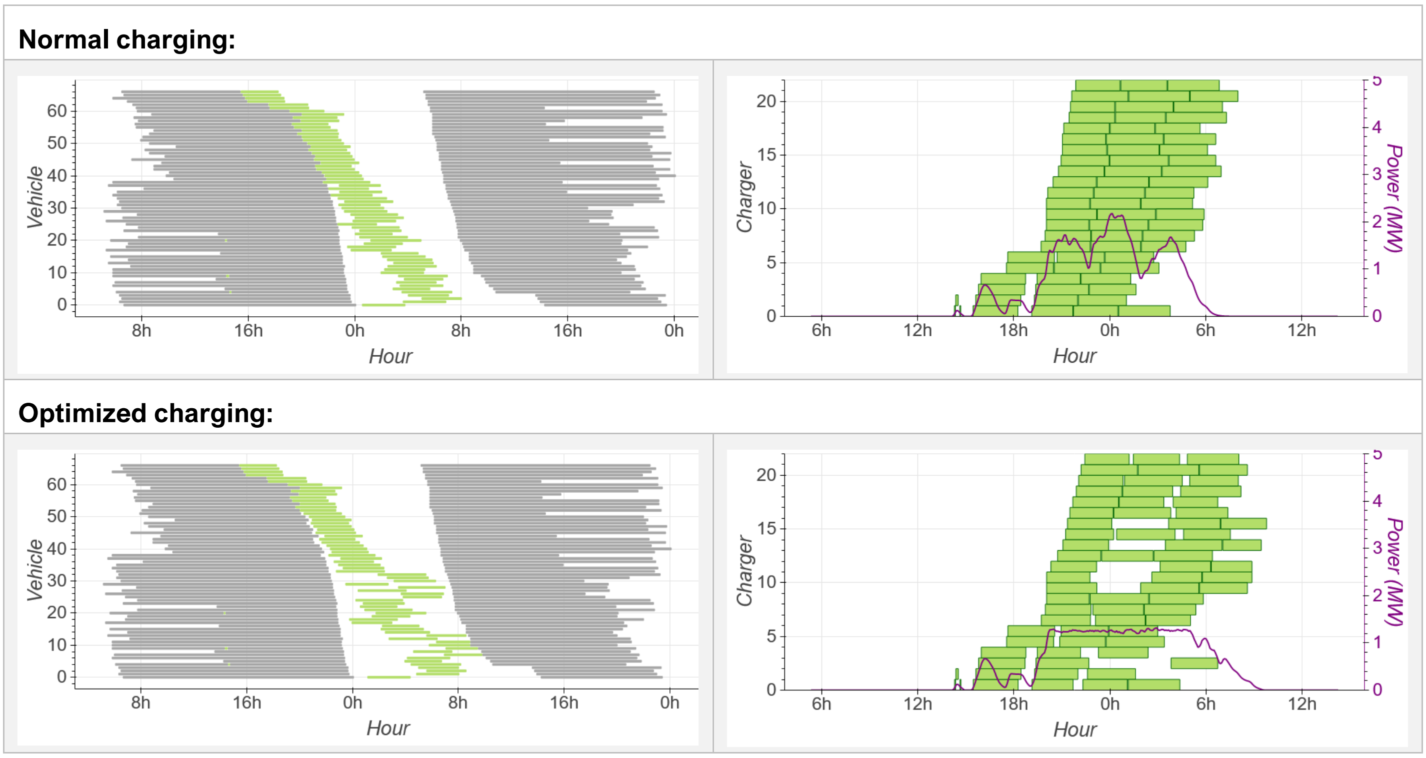


Figure 69. Charging activities per vehicle (left) and per charger (right) - Khapri Naka depot (400 kWh scenario)

From Figure 69, it can be noted that, even under “normal charging” conditions, the required power curve is relatively smooth due to the limited number of available chargers at the Khapri Naka depot. Indeed, it is considered that there is one charger for each 3 vehicles. As such, many vehicles cannot be charged as soon as they enter the depot area. Besides, the power drawn from the depot cannot exceed the maximum of “Number of chargers ***x*** Maximum charging power”.

When charging is optimized by delaying the charge of some buses, power peaks between 10 P.M. and 6 A.M. are distributed over a larger time range.

“Optimized charging” reduces the maximum required power from 2.3 MW to 1.4 MW. Consequentially, the loading factor is improved from 0.28 in “normal charging” to 0.47 with “optimized charging” (i.e., an improvement of 60%).

The higher the loading factor, the better the system is used. For instance, with a 50% loading factor, the installation operates, on average, at half the power it was designed for [17].

Some buses need to return to the depot during the day since they are not able to carry out both morning and evening tours due to a lack of battery energy. For this reason, there is limited use of the charging infrastructure during the afternoon. Some buses do not leave the depot area after their morning tour, other buses taking over. As seen on the left graphs in Figure 69, while some buses start their daily task at around 2 P.M., approximately the same number of buses end their daily task at around 3 P.M.

Furthermore, the depot charging simulation results show that there is enough time between the end of overnight charging activities and the first daily tasks on the following morning. This gives a good flexibility to the charging system, especially in case of temporary charging system failure. In "normal charging", 3 hours or less of downtime would not have any significant impact on the operation of the next day. For some vehicles, this flexibility range can reach over 12 hours.

Figure 70 hereafter illustrates the state of charge (remaining battery energy) of a vehicle performing the 107/02 task. With "optimized charging", even if the start of the charge is delayed by a few hours, the vehicle is fully charged on the following morning.

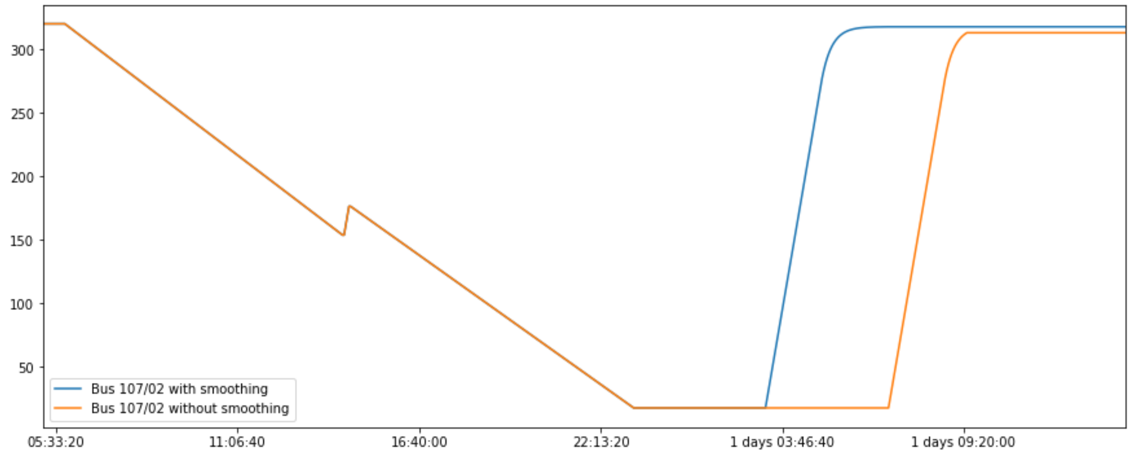


Figure 70. State of charge - Khapri Naka depot - Example for task n° 107/02 (400 kWh scenario)

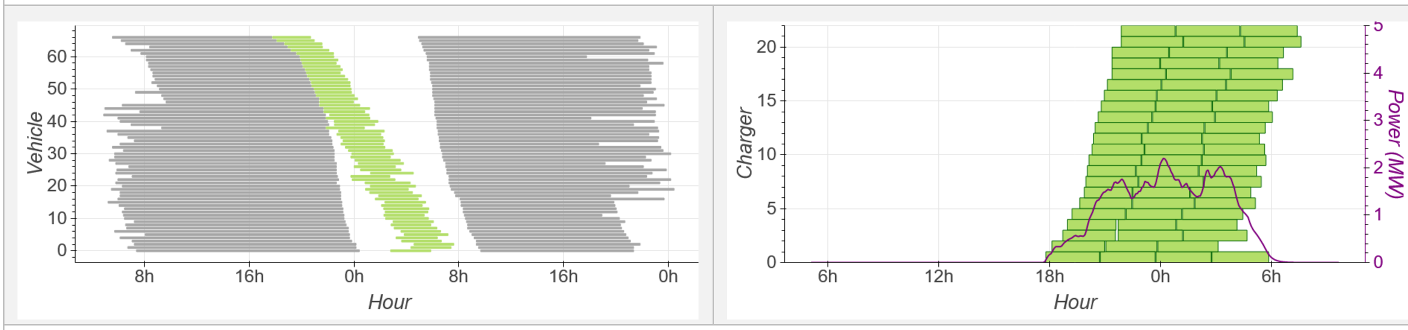
[17] The "loading factor" represents the ratio of the electrical energy really consumed over a given period (typically a day in this case) to the energy it would have consumed if it had been operating at its rated power (estimations from manufacturer) during the same period, i.e.:

$$\text{Loading factor} = \frac{\text{Energy consumed over the day}}{\text{Maximum power of the depot * 24 hours}}$$

20.1.2.2 Higna Naka depot

The following figures show the charging activities for the Higna Naka depot for each of the 67 buses.

Normal charging:



Optimized charging:

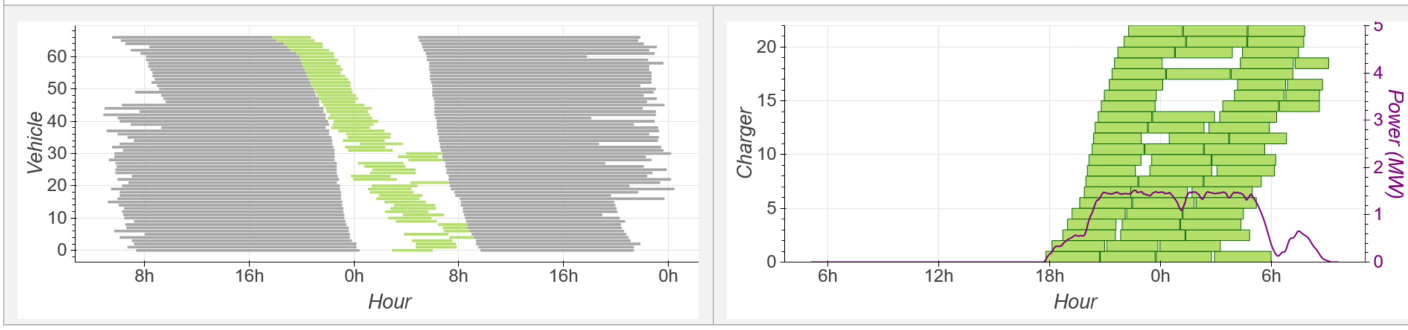


Figure 71. Charging activities per vehicle (left) and per charger (right) - Higna Naka depot (400 kWh scenario)

From Figure 71, it can be noted that, even under “normal charging” conditions, the required power curve is relatively smooth due to the limited number of available chargers at the Higna Naka depot.

When charging is optimized by delaying the charge of some buses, power peaks between 10 P.M. and 6 A.M. are distributed over a larger time range.

“Optimized charging” reduces the maximum required power from 2.3 MW to 1.6 MW. Consequentially, the loading factor is improved from 0.28 in “normal charging” to 0.41 with “optimized charging” (i.e., an improvement of 45%).

Furthermore, the depot charging simulation results show that there is enough time between the end of overnight charging activities and the first daily tasks on the following morning. This gives a good flexibility to the charging system, especially in case of temporary charging system failure. In “normal charging”, 2 hours or less of downtime would not have any significant impact on the operation of the next day. On the contrary, with “optimized charging”, some buses can still be in charge when their task starts in the morning (thus starting the task with partial charge).

Figure 72 hereafter illustrates the state of charge (remaining battery energy) of a vehicle performing the 106/08 task. With “optimized charging”, even if the start of the charge is delayed by a few hours, the vehicle is fully charged on the following morning.

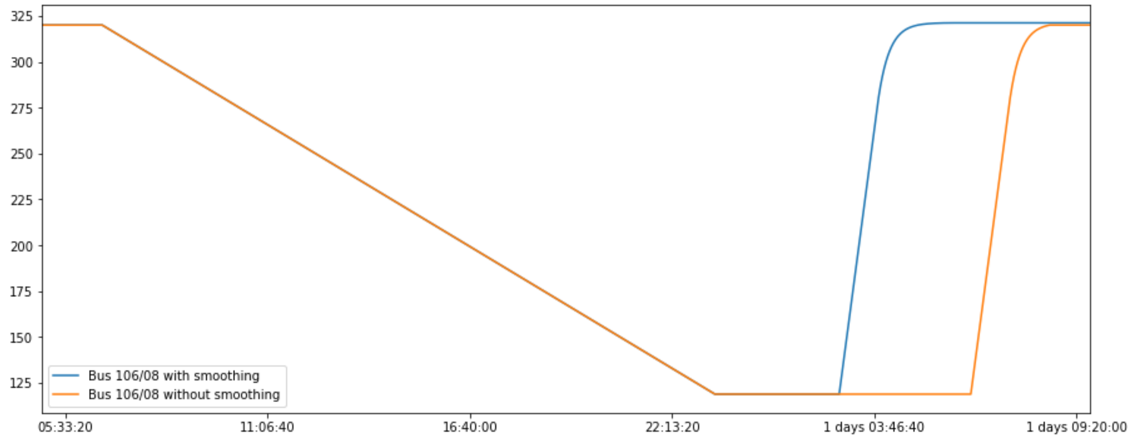


Figure 72. State of charge - Higna Naka depot - Example for task n° 106/08 (400 kWh scenario)

20.1.2.3 Patwardhan 2 depot

The following figures depict the charging activities for the Patwardhan 2 depot for each of the 52 buses.

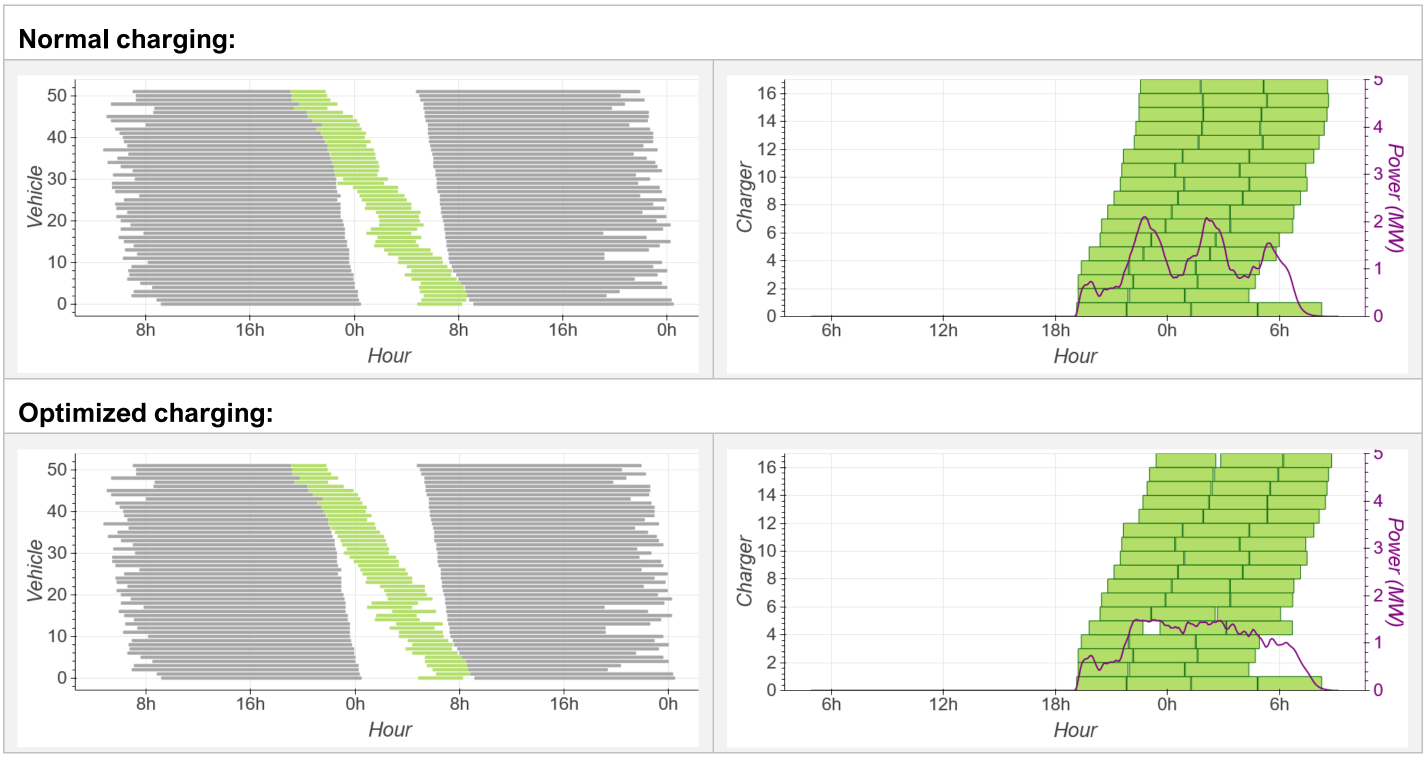


Figure 73. Charging activities per vehicle (left) and per charger (right) - Patwardhan 2 depot (400 kWh scenario)

From Figure 73, it can be noted that, even under "normal charging" conditions, the required power curve is relatively smooth due to the limited number of available chargers at the Patwardhan 2 depot.

When charging is optimized by delaying the charge of some buses, power peaks between 10 P.M. and 6 A.M. are distributed over a larger time range.

"Optimized charging" reduces the maximum required power from 2.2 MW to 1.6 MW. Consequentially, the loading factor is improved from 0.26 in "normal charging" to 0.37 with "optimized charging" (i.e., an improvement of 40%).

Furthermore, the depot charging simulation results show that for some buses, there is not enough time between the end of overnight charging activities and the first daily tasks on the following morning. In addition, it is noted that no bus can be charged during the afternoon since none of them goes back to the depot.

Figure 74 hereafter illustrates the state of charge (remaining battery energy) of a vehicle performing the 26/10 task. In this case, "optimized charging" does not delay the start of the charge.

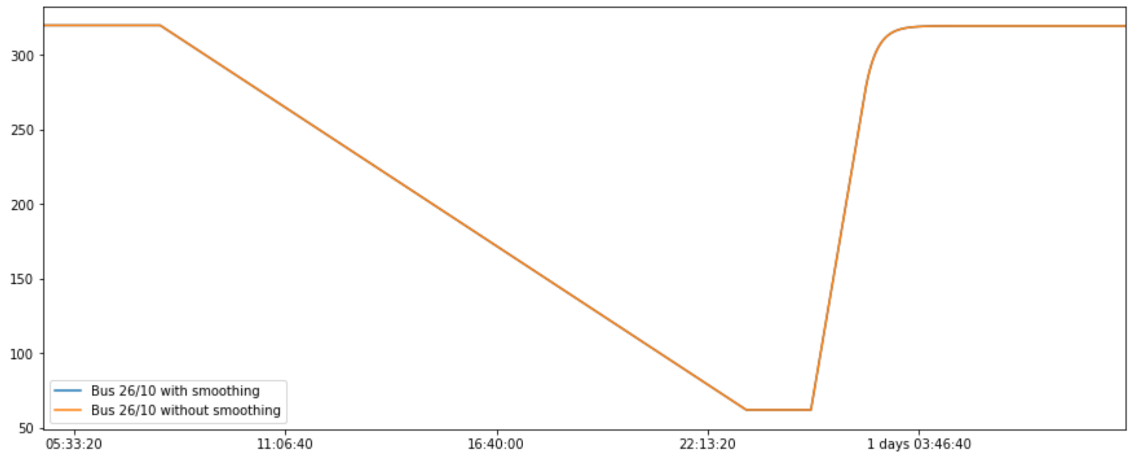


Figure 74. State of charge - Patwardhan 2 depot - Example for task n° 26/10 (400 kWh scenario)

20.1.2.4 Depot charging data summary

Table 48 summarizes the results of the depot charging simulations for each depot.

Table 48. Depot charging data summary (400 kWh scenario)

Bud depot	Number of vehicles	Number of chargers	Mileage (km/day)	Energy (kWh/day)	Charging option	Loading factor	Maximum power (kW)
Khapri Naka	67	22	15,456	15,588	normal	0.28	2,318
					optimized	0.47	1,381
Higna Naka	67	22	14,870	15,536	normal	0.28	2,291
					optimized	0.41	1,594
Patwardhan 2	52	17	13,910	13,778	normal	0.26	2,182
					optimized	0.37	1,572

Note: the average mileage consumption presented in this table is greater than the one presented earlier since here it considers a charger efficiency of 90%.

20.1.3 Depot charging flexibility

When operating electric buses, it is important to consider the charging flexibility. For this, three indicators are considered:

- **The state of charge (i.e., the remaining battery charge) at the beginning of the following day:** If every bus begins its duty with approximately 100% of charge, it guarantees the continuity of the operation from one day to the other,
- **The state of charge on return to the depot:** It quantifies the operation margin of buses at the end of their duty. A small margin can be risky if the bus encounters an unexpected situation on its way back to the depot area.
- **The time reserve between the end of charging and the start of the task**: It allows to evaluate the margin related to the charging activity.

20.1.3.1 State of charge at the beginning of the following day

Table 49 summarises the state of charge of the buses at the beginning of the following day, considering “normal charging” and “optimized charging” options.

Table 49. State of charge at the beginning of the following day (400 kWh scenario)

Bus depot	Khapri Naka		Higna Naka		Patwardhan 2	
Charging option	Normal	Optimized	Normal	Optimized	Normal	Optimized
Average	320	319,9	320	319,7	320,0	319,9
Minimum	320	315,3	320	311,9	319,8	318,9
Top 75%	320	320	320	320	320	320
Median	320	320	320	320	320	320
Maximum	320	320	320	320	320	320

On average, buses have at least 99.9% of their maximum capacity when they start their first run in the morning. In “normal charging”, all the buses have more than 99.9%. When considering “optimized charging”, the minimum state of charge is equal to 97.5% for Higna Naka depot, which is very close to 100% and thus considered acceptable. Finally, regardless of the chosen depot charging strategy (normal / optimized), at least 75% of the buses carry out their first tour the following day with a 100% state of charge (see Figure 75). These values confirm the operability of the buses from one day to the other.

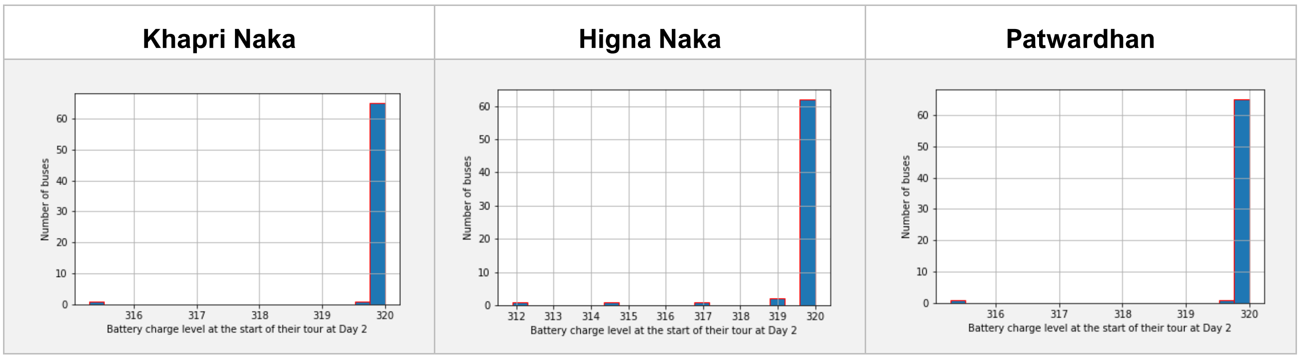


Figure 75. State of charge of each bus at the start of the next day of operation (400 kWh scenario)

20.1.3.2 State of charge on return to the depot

Table 50 summarises the state of charge of the buses when they return to the depot, considering both “normal” and “optimized” charging strategy.

Table 50. State of charge on return to the depot (400 kWh scenario)

Bus depot	Khapri Naka		Higna Naka		Patwardhan 2	
Charging option	Normal	Optimized	Normal	Optimized	Normal	Optimized
Average	36.0%	36.0%	34.8%	34.7%	25.5%	25.5%
Minimum	1.7% *	1.7% *	15.8%	15.8%	13.7%	13.7%
Median	39.2%	39.2%	35.2%	35.2%	19.4%	19.4%
Maximum	58.4%	58.4%	58.2%	58.2%	61.3%	61.3%

* A 5% minimum is generally recommended. However, in order to limit the number of additional vehicles, some buses are allowed to return to the depot with less than 5%. In **Volt@bus** simulations this is not a necessary condition as it is assumed that the daily service schedule can be reworked (with minor adjustments) to reallocate the tour.

On average, buses return to their depot with approximately 30% of their maximum battery (operational) capacity. This significant margin makes it possible to overcome unforeseen events (heavy congestion, traffic accidents, driving incidents, unscheduled additional trips…) without difficulty. For example, if a bus breaks down, one of the buses can possibly replace it at the end of its service.

The minimum state of charge for both Higna Naka and Patawardhan depots is largely acceptable. However, as seen in Table 50 and in Figure 76, for Khapri Naka, two buses would enter the depot with a remaining state of charge lower than 5%, which is a low margin leaving no room for unforeseen events. For these two duties, it is recommended to explore in detail the possibilities that could help overcome this problem (such as shortening the last trips at the end of service and/or assigning them other vehicles).

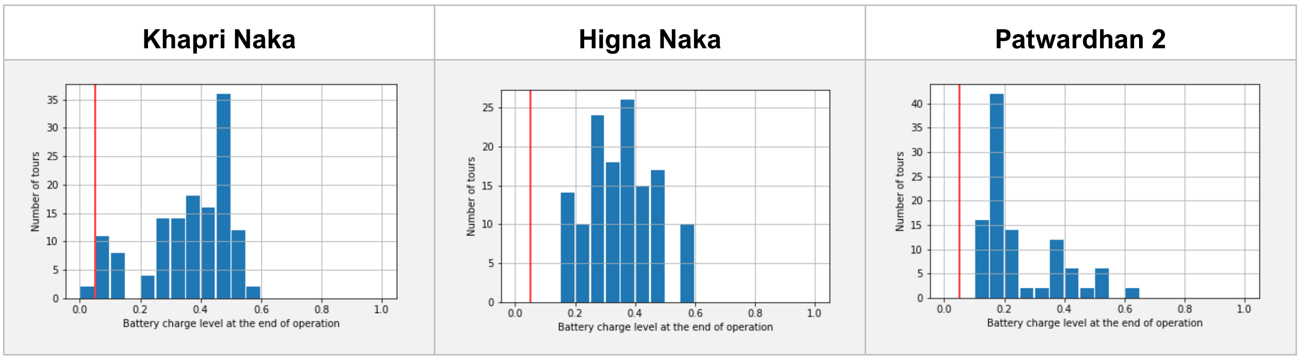


Figure 76. State of charge of each bus on return to the depot (400 kWh scenario)

20.1.3.3 Time reserve between end of charging and start of task

Table 51 allows to quantify the time reserve between the disconnection of buses and their departure for a task. If the reserve time is equal to 3 minutes, it corresponds to the buffer time needed for the bus to be disconnected and to leave the depot area. This means that the bus was still charging when it was disconnected, thus departing with partial charge (< 100% state of charge). When the time reserve exceeds this minimum, it means that the bus is fully charged when it starts its next task.

Table 51. Time reserve between end of charging and start of task (400 kWh scenario)

Bus depot	Khapri Naka		Higna Naka		Patwardhan 2	
Charging option	Normal	Optimized	Normal	Optimized	Normal	Optimized
Average	05:34	04:44	04:33	04:01	03:05	02:57
Minimum	00:03	00:03	01:43	00:03	00:03	00:03
Top 75%	04:00	02:34	02:57	02:23	01:19	00:53
Median	05:36	04:53	04:13	04:00	02:42	02:42
Maximum	10:54	10:54	08:13	08:13	07:26	07:26

"Optimized charging" options tend to decrease the time reserve of vehicles as the charging activity is widened over a longer span of time. Depending on the depot, some buses may need to start their task whereas they are still connected to a charger (i.e., they shall be promptly disconnected and put in operation = 3-minute buffer). For these vehicles, there is no time reserve at all. Nonetheless, at least for 75% of the buses, there is a time margin of approximately one hour or more. In addition, 50% of the tasks start over two hours and a half later the end of the bus charging. The results show that the time reserve is acceptable and allows flexibility for all three simulated depots.

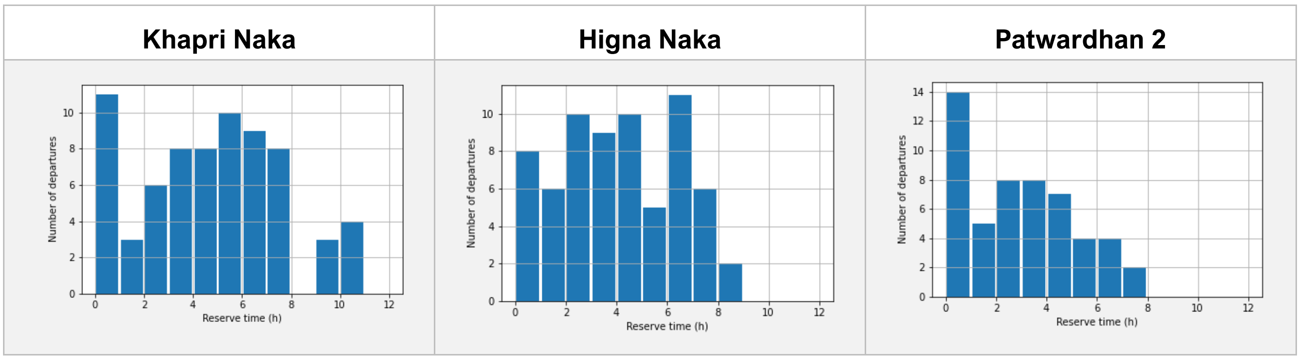


Figure 77. Time reserve between the end of charging and the departure of each bus (400 kWh scenario)

20.2 Scenario "350 kWh batteries"

Figure 78 presents the energy consumption of each scheduled task.

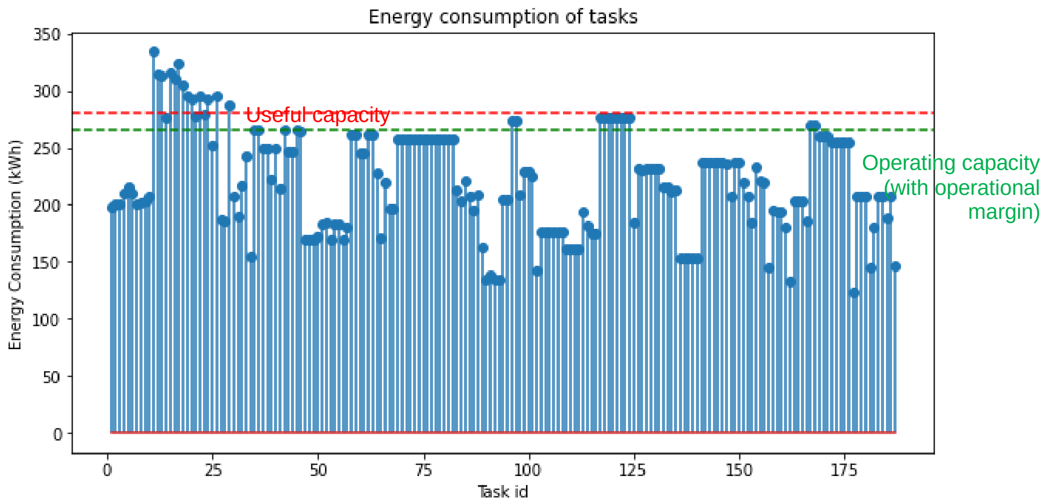


Figure 78. Energy consumption of each daily task (350 kWh scenario)

It is noted that 28 daily tasks shall require more energy that the batteries operating capacity, including 13 tasks that would need more than the total battery capacity (350 kWh).

As such, these 28 tasks must be split and assigned to other vehicles (i.e., another bus takes over from a bus that is running out of energy to finish an overconsuming task).

20.2.1 Impacts on bus fleet

The resulting daily service schedule for each bus depot is shown in Figure 79 (Khapri Naka), Figure 80 (Higna Naka) and Figure 81 (Patwardhan 2).

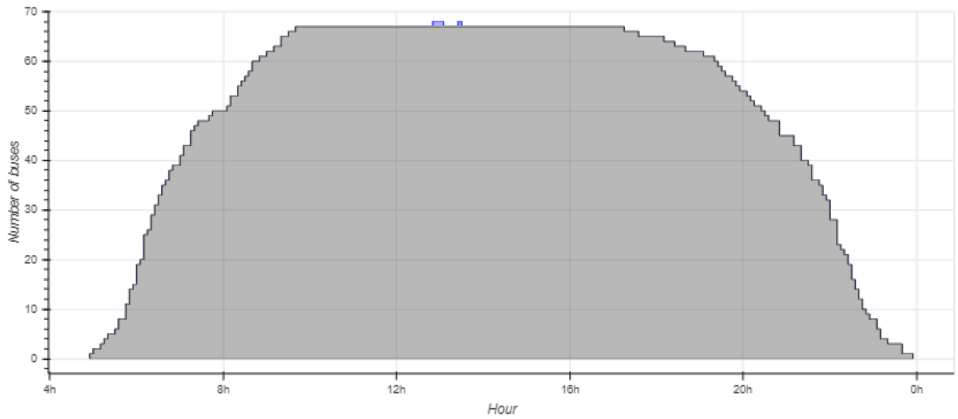


Figure 79. Number of buses simultaneously in operation - Khapri Naka depot (350 kWh scenario)

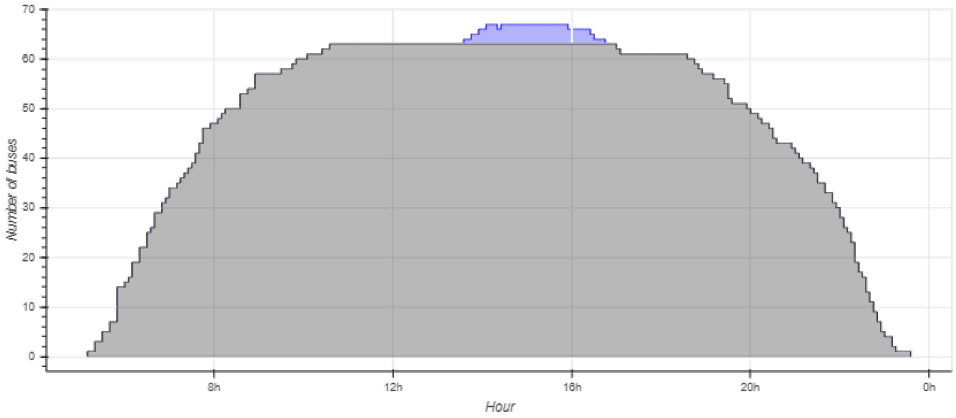


Figure 80. Number of buses simultaneously in operation - Higna Naka depot (350 kWh scenario)

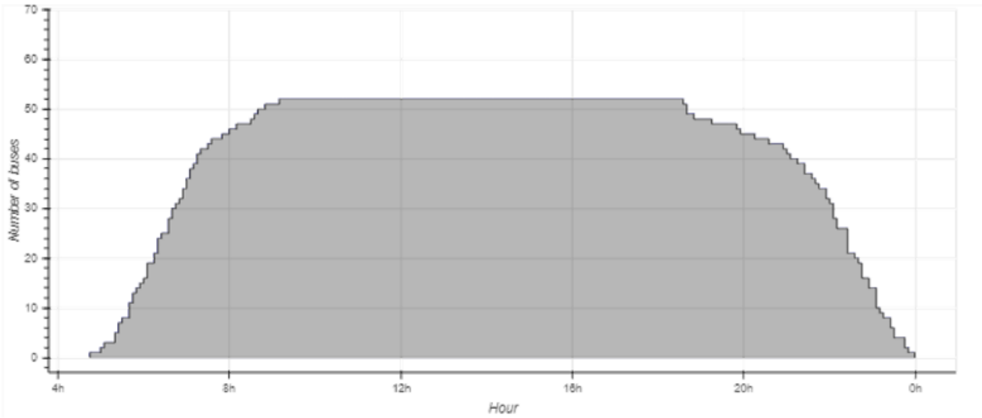


Figure 81. Number of buses simultaneously in operation - Patwhardhan 2 depot (350 kWh scenario)

We notice that, when considering the battery capacity limitation of 350 kWh, the service schedule for buses at all three depots may be modified. The theoretical planning for both Khapri Naka and Higna Naka depots require additional buses in order to be viable. For Patwardhan depot, this is not the case. This information is summarized in Table 51 hereafter.

Table 52. Minimum required number of vehicles for each bus depot (350 kWh scenario)

Bus depot	Khapri Naka	Higna Naka	Patwardhan 2
Theoretical number of buses	63	67	52
Number of buses operating simultaneously (result from simulations)	67	68	52
Minimum number of buses required (see ***note*** in page 203)	70	68	53

In the 350 kWh scenario (and opposite to the 400 kWh scenario), the charging simulations demonstrate that the total number of buses required is superior to the number of buses operating simultaneously (additional buses are required due to split tours).

The total increase on the number of required buses (compared to the theoretical number) leads to an increase of the mileage due to deadhead trips between the depot and a terminal (and vice versa). The resulting mileage for each depot, considering the data presented above, is shown in Table 53.

Table 53. Additional mileage due to deadhead (350 kWh scenario)

Bus depot	Khapri Naka	Higna Naka	Patwardhan 2
Initial mileage (km)	15,317.6	14,870.3	13,909.5
Additional mileage (km)	319.8	33.0	16.0
Proportion	2.1%	0.2%	0.1%
Final mileage (km)	15,637.4	14,903.3	13,925.5

For Khapri Naka depot, the additional 320 kilometres shall be covered by buses parked in this depot, representing around 2% of additional mileage. For Patwardhan and Higha Naka, the additional mileage is very marginal and lower than 0.2%, thus not impacting bus operation and maintenance.

20.2.2 Impacts on depot charging activities for a typical day

20.2.2.1 Khapri Naka depot

Figure 82 illustrates the charging activities for the Khapri Naka depot for each of the 70 buses.

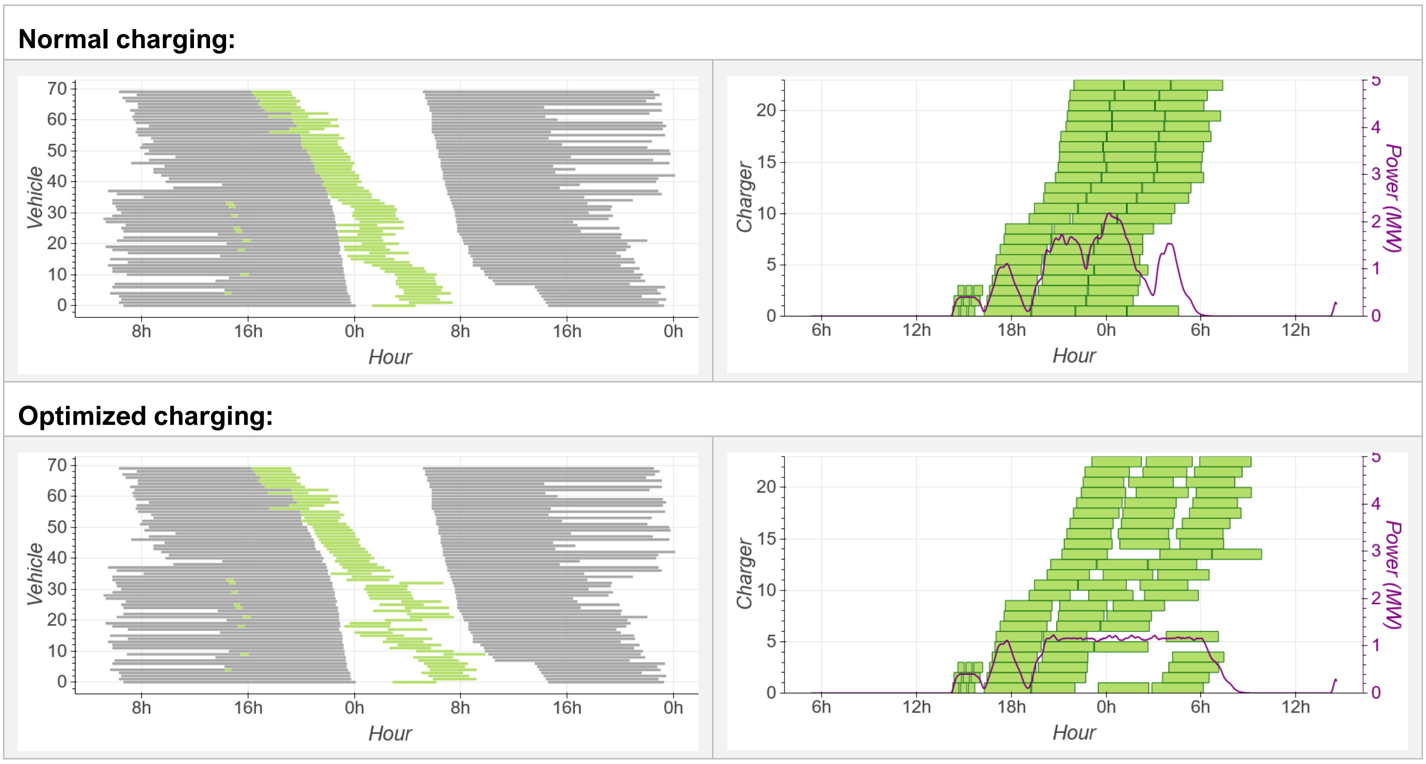


Figure 82. Charging activities per vehicle (left) and per charger (right) - Khapri Naka depot (350 kWh scenario)

From Figure 82, it can be noted that, even under “normal charging” conditions, the required power curve is relatively smooth due to the limited number of available chargers at the Khapri Naka depot.

When charging is optimized by delaying the charge of some buses, power peaks between 10 P.M. and 6 A.M. are distributed over a larger time range.

“Optimized charging” reduces the maximum required power from 2.3 MW to 1.3 MW. Consequentially, the loading factor is improved from 0.28 in “normal charging” to 0.52 with “optimized charging” (i.e., an improvement of 85%).

Furthermore, the depot charging simulation results show that there is enough time between the end of overnight charging activities and the first daily tasks on the following morning. In “normal charging”, 3 hours or less of downtime would not have any significant impact on the operation of the next day. For some vehicles, this flexibility range can reach over 12 hours.

Figure 83 hereafter illustrates the state of charge of a vehicle performing the 107/02 task. With “optimized charging”, even if the start of the charge is delayed by a few minutes, the vehicle is fully charged at the end of the night.

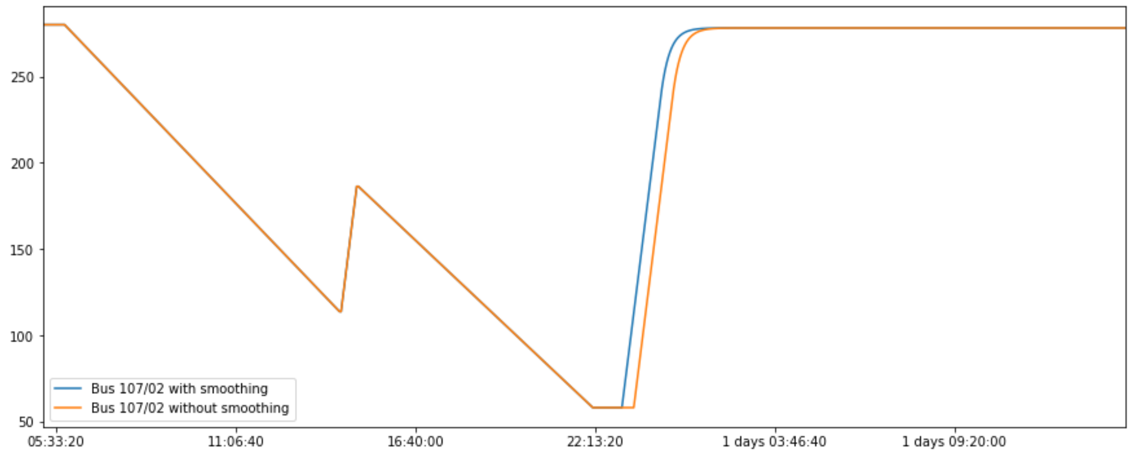


Figure 83. State of charge - Khapri Naka depot - Example for task n° 107/02 (350 kWh scenario)

20.2.2.2 Higna Naka depot

The following figures show the charging activities for the Higna Naka depot for each of the 68 buses.

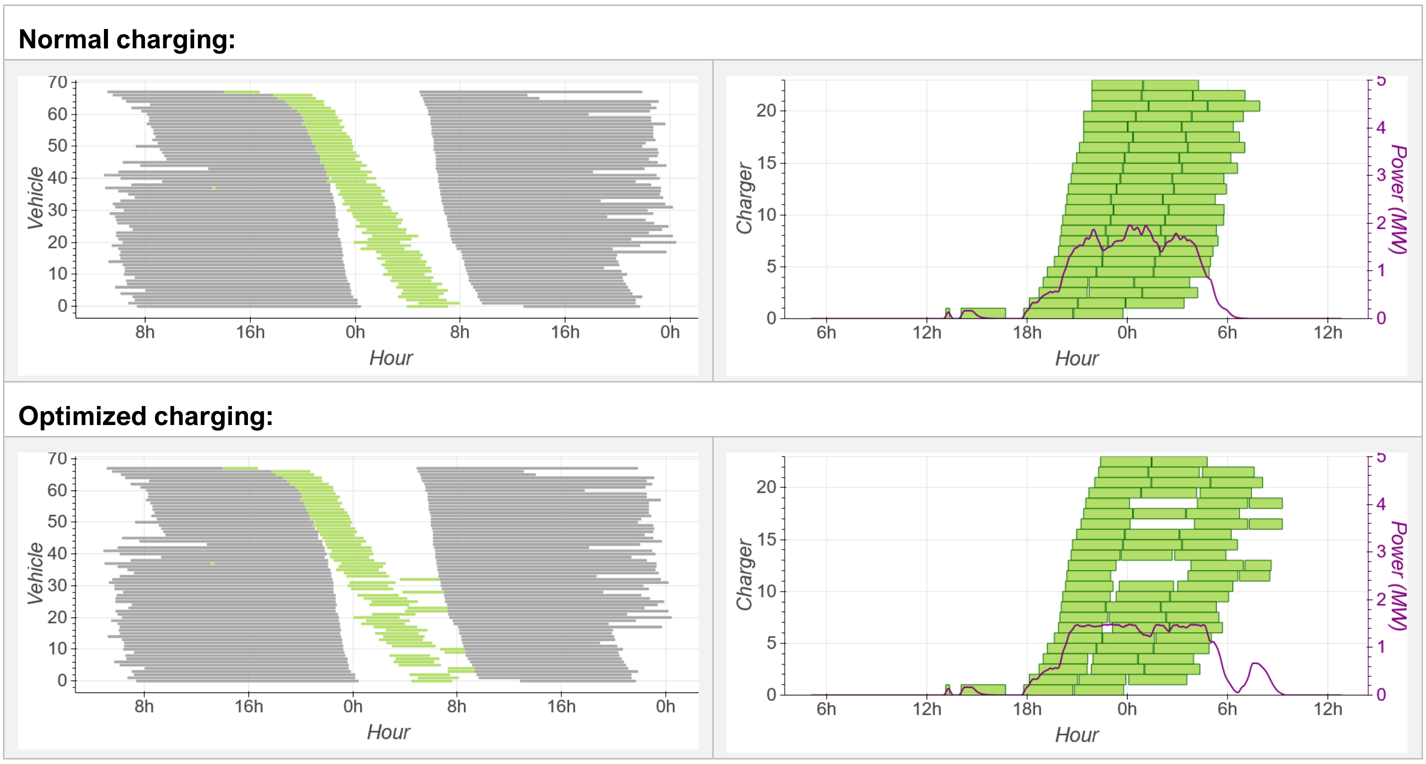


Figure 84. Charging activities per vehicle (left) and per charger (right) - Higna Naka depot (350 kWh scenario)

From Figure 84, it can be noted that, even under “normal charging” conditions, the required power curve is relatively smooth due to the limited number of available chargers at the Higna Naka depot.

When charging is optimized by delaying the charge of some buses, power peaks between 10 P.M. and 6 A.M. are distributed over a larger time range.

“Optimized charging” reduces the maximum required power from 2.1 MW to 1.6 MW. Consequentially, the loading factor is improved from 0.31 in “normal charging” to 0.42 with “optimized charging” (i.e., an improvement of 35%).

Furthermore, the depot charging simulation results show that there is enough time between the end of overnight charging activities and the first daily tasks on the following morning. In “normal charging”, 2 hours or less of downtime would not have any significant impact on the operation of the next day. On the contrary, with “optimized charging”, some buses can still be in charge when their task starts in the morning (thus starting the task with partial charge).

Figure 85 hereafter illustrates the state of charge of a vehicle performing the 106/08 task. With “optimized charging”, even if the start of the charge is delayed by a few minutes, the vehicle is fully charged at the end of the night.

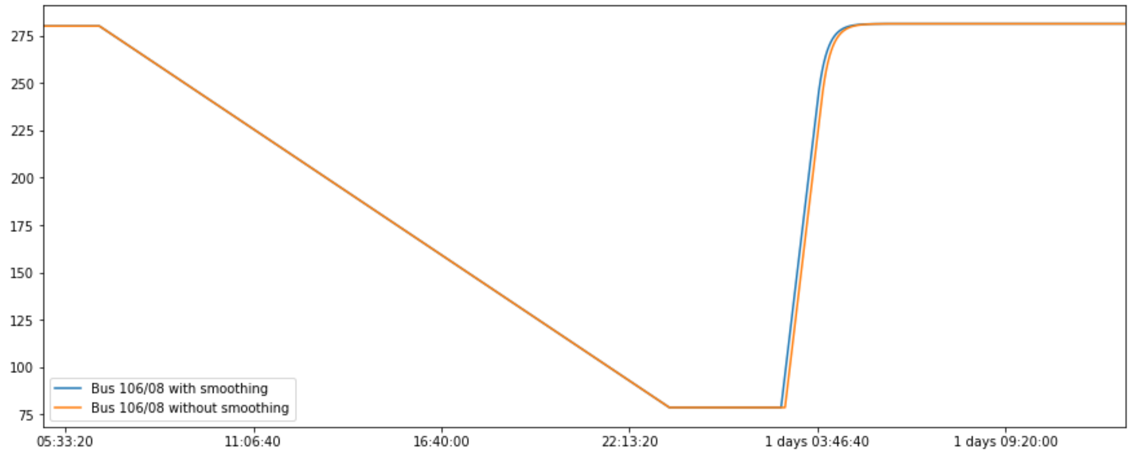


Figure 85. State of charge - Higna Naka depot - Example for task n° 106/08 (350 kWh scenario)

20.2.2.3 Patwardhan 2 depot

The following figures show the charging activities for the Patwardhan depot for each of the 53 buses.

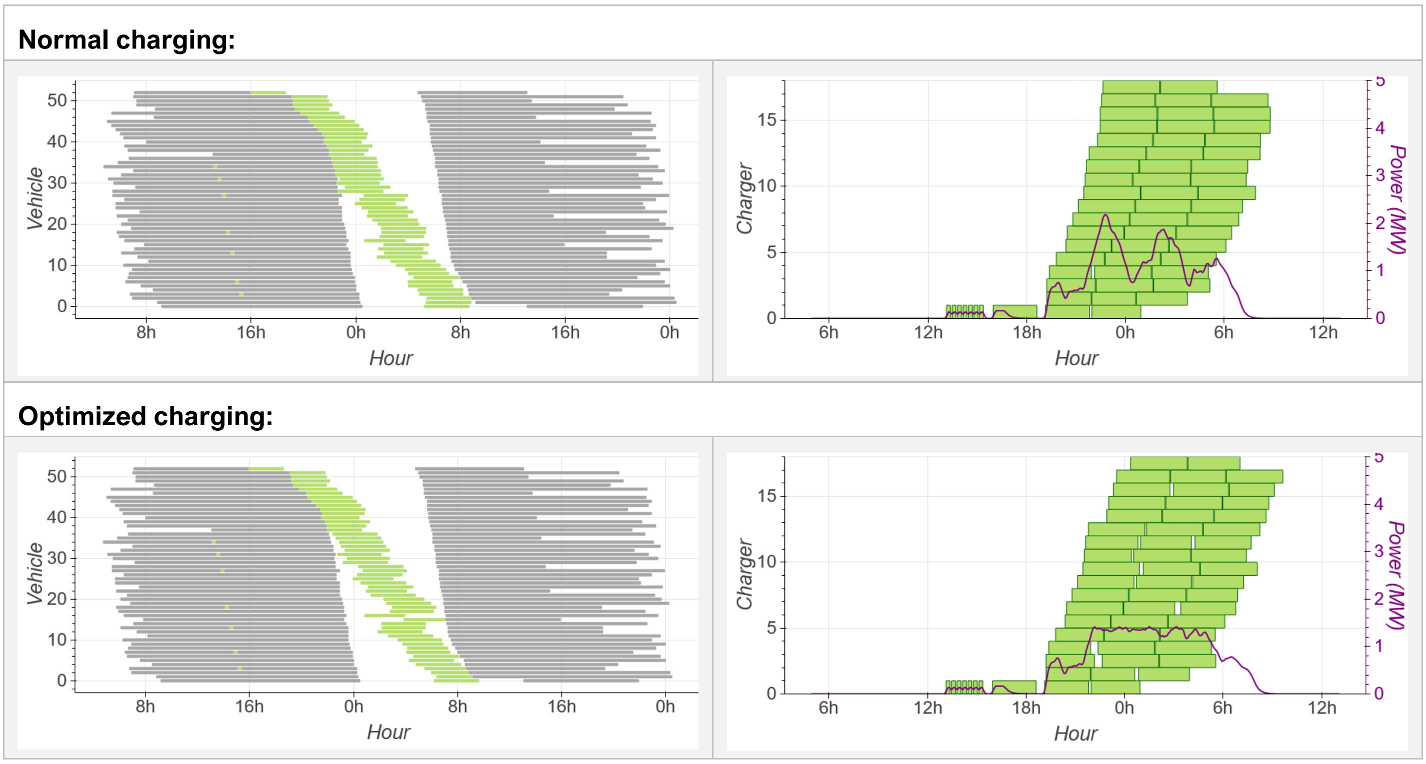


Figure 86. Charging activities per vehicle (left) and per charger (right) - Patwardhan 2 depot (350 kWh scenario)

From Figure 86, it can be noted that, even under “normal charging” conditions, the required power curve is relatively smooth due to the limited number of available chargers at the Patwardhan 2 depot.

When charging is optimized by delaying the charge of some buses, power peaks between 10 P.M. and 6 A.M. are distributed over a larger time range.

“Optimized charging” reduces the maximum required power from 2.3 MW to 1.5 MW. Consequentially, the loading factor is improved from 0.25 in “normal charging” to 0.39 with “optimized charging” (i.e., an improvement of 55%).

Contrary to the 400 kWh scenario, it is noted that a few buses are charged during the afternoon (before 4 P.M.).

Figure 87 hereafter illustrates the state of charge (remaining battery energy) of a vehicle performing the 38/01 task. In this case, “optimized charging” does not delay the start of the charge during the afternoon as only a small number of buses return to the depot. However, “optimized charging” delays by a few minutes the start of the charging during the night, but with no impact on available charge for the following day tasks.

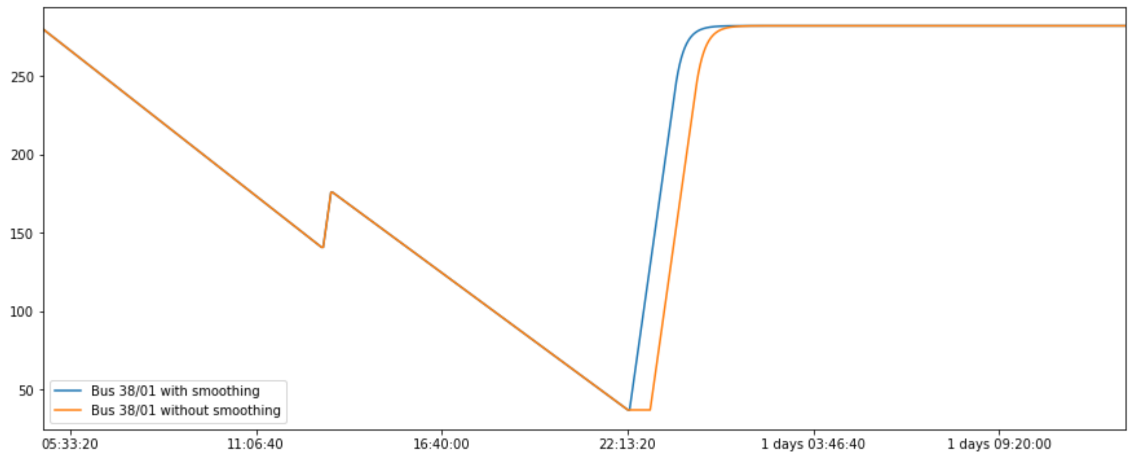


Figure 87. State of charge - Patwardhan 2 depot - Example for task n° 38/01 (400 kWh scenario)

20.2.2.4 Depot charging data summary

Table 54 hereafter summarizes the results of the depot charging simulations for each bus depot.

Table 54. Depot charging data summary (350 kWh scenario)

Bud depot	Number of vehicles	Number of chargers	Mileage (km/day)	Energy (kWh/day)	Charging option	Loading factor	Maximum power (kW)
Khapri Naka	70	23	15,637.4	15,775	normal	0,28	2,319
					optimized	0,52	1,265
Higna Naka	68	23	14,903.3	15,570	normal	0,31	2,092
					optimized	0,42	1,559
Patwardhan 2	53	18	13,925.5	13,794	normal	0,25	2,256
					optimized	0,39	1,475

Note: the average mileage consumption presented in this table is greater than the one presented in chapter 19.1 since here it considers a charger efficiency of 90%.

20.2.3 Depot charging flexibility

20.2.3.1 State of charge at the beginning of the following day

Table 55 summarises the state of charge of the buses at the beginning of the following day, considering “normal charging” and “optimized charging” options.

Table 55. State of charge at the beginning of the following day (350 kWh scenario)

Bus depot	Khapri Naka		Higna Naka		Patwardhan 2	
Charging option	Normal	Optimized	Normal	Optimized	Normal	Optimized
Average	280	280	280	279,7	280	280
Minimum	280	280	280	271,9	280	279,7
Top 75%	280	280	280	280	280	280
Median	280	280	280	280	280	280
Maximum	280	280	280	280	280	280

On average, buses have at least 99.9% of their maximum capacity when they start their first run in the morning. In “normal charging”, all the buses have more than 99.9%. When considering “optimized charging”, the minimum state of charge is equal to 97.1% for Higna Naka depot, which is very close to 100% and thus considered acceptable. Finally, regardless of the chosen depot charging strategy (normal / optimized), at least 75% of the buses carry out their first tour the following day with a 100% state of charge (see Figure 88). These values confirm the operability of the buses from one day to the other.

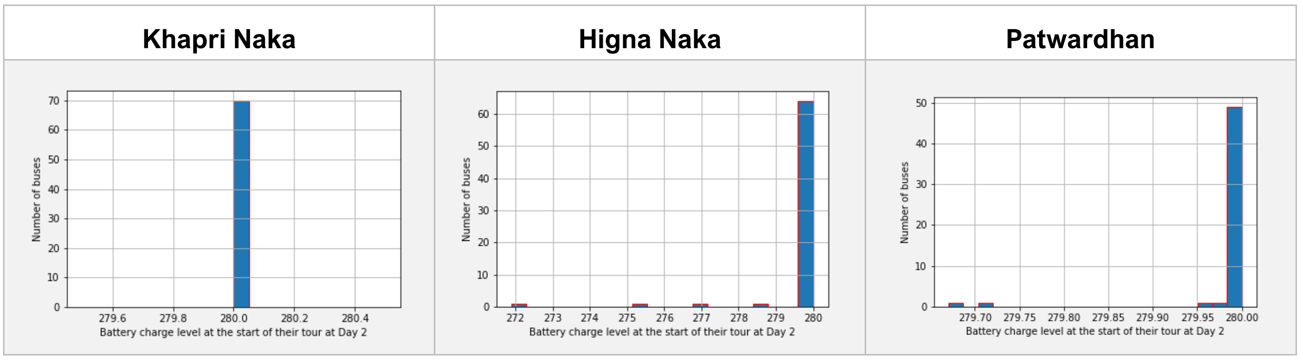


Figure 88. State of charge of each bus at the start of the next day of operation (350 kWh scenario)

20.2.3.2 State of charge on return to the depot

Table 56 summarises the state of charge of the buses when they return to the depot, considering both "normal" and "optimized" charging strategy.

Table 56. State of charge on return to the depot (350 kWh scenario)

Bus depot	Khapri Naka		Higna Naka		Patwardhan 2	
Charging option	Normal	Optimized	Normal	Optimized	Normal	Optimized
Average	32,6%	32,6%	27,0%	27,0%	22,3%	22,3%
Minimum	5,1%	5,1%	5,0%	5,0%	6,5%	6,5%
Median	24,1%	24,1%	15,5%	15,5%	7,9%	7,9%
Maximum	54,1%	54,1%	52,2%	52,2%	55,8%	55,8%

On average, buses return to their depot with approximately 27% of their maximum battery (operational) capacity. This significative margin makes it possible to overcome unforeseen events without difficulty.

The minimum state of charge for all three depots is acceptable. A 5% margin is limited but allows for slight detours in case of unexpected events.

Over 50% of the buses return to the depot with 8-25% of the maximum amount of energy that can be stored. This means that the buses are used to their full capacity. The schedule is therefore relatively well optimized for electric buses.

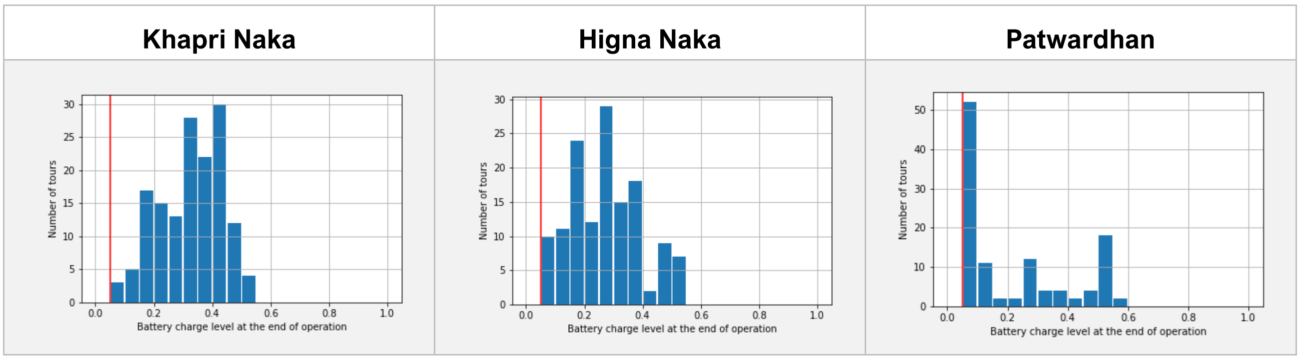


Figure 89. State of charge of each bus on return to the depot (350 kWh scenario)

20.2.3.3 Time reserve between end of charging and start of task

Table 57 allows to quantify the time reserve between the disconnection of buses and their departure for a task.

Table 57. Time reserve between end of charging and start of task (350 kWh scenario)

Bus depot	Khapri Naka		Higna Naka		Patwardhan 2	
Charging option	Normal	Optimized	Normal	Optimized	Normal	Optimized
Average	5:46	4:49	4:44	4:13	3:05	2:51
Minimum	0:03	0:03	0:03	0:03	0:03	0:03
Top 75%	4:27	3:03	3:11	2:33	0:59	0:38
Median	6:16	5:15	4:21	4:03	2:45	2:37
Maximum	10:02	10:02	12:12	12:12	10:08	10:08

"Optimized charging" options tend to decrease the time reserve of vehicles as the charging activity is widened over a longer span of time. Depending on the depot, some buses may need to start their task whereas they are still connected to a charger (i.e., they shall be promptly disconnected and put in operation = 3-minute buffer). For these vehicles, there is no time reserve at all. Nonetheless, at least for 75% of the buses, there is a time margin of approximately one hour or more. In addition, 50% of the tasks start over two hours and a half later the end of the bus charging. The results show that the time reserve is acceptable and allows flexibility for all three simulated depots.

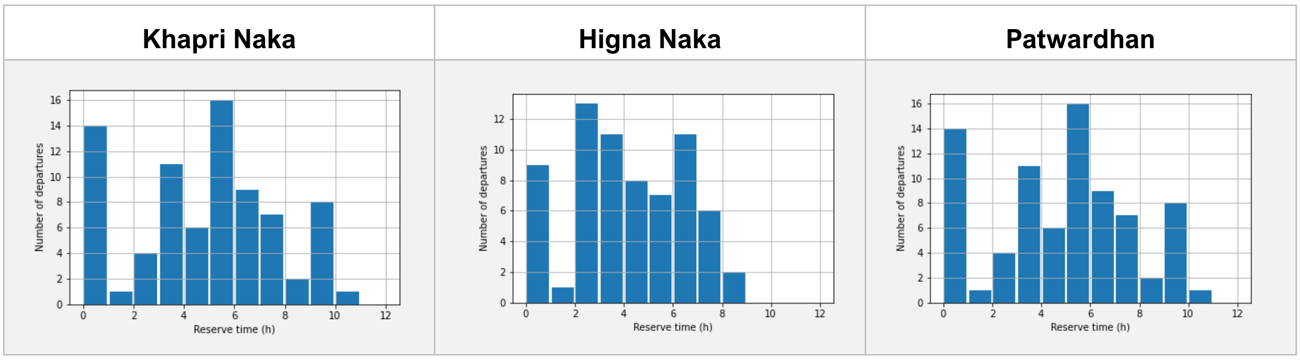


Figure 90. Time reserve between the end of charging and the departure of each bus (350 kWh scenario)

20.3 Scenario “300 kWh batteries”

The simulation of a scenario using 300 kWh battery has been attempted and, as seen in Table 58, the conclusions are significantly different from the two precedent ones.

Table 58. Minimum number of vehicles and additional mileage (300 kWh scenario)

Bus depot	Khapri Naka	Higna Naka	Patwardhan 2
Initial mileage (km)	15,317.6	14,870.3	13,909.5
Final mileage (km)	15,771.0	15,264.3	13,977.5
Initial number of buses	63	67	52
Number of buses operating simultaneously	75	77	56

It can be noted that a total of **22 additional vehicles (for all three depots) would be required** to carry out the same daily service schedule. This option would also result in a more expensive charging and electrical infrastructure in addition to the investment costs related to the rolling stock, the batteries, and the chargers.

As such, and for the matter of the present prefeasibility study, it is possible to conclude that **the 350 kWh scenario seems to be the minimum acceptable scenario in order to adequately perform the current service schedule without major investments**.

20.4 Conclusions from simulations

It has been seen that the reduction of the battery capacity from 400 kWh to 350 kWh results in an increase on the number of buses required to perform the theoretical daily service schedule. In total, 5 additional buses should be needed in the 350 kWh scenario: 1 at Patwardhan depot, 1 at Khapri Naka depot and 3 at Higna Naka depot. In addition, 1 additional charger should be installed in each depot. From an energy point of view, increasing the number of buses in operation would also increase the daily energy consumption, but to a very limited extent, as seen in Table 59 and Figure 91.

Table 59. Comparison of simulation results from the 400 kWh and 350 kWh scenarios

Bus depot	Battery capacity scenario	Number of vehicles	Number of chargers	Energy consumption for bus operation (kWh/day)	Charging option	Maximum required power (kW)
Khapri Naka	350-kWh	68	23	15,775	normal	2,319
					optimized	1,265
	400-kWh	67	22	15,588	normal	2,318
					optimized	1,381
Higna Naka	350-kWh	70	23	15,570	normal	2,092
					optimized	1,559
	400-kWh	67	22	15,536	normal	2,291
					optimized	1,594
Patwardhan 2	350-kWh	53	18	13,794	normal	2,256
					optimized	1,475
	400-kWh	52	17	13,778	normal	2,182
					optimized	1,572

As a conclusion and from a purely technical point of view, the option of using 350 kWh batteries would not have an important number of impacts on buses operation and maintenance (activities and costs) but could reduce investment costs. Furthermore, the same electrical infrastructure (in terms of number of equipment, sizing of the systems, etc.) could be used given the close number of chargers required in both scenarios. Further information on both aspects is given in chapters 21 and 13.3.

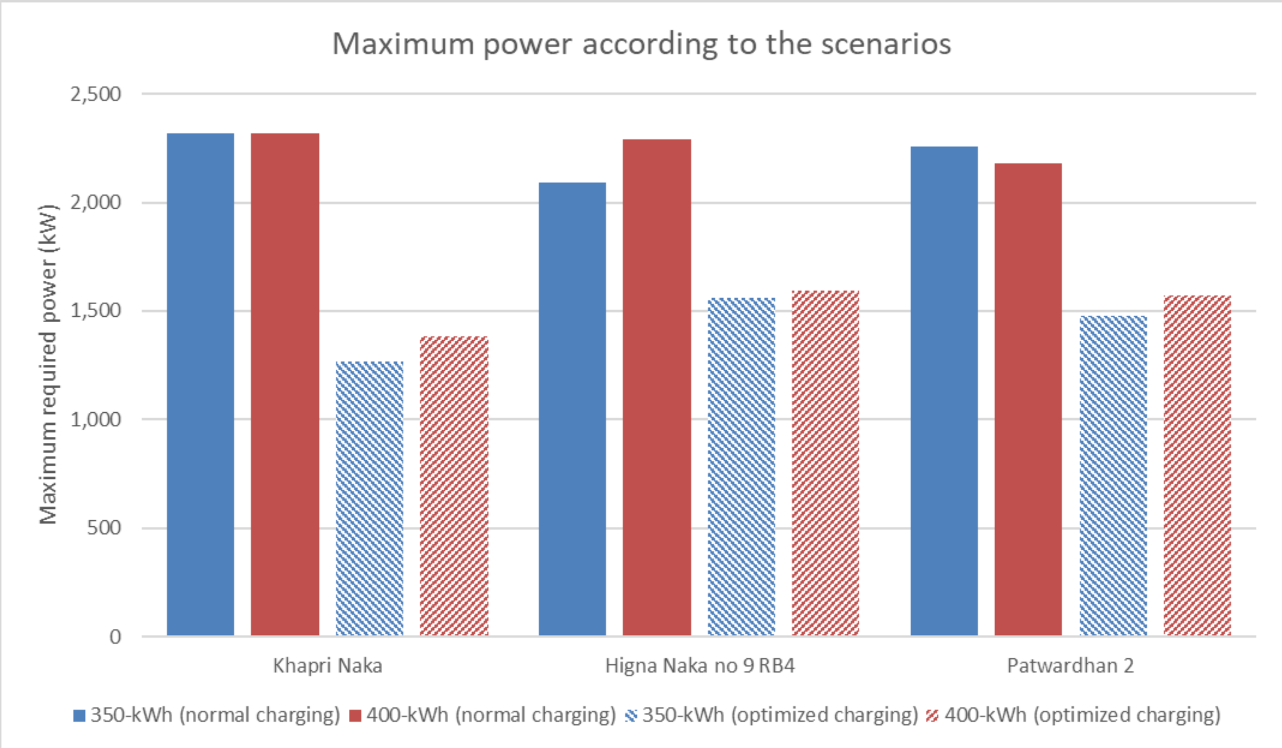


Figure 91. Maximum power according to the scenarios

21. Impacts on depot configuration

21.1 Recommendations on depot parking layout

Examples of individual parking layout (source: RATP)

Electric bus parking zones do not require any specific development apart from the installation of the charge boxes. The constraint lies in the temporary immobilization of vehicles in these charging zones for which charging times are directly dependent on the state of the battery of each vehicle. It is therefore necessary that the charging zones allow several charging immobilization times without hampering the manoeuvring of other vehicles. This is also dependent on the layout (current or possible) of the bus depot.

Regarding parking layout, 2 configurations are usually applied: individual parking, or stacked parking.

21.1.1 Individual parking

Examples of individual parking layout (source: RATP)

In both depots visited by SETEC-NODALIS, the vehicles were parked in an individual straight (perpendicular) or angled parking. In this case, we recommended to install the charger boxes on the ground, behind the buses, as shown in Figure 92.

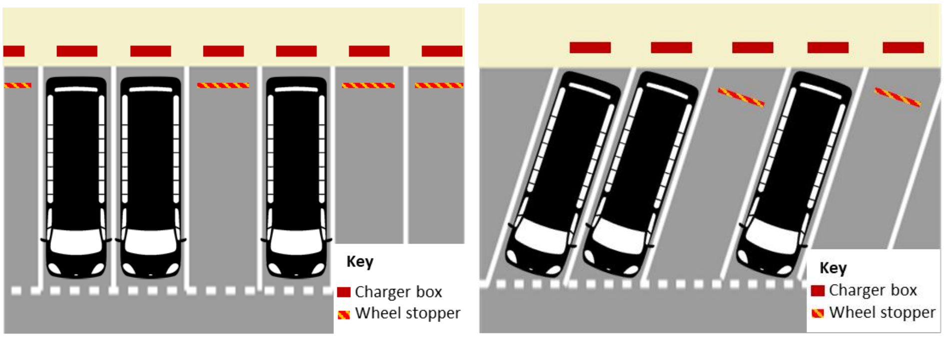


Figure 92. Parking layout – Perpendicular parking (left) and angled (right)

21.1.2 Stacked parking

Illustration of staked parking layout (source: ABB)

In stacked parking, the buses are parked one behind the other. In this case and if it is a design option adopted on one or several depots in Nagpur, we recommend to set up charger boxes beside each parking space, if possible between each space, ensuring that this arrangement does not penalize the movement of vehicles and staff, as shown Figure 93.

In some bus networks, when there is no space available to install the charger boxes on the ground, an aerial installation is possible. For this, a load-bearing metal structure is necessary to install the charger boxes and the cable reels.

Aerial structure specifications depend on the quantity of buses to charge.

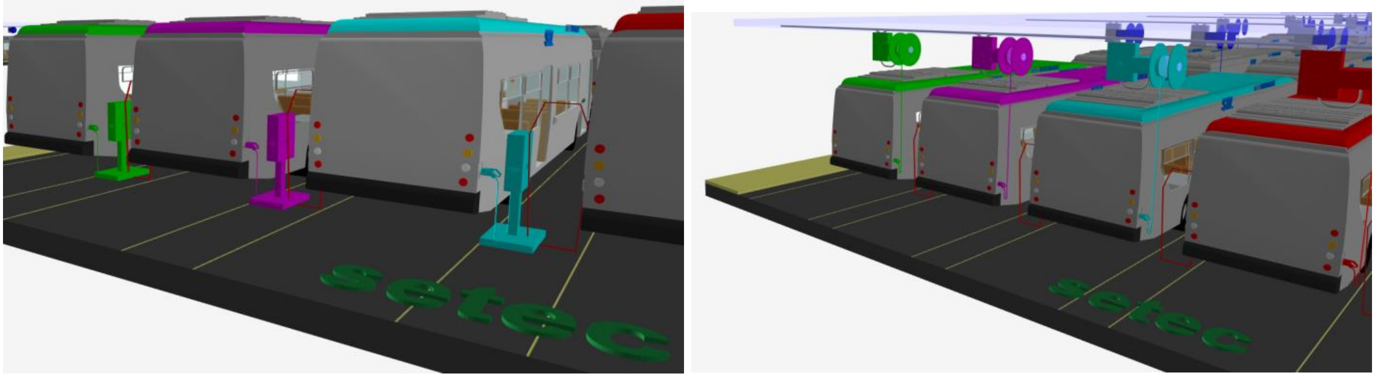


Figure 93. Stacked parking layout - rear positioning of charger (left) and aerial configuration (right) - STL electric bus network in Laval, Canada (BIM modeling by **setec**)

21.1.3 Recommendations

Table 60 describes the main advantages and disadvantages of each parking configuration.

Table 60. Advantages and disadvantages of bus parking configurations

Configuration	Advantages	Disadvantages
Individual parking spaces	• Easy operation and maintenance scheduling of the buses, • Configuration already used in Nagpur bus depots.	• More important space needed.
Stacked parking spaces	• Space proofing if the depot area is limited.	• Operation constraints regarding the use of buses, • Requirements for a building or metallic overhead structure to install the chargers.

In the light of Table 60, we recommend for future Nagpur electric bus depots the use of **individual parking spaces**, thus allowing easier bus operation, maintenance, and parking.

21.2 Depot charging electrical infrastructure

This chapter describes the charging infrastructure layout that could be envisioned for each Nagpur City bus depot considered in this prefeasibility study. Given the charging simulation results, **with either 350 or 400 kWh batteries, the same electrical infrastructure can be implemented**.

The dimensioning elements of the electrical infrastructure (for E-buses charging) are the number of chargers and their power. The charger's usual and recommended specifications are presented in Table 61.

Table 61. Electrical data for sizing – Depot charging

E-buses charger's specifications	
Unitary power	150 kW
Power factor (efficiency)	0.90
Input voltage	400 V
Current	230 A

A modular architecture is recommended (adaptable to bus fleet increases). Dimensioning is done based on the maximum number of chargers potentially connected to the infrastructure.

At this stage, the optimization allowed by the "optimized charging" option does not modify the infrastructure. Indeed, to ensure a high level of flexibility, it is recommended that the infrastructure is sized for the maximum possible power (including for example an unscheduled need to simultaneously charge more buses than in normal conditions due to operational constraints) and not for the maximum power observed on a typical operating day.

Based on the number of required buses and associated charging infrastructure, the dimensioning parameters for each depot are presented in Table 62.

Table 62. Dimensioning parameters for the charging infrastructure in each depot

Bus depot	Khapri Naka	Higna Naka	Patwardhan 2
Maximal number of chargers	24	24	18
Maximal number of electric buses	72	72	54
Total installed power (kW)	3,600 kW	3,600 kW	2,700 kW
Total installed power (kVA)	4,000 kVA *	4,000 kVA *	3,000 kVA *
Maximum current	5,774 A	5,774 A	4,330 A

For comparison purposes, it should be noted that 3,000 to 4,000 kVA is approximately the total installed power for a regular metro station (traction power and auxiliaries). This information may be of interest in further detailed studies, notably for the sizing of the electric connection of a bus depot to the Nagpur City's electricity grid.

Since Khapri Naka and Higna Naka could have the same infrastructure (in terms of equipment and system dimensioning), we propose to study two levels of redundancy to illustrate two possible options for the electric infrastructure:

- Khapri Naka is designed with a partial redundancy, and
- Higna Naka is design with full redundancy.

Comparing both options allows to quantify the cost difference between the two possible levels of redundancy.

21.2.1 Khapri Naka bus depot design

21.2.1.1 Electrical infrastructure assessment

Khapri Naka depot must accommodate a maximum of 70 E-buses and 23 chargers. The modular infrastructure proposed hereafter can accommodate up to 24 chargers and 72 vehicles.

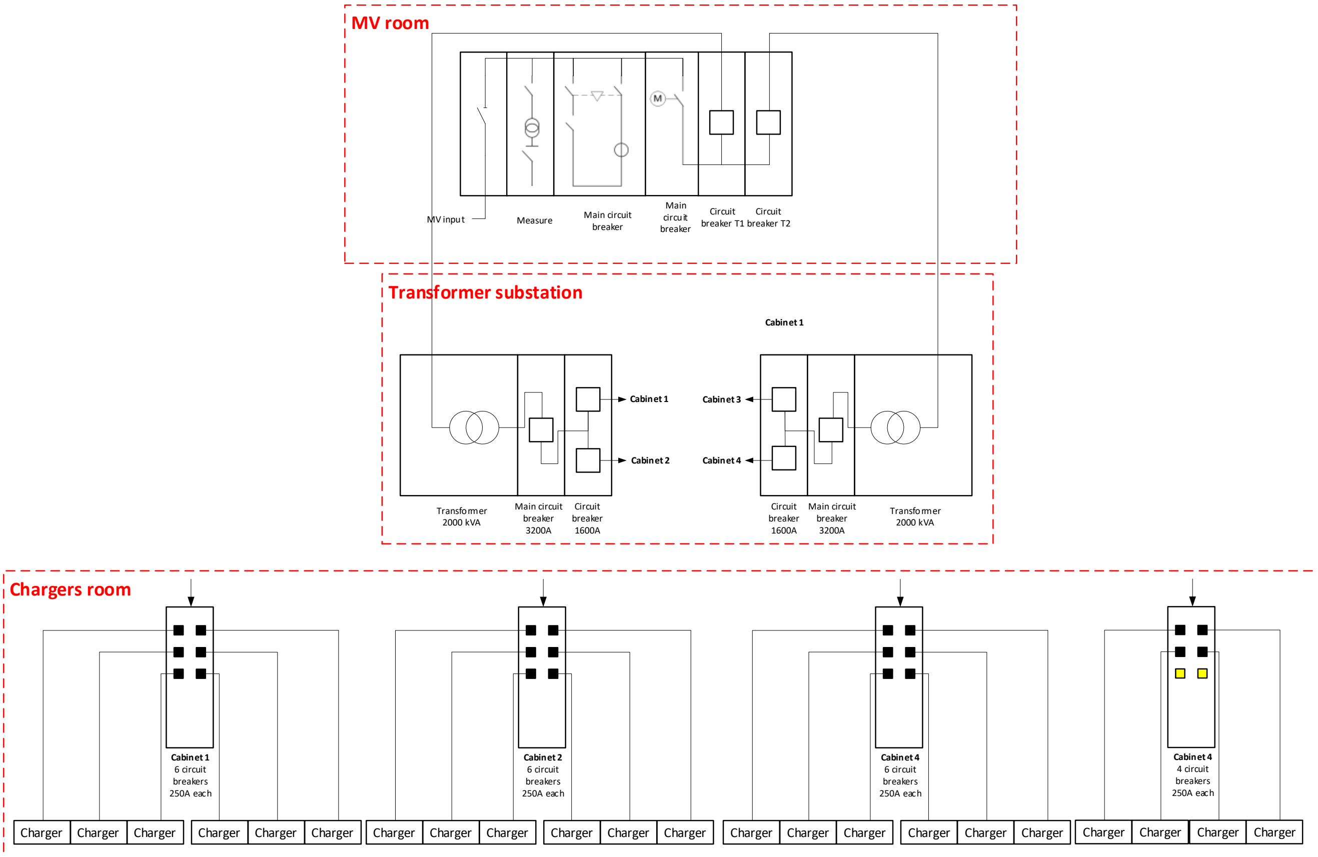


Figure 94. Khapri Naka electrical infrastructure architecture for 70 E-buses and 22 chargers (partial redundancy)

As shown in Figure 94, the electrical equipment and infrastructure (partial redundancy) comprises:

- Medium voltage equipment: switchgears for medium voltage feeders (Nagpur distribution network), electricity meter, general circuit breaker, circuit breakers for the transformer's inputs.

- Transformer substation: 2 transformers 2000 kVA (output voltage 400 V – 3 phases), 2 Main circuit breakers (3200 A), 4 Secondary circuit breakers (1600 A).
- Chargers room: 4 Electrical switchboards (with 6 x 250 A circuit breakers each), 22 Chargers terminals + 2 connection points if 400 kWh battery capacity, 22 Chargers terminals + 1 connection point if 350 kWh battery capacity.

If one transformer breaks down, half of the chargers can still be powered.

21.2.1.2 Technical rooms layout

MEDIUM VOLTAGE ROOM

The medium voltage (MV) equipment is installed in technical cabinets and is composed of: 1 cabinet for switchgears for medium voltage feeders, 1 cabinet for the electricity meter, 1 cabinet for general circuit breaker, 1 cabinet for the MV departure, and 1 circuit breaker cabinet per transformer.

The diagram presented in Figure 95 describes the layout of the technical room, including required maintenance spaces (represented in metres). The MV room's area is approximately equal to 20 m² and shall be air conditioned to keep a constant temperature.

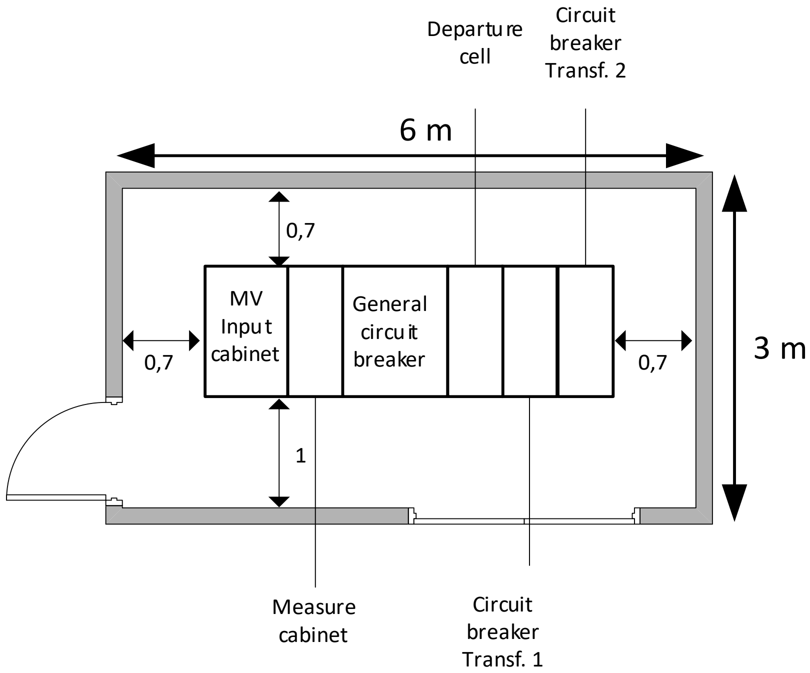


Figure 95. Required medium voltage room layout - Khapri Naka depot

TRANSFORMER SUBSTATION

The equipment installed in the transformer substation is the following: 2 pad-mounted transformers (for partial redundancy), 2 main switchgears cabinets, 4 secondary switchgears cabinets.

The diagram in Figure 96 describes the layout of this technical room, including required maintenance spaces (represented in metres).

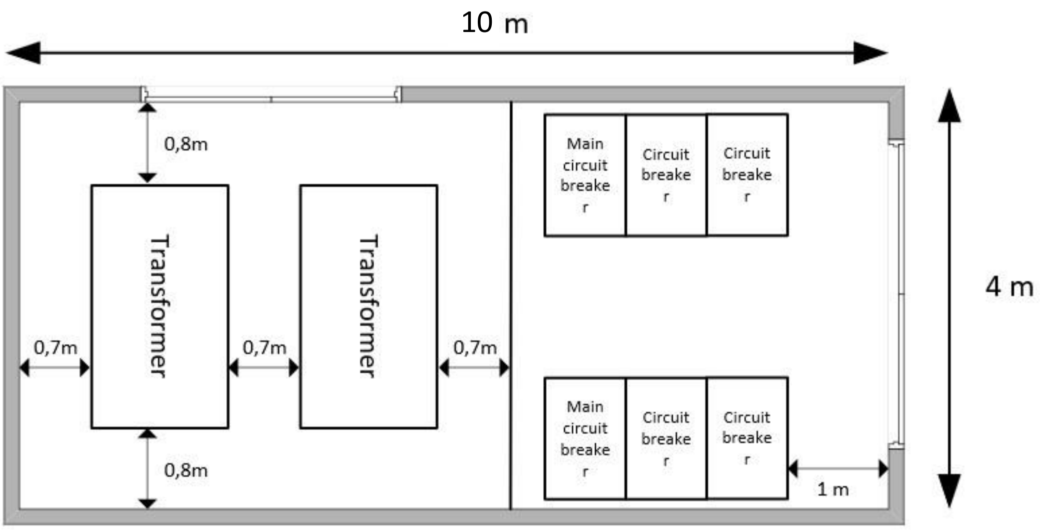


Figure 96. Required transformer substation layout - Khapri Naka depot

The transformer substation shall be air conditioned to keep a constant temperature. The required minimum area for this technical room is approximately 40 m². In addition, to optimize spaces, some manufacturers propose modular solutions combining the MV room and the transformer substation in a single prefabricated room (in a container, for example). The entire room is factory manufactured and upon arrival at the depot, only the wiring and configuration must be done. In that case, the size of the room will depend on the manufacturer and is usually smaller than the combined areas of both rooms separate.

CHARGERS ROOM

To optimize spaces and wiring, we recommend installing the chargers in a technical room near the transformer substation. Also, in this room, the charging terminals can be either:

- Placed side by side without space, or
- Placed near a wall with a 100mm space in between, or
- Placed back-to-back with a 200mm space in between.

The diagram in Figure 97 describes the layout of this technical room, including required maintenance spaces (represented in metres).

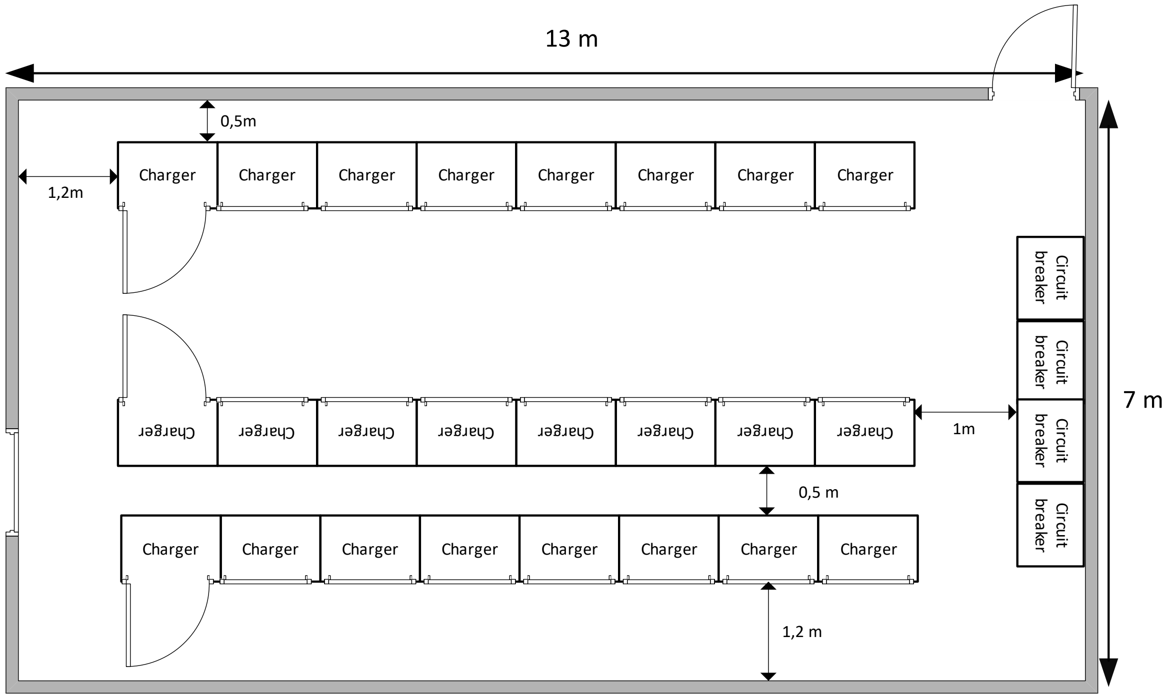


Figure 97. Required chargers room layout - Khapri Naka depot

The equipment installed in this room is the following: 4 cabinets for the electrical switchboards, and 22 chargers + 2 free slots (400 kWh batteries) or 23 chargers + 1 free slot (350 kWh batteries).

The required minimum area for this technical room is 90 m². The standard operating temperature of the charging terminals is between -10°C to +50 °C. However, the technical room, as an electric room, shall be air conditioned in order to keep a constant temperature.

BATTERY TECHNICAL ROOM

A battery storage room is recommended for Khapri Naka depot.

This room shall be ventilated and must be secure and equipped with a slow charger. It shall be sized for the storage of a set of 3 to 5 battery units. It can be integrated in the workshop, if possible, or it can be the subject of a separate room.

The required minimum area for this technical room is approximately 40 m².

21.2.1.3 Khapri Naka depot layout

E-buses parking zones do not require any specific development apart from the installation of the charger boxes close to each parking spot. The constraint lies in the temporary immobilization of vehicles in these charging zones for which charging times are directly dependent on the state of the battery of each vehicle. It is therefore necessary that the charging zones allow several charging immobilization times without hampering the manoeuvring of other vehicles. This is also dependent on the layout (current or possible) of the bus depot.

We consider the use of individual parking spaces layout, which allows easier bus operation, maintenance, and parking should be favoured provided there is enough space.

The proposed layout in Figure 98 and Figure 99 is structured in such a way as to guarantee the independence of the movement of the E-buses between them. This operating mode is the most flexible for the operator. Up to 70 standard 12-m buses can be parked and the charger boxes are installed on the ground, behind the buses (optimal configuration). It should however be noticed that this optimal configuration does not take into account the other parking and equipment needs for this depot area (for thermal buses).

The proposed depot layout considers:

- 70 parking spots for standard 12-m buses (13m x 4m each spot),
- 1 medium voltage room,
- 1 transformer substation,
- 1 charger room,
- 1 battery technical room.

All these electrical rooms are located to the garage. Some of these rooms could be integrated into the workshop if available space allows it.

We notice that on the middle lane some vehicles are parked back-to-back. Note that in this configuration, the corresponding charger box is not shared but are arranged on the same structure, side by side.

Figure 98. Aerial view - Khapri Naka depot

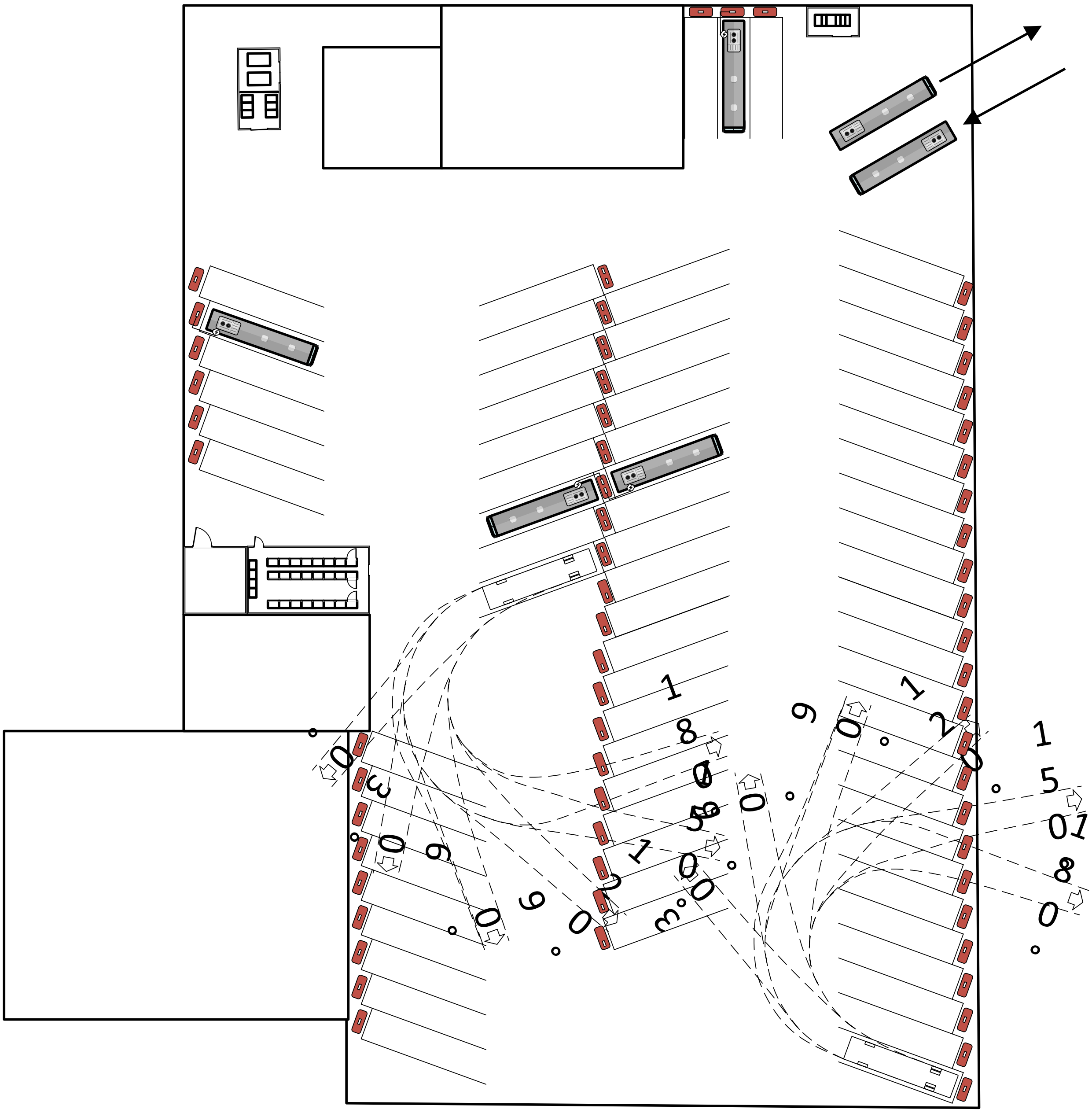


Figure 99. Proposed parking layout at Khapri Naka depot

21.2.2 Higna Naka bus depot

21.2.2.1 Electrical infrastructure assessment

Higna Naka depot must accommodate a maximum of 70 E-buses and 23 chargers. The modular infrastructure proposed hereafter can accommodate up to 24 chargers and 72 vehicles.

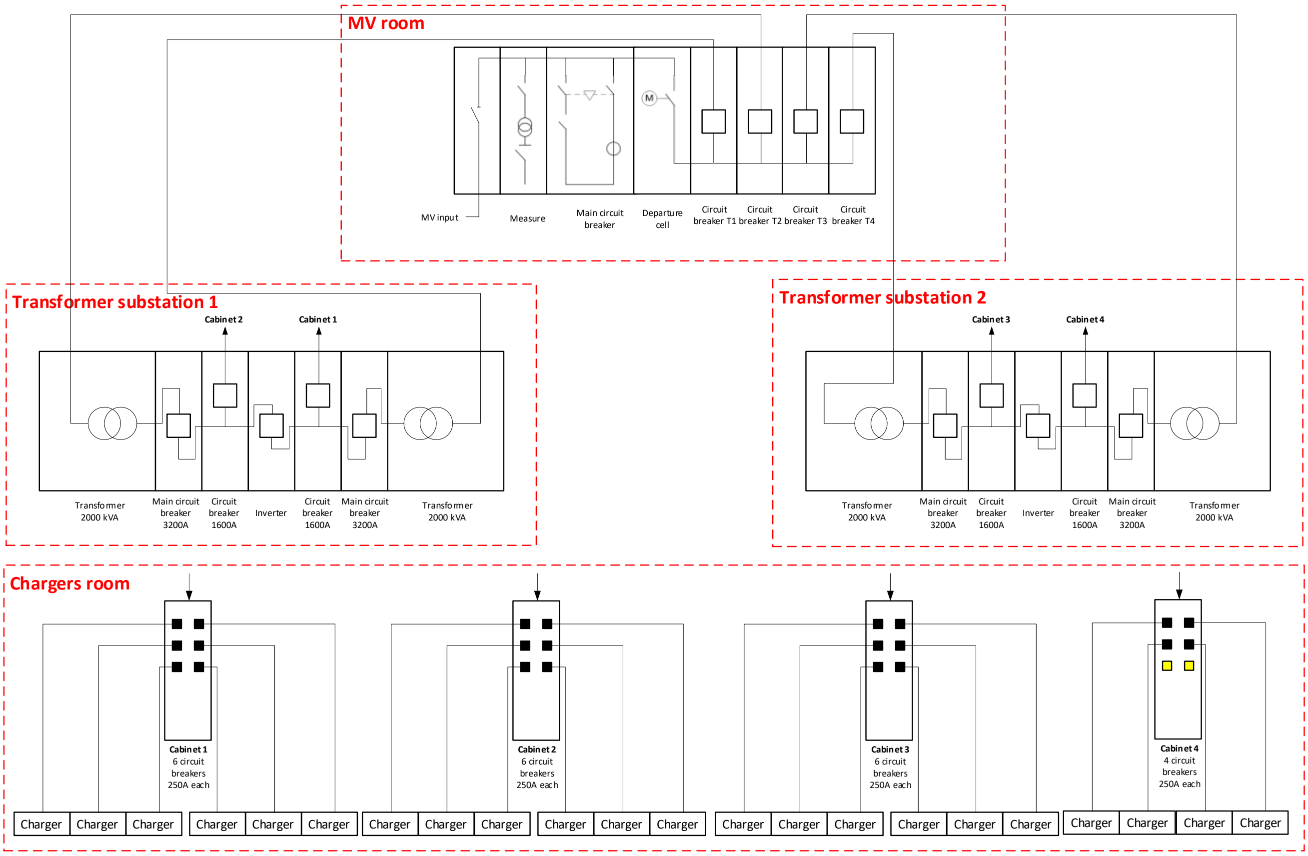


Figure 100. Higna Naka electrical infrastructure architecture for 70 E-buses and 22 chargers (full redundancy)

As shown in Figure 100, the electrical equipment and infrastructure (full redundancy) comprises:

- Medium voltage equipment: switchgears for medium voltage feeders (Nagpur distribution network), electricity meter, general circuit breaker, circuit breakers for the transformer's inputs.
- Redundant transformer substation: 4 transformers 2000 kVA (output voltage 400 V – 3 phases), 4 Main circuit breakers (3200 A), 4 Secondary circuit breakers (1600 A), inverter (for the redundancy).
- Chargers room: 4 Electrical switchboards (with 6 x 250 A circuit breakers each), 22 Chargers terminals + 2 connection points if 400 kWh battery capacity, 23 Chargers terminals + 1 connection points if 350 kWh battery capacity.

If one transformer breaks down, all chargers can still be powered.

This infrastructure can be upgraded by groups of 12 chargers. For each additional group, a transformer substation must be added. Circuits breakers for each transformer input should also be integrated in the MV Room.

21.2.2.2 Technical rooms layout

MEDIUM VOLTAGE ROOM

The medium voltage (MV) equipment is installed in technical cabinets and is composed of: 1 cabinet for switchgears for medium voltage feeders (Nagpur Power grid network), 1 cabinet for the electricity meter, 1 cabinet for general circuit breaker, 1 cabinet for the MV departure, and 1 circuit breaker cabinet per transformer.

The size of the MV technical room depends on the quantity of transformers, i.e., the quantity of chargers to install. The diagram presented in Figure 101 describes the layout of the technical room, including required maintenance spaces (represented in metres).

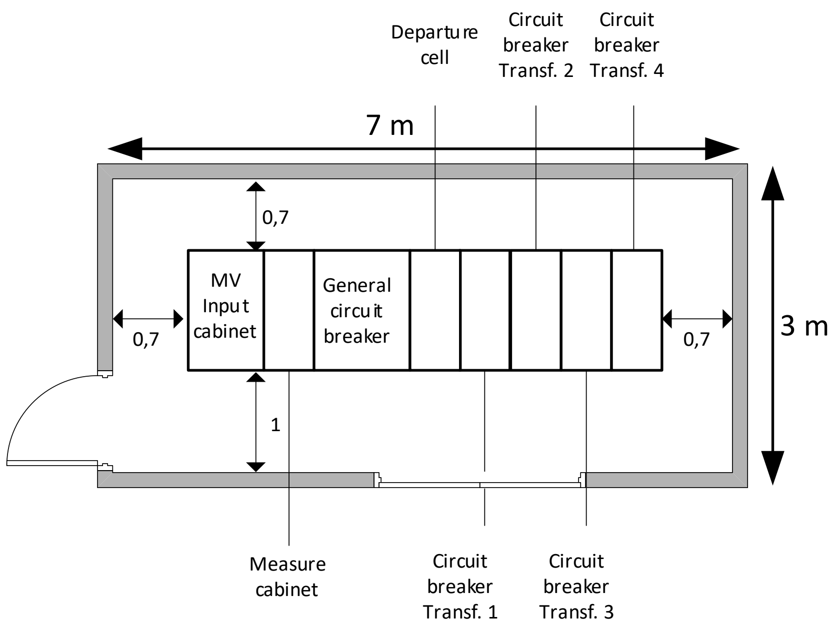


Figure 101. Required medium voltage room layout - Higna Naka depot

The MV room's area is approximately equal to 20 m². If there is a need to expand the bus fleet, it would be preferable to provide a slightly larger room to accommodate additional circuit breakers. The MV room shall be air conditioned to keep a constant temperature.

TRANSFORMER SUBSTATION

The equipment installed in each transformer substation is the following: 2 pad-mounted transformers (for redundancy), 2 main switchgears cabinets, 1 cabinet for the inverter, and 2 secondary switchgears cabinets.

Two transformer substations are placed side by side to supply all the chargers. Each substation can supply 12 chargers. The diagram in Figure 102 describes the layout of these technical rooms, including required maintenance spaces (represented in metres).

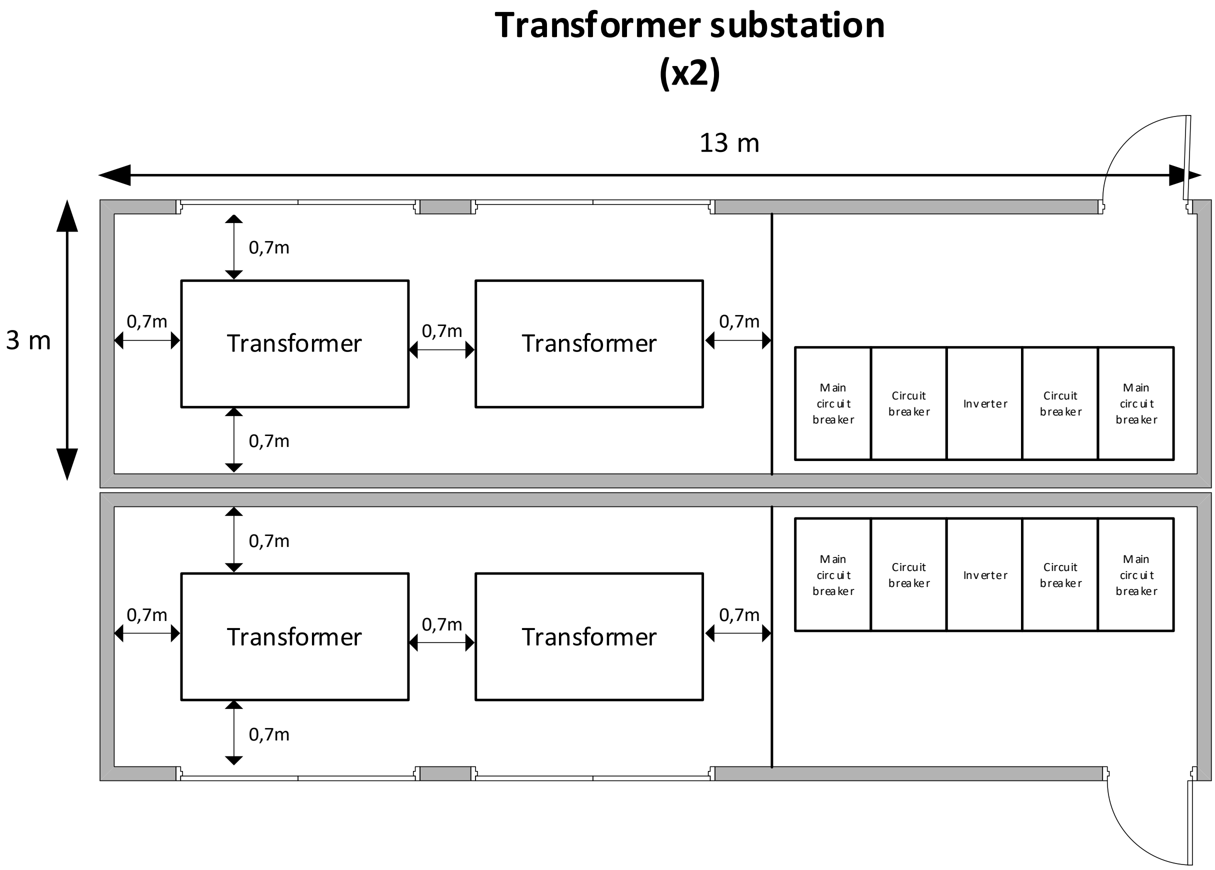


Figure 102. Required transformer substations layout - Higna Naka depot

Each transformer substation shall be air conditioned to keep a constant temperature. The required minimum area for each transformer room is approximately 40 m². In addition, to optimize spaces, some manufacturers propose modular solutions combining the MV room and the transformer substation in a single prefabricated room (in a container, for example). The entire room is factory manufactured and upon arrival at the depot, only the wiring and configuration must be done. In that case, the size of the room will depend on the manufacturer and is usually smaller than the combined areas of both rooms separate.

CHARGERS ROOM

To optimize spaces and wiring, we recommend installing the chargers in a technical room near the transformer substation. Also, in this room, the charging terminals can be either:

- Placed side by side without space, or

- Placed near a wall with a 100mm space in between, or
- Placed back-to-back with a 200mm space in between.

The diagram in Figure 103 describes the layout of this technical room, including required maintenance spaces (represented in metres).

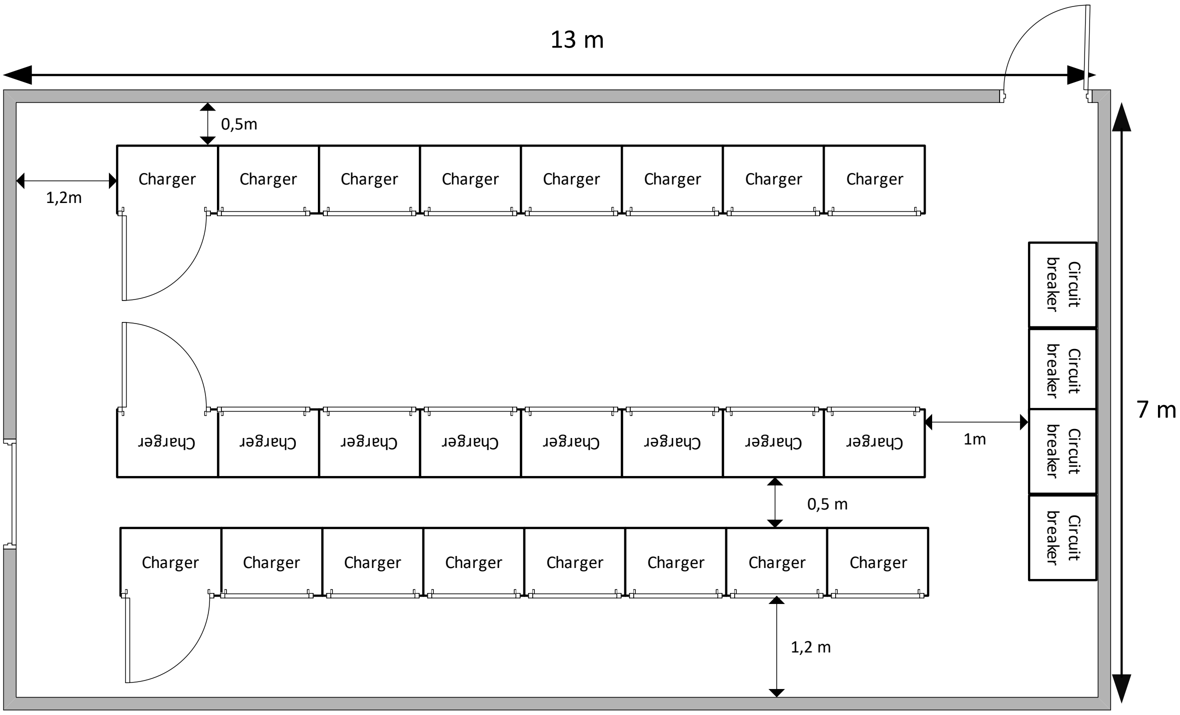


Figure 103. Required chargers room layout - Higna Naka depot

The equipment installed in this room is the following: 4 cabinets for the electrical switchboards, and 22 chargers + 2 free slots (400 kWh batteries) or 23 chargers + 1 free slot (350 kWh batteries).

The required minimum area for this technical room is 90 m². The standard operating temperature of the charging terminals is between -10°C to +50 °C. However, the technical room, as an electric room, shall be air conditioned in order to keep a constant temperature.

BATTERY TECHNICAL ROOM

A battery storage room is recommended for Khapri Naka depot.

This room shall be ventilated and must be secure and equipped with a slow charger. It shall be sized for the storage of a set of 3 to 5 battery units. It can be integrated in the workshop, if possible, or it can be the subject of a separate room.

The required minimum area for this technical room is approximately 40 m².

21.2.2.3 Higna Naka depot layout

The proposed layout in Figure 104 and Figure 105 is structured in such a way as to guarantee the independence of the movement of the E-buses between them. This operating mode is the most flexible for the operator. Up to 70 standard 12-m buses can be parked and the charger boxes are installed on the ground, behind the buses (optimal configuration). It should however be noticed that this optimal configuration does not take into account the other parking and equipment needs for this depot area (for thermal buses).

The proposed depot layout considers:

- 70 parking spots for standard 12-m buses (13m x 4m each spot),
- 1 medium voltage room,
- 2 transformer substations,
- 1 charger room,
- 1 battery technical room.

All these electrical rooms are located next to the garage. Some of these rooms could be integrated into the workshop if space permits.

Figure 104. Aerial view - Higna Naka depot

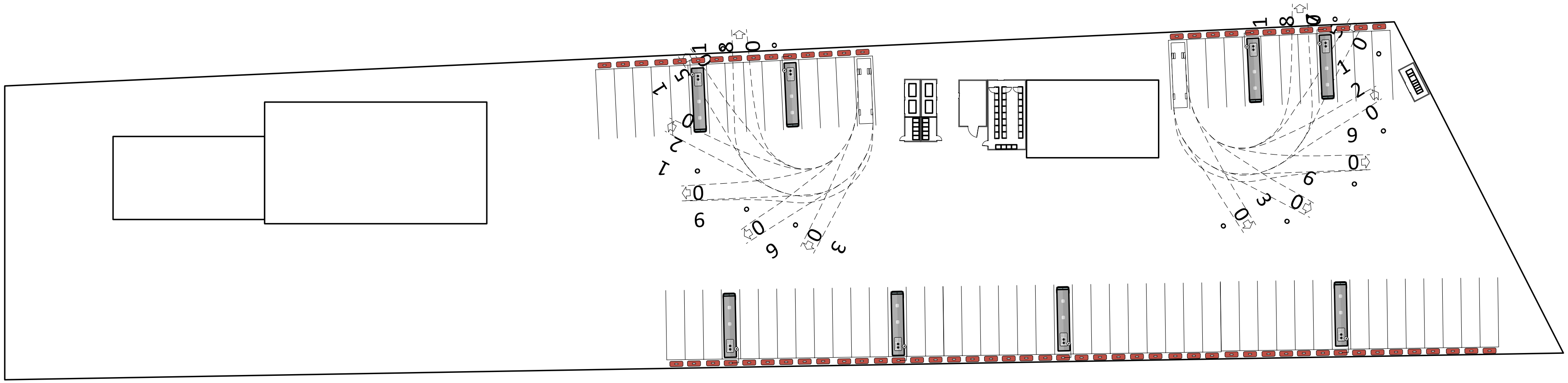


Figure 105. Proposed parking layout at Higna Naka depot

21.2.3 Patwardhan 2 bus depot

21.2.3.1 Electrical infrastructure assessment

Patwardhan depot must accommodate a maximum of 54 E-buses and 18 chargers. The modular infrastructure proposed is fit for this maximum number of vehicles and chargers.

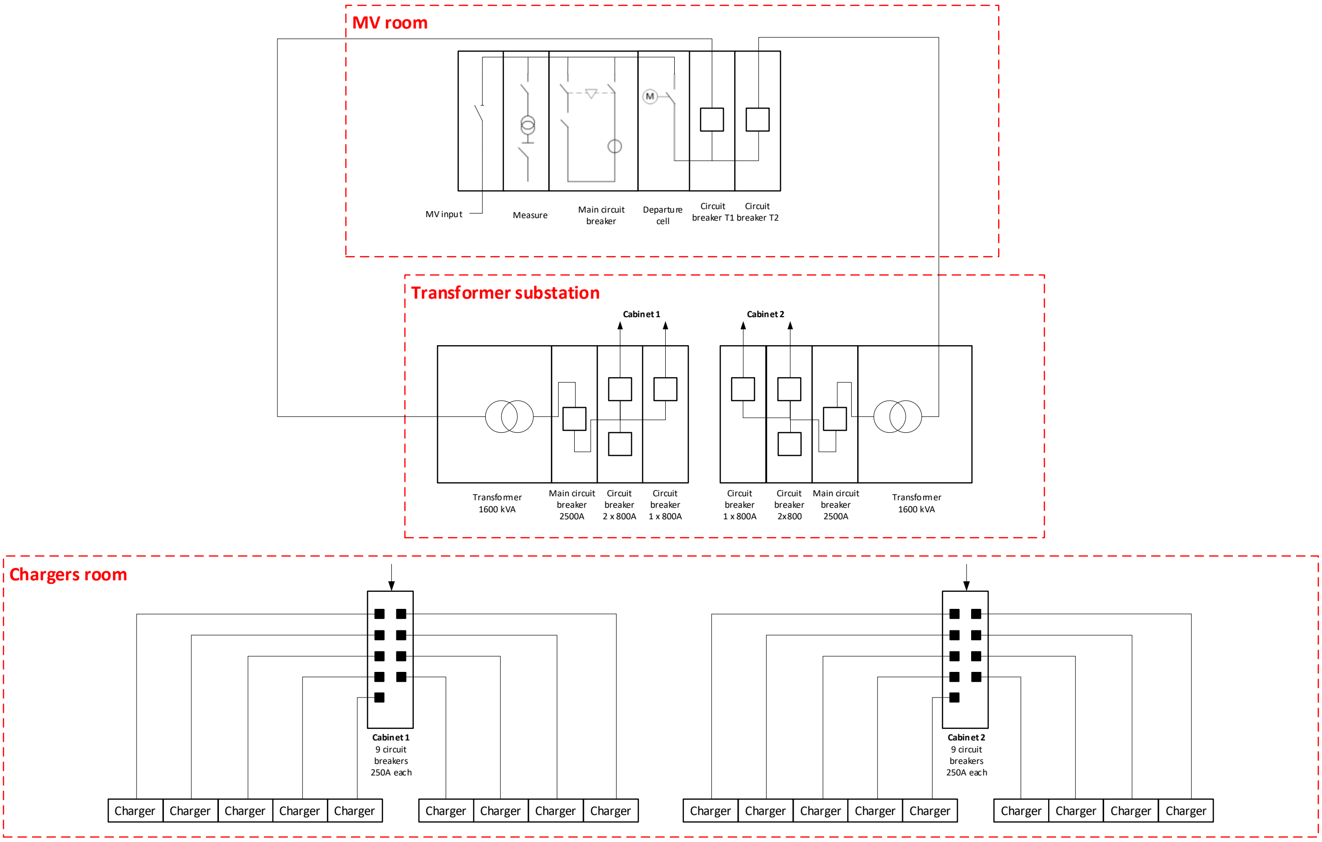


Figure 106. Patwardhan 2 electrical infrastructure architecture for 54 E-buses and 18 chargers (partial redundancy)

As shown in Figure 106, the electrical equipment and infrastructure (full redundancy) comprises:

- Medium voltage equipment: switchgears for medium voltage feeders (Nagpur distribution network), electricity meter, general circuit breaker, circuit breakers for the transformer's inputs.
- Transformer substation: 2 transformers 1600 kVA (output voltage 400 V – 3 phases), 2 Main circuit breakers (2500 A), 6 Secondary circuit breakers (800 A).
- Chargers room: 6 Electrical switchboards (with 3 x 250 A circuit breakers each), 17 Chargers terminals + 1 connection points if 400 kWh battery capacity, 18 Chargers terminals if 350 kWh battery capacity.

If one transformer breaks down, half of the chargers can still be powered.

This infrastructure can be upgraded by groups of 9 chargers. For each additional group, a transformer substation must be added. Circuits breakers for each transformer input should also be integrated in the MV Room.

21.2.3.2 Technical rooms layout

MEDIUM VOLTAGE ROOM

The medium voltage (MV) equipment is installed in technical cabinets and is composed of: 1 cabinet for switchgears for medium voltage feeders (Nagpur Power grid network), 1 cabinet for the electricity meter, 1 cabinet for general circuit breaker, 1 cabinet for the MV departure, and 1 circuit breaker cabinet per transformer.

The diagram presented in Figure 107 describes the layout of the technical room, including required maintenance spaces (represented in metres). The MV room's area is approximately equal to 20 m² and shall be air conditioned to keep a constant temperature.

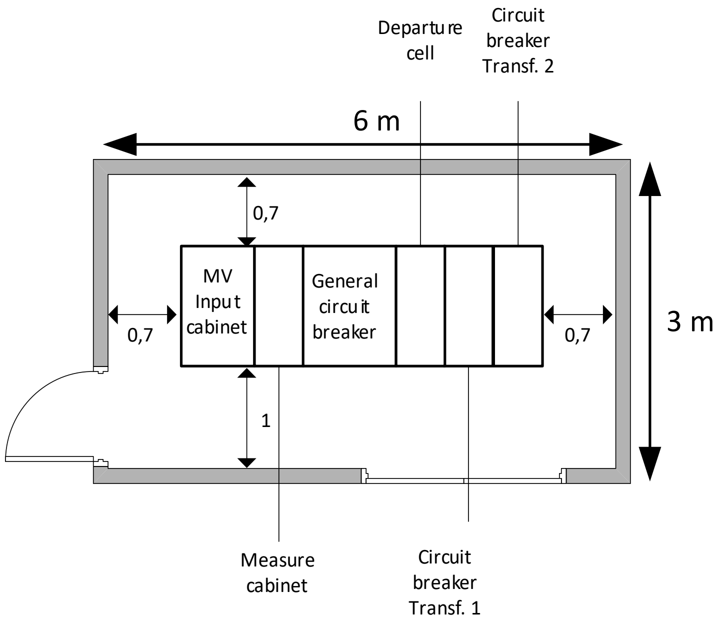


Figure 107. Required medium voltage room layout - Patwardhan 2 depot

TRANSFORMER SUBSTATION

The equipment installed in the transformer substation is the following: 2 pad-mounted transformers (for partial redundancy), 2 main switchgears cabinets, and 6 secondary switchgears cabinets.

The diagram in Figure 102 describes the layout of this technical room, including required maintenance spaces (represented in metres).

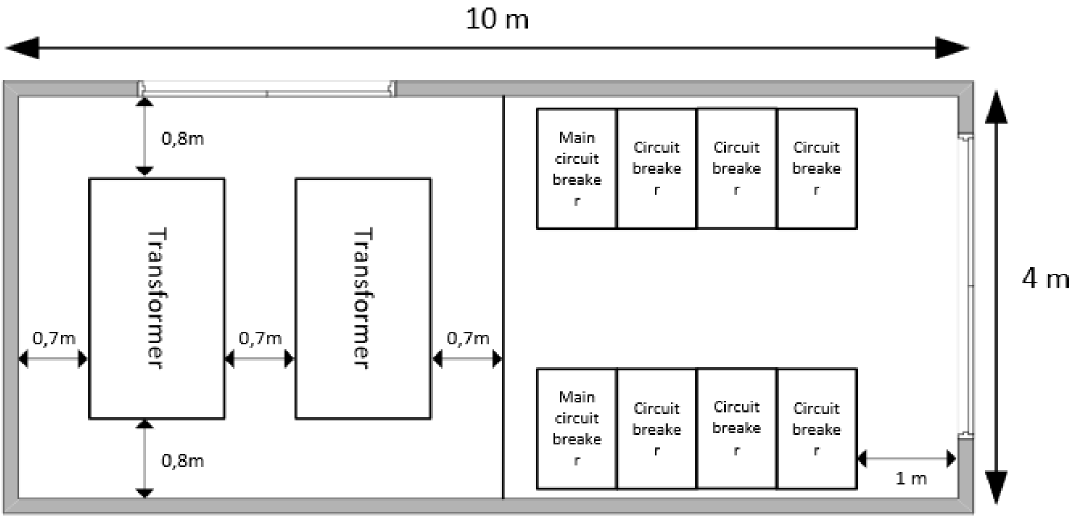


Figure 108. Required transformer substation layout - Patwardhan 2 depot

The transformer substation shall be air conditioned to keep a constant temperature. The required minimum area for this technical room is 40 m². In addition, to optimize spaces, some manufacturers propose modular solutions combining the MV room and the transformer substation in a single prefabricated room (in a container, for example). The entire room is factory manufactured and upon arrival at the depot, only the wiring and configuration must be done. In that case, the size of the room will depend on the manufacturer and is usually smaller than the combined areas of both rooms separate.

Chargers room

To optimize spaces and wiring, we recommend installing the chargers in a technical room near the transformer substation. Also, in this room, the charging terminals can be either:

- Placed side by side without space, or
- Placed near a wall with a 100mm space in between, or
- Placed back-to-back with a 200mm space in between.

The diagram in Figure 109 describes the layout of this technical room, including required maintenance spaces (represented in metres).

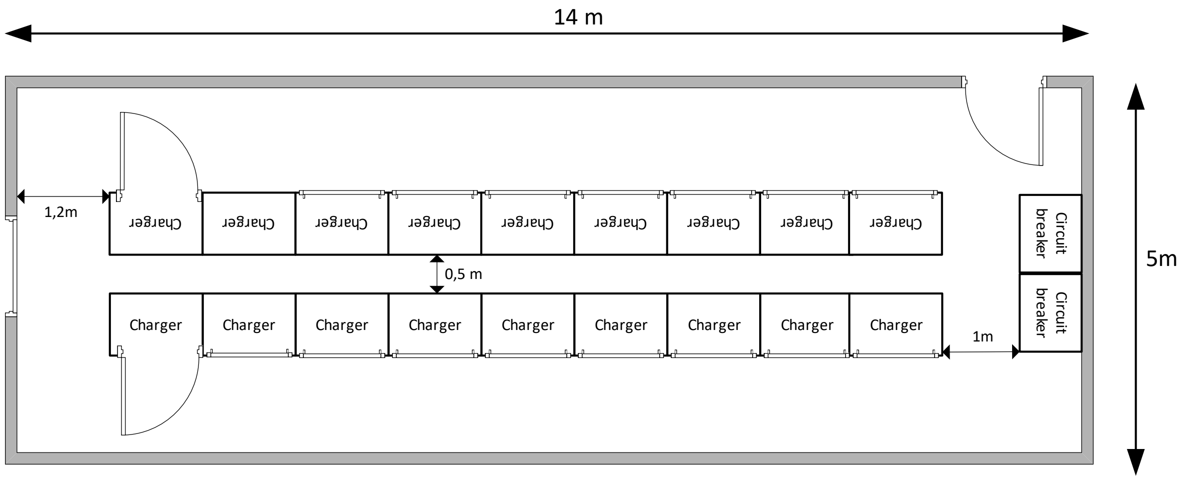


Figure 109. Required chargers room layout - Patwardhan 2 depot

The equipment installed in this room is the following: 2 cabinets for the electrical switchboards, and 17 chargers + 1 free slot (400 kWh batteries) or 18 chargers (350 kWh batteries).

The required minimum area for this technical room is 70 m². The standard operating temperature of the charging terminals is between -10°C to +50 °C. However, the technical room, as an electric room, shall be air conditioned in order to keep a constant temperature.

BATTERY TECHNICAL ROOM

A battery storage room is recommended for Khapri Naka depot.

This room shall be ventilated and must be secure and equipped with a slow charger. It shall be sized for the storage of a set of 3 to 5 battery units. It can be integrated in the workshop, if possible, or it can be the subject of a separate room.

The required minimum area for this technical room is approximately 40 m².

21.2.3.3 Patwardhan 2 depot layout

The proposed layout in Figure 110 and Figure 111 is structured in such a way as to guarantee the independence of the movement of the E-buses between them. This operating mode is the most flexible for the operator. Up to 54 standard 12-m buses can be parked and the charger boxes are installed on the ground, behind the buses (optimal configuration). It should however be noticed that this optimal configuration does not take into account the other parking and equipment needs for this depot area (for thermal buses).

Two rows of three buses are implemented due to a lack of space. In this depot, the 54 buses cannot all be parked in individual spots. The schematic view also presents a possible configuration for stacked parking of buses (i.e., non-individual parallel parking spots). Charger boxes are installed on the ground, next to each parking spot.

The proposed depot layout considers:

- 54 parking spots for standard 12-m buses (13m x 4m each spot),
- 1 medium voltage room,
- 1 transformer substation,
- 1 charger room,
- 1 battery technical room.

All these electrical rooms are located next to the garage. Some of these rooms could be integrated into the workshop if space permits.

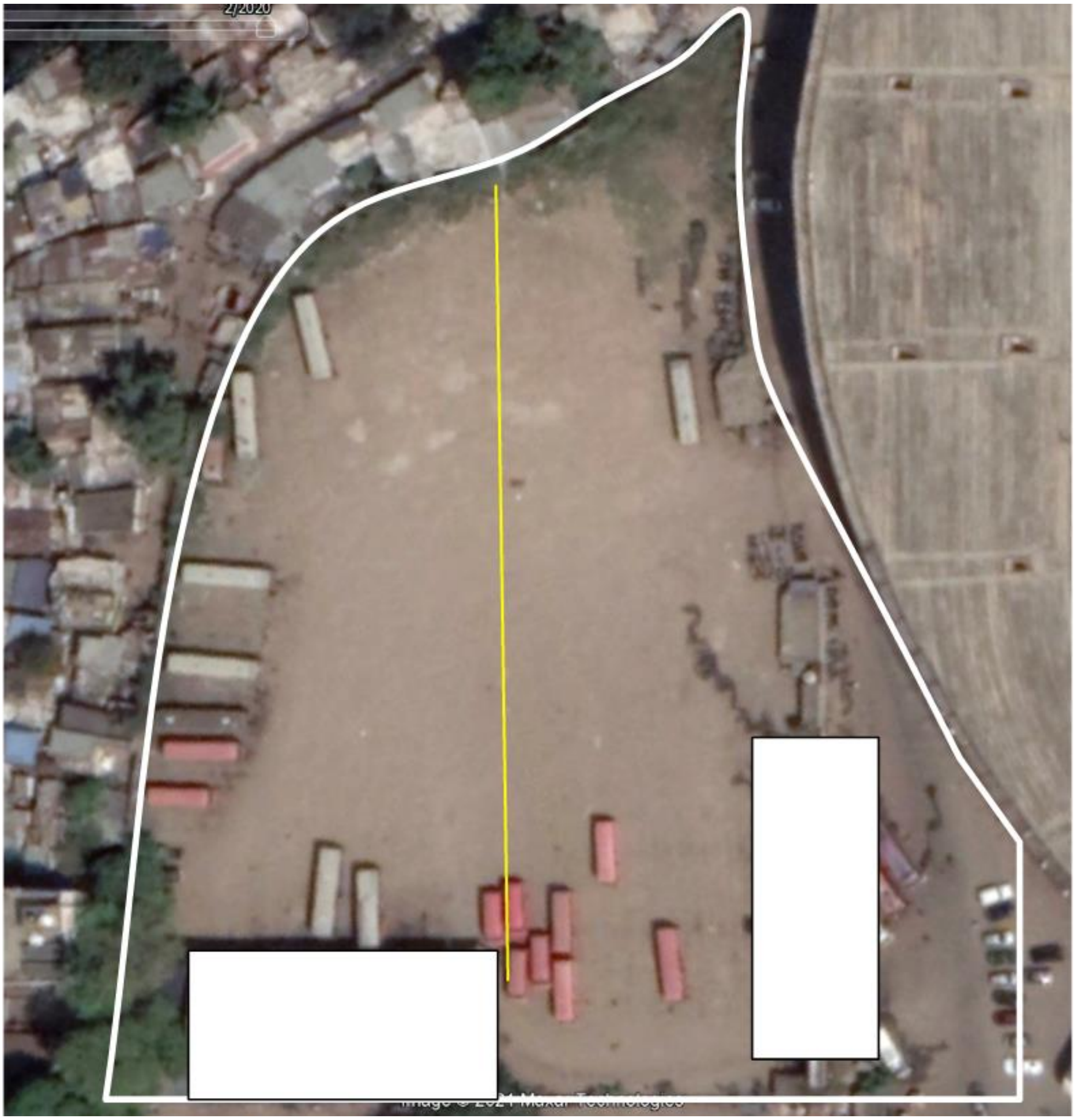


Figure 110. Aerial view - Ptwardhan 2 depot

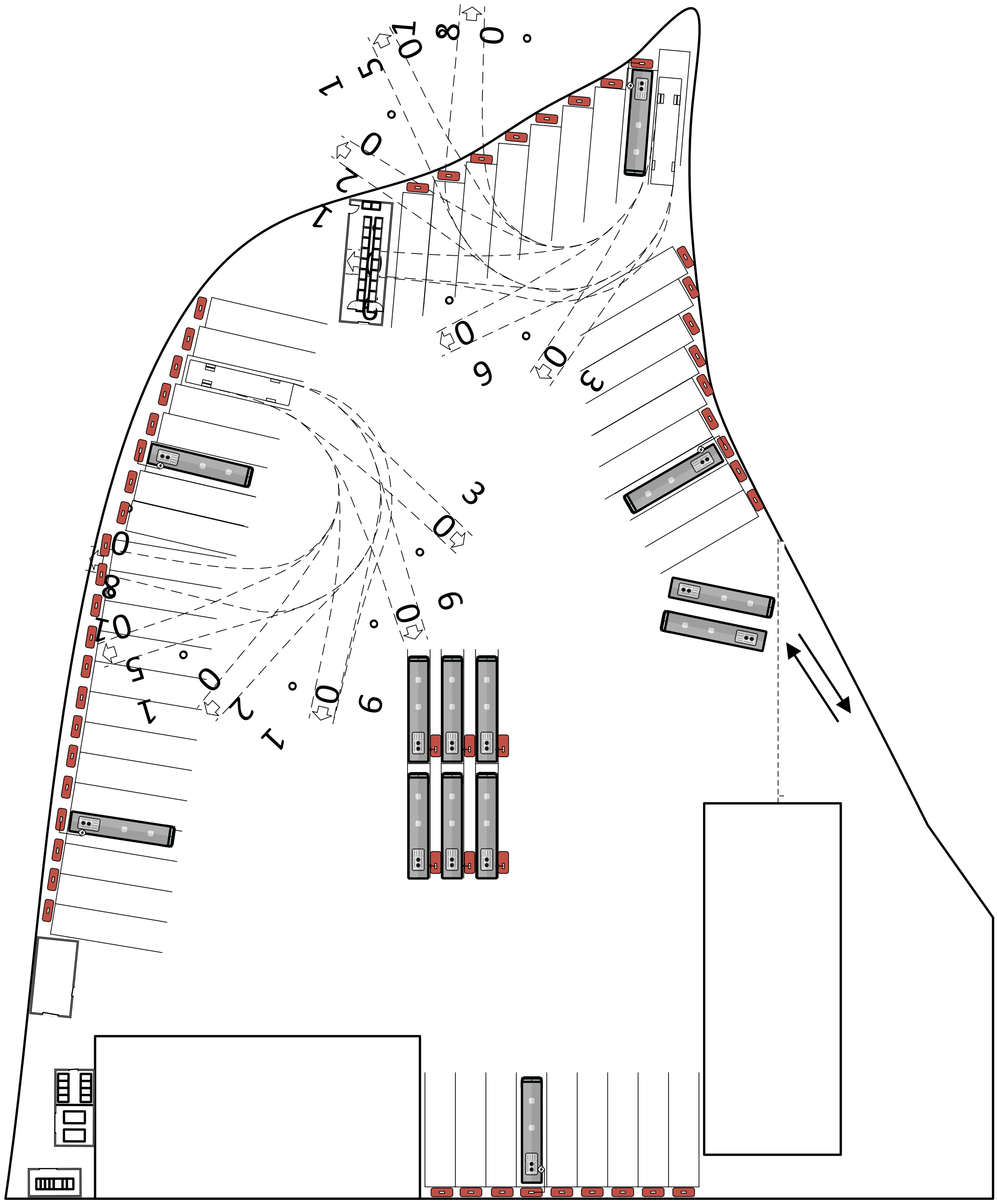


Figure 111. Proposed parking layout at Patwardhan 2 depot

22. CAPEX and OPEX analysis

This section describes the estimated unit CAPEX and OPEX costs based on the electric charging infrastructure described in the previous chapters. The analysis is based on the same two battery capacity scenarios considered in **Volt@bus** simulations (350 kWh and 400 kWh).

22.1 Investment cost analysis

Two types of investment costs for operators are here considered:

- Vehicles and batteries costs, and
- Investments costs for electric infrastructure and systems (only those related to electric buses) that could be borne by the operator.

In each of the following tables, the first column describes the unit price of each item. The investment costs are then calculated for the three depots.

22.1.1 Scenario “400 kWh batteries”

Investment costs considered for the analysis for the case of the 400 kWh batteries are shown in Table 63. Taking into account a battery price of 14 000 INR per kWh[18], the capital expenditures are as follows.

The total capital expenditures are estimated at:

- **Khapri Naka** depot = **155.9 Crores INR**,
- **Higna Naka** depot = **157.5 Crores INR**, and
- **Patwardhan 2** depot = **122.7 Crores INR**.

When comparing Khapri Naka (partial redundancy) and Higna Naka (full redundancy) depots, the **full redundancy** of the electrical infrastructure costs approximately **1.6 Crores INR** but allows a normal operation of the charging planning even if a transformer breaks down.

The purchase of electric buses and their batteries accounts for about 80% of the total capital expenditures for each depot. The share of capital expenditure allocated to the purchase of charging systems is estimated at about 15% whereas the last 5% are divided between the electrical infrastructure at the depot and the charging management system.

[18] Electric Vehicle Outlook 2020 report, Bloomberg NEF

Table 63. Investment cost analysis (400 kWh batteries scenario)

Bus depot		Khapri Naka		Higna Naka		Patwardhan 2	
CAPEX item	Unitary price (INR)	Quantity	Total cost (INR)	Quantity	Total cost (INR)	Quantity	Total cost (INR)
Electric buses and batteries			**1,26,54,00,000**		**1,26,54,00,000**		**99,18,00,000**
Vehicle (Standard - 12m)	1,15,00,000 / unit	67	77,05,00,000	67	77,05,00,000	52	59,80,00,000
Battery (400 kWh capacity)	56,00,000 / unit	67	37,52,00,000	67	37,52,00,000	52	29,12,00,000
Reserve vehicles (Standard - 12m)	1,15,00,000 / unit	7	8,05,00,000	7	8,05,00,000	6	6,90,00,000
Reserve batteries (400 kWh capacity)	56,00,000 / unit	7	3,92,00,000	7	3,92,00,000	6	3,36,00,000
Electrical infrastructure			**2,06,71,200**		**3,61,68,000**		**1,77,14,400**
MV room	depends on layout	1	96,00,000	1	1,44,00,000	1	96,00,000
Transformer substation	depends on layout	1	81,36,000	2	1,74,24,000	1	56,88,000
Low voltage switchgears (in the charger room)	depends on layout	1	10,56,000	1	10,56,000	1	8,16,000
Installation and wiring (10%)	10% of total	-	18,79,200	-	32,88,000	-	16,10,400
Charging infrastructure			**24,51,63,190**		**24,51,63,190**		**18,95,29,640**
Chargers (150 kW)	1,00,00,000 / unit	22	22,00,00,000	22	22,00,00,000	17	17,00,00,000
CCS plug	3,75,570 / unit	67	2,51,63,190	67	2,51,63,190	52	1,95,29,640
Charging management system			**2,65,00,000**		**2,65,00,000**		**2,65,00,000**
Charging management equipment and installation	2,65,00,000 / unit	1	2,65,00,000	1	2,65,00,000	1	2,65,00,000
Service connection charges			**3,23,000**		**3,23,000**		**3,23,000**
New high-voltage underground connection	3,23,000 / unit	1	3,23,000	1	3,23,000	1	3,23,000
Civil works			**8,55,000**		**10,35,000**		**7,65,000**
MV room	4,500 / m²	20	90,000	20	90,000	20	90,000
Transformer substation	4,500 / m²	40	1,80,000	80	3,60,000	40	1,80,000
Chargers room	4,500 / m²	90	4,05,000	90	4,05,000	70	3,15,000
Battery storage room	4,500 / m²	40	1,80,000	40	1,80,000	40	1,80,000
TOTAL			**155.9 Crores**		**157.5 Crores**		**122.7 Crores**

22.1.2 Scenario “350 kWh batteries”

Investment costs considered for the analysis for the case of the 350 kWh batteries are shown in Table 64.

The total capital expenditures are estimated at:

- **Khapri Naka** depot = **156.7 Crores INR** (+0.5% compared to the 400 kWh scenario),
- **Higna Naka** depot = **155.0 Crores INR** (-1.6%), and
- **Patwardhan 2** depot = **121.3 Crores INR** (-1.1%).

When comparing Khapri Naka (partial redundancy) and Higna Naka (full redundancy) depots, the **full redundancy** of the electrical infrastructure equally costs approximately **1.7 Crores INR** but allows a normal operation of the charging planning even if a transformer breaks down.

Compared to the 400 kWh scenario, the electrical infrastructure remains almost identical. In terms of CAPEX costs, the lower battery capacity respectively **saves 2.5 Crores and 1.4 Crores** for Higna Naka and Patwardhan 2 depots. On the contrary, in the case of Khapri Naka depot, the **total cost is 0.9 Crores higher** than with 400 kWh batteries due to a significant increase in the number of buses required (+3). Thus, there is a real interest in limiting the capacity of the batteries, provided that this does not lead to a substantial increase in the number of buses in operation.

The purchase of electric buses and their batteries accounts for about 80% of the total capital expenditures for each depot. The share of capital expenditure allocated to the purchase of charging systems is estimated at about 15% whereas the last 5% are divided between the electrical infrastructure at the depot and the charging management system.

Table 64. Investment cost analysis (350 kWh batteries scenario)

Bus depot		Khapri Naka		Higna Naka		Patwardhan 2	
CAPEX item	Unitary price (INR)	Quantity	Total cost (INR)	Quantity	Total cost (INR)	Quantity	Total cost (INR)
Electric buses and batteries			**1,26,28,00,000**		**1,23,00,00,000**		**96,76,00,000**
Vehicle (Standard - 12m)	1,15,00,000 / unit	70	80,50,00,000	68	78,20,00,000	53	60,95,00,000
Battery (400 kWh capacity)	49,00,000 / unit	70	34,30,00,000	68	33,32,00,000	53	25,97,00,000
Reserve vehicles (Standard - 12m)	1,15,00,000 / unit	7	8,05,00,000	7	8,05,00,000	6	6,90,00,000
Reserve batteries (400 kWh capacity)	49,00,000 / unit	7	3,43,00,000	7	3,43,00,000	6	2,94,00,000
Electrical infrastructure			**2,07,24,000**		**3,62,20,800**		**1,77,67,200**
MV room	depends on layout	1	96,00,000	1	1,44,00,000	1	96,00,000
Transformer substation	depends on layout	1	81,36,000	1	1,74,24,000	1	56,88,000
Low voltage switchgears (in the charger room)	depends on layout	1	11,04,000	1	11,04,000	1	8,64,000
Installation and wiring (10%)	10% of total	-	18,84,000	-	32,92,800	-	16,15,200
Charging infrastructure			**25,62,89,900**		**25,55,38,760**		**19,99,05,210**
Chargers (150 kW)	1,00,00,000 / unit	23	23,00,00,000	23	23,00,00,000	18	18,00,00,000
CCS plug	3,75,570 / unit	70	2,62,89,900	68	2,55,38,760	53	1,99,05,210
Advanced charging management system			**2,65,00,000**		**2,65,00,000**		**2,65,00,000**
Charging management equipment and installation	2,65,00,000 / unit	1	2,65,00,000	1	2,65,00,000	1	2,65,00,000
Service connection charges			**3,23,000**		**3,23,000**		**3,23,000**
New high-voltage underground connection	3,23,000 / unit	1	3,23,000	1	3,23,000	1	3,23,000
Civil works			**8,55,000**		**10,35,000**		**7,65,000**
MV room	4,500 / m²	20	90,000	20	90,000	20	90,000
Transformer substation	4,500 / m²	40	1,80,000	80	3,60,000	40	1,80,000
Chargers room	4,500 / m²	90	4,05,000	90	4,05,000	70	3,15,000
Battery storage room	4,500 / m²	40	1,80,000	40	1,80,000	40	1,80,000
TOTAL			**156.7 Crores**		**156.7 Crores**		**121.3 Crores**

22.2 Operation and maintenance cost analysis

Operational and maintenance costs (OPEX) for standard electric buses are estimated based on **Volt@bus** simulations and results. For other buses, those are estimated at 2% of the investment cost (CAPEX) per year during the item lifetime (usual ratio). The operating expenditures are presented in Table 65.

Table 65. Operation expenditures' assumptions

OPEX Assumptions	Unit	Electric buses	Diesel buses
Staff costs			
Drivers	Number of shifts	1.25	1.25
Operation staff	Number of routes	1.00	1.00
Maintenance staff	Number of buses	0.50	0.50
Maintenance costs			
Vehicle maintenance	INR / km	3.0	5.0
Electrical infrastructure	% of the CAPEX	2%	*N/A*
Charging infrastructure	% of the CAPEX	2%	*N/A*
Charging management system (advanced module)	INR / year	5,00,000	*N/A*
Insurances	% of the net asset value	2.5%	2.5%
Overheads	% of the total operating expenses	3%	3%

For standard E-buses, energy costs are calculated according to the electrical consumption of each bus depot as well as the maximum power required. The electrical consumption composes the variable part of the energy costs. On the contrary, the maximum power required for a depot determines the power to be subscribed and therefore the fixed charge of the energy costs. Thus, limiting the subscribed power reduces the fixed charge (due the interest of optimizing bus depot charging).

The OPEX analysis is declined in different aspects. Two variables are considered:

- Battery capacity: 350 kWh or 400 kWh,
- The use of an advanced charging management system (i.e., "optimized charging", as explained in chapters 20.1.2) or a regular charging management system (i.e., "normal charging").

Finally, for each depot, two reference electricity tariffs are considered:

- The reference tariff applicable for Electric Vehicle Charging Stations, as presented in Figure 112, and

- The tariff category applicable for electricity supply at High Voltage for public service such as State or Local Authority Transport establishments, as presented in Figure 113.

Tariff w.e.f. 1 April, 2021 to 31 March, 2022

Supply Voltage Level	Wheeling Charges (Rs. /kVAh)
EHV	-
HT	0.56

PLUS

Demand/Fixed Charge and Energy Charge (for all Supply Voltage Levels)

Consumer Category	Demand Charges (Rs. /kVA/month)	Energy Charges (Rs. /kVAh)
All Units	70.00	4.94
ToD tariff (in addition to above base tariffs)	**(Rs/kVAh)**	
2200 Hrs - 0600 Hrs		-1.50
0600 Hrs - 0900 Hrs & 1200 Hrs - 1800 Hrs		0.00
0900 Hrs - 1200 Hrs		0.80
1800 Hrs - 2200 Hrs		1.10

Figure 112. Tariff applicable for Electric Vehicle Charging Stations (source: see footnote 19)

Tariff w.e.f. 1 April, 2021 to 31 March, 2022

Supply Voltage Level	Wheeling Charges (Rs. /kVAh)
EHV	-
HT	0.56

PLUS

Demand/Fixed Charge and Energy Charge (for all Supply Voltage Levels)

Consumer Category	Demand Charges (Rs. /kVA/month)	Energy Charges (Rs. /kVAh)
All Units	432.00	9.21
ToD tariff (in addition to above base tariffs)	**(Rs/kVAh)**	
2200 Hrs - 0600 Hrs		-1.50
0600 Hrs - 0900 Hrs & 1200 Hrs - 1800 Hrs		0.00
0900 Hrs - 1200 Hrs		0.80
1800 Hrs - 2200 Hrs		1.10

Figure 113. Tariff applicable for Public Service (source: see footnote 20)

In addition, the analysis compares the OPEX of electric and diesel buses in order to evaluate the benefits.

[19] MERC Order – Case No. 322 of 2019, https://www.mahadiscom.in/consumer/wp-content/uploads/2020/03/Order-322-of-2019.pdf, p.706

[20] MERC Order – Case No. 322 of 2019, https://www.mahadiscom.in/consumer/wp-content/uploads/2020/03/Order-322-of-2019.pdf , p.703

22.2.1 Khapri Naka bus depot

22.2.1.1 Electric Vehicles Charging Stations tariff

Considering the Electric Vehicles Charging Stations incentive tariff, the annual operational and maintenance expenditures are presented in Table 66.

Regardless of the scenario, electric buses' operational costs per km are approximately half the operational costs of diesel buses. Energy/Fuel costs in particular are almost five times lower for electric buses than for diesel.

In addition, increasing the size of the batteries capacity slightly decreases the operational costs (lower insurance costs due to the lower number of buses + lower number of kilometres with 400 kWh batteries).

Besides, it is noted that charging optimization allows to reduce to a very limited extent the energy cost due to the incentive EV tariff.

22.2.1.2 Public service tariff

When considering the Public Service tariff, the annual operational and maintenance expenditures are presented in Table 67. Values modified in comparison with the incentive tariff are identifier in **dark red**.

Increasing the cost of electricity decreases the gap between electric and diesel buses. The operational costs per kilometre of electric vehicles are 25% lower than those of diesel vehicles.

On the other hand, with either 350 kWh or 400 kWh batteries, the operational costs are similar. However, the advanced charging management system reduces the global ratio per km by 1 Rs.

Table 66. Annual operating and maintenance cost analysis considering Incentive EV tariff - Khapri Naka depot

Bus motorization	Electric buses				
Battery capacity	350 kWh batteries		400 kWh batteries		Diesel buses
Charging option	Optimized (INR)	Normal (INR)	Optimized (INR)	Normal (INR)	
Energy / Fuel cost	**3,00,58,713**	**3,11,34,705**	**2,94,46,199**	**3,00,68,817**	**15,12,26,444**
Staff costs	**4,22,25,000**	**4,22,25,000**	**3,84,00,000**	**3,84,00,000**	**3,51,75,000**
Drivers	2,96,25,000	2,96,25,000	2,62,50,000	2,62,50,000	2,36,25,000
Operation staff	21,00,000	21,00,000	21,00,000	21,00,000	21,00,000
Maintenance staff	1,05,00,000	1,05,00,000	1,00,50,000	1,00,50,000	94,50,000
Maintenance costs	**2,23,56,798**	**2,18,56,798**	**2,15,44,224**	**2,10,44,224**	**2,60,40,600**
Vehicle maintenance	1,59,49,740	1,59,49,740	1,57,65,120	1,57,65,120	2,60,40,600
Electrical infrastructure	3,76,800	3,76,800	3,75,840	3,75,840	-
Charging infrastructure	55,30,258	55,30,258	49,03,264	49,03,264	-
Charging management system (advanced module)	5,00,000	0	5,00,000	0	-
Insurance	**3,90,00,923**	**3,90,00,923**	**3,69,85,860**	**3,69,85,860**	**98,43,750**
Overheads	**28,39,215**	**28,56,495**	**26,81,713**	**26,85,391**	**63,73,261**
TOTAL	**13.6 Crores / year**	**13.7 Crores / year**	**12.9 Crores / year**	**12.9 Crores / year**	**22.9 Crores / year**
Global ratio per km	**26 Rs / km**	**26 Rs / km**	**25 Rs / km**	**25 Rs / km**	**44 Rs / km**
OPEX ratios	**Electric buses**				**Diesel buses**
Energy / Fuel cost	6 Rs / km	6 Rs / km	6 Rs / km	6 Rs / km	29 Rs / km
Operating (drivers + operation staff)	6 Rs / km	6 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km
Vehicle maintenance (staff + spare parts)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	7 Rs / km
Infrastructure maintenance (staff + spare parts)	1 Rs / km	1 Rs / km	1 Rs / km	1 Rs / km	-
Global ratio (excluding insurance and overheads)	18 Rs / km	18 Rs / km	17 Rs / km	17 Rs / km	41 Rs / km

Table 67. Annual operating and maintenance cost analysis considering Public Service tariff - Khapri Naka depot

Bus motorization	Electric buses				
Battery capacity	350 kWh batteries		400 kWh batteries		Diesel buses
Charging option	Optimized (INR)	Normal (INR)	Optimized (INR)	Normal (INR)	
Energy / Fuel cost	**6,16,10,242**	**6,77,75,563**	**6,12,59,360**	**6,64,01,540**	**15,12,26,444**
Staff costs	**4,22,25,000**	**4,22,25,000**	**3,84,00,000**	**3,84,00,000**	**3,51,75,000**
Drivers	2,96,25,000	2,96,25,000	2,62,50,000	2,62,50,000	2,36,25,000
Operation staff	21,00,000	21,00,000	21,00,000	21,00,000	21,00,000
Maintenance staff	1,05,00,000	1,05,00,000	1,00,50,000	1,00,50,000	94,50,000
Maintenance costs	**2,23,56,798**	**2,18,56,798**	**2,15,44,224**	**2,10,44,224**	**2,60,40,600**
Vehicle maintenance	1,59,49,740	1,59,49,740	1,57,65,120	1,57,65,120	2,60,40,600
Electrical infrastructure	3,76,800	3,76,800	3,75,840	3,75,840	-
Charging infrastructure	55,30,258	55,30,258	49,03,264	49,03,264	-
Charging management system (advanced module)	5,00,000	0	5,00,000	0	-
Insurance	**3,90,00,923**	**3,90,00,923**	**3,69,85,860**	**3,69,85,860**	**98,43,750**
Overheads	**37,85,761**	**39,55,721**	**36,36,108**	**37,75,373**	**63,73,261**
TOTAL	**16.9 Crores / year**	**17.5 Crores / year**	**16.2 Crores / year**	**16.7 Crores / year**	**22.9 Crores / year**
Global ratio per km	**32 Rs / km**	**33 Rs / km**	**31 Rs / km**	**32 Rs / km**	**44 Rs / km**
OPEX ratios	**Electric buses**				**Diesel buses**
Energy / Fuel cost	12 Rs / km	13 Rs / km	12 Rs / km	13 Rs / km	29 Rs / km
Operating (drivers + operation staff)	6 Rs / km	6 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km
Vehicle maintenance (staff + spare parts)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	7 Rs / km
Infrastructure maintenance (staff + spare parts)	1 Rs / km	1 Rs / km	1 Rs / km	1 Rs / km	-
Global ratio (excluding insurance and overheads)	24 Rs / km	25 Rs / km	23 Rs / km	24 Rs / km	41 Rs / km

22.2.2 Higna Naka bus depot

22.2.2.1 Electric Vehicles Charging Stations tariff

Considering the Electric Vehicles Charging Stations incentive tariff, the annual operational and maintenance expenditures are presented in Table 68.

Regardless of the scenario, electric buses' operational costs per km are approximately half the operational costs of diesel buses. Energy/Fuel costs in particular are almost five times lower for electric buses than for diesel.

In addition, increasing the size of the batteries capacity slightly decreases the operational costs (lower insurance costs due to the lower number of buses + lower number of kilometres with 400 kWh batteries).

Besides, it is noted that charging optimization allows to reduce to a very limited extent the energy cost. Nonetheless, the advanced charging management system maintenance costs cancel the positive effect on energy costs due to the incentive EV tariff.

22.2.2.2 Public service tariff

When considering the Public Service tariff, the annual operational and maintenance expenditures are presented in Table 69. Values modified in comparison with the incentive tariff are identifier in **dark red**.

Increasing the cost of electricity decreases the gap between electric and diesel buses. The operational costs per kilometre of electric vehicles are 25% lower than those of diesel vehicles.

On the other hand, with either 350 kWh or 400 kWh batteries, the operational costs are similar. However, the advanced charging management system reduces the global ratio per km by 1 Rs.

Table 68. Annual operating and maintenance cost analysis considering Incentive EV tariff - Higna Naka depot

Bus motorization	Electric buses				
Battery capacity	350 kWh batteries		400 kWh batteries		Diesel buses
Charging option	Optimized (INR)	Normal (INR)	Optimized (INR)	Normal (INR)	
Energy / Fuel cost	**2,92,29,521**	**2,93,71,521**	**2,90,86,197**	**2,93,51,149**	**14,68,03,579**
Staff costs	**3,84,75,000**	**3,84,75,000**	**3,75,75,000**	**3,75,75,000**	**3,75,75,000**
Drivers	2,58,75,000	2,58,75,000	2,51,25,000	2,51,25,000	2,51,25,000
Operation staff	24,00,000	24,00,000	24,00,000	24,00,000	24,00,000
Maintenance staff	1,02,00,000	1,02,00,000	1,00,50,000	1,00,50,000	1,00,50,000
Maintenance costs	**2,18,63,299**	**2,13,63,299**	**2,12,28,264**	**2,07,28,264**	**2,52,79,000**
Vehicle maintenance	1,52,01,060	1,52,01,060	1,51,67,400	1,51,67,400	2,52,79,000
Electrical infrastructure	6,58,560	6,58,560	6,57,600	6,57,600	0
Charging infrastructure	55,03,679	55,03,679	49,03,264	49,03,264	0
Charging management system (advanced module)	5,00,000	0	5,00,000	0	0
Insurance	**3,85,35,119**	**3,85,35,119**	**3,73,73,280**	**3,73,73,280**	**1,04,68,750**
Overheads	**26,87,035**	**26,76,295**	**26,36,684**	**26,29,632**	**62,89,727**
TOTAL	**13.1 Crores / year**	**13.0 Crores / year**	**12.8 Crores / year**	**12.8 Crores / year**	**22.6 Crores / year**
Global ratio per km	**26 Rs / km**	**26 Rs / km**	**25 Rs / km**	**25 Rs / km**	**45 Rs / km**
OPEX ratios	**Electric buses**				**Diesel buses**
Energy / Fuel cost	6 Rs / km	6 Rs / km	6 Rs / km	6 Rs / km	29 Rs / km
Operating (drivers + operation staff)	6 Rs / km	6 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km
Vehicle maintenance (staff + spare parts)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	7 Rs / km
Infrastructure maintenance (staff + spare parts)	1 Rs / km	1 Rs / km	1 Rs / km	1 Rs / km	-
Global ratio (excluding insurance and overheads)	18 Rs / km	18 Rs / km	17 Rs / km	17 Rs / km	41 Rs / km

Table 69. Annual operating and maintenance cost analysis considering Public Service tariff - Higna Naka depot

Bus motorization	Electric buses				
Battery capacity	350 kWh batteries		400 kWh batteries		Diesel buses
Charging option	Optimized (INR)	Normal (INR)	Optimized (INR)	Normal (INR)	
Energy / Fuel cost	**6,18,72,056**	**6,45,86,290**	**6,18,41,939**	**6,54,70,559**	**14,68,03,579**
Staff costs	**3,84,75,000**	**3,84,75,000**	**3,75,75,000**	**3,75,75,000**	**3,75,75,000**
Drivers	2,58,75,000	2,58,75,000	2,51,25,000	2,51,25,000	2,51,25,000
Operation staff	24,00,000	24,00,000	24,00,000	24,00,000	24,00,000
Maintenance staff	1,02,00,000	1,02,00,000	1,00,50,000	1,00,50,000	1,00,50,000
Maintenance costs	**2,18,63,299**	**2,13,63,299**	**2,12,28,264**	**2,07,28,264**	**2,52,79,000**
Vehicle maintenance	1,52,01,060	1,52,01,060	1,51,67,400	1,51,67,400	2,52,79,000
Electrical infrastructure	6,58,560	6,58,560	6,57,600	6,57,600	0
Charging infrastructure	55,03,679	55,03,679	49,03,264	49,03,264	0
Charging management system (advanced module)	5,00,000	0	5,00,000	0	0
Insurance	**3,85,35,119**	**3,85,35,119**	**3,73,73,280**	**3,73,73,280**	**1,04,68,750**
Overheads	**36,66,311**	**37,32,738**	**36,19,356**	**37,13,215**	**62,89,727**
TOTAL	**16.4 Crores / year**	**16.7 Crores / year**	**16.2 Crores / year**	**16.5 Crores / year**	**22.6 Crores / year**
Global ratio per km	**32 Rs / km**	**33 Rs / km**	**32 Rs / km**	**33 Rs / km**	**45 Rs / km**
OPEX ratios	**Electric buses**				**Diesel buses**
Energy / Fuel cost	12 Rs / km	13 Rs / km	12 Rs / km	13 Rs / km	29 Rs / km
Operating (drivers + operation staff)	6 Rs / km	6 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km
Vehicle maintenance (staff + spare parts)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	7 Rs / km
Infrastructure maintenance (staff + spare parts)	1 Rs / km	1 Rs / km	1 Rs / km	1 Rs / km	-
Global ratio (excluding insurance and overheads)	24 Rs / km	25 Rs / km	24 Rs / km	24 Rs / km	41 Rs / km

22.2.3 Patwardhan 2 bus depot

22.2.3.1 Electric Vehicles Charging Stations tariff

Considering the Electric Vehicles Charging Stations incentive tariff, the annual operational and maintenance expenditures are presented in Table 70.

Regardless of the scenario, electric buses' operational costs per km are approximately half the operational costs of diesel buses. Energy/Fuel costs in particular are almost five times lower for electric buses than for diesel.

In addition, increasing the size of the batteries capacity slightly decreases the operational costs (lower insurance costs due to the lower number of buses + lower number of kilometres with 400 kWh batteries).

Besides, it is noted that charging optimization allows to reduce to a very limited extent the energy cost. Nonetheless, the advanced charging management system maintenance costs cancel the positive effect on energy costs due to the incentive EV tariff.

22.2.3.2 Public service tariff

When considering the Public Service tariff, the annual operational and maintenance expenditures are presented in Table 71. Values modified in comparison with the incentive tariff are identifier in **dark red**.

Increasing the cost of electricity decreases the gap between electric and diesel buses. The operational costs per kilometre of electric vehicles are 33% lower than those of diesel vehicles.

On the other hand, with either 350 kWh or 400 kWh batteries, the operational costs are similar. However, the advanced charging management system reduces the global ratio per km by 1 Rs.

Table 70. Annual operating and maintenance cost analysis considering incentive tariff - Patwardhan 2 depot

Bus motorization	Electric buses				
Battery capacity	350 kWh batteries		400 kWh batteries		Diesel buses
Charging option	Optimized (INR)	Normal (INR)	Optimized (INR)	Normal (INR)	
Energy / Fuel cost	**2,50,24,855**	**2,54,79,957**	**2,48,89,934**	**2,52,19,694**	**13,73,16,139**
Staff costs	**3,24,75,000**	**3,24,75,000**	**2,97,00,000**	**2,97,00,000**	**2,97,00,000**
Drivers	2,21,25,000	2,21,25,000	1,95,00,000	1,95,00,000	1,95,00,000
Operation staff	24,00,000	24,00,000	24,00,000	24,00,000	24,00,000
Maintenance staff	79,50,000	79,50,000	78,00,000	78,00,000	78,00,000
Maintenance costs	**1,93,31,898**	**1,88,31,898**	**1,87,99,853**	**1,82,99,853**	**2,36,45,300**
Vehicle maintenance	1,42,04,520	1,42,04,520	1,41,87,180	1,41,87,180	2,36,45,300
Electrical infrastructure	3,23,040	3,23,040	3,22,080	3,22,080	-
Charging infrastructure	43,04,338	43,04,338	37,90,593	37,90,593	-
Charging management system (advanced module)	5,00,000	0	5,00,000	0	-
Insurance	**3,00,14,603**	**3,00,14,603**	**2,89,61,101**	**2,89,61,101**	**81,25,000**
Overheads	**23,04,953**	**23,03,606**	**22,01,694**	**21,96,586**	**57,19,843**
TOTAL	**10.9 Crores / year**	**10.9 Crores / year**	**10.4 Crores / year**	**10.4 Crores / year**	**20.5 Crores / year**
Global ratio per km	**23 Rs / km**	**23 Rs / km**	**22 Rs / km**	**22 Rs / km**	**43 Rs / km**
OPEX ratios	**Electric buses**				**Diesel buses**
Energy / Fuel cost	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	29 Rs / km
Operating (drivers + operation staff)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km
Vehicle maintenance (staff + spare parts)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	7 Rs / km
Infrastructure maintenance (staff + spare parts)	1 Rs / km	1 Rs / km	1 Rs / km	1 Rs / km	-
Global ratio (excluding insurance and overheads)	16 Rs / km	16 Rs / km	16 Rs / km	15 Rs / km	40 Rs / km

Table 71. Annual operating and maintenance cost analysis considering public service tariff - Patwardhan 2 depot

Bus motorization	Electric buses				
Battery capacity	350 kWh batteries		400 kWh batteries		Diesel buses
Charging option	Optimized (INR)	Normal (INR)	Optimized (INR)	Normal (INR)	
Energy / Fuel cost	**54 396 351**	**58 618 757**	**54 704 388**	**57 974 643**	**13,73,16,139**
Staff costs	**3,24,75,000**	**3,24,75,000**	**2,97,00,000**	**2,97,00,000**	**2,97,00,000**
Drivers	2,21,25,000	2,21,25,000	1,95,00,000	1,95,00,000	1,95,00,000
Operation staff	24,00,000	24,00,000	24,00,000	24,00,000	24,00,000
Maintenance staff	79,50,000	79,50,000	78,00,000	78,00,000	78,00,000
Maintenance costs	**1,93,31,898**	**1,88,31,898**	**1,87,99,853**	**1,82,99,853**	**2,36,45,300**
Vehicle maintenance	1,42,04,520	1,42,04,520	1,41,87,180	1,41,87,180	2,36,45,300
Electrical infrastructure	3,23,040	3,23,040	3,22,080	3,22,080	-
Charging infrastructure	43,04,338	43,04,338	37,90,593	37,90,593	-
Charging management system (advanced module)	5,00,000	0	5,00,000	0	-
Insurance	**3,00,14,603**	**3,00,14,603**	**2,89,61,101**	**2,89,61,101**	**81,25,000**
Overheads	**3 186 097**	**3 297 770**	**3 096 127**	**3 179 235**	**57,19,843**
TOTAL	**13.9 Crores / year**	**14.3 Crores / year**	**13.5 Crores / year**	**13.8 Crores / year**	**20.5 Crores / year**
Global ratio per km	**29 Rs / km**	**30 Rs / km**	**29 Rs / km**	**29 Rs / km**	**43 Rs / km**
OPEX ratios	**Electric buses**				**Diesel buses**
Energy / Fuel cost	11 Rs / km	12 Rs / km	12 Rs / km	12 Rs / km	29 Rs / km
Operating (drivers + operation staff)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km
Vehicle maintenance (staff + spare parts)	5 Rs / km	5 Rs / km	5 Rs / km	5 Rs / km	7 Rs / km
Infrastructure maintenance (staff + spare parts)	1 Rs / km	1 Rs / km	1 Rs / km	1 Rs / km	-
Global ratio (excluding insurance and overheads)	22 Rs / km	23 Rs / km	22 Rs / km	22 Rs / km	40 Rs / km

22.3 Conclusions on CAPEX and OPEX analysis

The CAPEX and OPEX cost analysis show that the electrification option considering buses with 350 kWh battery capacity is generally cheaper than the option using 400 kWh batteries. Nonetheless, for Khapri Naka depot, the number of additional buses caused by the reduction in battery capacity induces a significant increase in CAPEX. This CAPEX increase is not compensated by the reduced-capacity-batteries (lower unitary prices).

Regarding OPEX, due to the highly subsidised incentive tariff, operating electric buses is significantly cheaper than operating diesel buses. The impact of battery capacity is almost negligible, as well as the potential savings allowed by charging optimization. However, it is to be noted that **a charging management system is very beneficial to operations and thus highly recommended for Nagpur City Service E-buses**. Charging management systems increase the flexibility of depot bus charging and allow a precise follow-up of the state of charge of the vehicles in real time. In a case of energy supply failure or electrical infrastructure malfunction, for instance, the charging schedule can be automatically adapted by the charging management system to limit the impacts on bus operation.

23. Environmental issues and overall assessment of impacts

23.1 General information on pollutants

The electrification of the bus fleet will yield positive externalities such as air pollution reduction or mitigation of greenhouse gas emissions. It is important to distinguish these two types of pollutants which have very different consequences and range of action.

23.1.1 Greenhouse gases

Greenhouse gases (GHG) have a global effect on the environment. The increase in the concentration of greenhouse gases in the atmosphere is one of the main accelerators of global warming. As their name implies, greenhouse gases intercept infrared radiation emitted by the earth's surface. The additional greenhouse effect induced by the increase in the concentration of GHGs traps the infrared radiation which can no longer escape from the atmosphere. They are thus reflected back to the earth's surface.

As a result, radiative forcing, which measures the difference between the energy entering the Earth's atmosphere and the energy leaving it, increases. The total energy contained in the atmosphere tends to increase. As a result, the temperature of the atmosphere, land surface and oceans increase.

Among the greenhouse gases, some are natural, while others are purely anthropogenic (i.e., "created" by man). Among the first ones, we can mention water vapor H_2O, carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, ozone O_3 or fluorinated gases. The halocarbons belong to the second family and have an even greater warming power than the previous ones.

If water vapor is the gas that contributes the most to the greenhouse effect, human emissions of water vapor do not contribute to the increase of the concentration of water vapor in the atmosphere. On the other hand, CO_2 contributes very strongly to the additional greenhouse effect induced by human activities. It accounts for about 65% of anthropogenic emissions. Its origin comes mainly from the combustion of fossil fuels. For the other gases, it is estimated that methane accounts for 15% of the additional greenhouse effect, halocarbons 10% and nitrous oxide 5%. Moreover, to simplify the analysis and to adopt a unique unit for comparison reasons, CO_2 is taken, by convention, as the reference unit to which all the other gases refer. Although CH_4 has a relatively short lifetime in the atmosphere (about ten years before being partly transformed into CO_2), it has a global warming potential 25 times higher than CO_2. CO_2, on the other hand, has a lifetime of about 100 years, which means that today's emissions will still have an impact in the next 100 years. N_2O has a lifespan of about 120 years and in addition has a global warming potential of 300 times that of CO_2.

We are therefore talking about a global scale, because the GHG emissions of yesterday, today, and tomorrow, because of their lifetime in the atmosphere, influence the climate on a planetary scale.

The objective of limiting global warming to 2°C by 2100 as set by the Paris Agreements in 2015 therefore requires a drastic reduction of these GHG emissions to reach net zero emissions in 2050.

23.1.2 Air pollutants

Air pollutants have effects on a local scale. They are characterized by their direct impact on the health of local populations or ecosystems. The concentration of these pollutants in the air makes it possible to estimate the air quality index. This pollution is directly generated by the human activities of the territory (or of the neighbouring territories being given air flows). It therefore varies greatly from region to region.

Among the main air pollutants, we find NOx, CO, HC or particulate matter. Some of them can have negative impacts on health and/or on the environment.

- **NOx: Nitrogen oxides (NO and NO_2)** have health and environmental impacts. NOx can cause respiratory irritation for sensitive individuals and children. On the environmental side, they contribute to the acidification of the environment but also promote the formation of ozone in the lower layers of the atmosphere.
- **CO: Carbon monoxide** can also have an impact on health and the environment. Since it influences the oxidizing power of the atmosphere, it contributes to the increase in concentrations of methane and nitrous oxide (a gas 300 times more warming than CO_2) which are powerful greenhouse gases. It can also have harmful consequences on health. Indeed, in high concentrations, it can affect the central nervous system by binding to haemoglobin and taking the place of oxygen.
- **HC: Unburned hydrocarbons** participate in the formation of ozone, a gas with a strong warming power. It can also have an impact on health since it has a depressing effect on the nervous system and thus promotes anxiety or depression. Moreover, if an individual is chronically exposed to it, he or she can develop brain degeneration.
- **PM: Suspended particulate matter** can also have adverse health effects, particularly on the cardiovascular and respiratory systems. Since they are micrometric in size, they can lodge in the respiratory tract and even in the alveoli. They are classified as certain carcinogens for humans.

23.2 Assumptions for the environmental impact overall analysis

To correctly quantify the benefits of electric buses compared to diesel buses, several assumptions need to be made.

23.2.1 Greenhouse gas emissions

23.2.1.1 Life cycle analysis of vehicles

Bus manufacturing is a non-negligible component regarding the total GHG emissions of a vehicle. During bus production, several processes generate GHG emissions such as raw material extraction, material processing, component production (chassis, frame, body, powertrain, etc). The emission factor for diesel, CNG and electric bus production (excluding batteries), is estimated at 100 tCO_2eq on average for 12-m buses[21].

For electric buses, the contribution of battery production must be added. The emission factor greatly depends on the country in which the battery is built, especially the grid emission factor, and the battery composition. Countries which produce batteries with a fossil fuel-rich mix for both electricity and heat, emit approximately 106 $kgCO_2eq$ per kWh capacity for cell production, pack assembly and including upstream materials[22]. Thus, 400-kWh battery production is responsible for the emission of approximately 42 tCO_2eq.

23.2.1.2 Energy production and consumption

Apart from the GHG emissions attributed to the manufacture of the vehicle, a large part of the emissions originates from both energy production (Well-To-Tank) and combustion (Tank-To-Wheel). For internal combustion engine (such as CNG or Diesel Buses), emissions come mainly from fuel combustion but upstream emissions from both CNG and diesel production are not negligible. Battery electric buses have zero tailpipe emissions. Their environmental impact depends on how the electricity is produced.

According to India GHG Program, the tailpipe emission factor for diesel and CNG is respectively equal to 2.6444 $kgCO_2/l$ and 2.692 $kgCO_2/kg$[23]. According to Knobloch *et al.* (2020), upstream emissions from the extraction and processing of diesel account for 28% of the tank-to-wheel emissions (i.e., tailpipe emissions)[24]. Concerning CNG, according to the French Ministry for an Ecological and Solidary Transition, upstream phase accounts for 24% of the tailpipe emissions[25].

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[21] Kristoffer W. Lie et al., « The Carbon Footprint of Electrified City Buses: A Case Study in Trondheim, Norway », *Energies* 14, nº 3 (1 février 2021): 770, https://doi.org/10.3390/en14030770.

[22] Erik Emilsson et Lisbeth Dahllöf, « Lithium-Ion Vehicle Battery Production », s. d., 47.

[23] Chirag Gajjar, Atik Sheikh, et India GHG Program, « India Specific Road Transport Emission Factors », 2015, https://doi.org/10.13140/RG.2.2.28564.32646.

[24] Florian Knobloch et al., « Net Emission Reductions from Electric Cars and Heat Pumps in 59 World Regions over Time », *Nature Sustainability* 3, nº 6 (juin 2020): 437-47, https://doi.org/10.1038/s41893-020-0488-7.

[25] Ministry for an ecological and solidary Transition, « GHG information for transport services », juin 2019, https://www.ecologie.gouv.fr/sites/default/files/Information_GES%20-%202019.pdf.

In total, well-to-wheel (WTW) emissions for respectively diesel and CNG are 3.385 $kgCO_2/l$ and 3.338 $kgCO_2/kg$.

On the other hand, the International Energy Agency (IEA) reports a grid emission factor of 725 gCO_2/kWh for 2019[26]. According to its estimates based on stated policies (STEP), the grid emission factor should decrease to 537 gCO_2/kWh in 2030 and 336 gCO_2/kWh in 2040.

23.2.2 Air pollutants

Vehicles with internal combustion engine are not only responsible for the emission of greenhouse gases but also local pollutant such as nitrogen oxides (NOx), particulate matters (PM), carbon monoxide (CO), hydrocarbons (HCs), etc. Air pollutants have a direct impact on the health of local populations. It is estimated that 8 million people die prematurely each year because of air pollution (especially PM) from fossil fuels (i.e., about one in five deaths)[27].

To reduce air pollutants, European standards have been imposed on bus vehicle manufacturers since 1990 and introduced similarly in India since 2000 via the Bharat Stage Emission Standards (BSES), based on European regulations. As emission restriction thresholds have been lowered, the technical performance of thermal engines has been greatly improved.

Currently the most recent European standard for buses is the Euro VI standard. Its equivalent in India, Bharat Stage VI (BS-VI), is applied nationwide since April 2020. The new standard imposes very low emission thresholds compared to older regulations.

Quantifying air pollutant emissions is an intricate exercise since the emission rates depend on the type of driving, motor combustion, the frequency of acceleration and deceleration, bus power…

However, feedbacks show that CNG buses emit about 10 times less PM than their diesel counterparts.

An estimation of air pollutants emission's reduction is done hereafter according to BS-VI standard for both CNG and diesel buses.

23.3 Estimation of emissions

The estimation of emissions presented is based on the "400 kWh batteries" scenario results. According to this scenario, on average, vehicles are expected to carry out approximately 80,900 kilometres each year. For the three bus depots, 182 diesel or CNG buses would be necessary, compared to 186 battery electric buses.

[26] International Energy Agency, *India Energy Outlook 2021* (OECD, 2021), https://doi.org/10.1787/ec2fd78d-en.
[27] Karn Vohra et al., « Global Mortality from Outdoor Fine Particle Pollution Generated by Fossil Fuel Combustion: Results from GEOS-Chem », *Environmental Research* 195 (avril 2021): 110754, https://doi.org/10.1016/j.envres.2021.110754.

The scenarios presented below compare the overall emissions of a fully Electric fleet and of a fully CNG/Diesel fleet. Greenhouse gases emissions for CNG buses are presented in the graphs but the comparison ("emission mitigation") is done between the 100% diesel and 100% electric scenarios.

Important disclaimer: the results presented hereafter are based on the results of the Pre-Feasibility Study as well as approximative data on buses operation collected during SETEC-NODALIS mission. Thus, they are to be considered for indicative and comparison reasons only and shall be thoroughly revised and updated in later stages of Bus Electrification Studies.

23.3.1 Greenhouse gas emissions

Figure 114 shows the CO_2 emission mitigation during the lifetime of vehicles depending on whether they are diesel, CNG or electric vehicles.

On average CNG buses do not reduce CO_2 emissions. Nonetheless, it greatly depends on CNG buses fuel consumption compared to diesel buses (taken at 1 kg of CNG for 1 litre of diesel here). In the best-case scenario, emission reduction can reach up to 20% approximately.

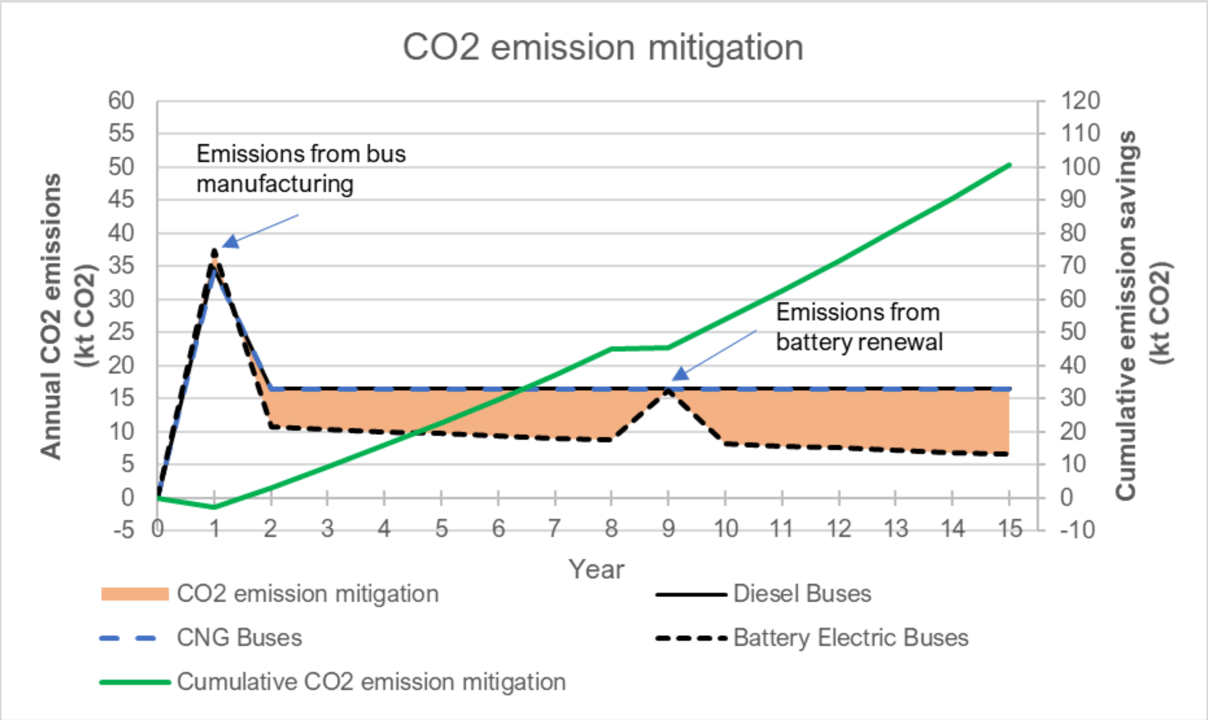


Figure 114. CO_2 emission mitigation estimations for Nagpur City Bus Service fleet

Regarding battery electric buses, emissions are generally lower than diesel buses. Even with a grid emission factor of approximately 700 gCO_2/kWh, battery electric buses emit over 30% less CO_2 than diesel buses. In 15 years, with the decarbonization of the electric mix, battery electric buses could emit almost 3 times less CO_2 than diesel buses. Electric vehicles achieve their maximum potential (regarding reducing emissions) as the electricity mix decarbonizes but, in any case, reduce greenhouse gas emissions compared to diesel vehicles.

Regarding electric bus emissions, two "emission peaks" exist, corresponding to bus and battery manufacturing. Battery electric buses manufacturing is greater than diesel buses production. Thus, if the emissions related to the production of vehicles and batteries are included in the year of purchase of the vehicles, the total emissions in the first year are higher for electric vehicles than for diesel vehicles. In the ninth year, the batteries must be renewed, inducing an increase of CO_2 emissions for electric buses.

In total, for the whole fleet and for a time span of 15 years, battery electric buses would save approximately 100 $ktCO_2$, or 38% of diesel buses total emissions.

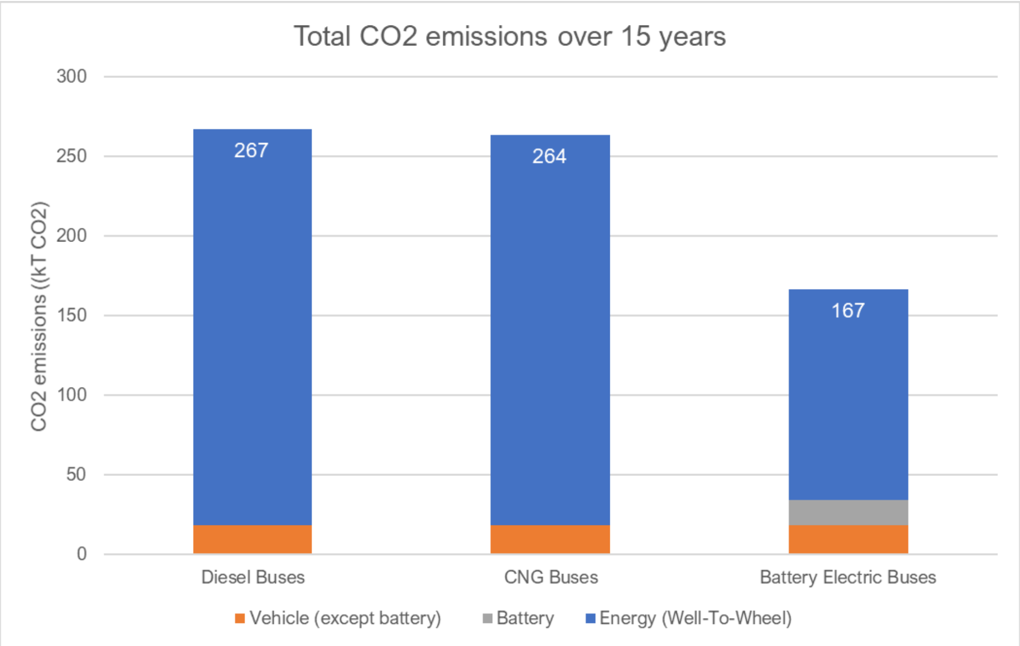


Figure 115. Estimation of total CO_2 emissions for 15 years for Nagpur City Bus Service fleet

On a per-kilometre basis, the diesel buses average emissions exceed 1,200 gCO_2/km whereas battery electric buses emissions are limited to 738 gCO_2/km.

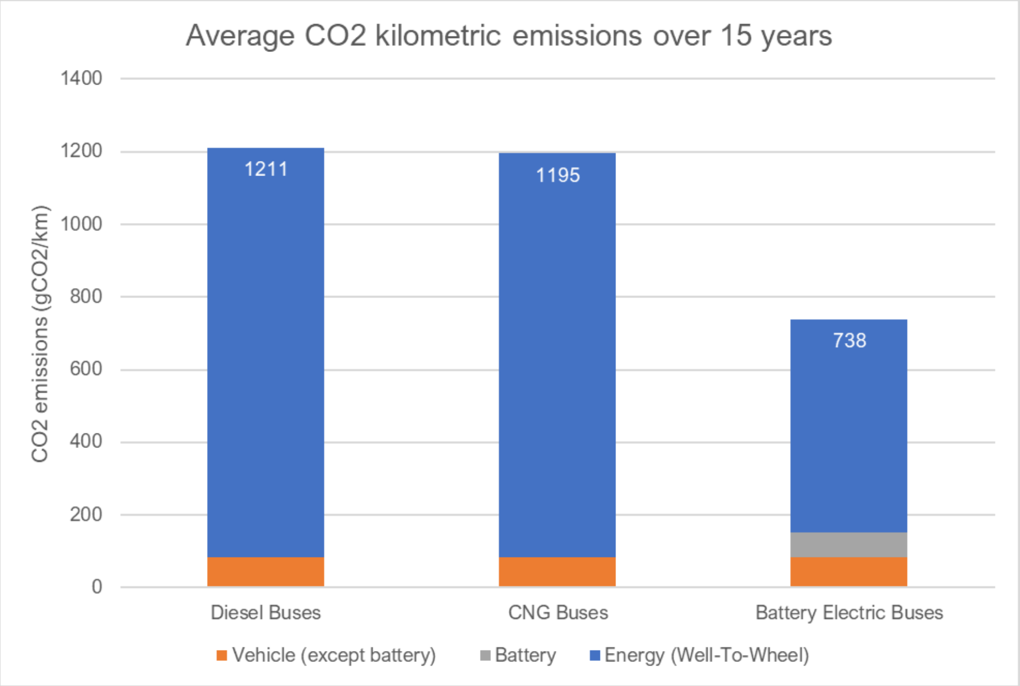


Figure 116. Estimation of CO_2 kilometric emissions for 15 years for Nagpur City Bus Service fleet

On the other hand, it can be noted a low share of “vehicle (+ battery)” manufacturing emissions on the overall life cycle, even for battery electric buses (20% for electric buses and 7% for diesel buses).

23.3.2 Air pollutants’ emissions

CNG and diesel buses emit almost the same amount CO, HC and NOx whereas battery electric buses do not release this kind of pollutants during operation (tailpipe emissions).

Since the volume of air pollutants emitted depends primarily on engine generation, it should remain approximately constant from year to year. For internal combustion engines, a next step on lowering air pollutants’ emissions shall come when new emission standards are introduced.

Figure 117 and Figure 118 illustrate the estimated annual emissions for each air pollutant for the required Nagpur City Bus Service fleet.

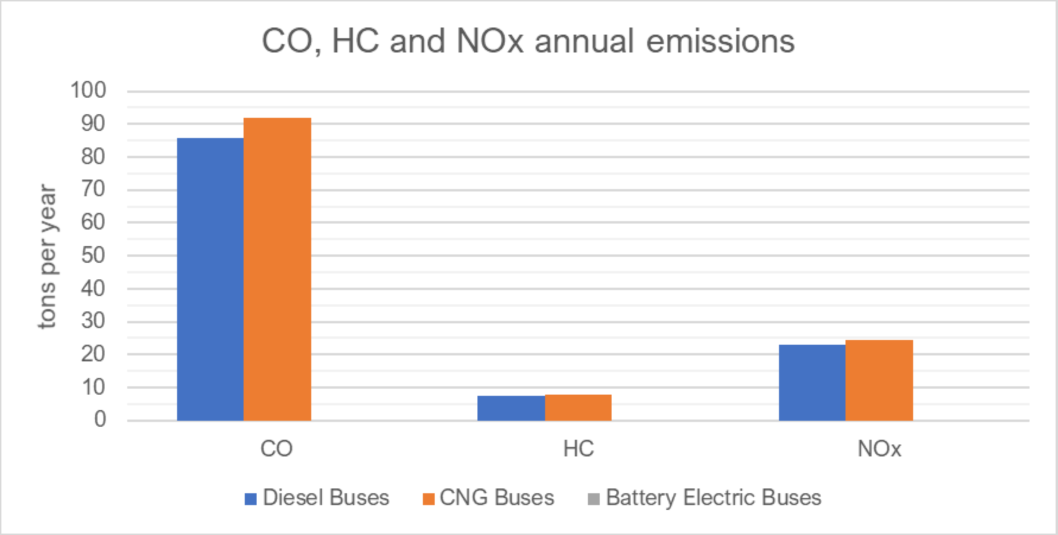


Figure 117. HC, CO, and NOx estimated annual emissions for Nagpur City Bus Service fleet

Each year, approximately 90 tons of carbon monoxide, 10 tons of hydrocarbon and 25 tons of nitrogen oxides would be saved thanks to the conversion from thermal to battery electric buses.

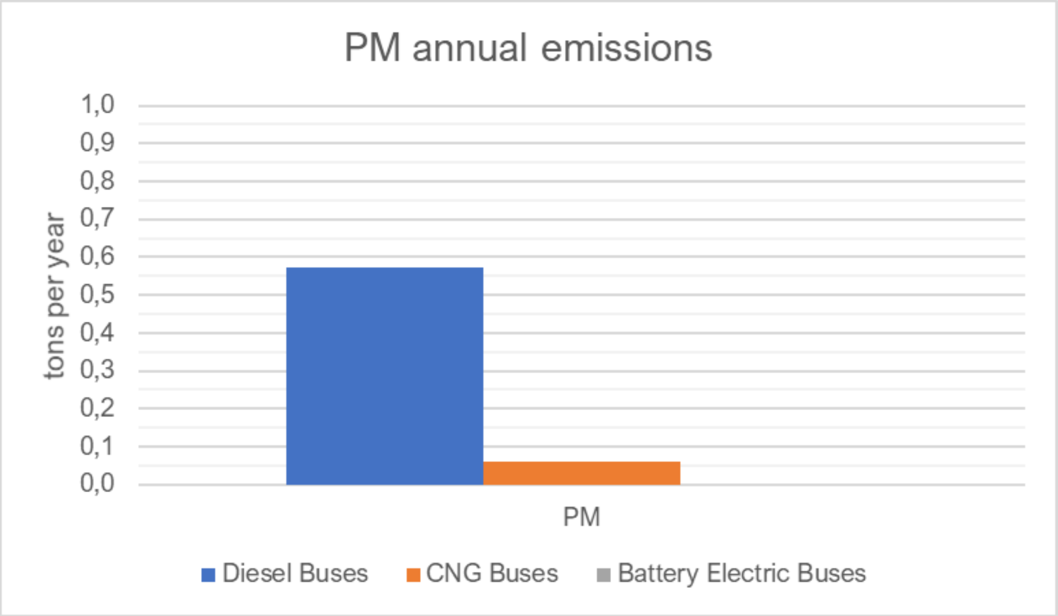


Figure 118. PM estimated annual emissions for Nagpur City Bus Service fleet

Regarding particulate matter, CNG buses already allow a great reduction of emissions compared to diesel buses. In the estimations, diesel buses would emit approximately 600 kg of PM each year, while CNG buses would emit around 60 kg of PM / year.

CITY BUS SERVICE FINANCIAL ASSESSMENT

This section presents a financial assessment of the Nagpur City Bus Service (revenues, expenses, viability). It firstly presents an overview of the current situation then provides a financial assessment of possible scenarios for bus fleet upgrade (electrification) and augmentation, as well as a review of the possible levers to enhance the financial sustainability of the system.

> Overview of the current financial situation of bus services in Nagpur
> Financial assessment of future bus fleet upgrade and augmentation plans
> Enhancing Nagpur City Bus System’s financial sustainability

24. Overview of the current financial situation of bus services in Nagpur

This section provides an overview of the financial situation of bus services in Nagpur based on the financial data received. The latter includes:

- Total monthly revenues collected by NMC for the period between December 2016 and January 2020, including revenues from: tickets, passes, Compound Ticket Fine (CFT) and other receipts (Excess, Miscellaneous),
- Monthly payments of NMC to bus operators, DIMTS and fare collection agencies for the period between December 2016 and January 2020.

The analysis of the service cashflows shows that operating revenues only cover a limited amount of the service costs. The coverage ratio was estimated at around 40%, 36% and 43%, in 2019, 2018 and 2017, respectively.

Significantly, what appears to be a significant increase in supply between 2018 and 2017, has not been met with a proportional increase in demand (the 2019 coverage ratio is still below the 2017 coverage ratio, despite some level of revenue ramp-up from 2018 to 2019). This points to the need to assess with caution the possible gross revenue and viability gap consequences of large increases in bus-km offered.

In 2019, NMC had to ensure an annual viability gap of around INR 94.2 Crores (around 11 M€ at current exchange rates, representing an annual viability gap per bus in the fleet of INR 21,66,606[28], or about 25,000€).

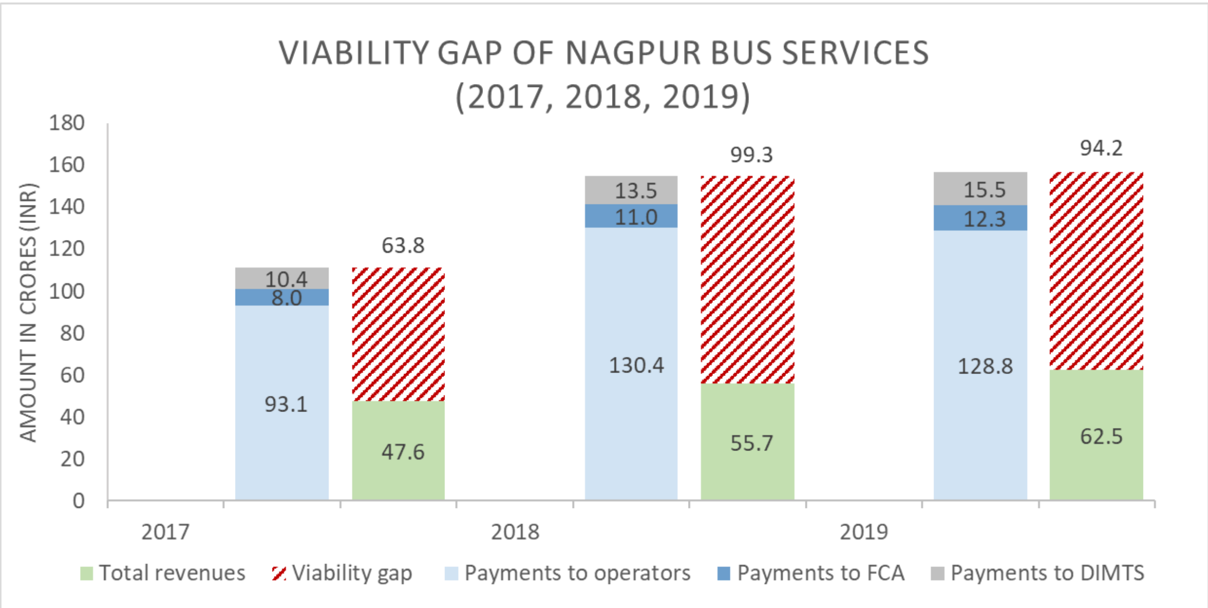


Figure 119. Overview of the financial situation of bus services in Nagpur

[28] Assuming 437 buses in the total fleet.

25. Financial assessment of future bus fleet upgrade and augmentation plans

25.1 Objectives and general approach

The objective of this chapter is to provide a summary of the financial assessment of the possible bus fleet augmentation and upgrade plans for the bus services in Nagpur conducted throughout the study.

A mid-term vision for the future of Nagpur's public transport was developed based on the available planning documents. This vision suggests a diesel-to-electric bus fleet transition with both a replacement of the existing diesel buses by electric ones and the augmentation of the overall fleet.

However, as discussed, the available planning documents and data do not provide for a reliable estimation of the expected ridership levels for the bus augmentation and upgrade plan. Ridership forecasts provided by the CMP (2018) appear to be overestimated when compared to the current ridership data. Hence, there are no consistent forecasts of the service revenues that could be used to assess the impact of the mid-term vision on NMC's overall financial situation.

Given all the above, in the current study, we focused on identifying the impact of electrification independently of the growth plan, and we have proceeded as follows:

- **We first assessed the impact of three possible fleet replacement scenarios on the financial sustainability of the service**, assuming **constant** ridership levels, commercial revenues, and fleet over the analysis period (2022-2037):
  - **Scenario 1:** Replacement of 20% (88) of the network fleet with electric buses in 2022,
  - **Scenario 2:** Replacement of 50% (219) of the network fleet with electric buses in 2022,
  - **A reference scenario:** Replacement of diesel buses (with 0% new electric buses) and the same overall fleet in 2022.
- **At the pre-feasibility stage, it was agreed with NSSCDCL and NMC (with consent of AFD) to focus the rest of the study on the upcoming replacement (in 2022) of the existing 237 standard diesel buses currently operated by three different operators (79 each)**. Different electrification options were thus compared in order to provide clear operational recommendations to support the replacement.

Hence, operational simulations were conducted for all the routes operated by the existing standard diesel buses (to be replaced in 2022) using the service schedule data provided by NMC, in order to assess the expected impact on energy consumption and depots' infrastructure of the different electrification options.

The operational simulations found that the current operation plan of standard buses could be further optimised. As such, a reduced number of diesel buses (202 standard diesel buses compared to 237 currently) would be necessary for the same level of service. It was consequently assumed that the replacement of the existing 237 standard buses in 2022 will also be the opportunity to optimise the operation plan on routes operated by these buses, and hence only 202 new standard diesel buses would be necessary if no electrification was envisaged. The number of the necessary standard electric buses (if all of these routes were to be electrified) was then estimated based on the technical characteristics of batteries in each electrification scenario. This number is higher than the necessary 202 standard diesel buses, given the considerations of the battery autonomy and the resulting changes in the operation plan.

The following replacement scenarios were thus considered and assessed:

- **Reference scenario:** Replacement of standard diesel buses with new ones, with no new electric buses (replacement of the existing 237 standard diesel buses with 202 new standard diesel buses).
- **Scenario 1:** Replacement of standard diesel buses with new electric buses of 350 kWh of battery capacity (replacement of the existing 237 standard diesel buses with 211 new standard electric buses of 350 kWh battery capacity).
- **Scenario 2:** Replacement of standard diesel buses with new electric buses of 400 kWh of battery capacity (replacement of the existing 237 standard diesel buses with 206 new standard electric buses of 400 kWh battery capacity).

The detailed assumptions for bus fleet replacement in these scenarios are presented in the table below. The existing midi and minibuses will also be replaced at the end of their contracts, but no technology changes are envisaged in these scenarios. The operation plans of the routes served by midi and minibuses have not been changed.

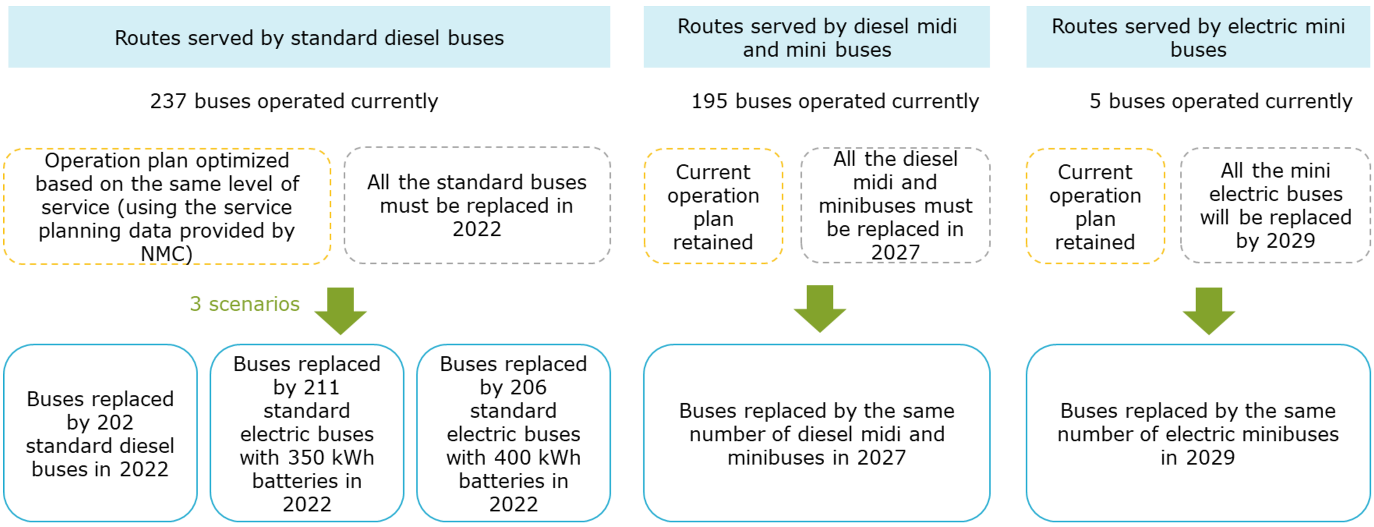


Figure 120. Characteristics of the Nagpur City Bus network replacement scenarios considered for the financial analysis at the prefeasibility stage

The financial assessment of these scenarios has also analysed the potential impact of the following parameters:

- The use or not of an advanced depot charging management system, and
- The electricity costs in Maharashtra state, by testing two possible tariffs: Electricity tariffs for EV charging stations (Tariff 1), and Electricity tariffs for public services (Tariff 2).

For clarity purposes, in the remainder of the report, these 2022 replacement scenarios will be called “**fleet replacement scenarios**”.

We also assessed the financial impact of the mid-term vision for Nagpur fleet augmentation and upgrade plan on the total bus service costs (without comparing these costs to an estimation of revenues). Early estimates were made in during Task 4 and were refined at the pre-feasibility stage (Task 6) to take into account the updated investment and operational costs. For clarity purposes, this scenario will be called “**fleet augmentation scenario**”.

In this chapter, we present the general financial modelling approach, the detailed assumptions as well as the main modelling results for the fleet replacement scenarios retained at the prefeasibility stage and the fleet augmentation scenario.

Table 72. Detailed bus replacement scenarios considered in the prefeasibility analysis

	Current fleet	2022	2027	2029
Reference scenario: Replacement with diesel buses (with 0% new electric buses)				
Standard diesel buses (operation plan optimized)	237 buses	237 buses replaced by 202 new standard diesel buses	no evolution	no evolution
Diesel midi and minibuses (no change in operation plan)	195 buses	no evolution	195 buses replaced by 195 diesel midi and minibuses	no evolution
Electric minibuses (no change in operation plan)	5 buses	no evolution	no evolution	5 buses replaced by 5 mini electric buses
Total bus fleet	**437**	**402**	**402**	**402**
Scenario 1: Electric - 350 kWh batteries				
Standard diesel buses (operation plan optimized)	237 buses	237 buses replaced by 211 new standard electric buses with 350 kWh batteries	no evolution	no evolution
Diesel midi and minibuses (no change in operation plan)	195 buses	no evolution	195 buses replaced by 195 diesel midi and minibuses	no evolution
Electric minibuses (no change in operation plan)	5 buses	no evolution	no evolution	5 buses replaced by 5 mini electric buses
Total bus fleet	**437**	**411**	**411**	**411**

	Current fleet	2022	2027	2029
Scenario 2: Electric - 400 kWh batteries				
Standard diesel buses (operation plan optimized)	237 buses	237 buses replaced by 206 new standard electric buses with 400 kWh batteries	no evolution	no evolution
Diesel midi and minibuses (no change in operation plan)	195 buses	no evolution	195 buses replaced by 195 diesel midi and minibuses	no evolution
Electric minibuses (no change in operation plan)	5 buses	no evolution	no evolution	5 buses replaced by 5 mini electric buses
Total bus fleet	**437**	**406**	**406**	**406**

25.2 Financial modelling approach and assumptions

25.2.1 Overview of the model

A financial model was used to assess the financial sustainability of the different scenarios detailed in Table 72. The model allows for the estimation of the total service costs for NMC and revenues of each analysed scenario and includes modules for the estimation of the kilometre charge applied by operators for the different types of buses.

The model's main parameters are:

- An analysis period of 15 years starting 2022,
- Number of replaced buses and new electric buses,
- Average bus tariff: a constant average bus tariff was considered (0% growth rate, in real terms). However, other growth rates can be defined in the model,
- Ridership growth rates: constant ridership levels were considered (0% growth rate). However, other growth rates can be defined in the model, and
- Indexation parameters: all revenues and costs in the model were indexed to inflation. However, other indexation parameters can be defined.

Based on the available financial and operational data, as well as the assumptions detailed in the next sections, the model provides the following main outputs:

- Forecasts of service revenues (i.e., fare box and non-fare box revenues)[29],
- Forecasts of the service costs: payments to operators, payments to DIMTS, and payments to fare collection agencies.
- Estimation of the viability gap over the analysed period.

[29] No growth rate is applied. Only indexation to inflation is considered.

25.2.2 General assumptions

The general assumptions used in the model are related to:

- Investment (CAPEX) and operation and maintenance (OPEX) costs,
- Operational assumptions for electric and diesel buses, and
- Macroeconomic parameters (inflation).

25.2.3 Estimation of the service operating costs – Payments to bus operators

Payments to bus operators are based on the operated bus.kilometres and the applicable kilometre charge for each type of bus. Considering current contracts with Nagpur City Bus Service operators, a base kilometre charge is defined at the bidding stage and revised (based on indexation formulas) throughout the contract period.

In order to estimate payments to bus operators, it is thus necessary to estimate the applicable kilometre charge for each type of bus, as well as the yearly operated number of bus.kilometres.

25.2.3.1 Kilometre charge

The kilometre charges of all types of buses operated in Nagpur were estimated and refined later to take into account the updated investment and operation costs as well as the new operational assumptions for the new diesel and electric standard buses in the replacement scenarios.

The base kilometre charges for the existing diesel buses and electric minibuses were not changed.

EXISTING DIESEL BUSES

Currently, there are three diesel bus operators (R.K. City Bus Operation, Travel Time Car Rental, and Hansa City Bus Services) operating each:

- 79 NMC-owned buses,
- 50 operator owned midi buses, and
- 15 operator owned minibuses.

Up to date, we have received only the contract of Hansa City Bus Services. Therefore, **in this analysis, we assume that the other two diesel operators apply the same kilometre charges**.

The detailed base kilometre charges and the corresponding bus types are presented in Table 73.

Table 73. Base kilometre charge for buses operated by Hansa City Bus Services (2016)

Base kilometre charge	INR / km
Diesel standard NMC owned buses	49.00
Diesel midi bus Operator owned buses	45.00
Diesel minibus Operator owned buses	35.00

Note: This corresponds to the **Base kilometre charge** stated in the contract of Hansa City Bus Services. These figures were adjusted to inflation over the analysis period to estimate the **applicable kilometre charge** for each year.

It shall be noted that:

- The kilometre charge for diesel standard NMC owned buses does not include investment costs for vehicles as these are provided by NMC. It however includes a repair cost to be borne by the operator at the beginning of the contract,
- The kilometre charges for midi and mini diesel buses take into account the investment cost of vehicles as these are provided by the operator.

These base kilometre charges will be used to estimate the applicable kilometre charge for the existing diesel buses until the end of their contracts. In the model, the applicable kilometre charge corresponds to the revised base kilometre charge to adjust to inflation.

- Estimation of diesel bus operators' profit

The objective of this section is to determine the operators' profit margin on the actual costs incurred and that will be applied to the new buses. Table 74 presents the estimated kilometre charge for the existing buses and compared it to the actual figures charged by the operators.

This analysis was limited to the existing diesel standard buses as we assume that the profit margin will be the same at least for the other types of diesel buses.

Table 74. Comparison of the estimated and actual kilometre charge for existing diesel standard buses (2019)

Kilometre charge 2019 (INR/km)		Estimated profit
Estimation*	Actual**	
52.55	54.85	4%

* Adjusted to include the repair cost borne by the operator at the beginning of the contract
** Adjusted to inflation based on the base kilometre charge stated in the contract.

The results show a 4% profit margin applied by the operator. **This figure seems reasonable and will be applied to all the new diesel buses**.

Indeed, in the case where operators own the buses, this comes in addition to profit margin already included in the Weighted Average Cost of Capital (WACC). For this reason, this margin would normally be different when the operator owns the buses from when it does not. However, the purpose of the modelling is not to prepare a transaction but to compare options, which requires using reasonable assumptions consistent with available cost data. This figure indicates that our unit cost assumptions fit this requirement.

EXISTING ELECTRIC BUSES

- Overview of the applied kilometre charges

There is currently one electric bus operator (Olectra BYD Greentech Ltd.) operating 5 minibuses. The base kilometre charge stated in the contract is 42.30 INR/km (2019).

This figure is adjusted to inflation and applied to the existing electric buses until the end of their contract.

- Estimation of electric bus operator's profit

It shall be noted that the kilometre charge for Olectra BYD Greentech does not include investment costs for vehicles, chargers, and charging infrastructure as these are covered by NMC. However, the contract states that the operator must provide some equipment and moveable infrastructure in the depots without providing the details (only an indicative list of equipment is provided in the contract's annex).

Therefore, it is not clear what are the exact investment costs borne by the operator and we are unable to provide an accurate estimation of the operator's profit that can be applied to the new electric buses.

It was thus decided that the 4% profit margin estimated for the diesel buses would also be applied to the electric ones.

NEW DIESEL BUSES

The new diesel buses are to be provided by the operators and hence their kilometre charges must include CAPEX for vehicles.

For the new standard diesel buses, a new kilometre charge was estimated to take into account the investment costs of vehicles for the fleet augmentation scenario and the updated operational assumptions for the fleet replacement scenarios. The estimated km charge is estimated at 57.63 INR/km for the replacement scenarios and 59.45 INR/km in the fleet augmentation scenario. The differences between these two scenarios could be explained by the different operational assumptions.

For the new midi and mini diesel buses, the kilometre charges for the existing midi and mini diesel buses were used (with adjustment to inflation over the years), as these already include investment costs for vehicles.

Finally, all kilometre charges were adjusted to consider inflation variations.

NEW ELECTRIC BUSES

The new electric buses are to be provided by the operators and hence their kilometre charges must include CAPEX and renewal costs for vehicles and related equipment and infrastructure.

As the new electric buses are to be provided by the operators, the estimated kilometre charges include the following costs (both investment and renewal costs include financing costs):

- Operating expenditures (OPEX),
- Investment costs (CAPEX), and
- Renewal costs.

All the estimates were conducted assuming that bus charging costs are borne by the operators. Different provisions were identified in the existing contracts and models (see section "*City Bus Service Contractual Framework Analysis*").

25.2.3.2 Annual operated kilometres

Based on the operational data received for Nagpur City Bus Services, an average yearly number of kilometres operated by each bus in the fleet was estimated at around 56,052 km / bus.

For the fleet augmentation scenario, this average was maintained for all the buses. For the fleet replacement scenarios, a new average was estimated for the new standard buses based on the proposed optimisation of the operation plan.

25.2.4 Estimation of the service operating costs – Payments to DIMTS

Payments to DIMTS are made based on a set of remuneration components related to the following services:

- Operations management support,
- Ticketing and revenue management,
- Provision of ITS backend systems & program management,
- Transaction advisory services, and
- Operation and management of pass issuance centres.

Remuneration is based on unit service charges for each one of the above services and the actual quantities of the provided services and/or the service characteristics (fleet size, number of depots, number of ticket issuance centres).

In this analysis, we used the service charges as stated in the contract of DIMTS and adjusted to inflation. All the services were taken into account in our payment estimation except for the transaction advisory services as these pertain to intermittent support provided by DIMTS for the selection of contractors (for the provision of fare collection personnel, GPS devices, electronic ticketing machines and passenger information display) that we have no means to forecast.

Our payment estimation considers a Goods and Services Tax (GST) at a rate of 18% paid by NMC to DIMTS in addition to the total payment (service charges are exclusive of taxes), as well as a Tax Deducted at Source at 2% that is deducted from the contracted amount.

Finally, DIMTS contract provides for performance incentives/penalties depending on the ridership levels on the network. In this analysis, no incentives/penalties were considered.

25.2.5 Estimation of the service operating costs – Payments to Fare Collection Agencies

Fare collection agencies deploy personnel to issue tickets and collect fares from passengers. Payments are made based on staff deployment in two shifts in bus operations.

For this analysis, we used the latest payment rates available (2020) that were adjusted to inflation for the future years in the analysis period. This corresponds to INR 587.70 per shift, per bus and per day.

A Tax Deducted at Source (TDS) at a rate of 2% was deducted from the contracted payments.

According to entry 3 notification 12/2017 of the Central GST Act, we understand that the fare collection agencies are exempt from GST as they only provide “pure services” to a governmental entity. Hence, **no GST was added to the total payments**.

25.2.6 Estimation of revenues

Fare box revenues are estimated based on the current ridership levels (assumed constant over the years) and the actual fare box revenues per passenger adjusted to inflation over the analysis period.

The current fare box revenues per passenger were estimated based on the available financial and ridership data. An average revenue per passenger was based on the total fare box revenues for 2019 and an estimation of the annual ridership based on the actual average daily ridership for the months of January 2020 and December 2019.

Data for March 2020 was excluded from the analysis given the possible impact of the global sanitary crisis on ridership levels.

NON-FARE BOX REVENUES

Currently, there are no paid advertisement revenues on buses. However, NMC is planning to implement advertisement on buses in the future years (1,500 to 2,000 INR/bus/month, according to discussions with NMC in February 2020).

Currently, there are no paid advertisement revenues on buses. However, NMC is planning to implement advertisement on buses in the future years (1,500 to 2,000 INR/bus/month, according to discussions with NMC in February 2020).

Revenues from advertisements in bus stops are under Sign Post contract which is currently managing all the network bus stops under a Build Operate Transfer (BOT) contract. A yearly royalty of 14,600 INR / bus stop is paid to NMC. **However, the viability statement of Nagpur bus services does not seem to include any non-fare box revenues**.

For the analysis period, we assumed that advertisements will be implemented in both buses and bus stops. The assumptions presented in the table below were considered for our analysis.

For the replacement scenarios, the actual number of bus stops were considered constant for the overall analysis period.

Table 75. Estimated non-fare box revenues (data source: discussion with NMC during the inception mission)

	Estimated amount (2018)
Average revenue (INR /bus / month)	2,000
Average revenue (INR / bus stop / year)	14,600

According to the CMP 2018, the current non-fare box revenue, which is limited to advertisements on bus stops, represents less than 5% of the total revenues of bus services. Other non-fare box revenues (for example, land valorisation and other secondary resources) could be mobilised for the service as discussed in the CMP 2018 and KfW report[30]. However, there are no current studies or documents that provide an estimation of the possible revenue streams from these resources. Hence, these were not included in this analysis.

30 Comprehensive Feeder Service Project for Nagpur Metro, KfW, 2018.

25.3 Financial modelling results

25.3.1 Impact of the electrification scenarios on the kilometre charge

The figure below provides a summary of the estimated kilometre charges for the new standard electric buses for each battery capacity, considering "optimized charging" and "normal charging", and a comparison to the estimated kilometre charge for the new standard diesel buses. Estimates were conducted using both the EV charging stations electricity cost - Tariff 1 (see Figure 121) and the Public Service electricity cost - Tariff 2 (see Figure 122) in Maharashtra state.

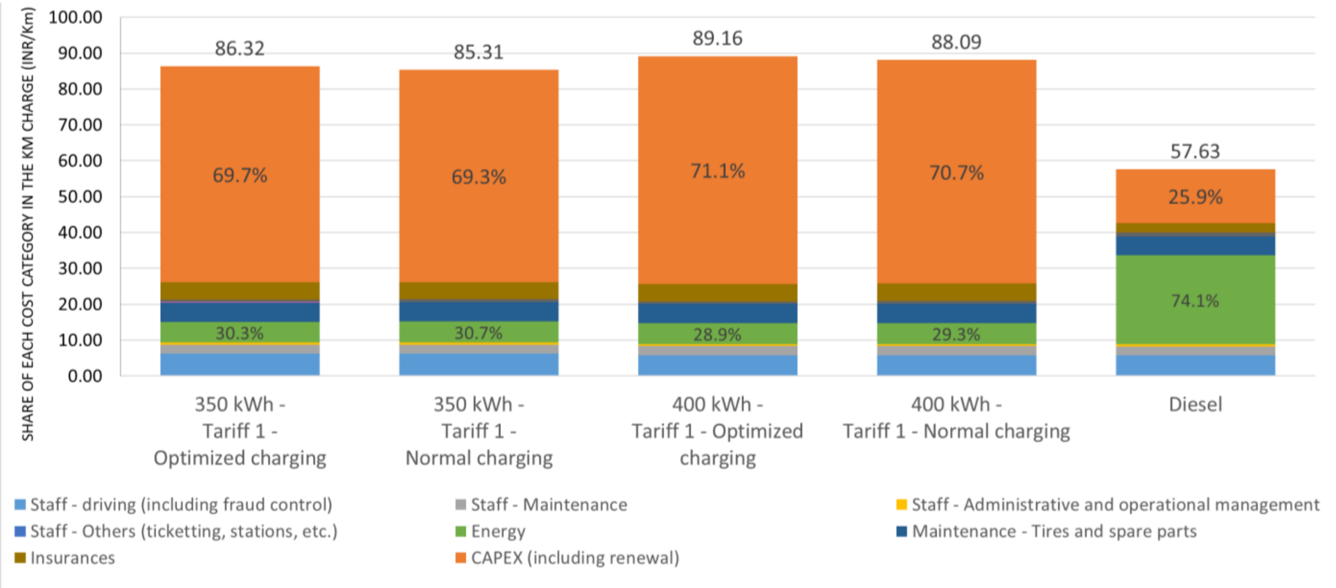


Figure 121. Comparison of the km charge for electric and diesel standard buses - Tariff 1 (incentive tariff)

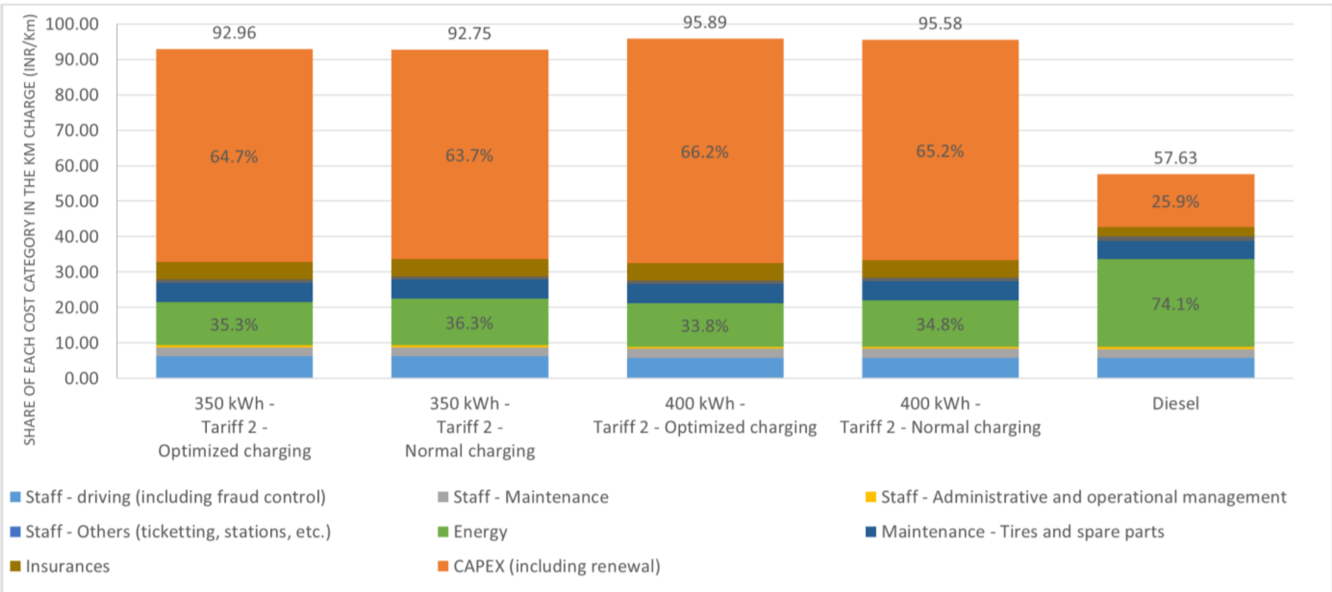


Figure 122. Comparison of the km charge for electric and diesel standard buses - Tariff 2 (regular tariff)

The main conclusions are the following:

- Even though buses with a 400 kWh battery capacity allow for an optimisation of the OPEX (due to less energy costs and shifts) compared to buses with a 350 kWh battery capacity (between 1 and 1.7% less depending on the scenarios), the higher investment costs (around 3%) result in a higher kilometre charge in all the analysed scenarios.
- If the incentive tariffs (Tariff 1) are applied to the new electric buses, this will result in a relatively significant decrease in the energy consumption costs and hence in the total kilometre charge of the operators. Depending on the scenarios the decrease can vary between around 8 and 9%.
- The energy economies allowed by the advanced depot charging management system ("optimized charging") are offset by the additional investment and maintenance costs. Hence, the installation of an advanced charging management system results in a higher kilometre charge in all the analysed scenarios. The increases are however very limited (to a maximum of +0.3%) when using a public service electricity tariff (Tariff 2) instead of an EV charging stations tariff (Tariff 1). Nonetheless, having a charging management system (in its regular configuration at least) is very beneficial from an operational point of view, as discussed earlier in this report.

Given all the above, and in line with the technical analyses' recommendations presented in the previous chapters of this report, **the following section focuses on assessing the financial impacts of the electrification scenario 1 (350 kWh batteries), and assuming that an advanced charging management system is installed.** The impact of the different possible electricity tariffs will also be assessed.

25.3.2 Impact of the electrification scenarios on the viability gap of Nagpur City Bus Service

Figure 123 shows the financial modelling results for the first year of the analysis period.

The results show that coverage of the service costs (including investment and financing costs in vehicles and related equipment, infrastructure, assumed to be borne by the operators and hence included in their kilometre charge) by the operating revenues (around 38% in the reference scenario) is reduced in the electrification scenarios (around 28 to 30%). The EV charging stations electricity tariff (tariff 1) allows to reduce the viability gap by around 7% compared to a standard public service electricity tariff (tariff 2).

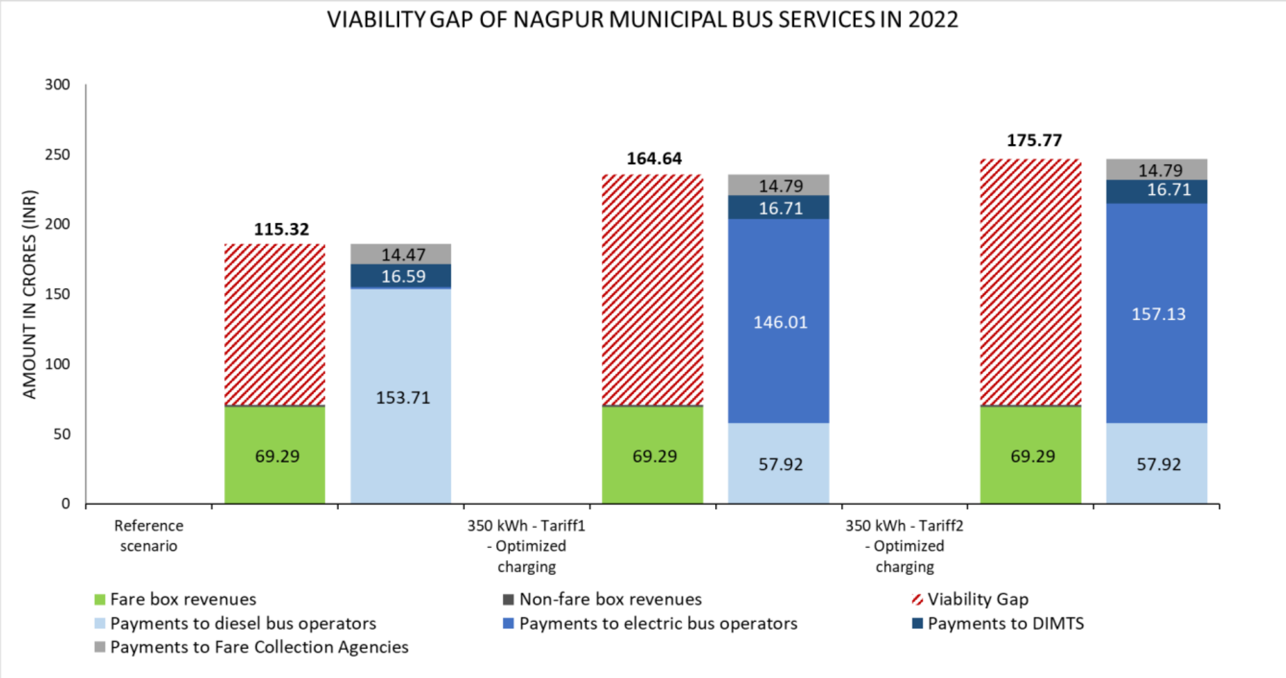


Figure 123. Viability gap of Nagpur City Bus Services in 2022

The comparison of these results with the current viability gap of Nagpur City Bus Services (adjusted to inflation) shows that all the replacement scenarios (with diesel or electric buses) will require additional resources to cover the operating expenses (see comparison in Figure 124). While the reference scenario would require around 10% more resources compared to the current situation, the introduction of buses with 350 kWh battery capacity would require much more. This is equivalent to **an increase of 58% with tariff 1 and 68% with tariff 2 compared to the current situation**.

The additional resources needed for the reference scenario compared to the current situation are explained by the fact that the new diesel buses are assumed to be purchased by the operator and thus, would yield a higher kilometre charge.

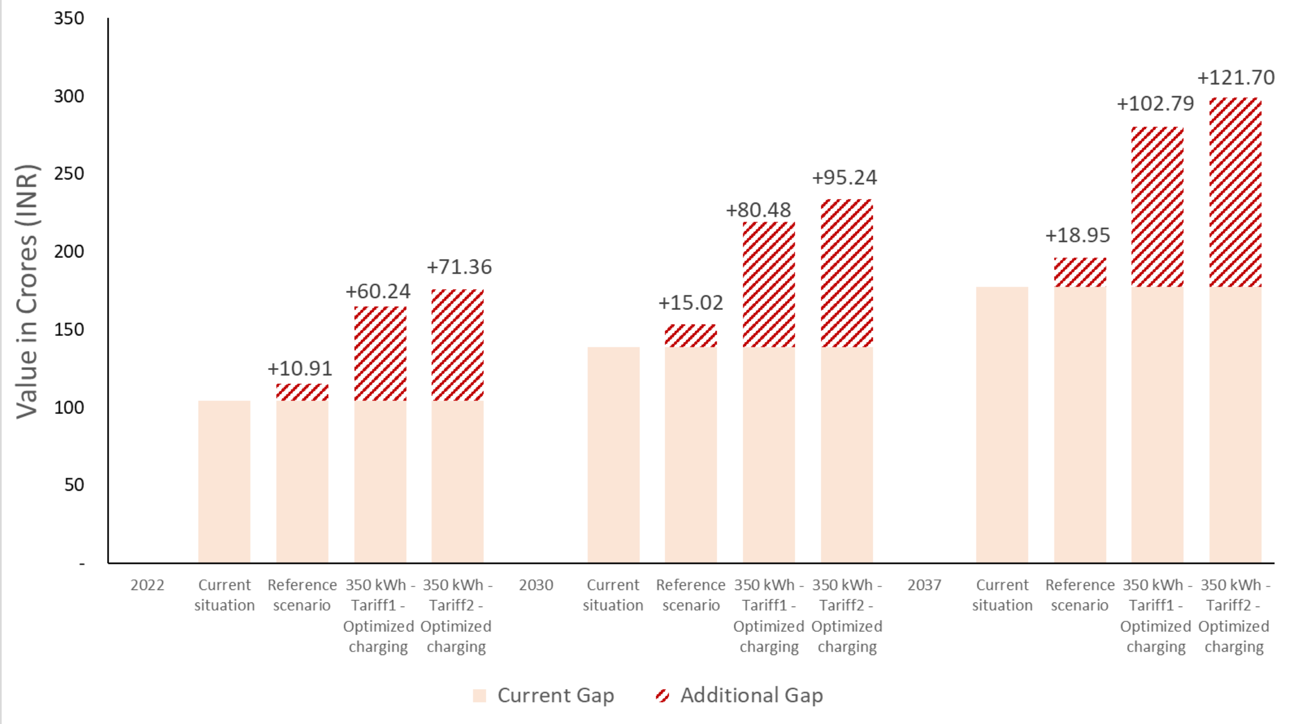


Figure 124. Comparison of the additional annual gap to the current one

25.3.3 Impact of the fleet augmentation scenario on the service costs

The service costs incurred by NMC for the fleet augmentation scenario[31] were estimated and compared to the current situation in nominal terms. The figure below presents costs increase for the years 2022, 2030 and 2037. All estimates were made assuming an advanced power management system is installed.

Assuming an EV charging station tariff (tariff 1), cost increase remains relatively limited in 2022 (+18% compared to the current situation, which is equivalent to INR 32 Crores of additional service costs). However, this becomes very significant over the analysis period. In 2037, the service costs of the fleet augmentation scenario exceed three times the service costs in the current situation[32] (equivalent to an additional INR 1027 Crores compared to the current situation). Considering a standard public service electricity tariff (tariff 2), cost increase over the analysis period is expected to be even higher. However, service revenues are unlikely to increase proportionally in both cases.

[31] In this scenario, we assume that 10% of the new fleet will be electric.
[32] Adjusted to inflation

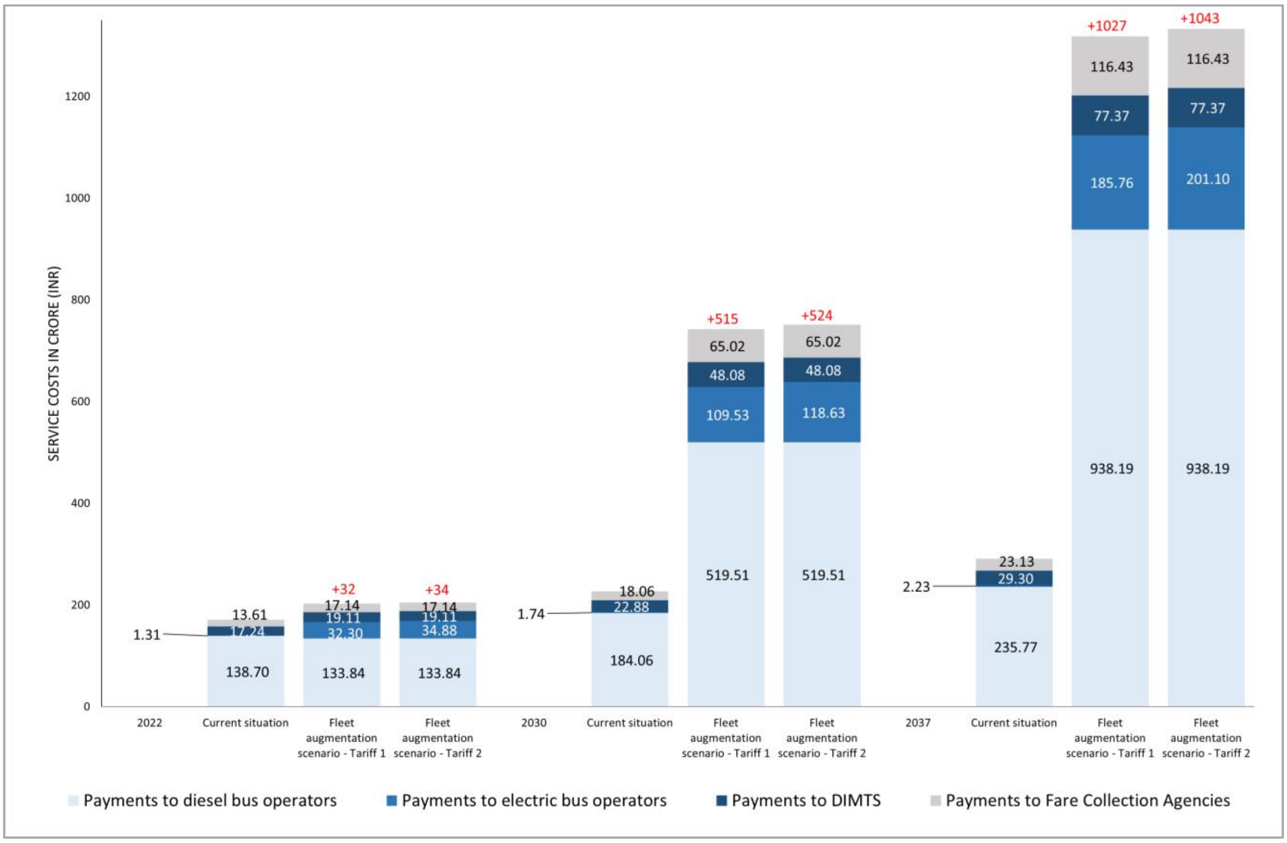


Figure 125: Estimated service cost increase in the fleet augmentation scenario over the analysis period

25.4 Conclusions of the financial assessment

The financial modelling results show that the electrification of the standard buses in 2022 will require additional resources compared to the reference scenario (replacement with standard diesel buses). However, the electrification of the bus fleet will yield positive externalities that are not captured by the financial analysis.

Hence, for the upcoming fleet replacement in 2022, if NMC were to consider an electrification, buses with a 350 kWh battery capacity seem more financially viable given the limited investment and operation costs compared to buses with a 400 kWh battery capacity. In fact, even though the first replacement scenario requires additional buses compared to the second one, the overall cost of service in the first case remains lower than the second one.

In addition, although the installation of an advanced charging management system would result in slightly higher kilometre charges and hence increased service costs (due to the additional investment and maintenance costs), **such system is greatly beneficial to operations and should be considered**.

Finally, if NMC were to consider the fleet augmentation scenario "Mid-Term Vison" where we increase the total fleet of the network and introduce electric buses, the service costs will be significantly higher, reaching more than three times the current costs (in nominal terms) at the end of the evaluation period. The service revenues are however unlikely to increase proportionally.

Hence, based on the chosen scenario, **it is necessary for NMC to find additional financial resources to cover cost increases and maintain the financial sustainability of the system.** The following chapter provides an overview of the possible financial support mechanisms that can be leveraged by NMC.

26. Enhancing Nagpur City Bus System's financial sustainability

To support public authorities in their decisions in terms of urban public transport financing, NODALIS has developed, and has been applying since 2014 in several countries around the world, a specific methodology to compare urban public transport policies in different cities and identify possible action areas for a given city. This is particularly important as urban public transport policies have a direct impact on the financial sustainability of the systems.

Henceforth before identifying the possible levers to enhance the financial sustainability of the service and support Nagpur's fleet transition and development plans, we suggest comparing urban public transport policy in Nagpur to other comparable agglomerations in order to identify the possible action areas. **This chapter will focus on Nagpur's policies in terms of public bus transport systems. In other words, the metro system is not taken into account in the analysis**.

26.1 Benchmark of the current urban public bus transport policy in Nagpur

26.1.1 Overview of our methodology

Our methodology is based on the following steps:

- Definition of the key parameters characterizing urban public transport policies,
- Identification of homogenous indicators to measure these parameters in a set of big cities,
- Collection of data necessary to estimate these indicators, and
- Analysis of the observed situation in a given city and its comparison with other cities in the same country or in the world.

26.1.1.1 Definition of the key parameters characterizing urban public transport policies

Every urban public transport policy is a balance between the following parameters or conflicting objectives (see also Figure 126):

- Affordability to the user,
- Supply density (frequency extension and density of service), and
- Budgetary sustainability for public authorities.

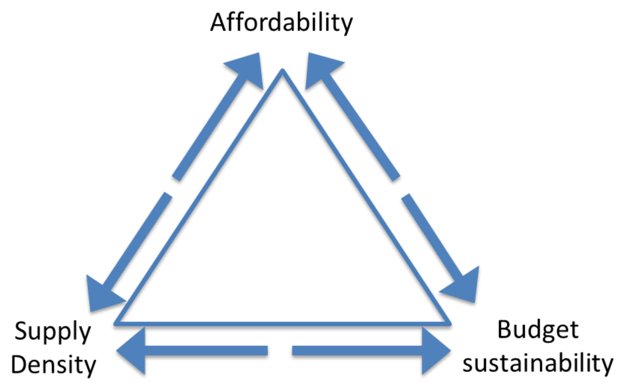


Figure 126. Transport policy trade-offs (assuming constant production efficiency)

While fixing the objectives of an urban public transport project or policy, the analysis framework above (Affordability, budget sustainability and supply density) allows not only to characterize the initial situation but also to identify the necessary trade-offs to achieve the chosen objectives (assuming constant production efficiency).

Consequently, assuming a constant level of public subsidies and constant production efficiency, increased supply levels require tariff augmentation to cover the additional viability gap. Vice versa, increasing transport affordability through a reduction of tariffs means reducing the service revenues (as price elasticity of demand is always less than 1) which will ultimately translate to reduced supply levels (constant level of public subsidies and production efficiency). In addition, in the case of inflation, if authorities refuse to increase tariffs overtime, this will lead to a reduction of the service revenues and thus to reduced supply levels.

Finally, all other parameters being equal, reducing public transport tariffs or increasing production levels is not feasible without additional public subsidies.

26.1.1.2 Identification of homogenous indicators to measure these parameters in a set of big cities

For the analysis of public bus transport policies in Nagpur, the following indicators have been chosen given data availability and the possible comparison with a wide range of cities around the world:

- Financial affordability to urban public transport is measured by the ratio between the average ticket price over the average GDP per capita in the agglomeration (or a proxy),
- Supply density is measured by the ratio of the number of buses per 1,000 inhabitants, and
- Budget sustainability is measured by the ratio of public transport subsidies per capita over the national public expenditure per capita.

26.1.1.3 Data collection

For the city of Nagpur, the data presented in Table 76 was used.

Table 76. Data used for the benchmark of urban transport policies

Data	Value	Source
National population in 2019	1,33,29,00,000 inhabitants	Population projections for India and States 2011-2036, Report of the technical group on population projections, November 2019 [33].
Population of Nagpur in 2019	28,50,000 inhabitants	Projections of Nagpur population for 2019 based on United Nations - World Population Prospects [34].
National spending	24,130 billion INR	Revised estimates for the fiscal year 2018 – 2019, Institute for Policy Research Studies, 2019.
Current public transport subsidies	94,16,83,592 INR	Viability Gap for Nagpur bus services in 2019, collected data.
Average per capita income in Nagpur– Proxy used per capita income for Maharashtra (2019 INR)	521 INR	Economic survey of Maharashtra 2018 – 2019 [35].
Average bus ticket price in 2019	12 INR	Collected data [36].

The other cities used for the benchmark were chosen based on the characteristics of their public transport systems. As we focus our analysis on the city bus service, cities with a significant public rail transport were excluded from the benchmark.

Hence, the following cities were considered: Cairo, Lagos, São Paulo, Medellín, Dakar, Addis Ababa, Rabat, Casablanca, and Marrakech. To compare to other Indian cities, Mumbai was also included in the benchmark even though it has a significant public transport rail network.

[33] Available online: https://nhm.gov.in/New_Updates_2018/Report_Population_Projection_2019.pdf
[34] Available online : https://www.macrotrends.net/cities/21347/nagpur/population?q=india+population
[35] Available online: https://mahades.maharashtra.gov.in/files/publication/ESM_18_19_eng.pdf
[36] Data for December 2019.

26.1.2 Benchmark results

Priority given to the affordability of bus services to citizens…

In Nagpur, the ratio of the average bus ticket price per daily income is the lowest in our sample. This shows the authorities' willingness to maintain a very affordable service compared to other agglomerations where authorities have made the choice of relatively high public transport tariffs (Marrakech, Casablanca, Rabat, Dakar, and São Paulo).

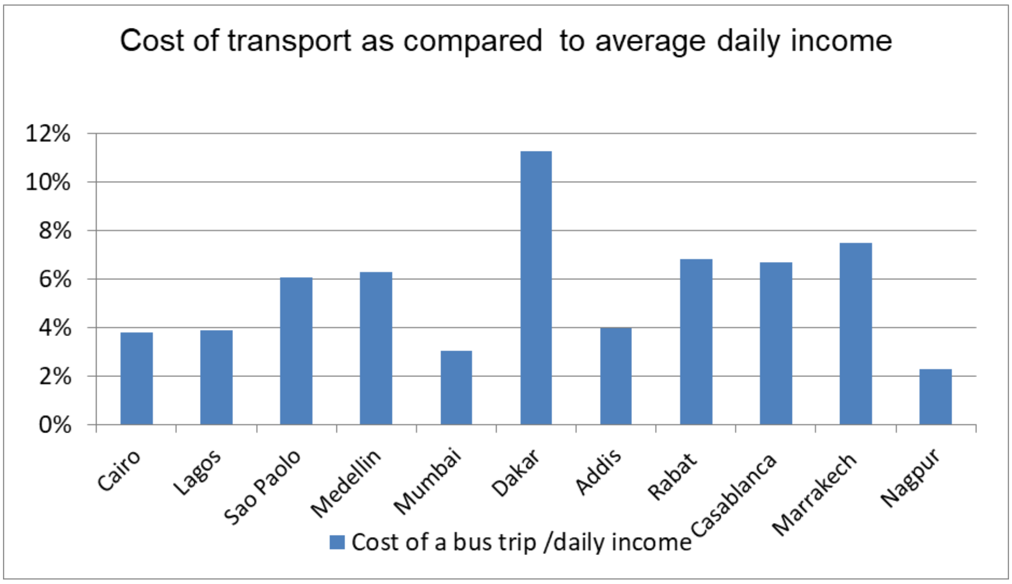


Figure 127. Cost of bus tickets compared to average daily income

…combined to relatively limited supply levels…

However, supply levels in Nagpur remain relatively limited. Nagpur has the lowest number of operational buses per 1,000 inhabitants in our sample.

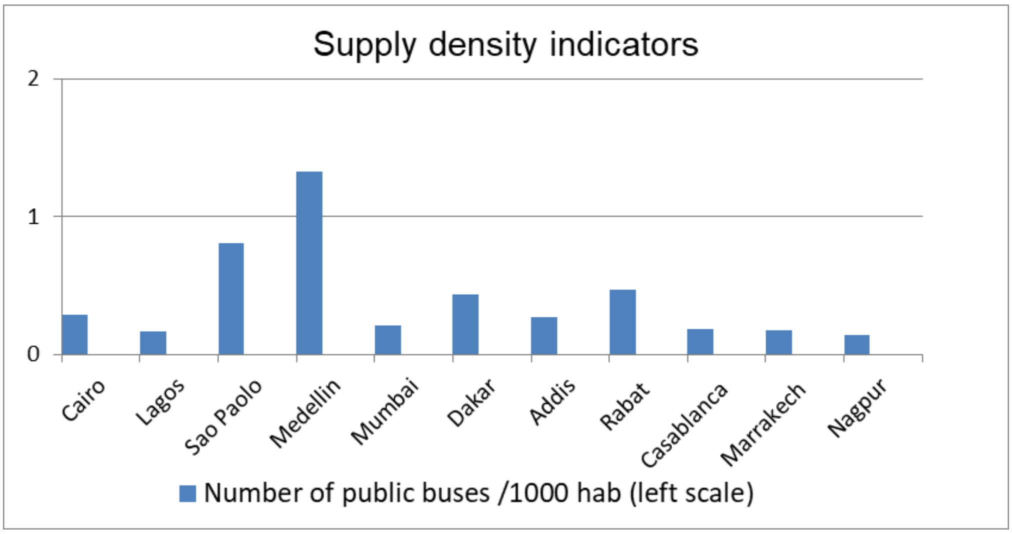


Figure 128. Number of public buses/1000 inhabitants

…and a limited budget sustainability.

The financial contribution of Nagpur's public authorities to bus services is relatively high compared to the analysed cities. In fact, Nagpur has the fourth highest public subsidy to urban transport services per capita after Addis Ababa, Cairo, and São Paulo. Mumbai has a relatively similar level of public subsidies to urban transport.

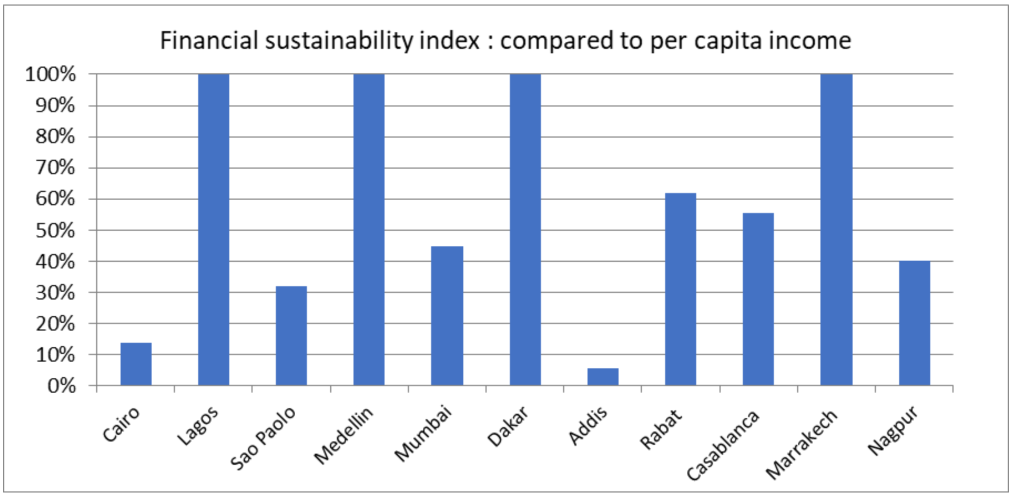


Figure 129. Financial sustainability index

To sum up, the results of the benchmark show that, **compared to other cities, public transport policies in Nagpur are characterized by** the following:

- **Priority is given to the affordability** of the bus services to citizens,
- A **limited supply level**, and
- A **limited budget sustainability**.

The following chart presents a comparison of the relative effort in the three dimensions for each city. It shall be noted that the graph does not present the absolute performance of each city compared to the others. In other words, it only shows the degree of importance provided by each city to a given action area compared to other cities. It hence allows to compare the priorities of cities in terms of urban public transport policies and does not allow an assessment of their performances in the respective dimensions.

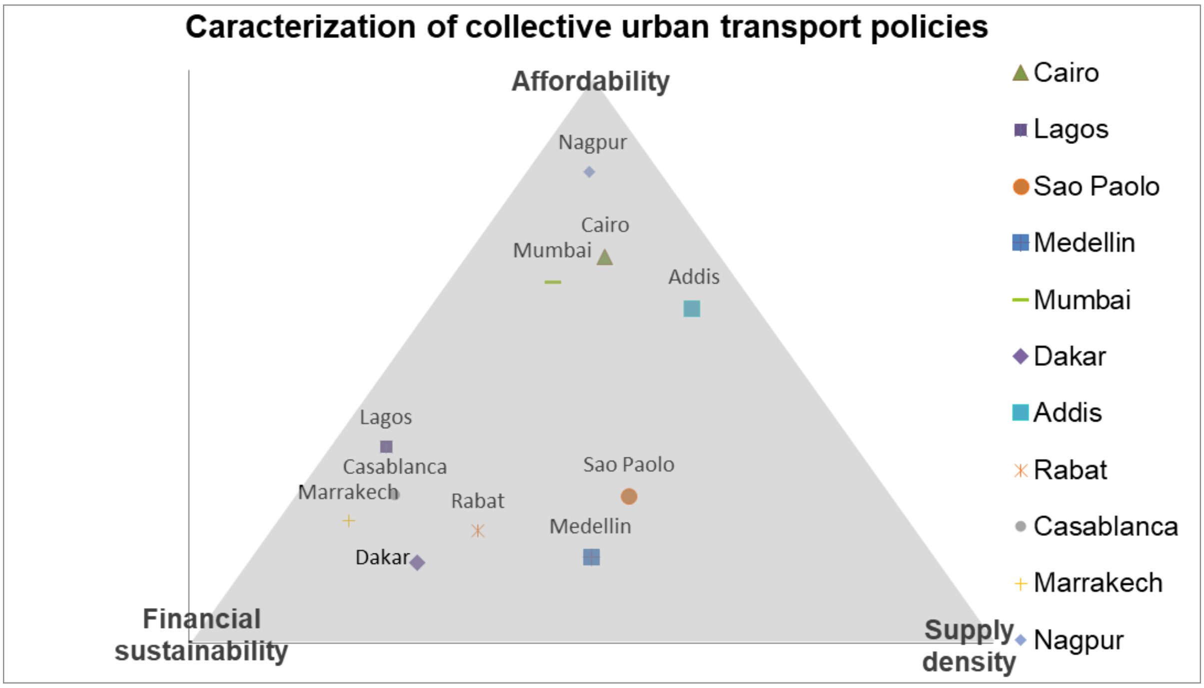


Figure 130. Characterization of public transport policies in different cities

26.2 Possible levers to enhance the service financial sustainability

The previous benchmark of Nagpur public bus transport policies with other comparable agglomerations shows that:

- Tariffs remain low as it seems that priority is given to the affordability of the service,
- Supply levels are limited and the number of buses per 1,000 inhabitants is the lowest in the analysed sample, and
- Public subsidies are comparatively high which limits the budget sustainability.

The conclusions on supply levels are consistent with the current situation and confirm the rationale for Nagpur's bus development plans (fleet augmentation plans).

However, as explained, assuming constant production efficiency, increased supply levels (and thus service costs) will necessary require additional public financial resources (i.e., subsidies), or increased service revenues. A third solution would be to improve production efficiency.

Nonetheless, while the comparatively current important level of subsidies limits the availability of additional public financial resources, the low tariff levels provide room for additional revenues. However, tariff increases must be realistic and progressive in order to limit the impact on ridership levels and achieve the overarching objective of increased service revenues.

In this context, we provided estimates for the additional resources to be ensured for the fleet replacement and augmentation plans (either by increased services revenues, and increased subsidies).

However, it is also necessary to analyse whether the current production efficiency, or in other words, operational performance of Nagpur's bus services could be improved in order to reduce the financing needs.

Hence, we estimated the operational performance of the system using commonly used ratios in the public transport industry:

$$\frac{R}{C}\ ,\ \frac{R}{P}\ ,\ \frac{C}{K}\ ,\ \frac{P}{K}$$

Where:

- ***R*** is the total system revenues (excluding subsidies and any fiscal or parafiscal resources),
- ***C*** is the total operating cost of the service,
- ***P*** is the number of transported passengers, and
- ***K*** is the number of produced bus-kilometres.

These four ratios are linked through the following formula:

$$\frac{R}{C} = \frac{R/_{P} \cdot P/_{K}}{C/_{K}}$$

Which translates to the following:

$$\textbf{Financial performance} \ll \frac{\textbf{Average effective tariff x Commercial efficiency}}{\textbf{Cost-efficiency}}$$

The "*Average effective tariff*", the "*Commercial efficiency*" and the "*Cost-efficiency*", are relatively independent and correspond to different urban transport policies.

This formula shows that, in addition to the service revenues increases (more specifically farebox revenues[37]) or additional subsidies, the financial performance of the system could be improved through two other action areas:

- Increased commercial efficiency through an increased number of transported passengers per operated kilometre (P/K), or
- Increased cost-efficiency through lower operating expenditures per operated kilometre (C/K).

[37] In this analysis we focus on the possible increases in fare-box revenues. Non-farebox revenues are assumed to be constant (in real terms) over the analysis period.

Given all the above, it appears that four action areas can be explored to enhance the financial sustainability of Nagpur's bus services and support the future transition and development plans:

- **Solution 1: Increase cost efficiency**,
- **Solution 2: Increase commercial efficiency**,
- **Solution 3: Investment subsidies**,
- **Solution 4: Increase fare-box revenues**.

Solutions 1 and 2 are to be explored first as they can have a significant impact on the financing needs of the systems. Solutions 3 and 4 are to be explored if the desired financial performance is not achieved with the previous solutions.

The following chapters provide an overview of each of the above-mentioned levers.

26.2.1 Solution 1: Increase cost-efficiency

Increased cost efficiency translates to a lower cost per operated bus.kilometre.

The costs per operated bus.kilometre depend on:

- Transport modes: standard buses, midi-buses, or minibuses,
- Characteristics of the fleet (mainly technology),
- Local macroeconomic characteristics (such as revenues and fuel price),
- Commercial speed,
- Operator's expertise and its operational management quality, and
- In a limited way, on the network's structure and the number of operated bus.kilometres.

Henceforth, the objective of reduced cost per bus.kilometre can be achieved mainly by optimising the operators' operating expenditure per kilometre (kilometre charge). However, as it is presented in the second section of this report, the current contractual framework for bus services in Nagpur allows only for a limited optimization of the cost per bus.kilometre, given that:

- Although bus operators in Nagpur are recruited through competitive bidding processes, no or few information is provided on the service plan (prepared mainly by DIMTS) at the bidding stage, which limits the operators' ability to further optimize the quoted kilometre charge.
- Once the contracts are signed, the kilometre charge cannot be further optimized.

Hence, the following section of this report provides a detailed review of the contractual provisions and possible optimization mechanisms for cost efficiency.

Increased commercial speed (from the actual 18.4 km/h in average) is also a possible lever that could be explored to enhance the cost-efficiency of the system. This could be achieved through infrastructure investments such as dedicated bus lanes, better traffic management (e.g., priority at traffic intersections). This lever is not further analysed in this report as it is not pertaining to contractual arrangements.

26.2.2 Solution 2: Increase commercial efficiency

Another way to enhance the financial performance and thus decrease the financing needs of the system is to increase the commercial efficiency through an optimisation of the number of transported passengers per operated kilometre.

We compared the commercial efficiency of Nagpur's bus services to the same set of comparable French and Moroccan agglomerations used earlier. Table 77 presents the results for the P/K ratio as well as the supply levels (measured as the number of operated bus.km/inhabitants) for the compared cities, using an average daily kilometres operated by bus of 56 052 km[38].

Excepting French cities where authorities have made the choice of heavily subsidized public transport systems in order to maintain a wide coverage (the highest number of operated bus.kilometres per inhabitant in our sample), the commercial efficiency in Nagpur is relatively low compared to Moroccan cities where the supply levels are more comparable.

Table 77. Commercial efficiency benchmark

		Nagpur bus services (2019)	French cities (+250 000 inhab. - Only bus services)	Casablanca bus services	Rabat bus services
P/K	Passenger/Bus.Kilometre (Pax/bus.km)	2.30	1.73	3.00	3.80
Supply levels (bus.km/inhabitant)		8.59	26.45	9.91	14.74

The commercial efficiency (P/K) depends on:

- The transport modes: standard buses, midi-buses, or minibuses, and
- The city and the transport network's characteristics: frequencies, urban density…

[38] Average daily kilometres operated per bus for 2019.

Hence, in order to support Nagpur's bus development plans, **commercial efficiency could be improved through more efficient service plans** (network characteristics). As it is presented later in this report (next section), currently the service plans are conceived by DIMTS (in consultation with NMC) with no apparent incentives to increase the commercial efficiency. The only contractual incentive for DIMTS appears to be related to ridership levels regardless of the total operated bus.km.

The detailed review of the contractual framework as well as recommendations for the optimization of commercial efficiency will be presented in the next part of the report.

26.2.3 Solution 3: Investment subsidies

If the optimisation of the operational performance of the system (cost-efficiency and commercial efficiency detailed in the previous sections) is not sufficient to cover the additional financing needs yielded by the bus transition and development plans, more resources must be ensured by NMC to cover the additional financing gap. One of the possible solutions are subsidies to investments in vehicles and related infrastructure.

In fact, Figure 131 presents the cost structure of City Bus Services in Nagpur compared to services revenues in bus replacement scenarios, the current viability gap, and the forecast financial gap for each replacement scenario.

Investment costs are comprised of investments in vehicles and related infrastructure/equipment (charging infrastructure and equipment for electric buses), and the service operating costs are comprised of the operating expenditures of operators (the OPEX part of the kilometre charge) and payments to DIMTS and fare collection agencies.

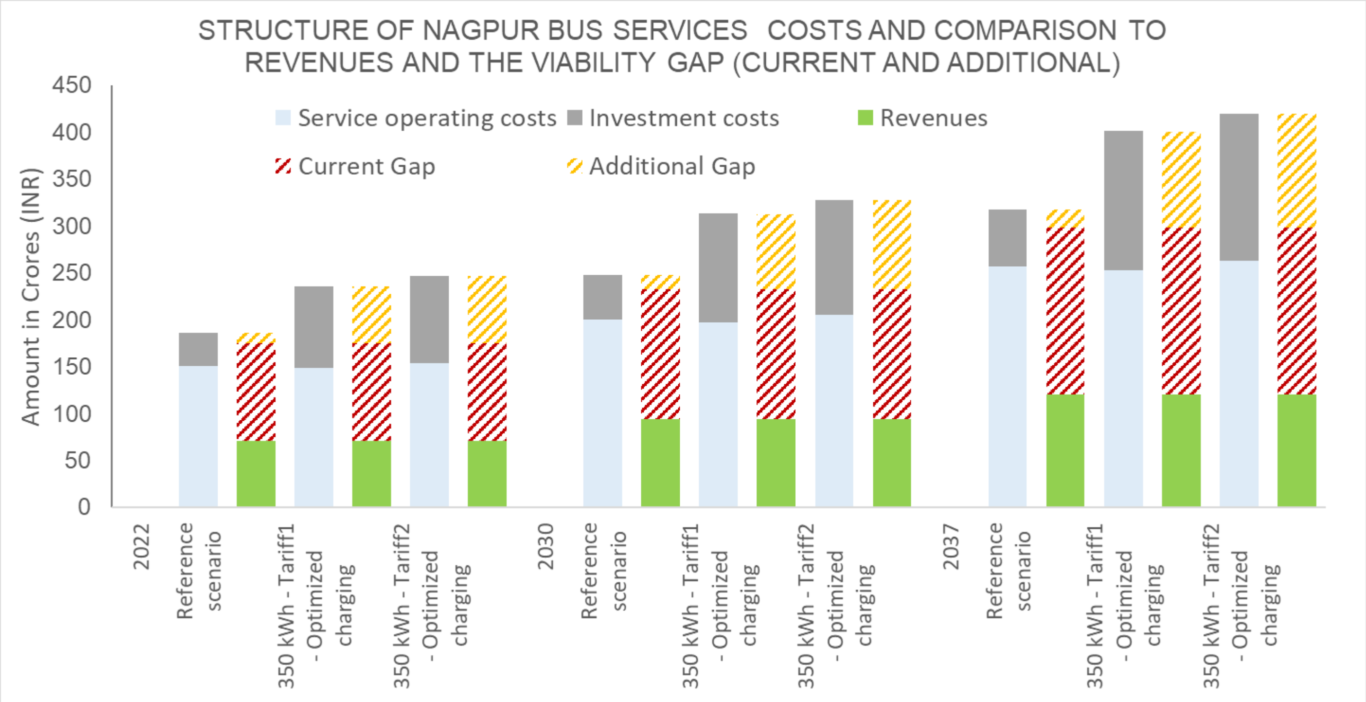


Figure 131. Cost structure of bus services in Nagpur and comparison to revenues and the viability gap

The analysis shows that the service revenues do not cover the service costs thus necessary to ensure the service sustainability. Nevertheless, we note that if NMC support was maintained at constant level (highlighted in red in the above chart), it would enable to reach the operation balance: the service operating cost would be covered by the service revenues and the operation subsidies provided by NMC (at the current level).

In this case, the remaining gap (highlighted in yellow in the above chart) could be covered by investment subsidies. In other words, the subsidy of the investment costs of the bus fleet would satisfy the global sustainability of the service providing that NMC maintains its current operation subsidies.

Hence, **investment subsidies could be used to finance part of the investment costs in vehicles and related infrastructure/equipment**. However, it should be noted that **these subsidies are not expected to cover renewal costs and hence suitable financial resources must be secured**.

In addition to local facilities, several international financial resources that support transitions of clean urban transport systems (including transition to e-mobility) are available and will be presented in the following chapter.

26.2.3.1 Available global financial resources to support Nagpur transition plans

GREEN CLIMATE FUND

The Green Climate Fund was created in 2010 through the association of 194 countries at the United Nations Framework Convention on Climate Change (UNFCCC).

GCF total resources amount to USD 19.6 billion among which 10.3 billion come from the first resource mobilization in 2014 and 9.3 billion from a replenishment completed in 2018.

Its objective is to trigger a paradigm shift toward sustainable development, the mitigation of greenhouse gas emissions and the adaptation of communities to climate change. Transport sector, as an important lever to mitigate GHG emissions, is part of the targeted result areas of the GCF.

The functioning of the GCF is specific. It is administered by a Board composed of 24 members: 12 representatives of developing countries and 12 representatives of developed countries. Its secretariat is responsible for current operations (project due diligences, contracting, project follow up). A technical committee, composed of six independent experts, is responsible for reviewing projects before their approval.

A large panel of institutions can benefit from GCF funds, not only multilateral development banks but also national entities such as public institutions or governments along with private companies. In order to be able to request GCF financing, an institution has to complete an accreditation process. The policies and procedures of the applying institution are reviewed through this process and will apply to GCF funds execution (along with GCF own policies). Accreditation is granted by the GCF Board and is a long and demanding process. Today 95 entities have been accredited by the GCF[39], including AFD and its private sector financing entity Proparco.

The GCF provides different financing tools such as grants, loans and guarantees. It is always involved as a co-financer and aims at leveraging additional funding.

As of June 2020, the GCF has committed financing to 93 projects (see Figure 132).

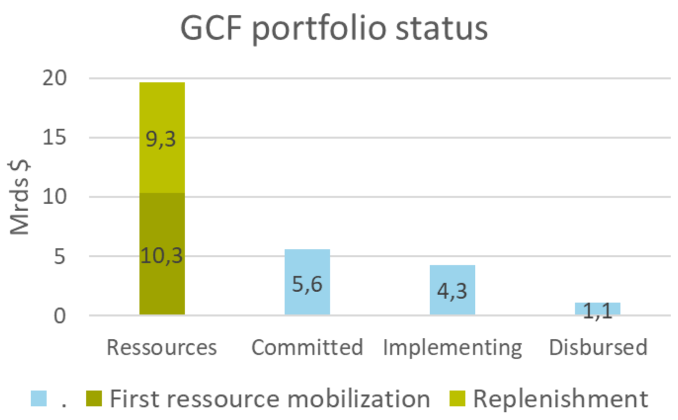


Figure 132. GCF project portfolio status

[39] The Small Industries Development Bank of India (SIDBI) is accredited by the GCF and can provide support to micro-, small- and medium-sized enterprises (MSMEs), primarily those in the manufacturing and services sectors. It promotes responsible business practices, including sustainable financing, energy efficiency and cleaner production.

Projects are prepared by the Accredited Entity (see Figure 133). At concept its note stage, a project has to be endorsed the National Designated Authority (focal point of the GCF appointed among national authorities). The National Designated Authority ensures the project is in line with national strategy and can also assist the Accredited Entity. After the concept note is approved by the Secretariat, the Accredited Entity prepares the funding proposal with the support of the secretariat. Then the Secretariat and the Independent Technical Advisory Panel perform a project due diligence before it is presented to the Board.

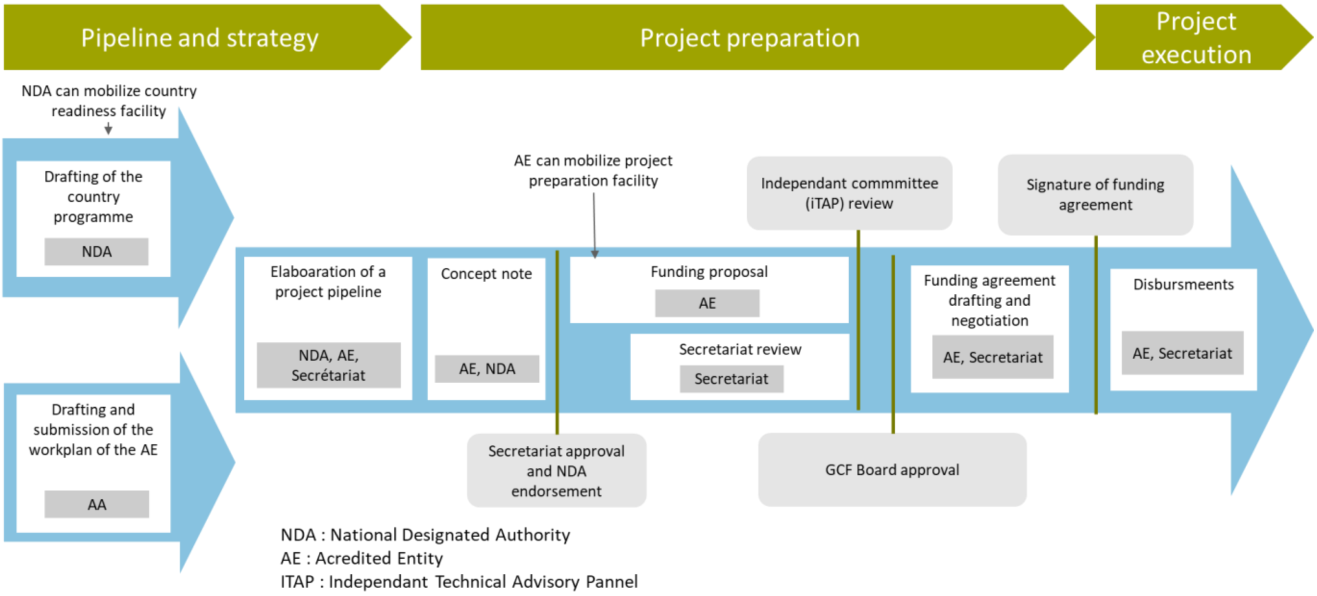


Figure 133. GCF process for project preparation and approval

The approval of a project by the GCF requires a complete package of studies and documents: feasibility, design, operation plan, environmental and social assessments, gender assessments, logical framework, procurement plan, detailed budget, disbursement plan, monitoring plan, baseline survey of performance indicators, stakeholders' consultations, capacity assessment of implementing entities, exit strategy.

Green BRT Karachi

In October 2018, the GCF has approved a financing for a BRT project in Pakistan. The project is implemented by the Asian Development Bank (ADB) and aims at developing a 30 km, fully segregated bus rapid transit system. Today, the urban mobility of the city of Karachi relies mainly on paratransit modes and the BRT would enable to shift toward a more organized, efficient, and clean transport system*. A biomethane hybrid bus fleet will be procured to reduce global emissions of the city transport system. The biomethane powering the buses will be produced from cattle wastes. The project has an expected direct GHG reduction impact of 2.6 $MtCO_{2,equiv}$ over 30 year.

The project investments raise to USD 583 million and is co-financed by the ADB, the Province of Sindh and the GCF. It includes the financing of the corridor infrastructure, depots, bus fleet and biogas facilities, restructuring of the public transport network, fleet scrapping program and compensation mechanism. The GCF provides a USD 37.2 million concessional loan and a USD 11.8 million grant.

The institutional framework is strengthened by the establishment of a single implementing public authority, the TransKarachi, that was established by the Sindh Mass Transit Authority. TransKarachi will implement and own the BRT infrastructure and assets and is responsible for BRT operations. Bus operation will be delegated to private companies through service contracts.

The Funding agreement has been effective since March 2020 and the project is currently under implementation.

**It must be noted that the energy mix in Pakistan is cleaner compared to India.*

To conclude, it could be worthwhile exploring the use of GCF funding to finance the transition of the Nagpur transport system. Clean mobility is part of GCF result areas and there is at least one case where the GCF granted funds to support an electric bus system (see case study above). In order to avoid applying for GCF accreditation (which is a long process), the NMC can resort to an existing accredited entity such as the AFD or the ADB. The Accredited Entity would be in charge of requesting the funds to the GCF and the NMC would be in charge of executing the project. The GCF funds would be retroceded to the NMC by the Accredited Entity through a subsidiary agreement.

The GCF has also a funding window dedicated to private companies. International private funds or banks that are accredited can mobilize GCF funds to finance their climate facilities or programmes. Nagpur private bus operators could turn to such funds to request financing.

CLEAN TECHNOLOGY FUND

The Clean Technology Fund (CTF) is a window of the Climate Investment Fund that was created in 2008. It provides large-scale financial resources to invest in clean technology projects in developing countries, which contribute to the demonstration, deployment, and transfer of low-carbon technologies with a significant potential for long-term greenhouse gas emissions savings.

Nine countries contributed to the fund and its resources amount to USD 5.6 billion as presented in Figure 134.

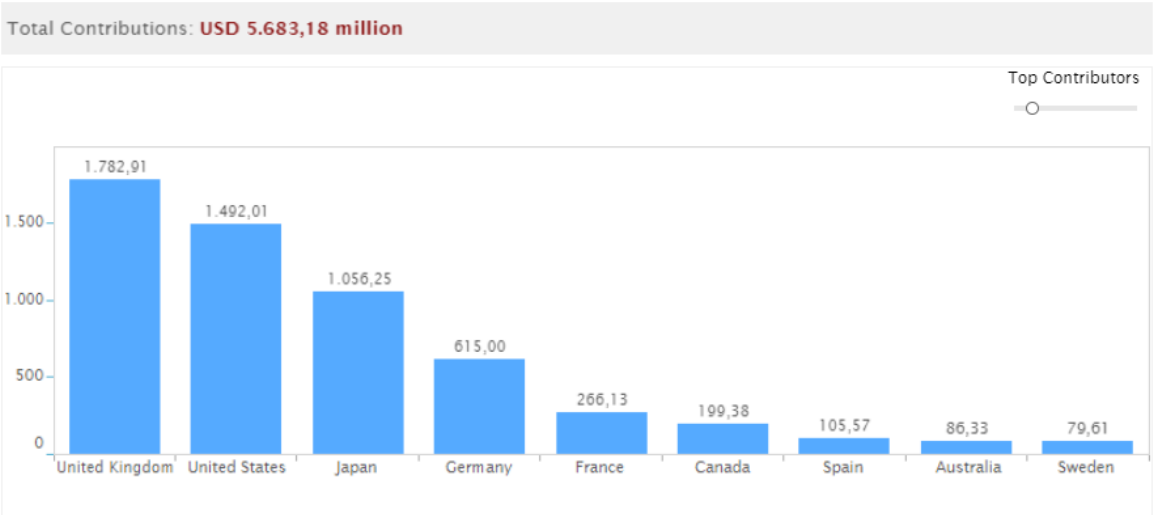
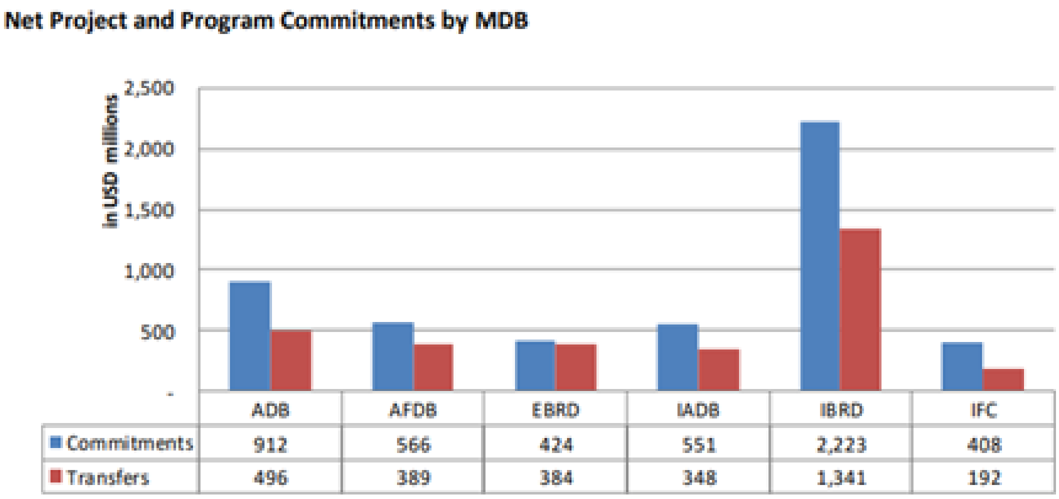


Figure 134. CTF resources (source: World Bank)

The CTF is governed by a committee that oversees and decides on its operations and activities. The committee is composed of representatives of 8 recipient countries and 8 contributor countries. The World Bank is responsible for the fund management.

CTF resources are implemented only by MDBs as shown in Figure 135.



	ADB	AFDB	EBRD	IADB	IBRD	IFC
Commitments	912	566	424	551	2,223	408
Transfers	496	389	384	348	1,341	192

Figure 135. CTF commitments by implementing MDB (source: CTF Trustee report, 2019)

The transport sector belongs to CTF priorities: modal shifts to public transportation, improved fuel economy, and fuel switching. Many transport projects have already been granted funds, as seen in Table 78.

Table 78. Example of transport projects approved by the CTF

Project	Country	Implementing MDB	CTF funds (M USD)	date
Technological Transformation Program for Bogota's Integrated Public Transport System	Colombia	IDB	40	2013
Strategic Public Transportation Systems (SETP) Program	Colombia	IDB	20	2011
Urban Transport Transformation Project	Mexico	IBRD	200	2009
Ha Noi Sustainable Urban Transport Program - Project 2: Strengthening Sustainable Urban Transport for Hanoi Metro Line 3	Vietnam	ADB	50	2014
Sustainable Urban Transport for Ho Chi Minh City Mass Rapid Transit Line 2 Project	Vietnam	ADB	50	2013
Ha Noi Sustainable Urban Transport Program - Project 1: Ha Noi Metro System Line 3	Vietnam	ADB	50	2014
Abuja Mass Transit Project	Nigeria	AFDB	50	2017
Cebu Bus Rapid Transit Project	Philippines	IBRD	25	2012
Metro Manila BRT-Line 1 Project	Philippines	IBRD	24	2016

India is a beneficiary of CTF funds, 13 projects have been approved for a total financing of USD 775 million. Most projects target the energy sector and solar photo-voltaic energy generation.

To conclude CTF can be a viable candidate to support Nagpur transport sector transition. However, the CTF has committed most of its resources. According to the 2019 Trustee Report, only USD 320 million remain for program/project commitments but most of these resources have already been affected to the CTF Dedicated Private Sector Program. A replenishment of its resources might be necessary for the CTF to support new transport projects.

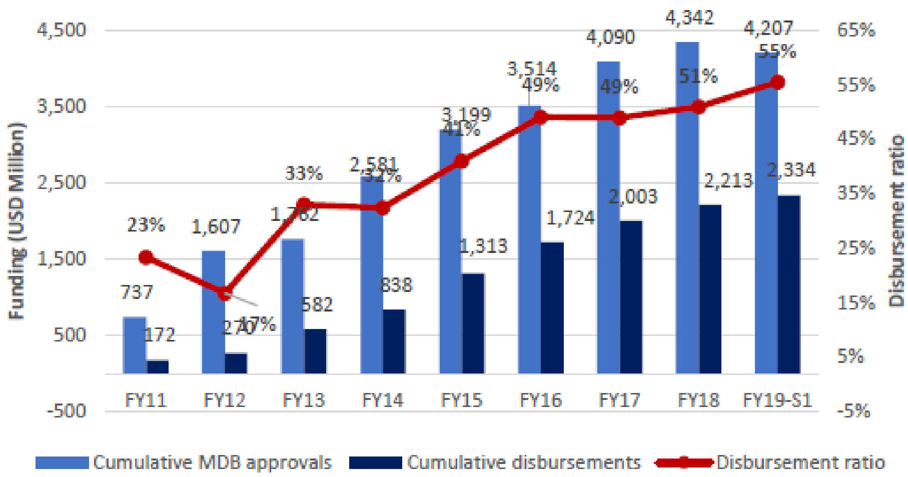


Figure 136. Evolution of CTF disbursements and commitments (source: CIF Disbursement Report, 2019)

26.2.4 Solution 4: Increase fare-box revenues

Another possible lever to NMC is to increase fare-box revenues[40]. This section provides an overview of the needed increase in fare-box revenues to support Nagpur's bus transition and development plans.

Given the limited data on ridership levels and service revenues for the fleet augmentation scenario, **we limited this analysis to the estimation of fare-box revenues' increases necessary to cover the additional operating gap created by the fleet replacement scenarios**. This will translate into an increase in the average effective tariff and thus an enhanced financial performance.

However, before detailing the findings of our analysis, we would like to confirm the results of the previous benchmark with a comparison of the average effective tariff (R/P) in Nagpur to a set of French (Lens, Perpignan, Toulon, Valence/Romans) and Moroccan cities, assuming a daily ridership of 165 892 passengers for Nagpur (average daily ridership for December 2019 and January 2020). The results are presented in Table 79.

Table 79. Average effective tariff

		Nagpur bus services (2019)	French cities (+250 000 inhab. - Only bus services)	Casablanca bus services	Rabat bus services
R/P	Revenues/Passenger (INR/pax)	11.08	37.20	32.32	13.08

However, in order to analyse the R/P ratio results, it is essential to take into account the differences of the standard of living between the different cities. Hence, the R/P ratio presented in Table 79 was adjusted to take into account the daily income per capita in each of the analysed cities, as seen in Table 80.

Table 80. Adjusted average effective tariff

	Nagpur bus services	French cities (+250 000 inhab. - Only bus services)	Casablanca bus services	Rabat bus services
Average daily income (INR)	521.3	5,830.7	458.8	451.6
R/P per daily income	0.02	0.01	0.07	0.03

[40] If changes in tariff policies were to be considered, changes in traffic levels are to be expected. We have no estimation of price elasticity of demand for public transport in India. However, it is likely to be between 0.3 and 1, provided the cost of using buses remains lower than other individual modes (e.g., Rickshaws).

The results show that, excepting French cities where public transport policies are based on high subsidies and low tariffs, Nagpur average effective tariff is low compared to the Moroccan cities. This is consistent with the results of the previous benchmark.

Therefore, based on the current fare-box revenues per passenger and the forecast additional service costs as presented in section, we estimated the average annual increase in fare-box revenues (in nominal terms) to cover the additional operating gap in the replacement scenarios (compared to the current situation) by the end of the analysis period (i.e. in 2037). The results are presented in Table 81.

Table 81. Necessary average annual fare-box revenues increase to cover the additional financial gap by 2037

	Inflation	Scenarios		
		Reference scenario	350 kWh - Tariff1 - Optimized charging	350 kWh - Tariff2 - Optimized charging
Fare box revenues annual growth rates (nominal terms)	3.6%	9.4%	10.8%	11.1%

An increase of non-fare box revenues would also contribute to limit the additional financial gap. However, as shown in the table below, this would require a significant annual increase of these revenues given the very limited current share in the total service revenues (estimated at less than 5% in the CMP 2018).

Table 82 : Necessary average annual non-fare box revenues increase to cover the additional financial gap by 2037

	Inflation	Scenarios		
		Reference scenario	350 kWh - Tariff1 - Optimized charging	350 kWh - Tariff2 - Optimized charging
Non-fare box revenues annual growth rates (nominal terms)	3.6%	38.7%	41.8%	42.5%

Note: The necessary growth rates of fare and non-fare box revenues presented above are slightly different from the figures presented in Task 4 Report (see reference document [R5]) given the differences in the analysed scenarios and the updated investment and operational assumptions.

CITY BUS SERVICE CONTRACTUAL FRAMEWORK ANALYSIS

This section presents an analytical review of the current contractual framework of Nagpur bus services and possible evolutions.

27. Review of the existing bus service contracts and models

27.1 Reviewed documents

Before starting this chapter, it must be noted that, during the inception mission conducted in Nagpur from 16th to 22nd of January 2020, **Gross Cost Contracts (GCC) were identified as the main contractual form currently implemented in India**, well known by all the stakeholders and thus easier to launch. It was therefore decided to focus the analysis on this contractual scheme and the possible adaptations required to make the contracts more effective and attractive to operators.

Therefore, this chapter focuses on a review of the existing gross cost contracts and models applicable in India and in Maharashtra state. The list of documents reviewed as part of this analysis is provided below:

- The contract between NMC and Hansa City Bus Services (Nagpur) Private Limited for operation and maintenance of diesel buses signed in 2017[41],
- The contract between NMC and Olectra BYD Greentech Ltd for procurement, operation and maintenance of 5 midi electric buses signed in 2019,
- Draft Bus Operator Agreement used for the request for proposals for the selection of a bus operator for the procurement, operation, and maintenance of 40 electric buses in Nagpur launched in December 2019 under FAME-II scheme,
- The Model Bus Operator Agreement (MBOA) for Operation and Maintenance of urban bus services through private sector participation on Gross Cost Contract (GCC) published by the Ministry of Urban Development in 2014,

The toolkit for Public-Private Partnerships in Urban Bus Transport for the State of Maharashtra published in 2011.

27.2 Comparative review of the existing documents

The review of the abovementioned documents raises several differences between the available gross cost contracts and models. The sections below summarise the main observed differences.

[41] Three operators are currently operating diesel buses in Nagpur (R.K. City Bus Operation, Travel Time Car Rental, and Hansa City Bus Services). A fourth operator (Olectra BYD) is operating 5 electric female-only buses. So far, we have only received the contracts of Hansa City Bus Services for diesel bused and Olectra BYD for electric buses. Hence, in the present report, we assume that other contracts with diesel bus operators are similar (which is most probably the case according to discussions with stakeholders during the inception mission).

27.2.1 Fleet purchase, ownership, and financing

27.2.1.1 Ownership modalities

While the MBOA states that buses are purchased by the transport authority, the urban transport PPP toolkit in the state of Maharashtra as well as the draft operator agreement used for the 40 electric buses tender under FAME-II scheme[42] provide for a contractual set-up where the operator purchases and owns the buses.

The existing contract between NMC and Hansa City Bus Services is a mixture of the two systems: the operator takes over 79 standard buses owned by NMC and provides 65 new buses (15 mini and 50 midi). The contract with Olectra BYD provides for a set up where the operator purchases the buses, but the cost is borne by the Authority.

In theory, contractual arrangements for fleet purchase and ownership can include any combination of options for each of the three stages of contract performance:

- Pre-operations, buses can be procured either by the authority or the operator,
- If they are procured by the operator, it can maintain ownership during operations or transfer them to the authority before the start of operations,
- If the ownership is with the operator during operations, they can be transferred, or not, to the authority at the end of the contractual operation period.

This translates into four different types of fleet ownership, three of which are used among the reviewed contracts[43], as shown in Table 83.

Table 83. Possible models for fleet ownership and comparison to the existing provisions in Nagpur

Type of private sector involvement	Procurement of buses	Ownership during the operation period	Ownership after the end of operations	Corresponding contract in Nagpur
Service contract to operate authority's assets	Authority	Authority	Authority	Hansa contract for NMC-owned buses
Procure/Buy, Transfer and Operate (BTO)	Operator	Authority	Authority	Olectra BYD contract

[42] In this scheme, the operator is expected to bear the initial cost of the buses. NMC is however expected to transfer a subsidy to be provided under FAME-India Scheme.

[43] Contractual provisions for bus ownership are not explicit in the Hansa City Bus Services contract (in particular, what happens at the end of operations is not specified). The table is filled using our understanding of these provisions, which would need to be confirmed.

Type of private sector involvement	Procurement of buses	Ownership during the operation period	Ownership after the end of operations	Corresponding contract in Nagpur
Procure/Buy, Operate and Transfer (BOT)	Operator	Operator	Authority	-
Service contract using operator's assets (BOO)	Operator	Operator	Operator	FAME Draft Agreement, Hansa contract for operator-supplied buses

The BOT model, whereby assets are procured and owned by the operator, but transferred to the authority at the end of the contract (thus allowing the authority to continue providing the service with these assets), does not appear to be used here while is quite common in other countries.

When the assets are owned by the operator, transferring them to the authority at the end of the contract may help secure continuity of service, and/or optimize the use of the assets if they are still in working condition. In such case, contracts should provide for a set compensation against the transfer of these assets that should be close to their economic value. Often, the net book value is used as a proxy for the economic value, which works provided that the contract specifies the amortization period.

27.2.1.2 Contract duration and asset life

The key issue in setting the duration of a contract delivering public services with private sector participation is to balance sufficiently short contract duration to allow for periodically conducting tenders for the service (thus keeping costs down through competition), with sufficiently long duration to allow for amortization of the assets over a period that is as close as possible to their service life (but never longer).

Having the authority provide or finance the fleet allows for setting a shorter contract period and re-tendering more frequently (for instance, every five years). If the operator finances the fleet, then it is best if contract duration matches the service life of the assets or the maximum financing tenor that can be obtained on the market, whichever is shorter.

Contract durations in Nagpur are:

- 5 years in the Hansa contract for NMC-owned buses (with an extension right by NMC for up to 10 years) which appears adequate,
- 10 years with the possibility of a 2-year extension (based on the condition and performance of the buses) in the Olectra BYD contract, with the buses returning for free to the authority at the end of the period, which appears adequate (if the buses have a significant residual value, it will benefit NMC),

- 10 years in the Hansa and FAME contracts, with the operator retaining ownership of the buses at the end of the period.

In the latter case, the operator preparing its bid will most likely finance the vehicles over 10 years, and likely not take the risk of assuming any residual value at the end of the contract: if there is such residual value, it will be a contractual upside for the operator. This is less favourable to NMC than the first two cases.

The contract duration issue becomes even more important for electric buses. If well maintained, they can likely reach a 15-year service life with a reasonably inexpensive mid-life refurbishment. However, it is likely difficult or excessively expensive for the operators to arrange financing with such a long maturity. In addition, the contracts make no mention of refurbishment.

Because CAPEX weighs considerably more in the total service cost for electric buses than for diesel ones, **optimizing electric fleet ownership and duration provisions in contracts is essential to minimizing the viability gap.**

One option to avoid losing the benefit of the extended service life of the electric technology could be to have 8 to 10-year contracts with buses returning to NMC ownership for free at the end of the contract. Corresponding financing would likely be easily secured by the operators. With some reinvestment, NMC could then extend the service life over another 5 to 10 years at minimal cost, lowering the average viability gap over its whole fleet.

A rule of thumb calculation shows that the reduction in the annual CAPEX charge per bus-km could be between 10% and 20% if the contract allows for full economic use and financing (including overhaul) over 15 years rather 10 years. Using the assumptions and outputs in our financial model, this translates into a 6 to 12% annual km charge reduction, and **a reduction in the overall network viability gap of 2.3% to 4.6% for the 20% electric scenario, and 4.9% to 9.7% for the 50% electric scenario**.

We therefore recommend further investigating this question. Interviews with market stakeholders would be essential to understanding current financing conditions and constraints (maximum maturity, rates, etc.), and optimize them in view of the new service life and life-cycle CAPEX associated to the electric technology.

27.2.2 Construction of depots and provision of equipment / machinery

The MBOA, the Maharashtra urban transport PPP toolkit and the existing contract between NMC and Hansa City Bus Services all state that the construction of maintenance depots and related basic civil infrastructure is borne by the transport authority. Only necessary moveable equipment or machinery are to be installed by the operator.

However, the model contract used for the 40 electric buses tender in 2019 states that the transport authority provides only land (along with any existing buildings, constructions or immovable assets if any) for setting up maintenance depots and charging stations, while the operator performs and bears all the costs related to the design and construction of maintenance depots. The construction works to be performed by the operator include structural work, electrical work, IT/Telecom systems, drainage systems, water supply systems, fire safety systems.

The contract with Olectra BYD states that depot sites are to be provided by the Authority. The Operator is however expected to provide any moveable equipment and/or machinery and infrastructure for charging including any civil and ancillary works required for parking, and maintenance.

The construction works to be conducted by the operator are not detailed in either the Hansa or the Olectra BYD contracts.

27.2.3 Payment terms

27.2.3.1 Calculation basis

In all reviewed documents, payments are based on the operated bus.kilometres and the applicable kilometre charge defined at the bidding stage and revised throughout the contract period. The PPP toolkit provides however for an additional option where the payment is based on a fixed hourly charge per bus.

27.2.3.2 Assured bus kilometres

All reviewed contracts and models provide for a guarantee to operate a minimum number of bus kilometres by the operator. More specifically, the transport authority (in the case of Nagpur, DIMTS on behalf of NMC) develops an operation plan that ensures that the average number of bus kilometres travelled by each bus will not be less than a minimum called "*Annual Assured Bus Kilometres*"[44]. The existing contracts with Hansa City Bus Services and Olectra BYD, as well as the draft contract used for the tender of the electric buses, set this volume at a minimum of 68 000 kilometres per bus per year (i.e., 200 km/day).

[44] The Model Bus Operator Agreement defines a "*Half Yearly Assured Bus Kilometres".* This could be explained by the fact that the MBOA provides for an evaluation of the achievement (or not) of the assured bus kilometres at the end of a period of six consecutive calendar months instead of a period of twelve consecutive calendar months in the other contracts/models. For the sake of simplification, we will refer to this minimum guaranteed bus kilometres in all the cases as the "*Annual Assured Bus Kilometres".*

27.2.3.3 Payment for unutilized bus kilometres

In the event where the *Annual Assured Bus Kilometres* are not achieved, the authority makes a payment to the operator for the unutilized bus kilometres in addition to the payments for the actual operated kilometres. Several differences were identified in the reviewed contracts and contract models regarding these provisions[45]:

- The MBOA: 25% of the total charge of the gap between actual bus kilometres and half yearly assured bus kilometres,
- Olectra BYD contract and the draft contract used for the tender of the 40 electric buses: 50% of the total charge pertaining to the gap between actual bus kilometres and annual assured bus kilometres,
- The existing contract with Hansa City Bus Services:
  - For NMC owned buses: 25% of the total charge pertaining to the gap between the annual assured bus kilometres and the actual operated bus kilometres,
  - For operator owned buses: 45% of the total charge pertaining to the gap between the annual assured bus kilometres and the actual operated bus kilometres.

The percentage of the total charge payable to the operator for unutilized kilometres pertains to the proportion of fixed costs borne by the operator as part of the total operation cost. Hence, the abovementioned differences could be explained by the different provisions for fleet procurement and ownership provided for in each contract/model as well as the chosen technology[46].

27.2.3.4 Payment for excess bus kilometres

In the event where the actual operated kilometres exceed the *Annual Assured Bus Kilometres*, an additional payment is made to the operator.

[45] The urban transport PPP toolkit for Maharashtra state does not provide detailed provisions on this subject.
[46] When the procurement of buses is under the purview of the authority, the operator bears fixed costs only for manpower, insurances for other assets and other expenses related to cleaning and washing which is estimated at 25% of the total operation cost per kilometre for diesel buses (according to the MBOA). The differences in payment for operator owned electric and diesel buses (i.e., between the provisions of draft contract used for the tender of the 40 electric buses and the existing contract with Hansa City Bus Services) could be explained by the fact that fixed costs for electric buses could be more important than for diesel ones (depreciation, insurances, registration…).

While both the MBOA and the existing contract with Hansa City Bus Services provide for an additional payment equivalent to 75% of the total charge pertaining to the additional kilometres, the draft contract used for the tender of the 40 electric buses and Olectra BYD's contract provide for an additional payment equivalent to 50% of the total charge of the additional kilometres[47].

27.2.3.5 Adequacy of contractual provisions for additional bus-km

Based on costs and financial assumptions made, we compared the actual costs incurred by bus operators to the payments provided for in the different available contracts and models, for both electric and diesel standard buses. The estimates were conducted for both cases: unachieved and exceeded Annual Assured Bus Kilometres. All the analysis is conducted for operator owned standard buses.

The objective of the analysis is to assess whether the payments formulas reflect the operators' costs. In fact, if payments are inconsistent with the actual costs incurred by the operators, at bid stage operators are likely to increase their margin in the quoted kilometre charge (to reflect the risk that actual km are far off from the assured km), which will translate into higher service costs.

The results show that although the payment terms seem to be adjusted for electric technology in the new contracts for electric buses, there might still be some room for improvement, although limited. More specifically, in case of exceeded Annual Assured Bus Kilometres per bus the operator is paid more than the actual costs incurred. Inversely, when the Annual Assured Bus Kilometres are not achieved by the operator, payments made do not cover the entire costs incurred by the operator. In addition, our payments estimations are based on the assumption that electricity charging costs are to be borne by the operators. Available contracts and models show different provisions for this aspect that should be specified.

[47] According to the MBOA, the 75% of the total charge pertains to the variable operating costs borne by the operator for this extra bus kilometres. In fact, it is assumed that the bus operators would be able to cover fixed costs by running the buses for the assured bus kilometres. Hence, by running the extra bus kilometres they are assumed to bear only variable costs such as fuel, spare parts, and consumable and which comprises of 70 to 75% of the total operating cost. Therefore, the differences between diesel and electric buses' contracts could be explained by the fact that the share of variable costs in the total operating costs is less important for electric buses than for diesel ones.

Table 84. Comparison of payments to operators and actual costs incurred in the case of excess and unutilized kilometres for new diesel and electric standard buses

	Excess	Inachievement
Annual assured kilometres per bus (km)	68 000	
Operated kilometres (km)	78 000	58 000
Diesel standard buses		
Payment as per MBOA		
Rate	75%	25%
Payments (INR)	4 488 690	3 596 897
Difference (Payment - Actual costs)	3.2%	-3.7%
Payment as per Hansa City Contract		
Rate	75%	45%
Payments (INR)	4 488 690	3 715 803
Difference (Payment - Actual costs)	3.2%	-0.5%
Actual costs incurred by the operator		
Costs (INR)	4 351 299	3 734 288
Electric standard buses		
Payment as per electric buses contracts		
Rate	50%	50%
Payments (INR)	6 043 894	5 215 963
Difference (Payment - Actual costs)	5.2%	-5.4%
Actual costs incurred by the operator		
Costs (INR)	5 747 760	5 512 096

27.2.4 Performance assessment, incentives, and penalties

The monitoring and evaluation of the operators' performance is based on performance assessment systems comprised of a set of indicators. Although these systems present some differences across the existing contracts/models (mainly related to the chosen indicators), they remain relatively similar given that all the selected indicators pertain to similar performance areas related to bus maintenance, bus operation, staff behaviour and passenger experience, safety and regulatory requirements.

Furthermore, some differences were also identified in the provisions, definition and calculation methods of incentives and penalties provided for in the reviewed documents.

In addition, none of the performance assessment systems include indicators related to (or having a direct impact on) operating expenditures. This is explained by the contracts' provisions for payment terms that are based on the operated bus.kilometres and the kilometre charge regardless of the actual costs incurred by the operator. Operators will naturally tend to optimise their operating expenditure in order to increase their margin, but this will not have an impact on the service costs (and hence on NMC's budget) as payments to operators are not linked to the cost-efficiency of the system.

In fact, the operating expenditures of a bus service could be optimised through two main action areas:

- *Optimised kilometre charges at the bidding stage.* This is possible when the bidding processes allow the operators to have sufficient details on the service plans and hence to make more accurate estimations of their expected costs. Inversely, when the service specifications are not detailed enough, operators tend to make larger margins to cover the possible risk of cost overruns.
  - In the current contractual framework, these aspects are not fully taken into account as only limited details on the service plans are provided in the bidding stage.
- Contractual provisions that allow to vary the operators' payments based on the possible cost-efficiency gains that could be achieved by the operators. The main action areas that could be leveraged for optimised operating expenditures (and hence operators' payments) are the following:
  - Enhanced commercial speed which will allow for reduced energy and staff costs. In the current contractual framework, this aspect is not considered.
  - Enhanced service production indicators, namely the total number of produced bus.kilometres (with a constant total fleet). This aspect is covered by the current contractual framework, as operators are paid for the excess kilometres at a lower rate.
  - Optimised energy consumption. For electric buses, if electricity charging costs are to be paid by the authority, the operators will have no incentives to optimise their consumption. If the operators are to pay only the excess electricity charging costs (as provided for in the draft contract used for the 40 electric buses), the operators will only be incentivised to not exceed the granted amount of electricity consumption. However, they will still have no incentive to reduce their electricity consumption through better driving and maintenance practices.

For the detailed comparative review of the provisions of each reviewed contract and model, see **Task 4 Report** (reference document [R5]).

27.3 Conclusions

The review of the existing gross cost contracts and models leads to the following conclusions:

- There are substantial differences between key provisions in the existing gross cost contracts and models. These differences pertain notably to the procurement and ownership of buses, contract duration, the construction and equipment of depots, payment terms, incentives, and penalties,
- Bus ownership and contract duration provisions in the case of electric buses would benefit from further review and optimization, which would require interviews with local stakeholders. This is especially important because of the much greater weight, for electric buses, of the annualized CAPEX in the annual service charge. As a very preliminary estimate based on desk review only, the network viability gap reduction over the long term from optimized provisions may be around 2% to 5% for the 20% electric scenario, and 5% to 10% for the 50% electric scenario,
- Operators are paid based on a fixed kilometre charge depending on the operated bus kilometres. However, the bus service plan (including routes planning and scheduling), which has a direct impact on the operators' costs, is determined by DIMTS (in consultation with NMC) with no or little information provided at the bidding stage. This configuration does not allow the operators to optimise the quoted kilometre charge at bid stage,
- Once the contract is signed, by nature of the gross cost structure, reductions in operating costs do not translate into reduced payments to the operators. The performance assessment systems and the corresponding incentives / penalties do not include aspects related to cost efficiency. Hence, optimizing service plans from a cost efficiency perspective would not translate into a reduced viability gap, unless amendments could be negotiated whereby gains would be shared between NMC and the operators.

28. Review of the integrated bus transport management contract

28.1 Key contract features

A contract for Integrated Bus Transport Management was signed between NMC and Delhi Integrated Multi-Modal Transit System Limited (DIMTS) in 2016. The duration of the contract is six years and can be extended by additional 6 years (maximum). The role of DIMTS under this contract includes the following:

- Operation management support, including: routes planning, management of operators' contracts on behalf of NMC, depot management, operation and management of the control centre, customer orientation (including passenger information systems, redress grievance mechanisms, etc.), human resource development (monitoring and ensuring personnel training requirements are fulfilled by bus operators and fare collection agency selected by NMC), bus stops monitoring and management, provision of inputs to NMC for integrating multi-modal services and increasing efficiency,
- Ticketing and revenue management through the monitoring and deployment in operation of fare collection personnel deployed by the outsource agency selected by NMC,
- Intelligent transportation systems (ITS) including contract management of ITS equipment/device supplier, applications for monitoring of live operation, issuance of bus passes,
- Provisions of transaction advisory services to NMC for contracts pertaining to fare collection, GPS devices, ticketing machines and passenger information systems,
- Operation and management of pass issuance centres,
- Deployment of a program management unit (PMU) at NMC office that monitors the implementation of the city bus services and supports/advises NMC on public transport issues.

Payments by NMC to DIMTS are made on a monthly basis and are based on fixed service charges for each remuneration component pertaining to the services described above.

DIMTS performance is evaluated based on monthly ridership and using a base average monthly passenger count of 45,00,000 passengers[48]. A penalty/incentive is to be paid by/to DIMTS if the actual average monthly passenger count is less/more than 45,00,000 passengers. Other penalties are to be paid by DIMTS in the event of observed deficiencies related to a set of predefined indicators pertaining to operation management, control and monitoring of bus operation, and revenue collection management. No other performance incentives are included in the contract.

[48] This figure excludes concession passes issued in the month.

28.2 Conclusions

The review of DIMTS contract with NMC raises a central issue that could have a direct impact on the economic balance of the system.

DIMTS is responsible for route planning and schedules (in consultation with NMC). The contract states that the proposed route planning should allow to achieve a balance between revenue maximization and accessibility for all areas. However, it also states that the only contractual performance incentive to DIMTS is the monthly ridership levels. Furthermore, although the contract provides for penalties related to monthly passenger count and deficiencies in operation management, bus operation monitoring and revenue collection management, none of these provisions evaluates the cost and the commercial efficiency of service delivery. Therefore, we understand that there is no contractual incentive for DIMTS to deploy a service plan that optimises cost and commercial efficiency.

NMC may consider discussing a contractual amendment with DIMTS whereby commercial and cost efficiency gains would be shared between NMC and DIMTS, thereby providing an incentive to DIMTS for reducing the viability gap (rather incentivising increased revenues without regard to the viability gap).

29. Conclusions of the contractual framework analysis

29.1 Summary of the analysis and general recommendations

Our review of the current contractual framework for Nagpur bus services has encompassed the contracts between the operators and NMC, and between DIMTS and NMC. They must be reviewed together because DIMTS has a key role in enforcing and optimizing the service.

Despite being all based on the same gross cost principle, the details of the provisions in existing or template bus operator contracts in Nagpur vary significantly.

We have identified two main areas that could reduce the potentially increased viability gap in bus electrification scenarios:

- Optimizing contract duration and bus ownership provisions to reduce the annualized CAPEX charge, and
- Providing for contractual incentives in both the NMC-DIMTS and the NMC-Operators contracts for improving commercial efficiency and cost efficiency.

The first area stems directly from the increased share of CAPEX in the annual service charge for electric buses, and the potentially increased service life of electric buses. Current provisions appear somewhat misaligned, with a potential upside to operators that does not benefit NMC nor increases competition for the contract.

The second area stems from the misalignment of current contractual incentives with the objective of reducing the viability gap.

On the cost efficiency side (C/K), although bus operators are recruited through competitive bidding processes, the absence or the limited information on the service plan provided at the bidding stage limits the operators' ability to optimize the quoted kilometre charge. Later on, the contractual framework does not allow NMC to benefit from any possible cost-efficiency gains that could be achieved by the operators and DIMTS has no incentive to adjust service plans to allow for such efficiency gains.

On the commercial efficiency side (P/K), DIMTS is responsible for the design of service plans without any contractual incentives for optimisation. In fact, for DIMTS, the only incentive is related to increasing ridership and exceeding the base monthly passenger count[49].

Therefore, we recommend the following actions to optimise the contractual framework for an enhanced financial performance of the system:

[49] For example, tortuous routes to provide a wider service coverage may maximize ridership levels at the expense of disproportionately higher operating costs through higher km payments to operators.

- Reviewed bus ownership and contract duration clauses,
- More information at the bidding stage on the service plans to be operated by bus operators in order to allow for more optimisation of the kilometre charge at the bidding stage,
- Revised contractual provisions to allow NMC to partially benefit from some cost-efficiency gains by operators during the contract period, in particular regarding optimised energy consumption or gains from higher commercial speeds,
- Revision of DIMTS' contract in order to introduce contractual incentives for commercial efficiency,
- Revision of payment terms to better reflect the actual costs incurred by bus operators[50].

The above recommendations are preliminary and would need to be refined and confirmed through interviews with key stakeholders (NMC, DIMTS, bus operators, finance providers).

29.2 Specific recommendations for the upcoming standard buses replacement in 2022

Contracts with the existing operators for diesel buses were signed in 2017 for:

- A five-year duration for standard buses owned by NMC (expiration in 2022), with a possible extension of up to 10 years, and
- A 10-year duration for midi and minibuses provided by the operator (expiration in 2027).

If one of the electrification scenarios proposed in the pre-feasibility study (replacement of all the existing 237 diesel standard buses by electric ones in 2022) is retained by NMC, two options could be envisaged:

- Renegotiate contracts with the existing operators to include the electric buses and hence extend the duration by an additional 10 years for standard buses, or
- Launch a new competitive call for tenders to recruit one or several operator(s) for the operation of the new electric standard buses.

[50] These improvements are however expected to be limited as the current contracts and models are already relatively adjusted to the different types of bus and need only minor adjustments/revisions.

However, given (i) the close expiration date of the existing contracts and the generally long time necessary for renegotiations, and (ii) the change in the technology and in the bus ownership which requires a different set of operation and maintenance skills as well as significantly higher investments from the operators, **it is highly recommended for NMC to launch a new call for tenders for the new electric buses**. This will allow to select the operator(s) with the most adequate set of skills for the operation and maintenance of electric buses and the financial capacities to bear the significantly higher investment costs (which might not be ensured by the existing operators), as well as to optimise the operators' kilometre charge through the competitive process.

In addition, **NMC should seize the opportunity of this replacement to improve the tender processes and contracts** namely by: (i) providing more information on the operation plans at the bidding stage to allow the bidders to optimise their kilometre charge, (ii) verifying that the remuneration formula for an increase or decrease in the annual number of km matches the operation cost structure, and (iii) including an objective contractual mechanism to allow for an adjustment of the km charge in case the service plan specified in the tender documents is changed in such a way that it results in a significant increase or decrease of the km charge (for instance, as a result of the construction of priority lanes that would improve the commercial speed).

CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the main element of this report and its main recommendations.

30. Conclusions and recommendations

30.1 Analysis and mid-term view for the future of public transport in Nagpur

30.1.1 Nagpur's public transport is developing but still needs improvement

Regarding general traffic aspects, it is noted an increase in transport time for Nagpur citizens for all modes, and **a slow but important evolution in the modal share from 2-wheelers and private cars to public transportation**.

From an organizational point of view, the need for a Unified Metropolitan Transport Authority (UMTA) is repeatedly included in transport planning documents. However, up to date, there have been little progress on the matter, and **a UMTA is still not operational in Nagpur City nor in Maharashtra state**. The same is noted for the formation of the Nagpur Transport Fund.

On the other hand, **substantial development has been verified regarding ITS** and the setting up of a traffic information management control centre.

The planning documents have identified a **TOD opportunity**, and it is verified that this principle has been applied to the recent urban and transport development in Nagpur.

30.1.2 The necessary rationalization of Nagpur City Bus Service

The study of the development of City Bus Service network should be focused on the **implementation of the 76 rationalized bus routes, specially the 19 trunk routes**.

Furthermore, we propose that the development of the rationalized City Bus Service routes using an "**approach by depot location**", as it shall allow to maintain coherent operation and maintenance units. For this, we recommend that the 3 existing depot locations and the 6 new depot locations shall be used for the organization of the "feeder and trunk" bus routes.

The **Orange and Aqua Metro Lines shall contribute to a fast-paced and sustainable development of public transport in Nagpur City**, and the metro Feeder Bus Service shall be an essential backbone. It is to be noted that the metro feeder buses shall equally **have a positive impact on the City Bus Service** (as of increase in ridership), **provided that both systems are complementary** (and not concurrent, as it is mainly the current case in Nagpur).

30.2 E-buses systems, equipment, and technology recommendations

The study of transition from diesel/CNG to electric buses prompted us to make the following technical choices:

- The **electric motorisation** is the most adequate with weak tailpipe & GHG emissions, very low noise emissions, low maintenance activity, low impacts on the depot and lower fuels costs.
- The **slow charging strategy** (and therefore **depot charging technology**) is recommended considering the average distance travelled per day.
- The **CCS plug** is recommended for Nagpur City Electric Buses charging stations in depots.
- The **sequential charger** is recommended as it optimizes infrastructure and energy consumption.
- In terms of thermal comfort, **RFMV and glazing openings** are recommended.
- The **medium power rating** is recommended in order to guarantee the best compromise between performance and range with 120 kW for a minibus, 160 kW for a midi bus and 200 kW for a standard bus.
- The use of **individual parking spaces** at depots is recommended for easier bus operation, maintenance, and parking.
- A series of **workshop upgrades** are either necessary or highly recommended for the operation of E-buses. In addition, **impacts on required human resources and qualifications** have been identified and should be taken into account.

30.3 Case study: replacement of standard buses by 2022

Firstly, we have carried out two sensitivity analysis using the E-buses energy consumption simulations. We have seen **that the bus ridership has not a significant impact**, indeed the average difference between the two scenarios (empty bus and 20 passengers 'bus) is close to 5%. In another hand, the **average mileage consumption is estimated to be 70% greater when considering an air-conditioning system**. It is important to optimize these two parameters in order to reduce buses consumption.

Secondly, it has been seen that **the reduction of the battery capacity from 400 kWh to 350 kWh results in an increase on the number of buses required to perform the theoretical daily service schedule**. In total, 5 additional buses should be needed in the 350 kWh scenario: 1 at Patwardhan depot, 1 at Khapri Naka depot and 3 at Higna Naka depot. In addition, 1 additional charger should be installed in each depot, this would increase the daily energy consumption.

From a purely technical point of view, **the option of using 350 kWh batteries would not have an important number of impacts on buses operation and maintenance** (activities and costs) but could reduce investment costs (however, we verified that investment costs are actually higher when considering financial aspects). We have also seen the importance of the optimisation process which allows to reduce the maximum charging power by avoiding charging too many vehicles at the same time.

Third, we described the impact on depot configuration and proposed depot layout for the three different sites, including all technical rooms with medium voltage room, transformer substation, chargers' room and battery technical room.

Finally, an overall assessment of the environmental impacts related to the electrification of the standard buses to be replaced by 2022 has been done, demonstrating the **many benefits from the conversion from diesel and CNG to E-buses**. Indeed, **battery electric buses emit over 30% less CO_2 than diesel buses**. Electric vehicles achieve their maximum potential (regarding reducing emissions) as the electricity mix decarbonizes but, in any case, reduce greenhouse gas emissions compared to diesel vehicles. In addition, it has been estimated that **each year, approximately 90 tons of carbon monoxide, 10 tons of hydrocarbon and 25 tons of nitrogen oxides would be saved** thanks to the conversion from thermal to battery electric buses.

30.4 Financial and contractual aspects

30.4.1 The electrification scenarios will require additional resources

The financial assessment showed that if NMC were to consider an electrification of the standard buses for the upcoming replacement in 2022 (assuming constant fleet levels over the upcoming 15 years), this will require additional resources compared to a reference scenario where the existing buses are replaced with diesel ones. In that case, buses with a 350 kWh battery capacity seem more financially viable compared to buses with a 400 kWh battery capacity. In addition, although the installation of an advanced charging management system would result in slightly higher kilometre charges and hence increased service costs (due to the additional investment and maintenance costs), such system is very beneficial to operations and should be considered.

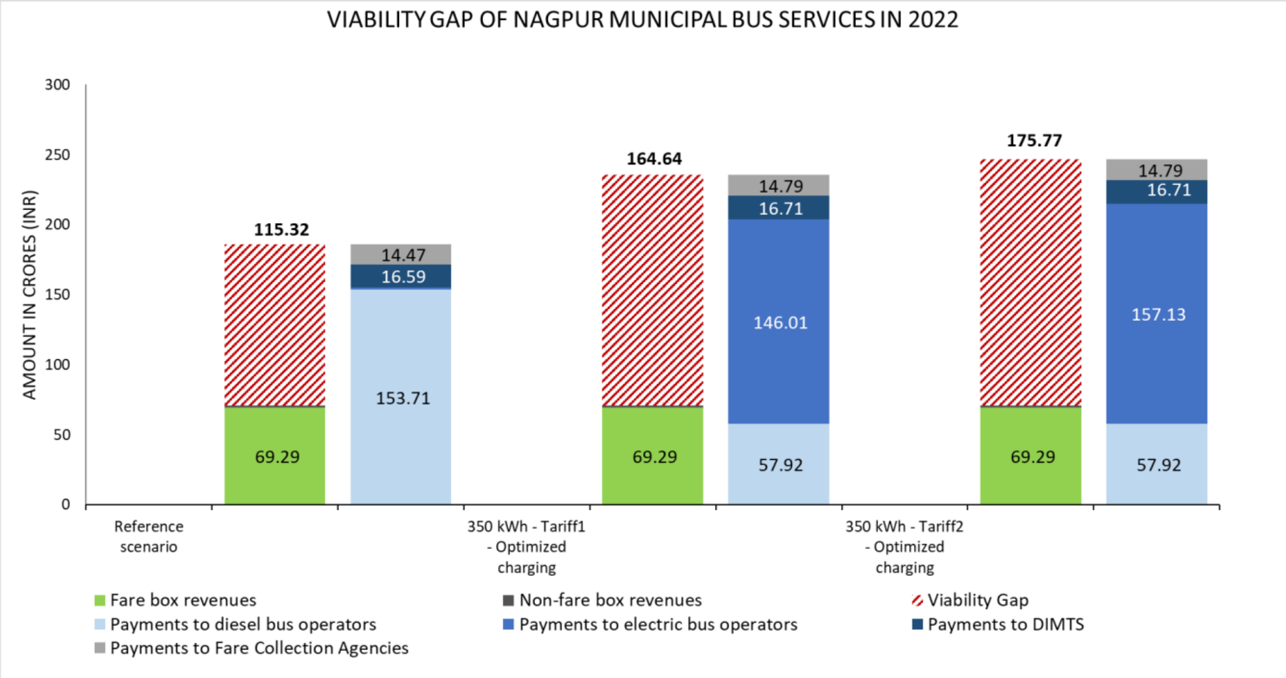


Figure 137. Viability gap of Nagpur City Bus Services in 2022

If however NMC were to consider the fleet augmentation scenario “Mid Term Vison” where we increase the total fleet of the network and introduce electric buses, the service costs will be significantly higher, reaching more than three times the current costs (in nominal terms) at the end of the evaluation period. The service revenues are however unlikely to increase proportionally.

In conclusion, the electrification of the bus fleet will deteriorate the financial sustainability of the system in all cases. However, the shift to a cleaner technology will yield positive externalities that are not captured by the financial analysis.

Four levers were hence identified to enhance the financial sustainability of the system and support the diesel-to-electric transition:

- Solution 1: Increased cost efficiency,
- Solution 2: Increased commercial efficiency,
- Solution 3: Investment subsidies,
- Solution 4: Increased fare-box revenues.

While increased fare-box revenues could be achieved through increased tariffs and/or ridership levels, and investment subsidies could be ensured from globally available financial resources[51] (such as the Green Climate Fund and the Clean Technology Fund), optimized cost and commercial efficiency require an optimization of the current contractual framework.

[51] This report focuses on globally available financial resources given the inability to conduct missions to Nagpur and interviews with the local stakeholders.

30.4.2 The existing contractual framework could be optimized to support the shift

The analytical review of the existing contractual framework identified some room for optimization that could reduce the potentially increased viability gap in bus electrification scenarios. Five main preliminary recommendations were hence formulated and would need to be confirmed and refined through interviews with key stakeholders (NMC, DIMTS, bus operators, finance providers):

- Reviewed bus ownership and contract duration clauses. This stems directly from the increased share of CAPEX in the annual service charge for electric buses, and the potentially increased service life of electric buses. Current provisions appear somewhat misaligned, with a potential upside to operators that does not benefit NMC nor increases competition for the contract,
- More information at the bidding stage on the service plans to be operated by bus operators in order to allow for more optimization of the kilometre charge at the bidding stage. Currently, although bus operators are recruited through competitive bidding processes, the absence or the limited information on the service plan provided at the bidding stage limits the operators' ability to optimize the quoted kilometre charge,
- Revised contractual provisions to allow NMC to partially benefit from some cost-efficiency gains by operators during the contract period, in particular optimized energy consumption or gains from higher commercial speed,
- Revision of DIMTS' contract in order to introduce contractual incentives for commercial efficiency,
- Revision of payment terms to better reflect the actual costs incurred by bus operators[52].

For the upcoming replacement of buses in 2022, and if one of the electrification scenarios proposed in the pre-feasibility study (replacement of all the existing 237 diesel standard buses by electric ones in 2022) is retained by NMC, two options could be envisaged:

- Renegotiate contracts with the existing operators to include the electric buses and hence extend the duration by an additional 10 years for standard buses, or
- Launch a new competitive call for tenders to recruit one or several operator(s) for the operation of the new electric standard buses.

[52] These improvements are however expected to be limited as the current contracts and models are already relatively adjusted to the different types of bus and need only minor adjustments/revisions.

However, given (i) the close expiration date of the existing contracts and the generally long time necessary for renegotiations, and (ii) the change in the technology and in the bus ownership which requires a different set of operation and maintenance skills as well as significantly higher investments from the operators, **it is highly recommended for NMC to launch a new call for tenders for the new electric buses**. **In addition, NMC should seize the opportunity of this replacement to improve the tender processes and contracts in line with above-mentioned recommendations.**

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