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

PRE-FEASIBILITY STUDY REPORT

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Task 6 – Pre-feasibility study for electric buses deployment

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SUMMARY TABLE

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EXECUTIVE SUMMARY

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This section presents a summary of the Pre-feasibility Study for Electric Buses Deployment Report.

The main simulations assumptions, results and impacts on depots, as well as updated financial and contractual assessment are here summarized.

I. REPORT OBJECTIVES

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. 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.

II. 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.).

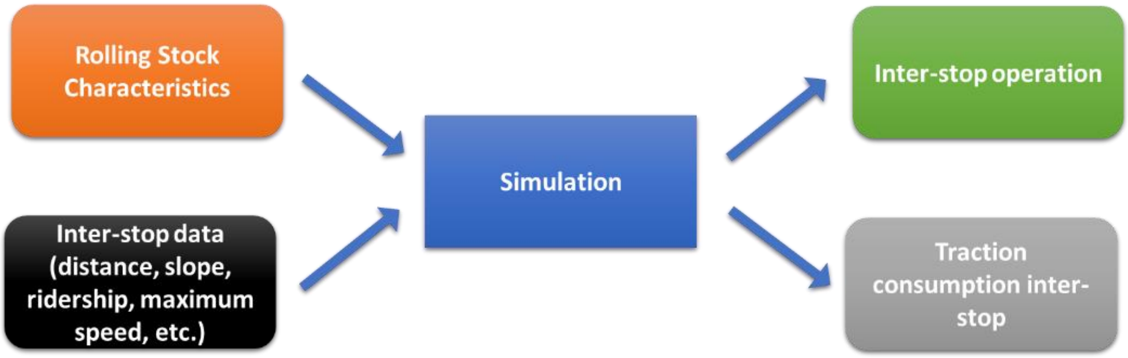

Figure 1. Traction consumption calculation for each inter-stop

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.

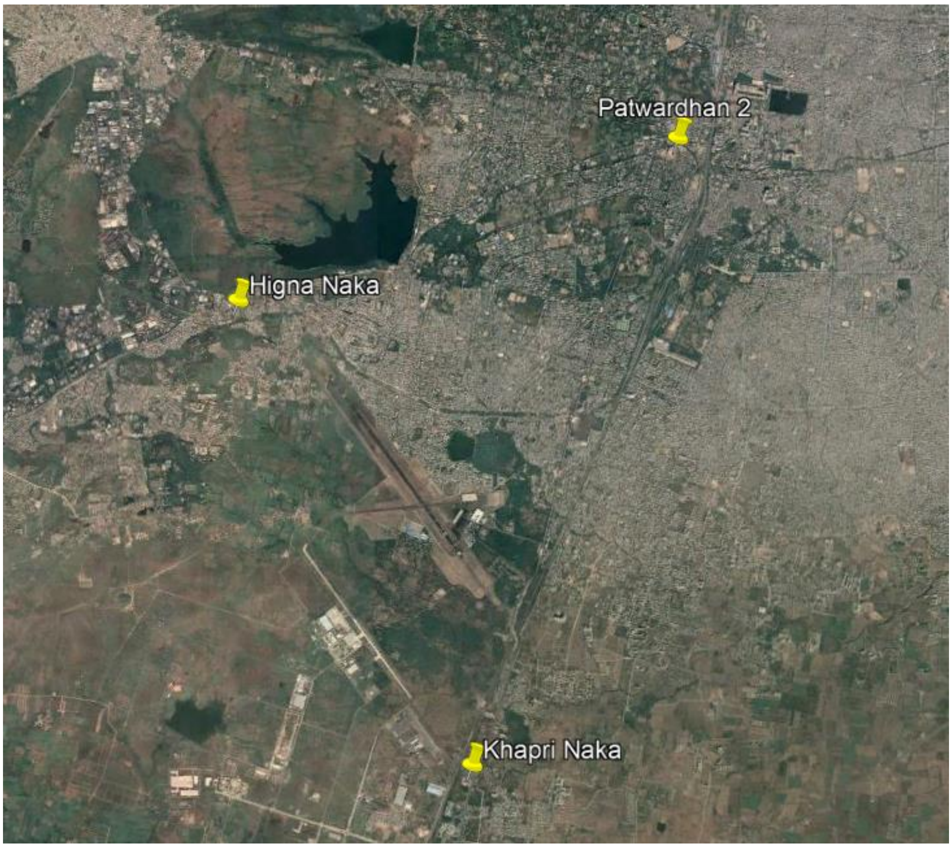

Figure 2. Location of the bus depots considered in the study (base map: Google Earth®)

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**.

III. 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.

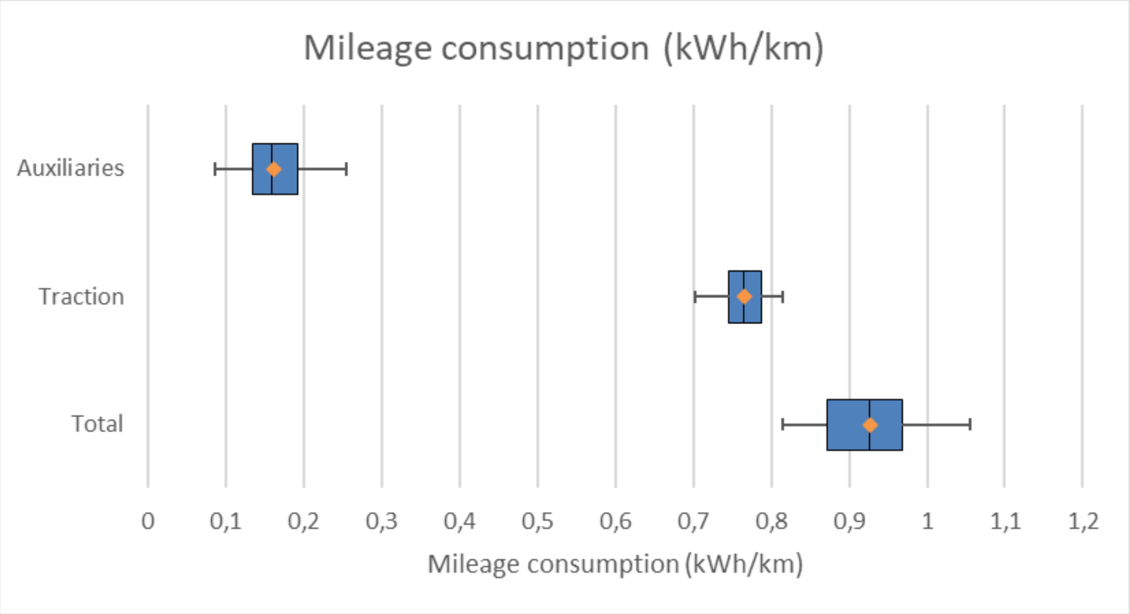

Figure 3. Distribution of mileage consumption on the network

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**.

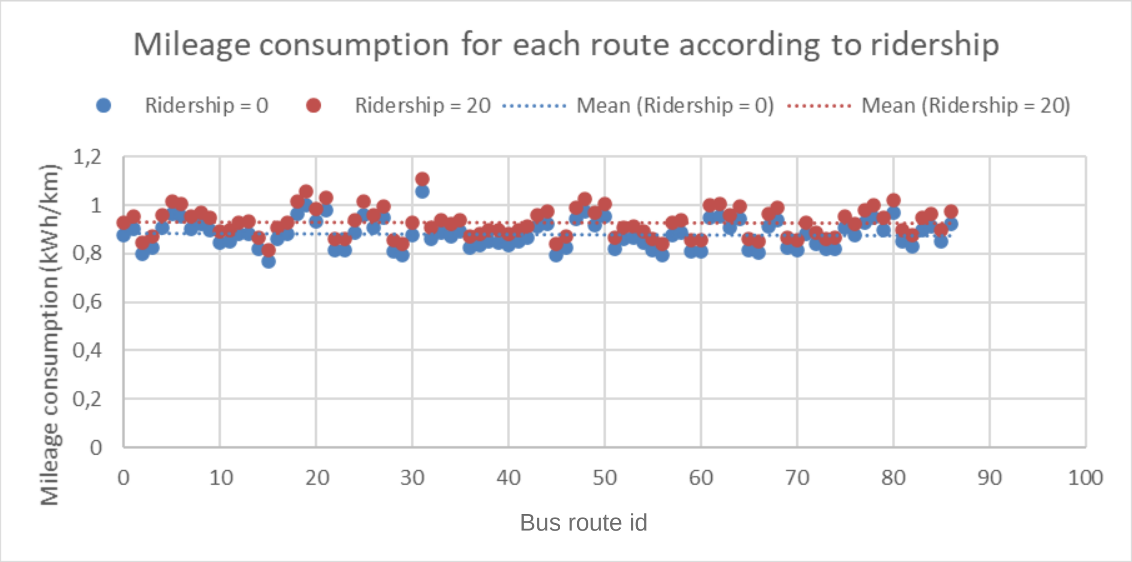

Figure 4. Average mileage consumption per bus route according to ridership

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)**.

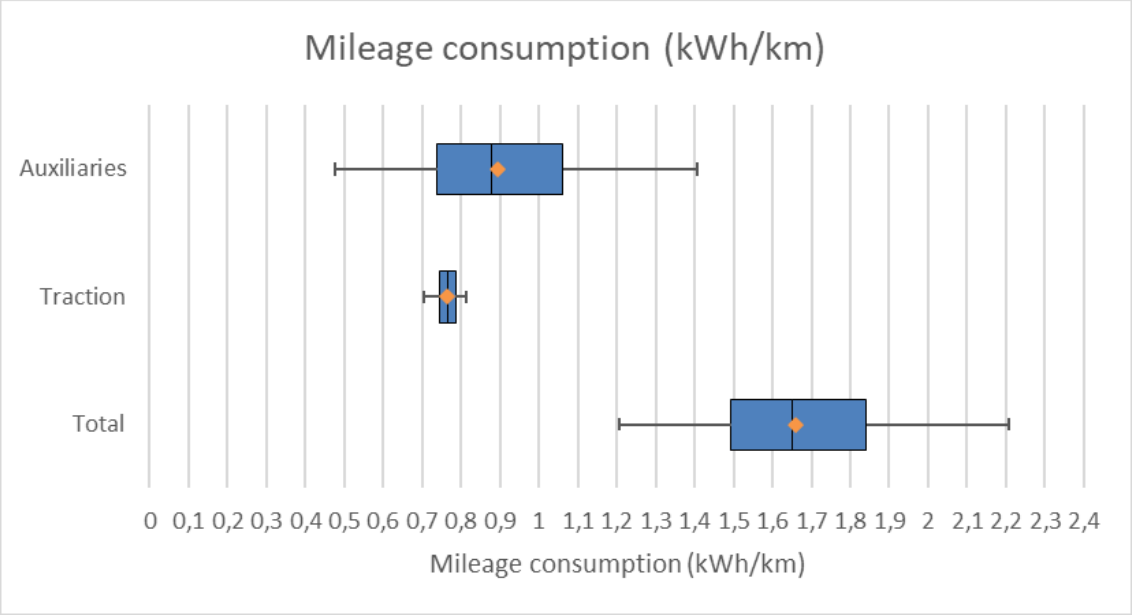

Figure 5. Distribution of mileage consumption on the network (with air-conditioning)

IV. 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 recharge, 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 recharge patterns to limit the power demand peaks.

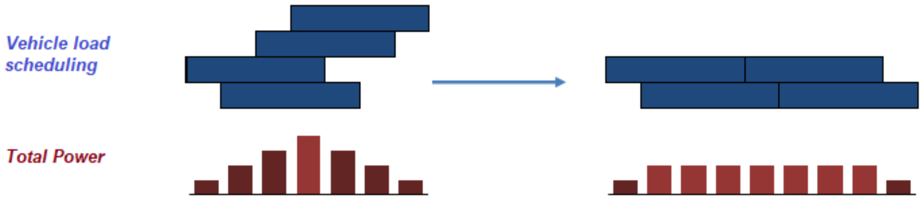

Figure 6. **Volt@bus** principle of electrical recharging planning reorganization (in blue) to optimize the required electrical power (in red)

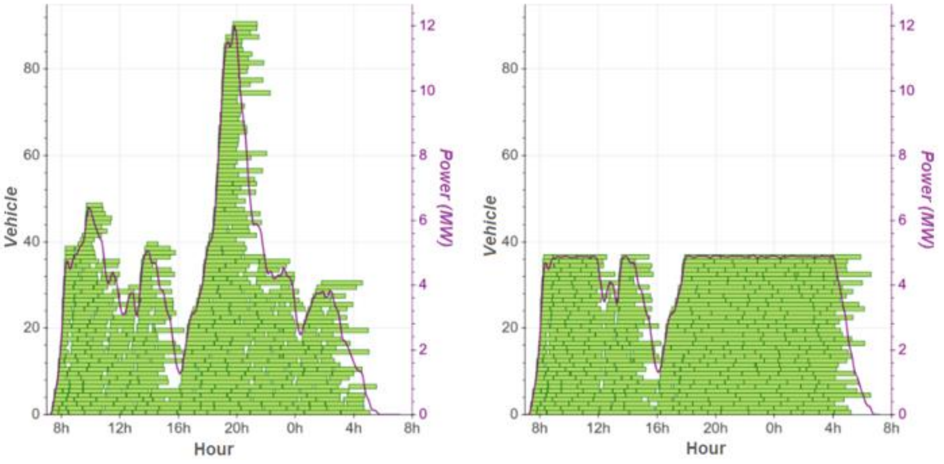

Figure 7. Charging power required without (left graph) and with (right graph) optimization of operation and charging schedule using **Volt@bus** software simulations

The principle is to reorganize the programming of the vehicles recharging 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 recharge 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 recharged 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.

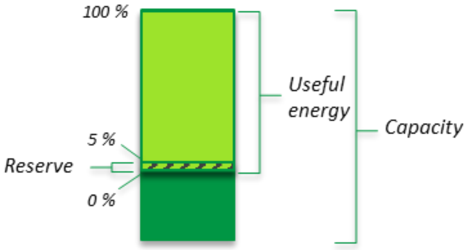

Figure 8. Visual explanation of bus battery parameters and assumptions

V. 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.

Table 1. 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.

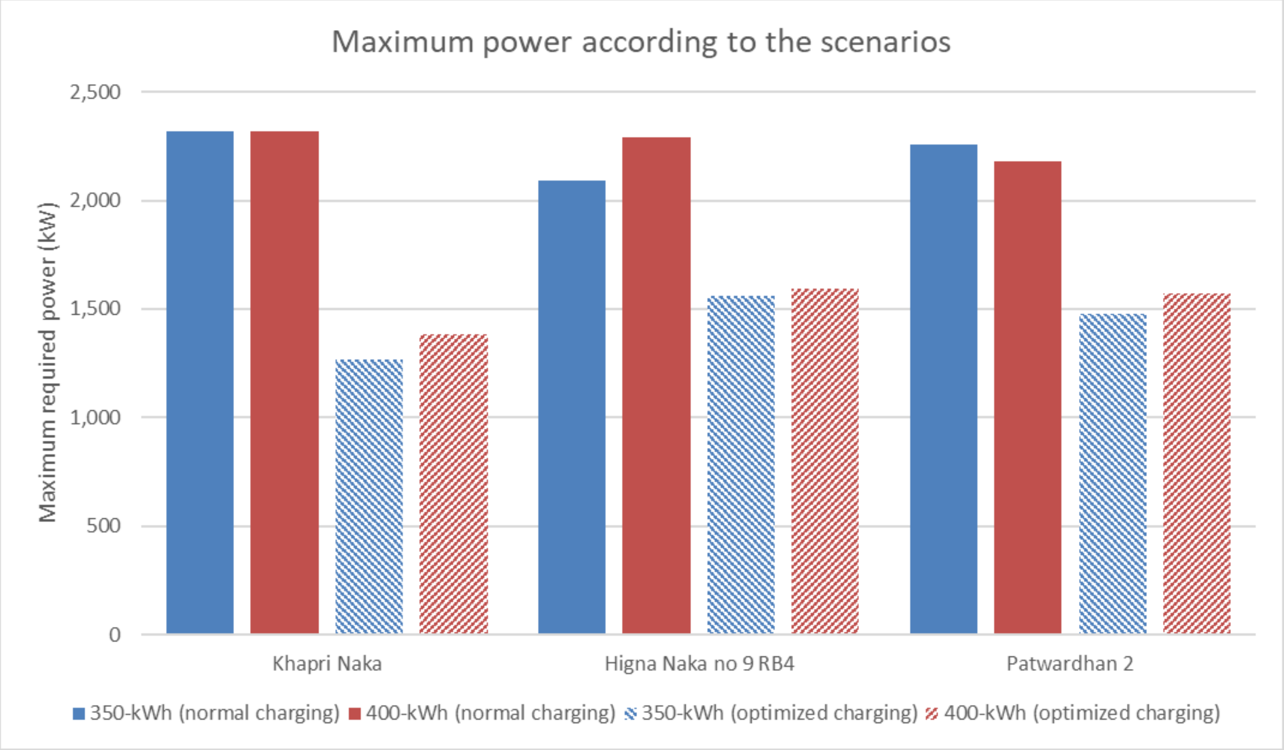

Figure 9. Maximum power according to the scenarios

VI. 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.

VII. 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[1].

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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[1] 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).

VIII. 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 <u>approximately half</u> the operational costs of diesel buses** (see details in Table 2). 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** (see details in Table 3).
  - 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 2. 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**

Table 3. 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**

IX. 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.

X. 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).

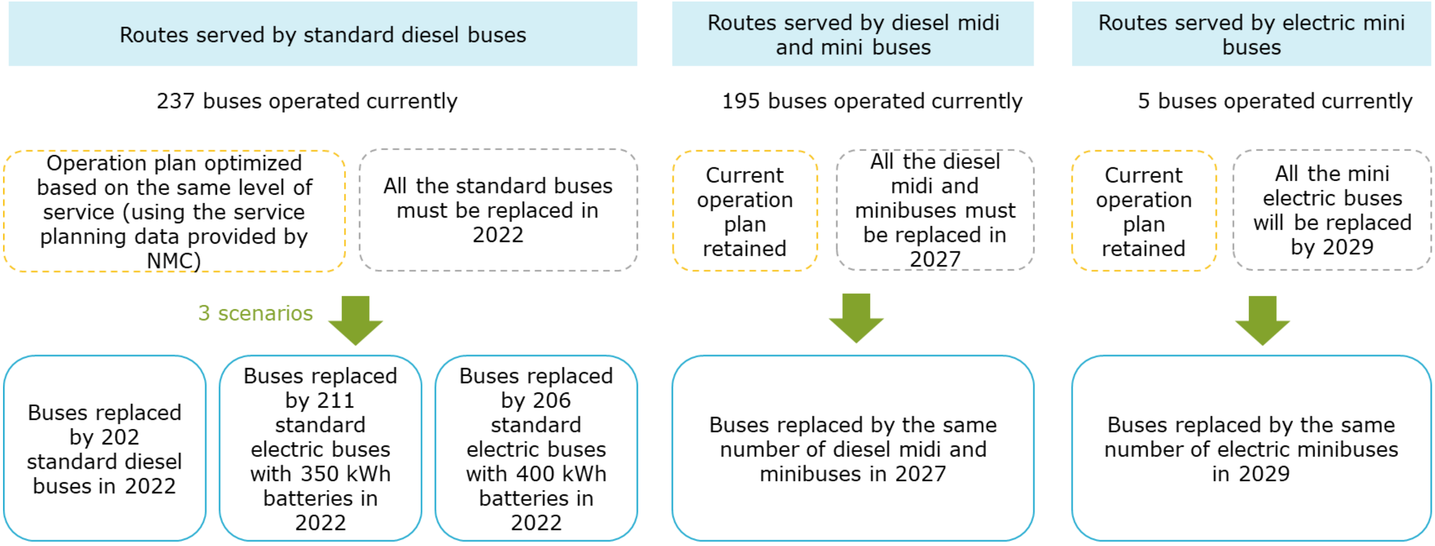

Figure 10. Characteristics of the Nagpur City Bus network considered for the financial analysis

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.

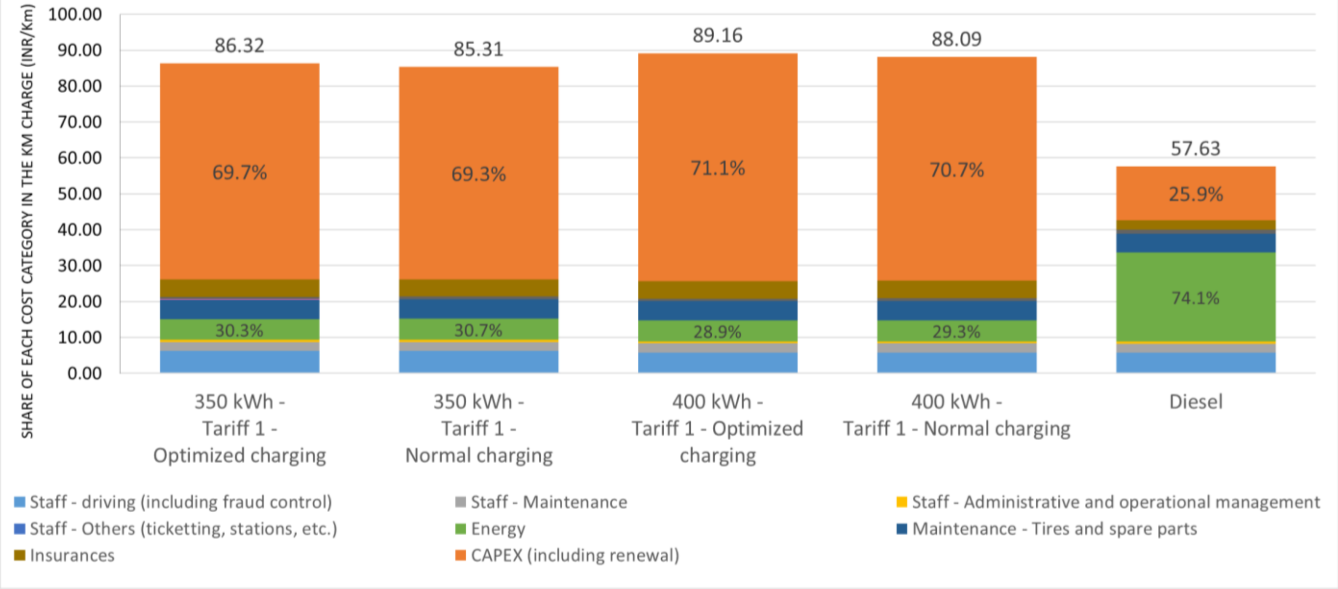

Figure 11. Comparison of the km charge for electric and diesel standard buses - Tariff 1 (incentive tariff)

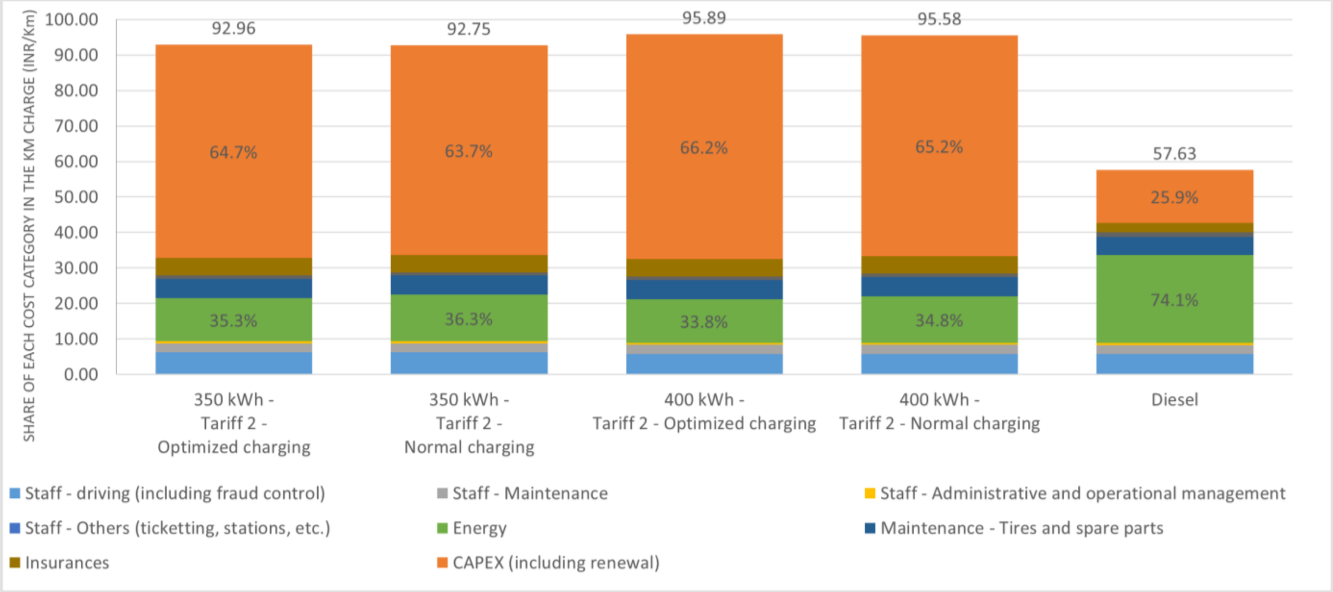

Figure 12. Comparison of the km charge for electric and diesel standard buses - Tariff 2 (regular tariff)

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.

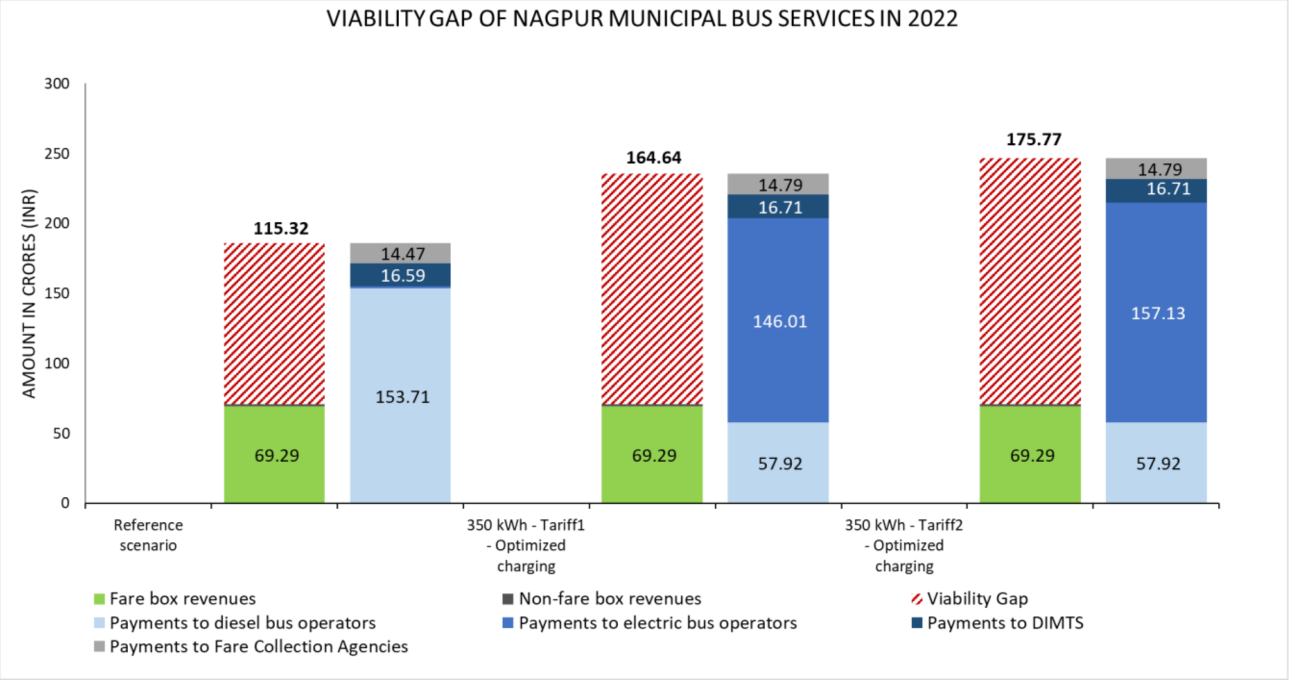

Figure 13. Viability gap of Nagpur City Bus Services in 2022

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.

Figure 14 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).

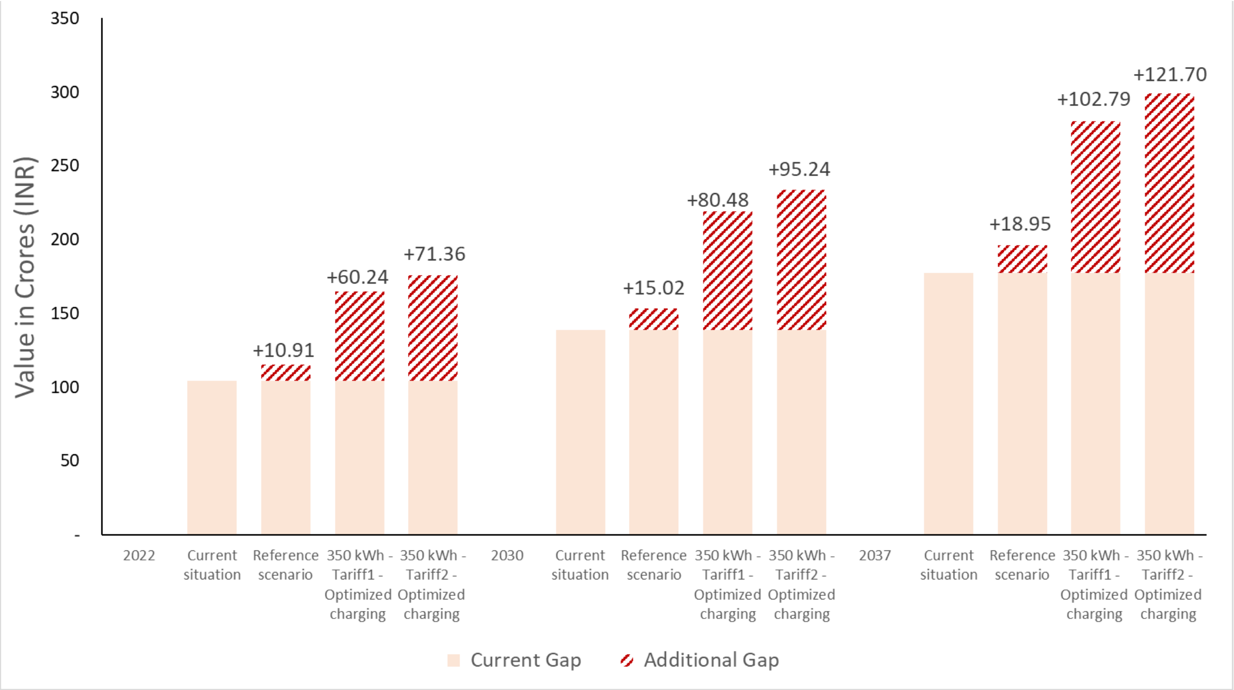

Figure 14. Comparison of the additional annual gap to the current one

XI. 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.

XII. 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).

XIII. 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.

Figure 99 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.

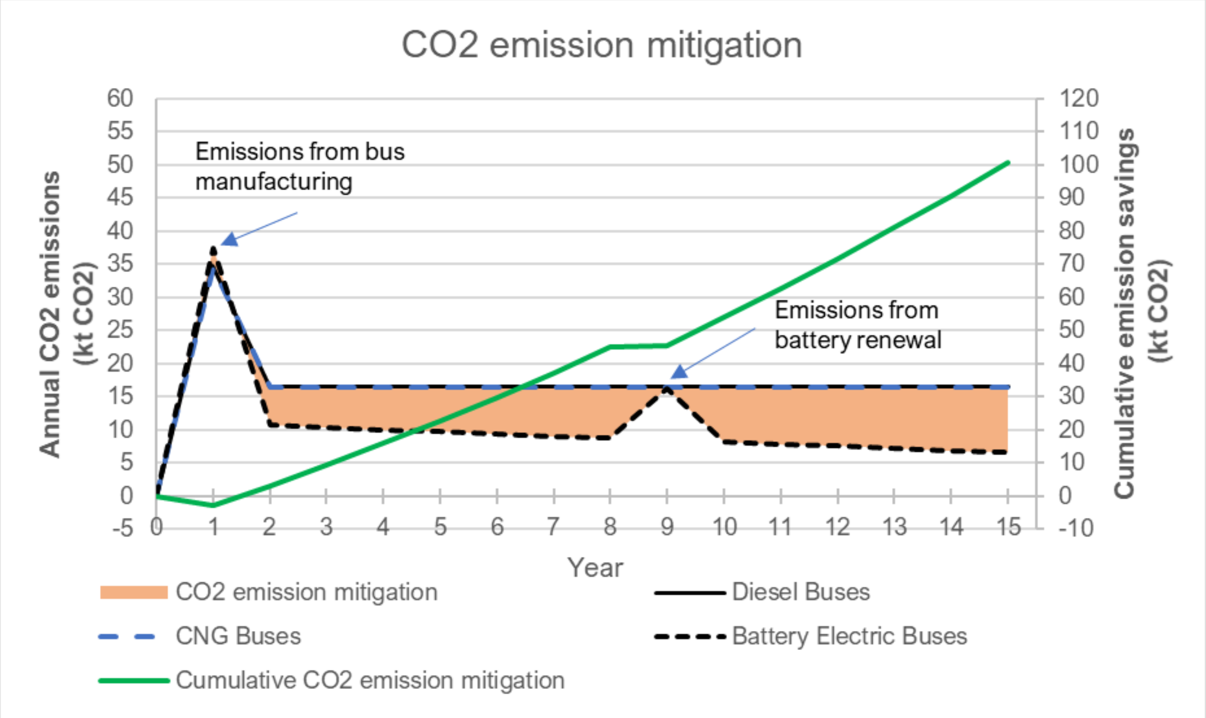

Figure 15. CO_2 emission mitigation estimations for Nagpur City Bus Service fleet

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**.

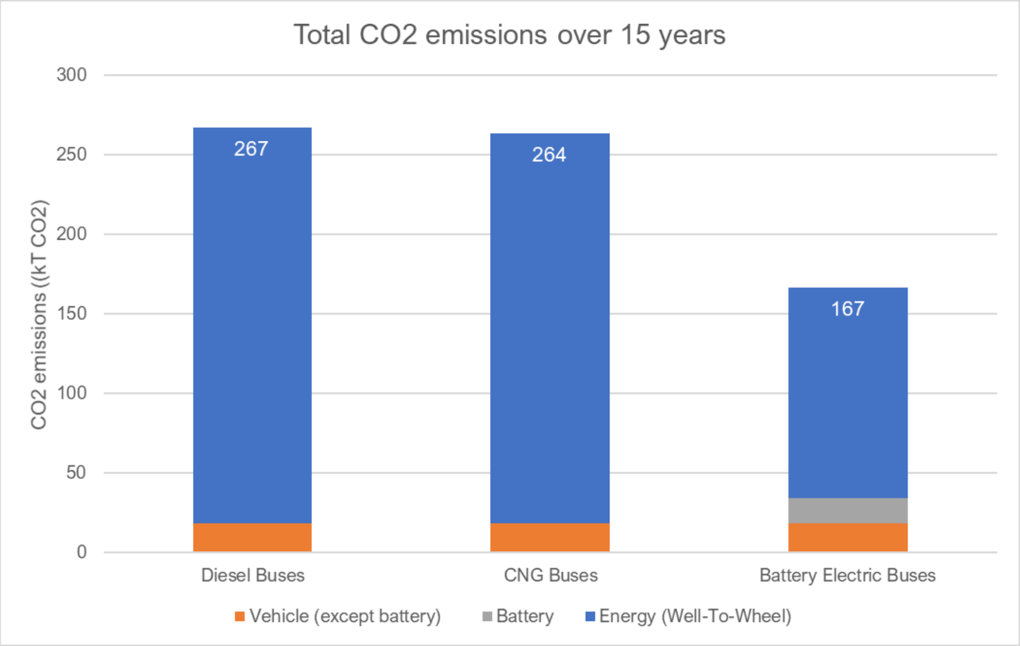

Figure 16. Estimation of total CO$_2$ emissions for 15 years for Nagpur City Bus Service fleet

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.

XIV. 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.

XV. 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.

- Project presentation and context
- Report objective and content
- Reference documents
- List of acronyms and abbreviations

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 1,000,000 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

This report consists the main deliverable for **Task 6 - Pre-feasibility study for electric buses deployment**.

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 is structured in three sections:

- **Report assumptions**,
- **Simulations results and outputs**,
- **Financial and contractual assessment**, and
- **Urban planning and environmental assessment**.

The **first section** 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** 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. 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 section** 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.

The **fourth and final section** presents an overall assessment of the environmental issues and impacts related to the electrification of buses in Nagpur. It also presents general recommendations in terms of urban and street planning to upgrade Nagpur City Bus Service efficiency and attractivity

Details on simulations' input data and results are presented in this report's **Annexures 1 through 5**.

1.3 Reference documents

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

Table 4. Report reference documents

	Document title / description	Document Reference	Date
[R1]	Inception Report - Part A *Nagpur Inception Mission Report*	MOB-AC2-09-RPT-101	28-02-2020
[R2]	Engine and O&M Strategy Report - Part A *Rolling Stock & Infrastructure Benchmark*	MOB-AC2-09-RPT-301	11-05-2020
[R3]	Engine and O&M Strategy Report - Part B *Operation and Maintenance Strategy*	MOB-AC2-09-RPT-302	07-05-2020
[R4]	Financial and Contractual Framework Analysis Report	MOB-AC2-09-RPT-401	27-11-2020
[R5]	DIMTS data on bus types per bus route for each Nagpur City Bus Operator	See **Annexure 1**	Received on 28-12-2020
[R6]	DIMTS data on Nagpur City Service bus schedules per route for a typical day	See **Annexure 2**	Received on 21-01-2020
[R7]	DIMTS data on Nagpur City Service detailing bus stops' Names and Coordinates for each bus route	See **Annexure 3**	Received on 28-12-2020
[R8]	DIMTS data on Nagpur City Bus Service depot locations and GPS coordinates	See **Annexure 4**	Received on 28-12-2020

1.4 List of acronyms and abbreviations

Acronyms and abbreviations used in this report are listed in Table 5.

Table 5. Acronyms and abbreviations

A	Ampere (*unit*)
A.M. / P.M.	*ante meridiem / post meridiem*
AC / DC	Alternate Current / Direct Current
AFD	*Agence Française de Développement* French Development Agency
BMS	Battery Management System
BOT	Build Operate Transfer
BRT	Bus Rapid Transit system
C/K	Cost Efficiency
CAPEX	Capital Expenditures

CMP	Comprehensive Mobility Plan
CNG	Compressed Natural Gas
DIMTS	Delhi Integrated Multi-Modal Transit System
ELV	Extra Low Voltage
EV	Electric Vehicles
FAME	Faster Adoption and Manufacture of Electrical Vehicles
GCC	Gross Cost Contract
GPS	Global Positioning System
GST	Goods and Services Tax
HV	High Voltage
HVAC	Heating, Ventilation and Air-Conditioning
INR / Rs	Indian Rupees
ITS	Intelligent Transport System
LAN / VLAN	Local Area Network / Virtual Local Area Network
LV	Low Voltage
MBOA	Model Bus Operator Agreement
MV	Medium Voltage
NMC	Nagpur Municipal Corporation
NSSCDCL	Nagpur Smart and Sustainable City Development Corp. Ltd.
O&M	Operation and Maintenance
OPEX	Operation Expenditures
P/K	Commercial Efficiency
PLC	Programmable Logic Controllers
RFMV	Refrigerated Forced Mechanical Ventilation
RTA	Resistance to Forward Motion
SCADA	Supervisory Control And Data Acquisition
TDS	Tax Deducted at Source
kW / kWh	kilowatt (*unit*) / kilowatt-hour (*unit*)
WACC	Weighted Average Cost of Capital
V	Volt (*unit*)
kVA	kilo-Volt-Ampere (*unit*)

Nagpur City – Fruit street market

Nagpur City – New Smart City bus shelters

Nagpur City – Public electric cars charger

REPORT ASSUMPTIONS

This section presents the purpose, assumptions and parameters considered for the E-Buses energy consumption and depot charging simulations presented in this Pre-feasibility Study.

- E-buses energy consumption simulation purposes
- E-buses depot charging simulation purposes and input data
- CAPEX and OPEX estimation assumptions

2. Energy consumption simulations

2.1 Simulation purpose

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), 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.

2.1.1 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 17) 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.

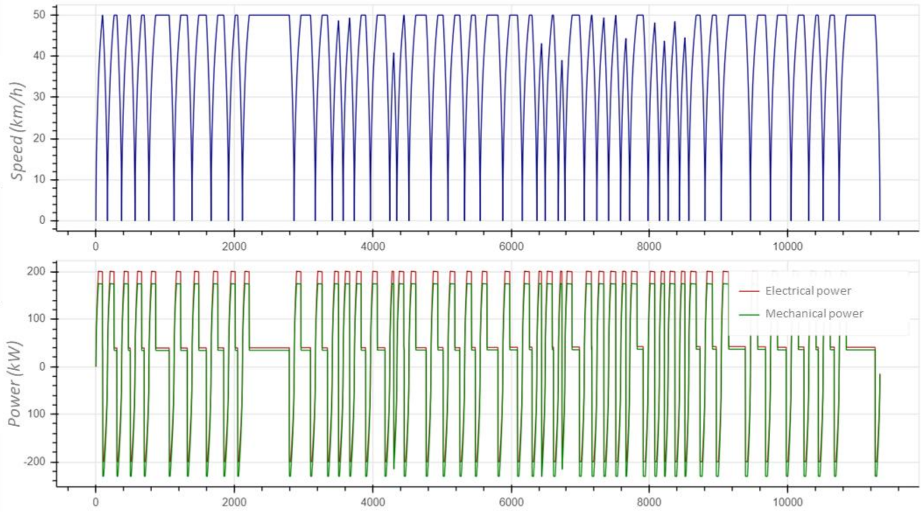

Figure 17. Typical electric bus trip (example from a Canadian study)

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 (see details in chapter 2.3).

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,
  - 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),
  - Average ridership of the inter-stop section.

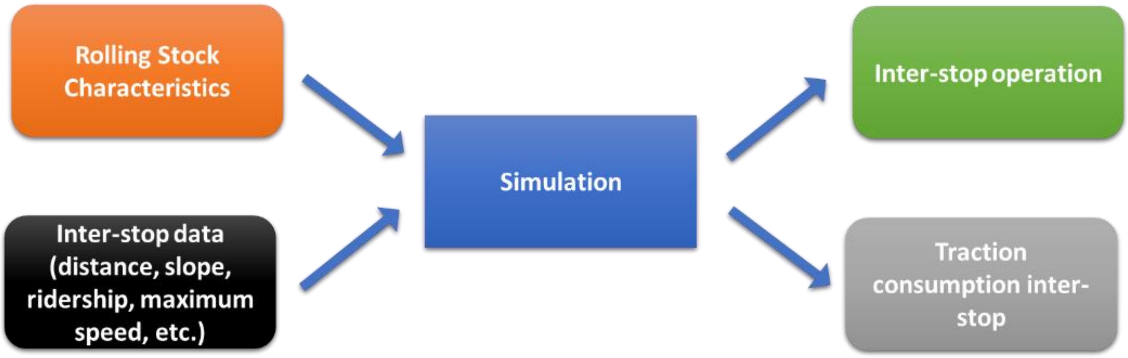

Figure 18. Traction consumption calculation for each inter-stop

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.).

2.1.2 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 (see details in chapter 2.4.4),
- 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.

2.2 Nagpur City Service parameters

2.2.1 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 on reference document [R5] shared by DIMTS on 28-12-2020, the corresponding routes are presented in Table 6.

Table 6. Main Nagpur City Service bus routes simulated (data source: [R5])

Bus route number / Bus route operated by		
Traveltime City Bus Services	R.K. City Bus Operations	Hansa City Bus Services
4	20	28
35	26	32
47	38	35
48	54	40
49	79	42
107	111	54
232	210	106
	231	135

The energy consumption of these 21 bus routes is simulated.

Nonetheless, according to the service schedule information shared by DIMTS on 21-01-2020 (see reference document [R6]), these routes take (partial or complete) itineraries of other Nagpur City Service bus routes. Consequently, the additional routes presented in Table 7 shall equally be included in the **Volt@bus** model.

Table 7. Additional Nagpur City Service bus routes simulated (data sources: [R5], [R6], and [R7])

Bus route number / Bus route operated by		
Traveltime City Bus Services	R.K. City Bus Operations	Hansa City Bus Services
02 STL	02 STL	08 STL
08 STL	03	11 STL
12 STL	07	12 STL
13	08 STL	23
61	11 STL	52
61 ASTL	61 ASTL	61
61 D1	61 D1	61 D1
108	68	86
155	250	134
239	304	174
245		188
246		222
253		228 / 228 A
302		244
304		249
		250
		252
		263
		274
		277
		304
		306

The mileage consumption for the bus routes highlighted in red in Table 7 cannot be calculated because their topography (bus stops and coordinates) has not been provided (according to input data provided by DIMTS on 28-12-2020, see reference document [R7]).

Moreover, to simplify the study, we suppose that the mileage consumption on the declinations of the routes (for instance 54 and 54STL / 135, 135A and 135MSTL, etc.) is the same as the original route.

Thus, **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).

2.2.2 Bus depots' locations and configuration

The map in Figure 19 shows the location of the three Nagpur depots considered in this pre-feasibility 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 (see reference document [R1]), 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 (see reference [R8]) and aerial views [2].

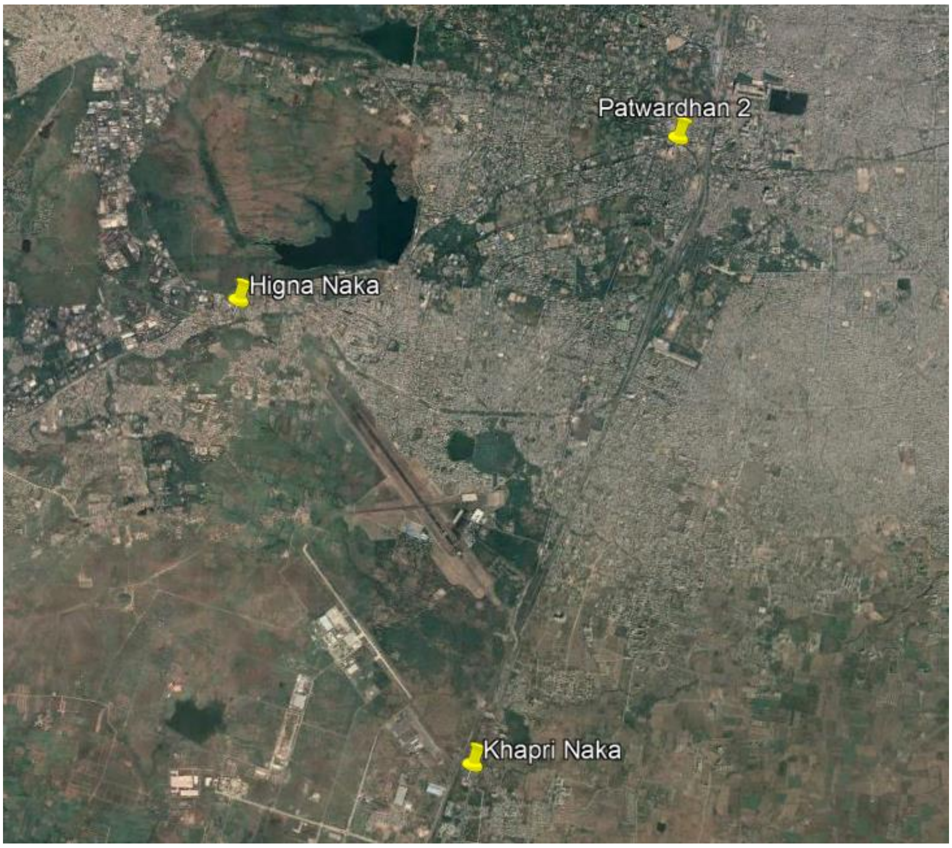

Figure 19. Location of the bus depots considered in the study (base map: Google Earth®)

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.

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[2] In order to update the data received from DIMTS, adjustments have been made on the definition of the perimeters of Patwardhan 2 depot (based on our site visit, we considered the south-western area of the Yashwant Stadium instead of the south-eastern area) and of Higna Naka depot (based on recent Google Earth views, we considered the bus depot area located south of Vasudev Nagar Metro Station, between Rajendra Nagar and Shivaji Nagar, instead of the previous depot area nowadays occupied by the Vasudev Nagar metro station building).

2.3 Bus routes parameters

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.

The “inter-stop distance” parameter is determined from the distances indicated in the description sheet of the Nagpur City Service bus routes (see reference document [R7]).

The “inter-stop slope” parameter considers bus stops’ X and Y GPS Coordinates indicated in DIMTS input data (see [R7]) 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 (see reference document [R6]) as “total distance of the daily task divided by total driving time”. Average speed is considered **uniform throughout each daily task**.

2.4 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.

2.4.1 General parameters

The general parameters of the rolling stock (standard E-bus) are as follows:

- Length: 12 meters,
- No-load static mass, including batteries (**sm**): 13.5 tons,
- Passenger mass: 70 kg per passenger,
- Inertial coefficient (ic): 1.05,
- Total dynamic mass (dm): 14.175 tons, and
- Rolling stock maximum speed: 90 km/h.

2.4.2 Kinetic parameters

Acceleration and braking parameters for 12-meter standard E-buses considered in the simulations are as follows:

- Maximum acceleration / Maximum deceleration: 1.3 m/s² (each),
- Maximum tractive effort / Maximum braking effort: 18.5 kN (each),
- Resistance to forward motion coefficient (**R0**): 85 $N.t^{-1}$ (for a dry road),
- Resistance to forward motion coefficient (**R1**): 0 $N.km^{-1}.h^{-1}$, and
- Resistance to forward motion coefficient (**R2**): 0.51 $N.km^{-2}.h^{-2}$.

The "resistance to forward motion" coefficients are defined such that the total resistance to forward motion (**RTA**) is equal to:

$$\boxed{\mathbf{RTA = (R0 * sm + R1 * s + R2 * s^2)}}$$

with **s** representing rolling stock speed (in km/h).

Figure 20 shows the evolution of the different efforts (tractive, braking, resistance to forward motion) depending on the speed applied to an empty bus.

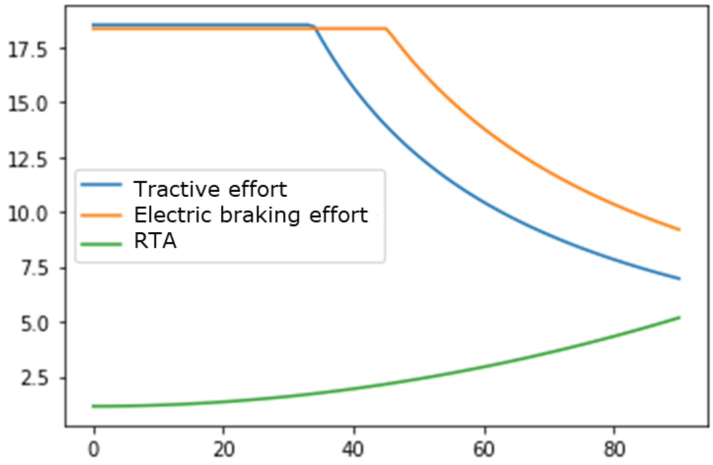

Figure 20. Rolling stock "Effort x Speed" diagram for a standard E-bus (data source: SETEC-NODALIS experience and feedback from international electric buses suppliers)

2.4.3 Electrical parameters

Acceleration and deceleration electrical parameters are as follows:

- Electric tractive power: 200 kW,
- Electric braking power: 200 kW,
- Overall efficiency of the traction chain: 87% (i.e., 13% of energy loss).

2.4.4 Energy consumption related to auxiliary systems

2.4.4.1 HVAC contribution

In the previous reports (see [R2] and [R3]), the 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**.

A brief sensitivity analysis related to HVAC energy consumption (with and without HVAC system) will be proposed in the study report.

2.4.4.2 High Voltage System

The High Voltage (HV) system is responsible for a small part of the overall electric consumption of the bus. Equipment that consumes energy are the following:

- Compressor,
- Power steering.

The average power n of these equipment combined is approximately **0.7 kW**.

2.4.4.3 Extra Low Voltage System

The Extra Low Voltage (ELV) system is composed of on-board auxiliary and control devices such as:

- Lighting,
- Alarms,
- Passenger information equipment,
- Ticketing equipment,
- Vehicle starting.

The average power dissipated by this equipment is approximately **1.4 kW**.

3. Depot charging simulations

3.1 Simulation purpose

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 (see reference document [R6]). 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),
- Sizing the necessary electrical infrastructures in the depot.

The bus consumption per kilometre and the route planning provided (reference [R6]) 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.

3.2 Simulation methodology

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 recharge,
- 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 recharge patterns to limit the power demand peaks. The principle is to reorganize the programming of the vehicles recharging 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 recharge 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 recharged in time, but with the lowest installed power.

Figure 21 and Figure 22 illustrate some of the principles of the methodology and outputs from **Volt@bus** software.

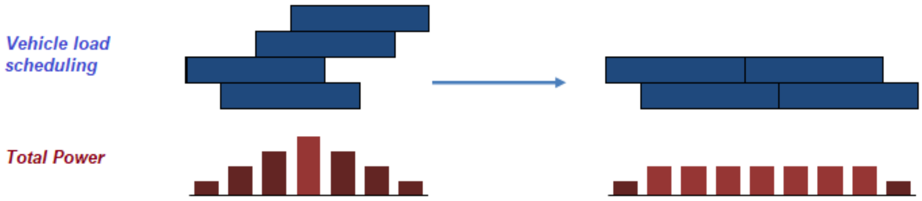

Figure 21. **Volt@bus** principle of electrical recharging planning reorganization (in blue) to optimize the required electrical power (in red)

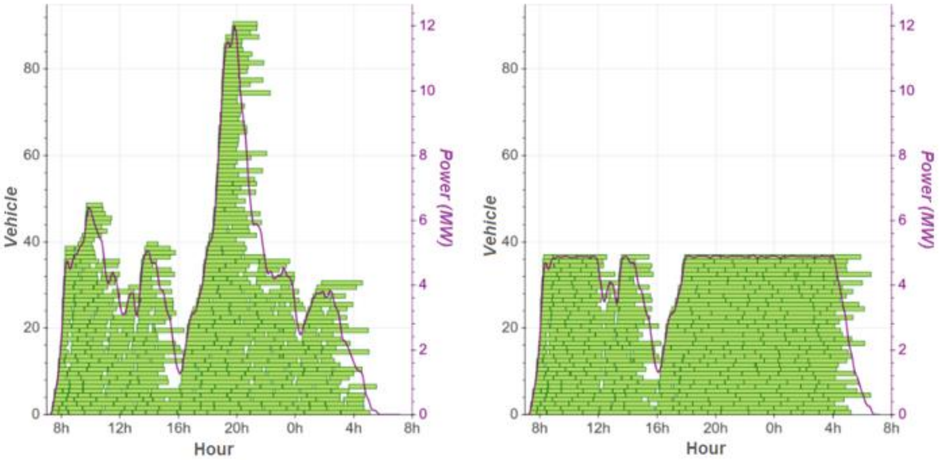

Figure 22. Charging power required without (left graph) and with (right graph) optimization of operation and charging schedule using **Volt@bus** software simulations

Horizontal bars (blue in Figure 21 and green in Figure 22) represent the recharging time for a particular bus (the horizontal axis in Figure 22 graphs represent the hours of a day). Stacked horizontal bars represent buses that are recharged at the same time (left vertical axis of Figure 22 graphs), assuming the number of available rechargers at the depot is compatible. The bigger the stack, the higher is the peak required power (right vertical axis of Figure 22 graphs) for the depot (regarding bus recharging).

Figure 22 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 recharge 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.

3.3 Simulation input data

The bus charging simulations are carried out considering the mileage consumption for each route estimated in the previous step (see section 2).

The current operational data (references [R5], [R6], and [R7]) allows 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.

3.3.1 Bus service schedule

Operational data (references [R5], [R6], and [R7]) 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.

Reminder: only the routes listed under chapter 2.2 are simulated, corresponding to the routes currently being operated by standard (12m) thermal buses (diesel / CNG) and to be renewed by 2022.

We understand from the service planning data (reference [R6]) 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 will be 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,
- 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.

3.3.2 Electric battery capacity

In accordance with SETEC-NODALIS recommendations on deliverables [R2] and [R3], the standard E-buses battery capacity of buses is of 400 kWh.

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 (as explained in chapter 3.3.1).

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. Table 8 and Figure 23 summarize these parameters.

Table 8. 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

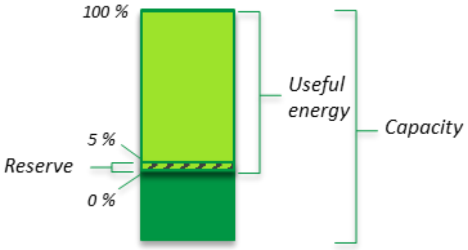

Figure 23. Visual explanation of bus battery parameters and assumptions

3.3.3 Bus charging infrastructure

According to SETEC-NODALIS recommendations on deliverable [R3], 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 9.

Table 9. Bus chargers' parameters considered in the simulations (data source: [R3])

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)

3.4 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[3],
- 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.

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[3] 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).

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.

4. Macroeconomic and operational assumptions

4.1 Macroeconomic assumptions

The main macroeconomic parameters used in the financial model are summarized in Table 10.

Table 10. 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%

4.2 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 11, Table 12, and Table 13 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 reference document [R6], 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 11). 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 and is further analysed in chapter 10 (for comparison reasons only).

For the other types of buses, the same operational assumptions considered in *Task 4 Report* (see reference document [R4]) were used.

Table 11. Operation assumptions for standard diesel buses (data source: [R6])

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 12. 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 13. 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

SIMULATIONS RESULTS AND OUTPUTS

This section presents and analyses the results of the E-buses energy consumption and depot charging simulations, as well as the identification of impacts on depots and O&M activities.

- E-buses energy consumption simulation results
- E-buses depot charging simulation results
- Impacts on depot configuration
- Required resources and qualifications

5. E-buses energy consumption simulation results

5.1 Network mileage consumption

Energy consumption simulations have been carried out for the 45 routes identified in chapter 2.2 through **Volt@bus** software.

The box-and-whisker plot shown in Figure 24 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 24 presents the distribution of mileage consumption on the network for the 45 simulated bus routes.

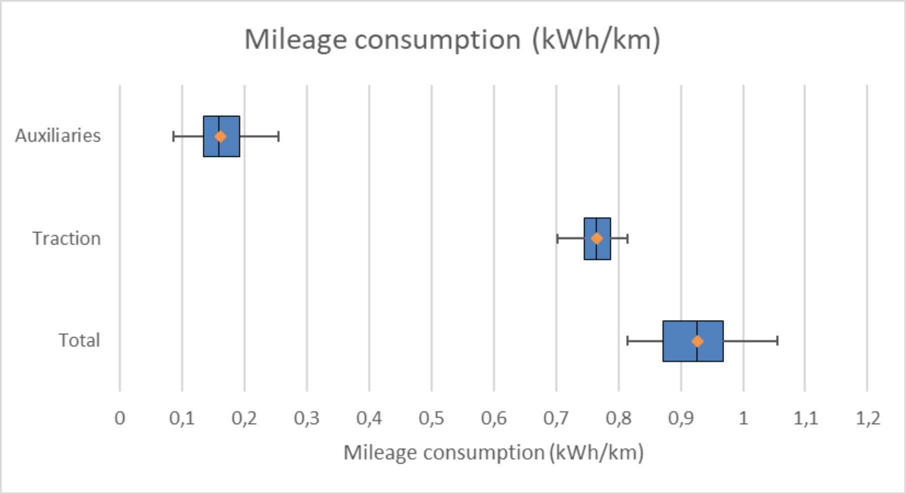

Figure 24. Distribution of mileage consumption on the network

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 (see chapter 2.4.4.1). Indeed, traction power represents over 83% of the total mileage energy consumption, as shown in Figure 25.

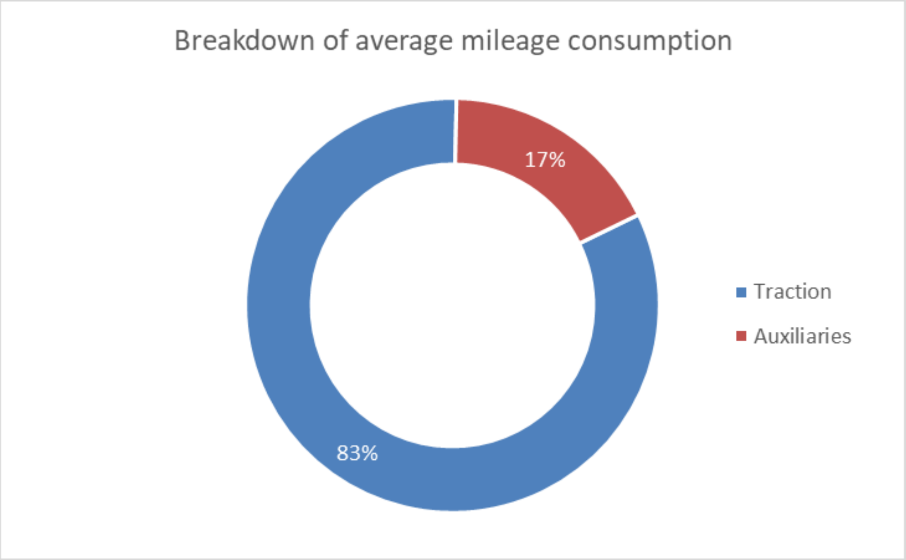

Figure 25. Breakdown of the average mileage consumption

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” [4], [5]. 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).

5.2 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 26 and Figure 27).

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[4] IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020.

[5] 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).

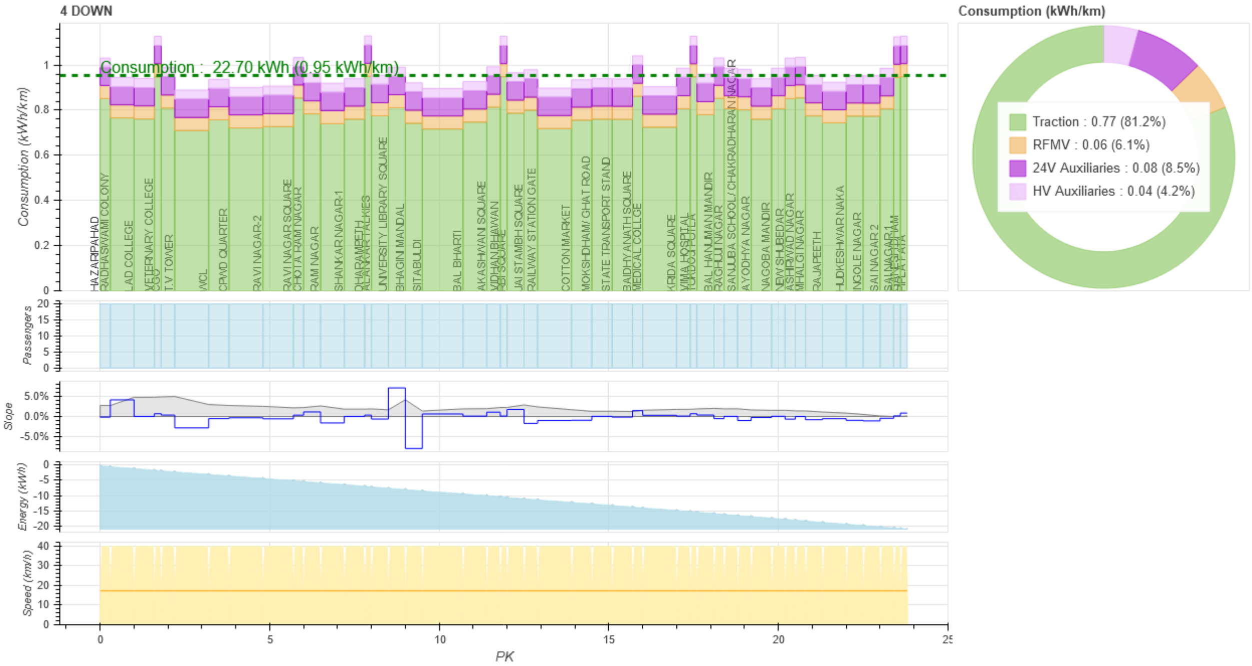


Figure 26. Estimated energy consumption for bus route n° 4 Down

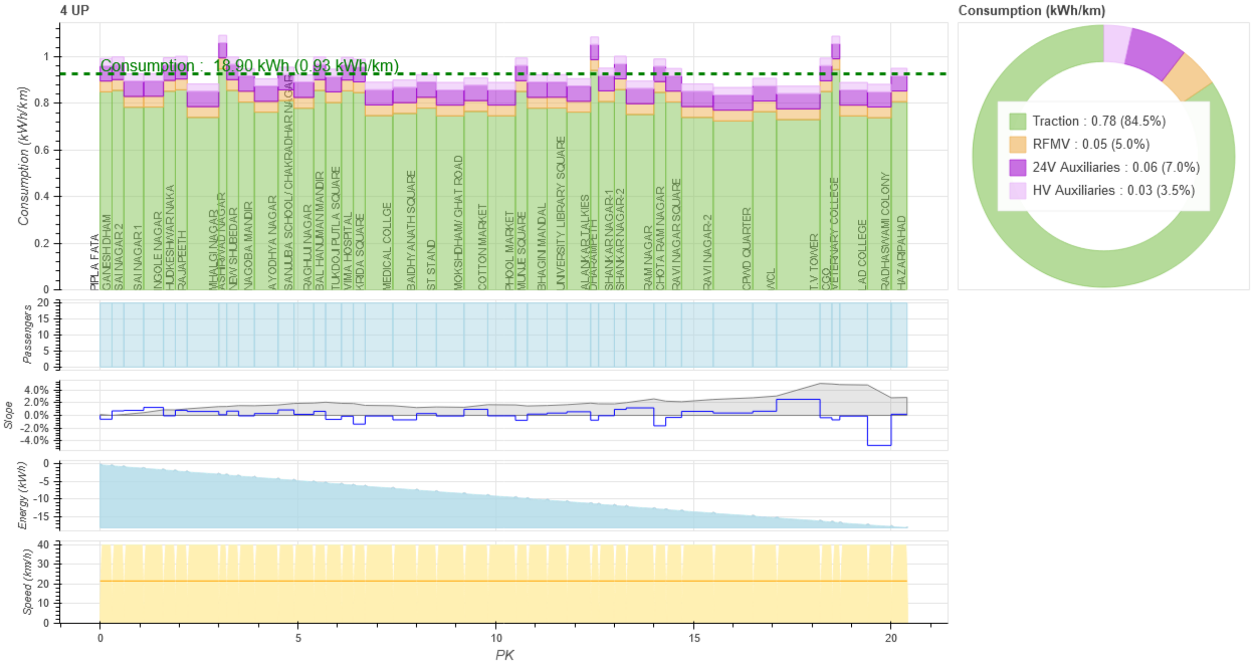


Figure 27. Estimated energy consumption for bus route n° 4 Up

Regarding route n°48 (see Figure 28 and Figure 29), 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 (reference document [R6]) by dividing trips distance by their duration.

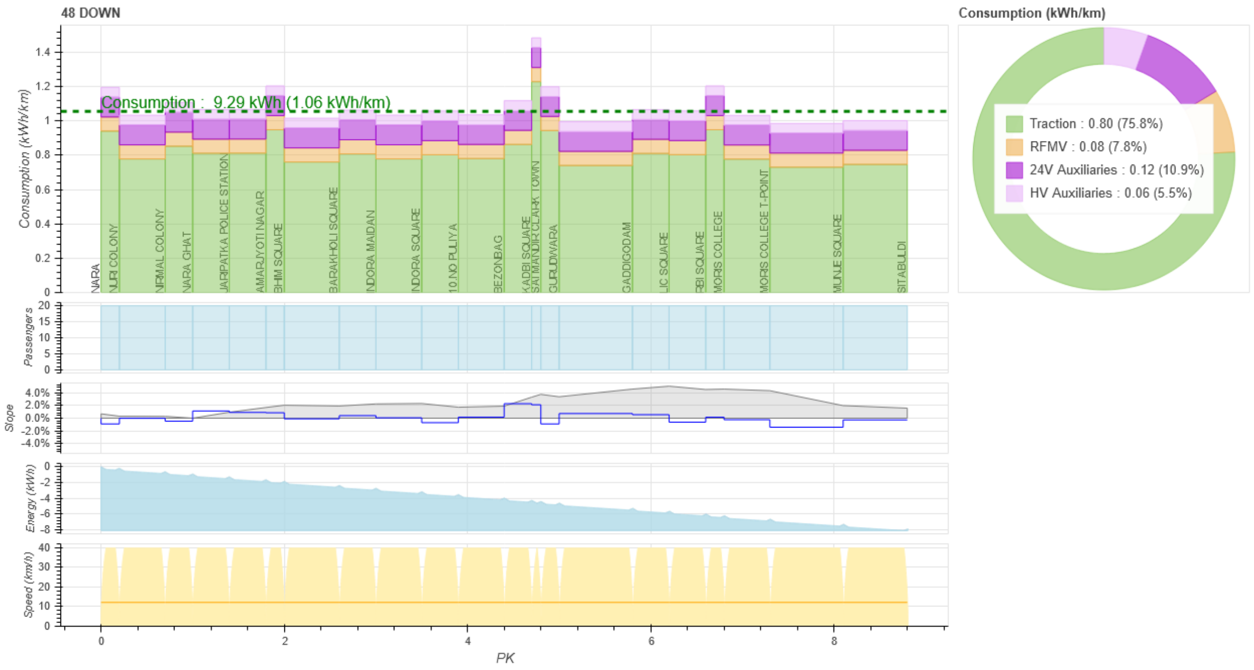


Figure 28. Estimated energy consumption for bus route n° 48 Down

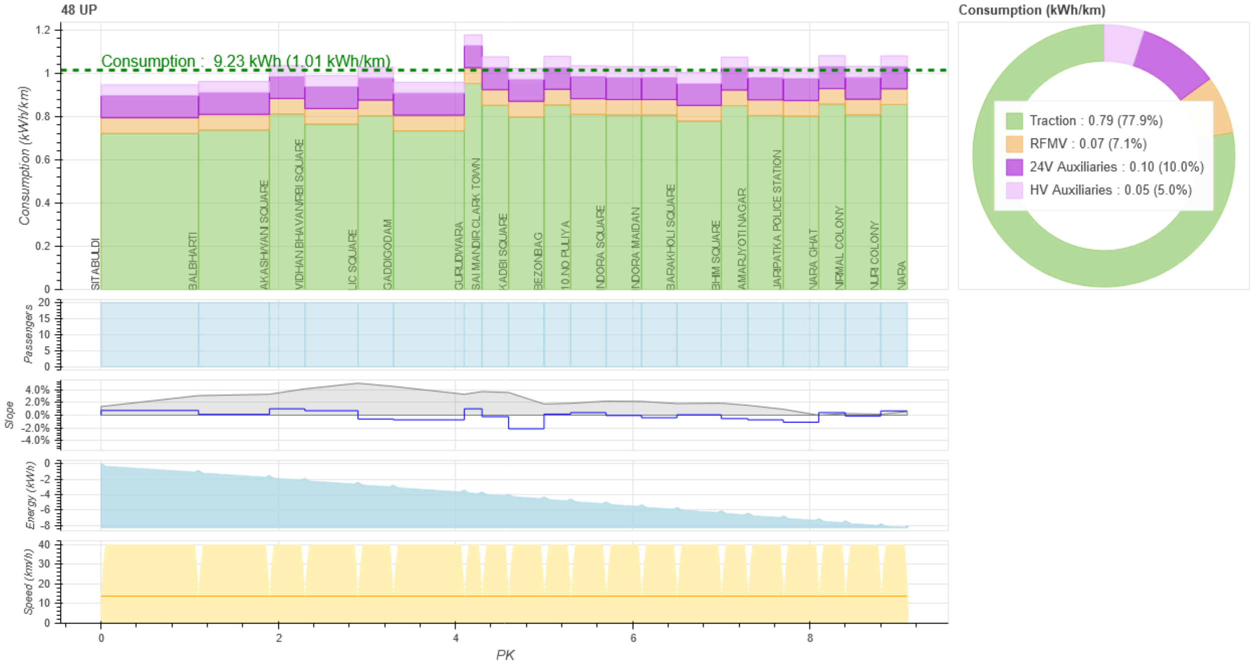


Figure 29. Estimated energy consumption for bus route n° 48 Up

5.3 Detailed consumption for each bus route

The detailed consumption tables and graphs for each simulated Nagpur City Bus Service route is presented in **ANNEXURE 5**.

5.4 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 (see details on assumptions in chapter 2.3), and
- Impact of the air-conditioning system on electric consumption.

5.4.1 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 30 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**.

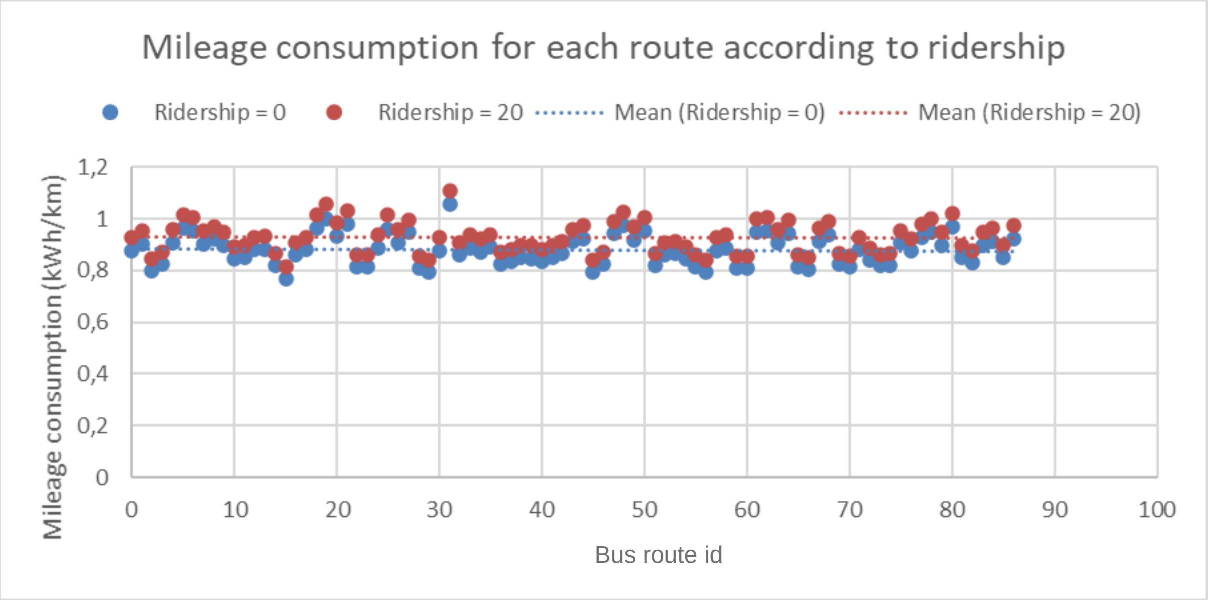


Figure 30. Average mileage consumption per bus route according to ridership

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).

5.4.2 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 31).

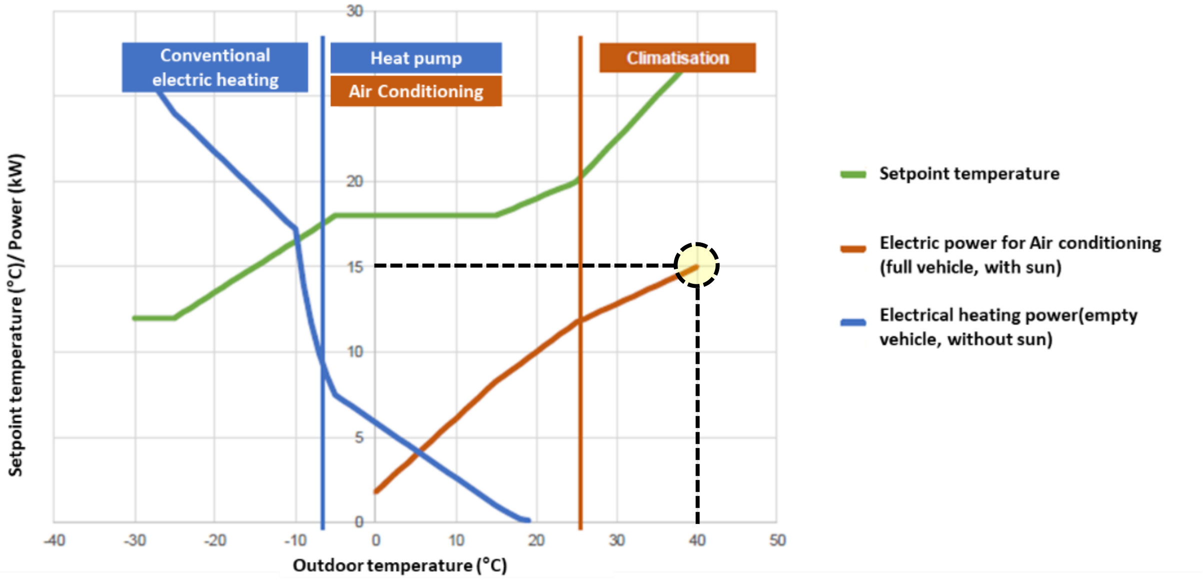


Figure 31. Relation between air conditioning / heating power and outdoor temperature considered in **Volt@bus**

Figure 32 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 24).

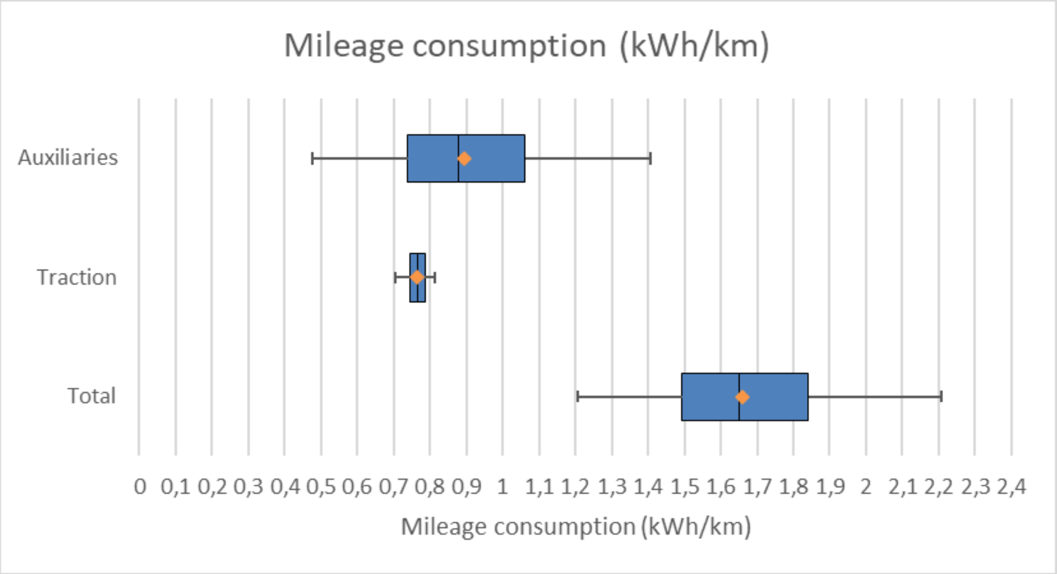


Figure 32. Distribution of mileage consumption on the network (with air-conditioning)

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 33).

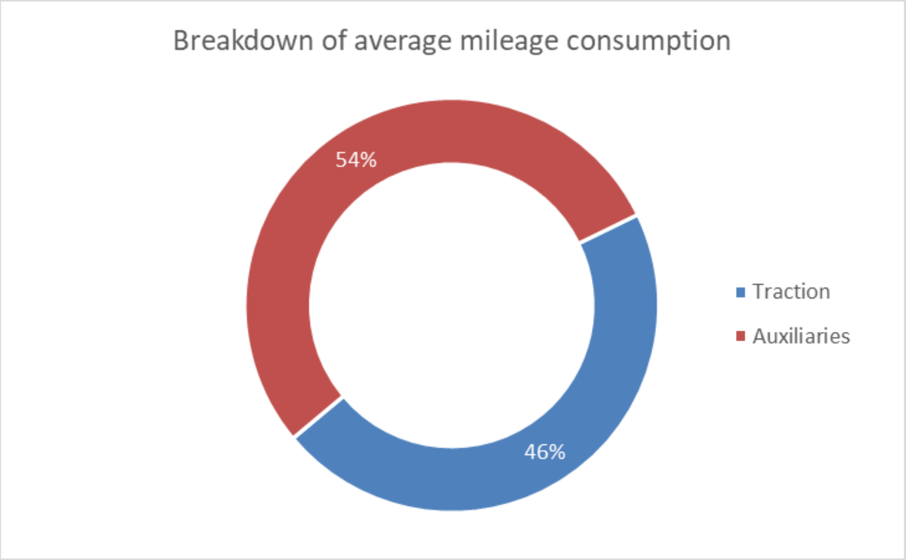


Figure 33. Breakdown of the average mileage consumption (with air-conditioning)

Finally, the graph in Figure 34 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).

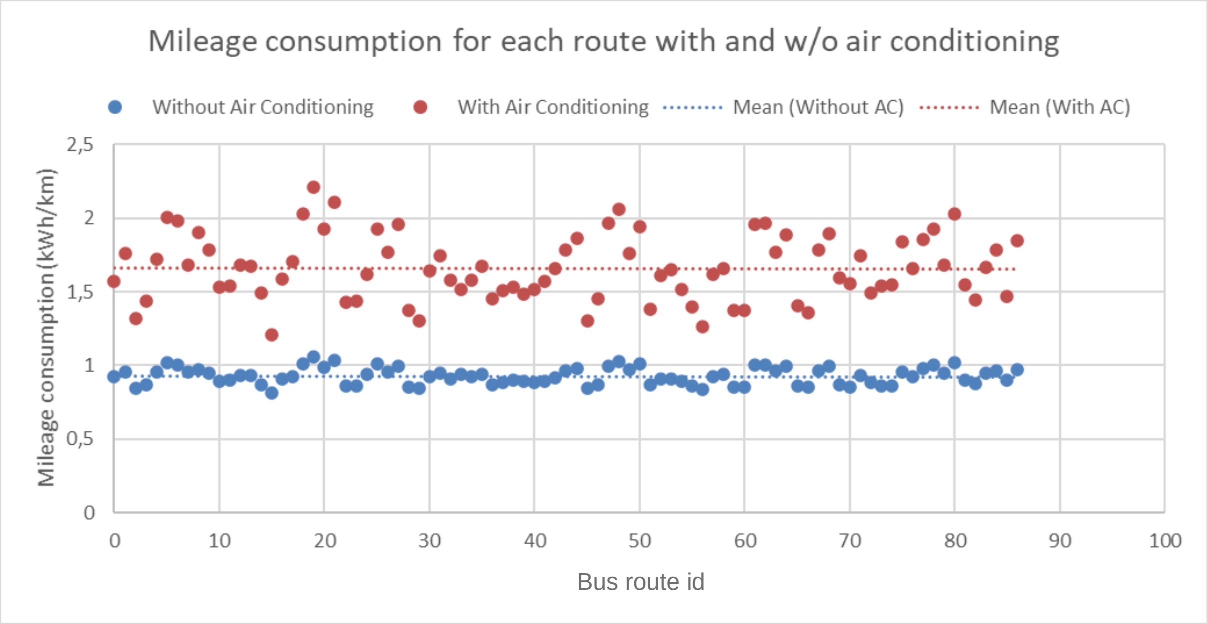


Figure 34. Average mileage consumption per bus route with / without air-conditioning

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.

It should be noted that an HVAC system efficiency for diesel buses is lower than for electric buses. Indeed, the AC compressor is driven by the thermal engine or the electrical engine, respectively. Electrical engines are at least twice more efficient than thermal engines. Thus, in hot weather, battery electric buses consume about half the energy of combustion engine vehicles for cooling.

6. 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 in chapter 3.2, 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 in reports [R2] and [R3],
- 350 kWh batteries, and
- 300 kWh batteries.

6.1 Terminology definition

The terminology used in this chapter is as follows (see also Figure 35):

- 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).

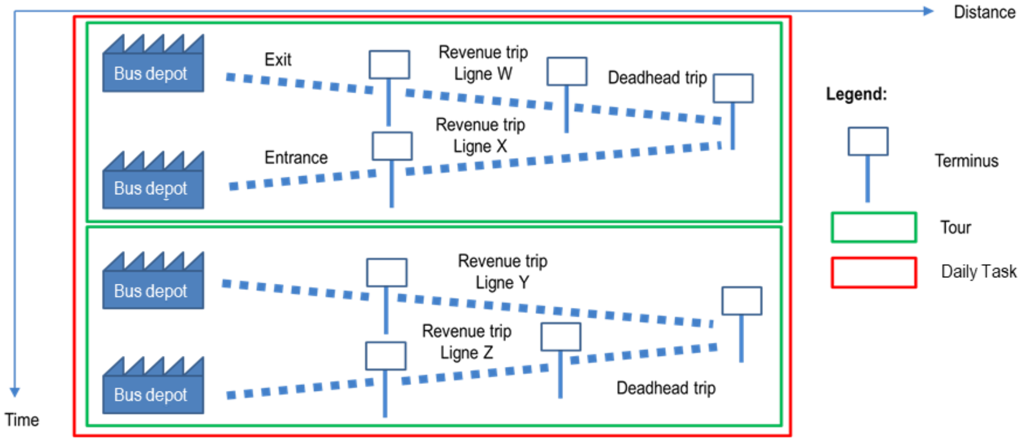


Figure 35. Definition of the terminology used in this report

We understand from the service planning data (reference document [R6]) 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.

6.2 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 36 presents the energy consumption of each scheduled task.

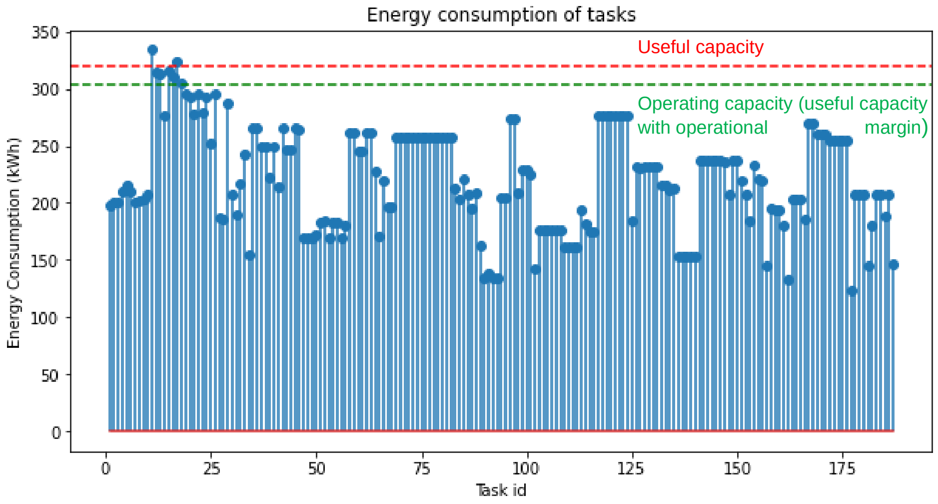


Figure 36. Energy consumption of each scheduled daily task (400 kWh scenario)

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.

6.2.1 Impacts on bus fleet

The resulting daily service schedule for each bus depot is shown in Figure 37 (Khapri Naka), Figure 38 (Higna Naka) and Figure 39 (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).

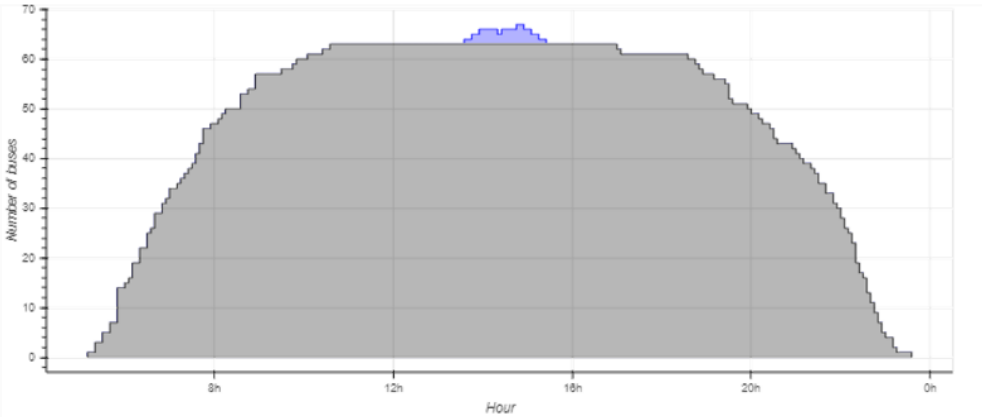


Figure 37. Number of buses simultaneously in operation - Khapri Naka depot (400 kWh scenario)

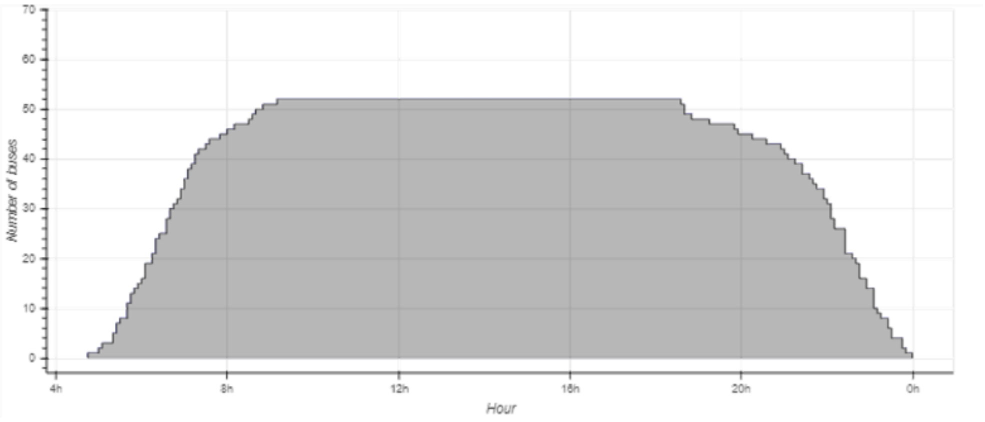


Figure 38. Number of buses simultaneously in operation - Higna Naka depot (400 kWh scenario)

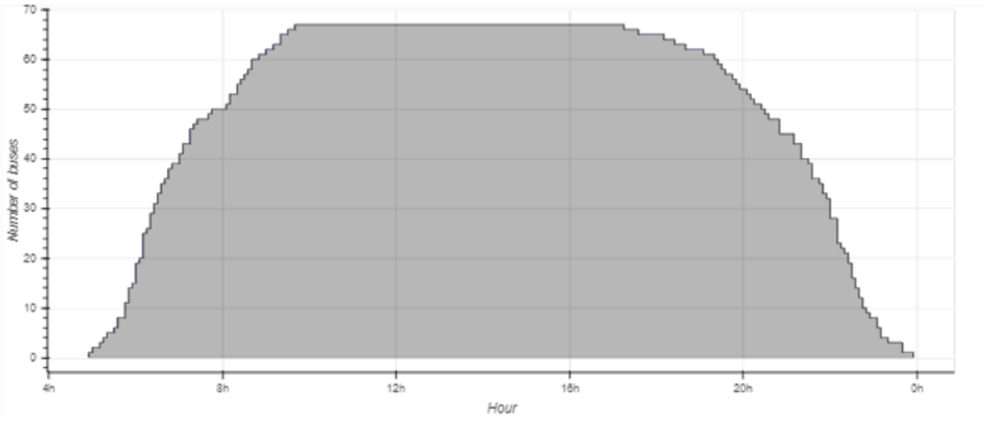


Figure 39. Number of buses simultaneously in operation - Patwardhan 2 depot (400 kWh scenario)

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 14 hereafter.

Table 14. 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 15.

Table 15. 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.

6.2.2 Impacts on depot charging activities

Depot charging activities for a typical day are illustrated in the following chapters. In each graph (Figure 40, Figure 42, and Figure 44), 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**).

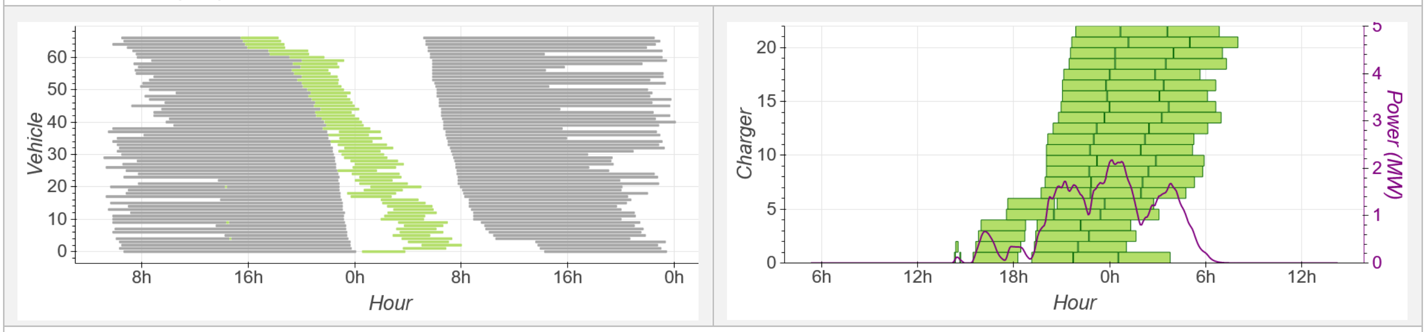
As explained in chapter 3.4, the charging principle is based on a "first in = first out" practice. It should also be noted that two charging options are considered:

- **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 7.

6.2.2.1 Khapri Naka depot

Figure 40 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.

Normal charging:



Optimized charging:

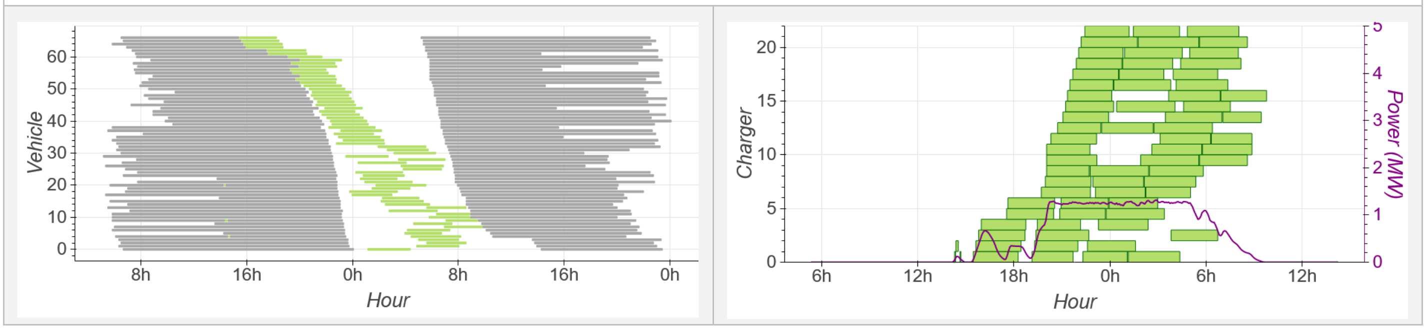


Figure 40. Charging activities per vehicle (left) and per charger (right) - Khapri Naka depot (400 kWh scenario)

From Figure 40, 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 (for details on depot configuration, see chapter 7.1.2). Indeed, it is considered that there is one charger for each 3 vehicles. As such, many vehicles cannot be recharged 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 [6].

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 40, 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 41 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.

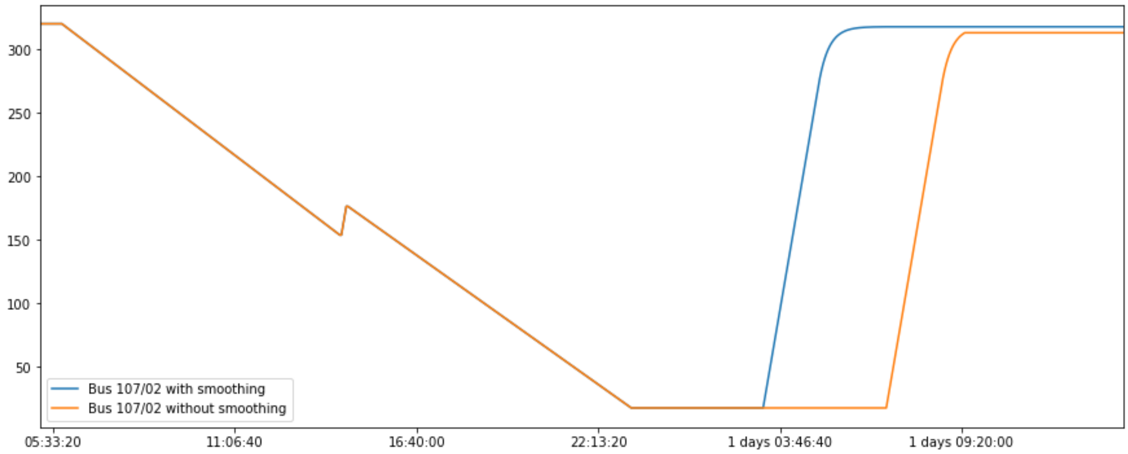


Figure 41. State of charge - Khapri Naka depot - Example for task n° 107/02 (400 kWh scenario)

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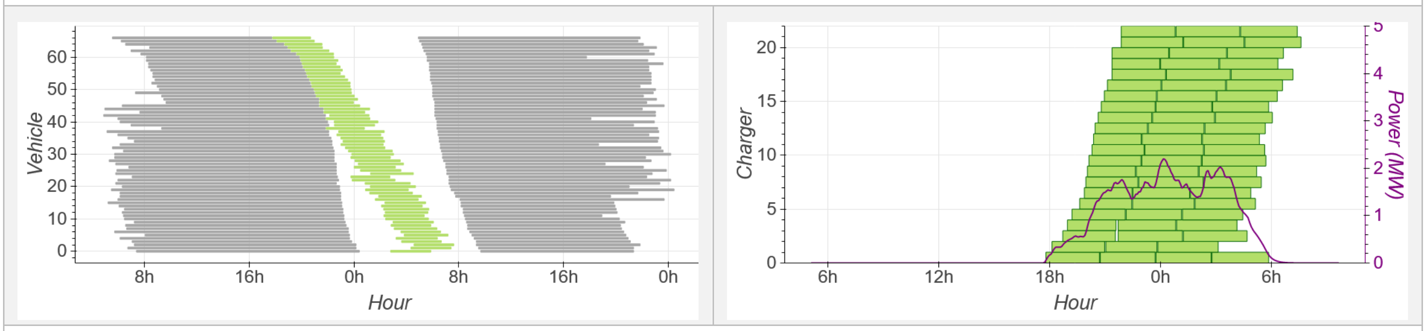
[6] The “loading factor” represents the ratio of the electrical energy really consumed over a given period (typically a day in this case) to the energy it would have consumed if it had been operating at its rated power (estimations from manufacturer) during the same period, i.e.:

$$\text{Loading factor} = \frac{\text{Energy consumed over the day}}{\text{Maximum power of the depot} * 24 \text{ hours}}$$

6.2.2.2 Higna Naka depot

The following figures show the recharging activities for the Higna Naka depot for each of the 67 buses.

Normal charging:



Optimized charging:

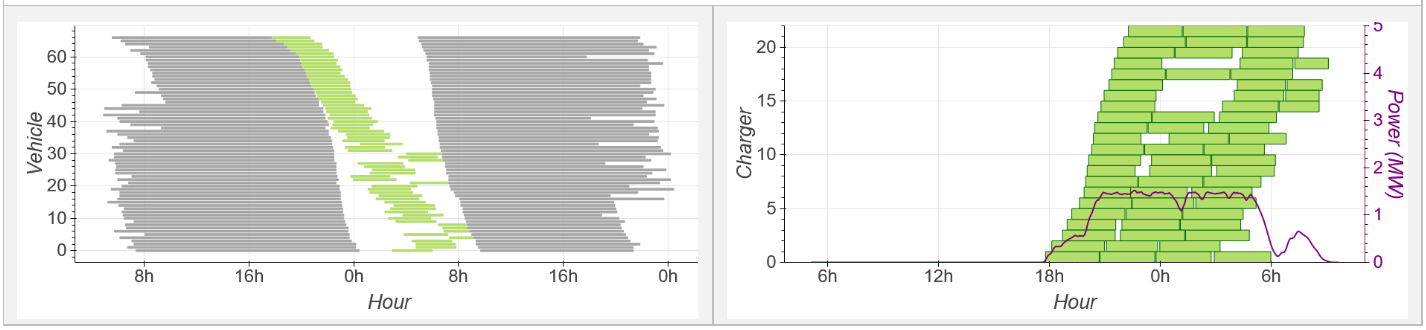


Figure 42. Charging activities per vehicle (left) and per charger (right) - Higna Naka depot (400 kWh scenario)

From Figure 42, 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 (for details on depot configuration, see chapter 0).

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 43 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.

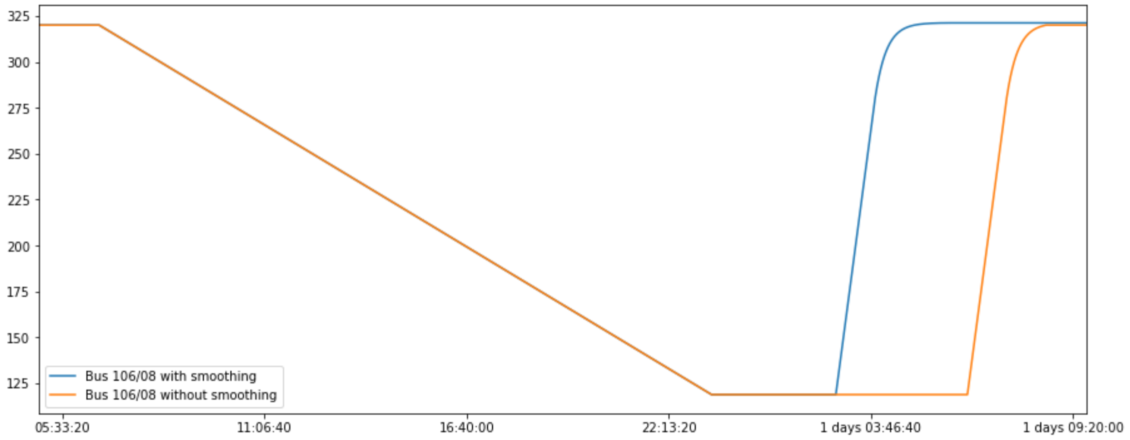
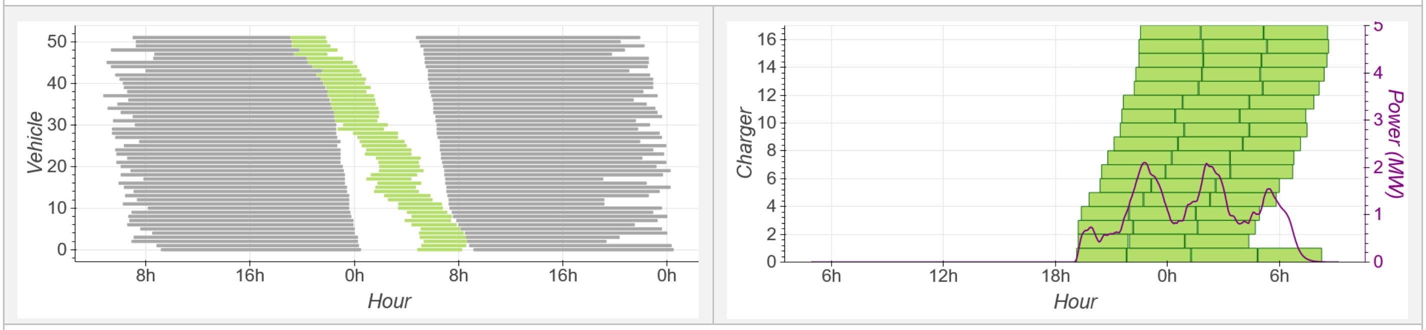


Figure 43. State of charge - Higna Naka depot - Example for task n° 106/08 (400 kWh scenario)

6.2.2.3 Patwardhan 2 depot

The following figures depict the recharging activities for the Patwardhan 2 depot for each of the 52 buses.

Normal charging:



Optimized charging:

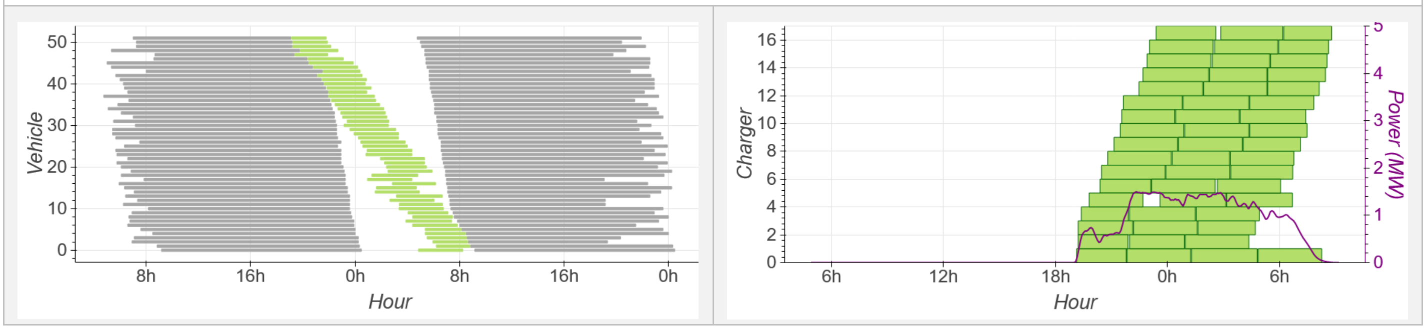


Figure 44. Charging activities per vehicle (left) and per charger (right) - Patwardhan 2 depot (400 kWh scenario)

From Figure 44, 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 (for details on depot configuration, see chapter 7.1.4).

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 45 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.

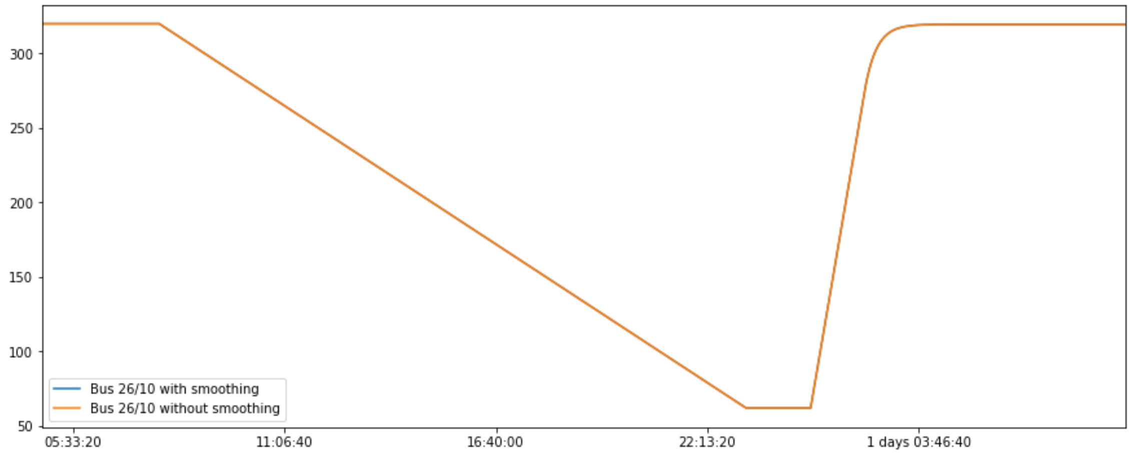


Figure 45. State of charge - Patwardhan 2 depot - Example for task n° 26/10 (400 kWh scenario)

6.2.2.4 Depot charging data summary

Table 16 summarizes the results of the depot charging simulations for each depot.

Table 16. Depot charging data summary (400 kWh scenario)

Bud depot	Number of vehicles	Number of chargers	Mileage (km/day)	Energy consumption for bus operation (kWh/day)	Charging option	Loading factor	Maximum required 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 in chapter 5.1 since here it considers a charger efficiency of 90%.

6.2.3 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.

6.2.3.1 State of charge at the beginning of the following day

Table 17 summarises the state of charge of the buses at the beginning of the following day, considering “normal charging” and “optimized charging” options.

Table 17. 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 46). These values confirm the operability of the buses from one day to the other.

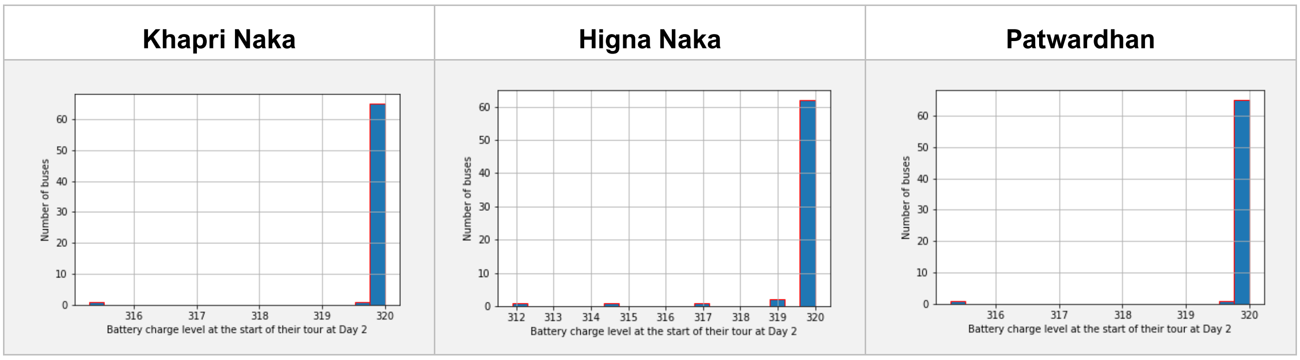


Figure 46. State of charge of each bus at the start of the next day of operation (400 kWh scenario)

6.2.3.2 State of charge on return to the depot

Table 18 summarises the state of charge of the buses when they return to the depot, considering both “normal” and “optimized” charging strategy.

Table 18. 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 (as described in chapter 3.3.2). 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 18 and in Figure 47, 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).

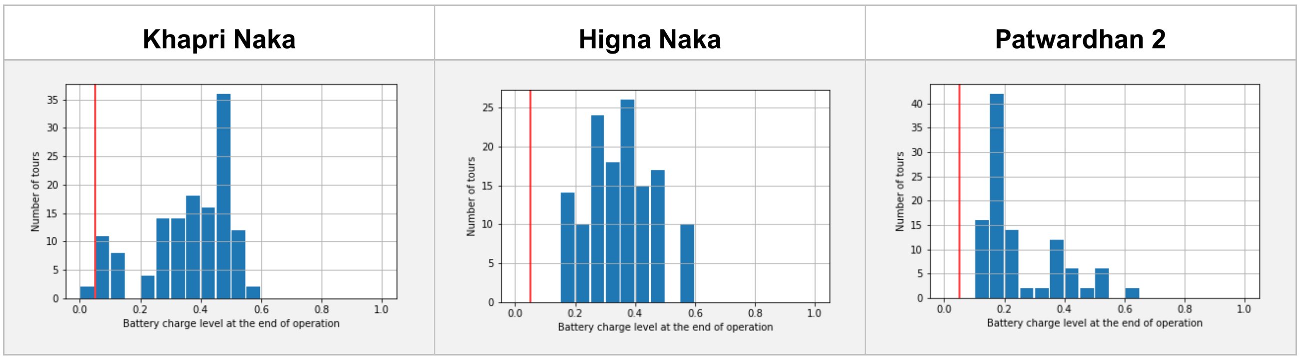

Khapri Naka **Higna Naka** **Patwardhan 2**

Figure 47. State of charge of each bus on return to the depot (400 kWh scenario)

6.2.3.3 Time reserve between end of charging and start of task

Table 19 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 19. 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.

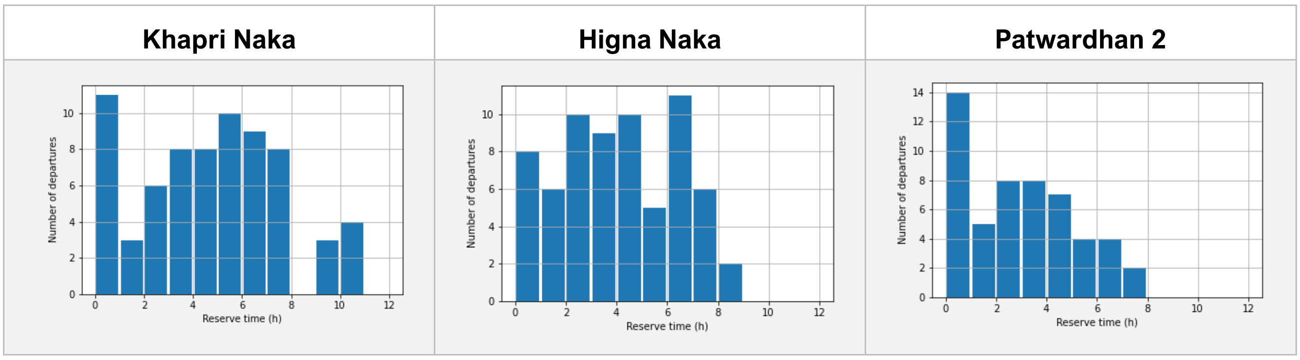

Khapri Naka | **Higna Naka** | **Patwardhan 2**

Figure 48. Time reserve between the end of charging and the departure of each bus (400 kWh scenario)

6.3 Scenario “350 kWh batteries”

Figure 49 presents the energy consumption of each scheduled task.

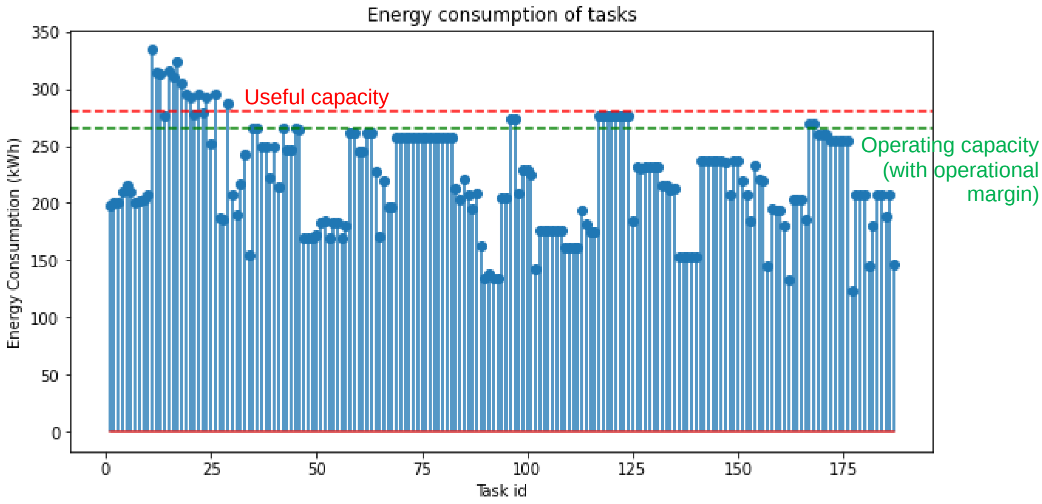


Figure 49. Energy consumption of each daily task (350 kWh scenario)

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), as discussed in chapter 6.2.

6.3.1 Impacts on bus fleet

The resulting daily service schedule for each bus depot is shown in Figure 50 (Khapri Naka), Figure 51 (Higna Naka) and Figure 52 (Patwardhan 2).

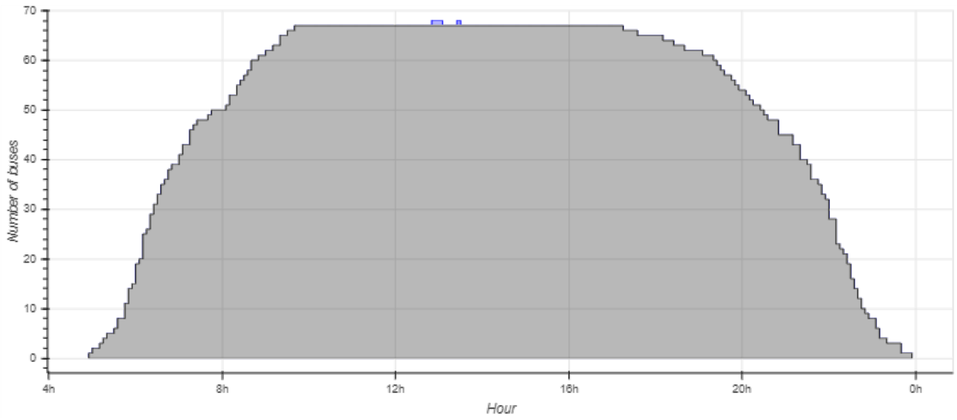


Figure 50. Number of buses simultaneously in operation - Khapri Naka depot (350 kWh scenario)

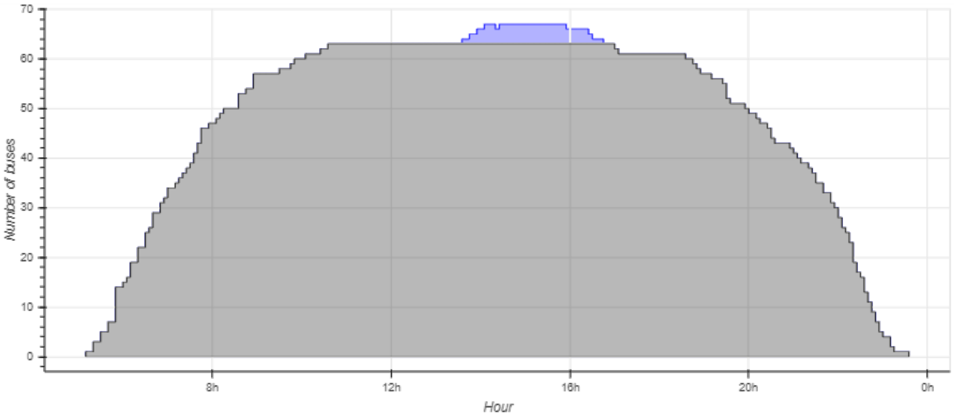


Figure 51. Number of buses simultaneously in operation - Higna Naka depot (350 kWh scenario)

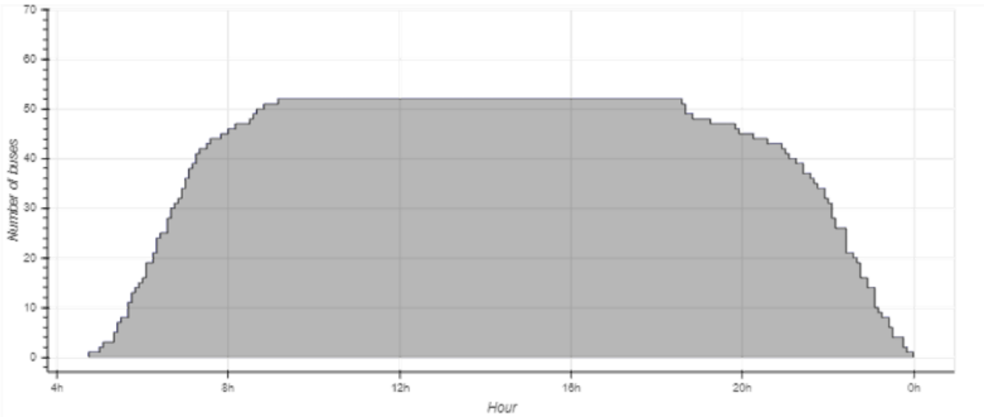


Figure 52. Number of buses simultaneously in operation - Patwhardhan 2 depot (350 kWh scenario)

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 19 hereafter.

Table 20. 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 71)	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 21.

Table 21. 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.

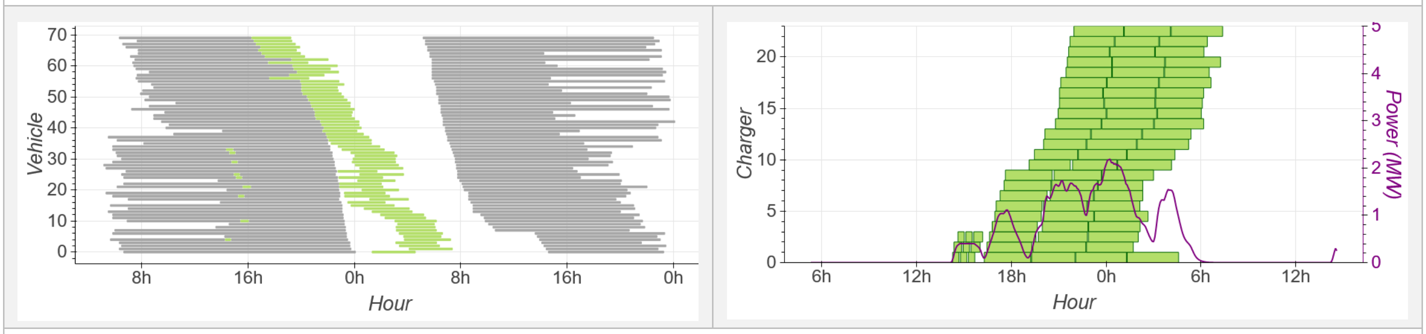
6.3.2 Impacts on depot charging activities

Depot charging activities for a typical day are illustrated in the following chapters.

6.3.2.1 Khapri Naka depot

Figure 53 illustrates the charging activities for the Khapri Naka depot for each of the 70 buses.

Normal charging:



Optimized charging:

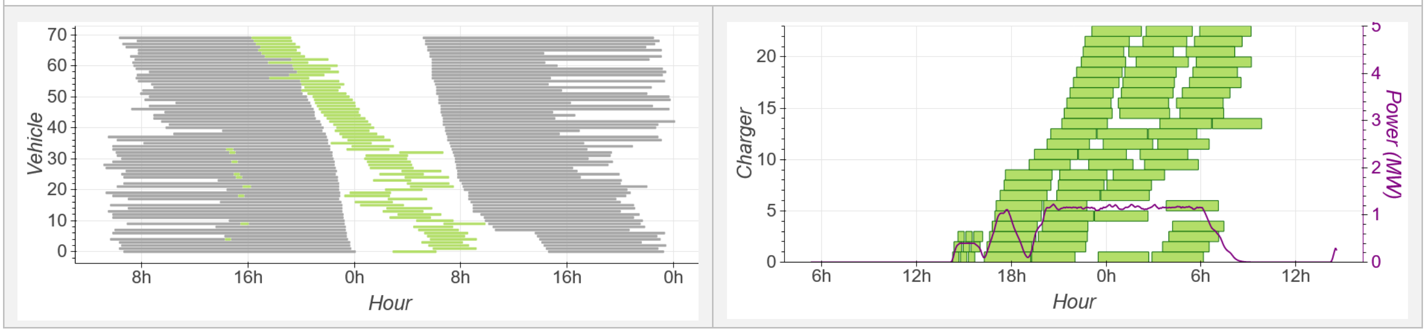


Figure 53. Charging activities per vehicle (left) and per charger (right) - Khapri Naka depot (350 kWh scenario)

From Figure 53, 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 54 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.

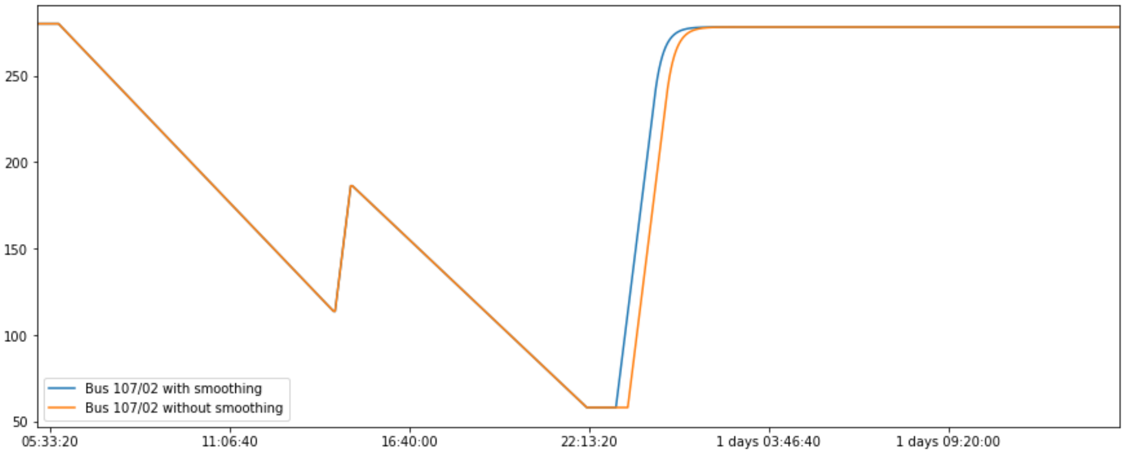
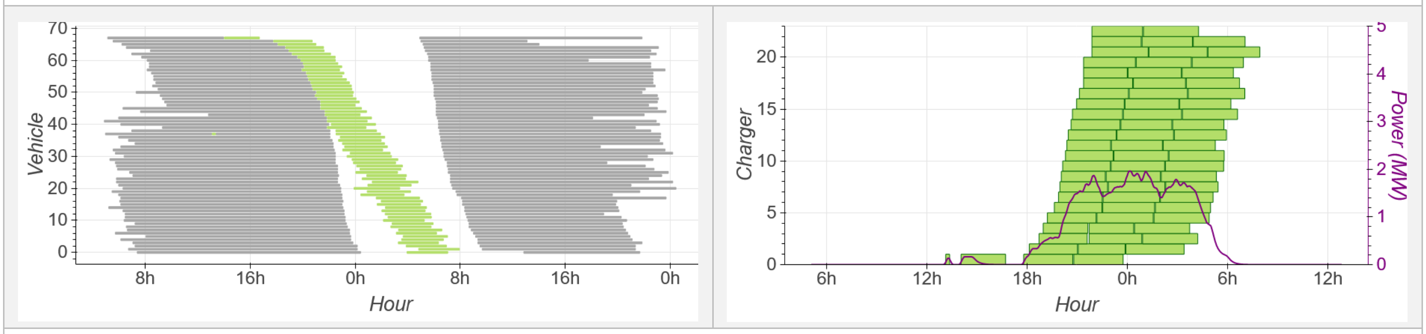


Figure 54. State of charge - Khapri Naka depot - Example for task n° 107/02 (350 kWh scenario)

6.3.2.2 Higna Naka depot

The following figures show the recharging activities for the Higna Naka depot for each of the 68 buses.

Normal charging:



Optimized charging:

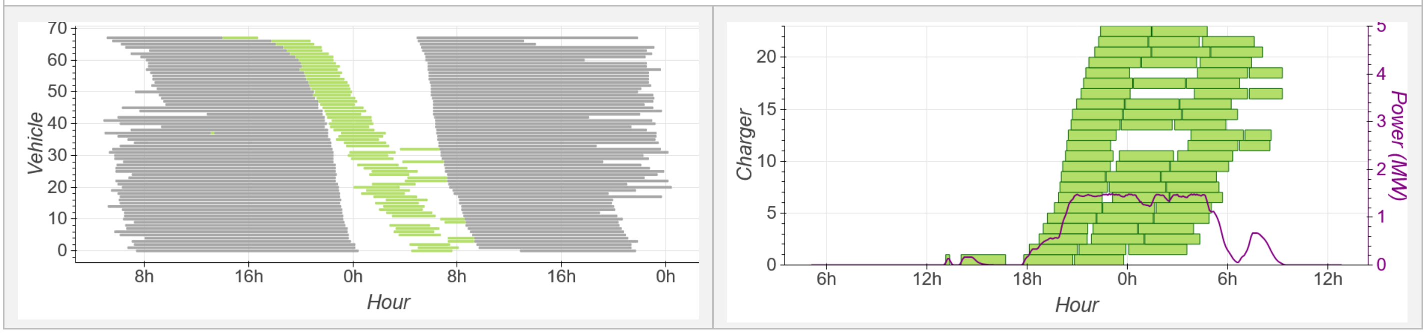


Figure 55. Charging activities per vehicle (left) and per charger (right) - Higna Naka depot (350 kWh scenario)

From Figure 55, 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 56 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.

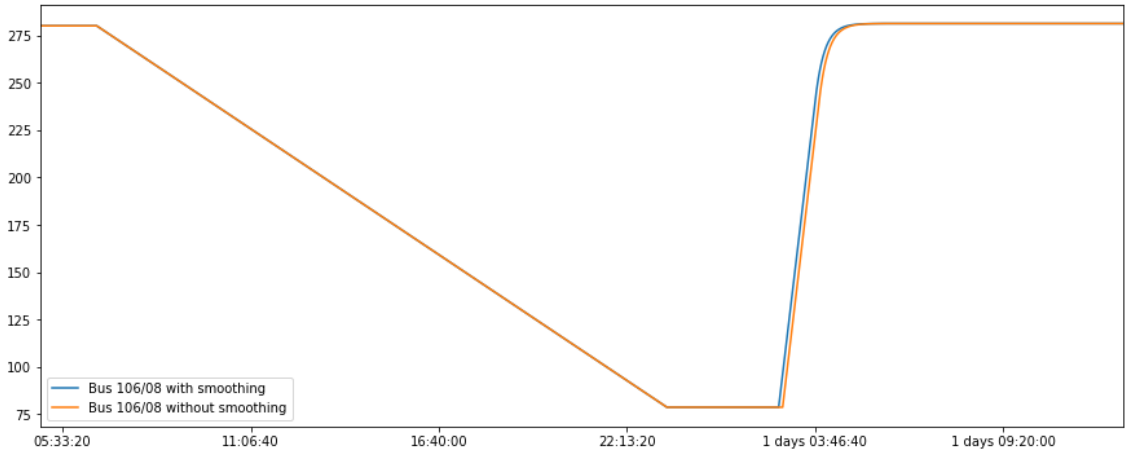
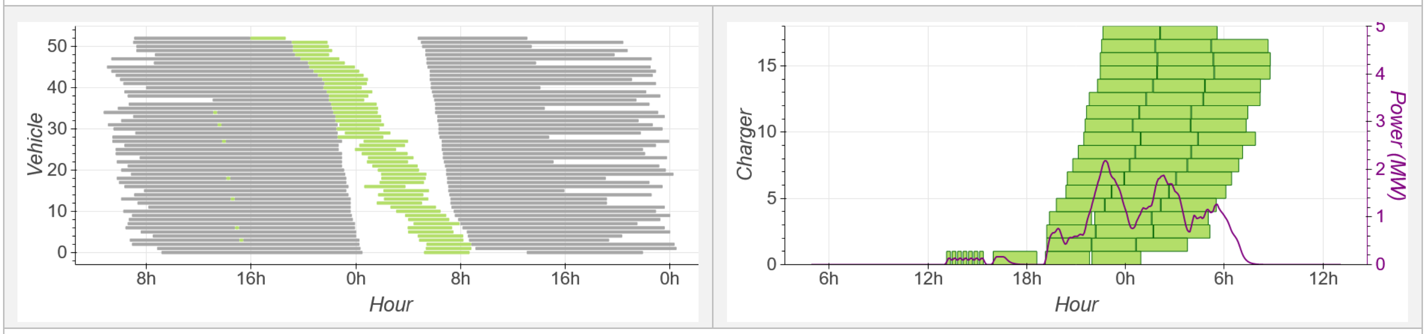


Figure 56. State of charge - Higna Naka depot - Example for task n° 106/08 (350 kWh scenario)

6.3.2.3 Patwardhan 2 depot

The following figures show the recharging activities for the Patwardhan depot for each of the 53 buses.

Normal charging:



Optimized charging:

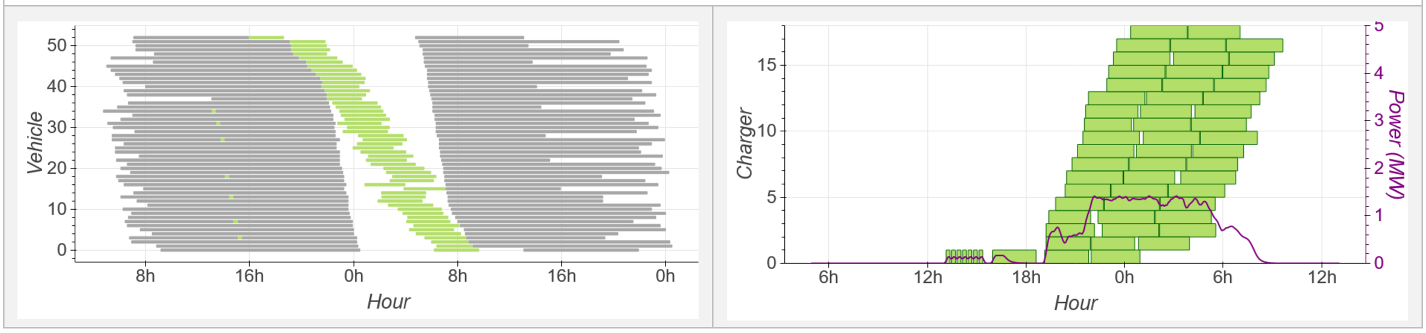


Figure 57. Charging activities per vehicle (left) and per charger (right) - Patwardhan 2 depot (350 kWh scenario)

From Figure 57, 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 58 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.

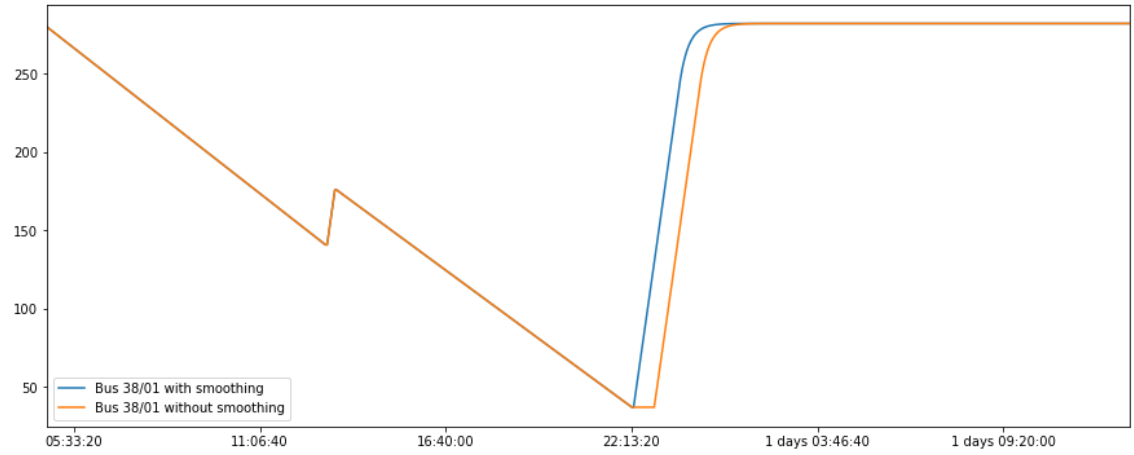


Figure 58. State of charge - Patwardhan 2 depot - Example for task n° 38/01 (400 kWh scenario)

6.3.2.1 Depot charging data summary

Table 22 hereafter summarizes the results of the depot charging simulations for each bus depot.

Table 22. Depot charging data summary (350 kWh scenario)

Bud depot	Number of vehicles	Number of chargers	Mileage (km/day)	Energy consumption for bus operation (kWh/day)	Charging option	Loading factor	Maximum required 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 5.1 since here it considers a charger efficiency of 90%.

6.3.3 Depot charging flexibility

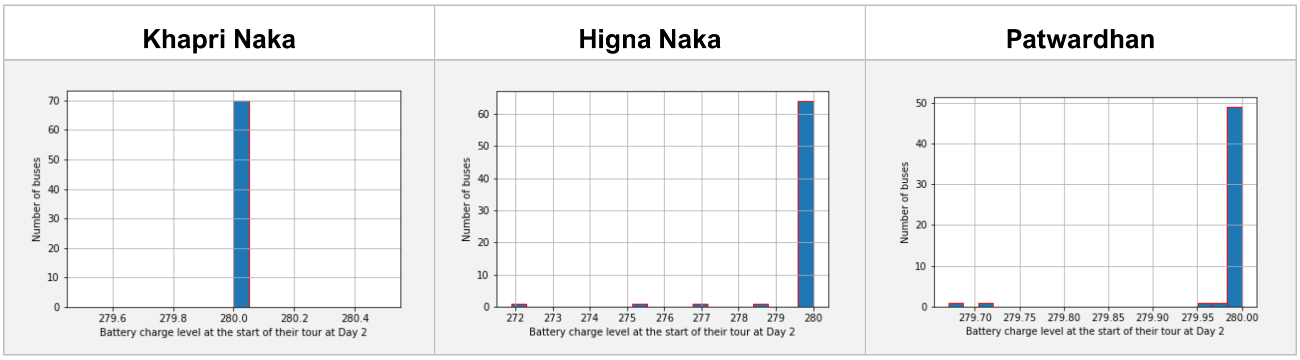
6.3.3.1 State of charge at the beginning of the following day

Table 23 summarises the state of charge of the buses at the beginning of the following day, considering “normal charging” and “optimized charging” options.

Table 23. 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 59). These values confirm the operability of the buses from one day to the other.



Khapri Naka | **Higna Naka** | **Patwardhan**

Figure 59. State of charge of each bus at the start of the next day of operation (350 kWh scenario)

6.3.3.1 State of charge on return to the depot

Table 24 summarises the state of charge of the buses when they return to the depot, considering both “normal” and “optimized” charging strategy.

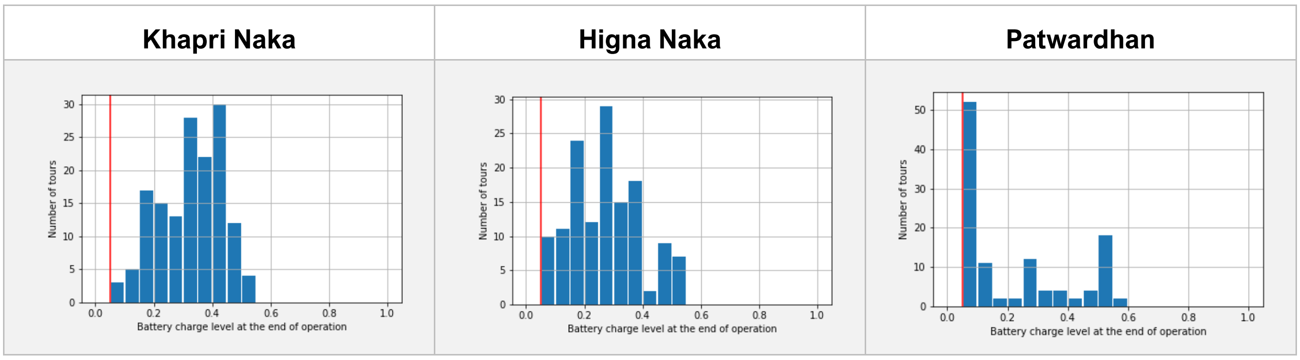
Table 24. State of charge on return to the depot (350 kWh scenario)

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.



Khapri Naka | **Higna Naka** | **Patwardhan**

Figure 60. State of charge of each bus on return to the depot (350 kWh scenario)

6.3.3.1 Time reserve between end of charging and start of task

Table 25 allows to quantify the time reserve between the disconnection of buses and their departure for a task.

Table 25. 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.

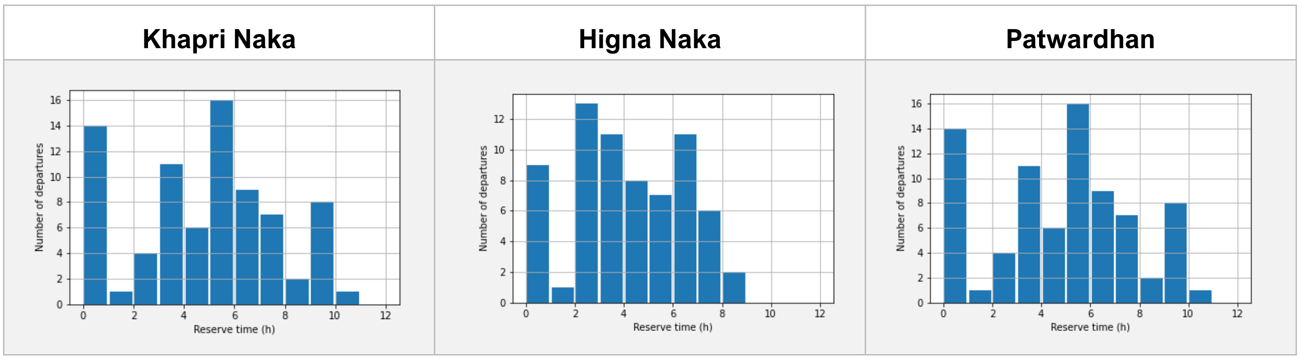


Figure 61. Time reserve between the end of charging and the departure of each bus (350 kWh scenario)

6.4 Scenario “300 kWh batteries”

The simulation of a scenario using 300 kWh battery has been attempted and, as seen in Table 26, the conclusions are significantly different from the two precedent ones.

Table 26. 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**.

6.5 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 27 and Figure 62.

Table 27. 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 7 and 8.

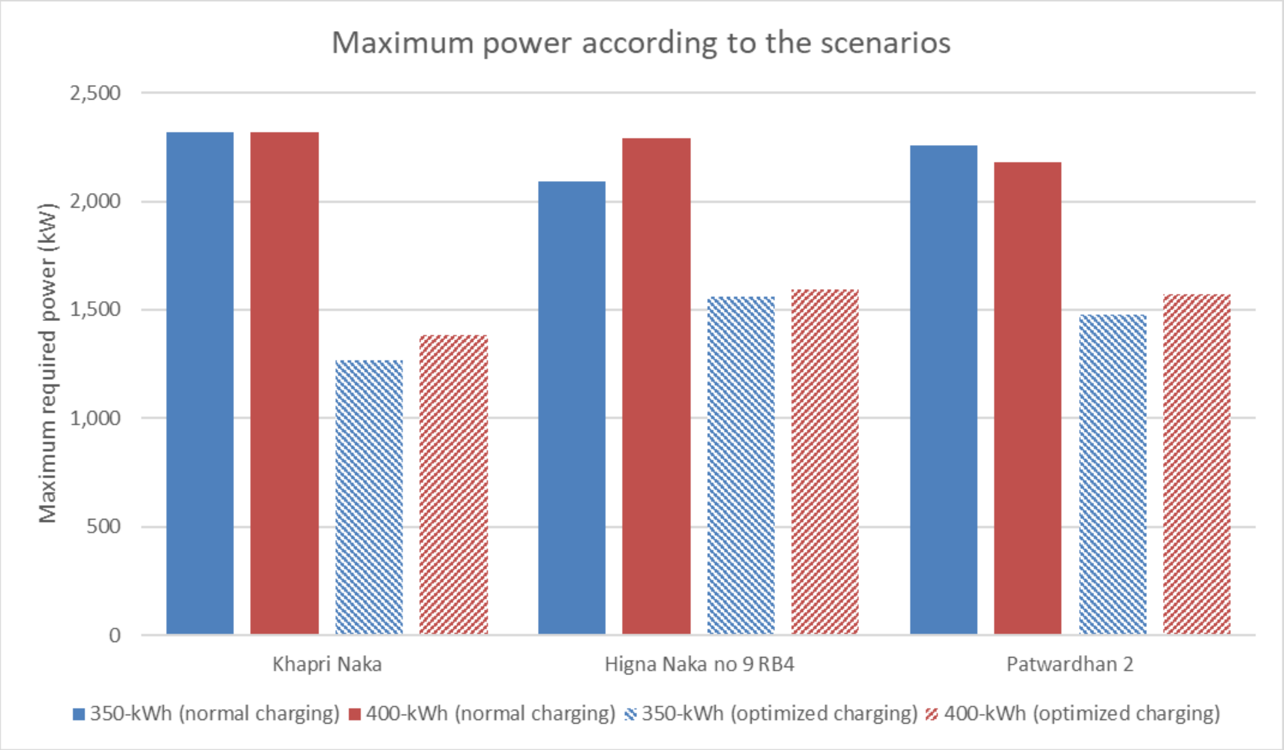


Figure 62. Maximum power according to the scenarios

7. Impacts on depot configuration

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**.

7.1 Depot charging electrical infrastructure

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 28.

Table 28. 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

As developed in *Task 3B Report* (see reference [R3]), 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 29.

Table 29. 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.

7.1.1 Assessment of chargers

As described in *Task 3B Report* (see reference document [R3]), sequential chargers (see Figure 63) are recommended as they optimize infrastructure and energy consumption for all depots.

As a reminder, a sequential charging terminal allows up to 3 buses to be charged serially 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. For a group of 3 charging spots, the charging system consists of the following elements:

- 1 charging terminal (charger) of 150 kW, at a maximum distance of 150 meters from the first remote module (charge box),
- 3 charge 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, with a maximum length of 10 meters (optimal length: 7 meters).

This connection principle is illustrated in Figure 63.

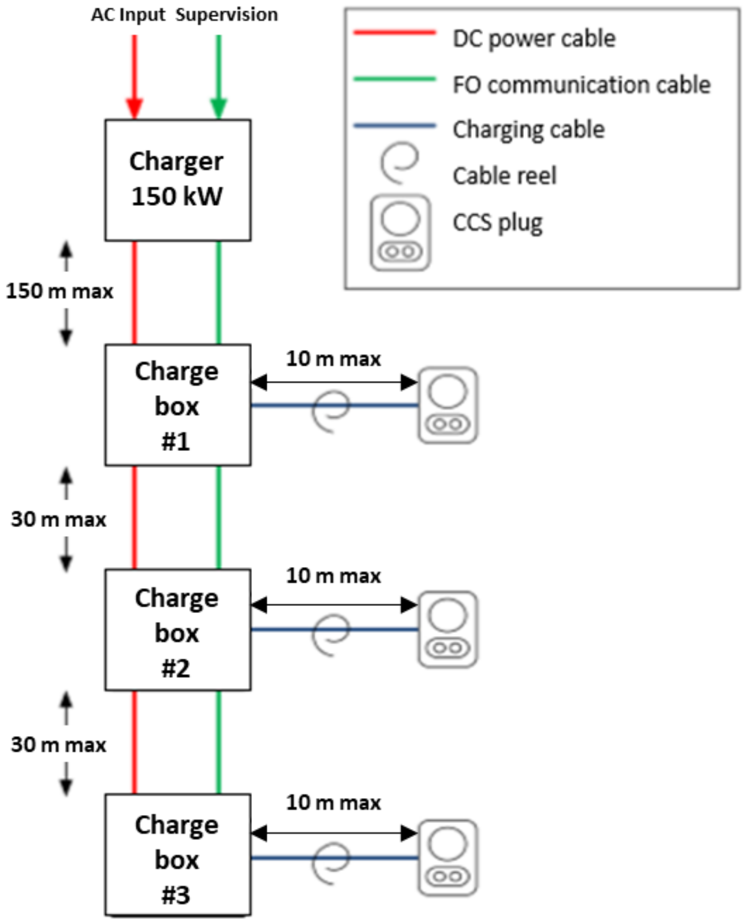


Figure 63. Sequential charging connection principles

The main specifications of the charging equipment are presented in Table 30.

Table 30. Equipment specifications (data source: ABB manufacturer)

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

The charge boxes shall be installed no more than 10 meters from buses (optimal distance is 7 meters). Their position shall depend on how the buses are parked (stacked or parallel).

7.1.2 Khapri Naka bus depot design

7.1.2.1 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.

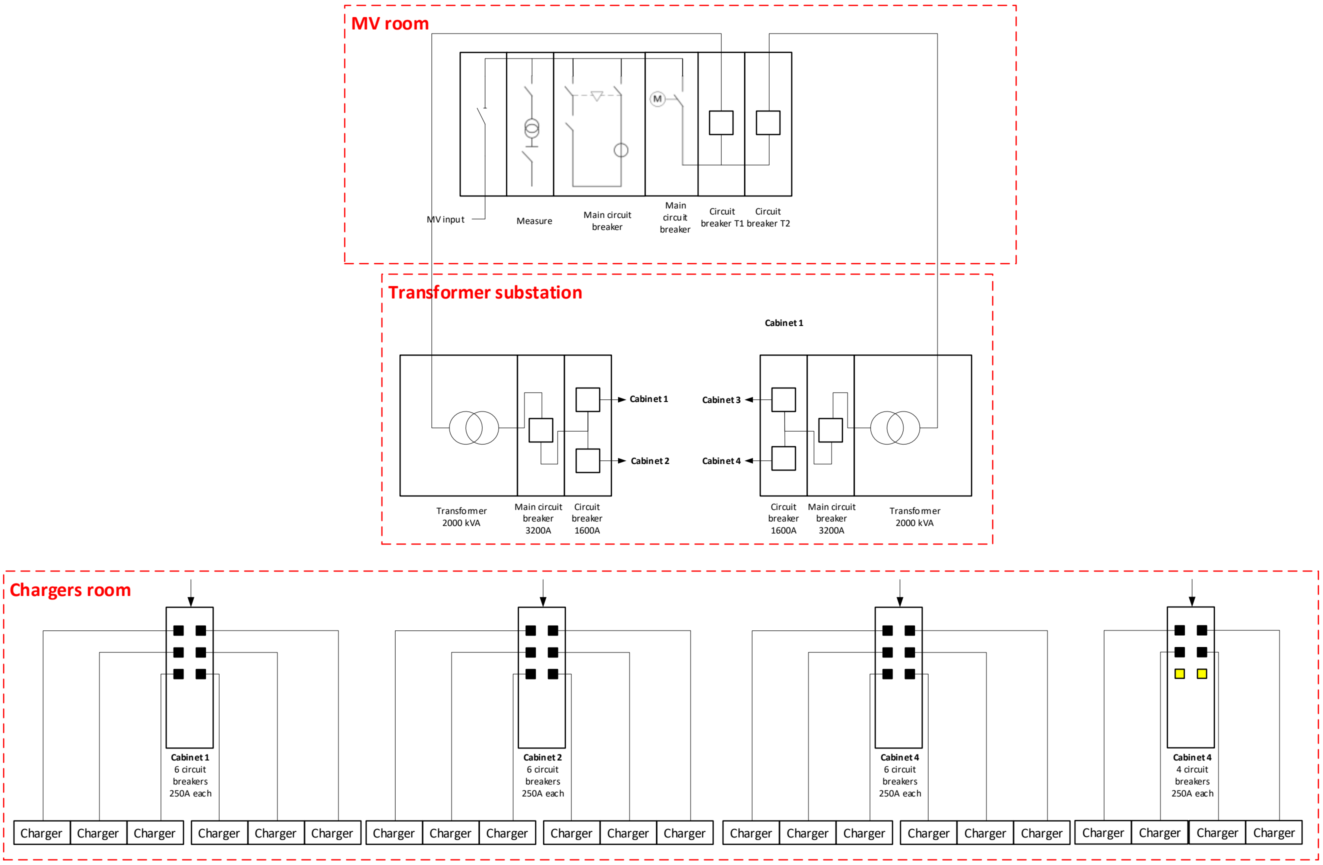


Figure 64. Khapri Naka electrical infrastructure architecture for 70 E-buses and 22 chargers (partial redundancy)

As shown in Figure 64, 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.

7.1.2.2 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,
- 1 circuit breaker cabinet per transformer.

The diagram presented in Figure 65 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.

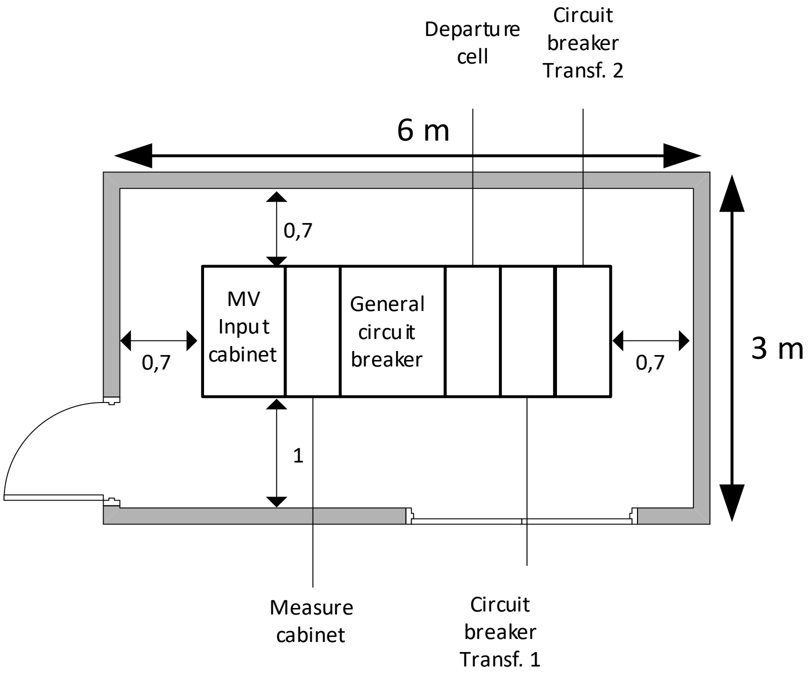


Figure 65. Required medium voltage room layout - Khapri Naka depot

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 66 describes the layout of this technical room, including required maintenance spaces (represented in metres).

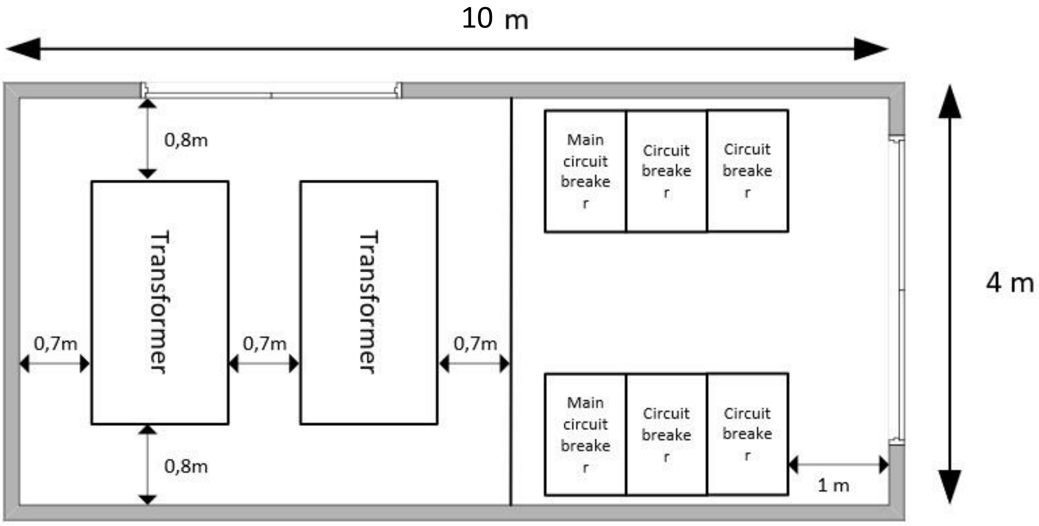


Figure 66. Required transformer substation layout - Khapri Naka depot

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 67 describes the layout of this technical room, including required maintenance spaces (represented in metres).

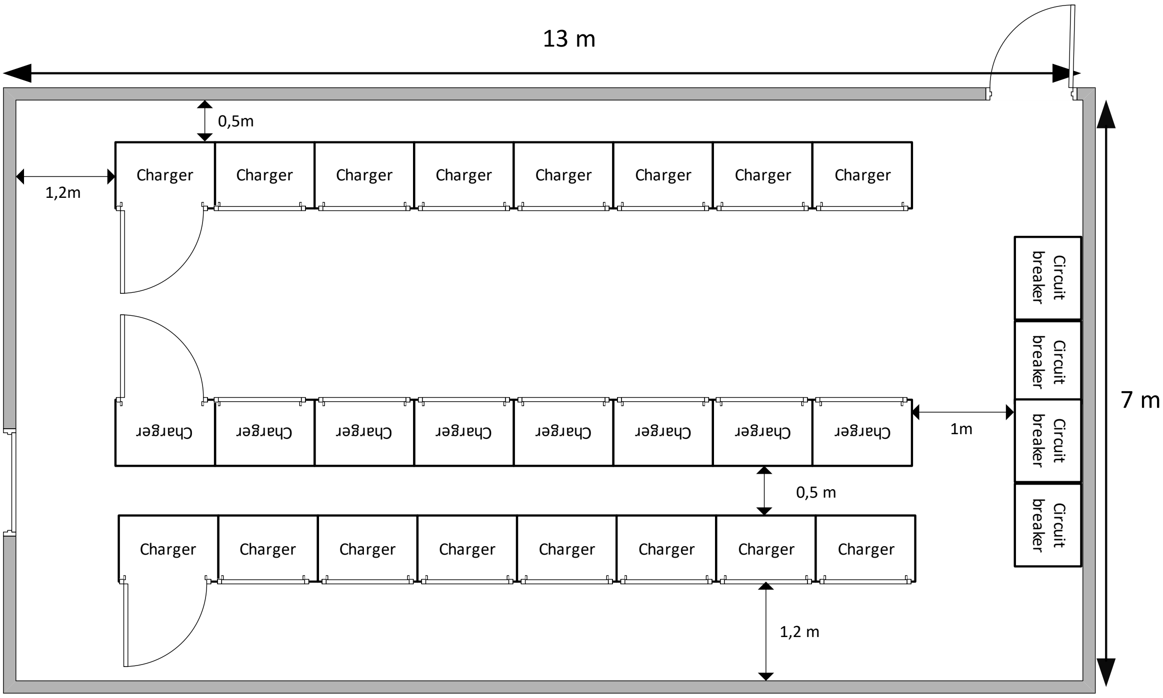


Figure 67. Required chargers room layout - Khapri Naka depot

The equipment installed in this room is the following:

- 4 cabinets for the electrical switchboards,
- 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.

7.1.2.3 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 recharging immobilization times without hampering the manoeuvring of other vehicles. This is also dependent on the layout (current or possible) of the bus depot.

As recommended in *Task 3B Report* (see reference document [R3]), 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 68 and Figure 69 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 68. Aerial view - Khapri Naka depot

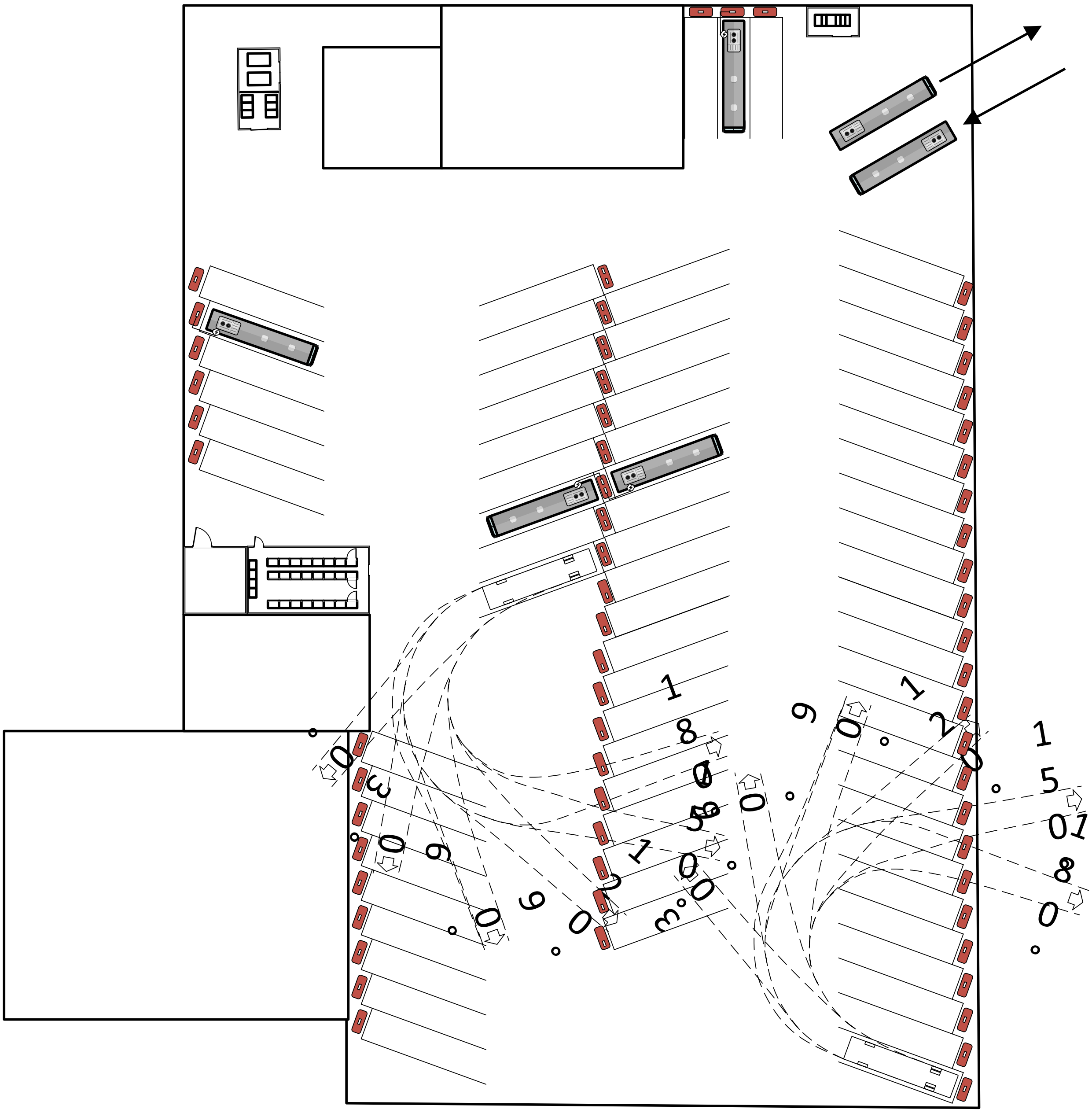


Figure 69. Proposed parking layout at Khapri Naka depot

7.1.3 Higna Naka bus depot

7.1.3.1 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.

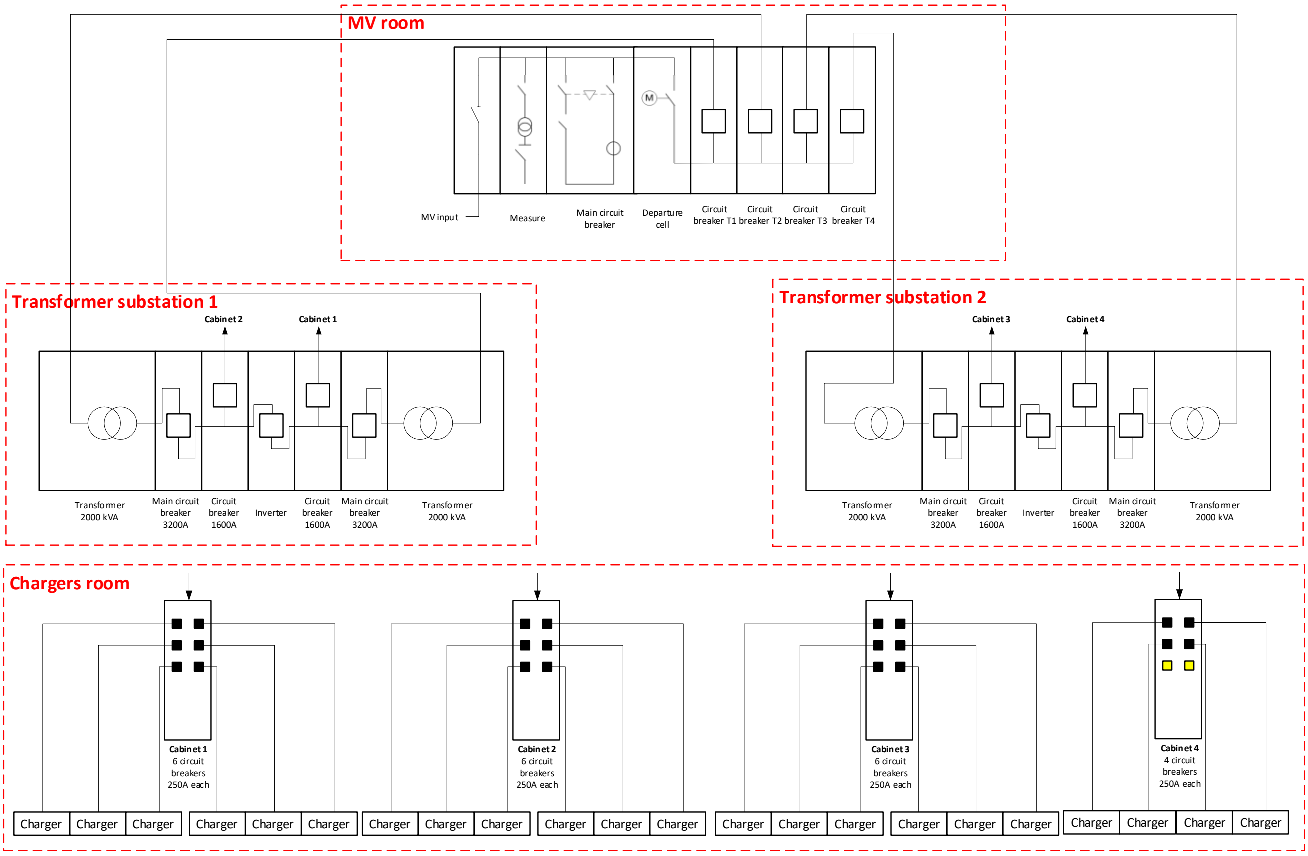


Figure 70. Higna Naka electrical infrastructure architecture for 70 E-buses and 22 chargers (full redundancy)

As shown in Figure 70, 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.

7.1.3.2 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,
- 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 71 describes the layout of the technical room, including required maintenance spaces (represented in metres).

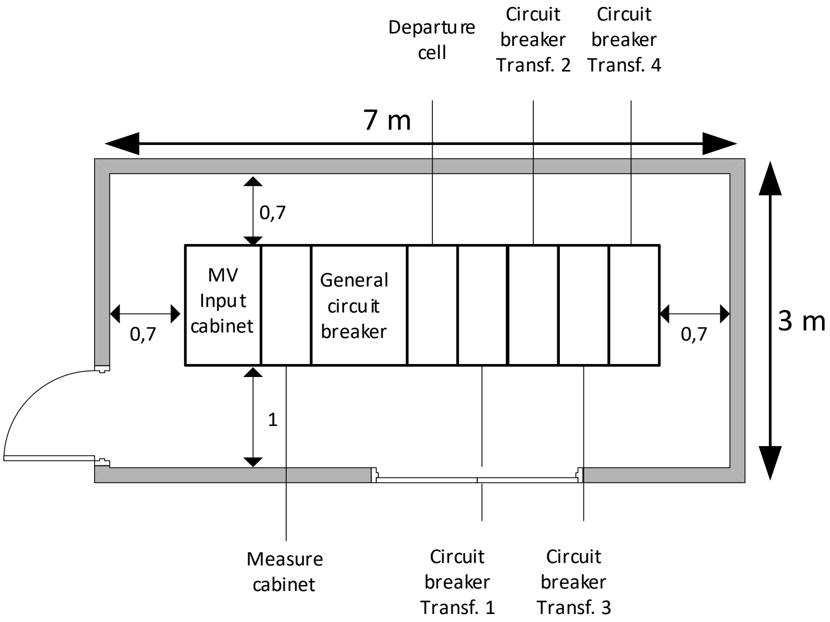


Figure 71. Required medium voltage room layout - Higna Naka depot

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,
- 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 72 describes the layout of these technical rooms, including required maintenance spaces (represented in metres).

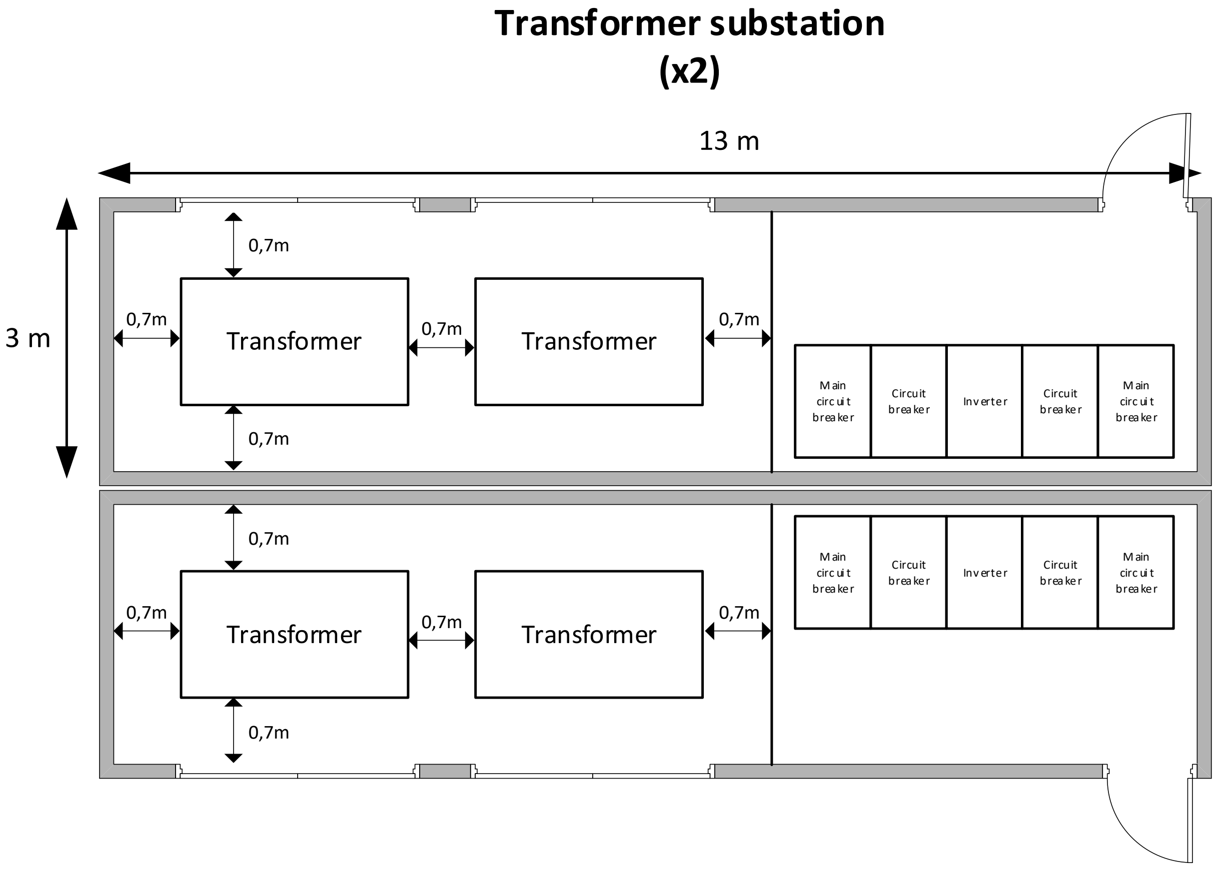


Figure 72. Required transformer substations layout - Higna Naka depot

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 73 describes the layout of this technical room, including required maintenance spaces (represented in metres).

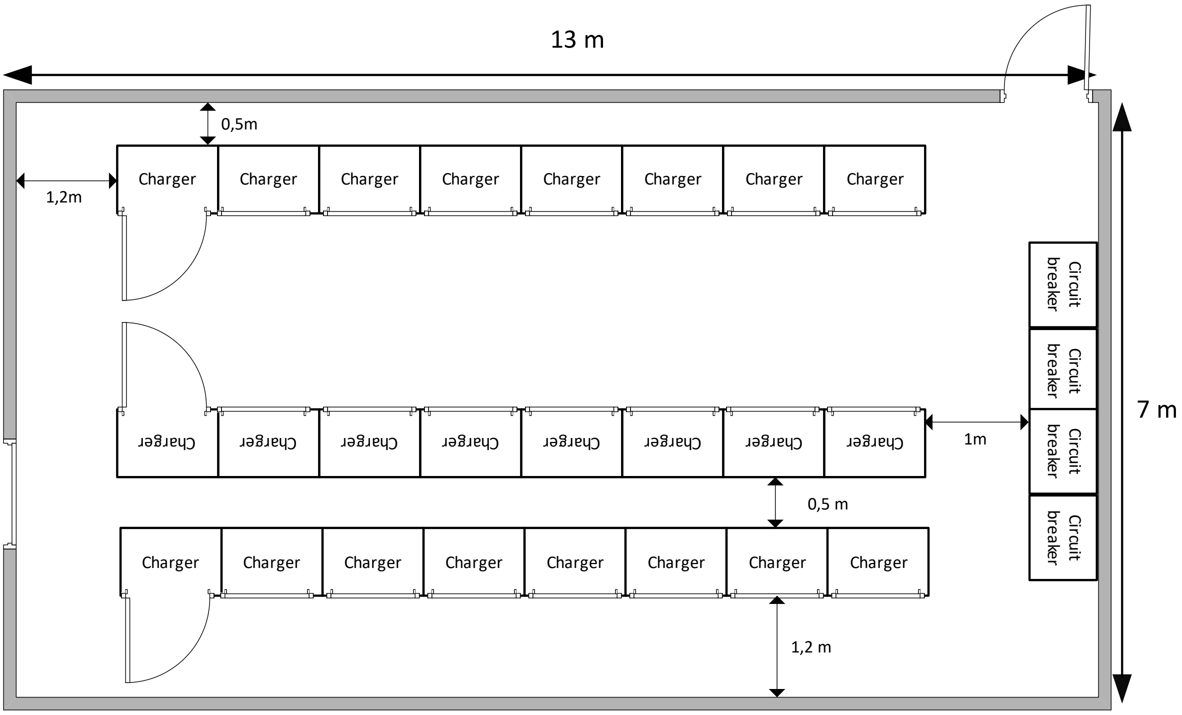


Figure 73. Required chargers room layout - Higna Naka depot

The equipment installed in this room is the following:

- 4 cabinets for the electrical switchboards,
- 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.

7.1.3.3 Higna Naka depot layout

The proposed layout in Figure 74 and Figure 75 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 74. Aerial view - Higna Naka depot

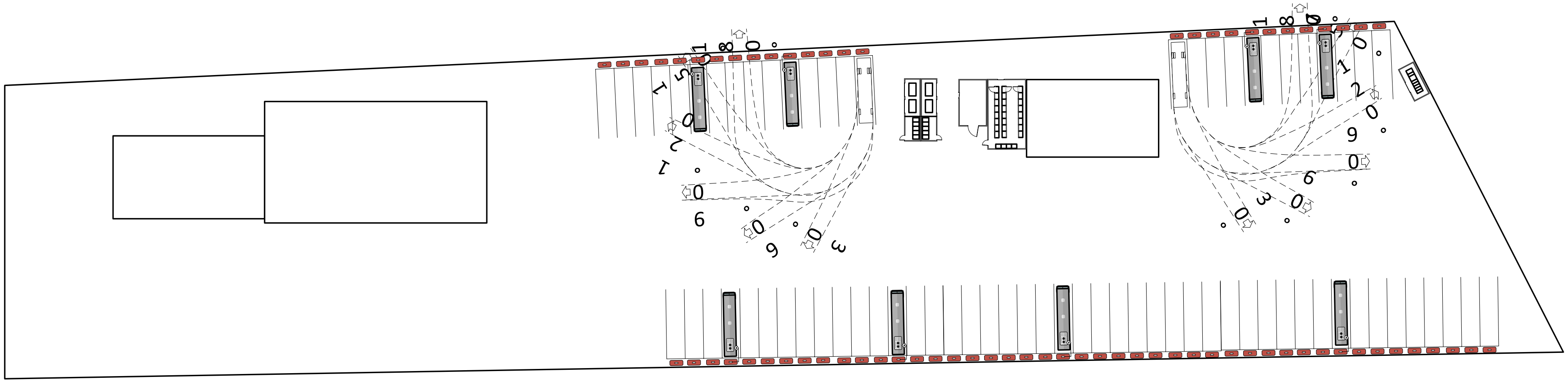


Figure 75. Proposed parking layout at Higna Naka depot

7.1.4 Patwardhan 2 bus depot

7.1.4.1 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.

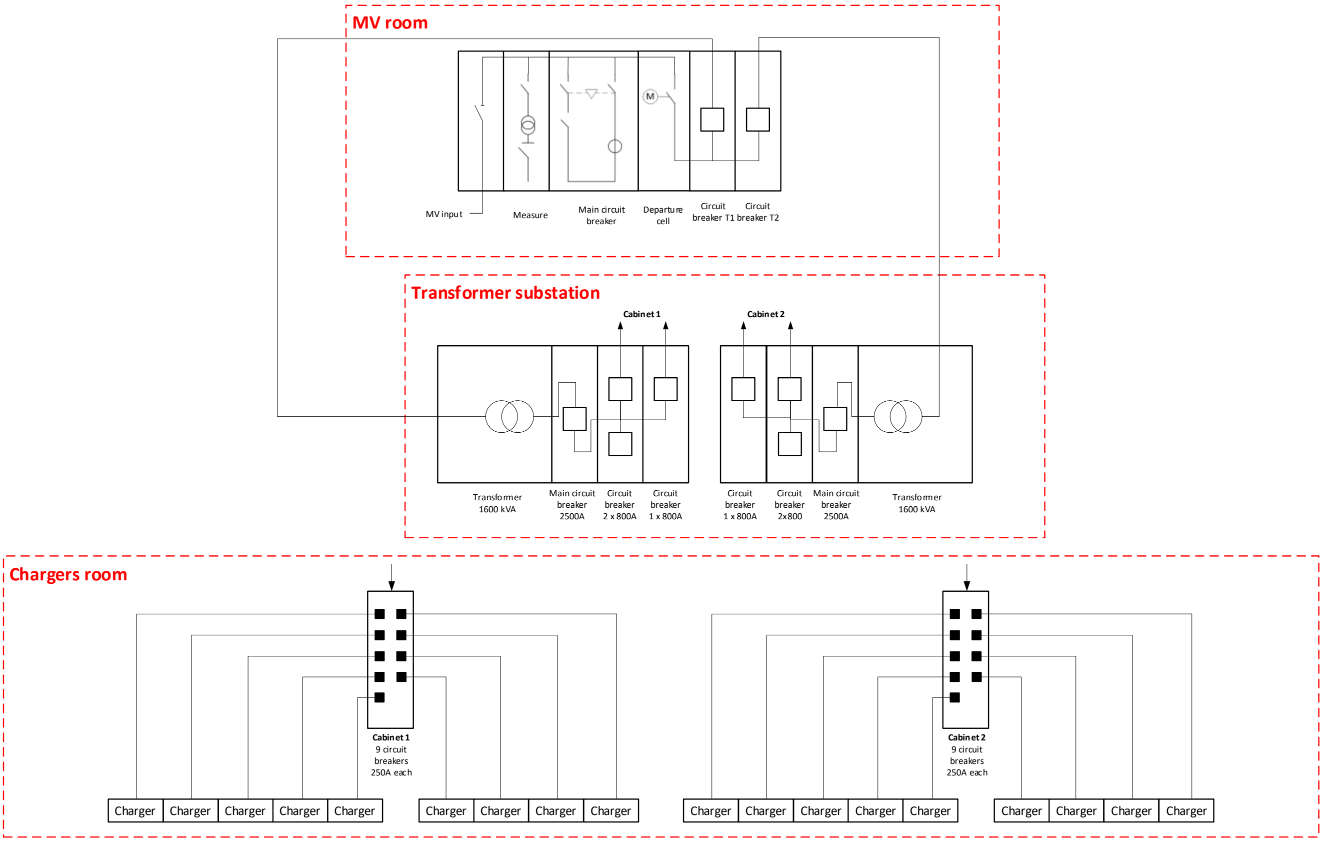


Figure 76. Patwardhan 2 electrical infrastructure architecture for 54 E-buses and 18 chargers (partial redundancy)

As shown in Figure 76, 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.

7.1.4.2 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,
- 1 circuit breaker cabinet per transformer.

The diagram presented in Figure 77 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.

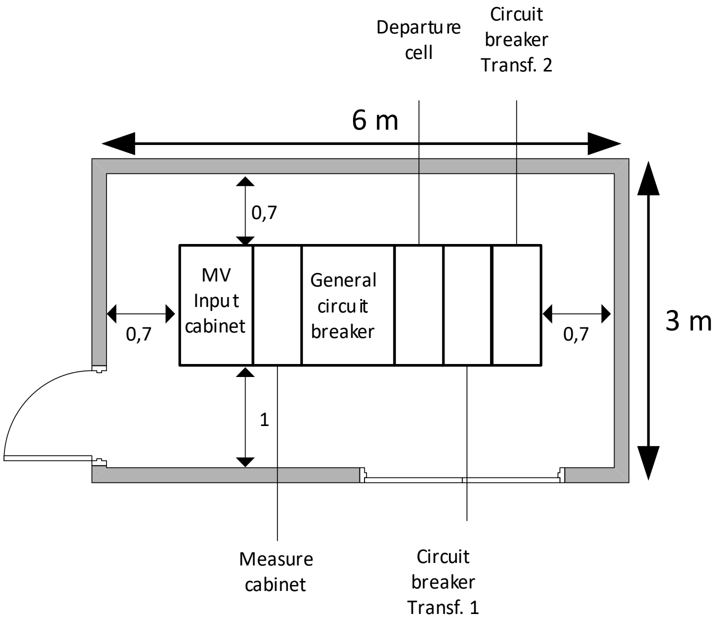


Figure 77. Required medium voltage room layout - Patwardhan 2 depot

TRANSFORMER SUBSTATION

The equipment installed in the transformer substation is the following:

- 2 pad-mounted transformers (for partial redundancy),
- 2 main switchgears cabinets,
- 6 secondary switchgears cabinets.

The diagram in Figure 72 describes the layout of this technical room, including required maintenance spaces (represented in metres).

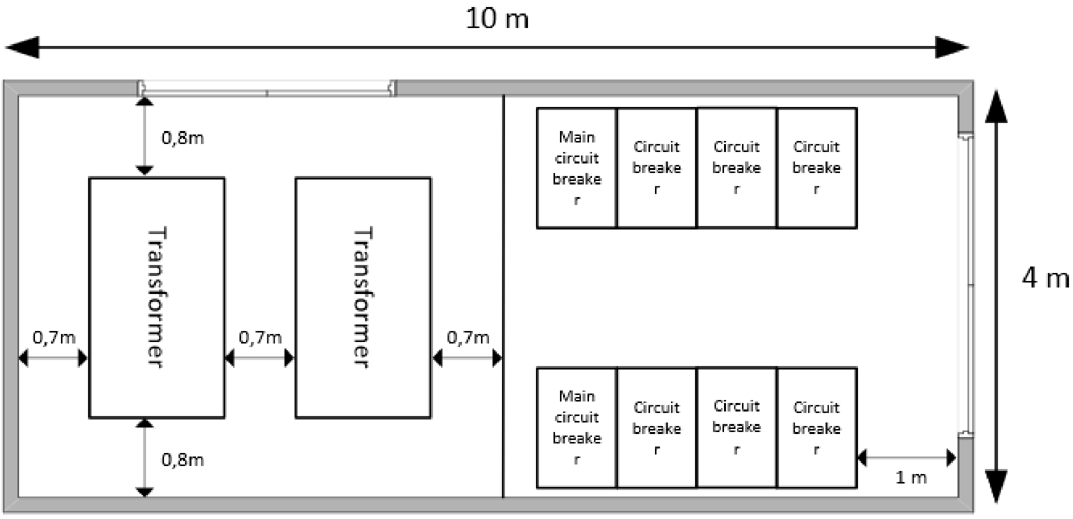


Figure 78. Required transformer substation layout - Patwardhan 2 depot

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 79 describes the layout of this technical room, including required maintenance spaces (represented in metres).

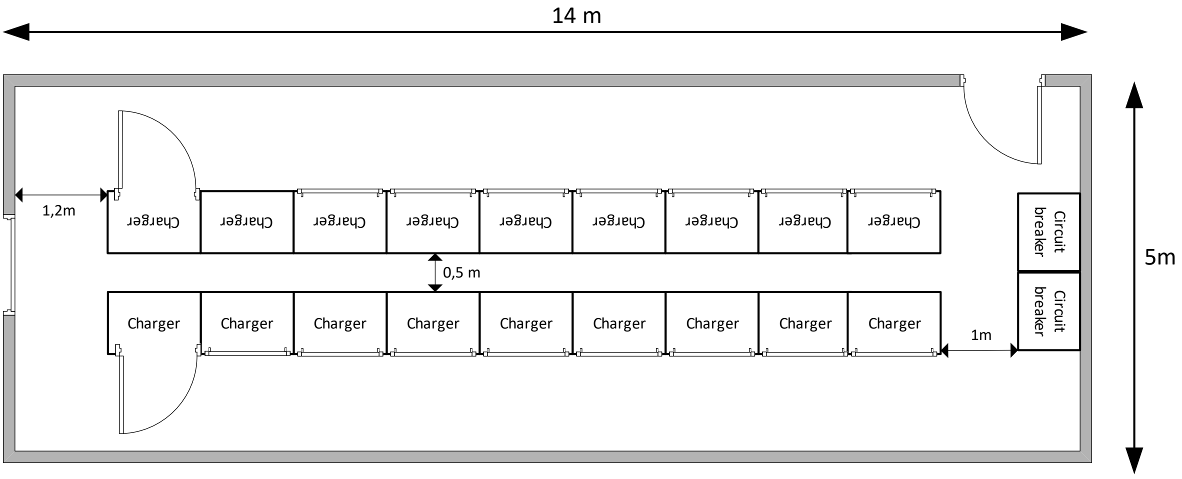


Figure 79. Required chargers room layout - Patwardhan 2 depot

The equipment installed in this room is the following:

- 2 cabinets for the electrical switchboards,
- 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.

7.1.4.3 Patwardhan 2 depot layout

The proposed layout in Figure 80 and Figure 81 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.

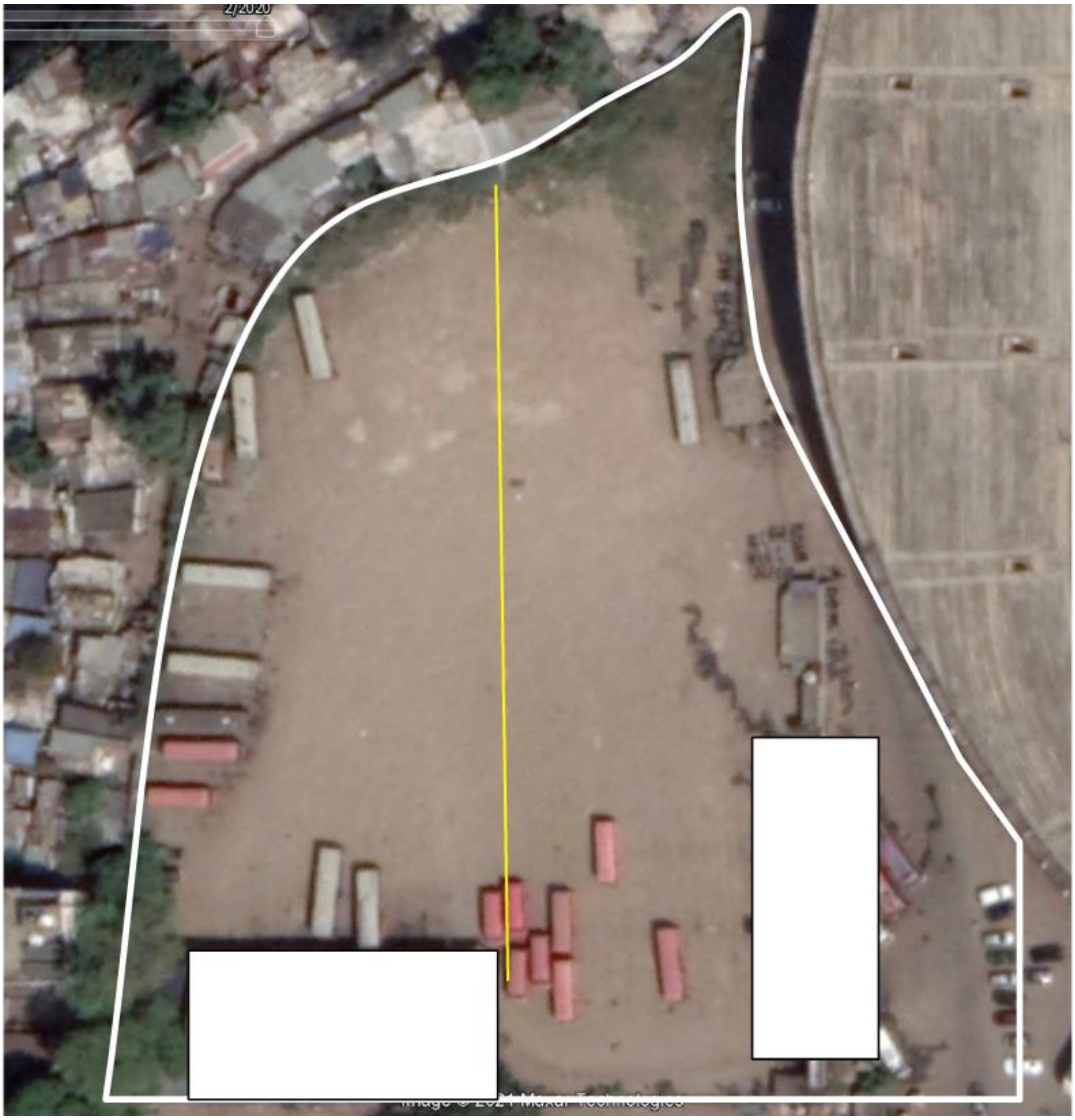


Figure 80. Aerial view - Ptwardhan 2 depot

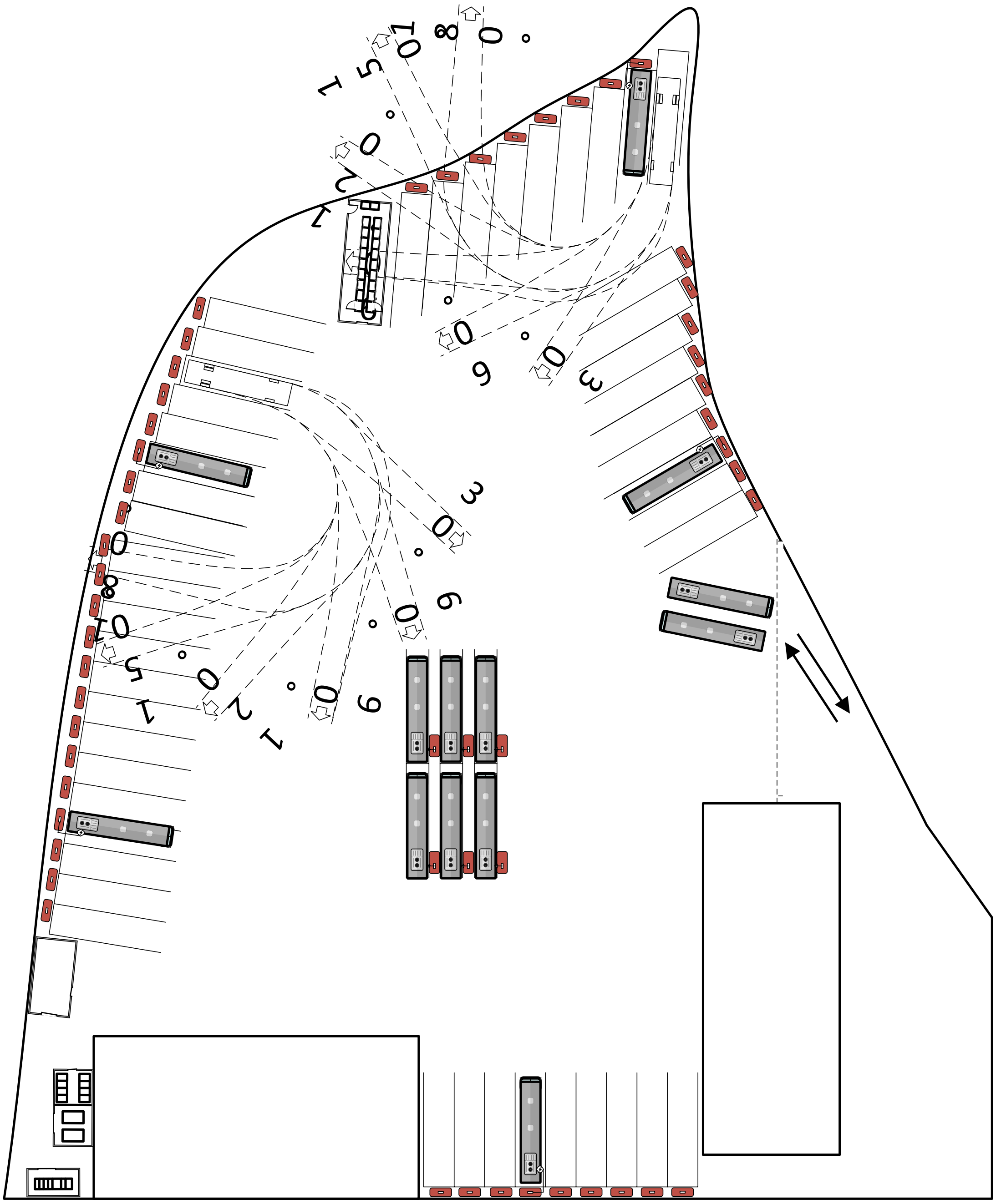


Figure 81. Proposed parking layout at Patwardhan 2 depot

7.2 Depot charging management system

A charge management system provides global control of the chargers on a shop floor level.

A **regular charging management system** performs the functionalities presented in this chapter. An **advanced charging management system** (in addition to the functionalities hereafter) can also **enable the automatic distribution of bus recharging in order to limit the maximum power demand on a depot**. The system therefore controls the chargers sequentially on/off and the bus to be charged, as the chargers can be connected to several buses.

7.2.1 Base functionalities

A charging management system allows to:

- Collect data on the state of charge of the busses by data exchange with the chargers,
- Consider the bus scheduling data (service end time / service start time) and scheduled maintenance tasks,
- Calculate a bus recharge schedule that minimizes the maximum power demand,
- Start and stop the bus recharge according to this schedule,
- Adapt scheduling in real time according to operation 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 (charging complete or sufficient for the vehicles following task).

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 system between depot and the electric 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.

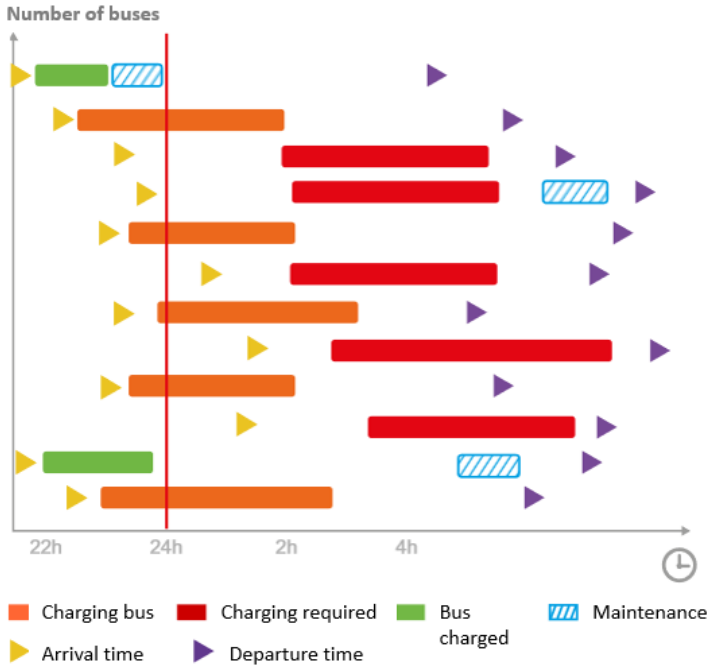


Figure 82. Example of recharge management system (source: C-Way)

7.2.2 Required system infrastructure

The equipment required for the charging management system is as follows (see also Figure 83):

- 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.

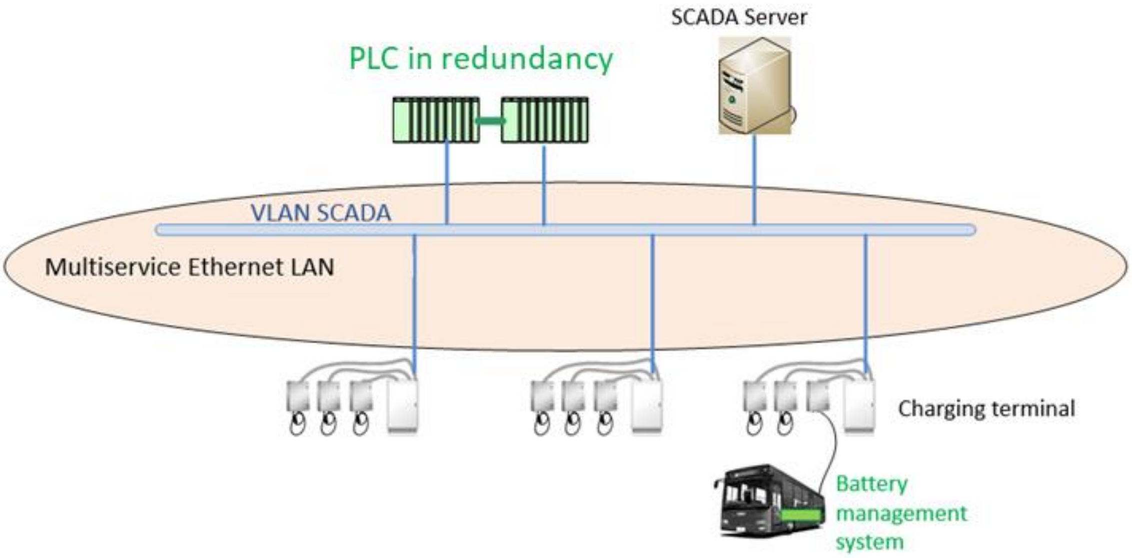


Figure 83. Schematic diagram of the recharge management system

7.3 Depot 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.

7.3.1 Vehicle's maintenance

7.3.1.1 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.

7.3.1.2 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.).

7.3.1.3 Summary of workshop upgrade items required

Table 31 summarizes the different workshops and their needs.

Table 31. 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 favour 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.

7.3.2 Specific equipment required

Regarding required workshop equipment, the recommendations are presented in Table 32.

Table 32. 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	

8. Required resources and qualifications

8.1 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.

8.1.1 Safety during vehicle operation

8.1.1.1 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 recharge 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.

8.1.1.2 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 recharging phase, a centralized monitoring (at depot) shall allow real-time supervision. The electrical recharging 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 recharging 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.

8.1.2 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.

8.1.2.1 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 33 describes the additional check tasks related to electric buses.

Table 33. 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.

8.1.2.2 Preventive and corrective maintenance

BATTERY REPLACEMENT

Figure 84. Battery pack – Martinique 24m BRT (source: setec)

Figure 85. 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.

8.1.3 Safety during charging infrastructure maintenance

8.1.3.1 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 recharge 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:

- 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.

Figure 86. Example of electrical measurement (source: Novabus)

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.

8.1.3.2 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.

8.1.3.3 Medium voltage and low voltage infrastructure

The medium voltage (MV) and low voltage (LV) distribution infrastructure supplying vehicle recharging and auxiliary building loads require recurring maintenance.

Figure 87. Example of thermographic inspection (source: Veritas Technologies Ltd.)

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.

8.1.4 Other general safety aspects

This chapter presents the general safety recommendations for recharging 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.

8.1.4.1 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.

RECHARGING AREAS

Bus recharging 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.

8.1.4.2 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 recharging 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.

8.2 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.

8.2.1 Additional driving time

As discussed in chapters 6.2.1 and 6.3.1, 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.

Table 34 presents the additional driving time for each depot, based on the **Volt@bus** simulations results.

Table 34. Additional driving hours (400 kWh batteries scenario)

	Khapri Naka	Higna Naka	Patwardhan 2
Initial driving time (hours)	735	775	652
Additional driving time (hours)	5	0	0
Proportion	+0.8%	-	-
Final driving time (hours)	740	775	652

Table 35. Additional driving hours (350 kWh batteries scenario)

	Khapri Naka	Higna Naka	Patwardhan 2
Initial driving time (hours)	735	775	652
Additional driving time (hours)	13	1	1
Proportion	+1.8%	+0.2%	+0.2%
Final driving time (hours)	748	777	653

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.

8.2.2 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).

Figure 88. Example of Traction inverter (source: ELFA II Traction inverter – Siemens)

8.2.3 Charging equipment maintenance

Charging equipment maintenance includes the off-power and under-voltage operations described in chapter 8.1.3.1, as well as operations described in chapter 8.1.3.2.

The maintenance hours associated to these tasks depend on the quantity of recharges (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.

8.2.4 Electrical infrastructure maintenance

Figure 89. Typical protection equipment for electrical maintenance (source: MEDIAPREV)

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, ...).

8.3 Impacts on staff training

The elements presented in chapters 8.1 and 8.2 show 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.

8.3.1 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.

8.3.2 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 recharging 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 (see chapter 8.1.1.1),
- 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.

8.3.3 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.

8.3.4 Training responsibility and contractual performance

In case of Gross Cost Contracts, the operator is responsible for delivering a quality service in line with the performance indicators of its contract. The operator is consequently responsible for training its staff to maintain, operate, and drive the bus fleet (diesel, CNG, or electrical).

Training is generally included as part of the services offered by manufacturers when purchasing new vehicles / acquiring new equipment. In the recent bidding document used for the procurement and O&M of 40 electric buses in Nagpur, the bidders were supposed to provide an undertaking from the original bus manufacturer that includes, in addition to the provision of the buses, the provision of trainings to the drivers and technicians of the bidder.

We recommend NMC to include performance clauses in the contracts with bus providers-operators-maintainers, in order to guarantee a good level of service and continuous training of the staff. Employing the staff directly by NMC may not be a viable solution in terms of costs and permanent training required.

FINANCIAL AND CONTRACTUAL ASSESSMENTS

This section presents an update of the financial and contractual assessment developed in *Task 4 Report*. The section comprises the financial modelling approach, assumptions, and results, as well as the contractual framework analysis.

- CAPEX and OPEX analysis
- Updated financial assessment
- Contractual aspects

9. 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).

9.1 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 (see also the analysis of the contractual framework in chapter 11).

In each of the following tables, the first column describes the unit price of each item (please note that some unitary prices may differ from those presented in *Task 3A* and *Task 3B Reports* due to updated data). The investment costs are then calculated for the three depots.

9.1.1 Scenario “400 kWh batteries”

Investment costs considered for the analysis for the case of the 400 kWh batteries are shown in Table 36. Taking into account a battery price of 14 000 INR per kWh[7], 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.

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[7] Electric Vehicle Outlook 2020 report, Bloomberg NEF

Table 36. Investment cost analysis (400 kWh batteries scenario - unitary prices sources: SETEC prices benchmark and estimations, see also Task 3A and Task 3B Reports)

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**

9.1.2 Scenario “350 kWh batteries”

Investment costs considered for the analysis for the case of the 350 kWh batteries are shown in Table 37.

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 37. Investment cost analysis (350 kWh batteries scenario - unitary prices sources: SETEC prices benchmark and estimations, see also Task 3A and Task 3B Reports)

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**

9.2 Operation and maintenance cost analysis

As introduced in *Task 3B Report* (see reference document [R3]), 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 same operating expenditures considered in *Task 4 Report* (see reference document [R4]) and presented in Table 38 were considered for this analysis (please note that some unitary prices may differ due to updated data).

Table 38. Operation expenditures' assumptions (data source: [R4])

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%

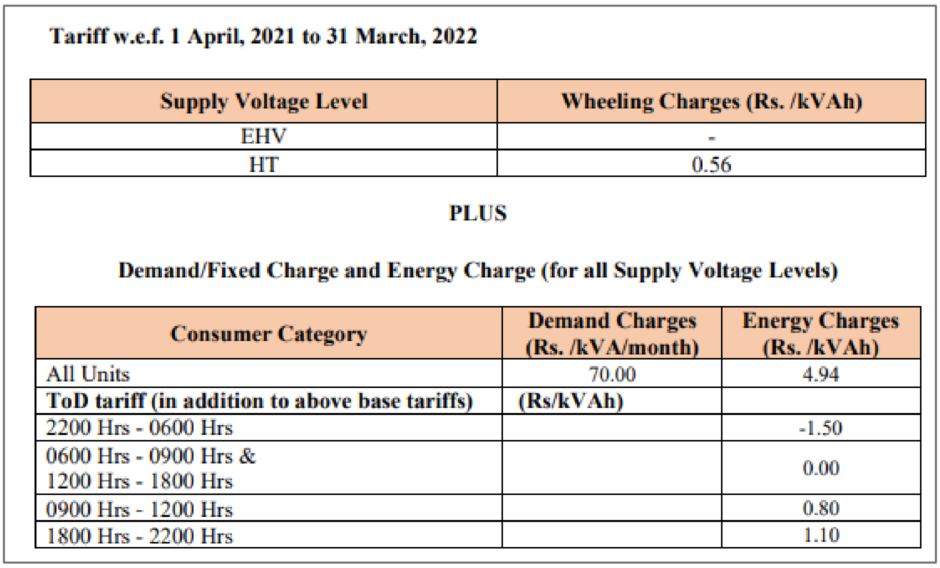
For standard E-buses, energy costs are calculated according to the electrical consumption of each bus depot as well as the maximum power required, as presented in chapter 0. The electrical consumption composes the variable part of the energy costs. On the contrary, the maximum power required for a depot 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 6.2.2) 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 90, 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 91.



Tariff w.e.f. 1 April, 2021 to 31 March, 2022

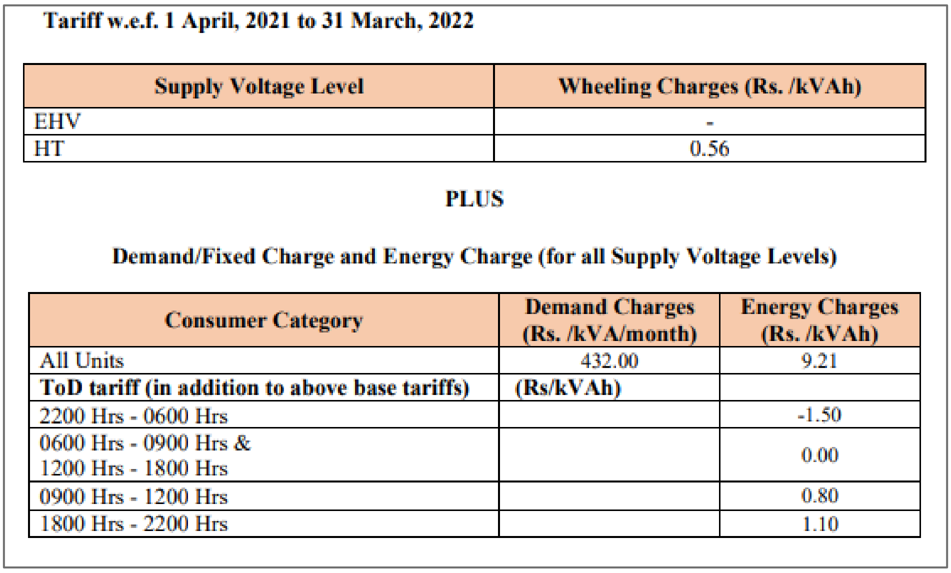
Supply Voltage Level	Wheeling Charges (Rs. /kVAh)
EHV	-
HT	0.56

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 90. Tariff applicable for Electric Vehicle Charging Stations (source: see footnote 8)



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 91. Tariff applicable for Public Service (source: see footnote 9)

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[8] MERC Order – Case No. 322 of 2019, https://www.mahadiscom.in/consumer/wp-content/uploads/2020/03/Order-322-of-2019.pdf, p.706

[9] MERC Order – Case No. 322 of 2019, https://www.mahadiscom.in/consumer/wp-content/uploads/2020/03/Order-322-of-2019.pdf , p.703

In addition, the analysis compares the OPEX of electric and diesel buses in order to evaluate the benefits.

9.2.1 Khapri Naka bus depot

9.2.1.1 Electric Vehicles Charging Stations tariff

Considering the Electric Vehicles Charging Stations incentive tariff, the annual operational and maintenance expenditures are presented in Table 39.

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, as seen in chapter 6.2.1).

Besides, it is noted that charging optimization allows to reduce to a very limited extent the energy cost due to the incentive EV tariff.

9.2.1.2 Public service tariff

When considering the Public Service tariff, the annual operational and maintenance expenditures are presented in Table 40. 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 39. 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 40. 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

9.2.2 Higna Naka bus depot

9.2.2.1 Electric Vehicles Charging Stations tariff

Considering the Electric Vehicles Charging Stations incentive tariff, the annual operational and maintenance expenditures are presented in Table 41.

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, as seen in chapter 6.2.1).

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.

9.2.2.2 Public service tariff

When considering the Public Service tariff, the annual operational and maintenance expenditures are presented in Table 42. 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 41. 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 42. 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

9.2.3 Patwardhan 2 bus depot

9.2.3.1 Electric Vehicles Charging Stations tariff

Considering the Electric Vehicles Charging Stations incentive tariff, the annual operational and maintenance expenditures are presented in Table 43.

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, as seen in chapter 6.2.1).

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.

9.2.3.2 Public service tariff

When considering the Public Service tariff, the annual operational and maintenance expenditures are presented in Table 44. 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 43. 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 44. 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

9.3 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.

10. Updated financial assessment

10.1 Objectives and general approach

The objective of this chapter is to provide a financial assessment of the bus fleet replacement scenarios retained for the pre-feasibility study.

10.1.1 Summary of Task 4 Report conclusions

Task 4 Report (see reference document [R6]) provides an assessment of the possible fleet development and replacement plans of Nagpur City Bus Services, and includes:

- An assessment of the financial impact of the mid-term vision for Nagpur fleet augmentation and upgrade plan (developed as part of *Task 2*) on the total bus service costs; and
- An assessment of the impact of the electrification of the fleet independently of the growth plan. Three possible fleet replacement scenarios were then assessed 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.

The financial modelling of the overall service showed that both fleet replacement scenarios and the fleet augmentation scenario will yield higher service costs compared to the current situation. In other words, the electrification of part of the network, with constant fleet levels (replacement scenarios), will increase the service costs. But, if this is also coupled with an increase in the overall network fleet (fleet augmentation scenario), this will result in more important additional service costs compared to the current situation, reaching more than three times the current service costs (in nominal terms) at the end of the evaluation period. Service revenues are however unlikely to increase proportionally which may deepen NMC’s current viability gap.

The financial modelling also showed that all replacement scenarios (assuming constant fleet over the analysis period) will require around 4%, 16% and 35% more yearly additional resources compared to the current operational subsidies provided by NMC.

10.1.2 Objectives of the updated financial assessment

As agreed with NSSCDCL and NMC (with consent of AFD), the objective of the current pre-feasibility study in *Task 6* is to provide a comparison of the different electrification options and clear operational recommendations for the upcoming replacement (in 2022) of the existing 237 standard diesel buses currently operated by three different operators (79 each).

Operational simulations were conducted (as presented in chapters 0 and 7) for all the routes operated by these buses (standard diesel) 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 explained in chapter 4.2. 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[10]. 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.

This section provides an assessment of the financial impact of these different electrification options. For this purpose, 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).

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[10] Simulations only included routes operated by the standard diesel buses, and hence only this part of the network could potentially be optimized. Routes operated by the other types of buses (midi and minibuses) were not simulated and the corresponding number of buses is assumed constant over the analysis period.

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.

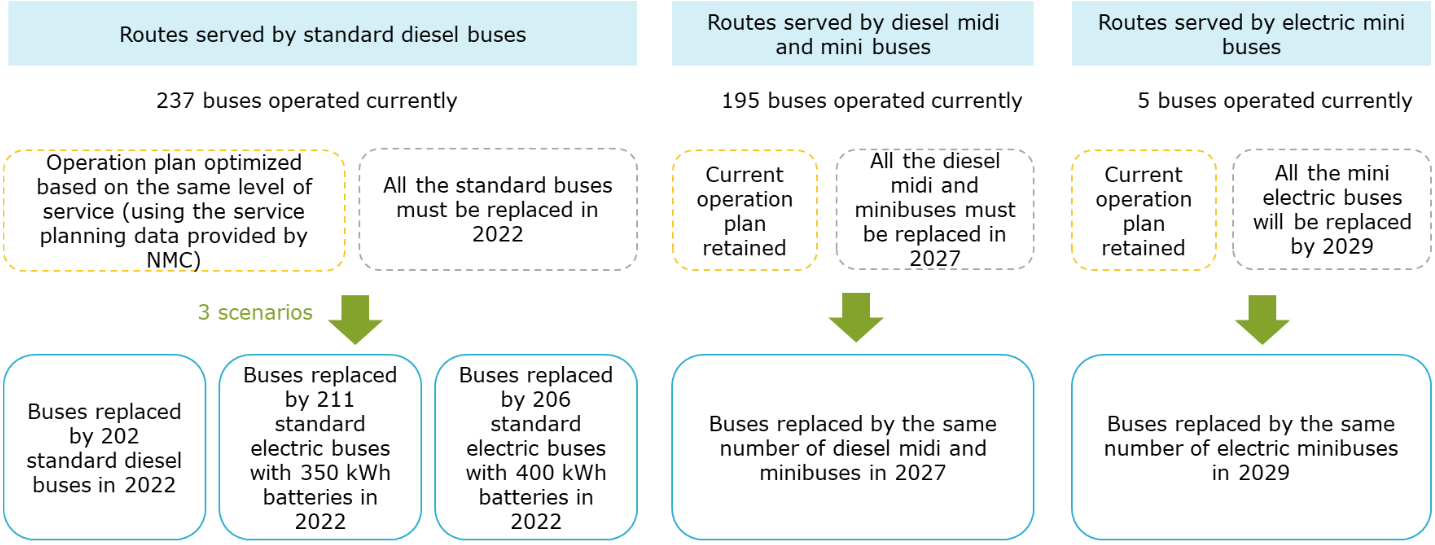

Figure 92. Characteristics of the Nagpur City Bus network considered for the financial analysis

The financial assessment also analyses 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 (as presented in chapter 9.2), by testing two possible tariffs:
  - Tariff 1: Electricity tariffs for EV charging stations, and
  - Tariff 2: Electricity tariffs for public services.

Table 45. Detailed bus replacement scenarios considered in the 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**
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**

10.2 Financial modelling approach and assumptions

10.2.1 Overview of the model

The financial model developed during Task 4 (see reference document [R4]) was used to assess the financial sustainability of the different scenarios detailed in Table 45. 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)[11],
- 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.

10.2.2 General assumptions

The general assumptions used in the model are related to:

- Investment (CAPEX) and operation and maintenance (OPEX) costs (see chapter 9,
- Operational assumptions for electric and diesel buses (see chapter 4.2), and
- Macroeconomic parameters (inflation, see chapter 4.1).

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[11] No growth rate is applied. Only indexation to inflation is considered.

10.2.3 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 (see details in reference document [R4]), 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.

10.2.3.1 Kilometre charge

The kilometre charges of all types of buses operated in Nagpur were already estimated in Task 4. In this task, those estimations were refined 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.

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 46.

Table 46. 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. Based on the costs' assumptions detailed in chapter 9.2, Table 47 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 47. 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 and the updated operational assumptions compared to Task 4 Report. The new kilometre charge is estimated at 57.63 INR/km in 2019 (including the 4% profit margin of the operator).

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.

For the new electric buses (standard), kilometre charges estimated in *Task 4 Report* were updated using the updated cost and operation assumptions and applying a 4% operator's profit margin.

The kilometre charges include the following costs (both investment and renewal costs include financing costs):

- Operating expenditures (OPEX),
- Investment costs (CAPEX), and
- Renewal costs.

The detailed results of the kilometre charge for each one of the analysed scenarios is presented in chapter 10.3.

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 *Task 4 Report*, reference document [R4], for a detailed analysis of the current contractual framework).

10.2.3.2 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.

The detailed assumptions used for new standard diesel buses are presented in chapter 4.2. For the existing buses, the average yearly number of kilometres estimated in *Task 4 Report* (56,052 km / bus) was maintained in the current analysis.

10.2.4 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.

10.2.5 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**.

10.2.6 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.

Additional data received at the beginning of the current pre-feasibility study did not allow to conduct a new estimation of revenues per passengers for 2020.

10.2.6.1 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).

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 48. Estimated non-fare box revenues (data source: discussion with NMC during the inception mission, see reference document [R1])

	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[12]. 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.

10.3 Financial modelling results

10.3.1 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 93) and the Public Service electricity cost - Tariff 2 (see Figure 94) in Maharashtra state.

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[12] Comprehensive Feeder Service Project for Nagpur Metro, KfW, 2018.

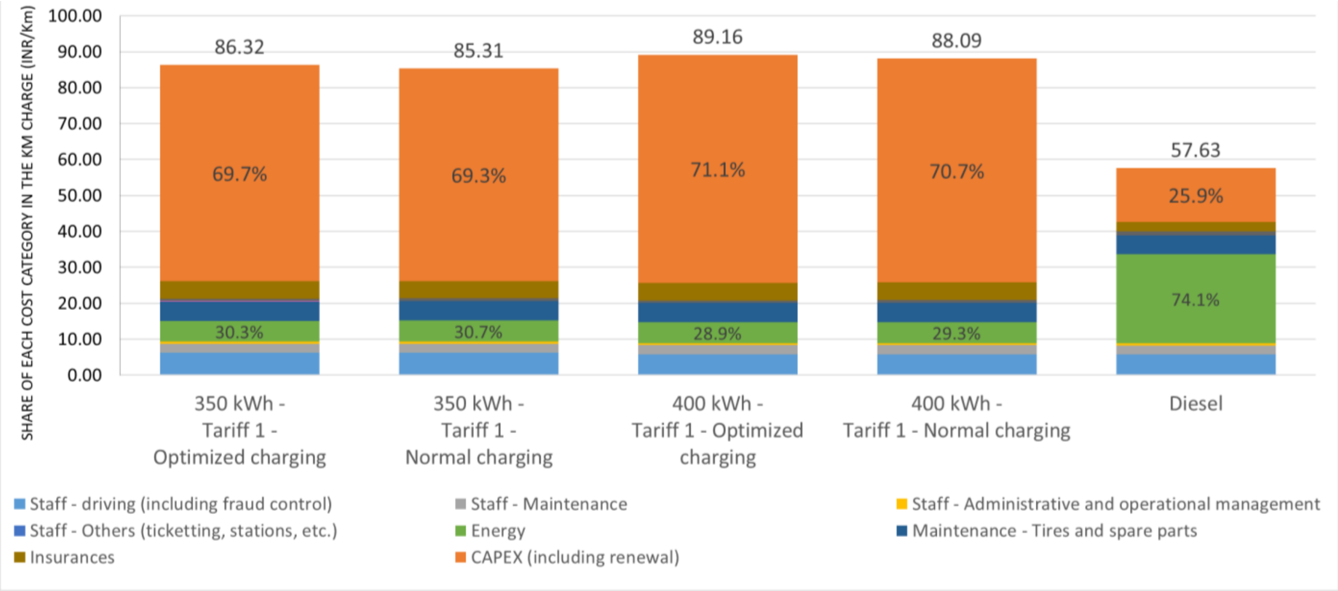

Figure 93. Comparison of the km charge for electric and diesel standard buses - Tariff 1 (incentive tariff)

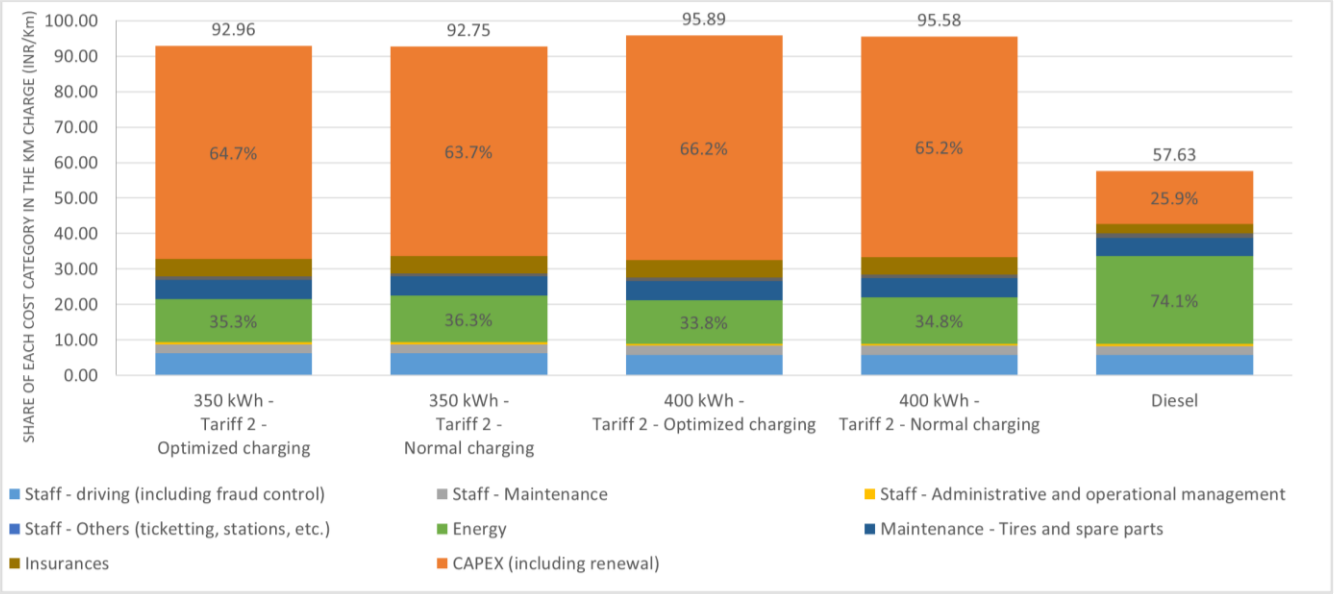

Figure 94. Comparison of the km charge for electric and diesel standard buses - Tariff 2 (regular tariff)

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.

10.3.2 Impact on the viability gap of Nagpur City Bus Service

Figure 95 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 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* (see reference document [R4]) 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.

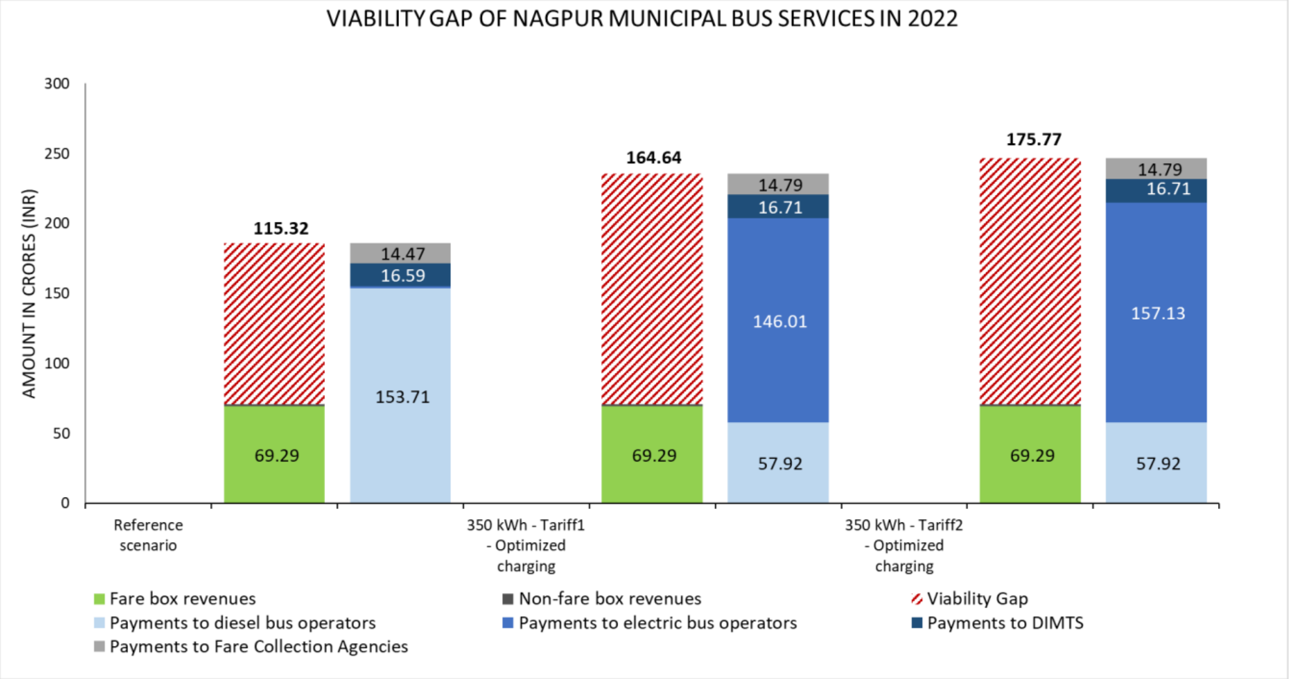

Figure 95. Viability gap of Nagpur City Bus Services in 2022

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 96). 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.

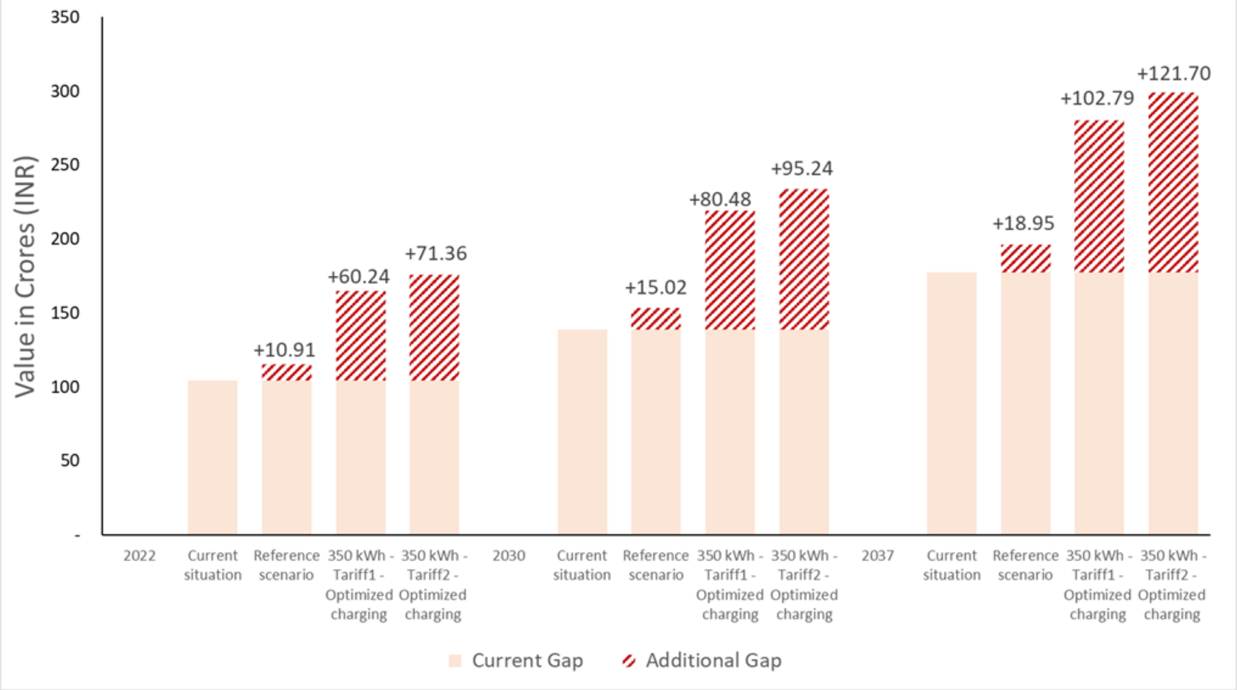

Figure 96. Comparison of the additional annual gap to the current one

10.4 Conclusions on the 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.

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.** The following chapter provides an overview of the possible financial support mechanisms that can be leveraged by NMC. A more detailed analysis is presented in *Task 4 Report* (see reference document [R4]).

10.5 Possible levers to enhance system's financial sustainability

During *Task 4*, we conducted a benchmark of Nagpur's urban public transport policies with other comparable agglomerations and identified four possible levers to enhance the system's financial sustainability. The detailed analysis is provided in section 4 of *Task 4 Report* (see reference document [R4]).

The benchmark showed 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 scenarios envisaged in the planning documents).

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.

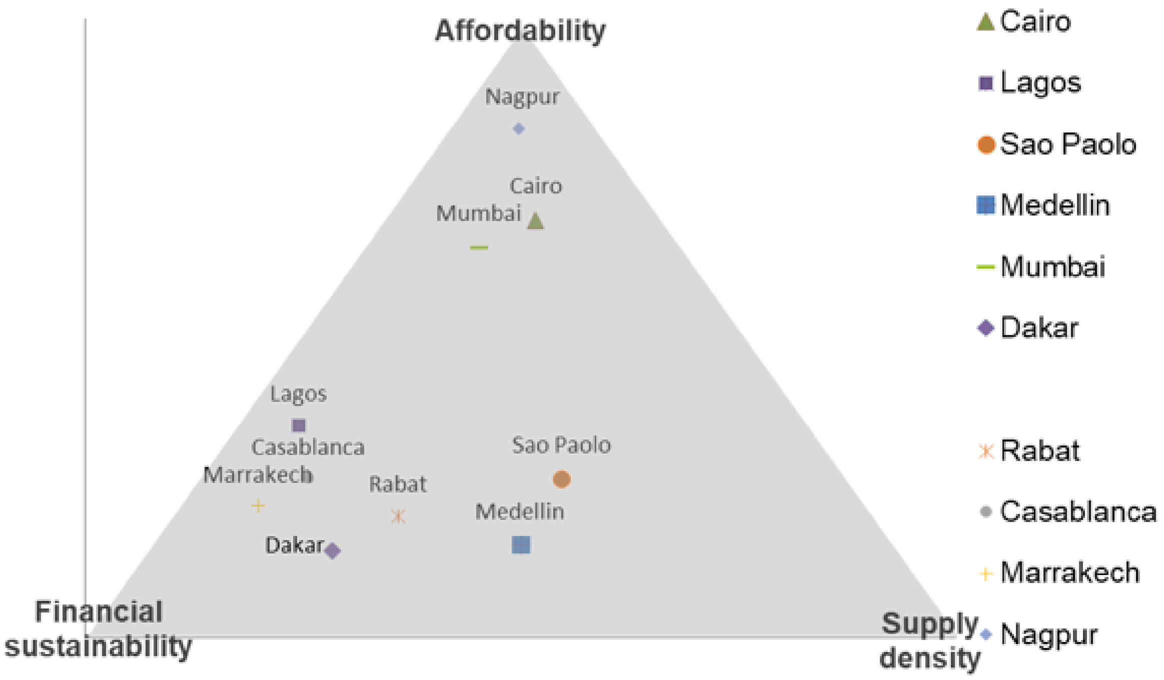

Figure 97. Characterization of public transport policies in different cities

Therefore, based on these conclusions and the analysis of the operational performance determinants, four action areas 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 or concessional financing may be available from global financial resources[13] (such as the Green Climate Fund[14] and the Clean Technology Fund), optimized cost and commercial efficiency require an optimization of the current contractual framework.

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[13] The analysis focused on globally available financial resources given the inability to conduct missions to Nagpur and interviews with the local stakeholders.

[14] The mobilization of such resources could however be difficult given the characteristics of the Indian energy mix, currently dominated by fossil fuels.

11. Contractual aspects

Task 4 Report (see reference document [R4]) provides a detailed analysis of the existing contractual framework for Nagpur City Bus Services and issues preliminary recommendations for an optimised framework.

The first section of this chapter provides a summary of this review and its main conclusions. The second section provides some specific recommendations on the best contractual solution for the upcoming replacement of diesel standard buses in 2022.

11.1 Summary of *Task 4 Report* conclusions

The review has encompassed the contracts between the operators and NMC [15], and between DIMTS and NMC. They must be reviewed together because DIMTS has a key role in enforcing and optimizing the service. Our review also included existing contract models[16] and the draft bus 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.

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 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.

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[15] 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).

[16] 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, and the toolkit for Public-Private Partnerships in Urban Bus Transport for the State of Maharashtra published in 2011.

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 (in particular regarding optimised energy consumption or gains from higher commercial speeds).

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. For instance, 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

Therefore, the following actions could be recommended to optimise the contractual framework for an enhanced financial performance of the system:

- 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[17].

The above recommendations are preliminary and would need to be refined and confirmed through interviews with key stakeholders (NMC, DIMTS, bus operators, finance providers).

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[17] 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.

11.2 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 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 (see Task 4 Report, reference document [R4], p. 63), 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).

TENTATIVE SCHEDULE FOR THE OPERATION

▼

This section presents a tentative schedule for the replacement of standard diesel buses to standard E-buses by 2022.

12. Tentative schedule for the operation

Figure 98 presents a tentative schedule recommended for the replacement of the Standard diesel buses to Standard E-buses by 2022.

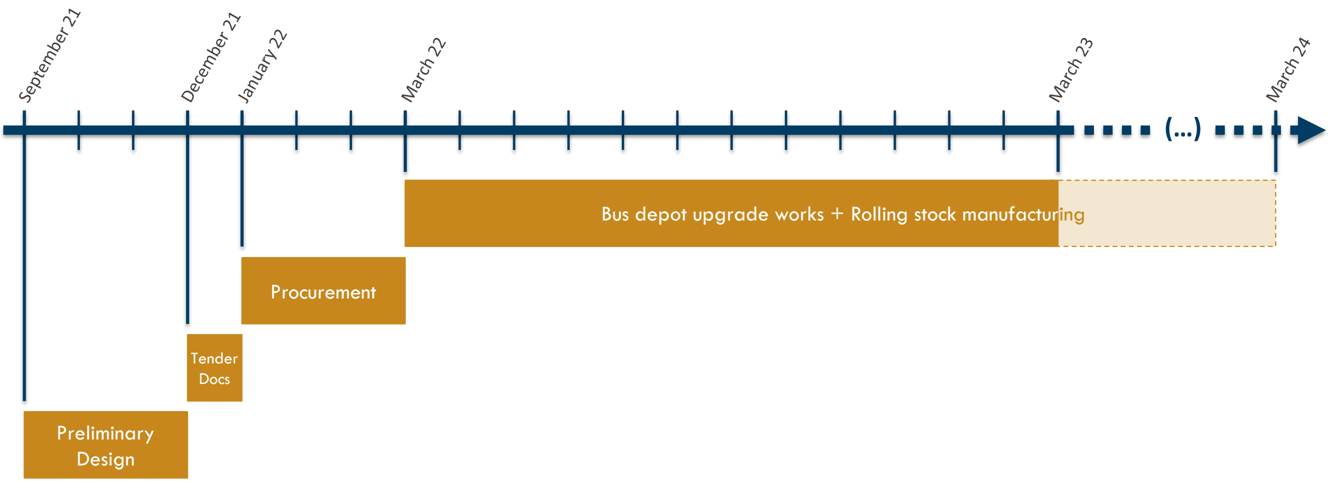

Figure 98. Tentative schedule for the operation (standard buses replacement by 2022)

12.1 Preliminary Design stage

During the Preliminary Design stage, the **main goals** are:

- To perform the final selection of the bus routes to be electrified,
- To refine the technical specifications of E-buses (autonomy, trim level, etc.) according to actual operation data (includes possible traffic management systems, CCTV, etc.),
- To define the Key Performance Indicators to be achieved by the future Contractor/Operator,
- To confirm the necessary bus fleet according to the bus routes characteristics,
- To perform Depot Electrification works preliminary design,
- To define of the necessary training requirements,
- To refine the Procurement and Construction Planning,
- All the above to be included in the Tender to provide necessary information to limit the operator's risk and decrease the price
- And finally, to refine CAPEX and OPEX for future reference for Tender Evaluation and consideration in the Municipal Budget and subventions requirements (preliminary estimates and ratios given in Task 4 and Taks 6 reports).

This stage shall span over **3 months** for the first studies (can be reduced afterwards for subsequent electrifications).

The main stakeholders shall be **NSSCDCL**, **NMC Transport Department**, **DIMTS** (for the operation data and routes selection), as well as a **Consultant** for the Preliminary Design.

12.2 Tender Documents and Procurement stages

For the Tender Documents and Procurement stages, the **main goals** are:

- To prepare the Tender Documents for the selection of Bus Operator (in Gross Cost Contract Model): Expression of Interest, Prequalification, Terms of Reference, etc.,
- To refine the Key Performance Indicators to be achieved by the future Contractor/Operator, and corresponding incentives / penalty mechanisms,
- To execute the Tender Evaluation and Contract Negotiations.

These stages shall have a duration of **1 month** for Tender Documents elaboration and **3 months** for Tender Submission and Contract Negotiations (sufficient time shall be given to bidders).

The main stakeholders on this phase are **NSSCDCL**, **NMC Transport Department** and possibly a **Consultant** as Project Management / Technical Assistance.

12.3 Bus depot upgrade works and Rolling Stock manufacturing

Finally, the Bus depot upgrade works and Rolling Stock manufacturing stage should present the following **main goals**:

- To perform detailed design studies by Contractor/Operator,
- To execute Rolling Stock manufacturing, delivery and testing,
- To execute Depot electrification works (connection to power grid, electric substations construction, installation of chargers, etc.),
- To perform Testing and Commissioning,
- As well as staff training.

This stage shall span over **12 to 24 months** depending on the quantity of buses, and magnitude of depot works, requirements for keeping diesel and CNG buses parking during construction works, etc.

The main stakeholders during this stage shall be **NSSCDCL**, **NMC Transport Department** + **DIMTS** (specially for the testing and revenue service) and possibly a **Consultant** as Project Management / Technical Assistance.

URBAN PLANNING AND ENVIRONMENTAL ASSESSMENT

This section presents an overall assessment of the environmental issues and impacts related to the electrification of buses in Nagpur. It also presents general recommendations in terms of urban and street planning to upgrade Nagpur City Bus Service efficiency and attractivity.

- Environmental issues and overall assessment of impacts
- Focus on electric batteries “end-of-life”
- General urban planning and street upgrades recommendations

13. Environmental issues and overall assessment of impacts

13.1 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.

13.1.1 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.

13.1.2 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.

13.2 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.

13.2.1 Greenhouse gas emissions

13.2.1.1 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[18].

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[19]. Thus, 400-kWh battery production is responsible for the emission of approximately 42 tCO_2eq.

13.2.1.2 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 $kgCO_2/kg$[20]. 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)[21]. Concerning CNG, according to the French Ministry for an Ecological and Solidary Transition, upstream phase accounts for 24% of the tailpipe emissions[22].

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[18] 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.

[19] Erik Emilsson et Lisbeth Dahllöf, « Lithium-Ion Vehicle Battery Production », s. d., 47.

[20] 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.

[21] 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.

[22] 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[23]. 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.

13.2.2 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)[24].

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, as seen in Table 49.

Table 49. 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) was skipped to accelerate lowering of polluting emissions in India.

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[23] International Energy Agency, *India Energy Outlook 2021* (OECD, 2021), https://doi.org/10.1787/ec2fd78d-en.

[24] 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.

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.

13.3 Estimation of emissions

The estimation of emissions presented is based on the "400 kWh batteries" scenario results (see Table 11 and Table 12, page 58). 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.

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.

13.3.1 Greenhouse gas emissions

Figure 99 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.

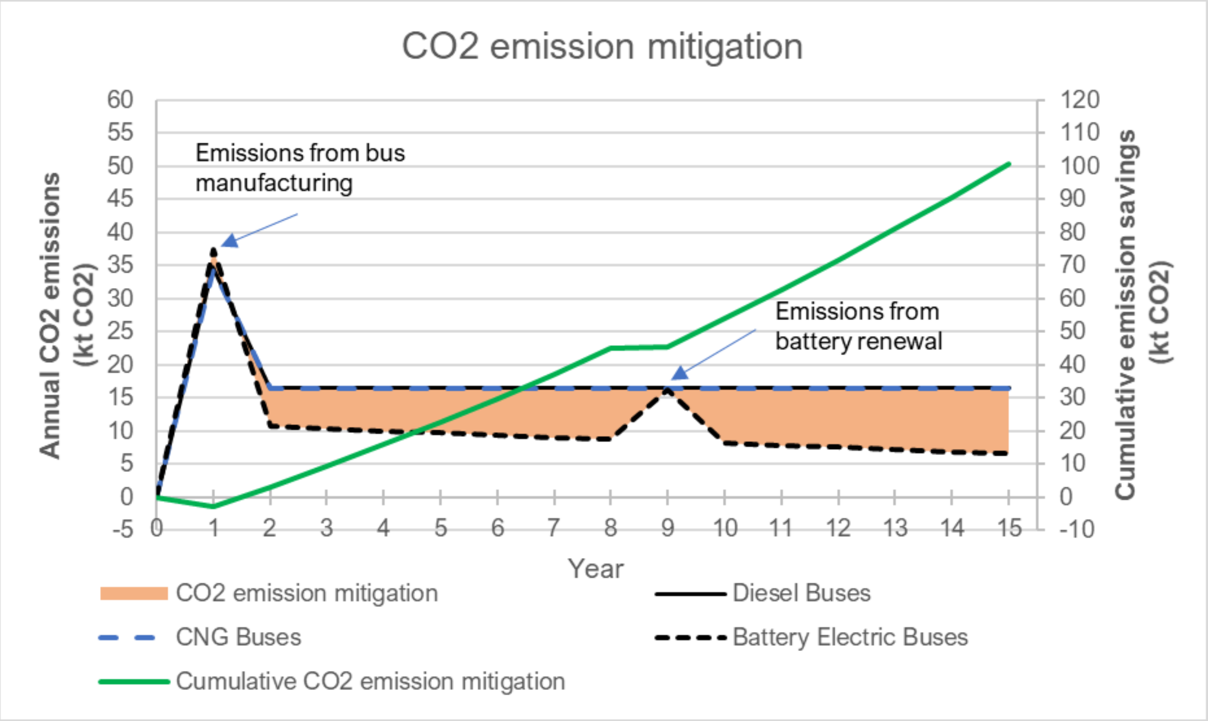

Figure 99. CO_2 emission mitigation estimations for Nagpur City Bus Service fleet

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. As presented in the assumptions section (see §13.2.1.1), 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.

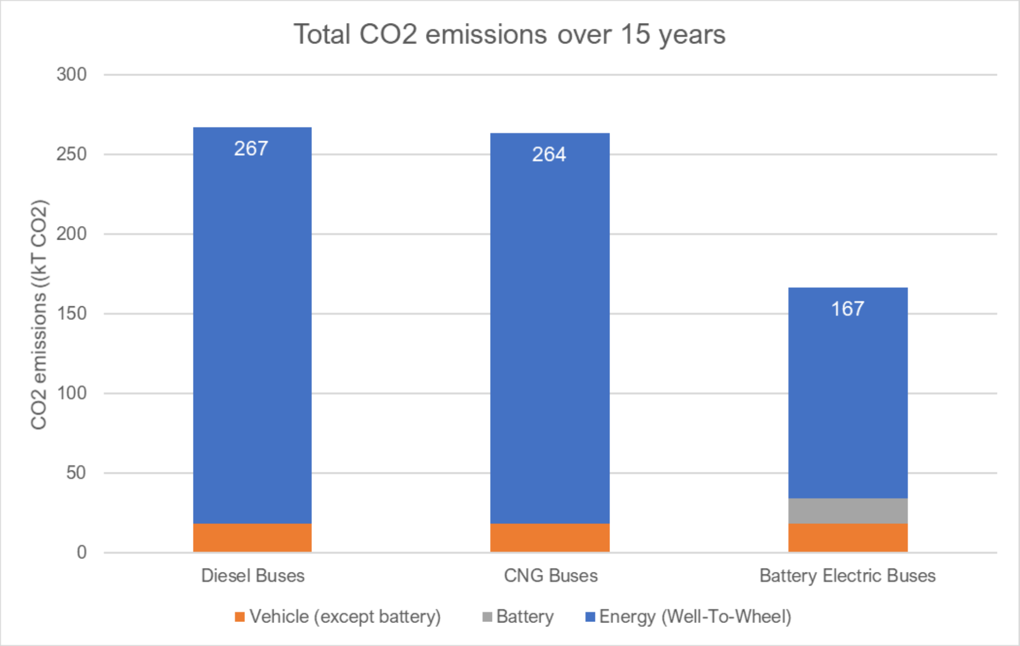

Figure 100. Estimation of total CO_2 emissions for 15 years for Nagpur City Bus Service fleet

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.

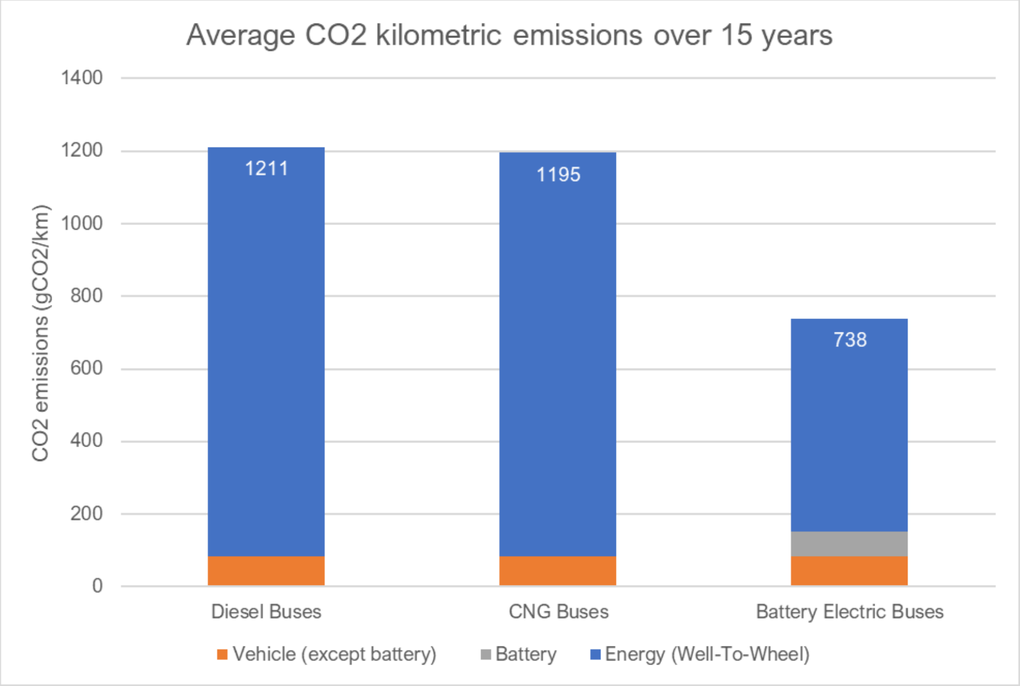

Figure 101. Estimation of CO_2 kilometric emissions for 15 years for Nagpur City Bus Service fleet

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).

13.3.2 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 102 and Figure 103 illustrate the estimated annual emissions for each air pollutant for the required Nagpur City Bus Service fleet.

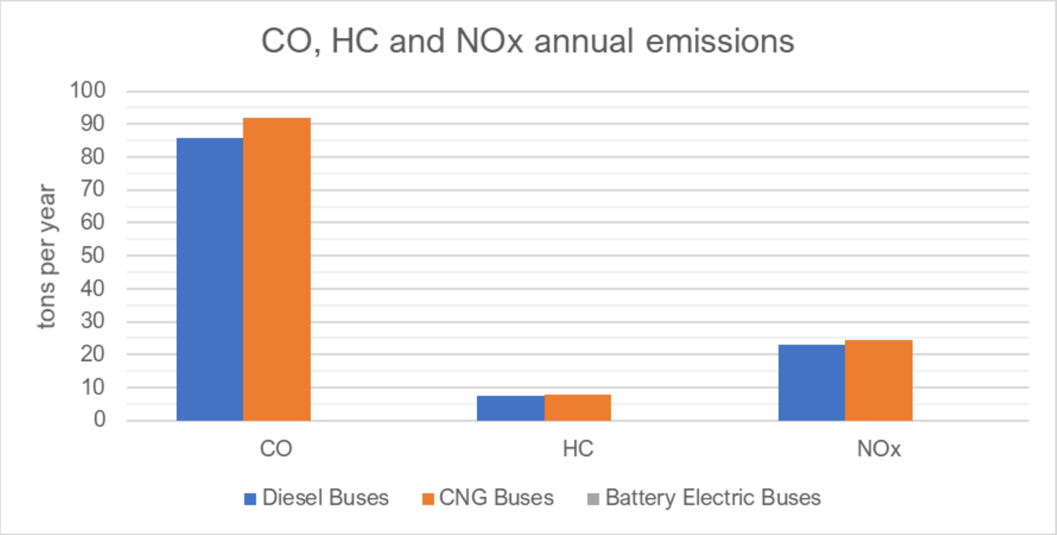

Figure 102. HC, CO, and NOx estimated annual emissions for Nagpur City Bus Service fleet

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.

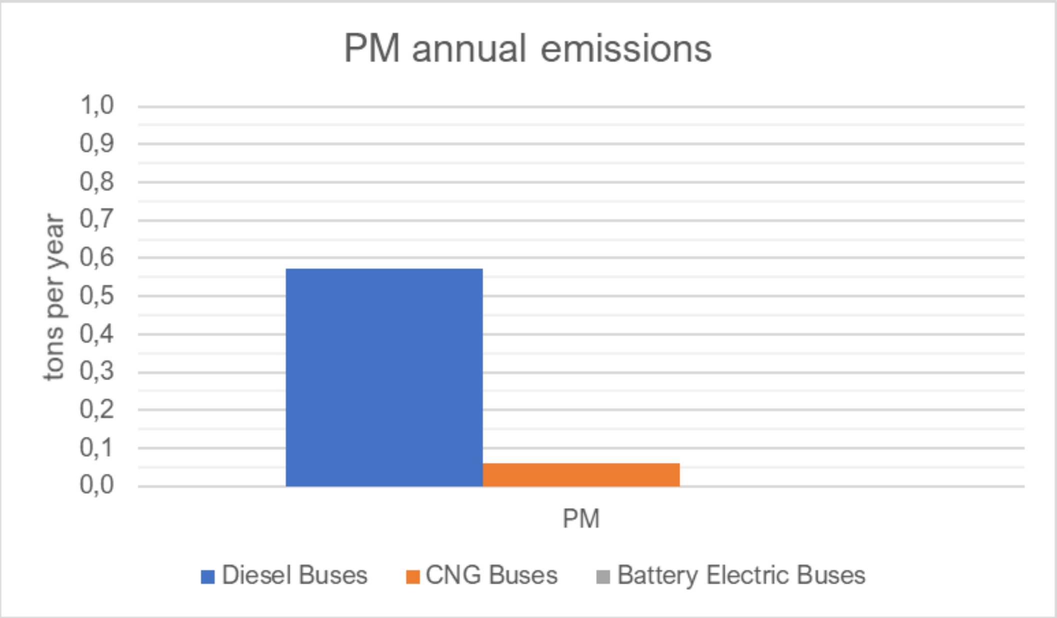

Figure 103. PM estimated annual emissions for Nagpur City Bus Service fleet

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.

14. Focus on electric batteries “end-of-life”

14.1 General aspects

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[25].

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.).

14.2 Battery end of life

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

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[25] 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.

- 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.

14.2.1 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[26].

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[27],

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

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

- 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.

14.2.2 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.

14.2.2.1 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 50.

Table 50. 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 51.

Table 51. 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[28], more than 10 companies have a concrete plan and could recycle more than 15 kt of additional batteries in the very short term.

14.2.2.2 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%[29]), 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.

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[28] https://circularenergystorage.com/

[29] 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.

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”).

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[30]. 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.

14.2.2.3 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[31], 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.

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[30] https://recellcenter.org/

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

15. 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.

15.1 Improving performance

15.1.1 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 104): 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 104. Elevated exclusive bus corridor in Nantes, France

15.1.2 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 105. 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).

15.2 Improving quality of service

15.2.1 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 106), water fountains, vending machines…

Figure 106. New Nagpur City Bus stop and Smart City Kiosk

15.2.2 Bus corridors and cycling[32]

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.

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[32] Content in chapter 14.2.2 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).

15.2.3 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**.

ANNEXURES

▼

This section presents the following annexures to the Pre-Feasibility Study Assumptions Note:

- DIMTS data on bus types per bus route for each Nagpur City Bus Operator (reference [R5])
- DIMTS data on Nagpur City Service bus schedules per route for a typical day (reference [R6])
- DIMTS data on Nagpur City Service detailing bus stops’ Names and Coordinates for each bus route (reference [R7])
- DIMTS data on Nagpur City Bus Service depot locations and GPS coordinates (reference [R8])
- Detailed consumption tables and graphs for each simulated Nagpur City Bus Service route

ANNEXURE 1 - DIMTS DATA ON BUS TYPES PER BUS ROUTE FOR EACH NAGPUR CITY BUS OPERATOR (REFERENCE [R5])

Please refer to file

MOB-AC2-09-NAGPUR-NTE-600_Pre-Feasibility-Study_Assumptions-Note_Annexure-1_2021-04-19

ANNEXURE 2 - DIMTS DATA ON NAGPUR CITY SERVICE BUS SCHEDULES PER ROUTE FOR A TYPICAL DAY (REFERENCE [R6])

Please refer to file

MOB-AC2-09-NAGPUR-NTE-600_Pre-Feasibility-Study_Assumptions-Note_Annexure-2_2021-04-19

ANNEXURE 3 - DIMTS DATA ON NAGPUR CITY SERVICE DETAILING BUS STOPS' NAMES AND COORDINATES FOR EACH BUS ROUTE (REFERENCE [R7])

Please refer to file

MOB-AC2-09-NAGPUR-NTE-600_Pre-Feasibility-Study_Assumptions-Note_Annexure-3_2021-04-19

ANNEXURE 4 - DIMTS DATA ON NAGPUR CITY BUS SERVICE DEPOT LOCATIONS AND GPS COORDINATES (REFERENCE [R8])

Please refer to file

MOB-AC2-09-NAGPUR-NTE-600_Pre-Feasibility-Study_Assumptions-Note_Annexure-4_2021-04-19

ANNEXURE 5 - DETAILED CONSUMPTION TABLES AND GRAPHS FOR EACH SIMULATED NAGPUR CITY BUS SERVICE ROUTE

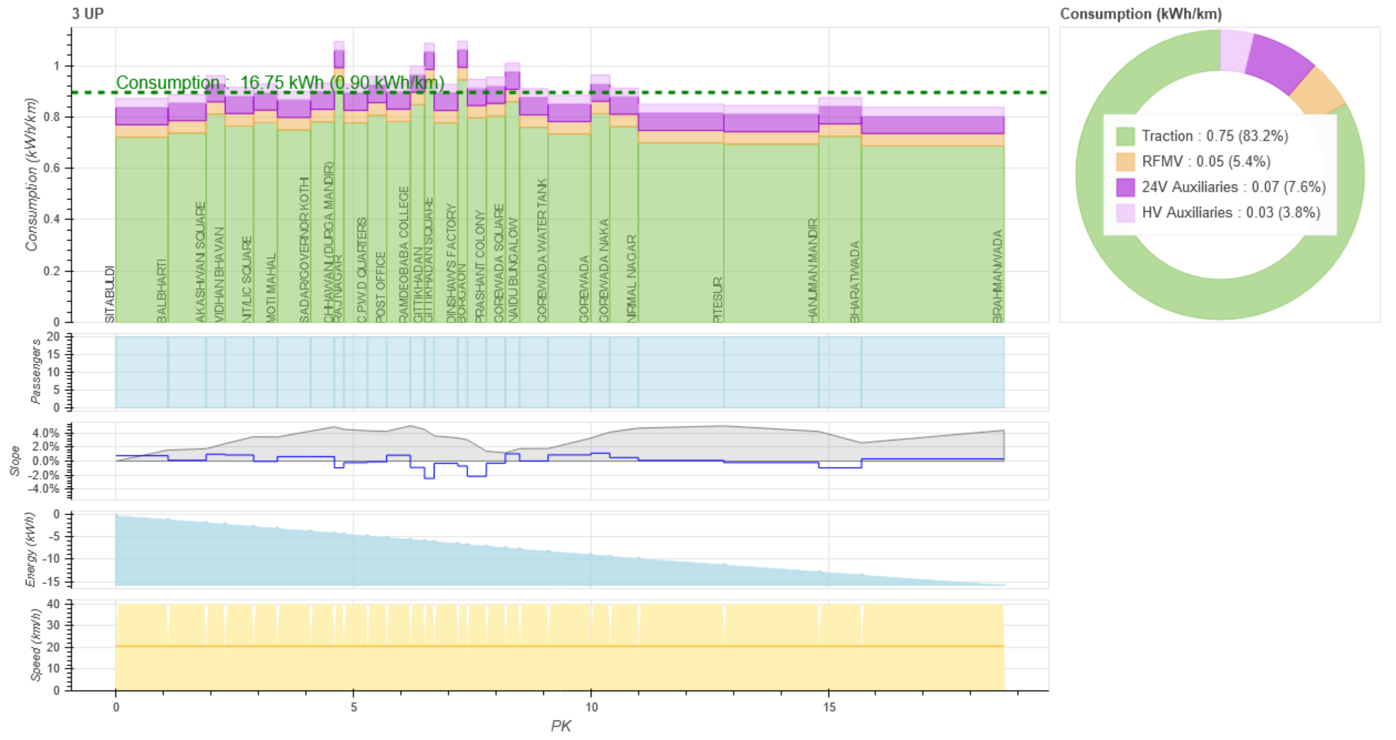
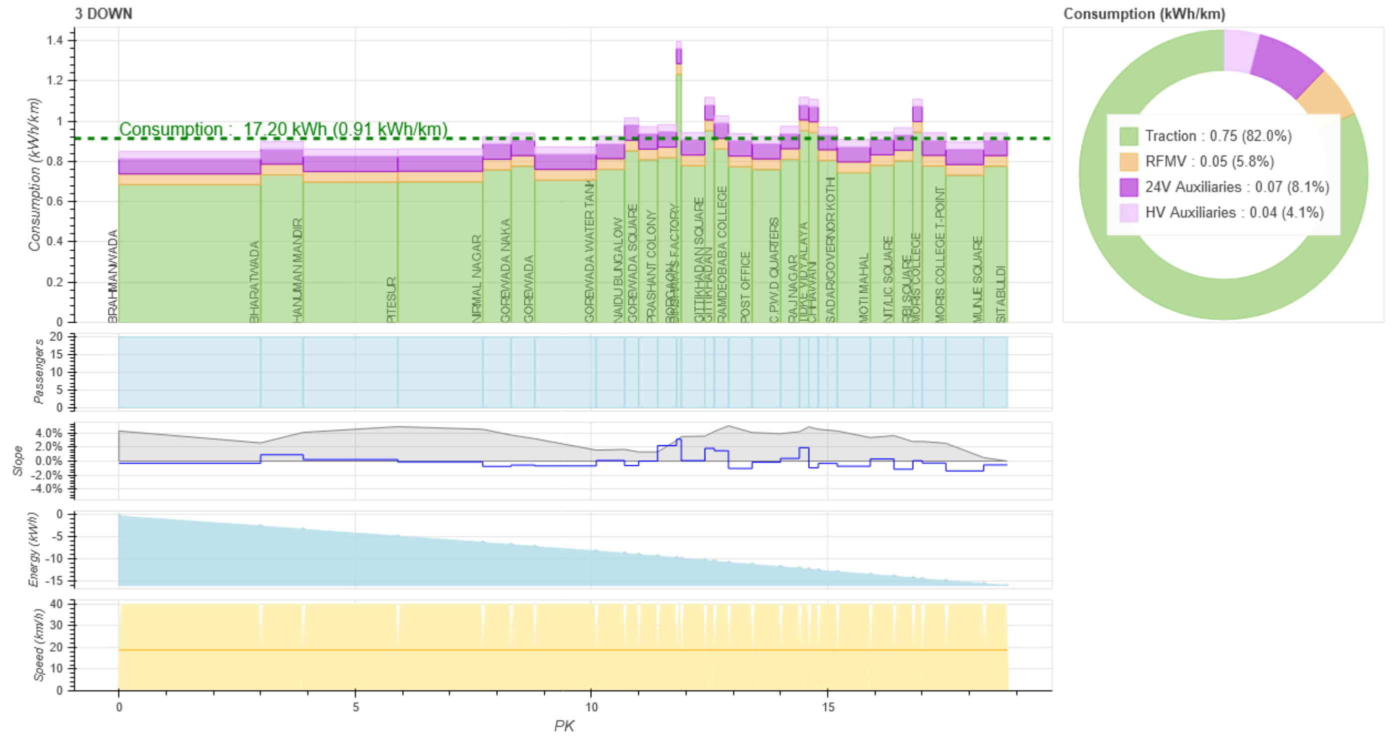
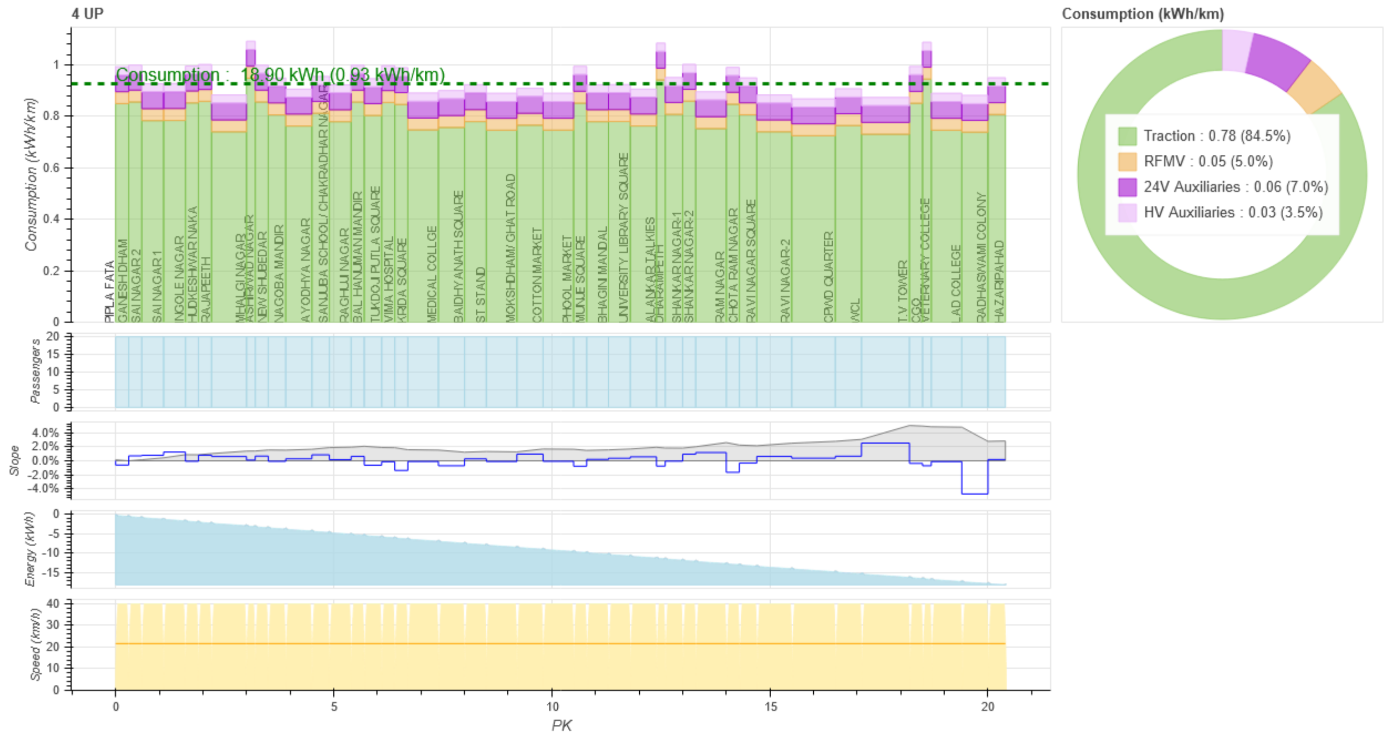
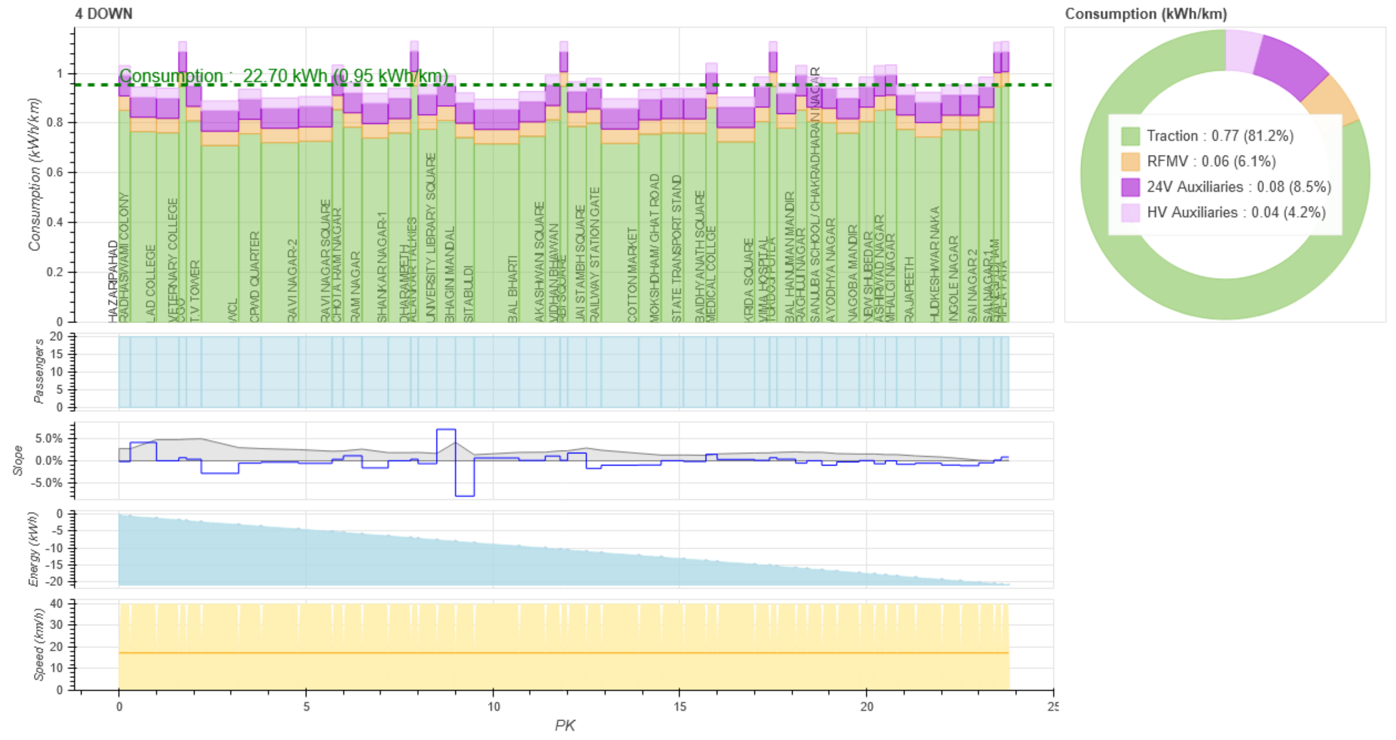
E-buses consumption simulations results

Route	Direction	Total Consumption (kWh/km)	Traction Consumption (kWh/km)	Distance (m)
3	UP	0.895803545	0.745450811	18,700
3	DOWN	0.914712755	0.749819138	18,800
4	UP	0.926512320	0.782993801	20,400
4	DOWN	0.953673778	0.774275630	23,800
7	UP	0.961764309	0.779839426	14,300
7	DOWN	0.975823782	0.778622765	13,600
13	UP	0.841803995	0.739638270	17,000
13	DOWN	0.871491239	0.743038201	17,700
20	UP	0.898398865	0.758000314	18,400
20	DOWN	0.896006879	0.765388901	17,700
23	UP	0.992442269	0.777164492	10,100
23	DOWN	1.025233084	0.795603455	9,600
26	UP	0.847084372	0.743336045	24,200
26	DOWN	0.871680507	0.747182515	24,500
28	UP	0.958190433	0.788791526	11,900
28	DOWN	1.014934971	0.796008418	11,300
32	UP	1.005969535	0.790691757	15,000
32	DOWN	0.955810958	0.794352624	14,400
35	UP	0.971410650	0.764743983	23,600
35	DOWN	0.948721142	0.764197333	23,500
38	UP	0.893131151	0.751301085	25,800
38	DOWN	0.897752913	0.756476872	25,100
40	UP	0.928723719	0.762057052	15,500
40	DOWN	0.932124611	0.768622501	15,800
42	UP	0.865335704	0.726233140	26,000
42	DOWN	0.815102758	0.728671531	26,900
47	UP	0.907209344	0.756357762	14,600
47	DOWN	0.927295517	0.755073295	13,800
48	UP	1.014347810	0.789710129	9,100
48	DOWN	1.055704170	0.800560137	8,800
49	UP	0.985963281	0.777209072	9,600
49	DOWN	1.033727827	0.796179935	8,700
52	UP	0.967867813	0.793055783	13,700
52	DOWN	1.007888859	0.800299573	11,800
54	UP	0.861391484	0.735375224	24,900
54	DOWN	0.861617668	0.735087056	24,400
68	UP	0.866578522	0.752775291	25,500
68	DOWN	0.909932654	0.754041850	22,500
79A	UP	0.937264122	0.786778685	21,500

Route	Direction	Total Consumption (kWh/km)	Traction Consumption (kWh/km)	Distance (m)
79A	DOWN	0.990160137	0.787779185	22,700
86	UP	0.911155789	0.747653679	16,100
86	DOWN	0.892420935	0.754028078	16,600
106	UP	0.958144570	0.779298416	13,400
106	DOWN	0.997545074	0.784242322	11,500
107	UP	0.855405136	0.740224669	33,600
107	DOWN	0.841646478	0.739940441	33,100
108	UP	0.863375628	0.744510597	34,600
108	DOWN	0.839187897	0.746094804	34,100
111	UP	0.926173435	0.767010718	21,100
111	DOWN	0.948084168	0.772255197	21,400
134	UP	0.926982221	0.773212380	17,300
134	DOWN	0.937608893	0.778143872	16,700
135	UP	0.909515850	0.761896802	18,300
135	DOWN	0.940911536	0.813862356	18,700
155	UP	0.855204405	0.739877024	34,500
155	DOWN	0.855340743	0.740013362	33,900
174	UP	1.000706805	0.788958171	11,900
174	DOWN	1.005749455	0.794000821	12,800
188	UP	0.960311781	0.782150862	11,600
188	DOWN	0.997603723	0.800778327	10,500
210	UP	0.923966895	0.778654395	18,000
210	DOWN	0.941438923	0.779980590	16,400
222	UP	0.859125468	0.738322111	27,700
222	DOWN	0.852210930	0.740700139	27,200
228	UP	0.966066707	0.784426082	25,600
228	DOWN	0.992602762	0.793137590	21,400
231	UP	0.870304278	0.741137611	22,000
231	DOWN	0.883536141	0.744522688	22,300
232	UP	0.883360322	0.744138765	16,700
239	UP	0.867620827	0.707276000	14,500
239	DOWN	0.856945950	0.702972440	15,100
244	UP	0.929070727	0.749360582	25,000
244	DOWN	0.886785397	0.752834780	24,300
245	UP	0.863474774	0.713913371	22,700
245	DOWN	0.864971899	0.714619165	22,600
246	UP	0.956370820	0.760393809	14,500
246	DOWN	0.922663573	0.760076161	14,300
249	UP	0.980416660	0.787630591	13,400
249	DOWN	1.001373046	0.796346591	12,600

Route	Direction	Total Consumption (kWh/km)	Traction Consumption (kWh/km)	Distance (m)
250	UP	0.950315546	0.788857212	12,800
250	DOWN	1.021882671	0.799181521	11,900
253	UP	0.899236442	0.756510843	16,900
253	DOWN	0.876625927	0.751221396	19,300
263	UP	0.947123130	0.788636422	16,300
263	DOWN	0.965591335	0.784938655	14,300
277	UP	0.900027701	0.774775176	16,500
277	DOWN	0.974963198	0.782416614	16,100

E-buses consumption simulations results (graphs)

Route	Direction "UP"	Direction "DOWN"
3		
4		

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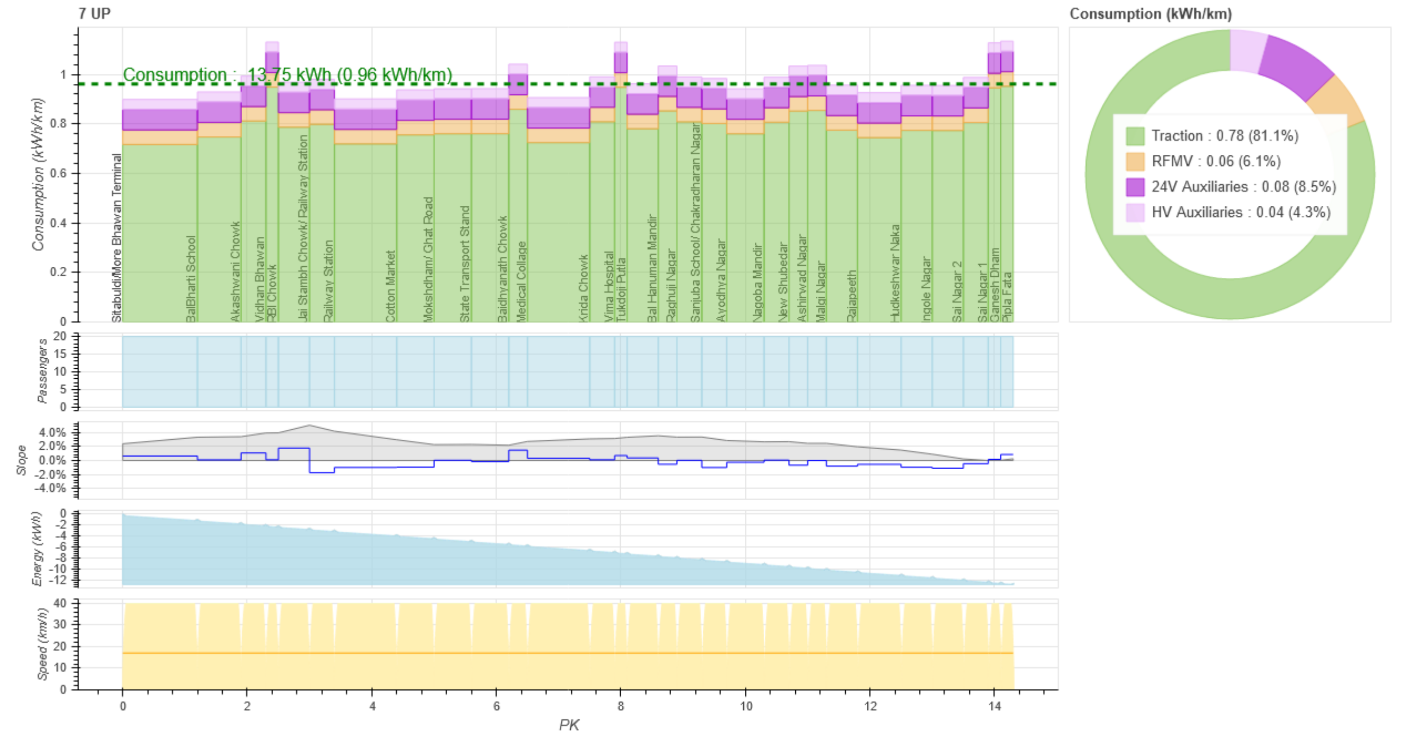
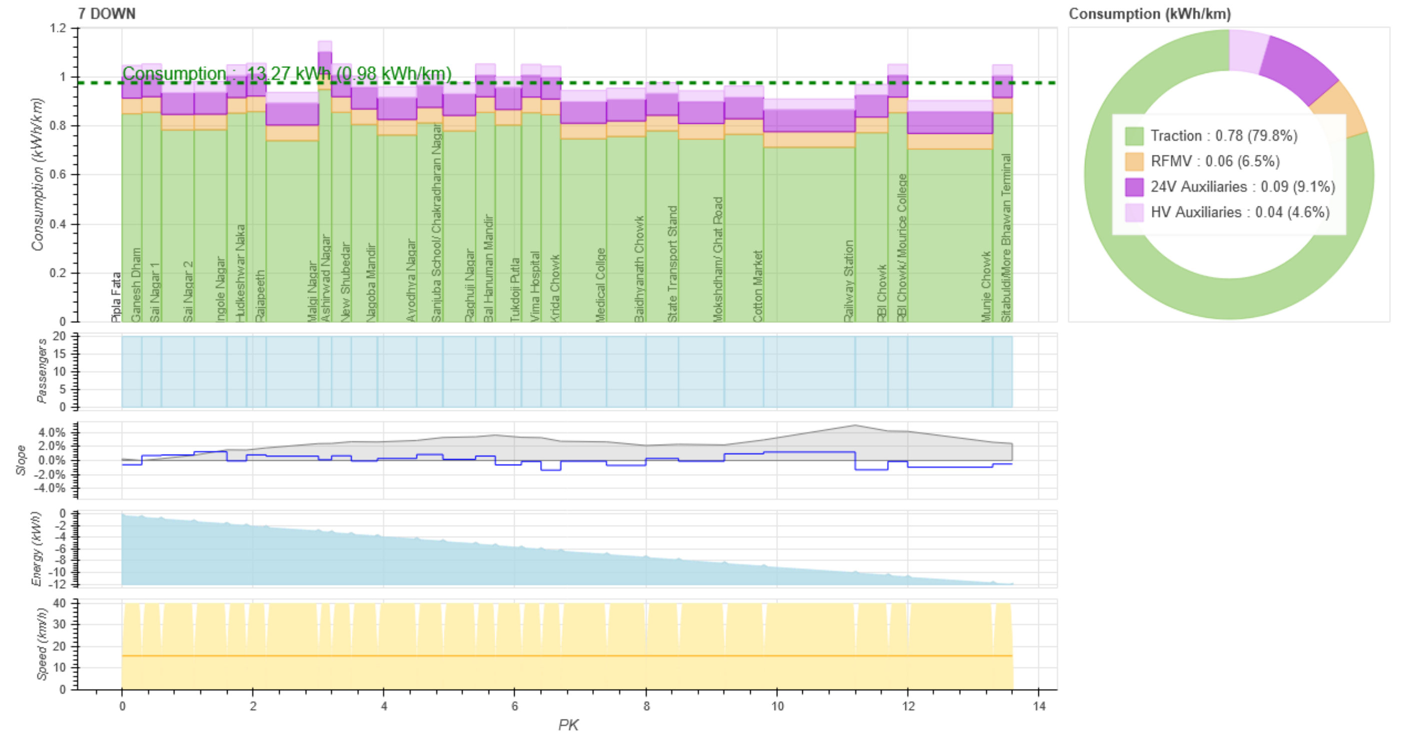
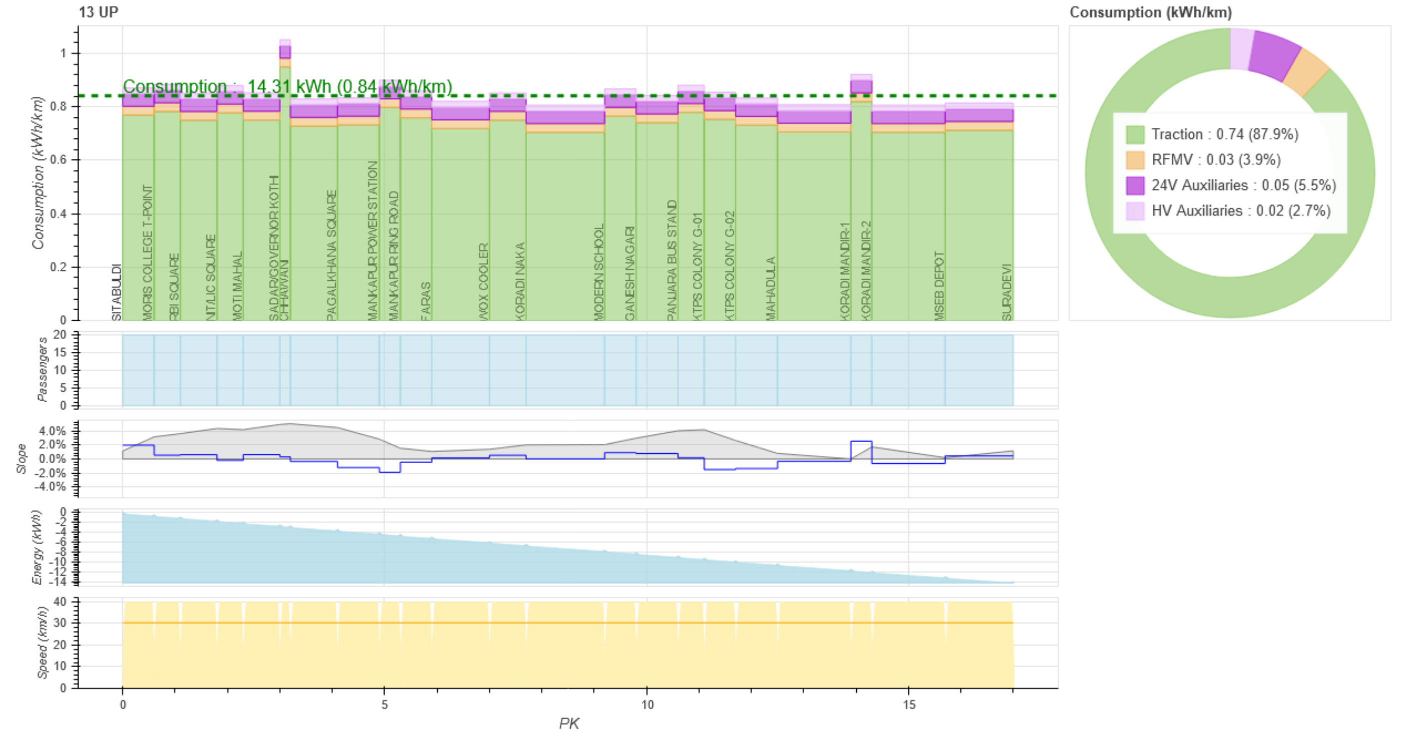
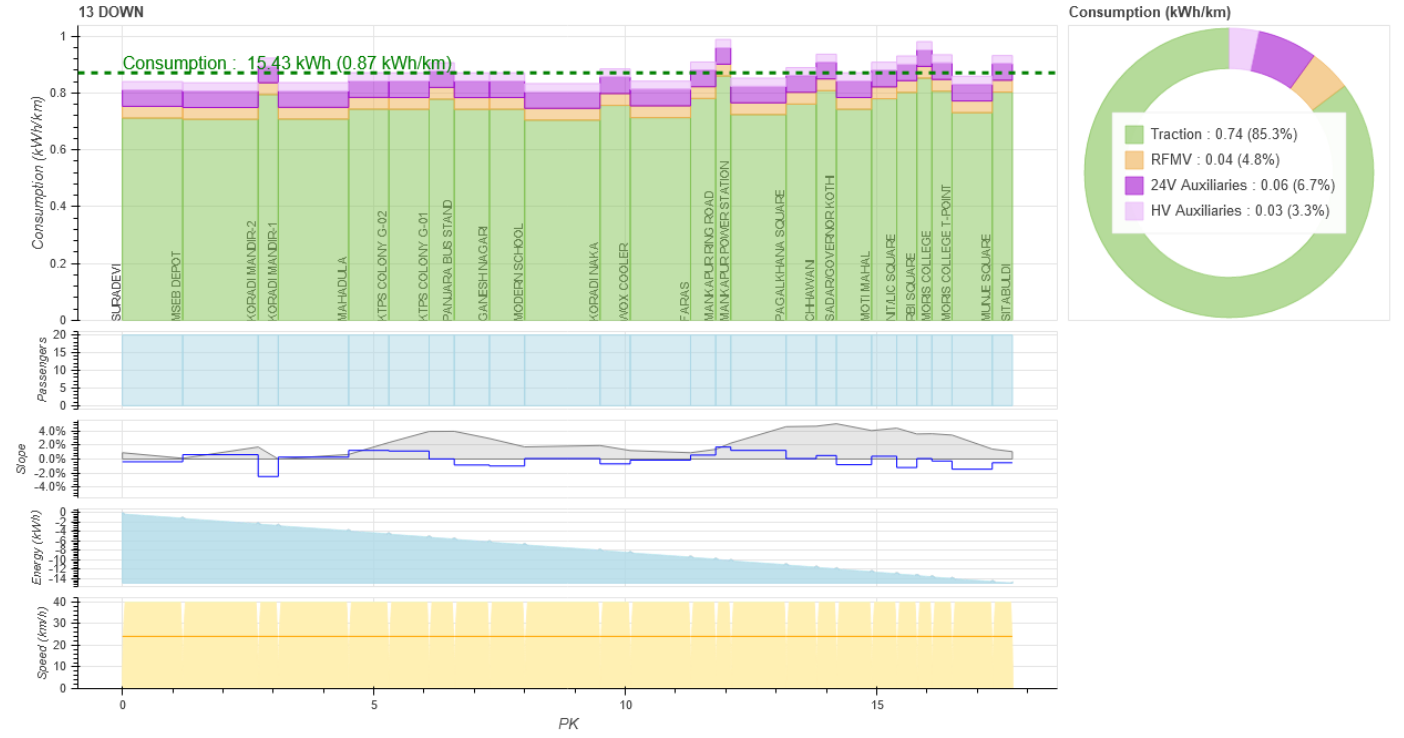
7		
13		

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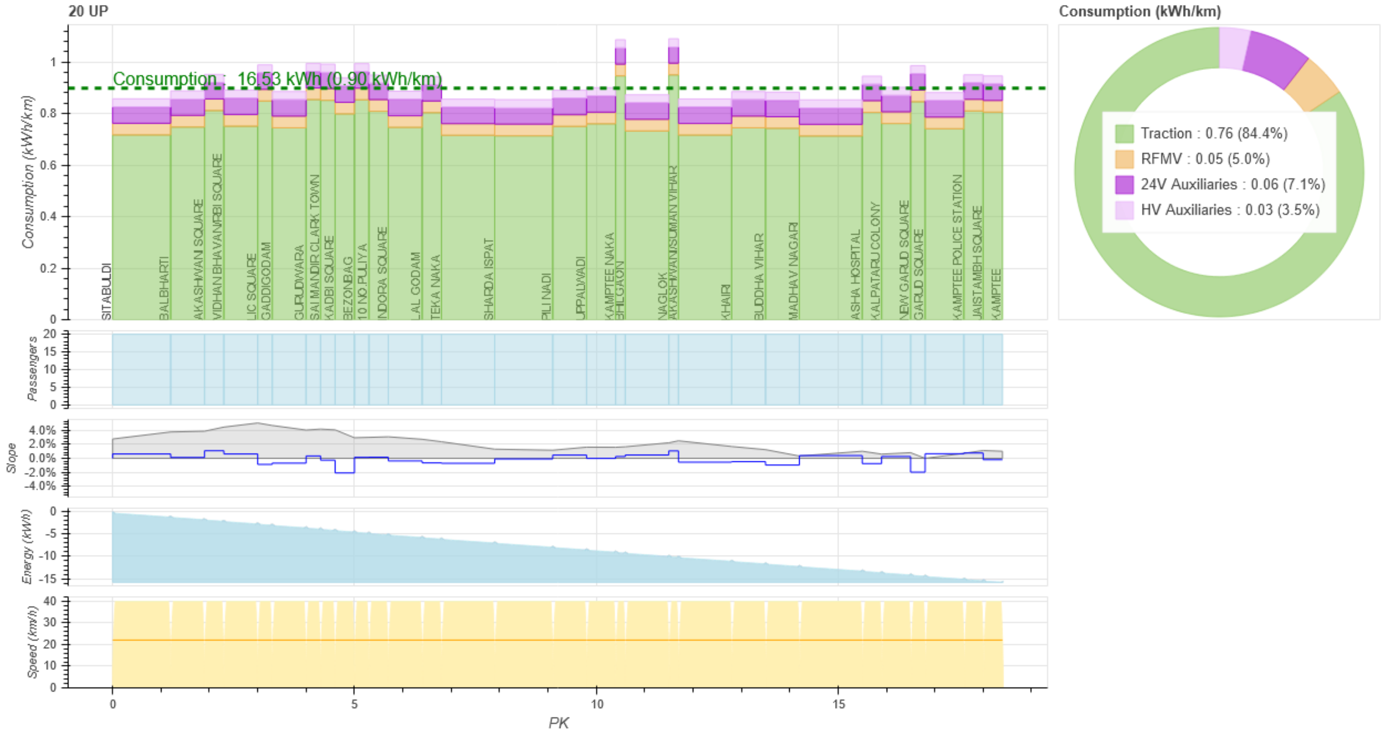
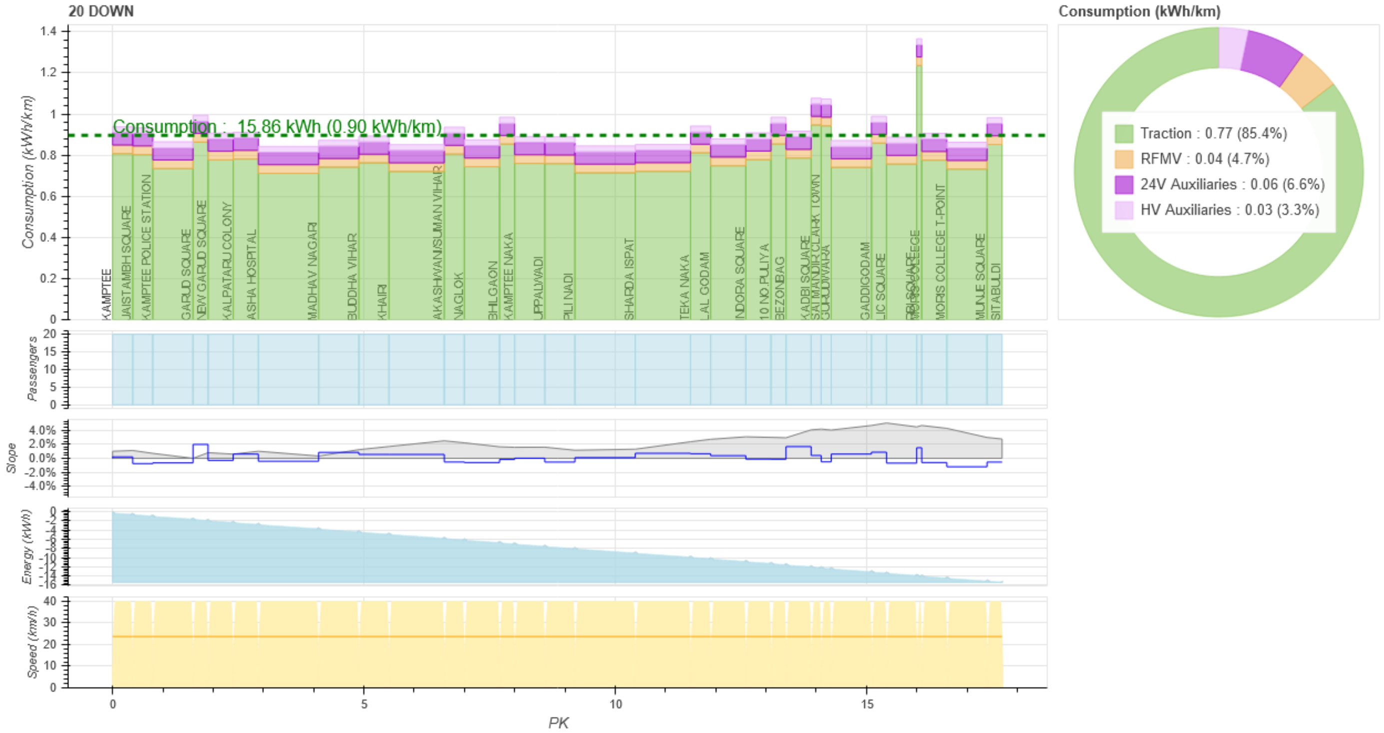
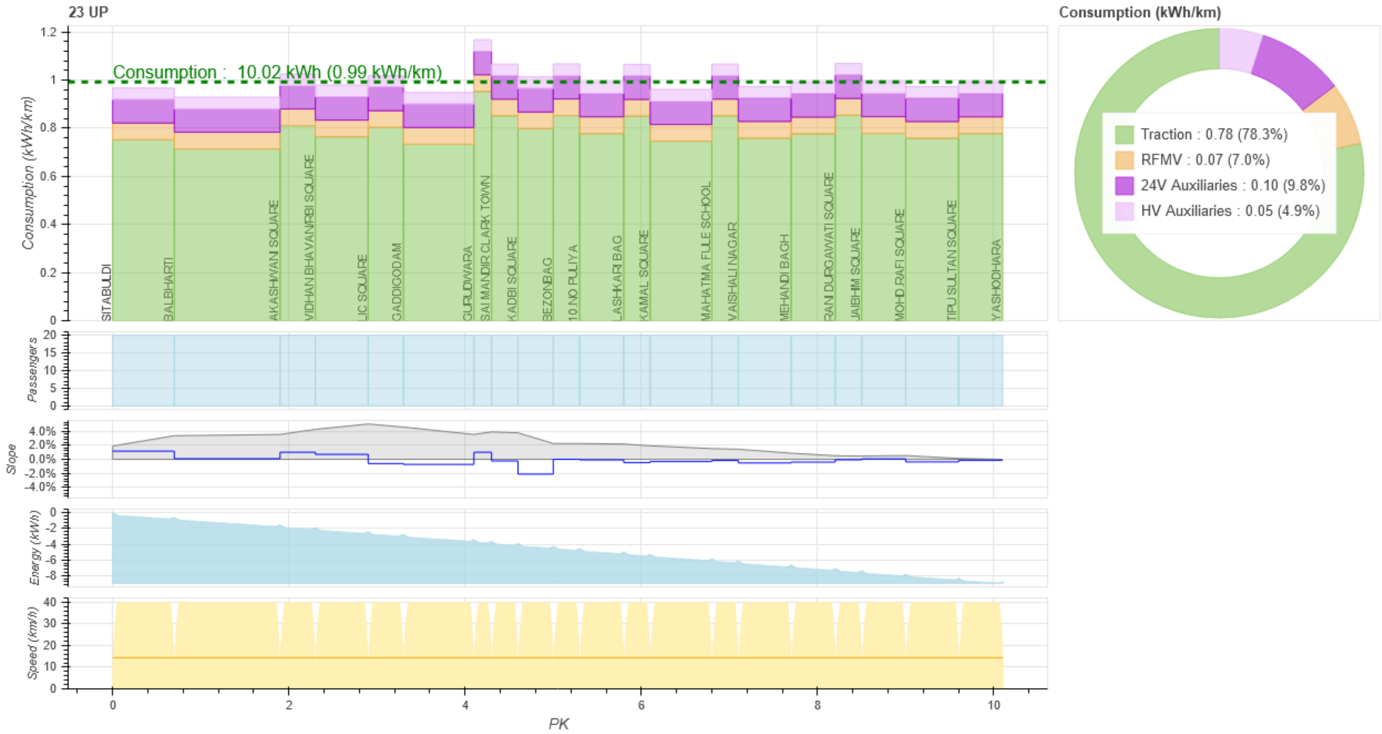
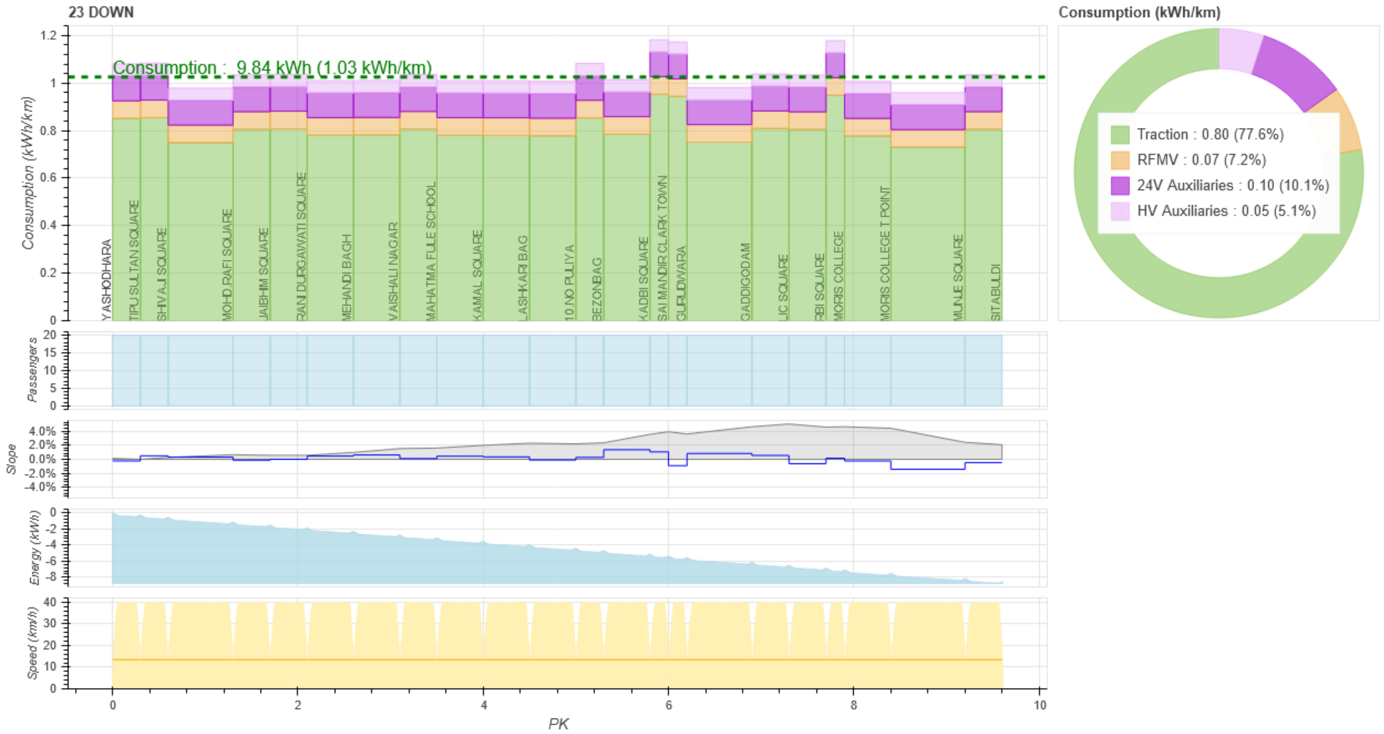
20		
23		

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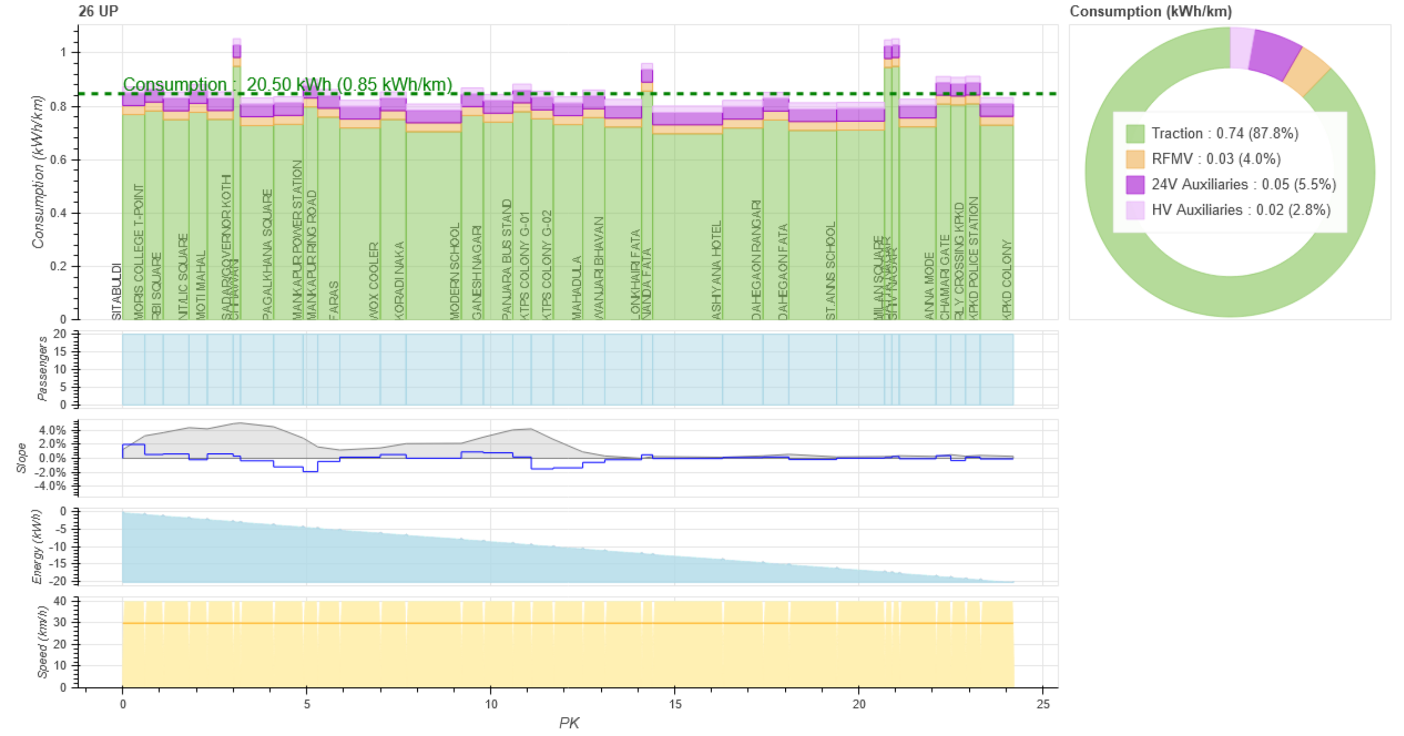
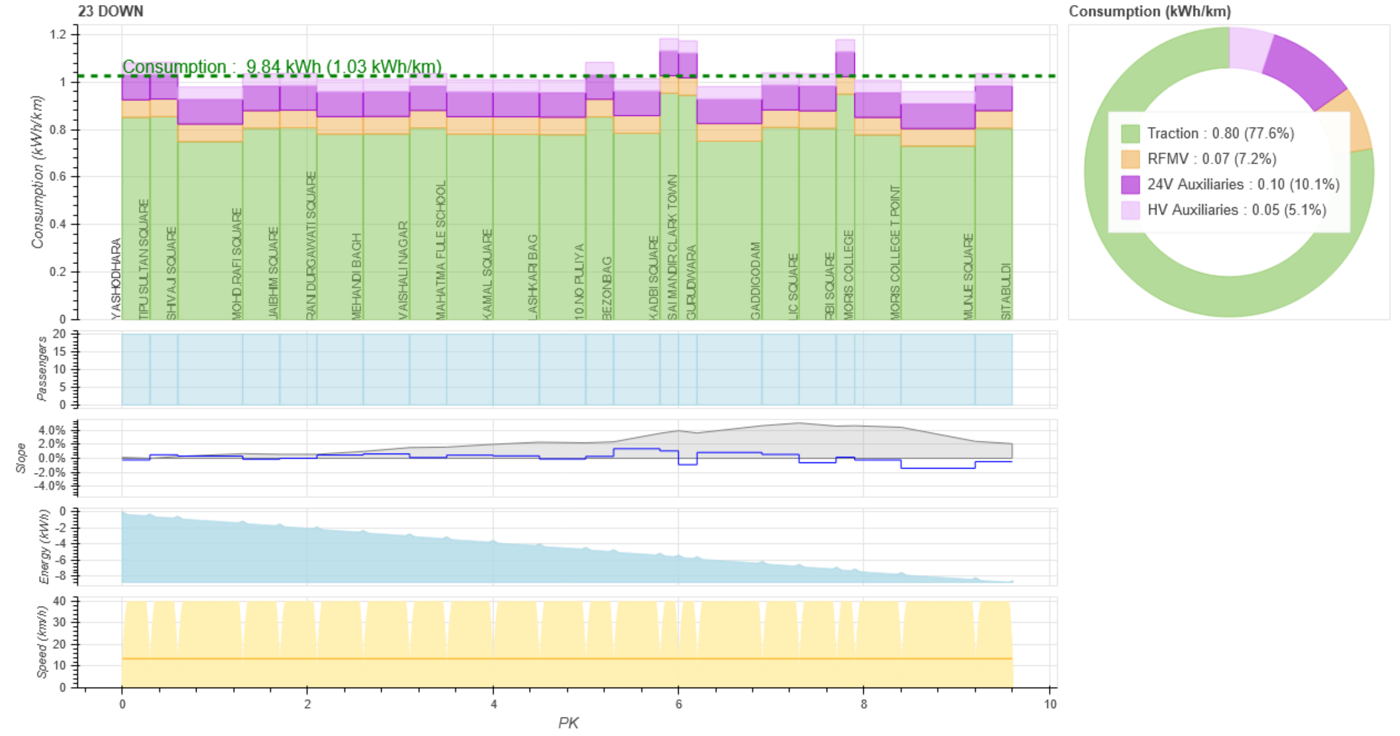
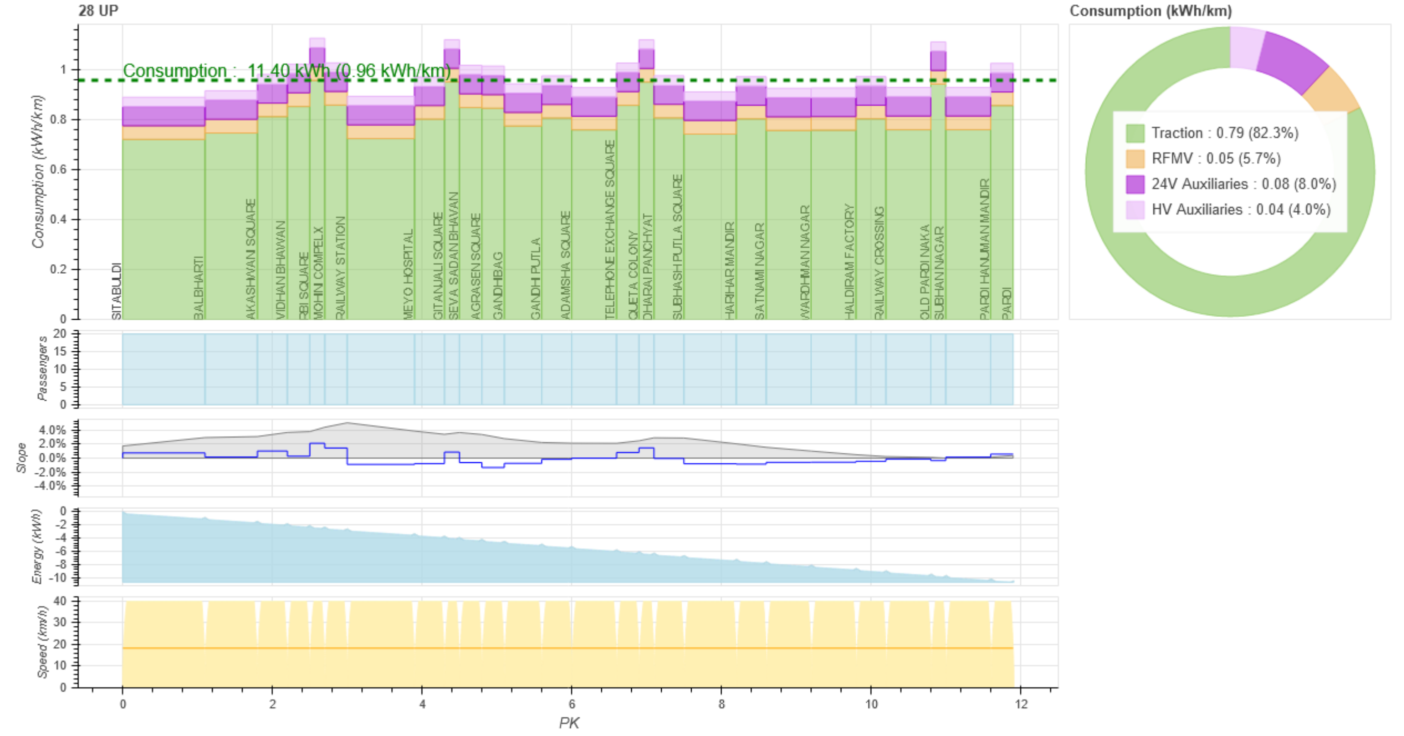
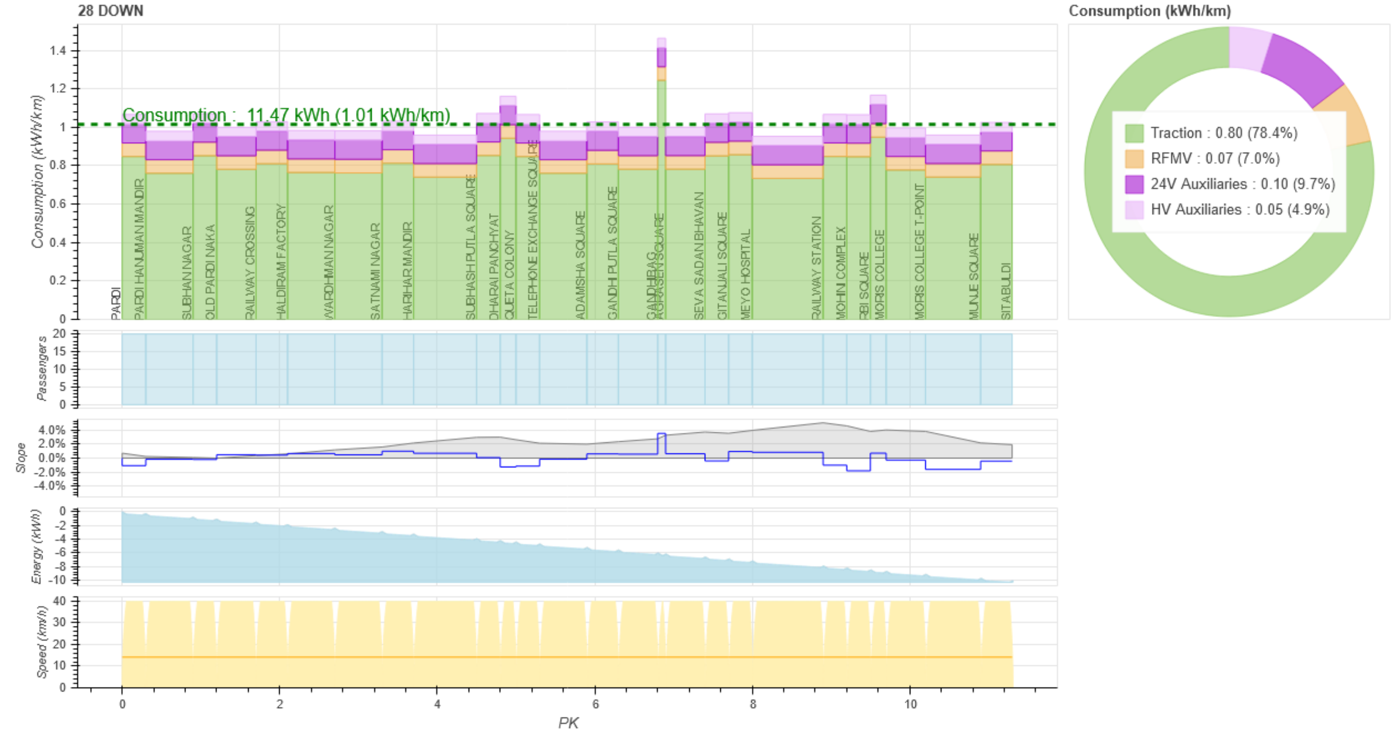
26		
28		

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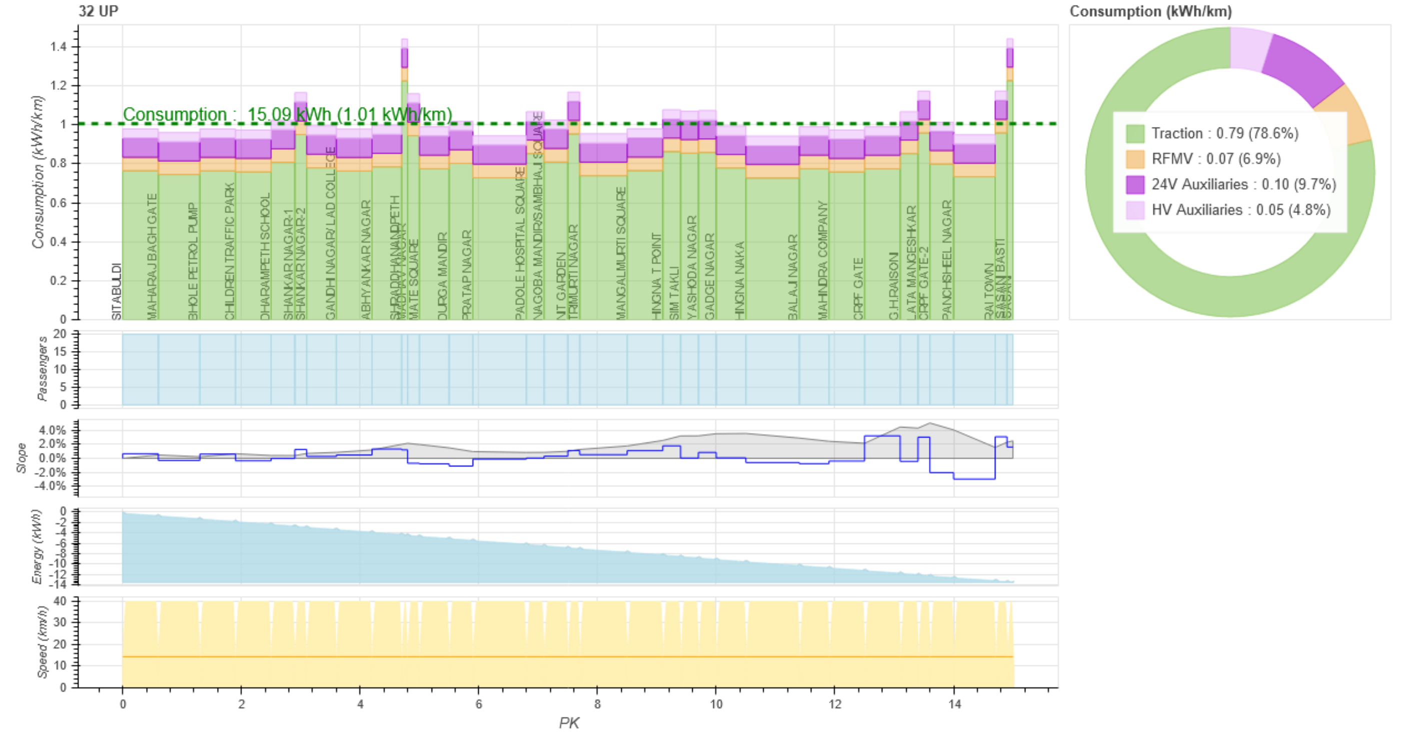
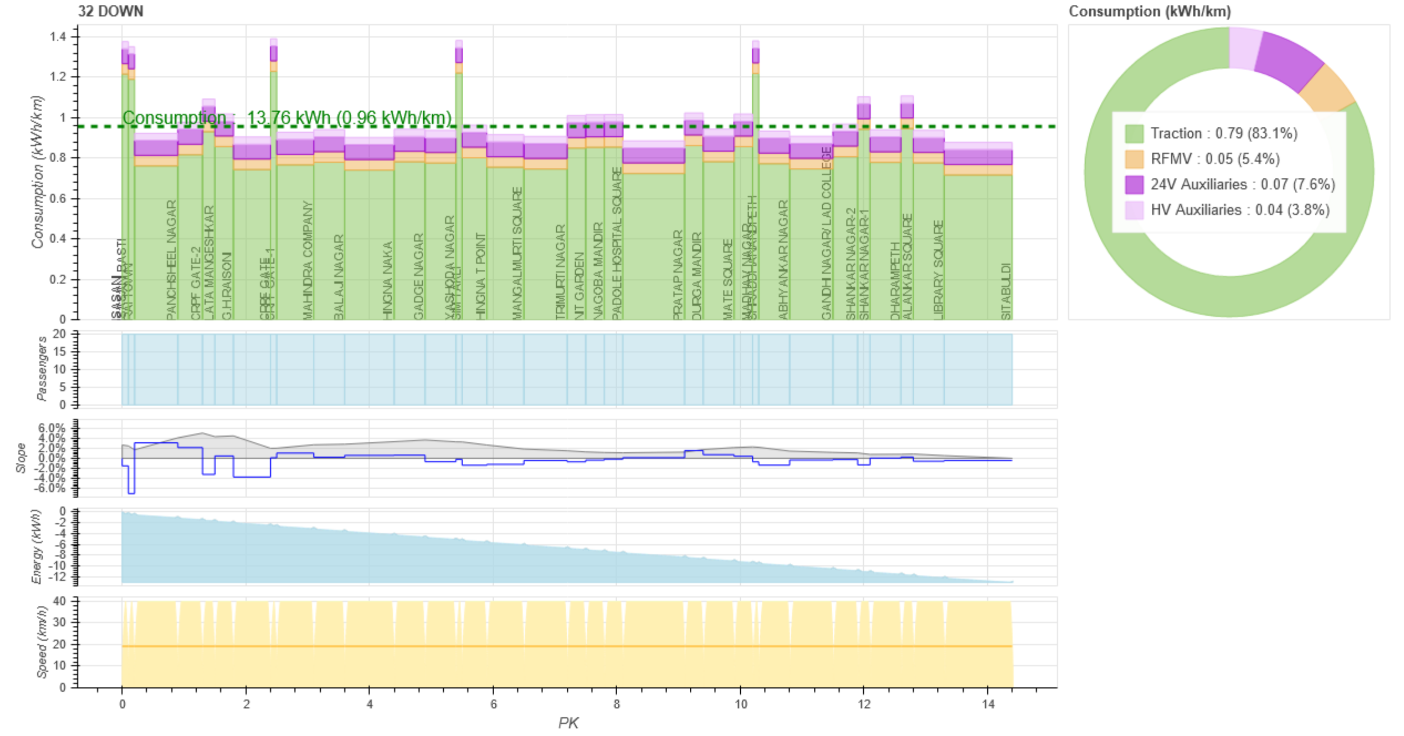
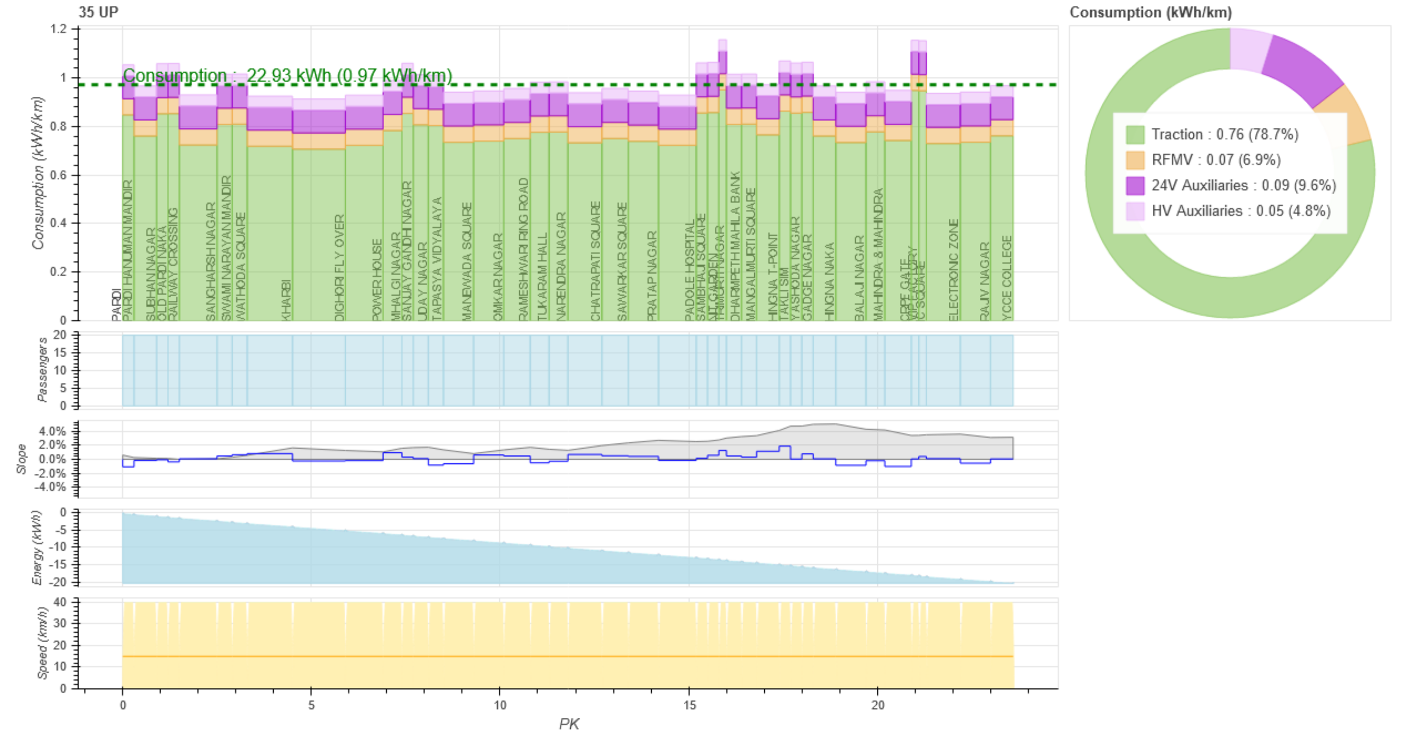
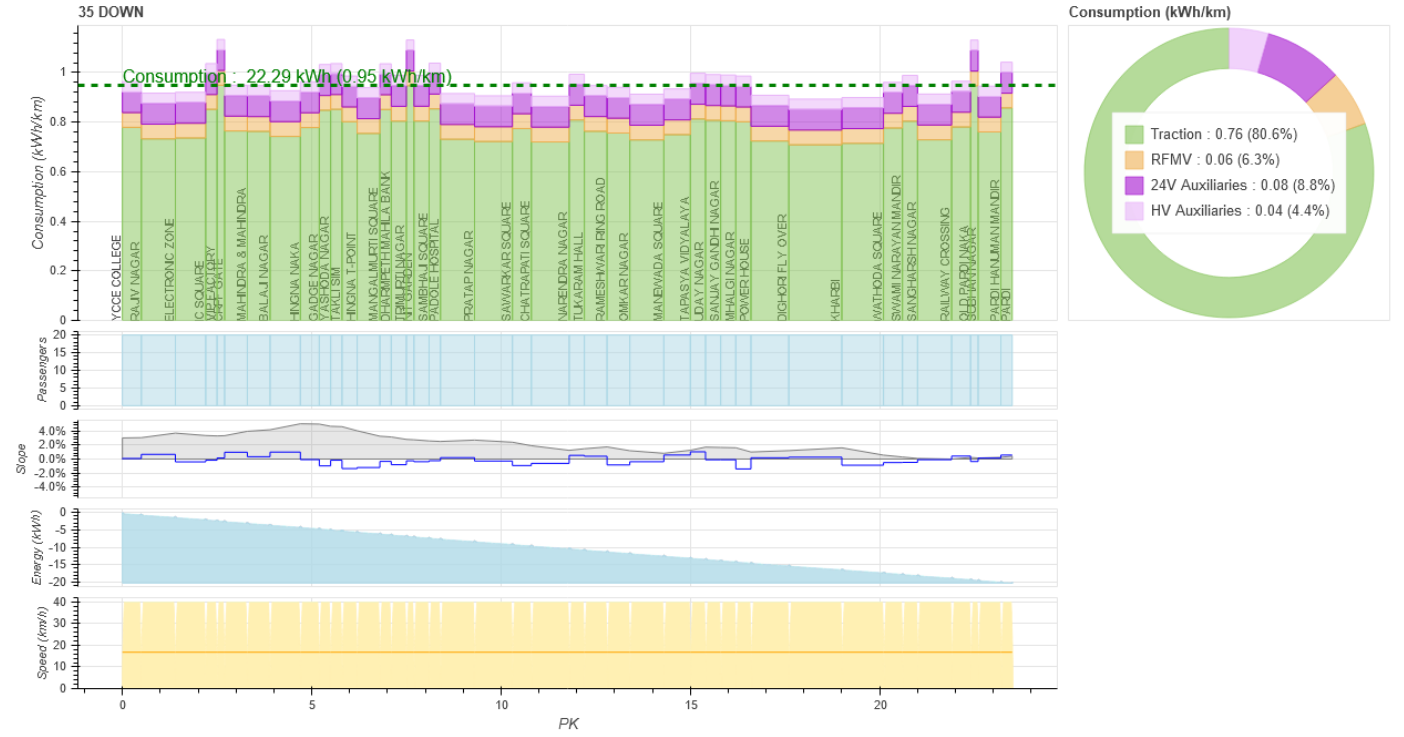
32		
35		

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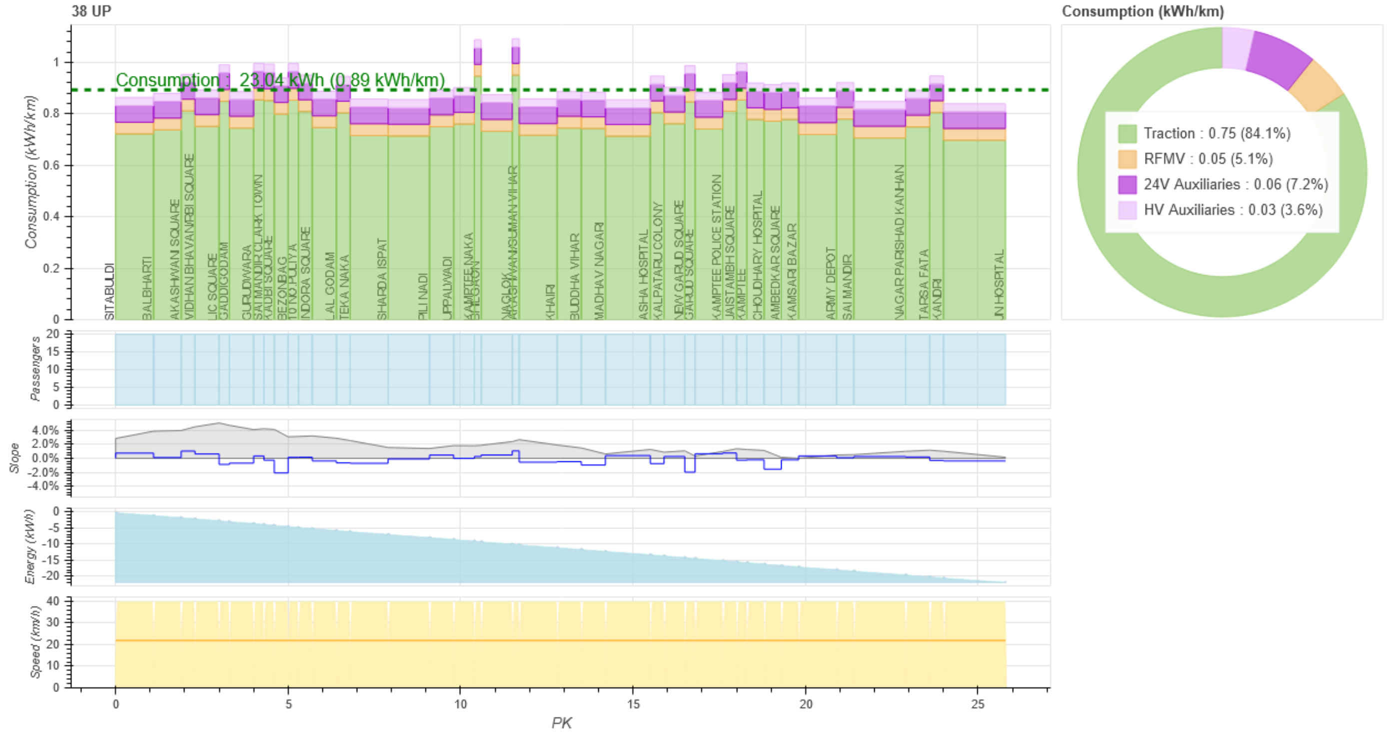
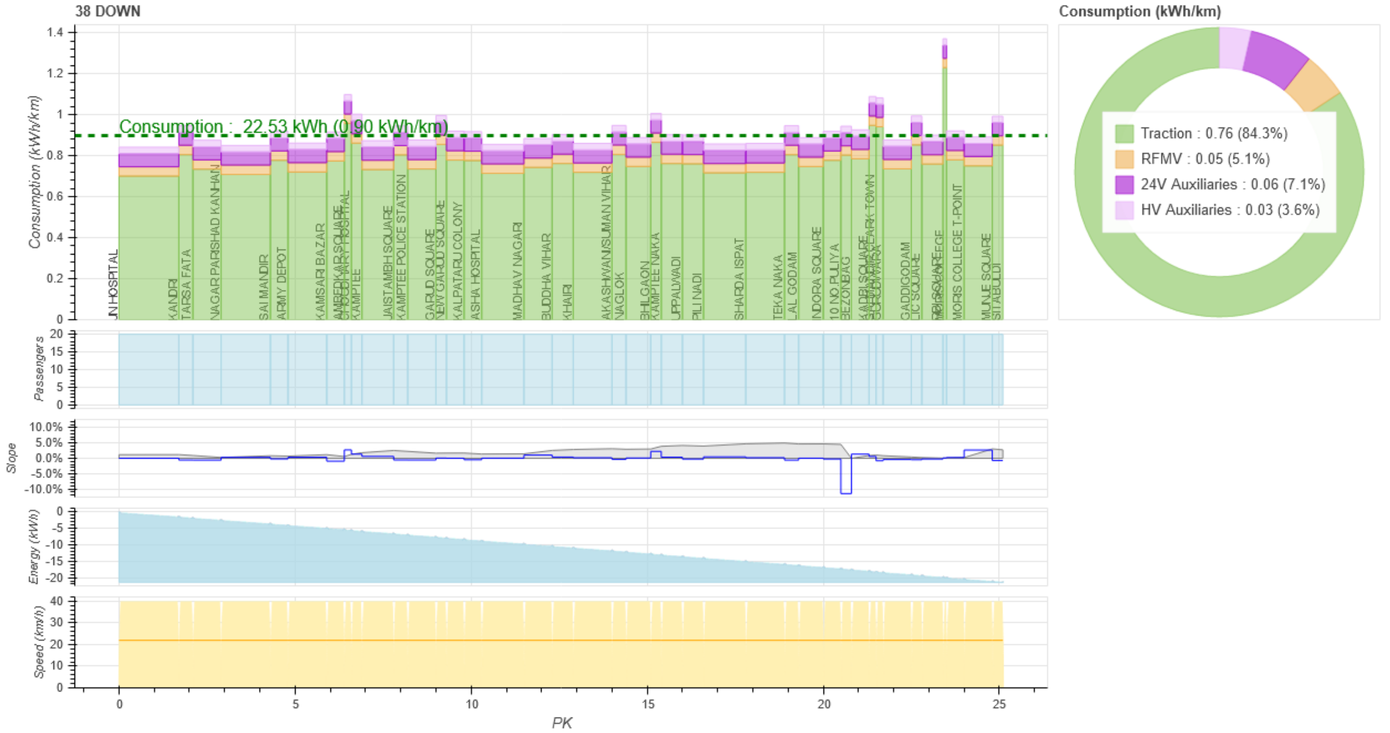
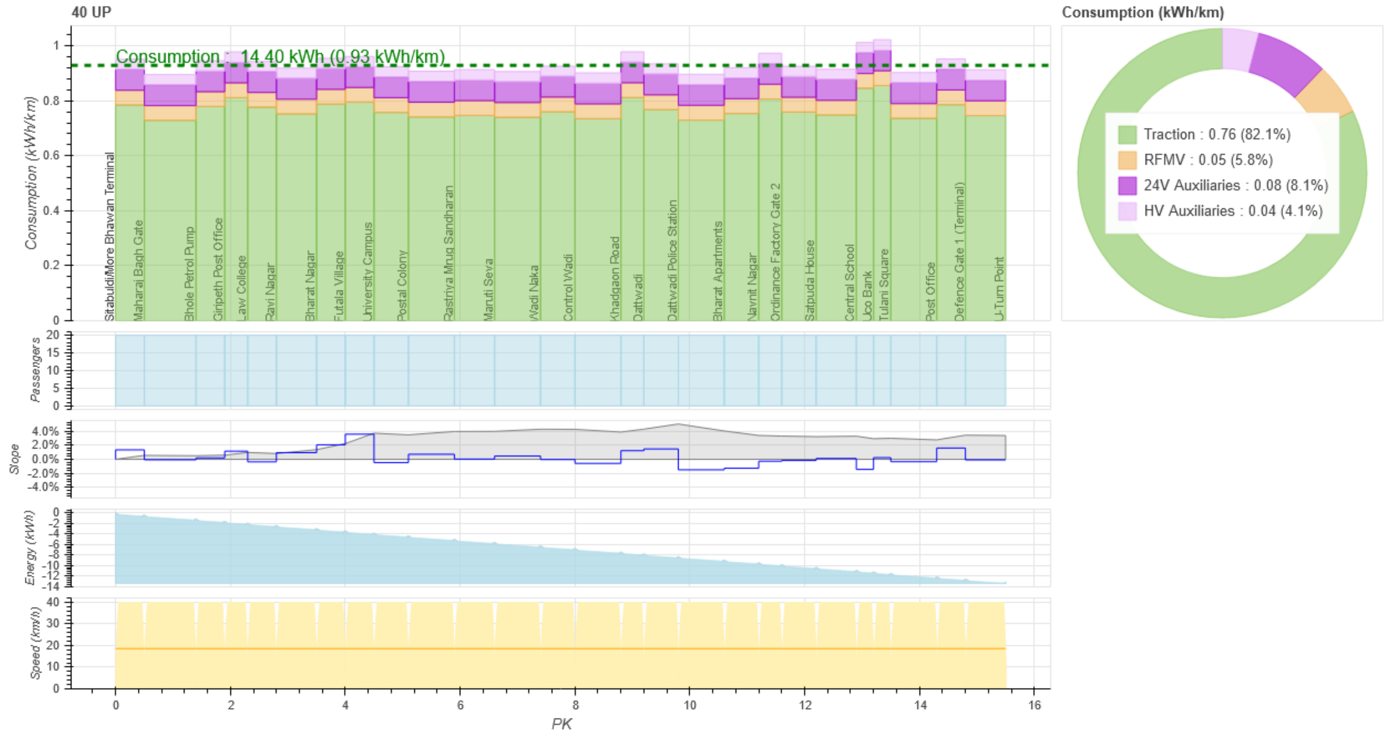
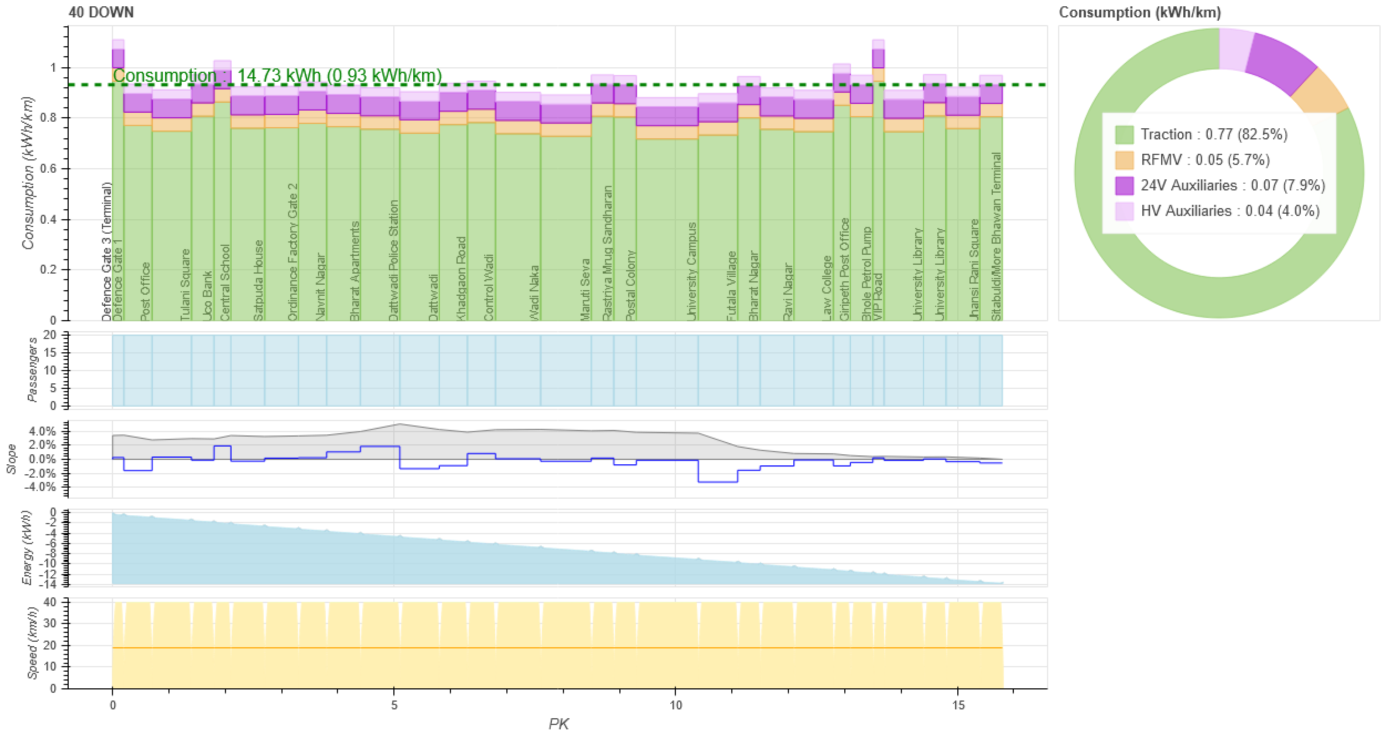
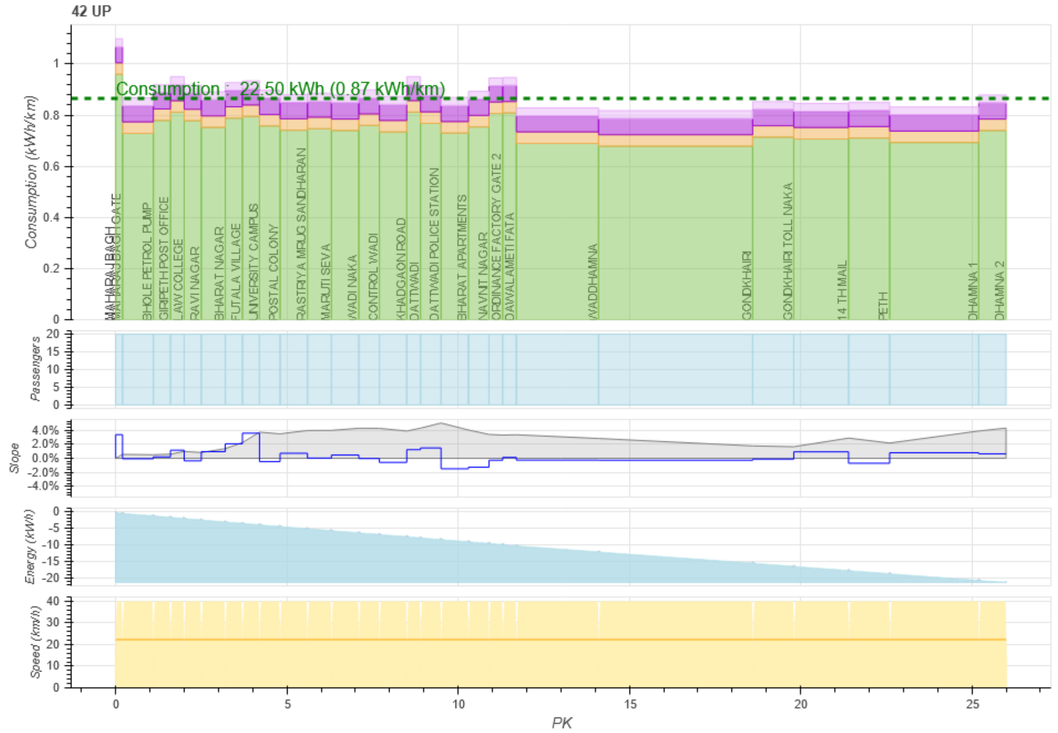
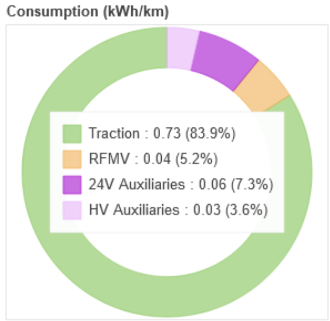
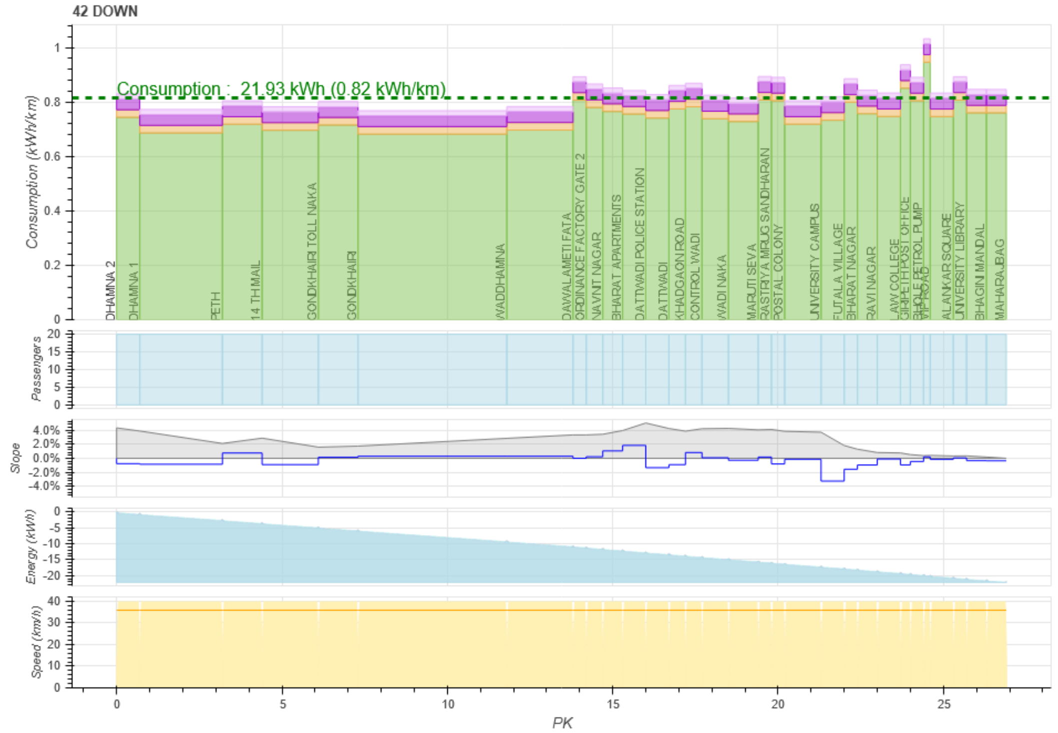
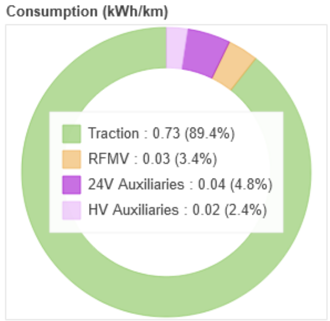
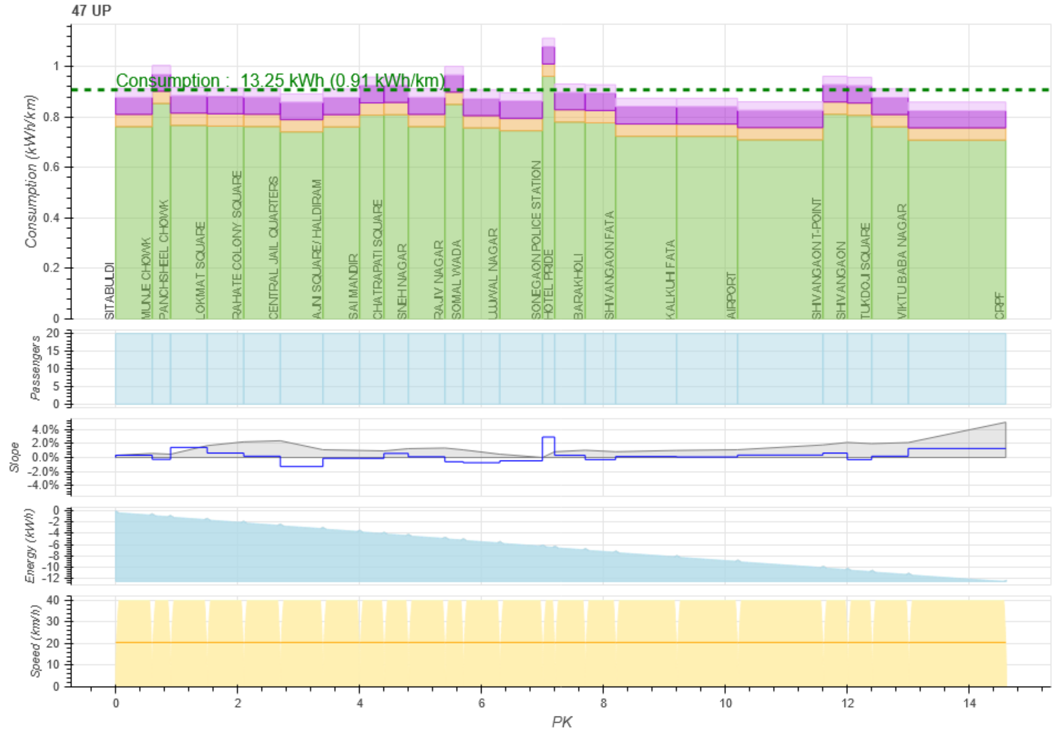
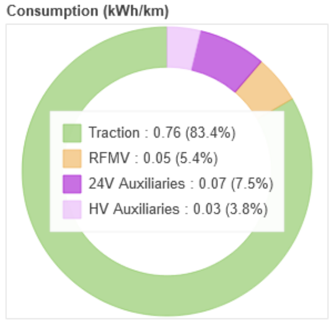
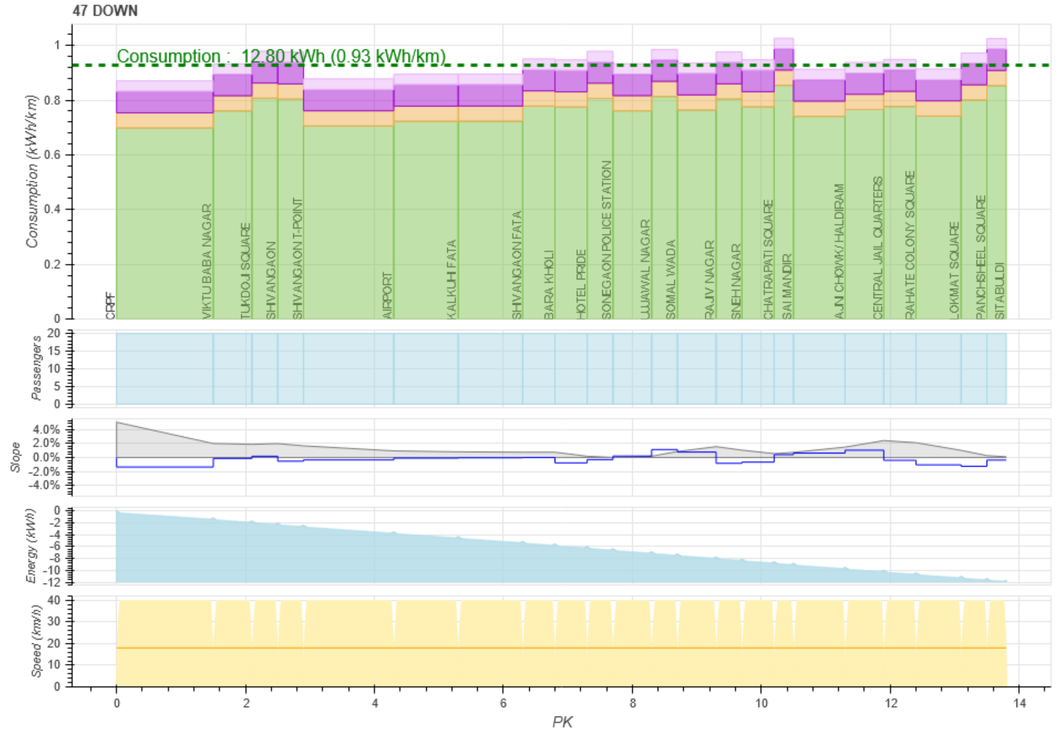
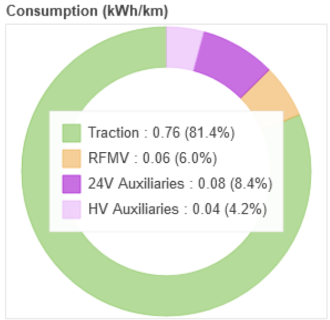
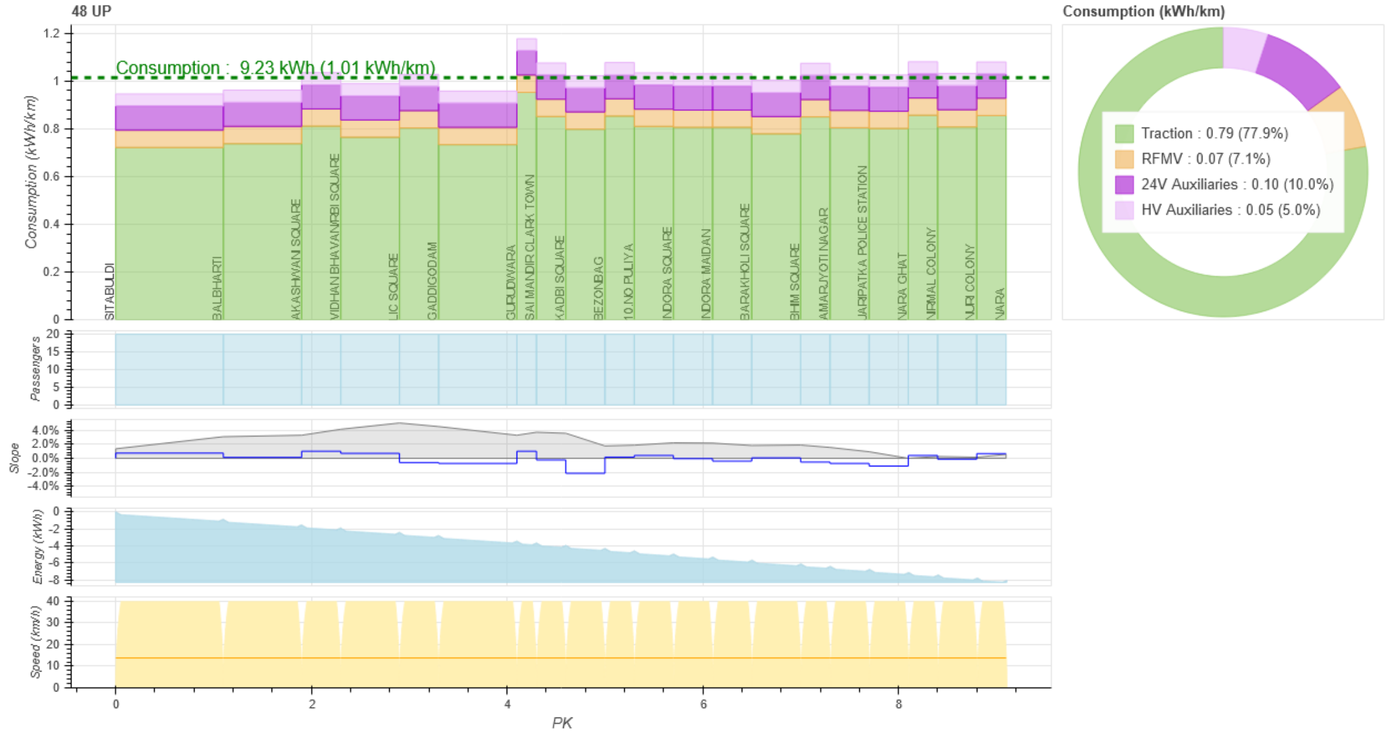
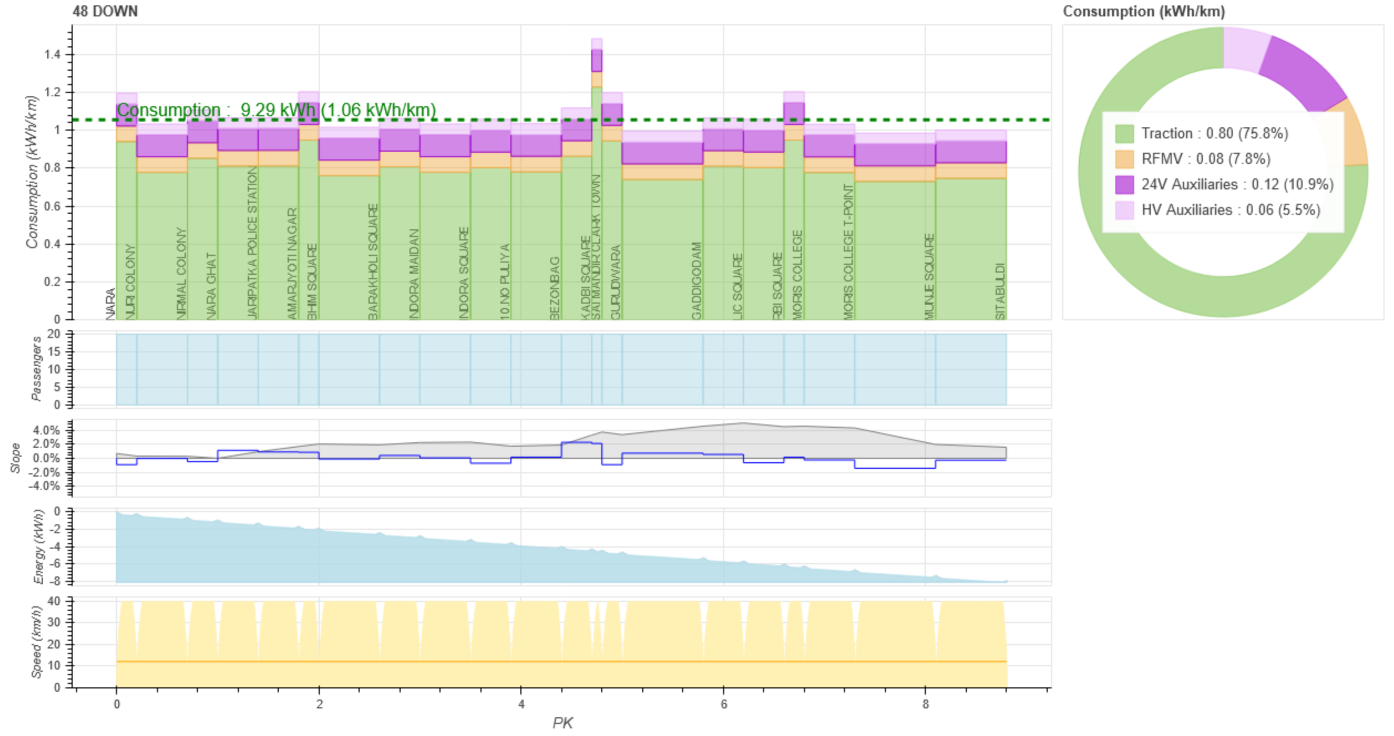
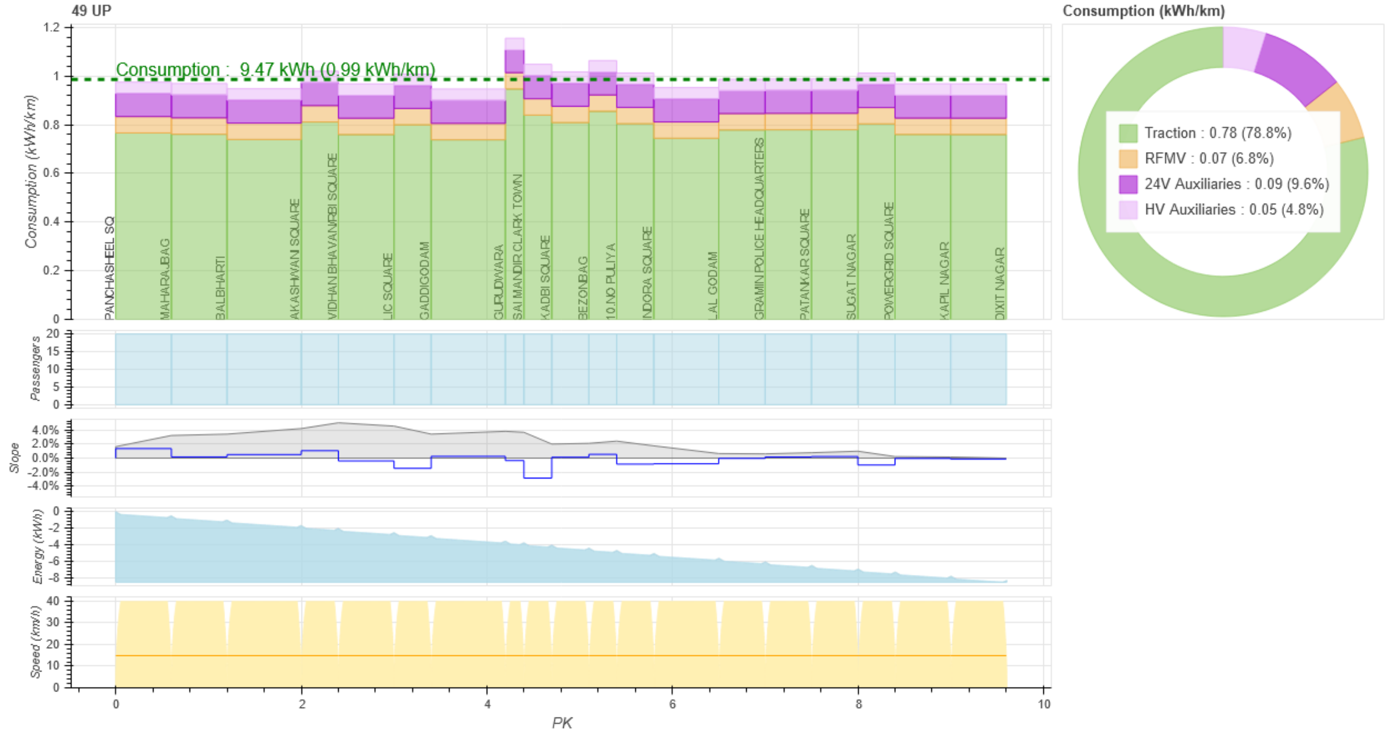
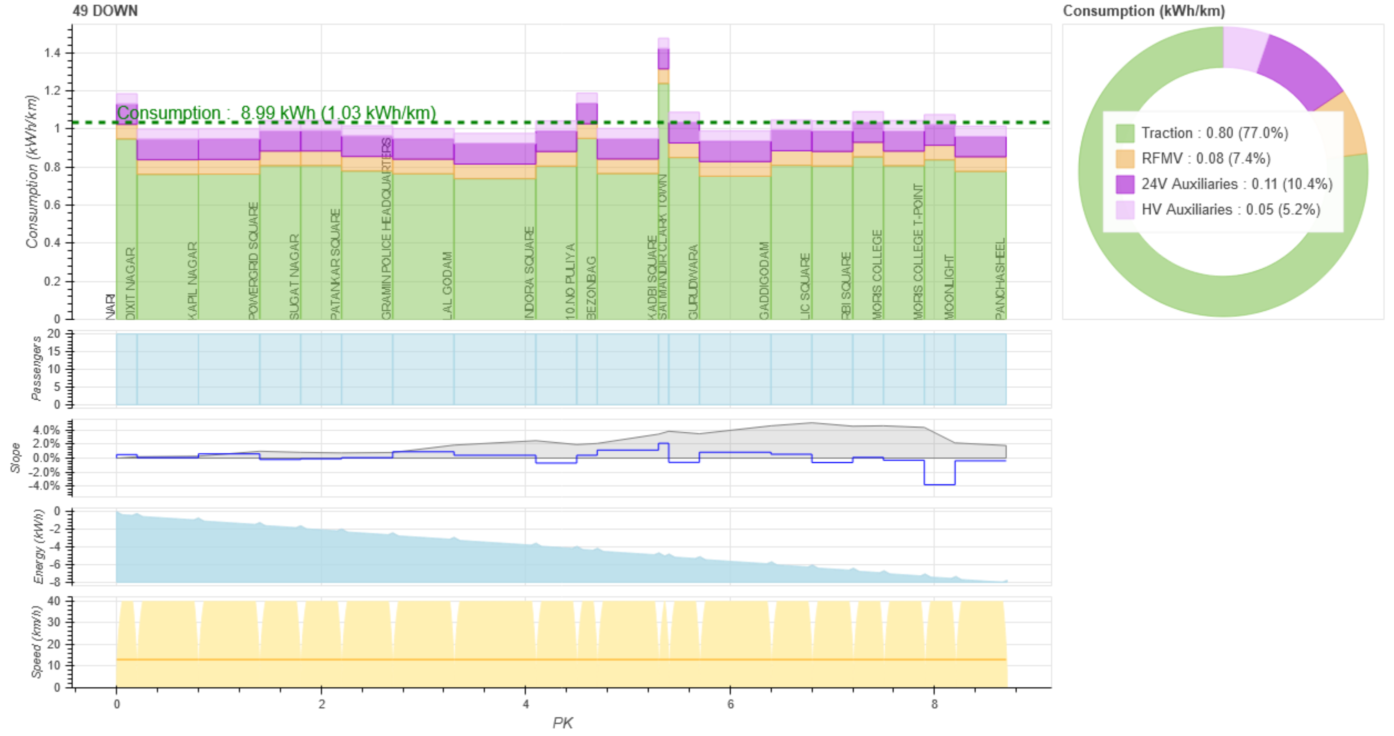
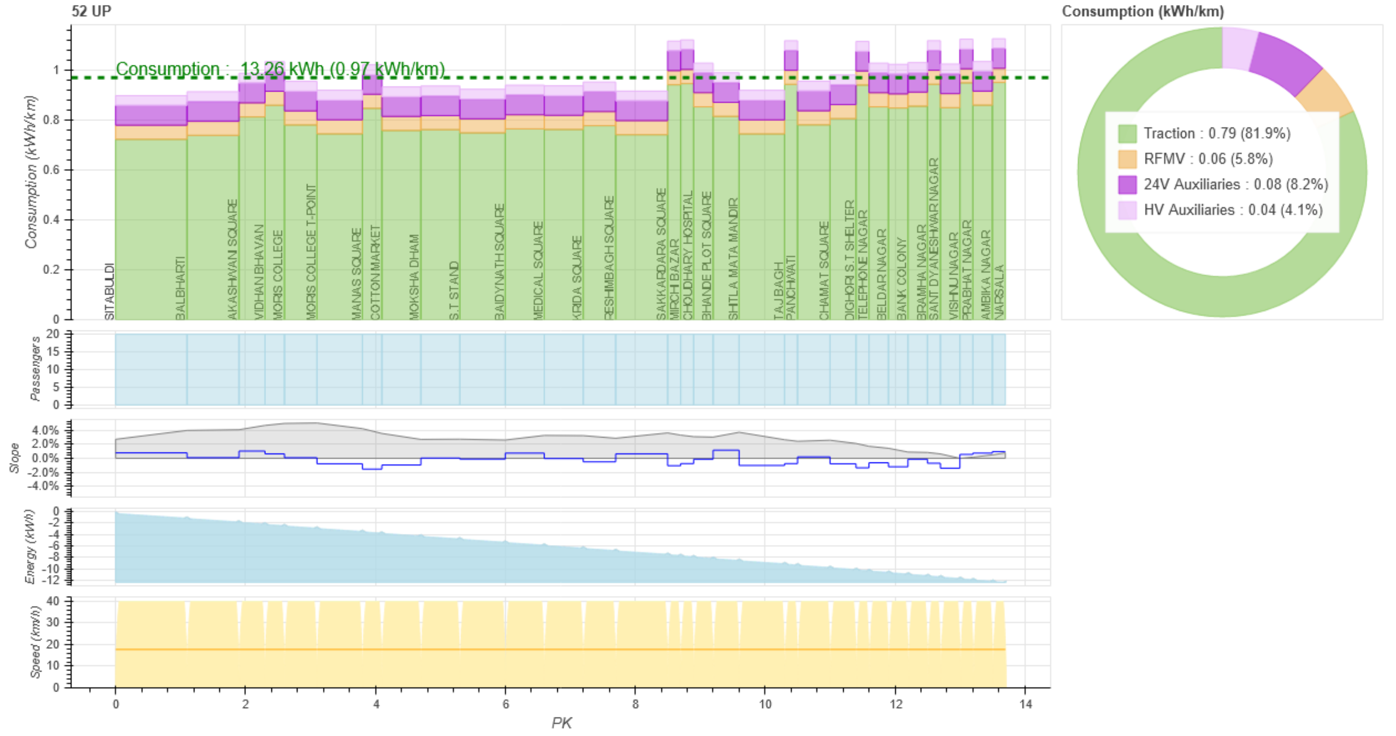
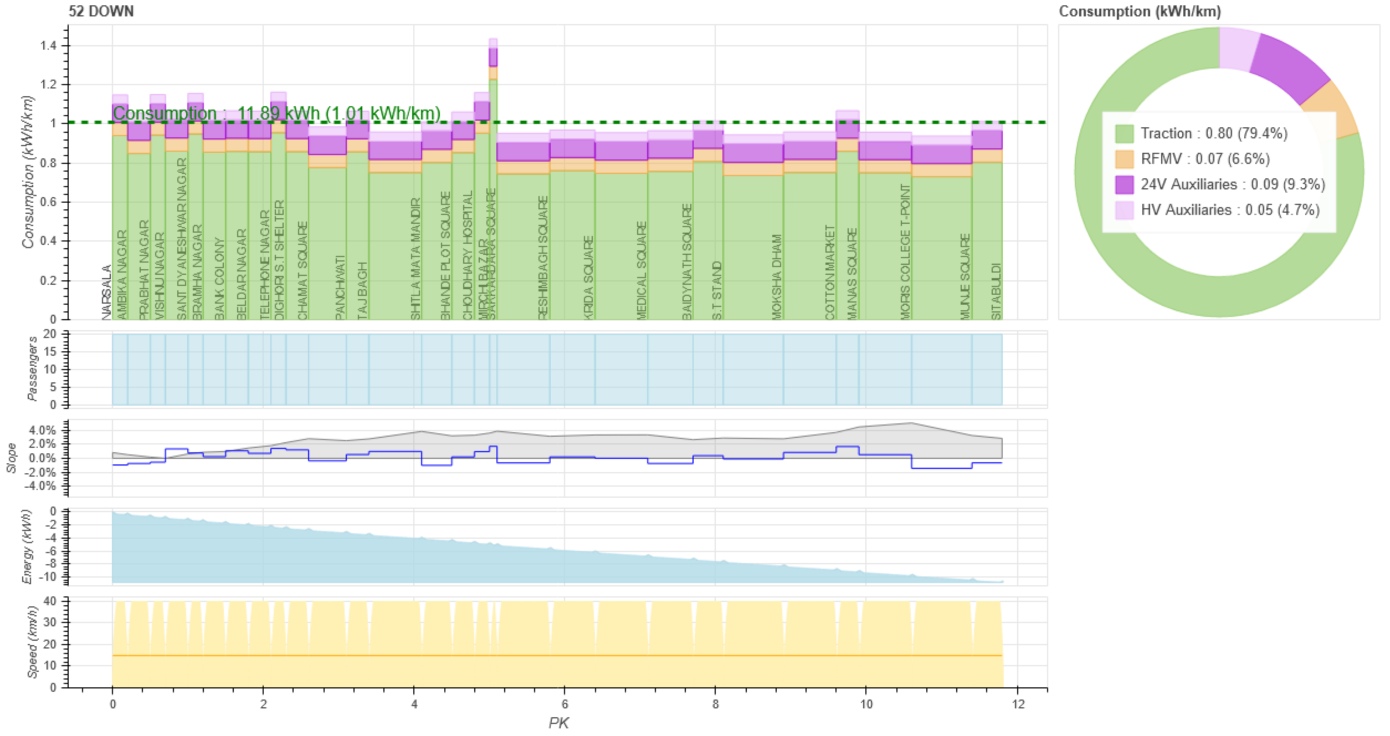
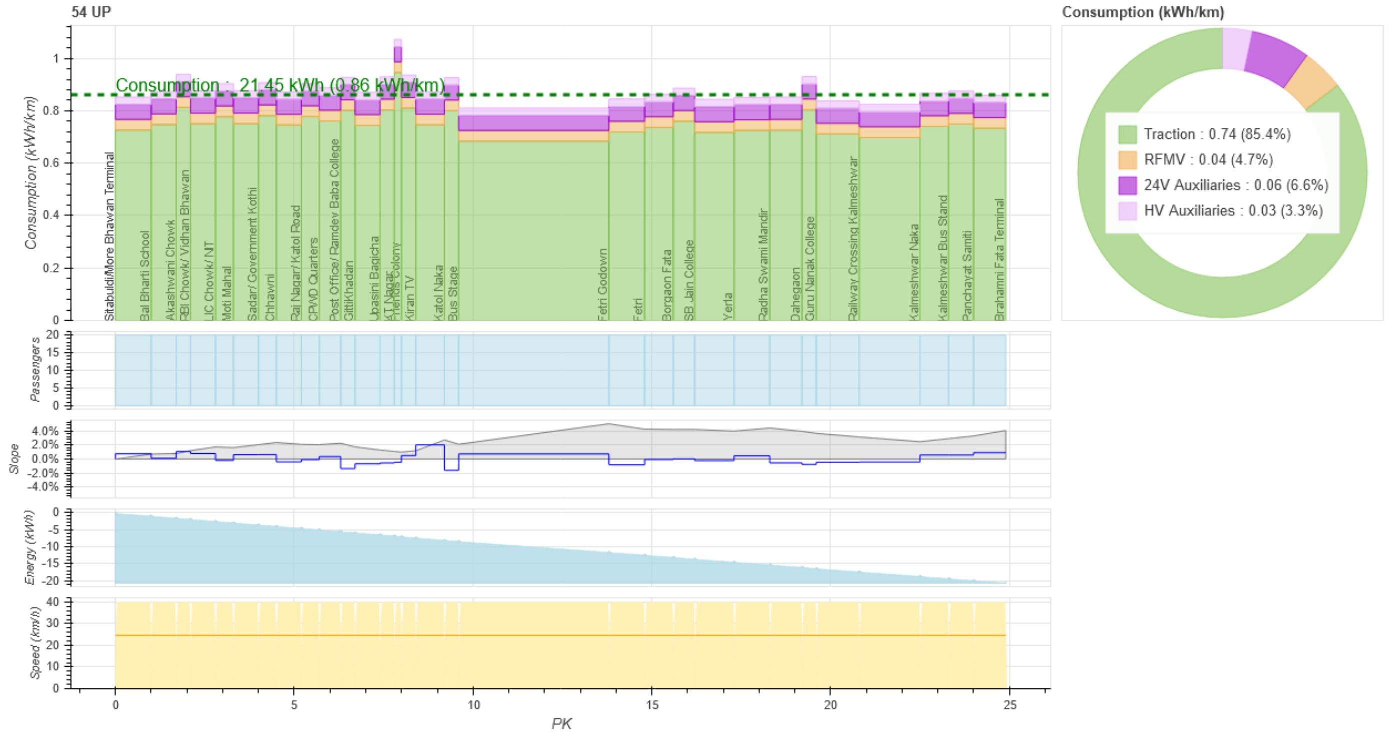
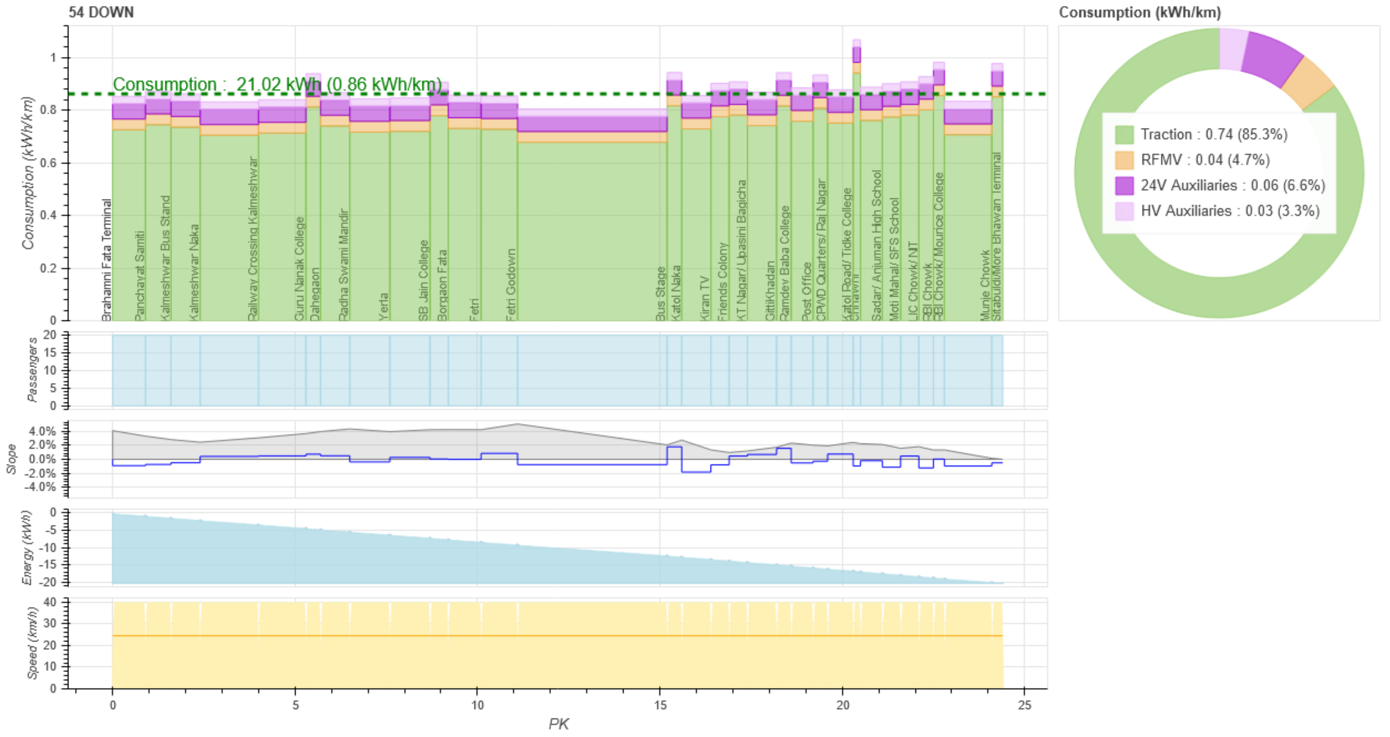
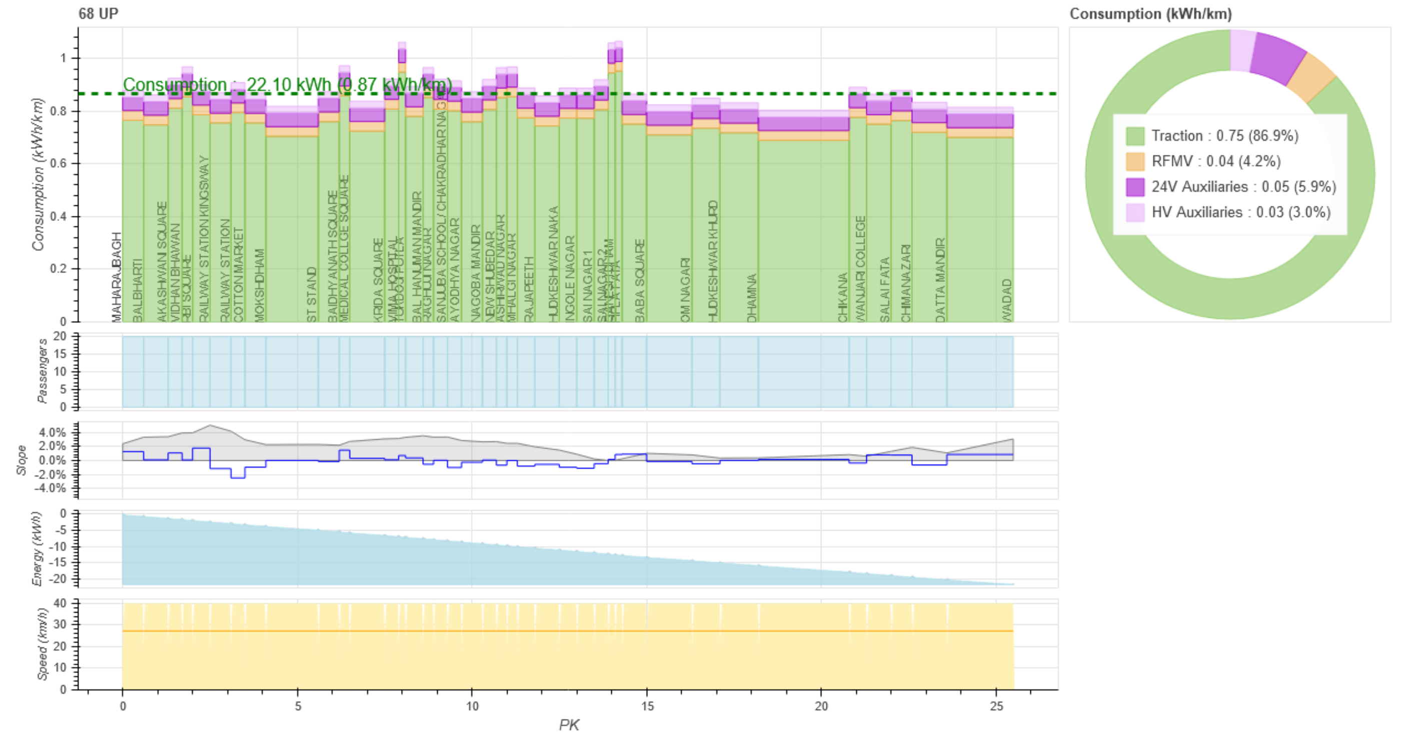
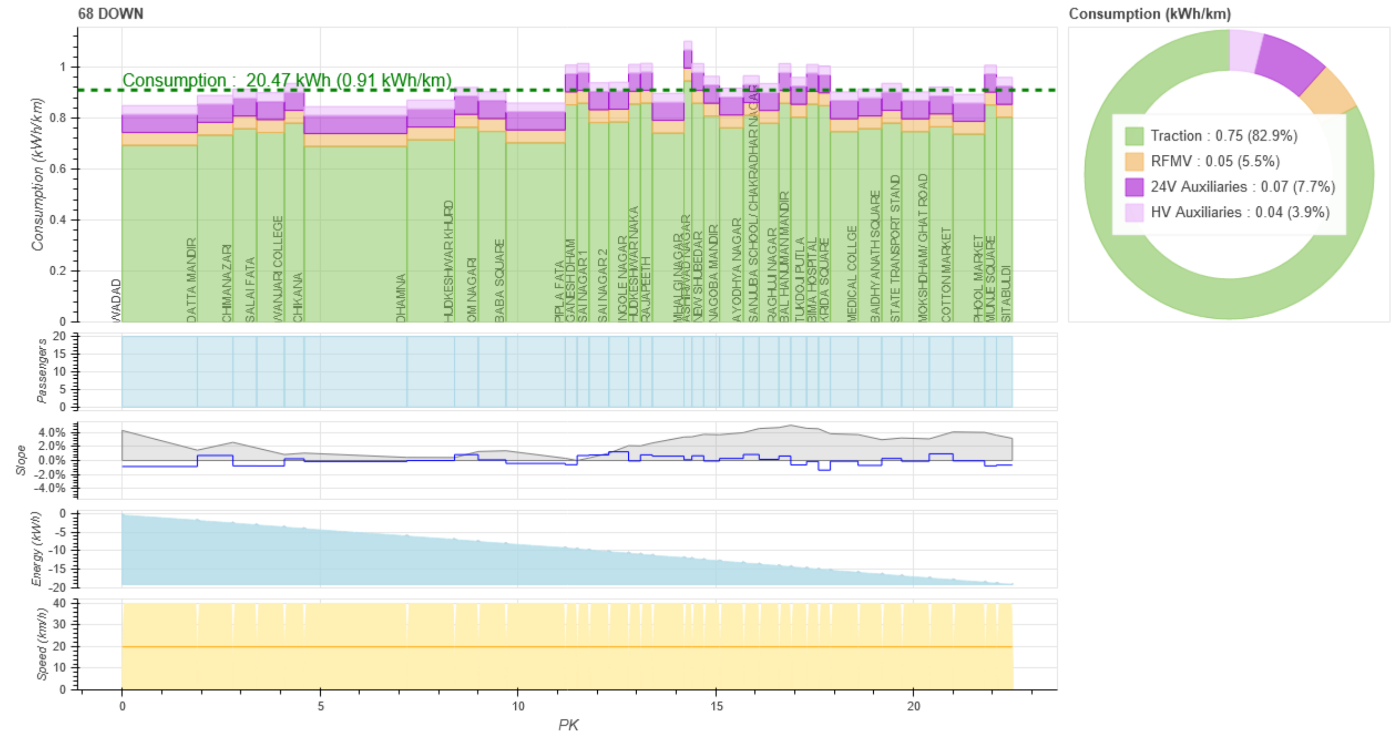
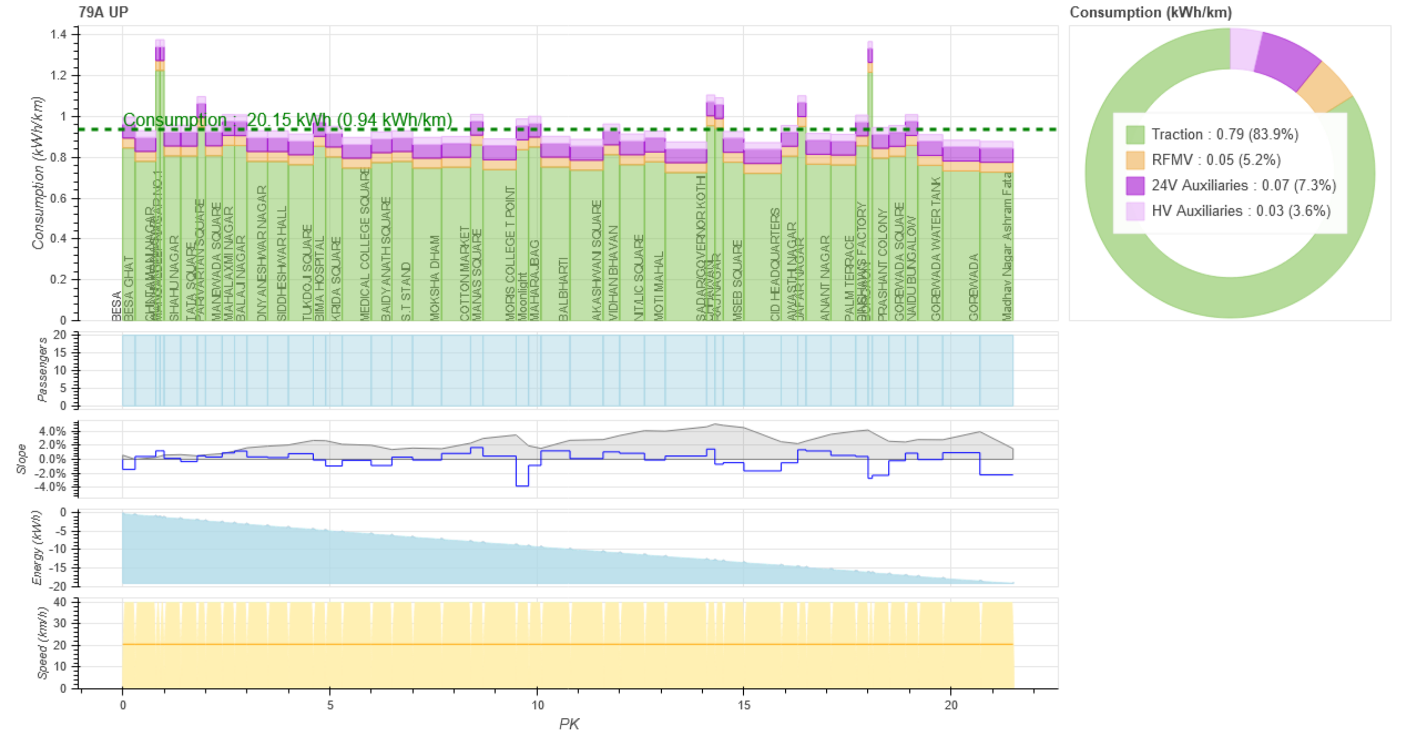
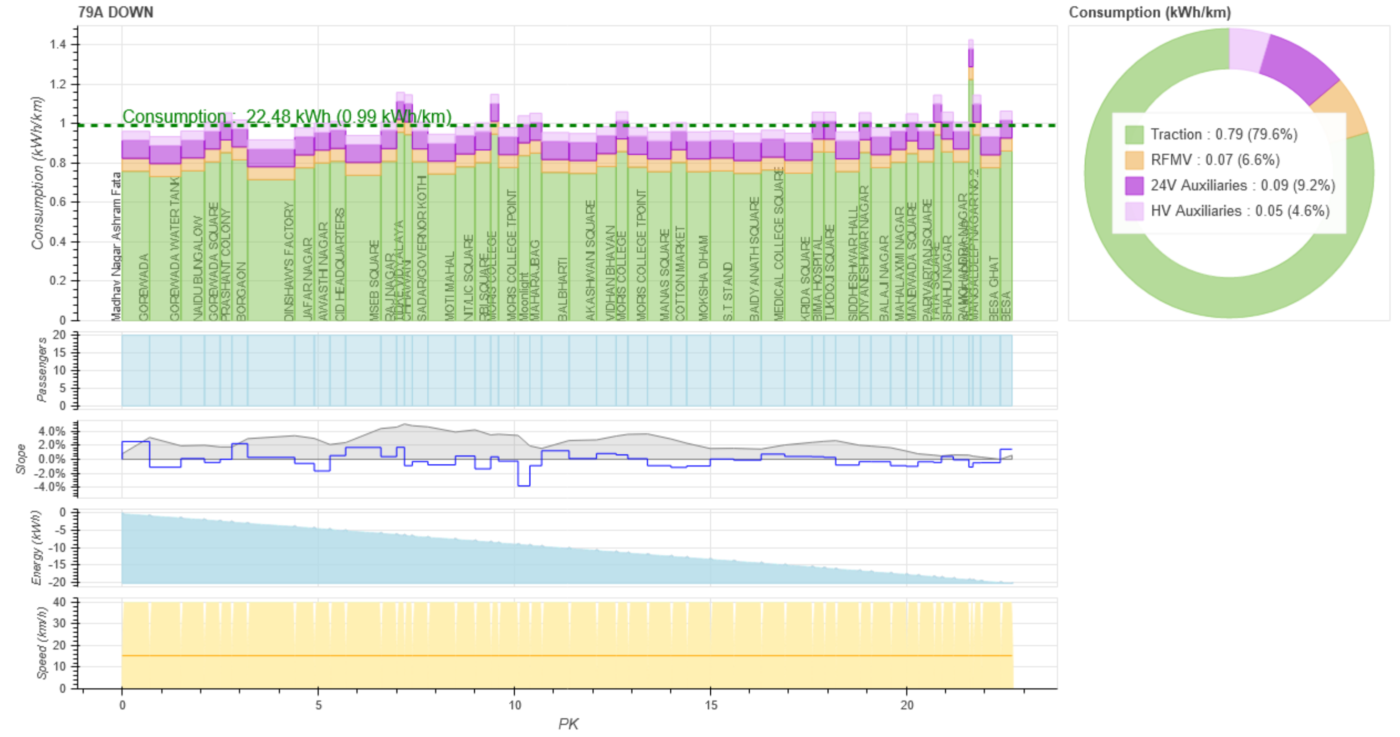
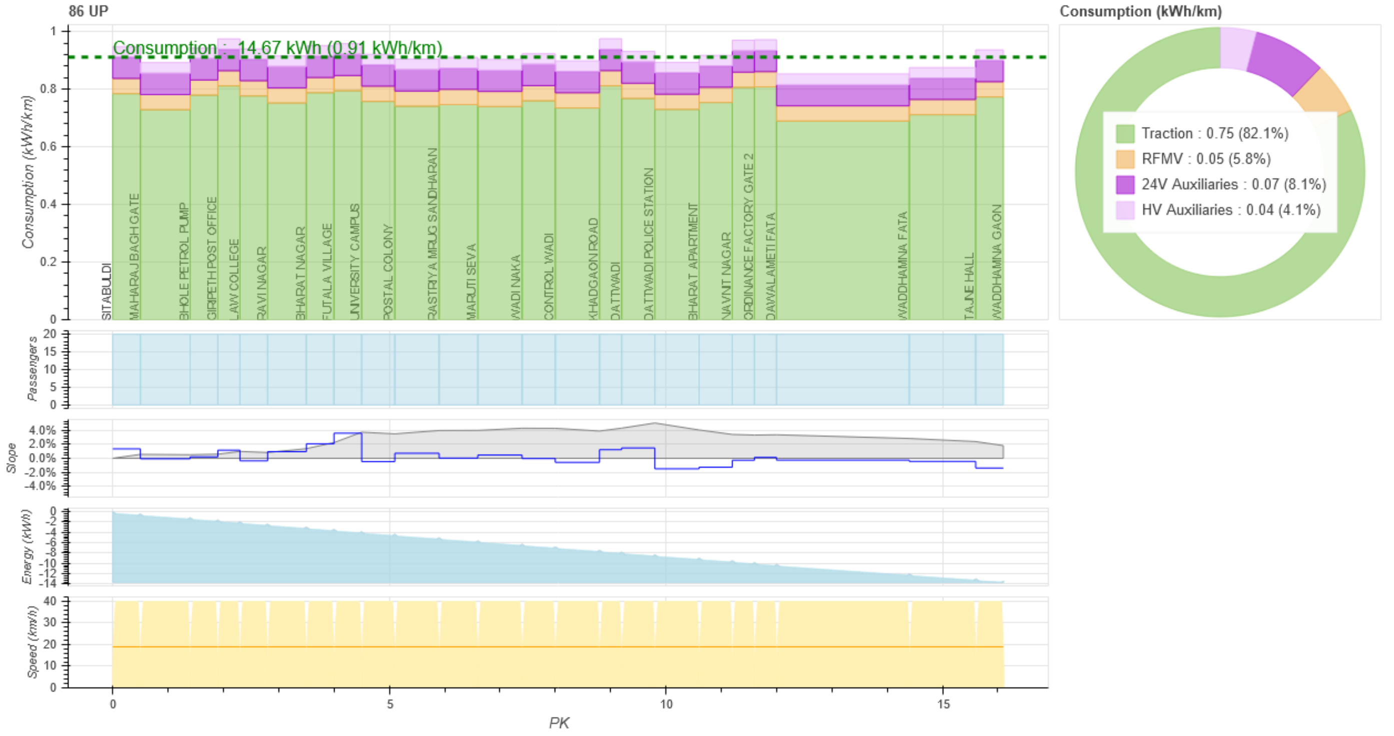
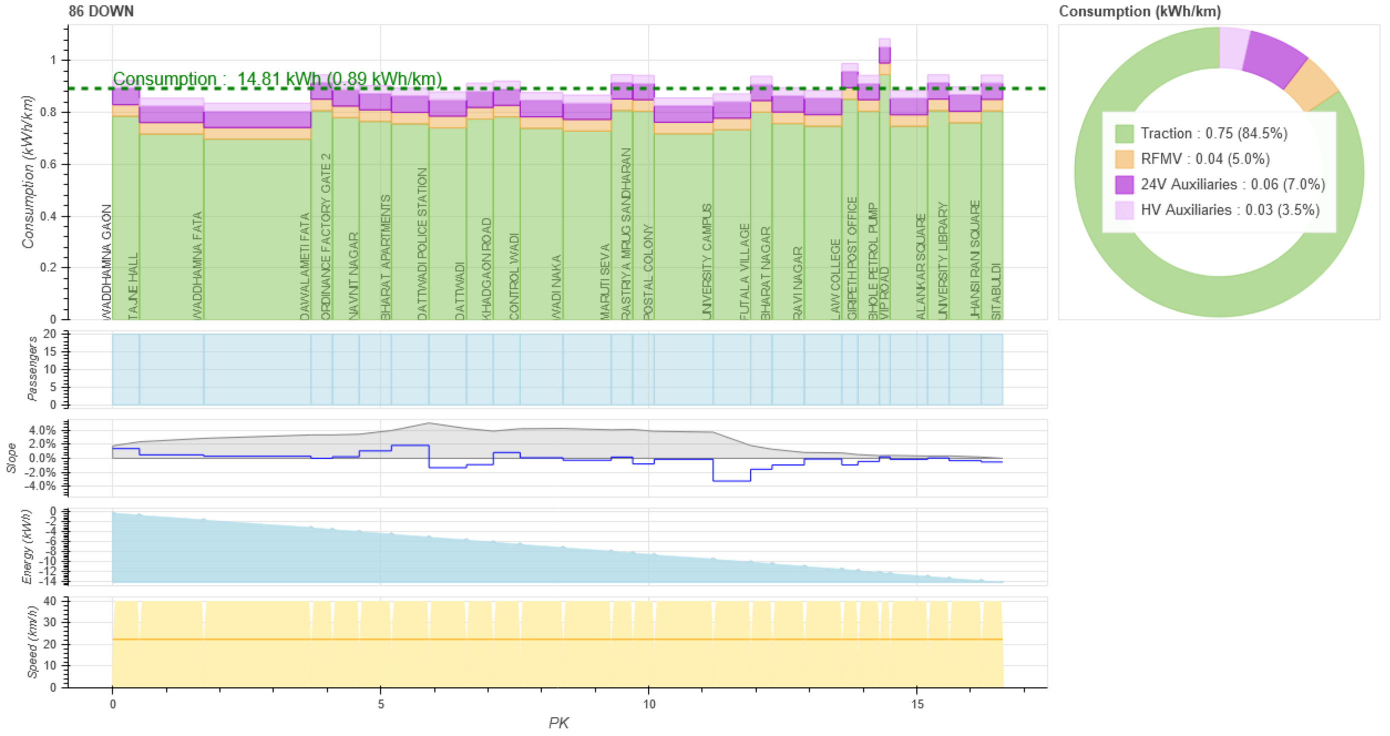
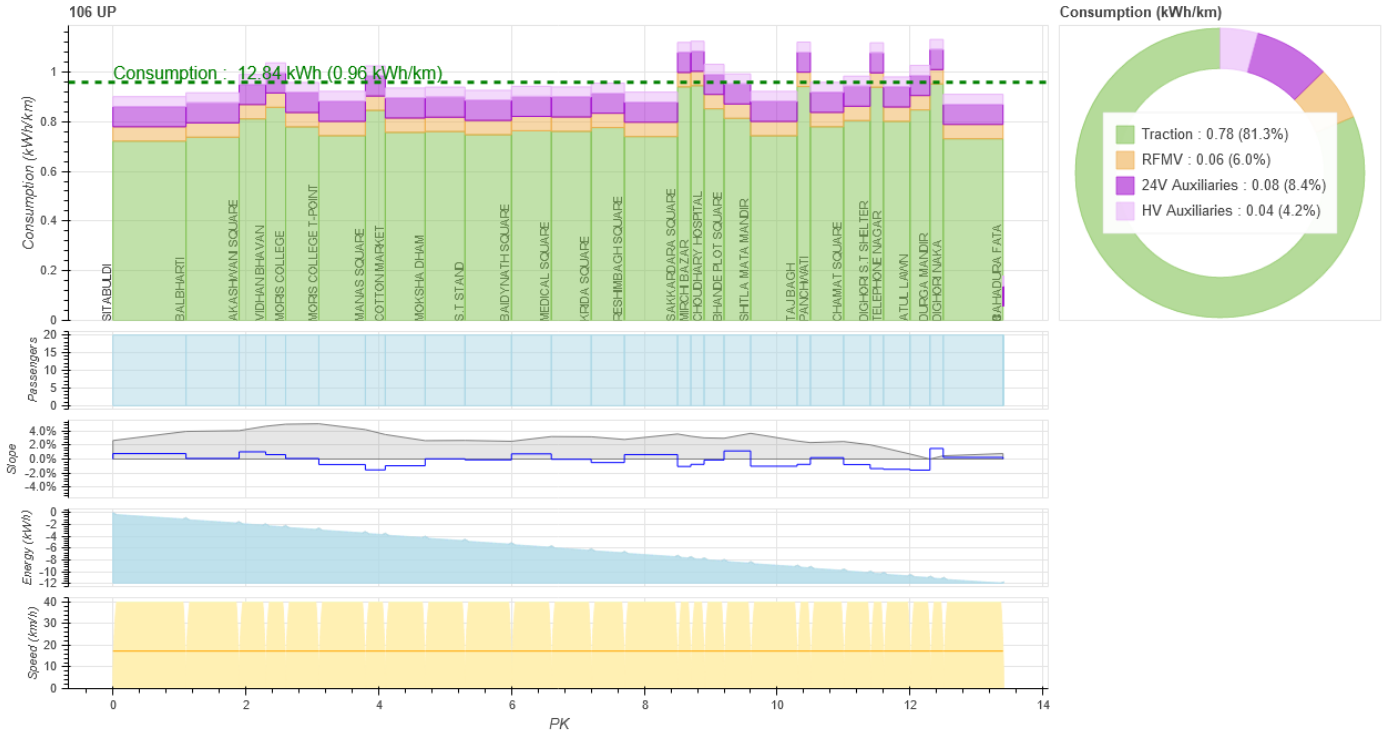
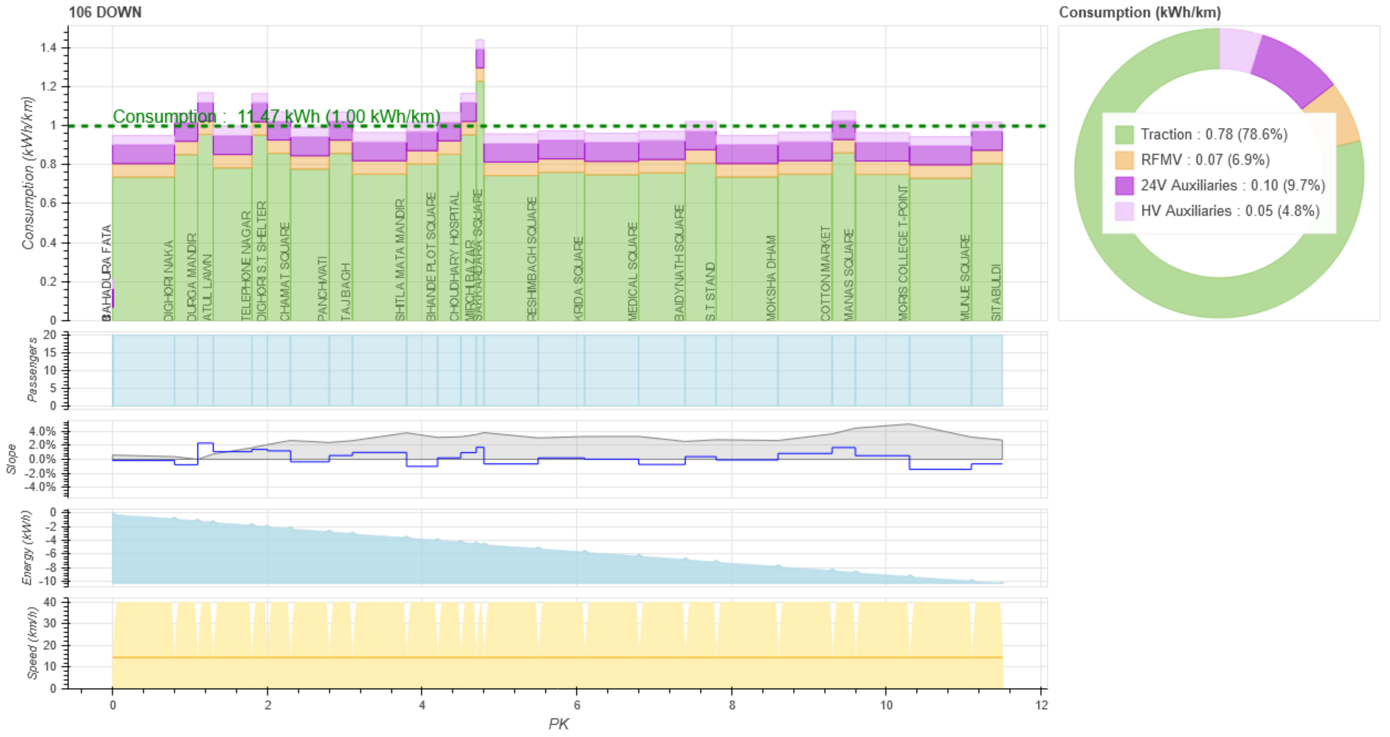
38		
40		

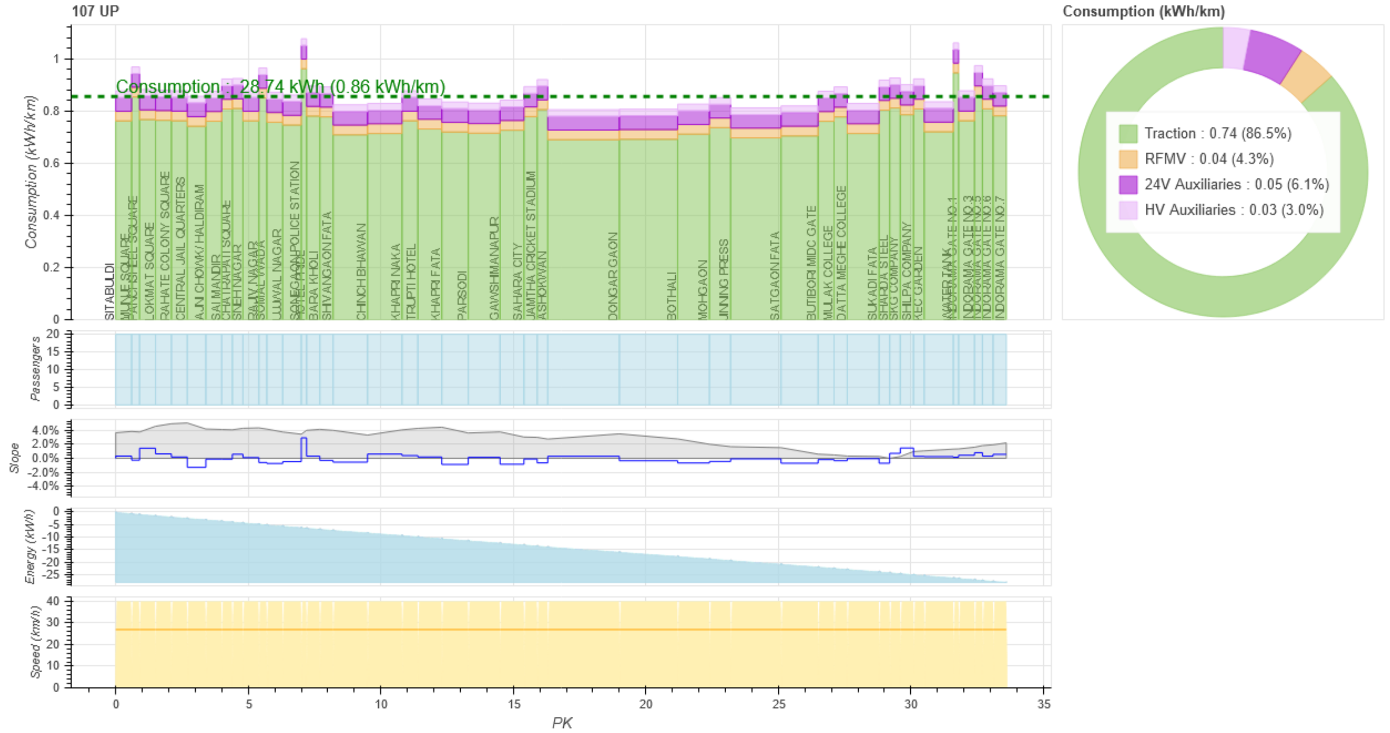
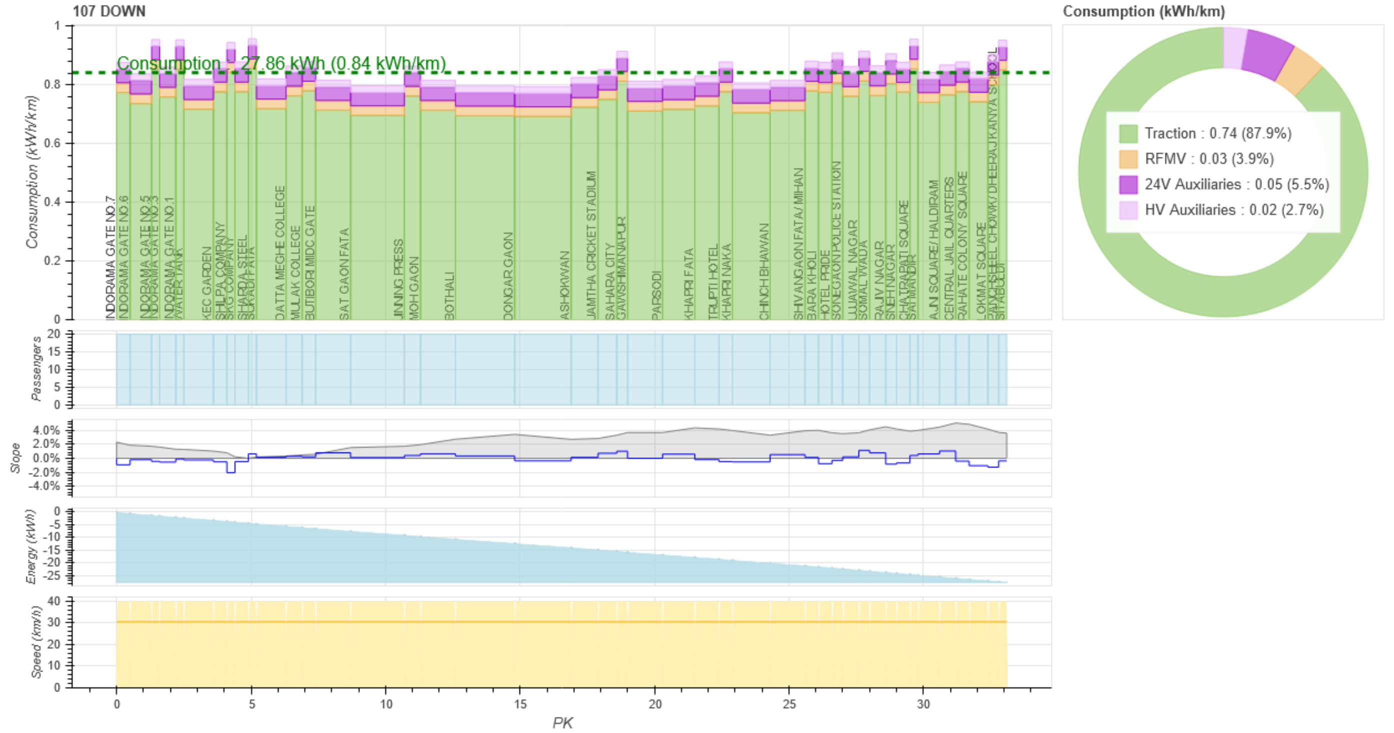
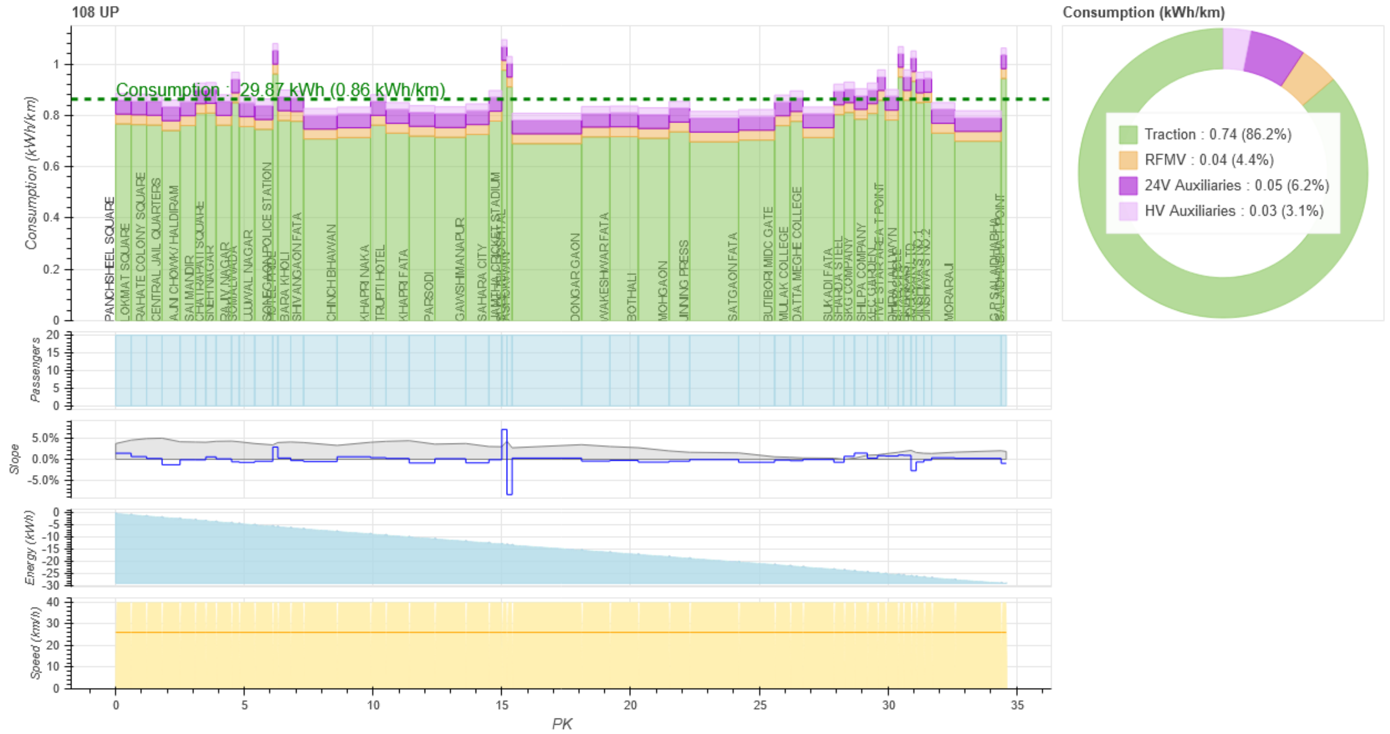
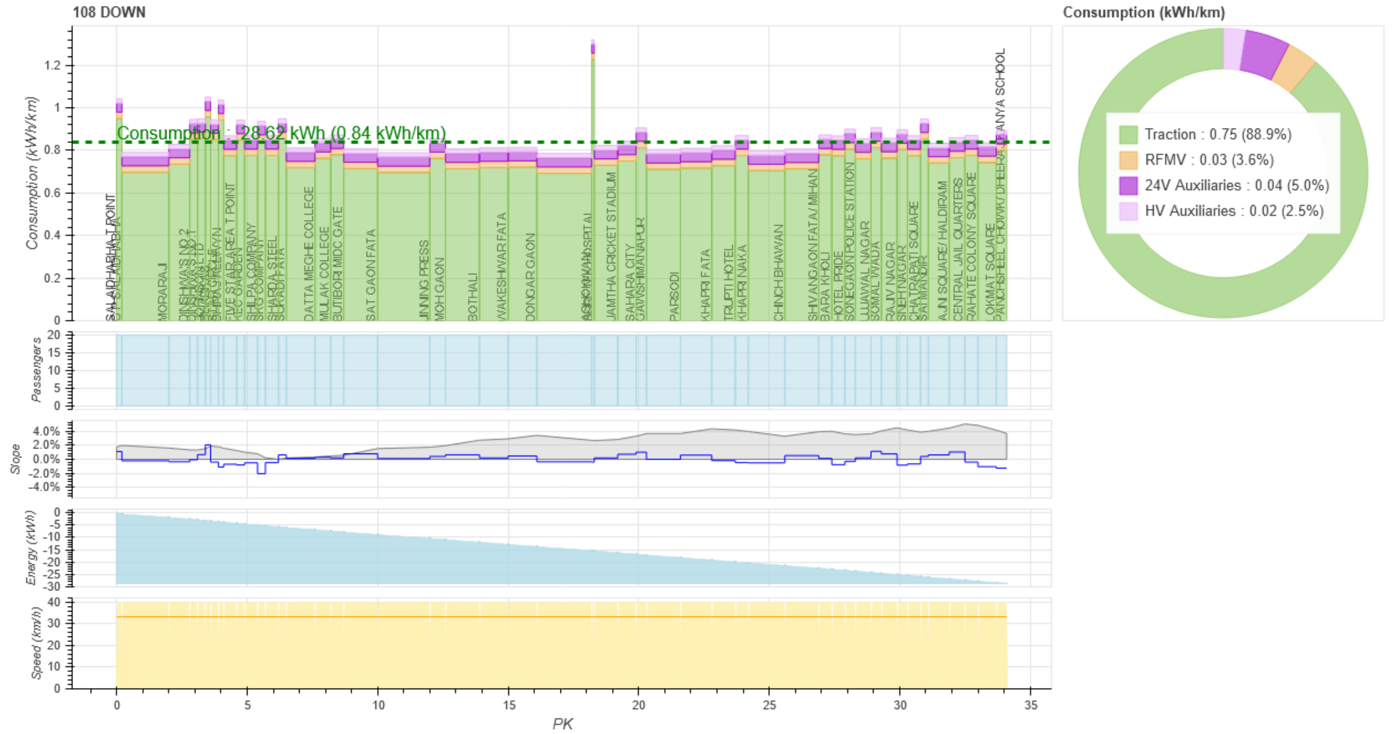
Route	Direction "UP"		Direction "DOWN"	
42		 Consumption (kWh/km)		 Consumption (kWh/km)
47		 Consumption (kWh/km)		 Consumption (kWh/km)

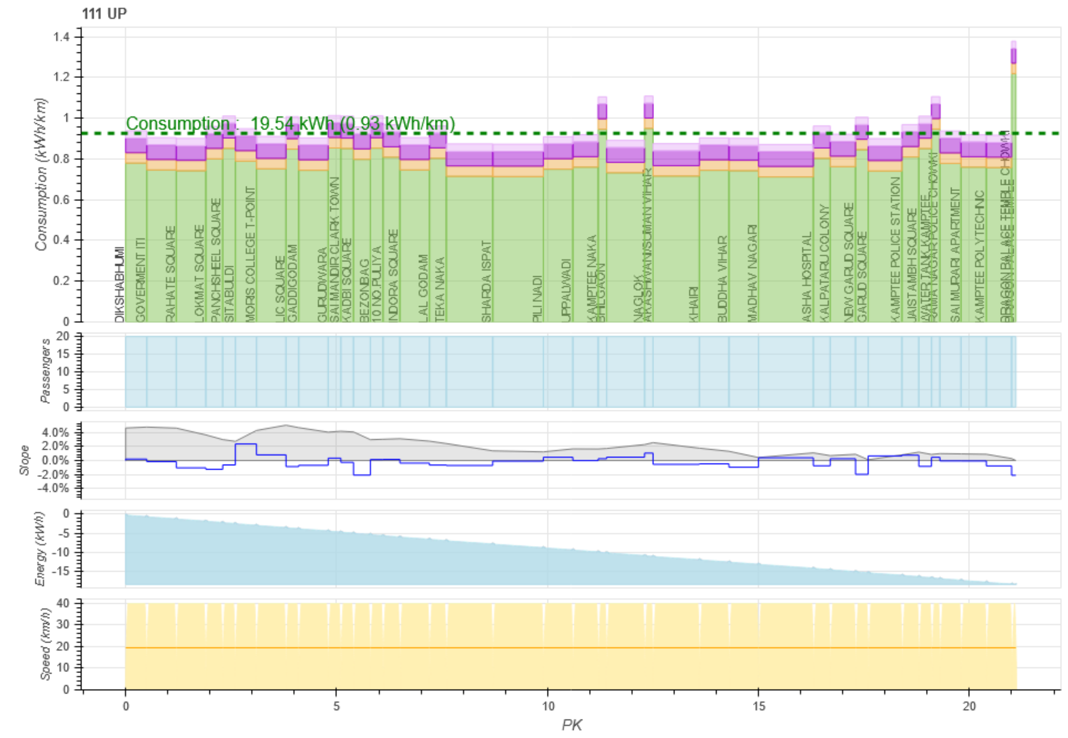
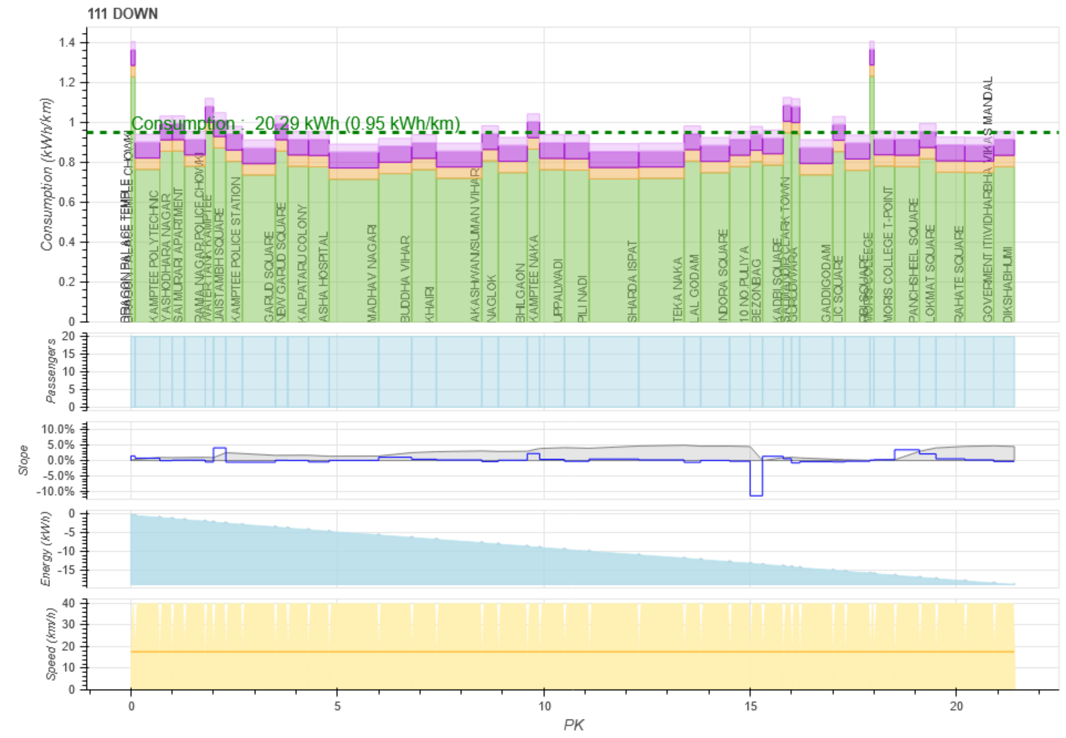
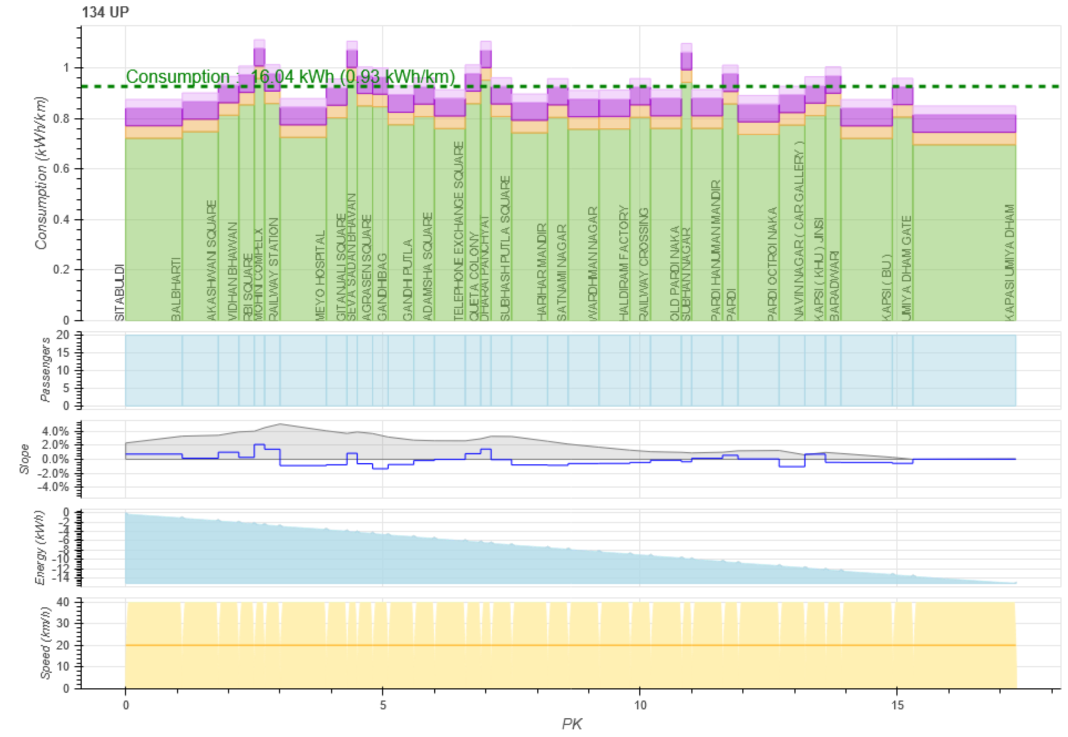
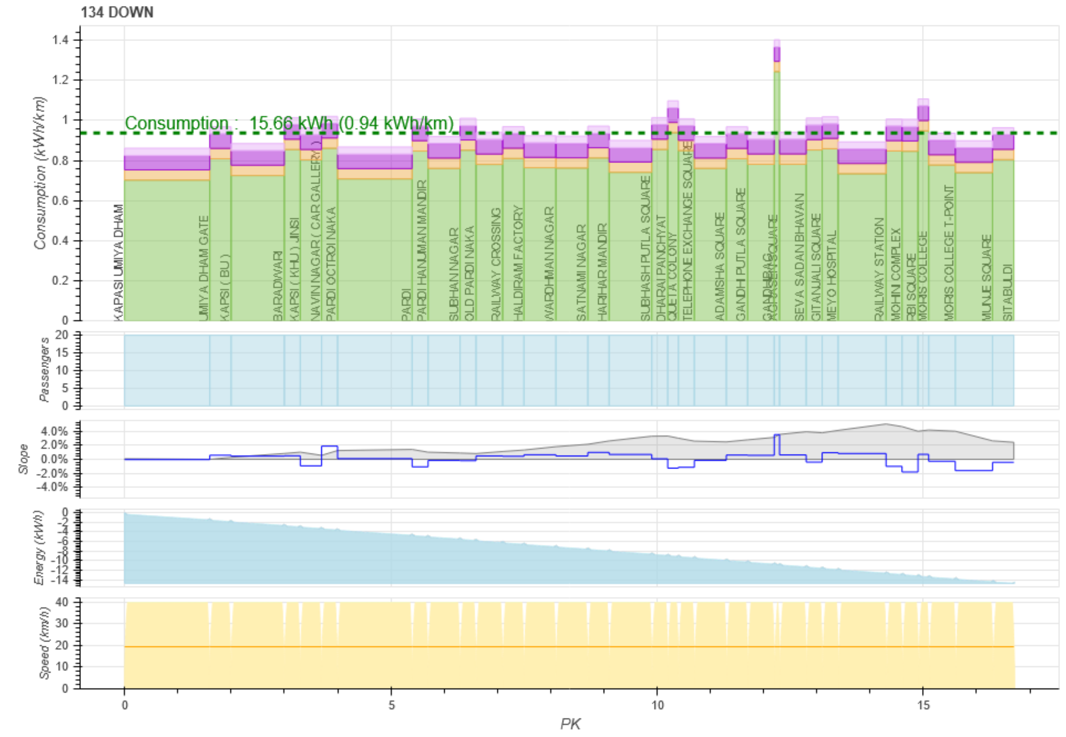
Route	Direction "UP"	Direction "DOWN"
48		
49		

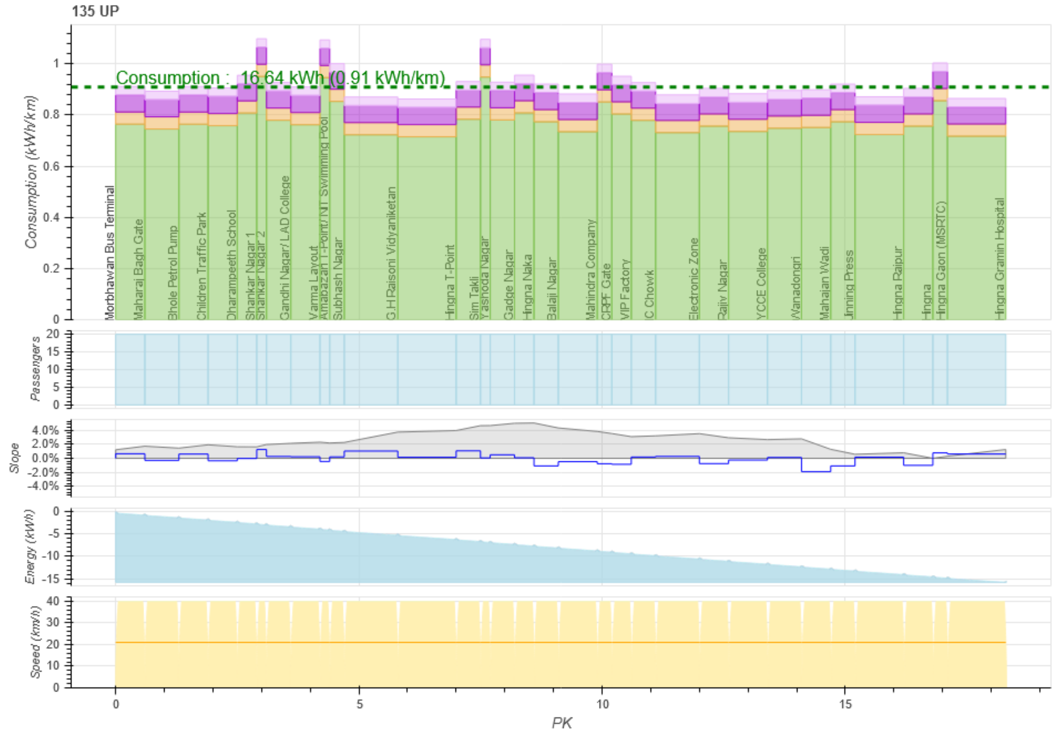
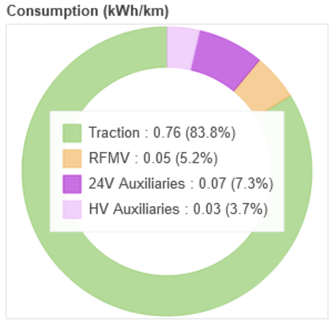
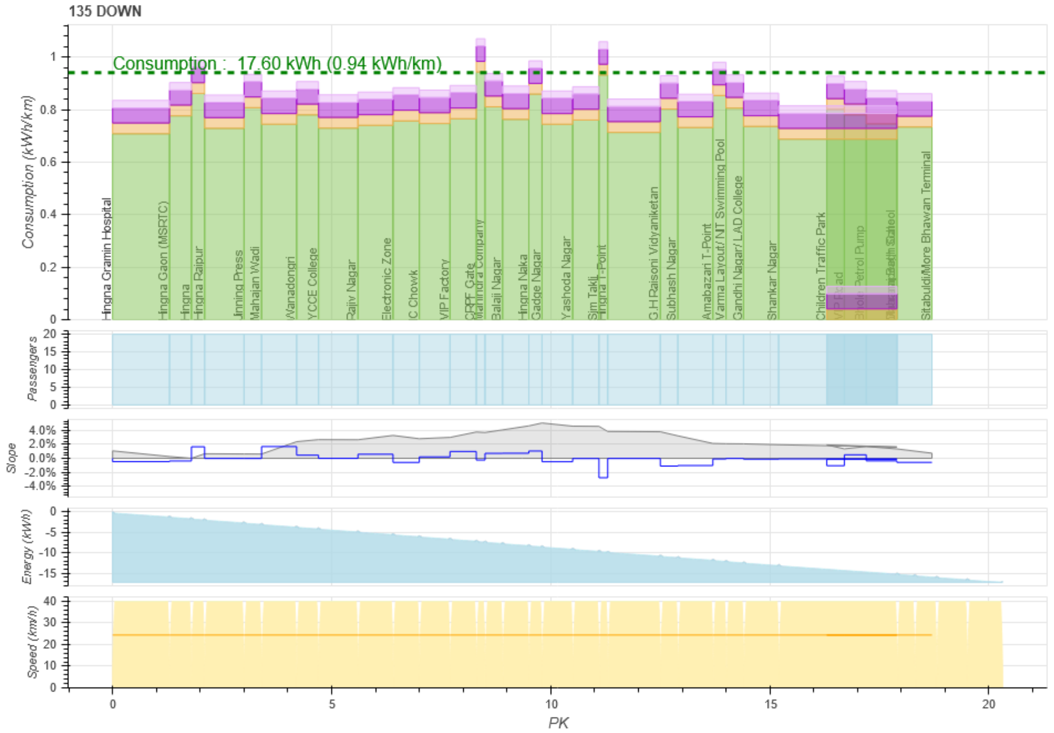
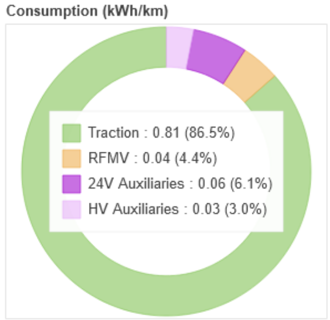
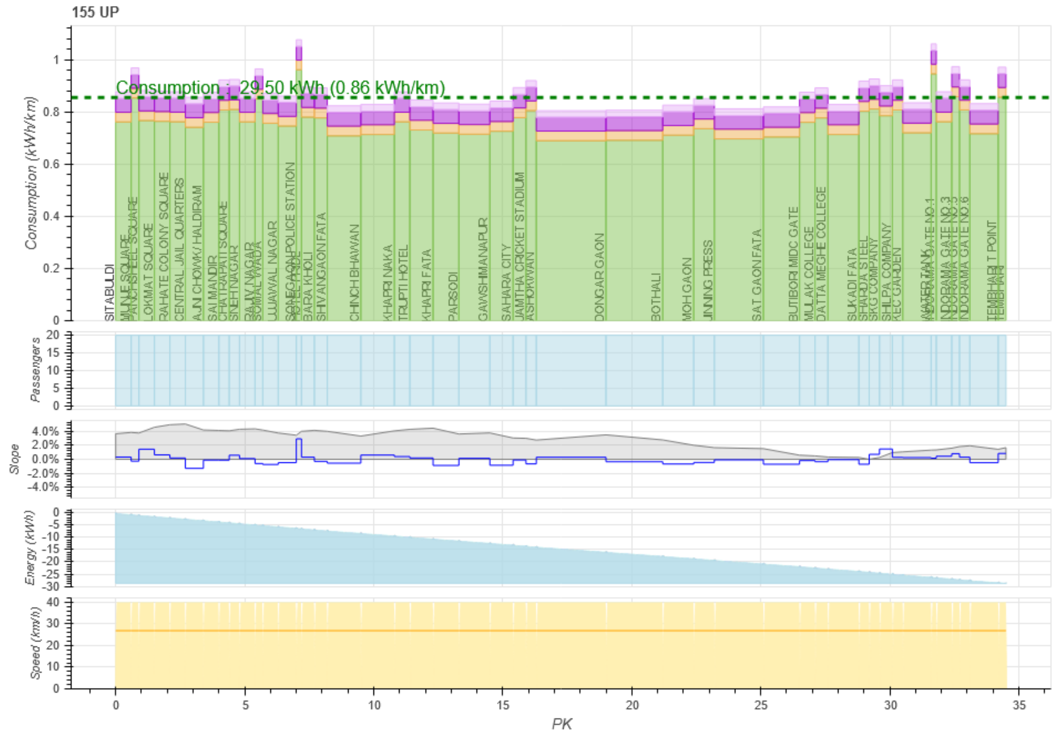
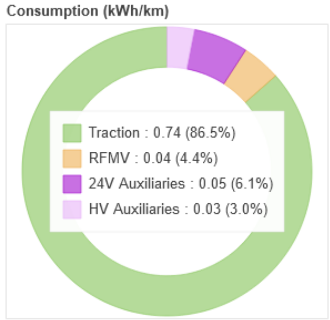
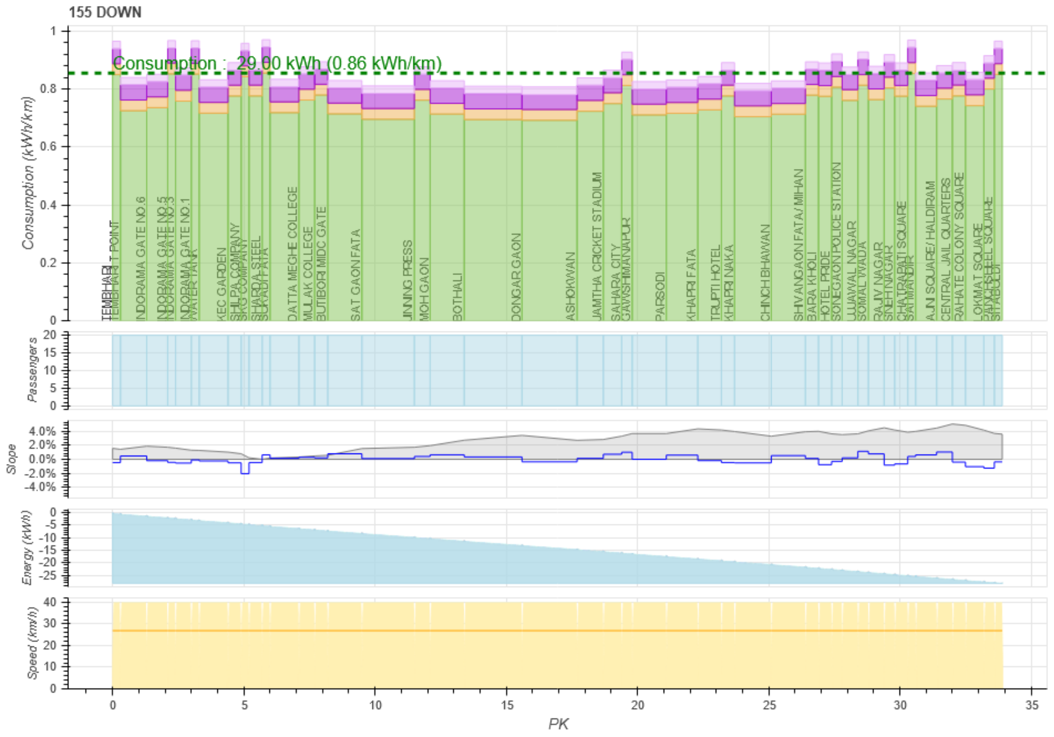
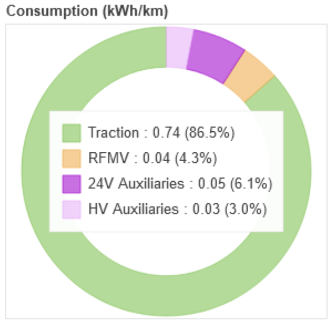
Route	Direction "UP"	Direction "DOWN"
52		
54		

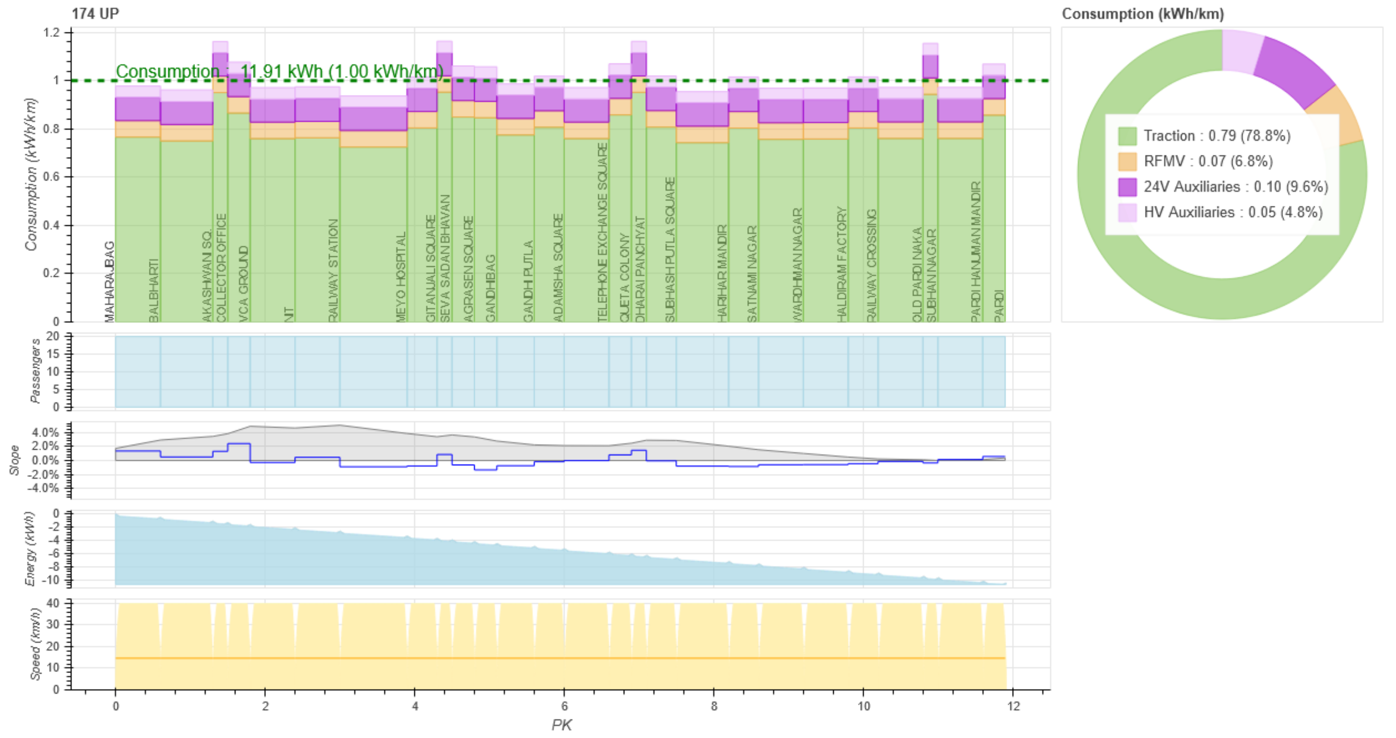
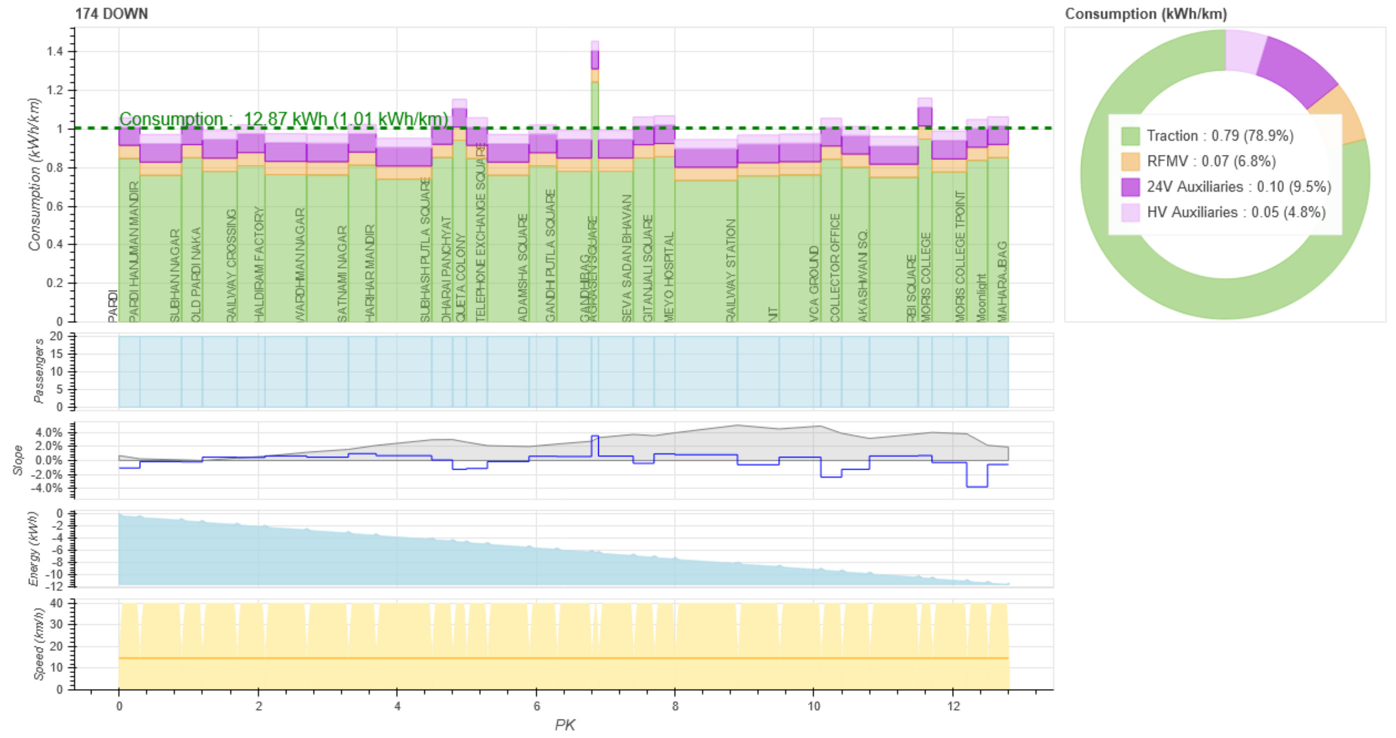
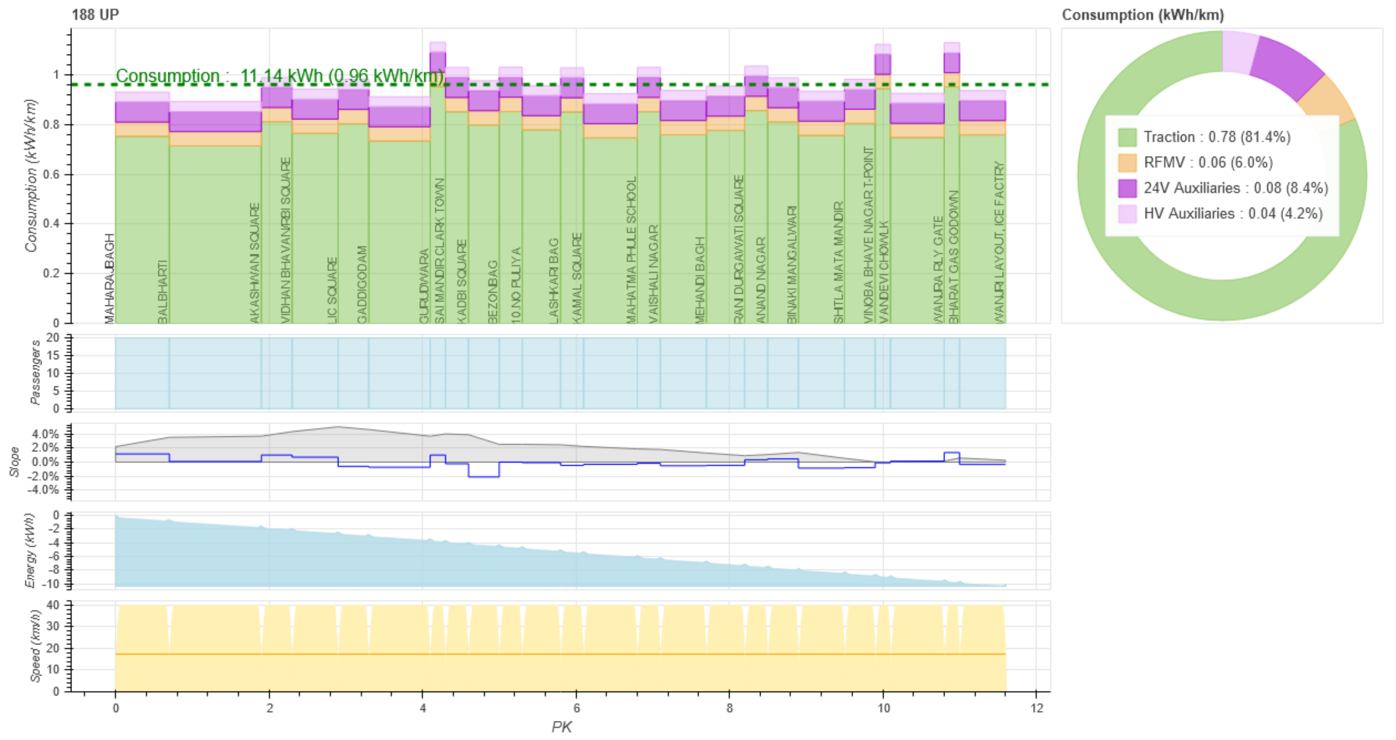
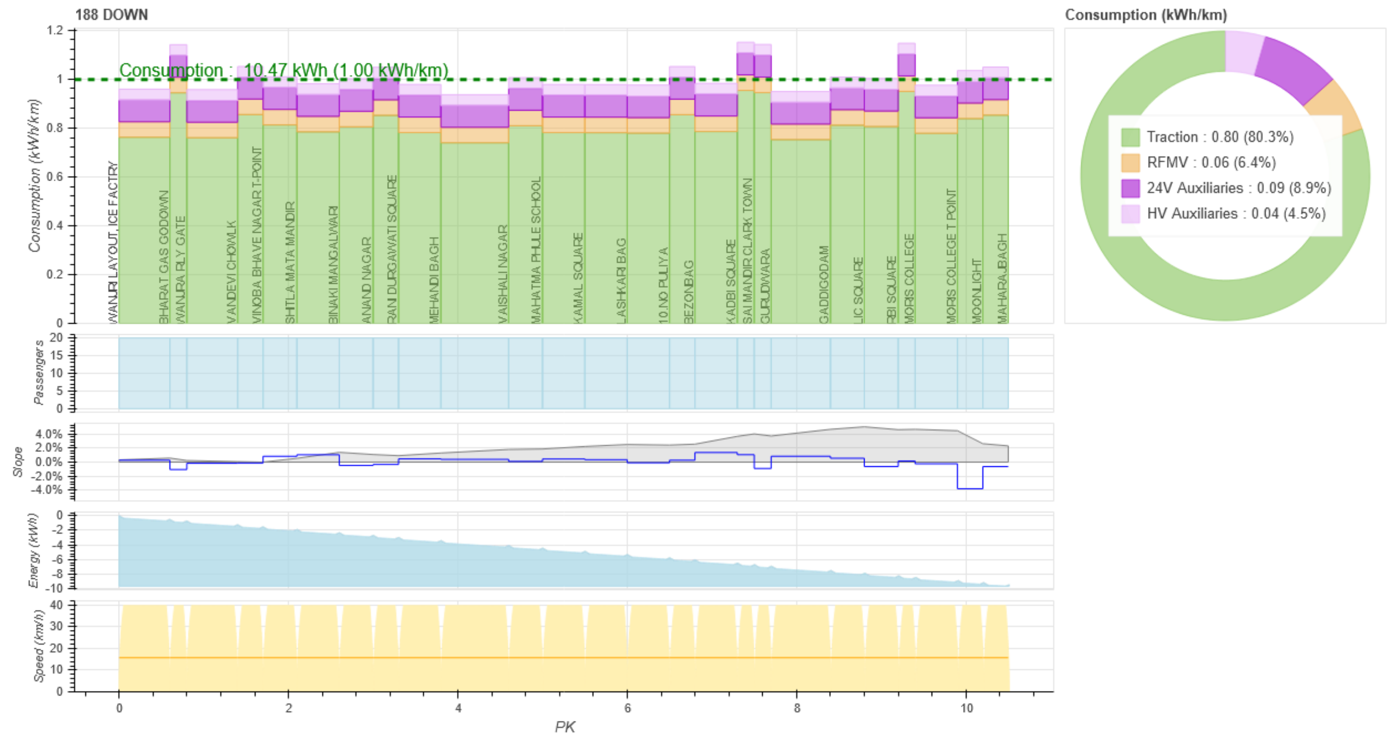
Route	Direction "UP"	Direction "DOWN"
68		
79A		

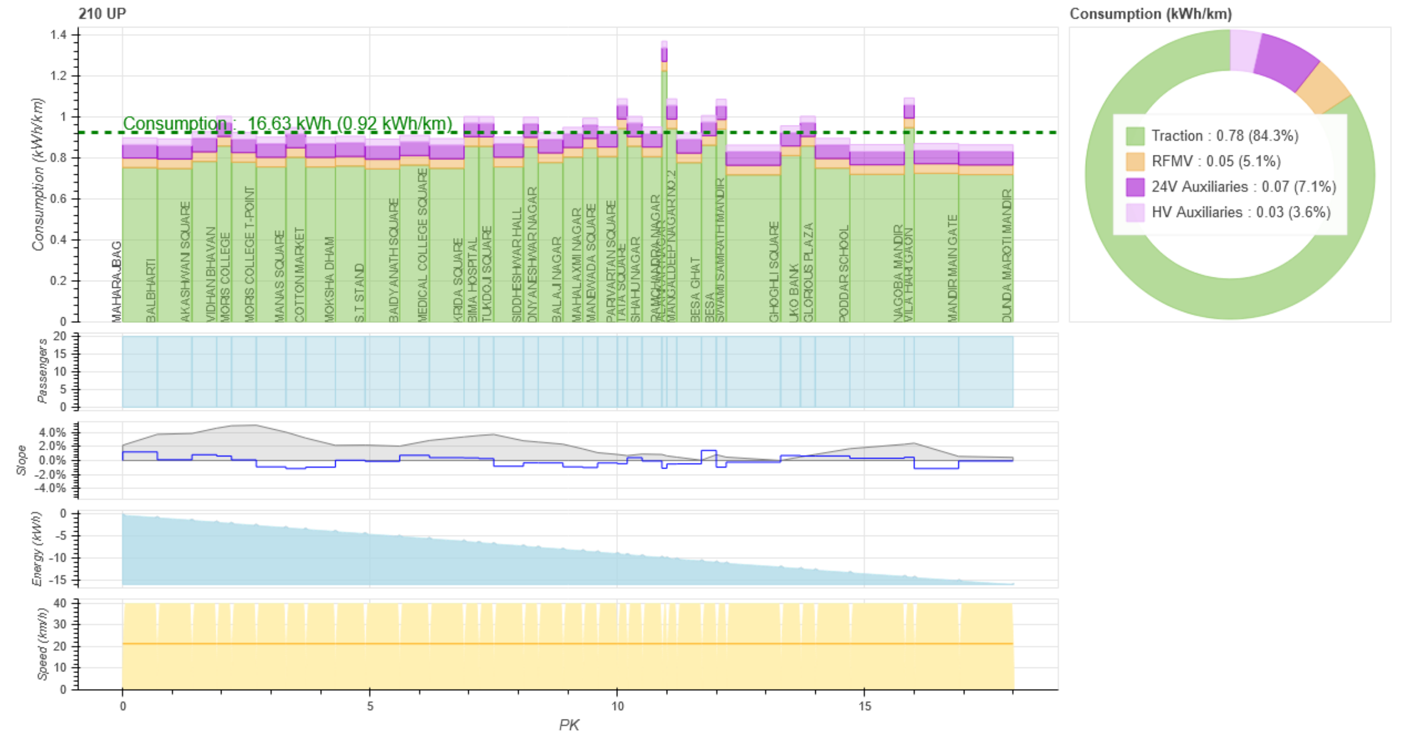
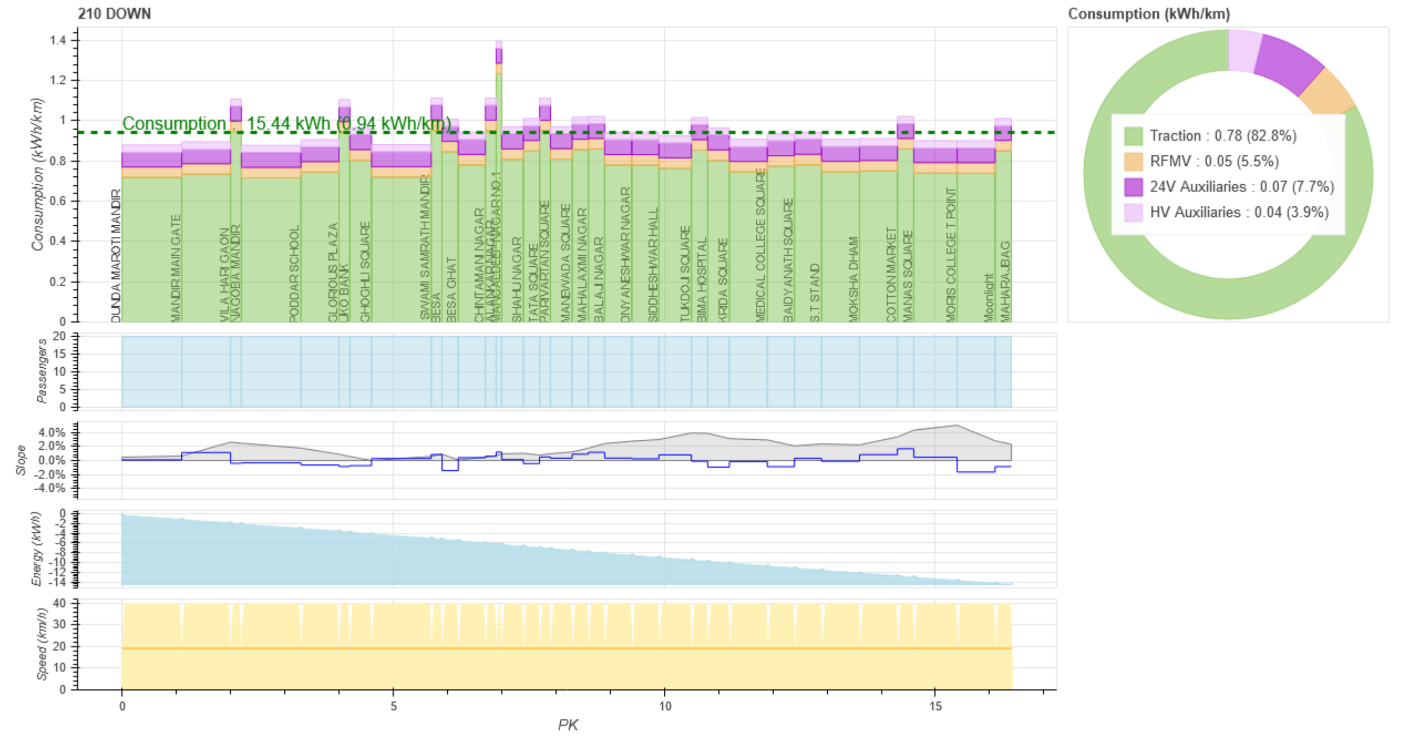
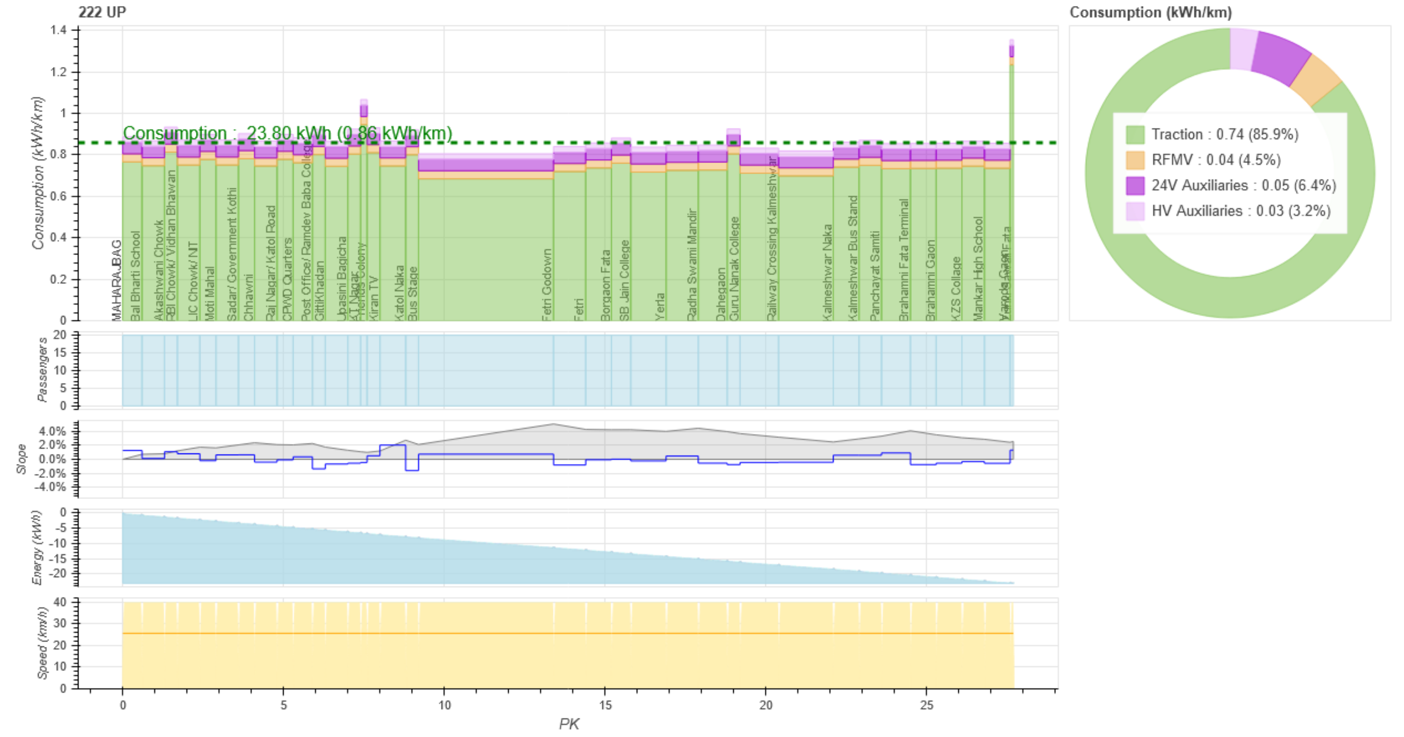
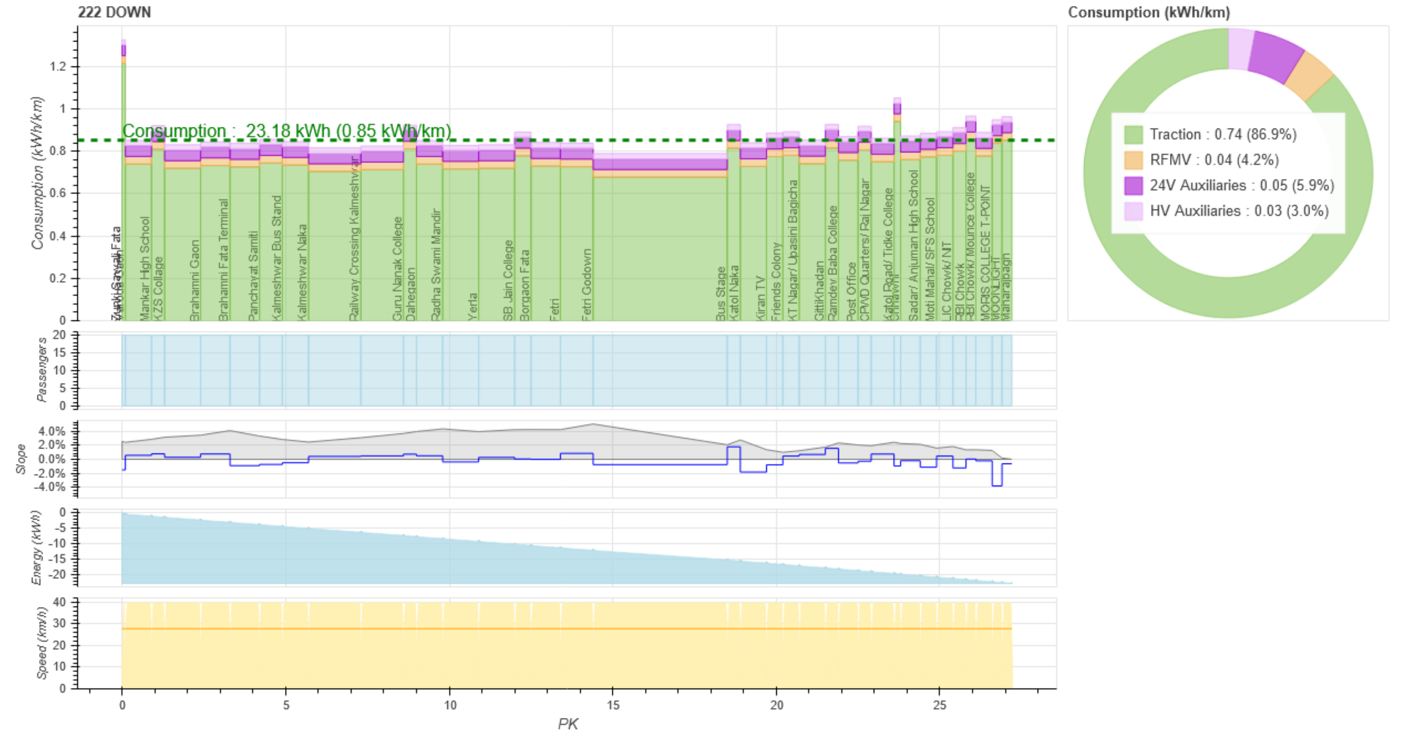
Route	Direction "UP"	Direction "DOWN"
86		
106		

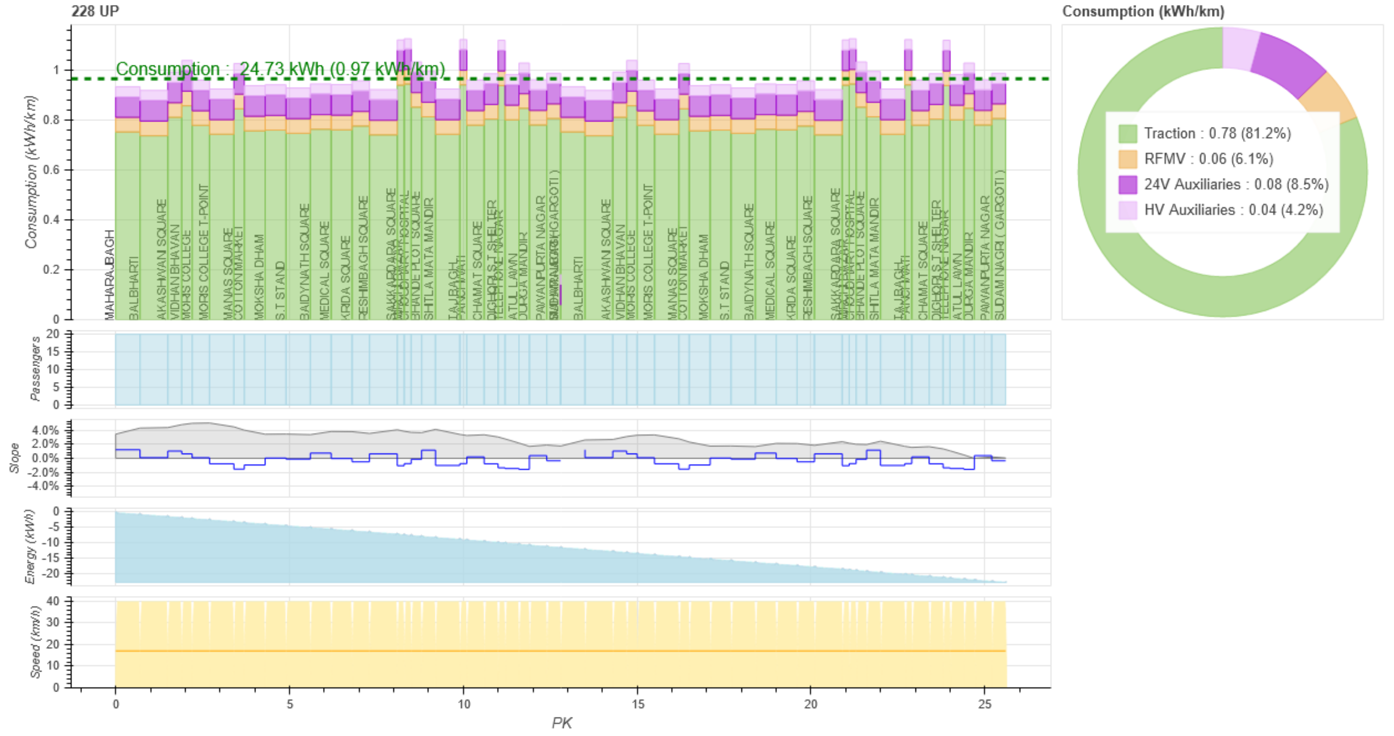
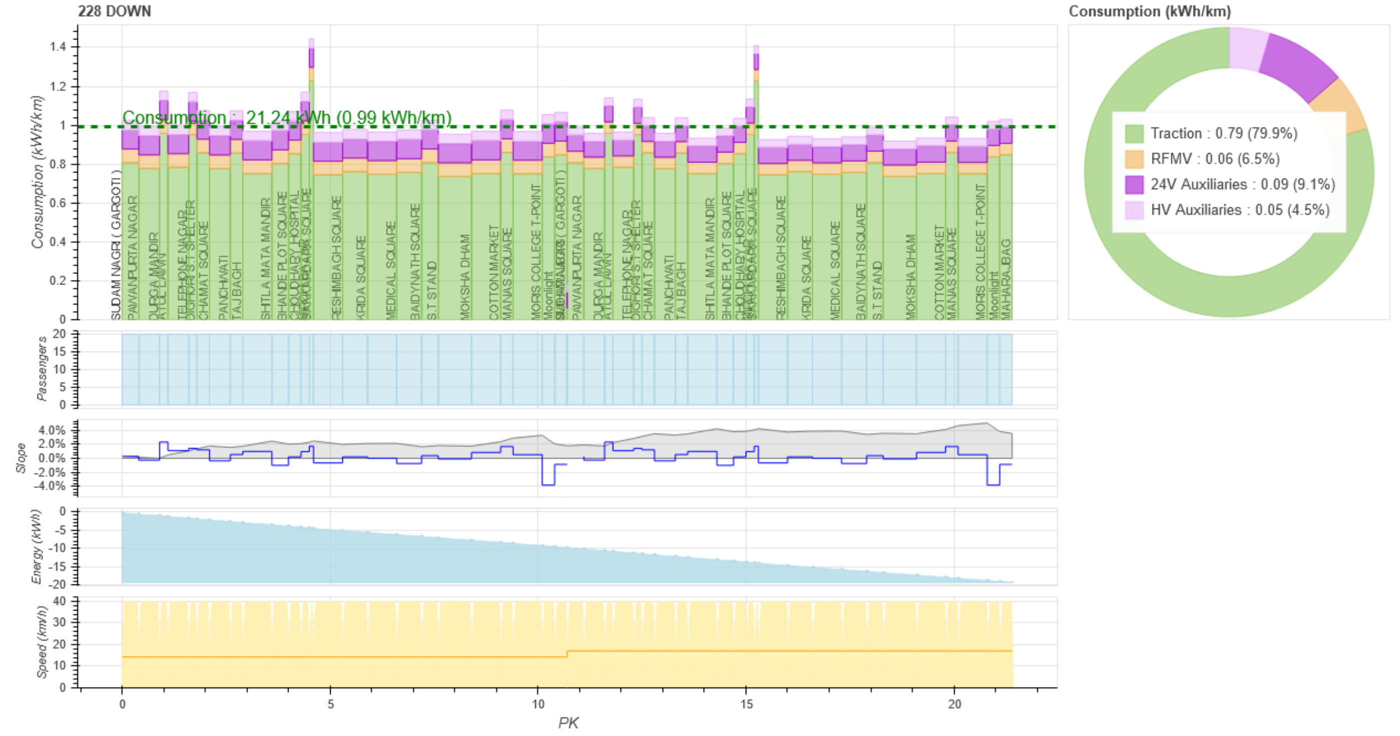
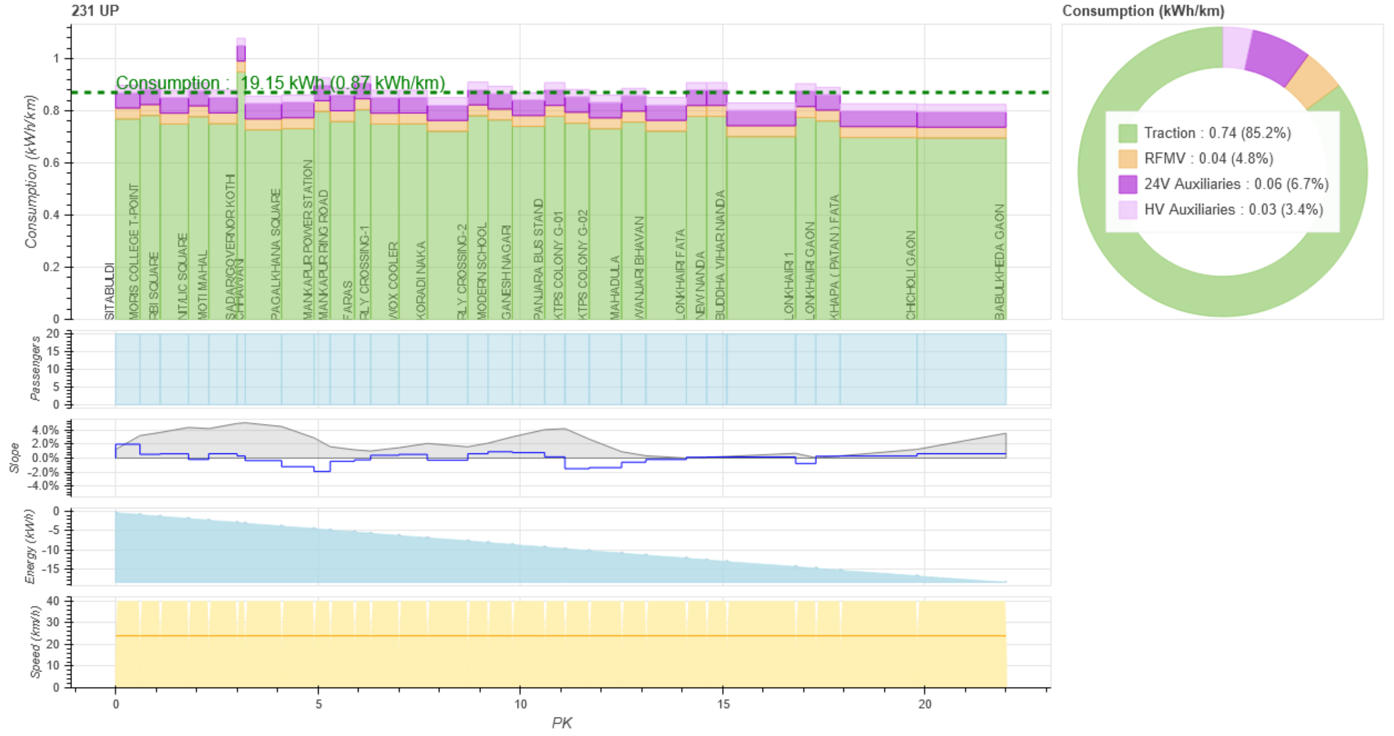
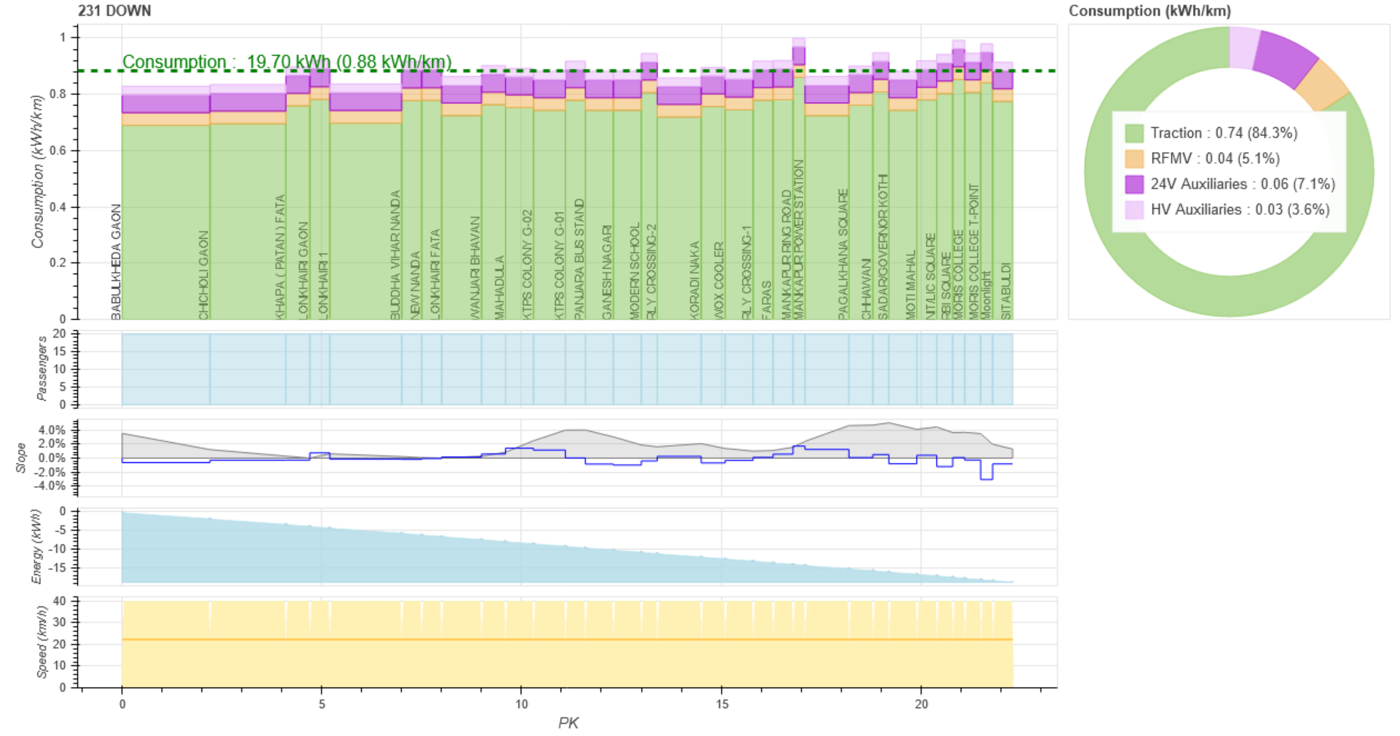
Route	Direction "UP"	Direction "DOWN"
107		
108		

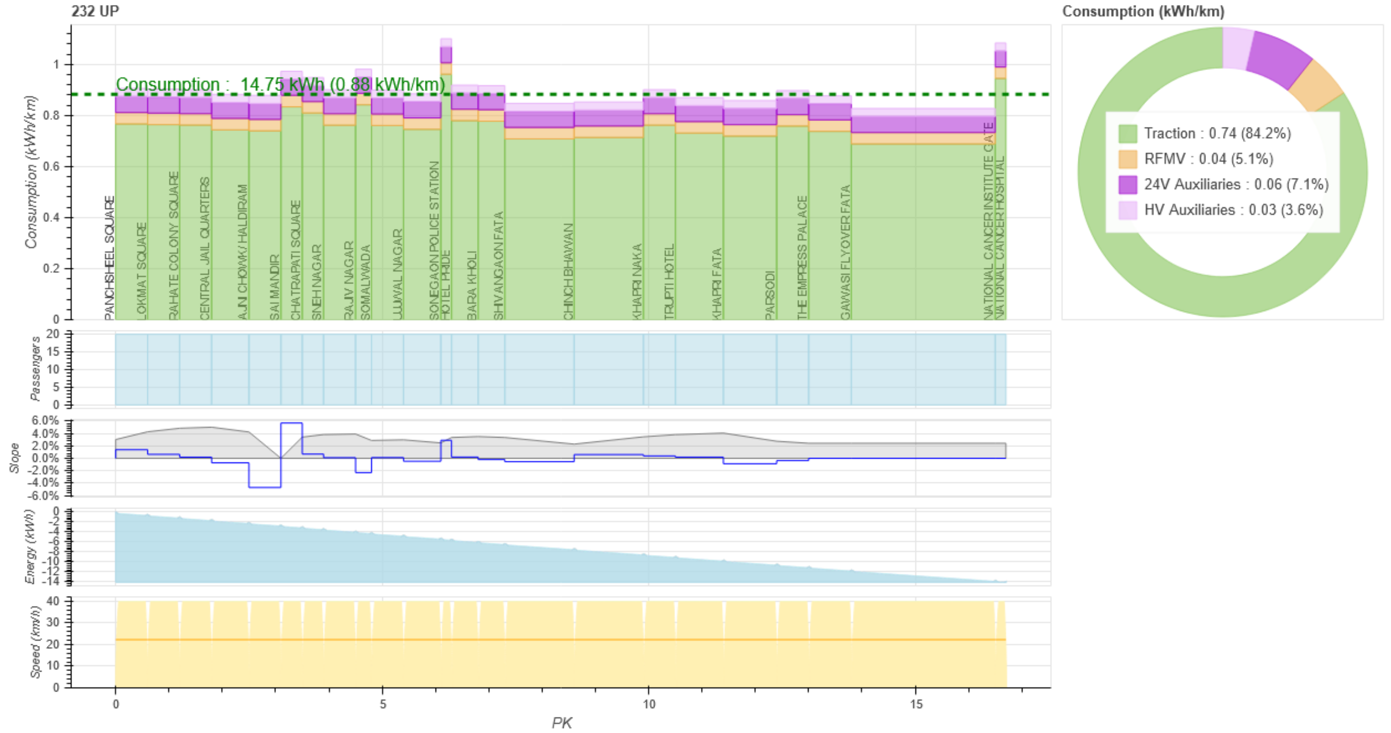
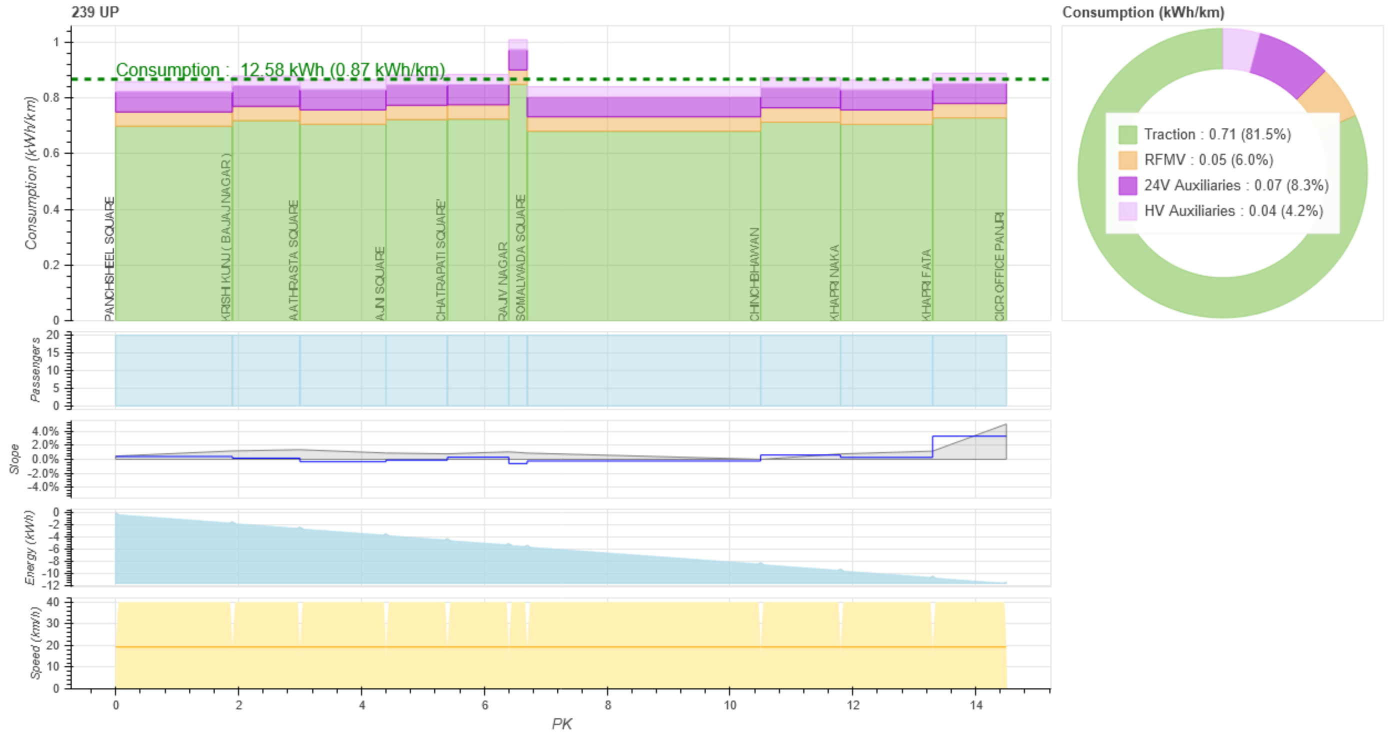
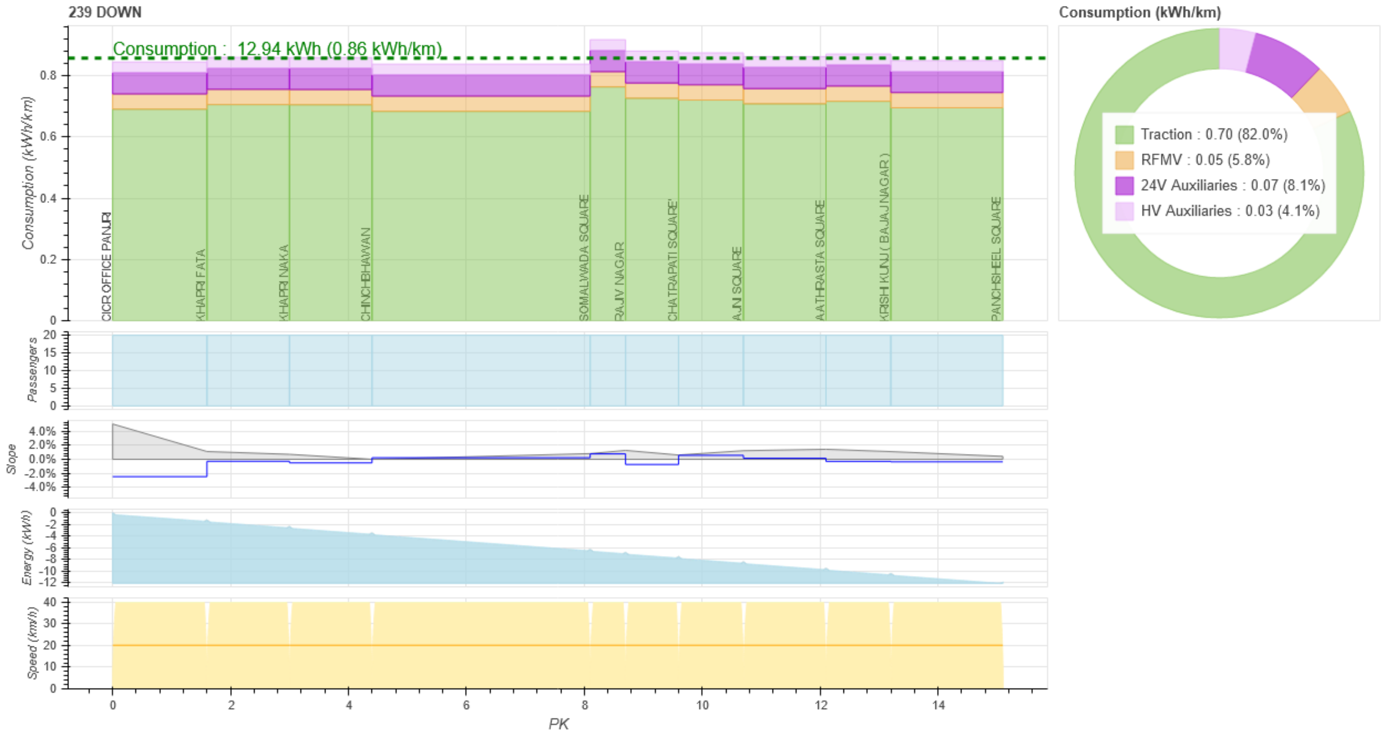
Route	Direction "UP"	Direction "DOWN"
111		
134		

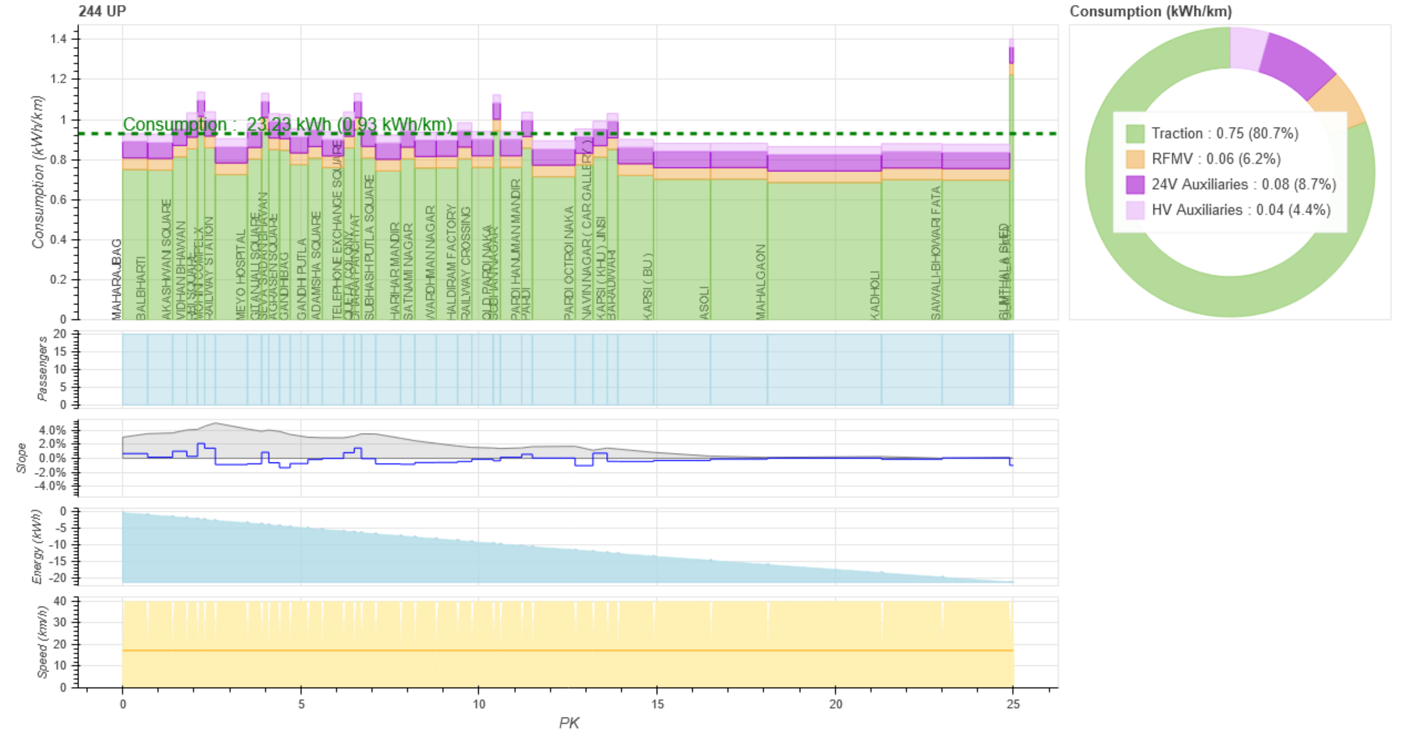
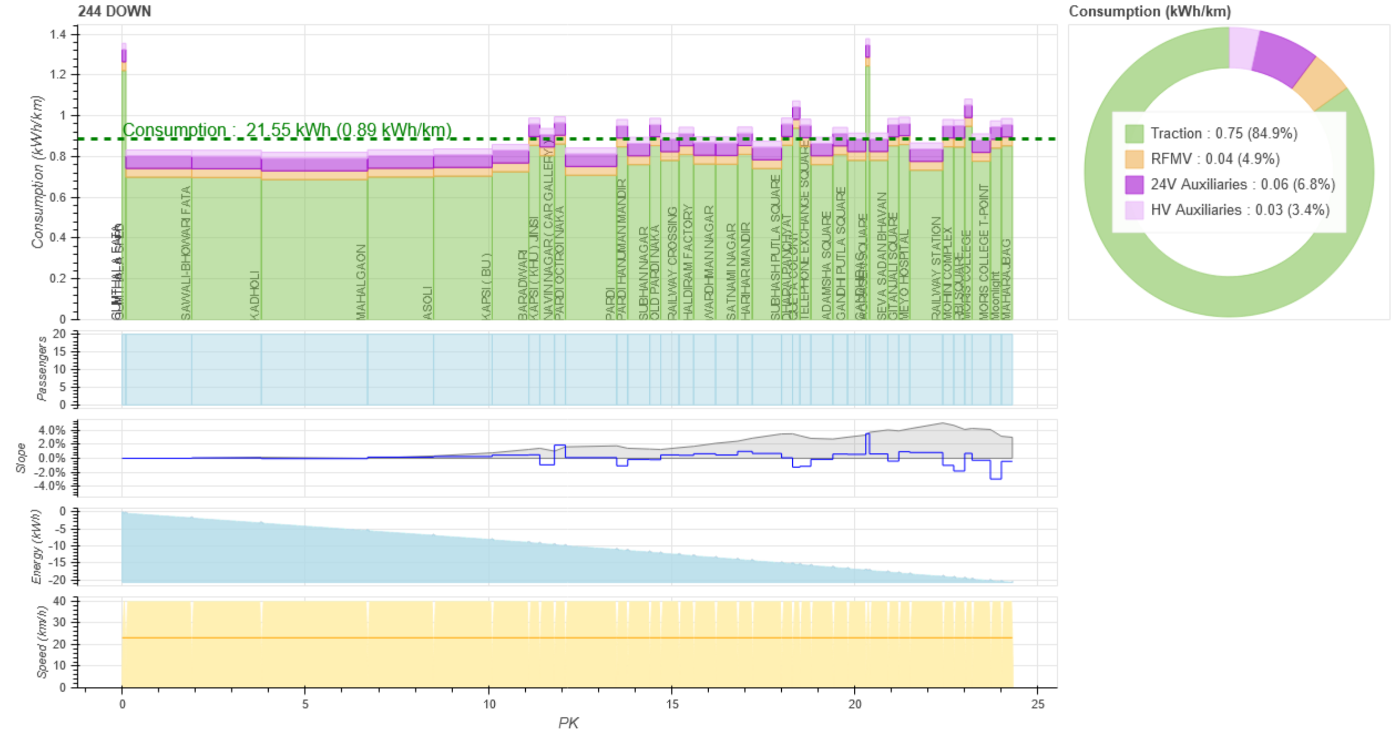
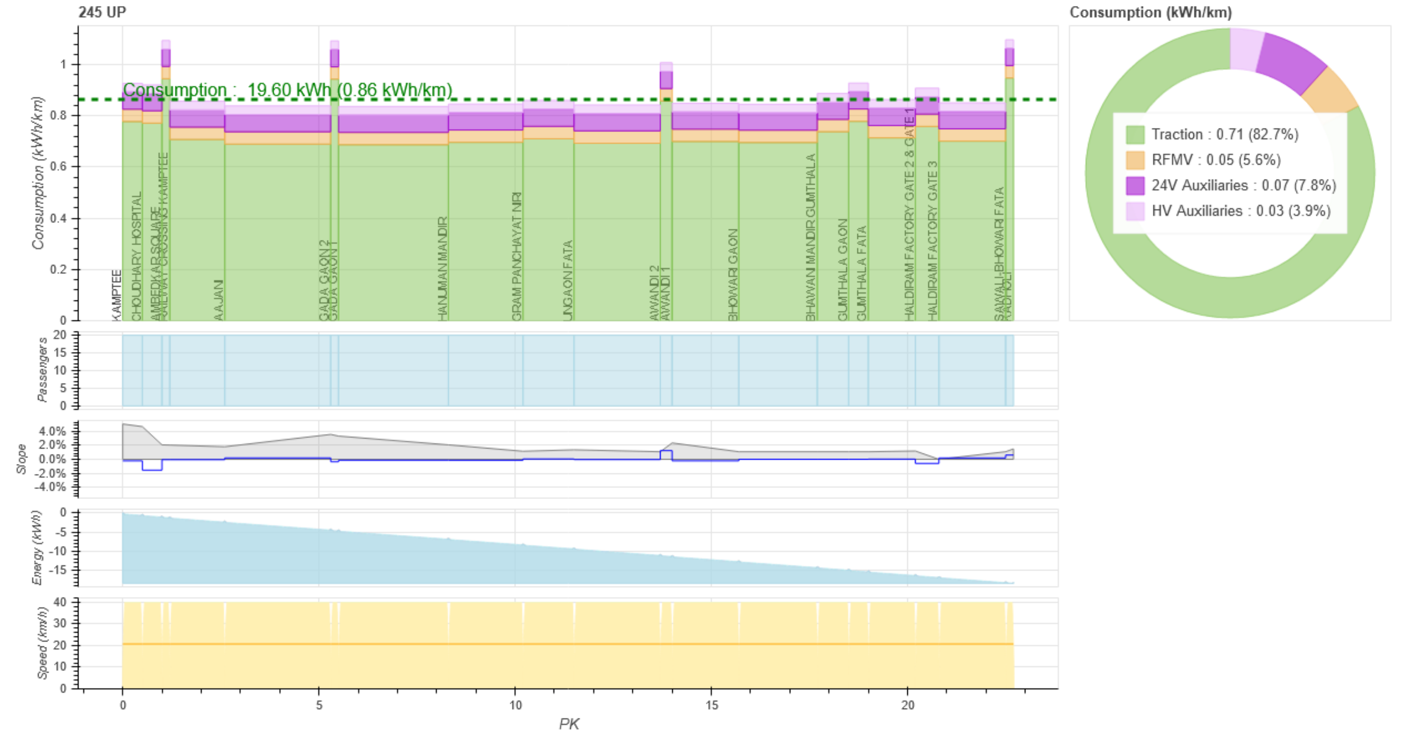
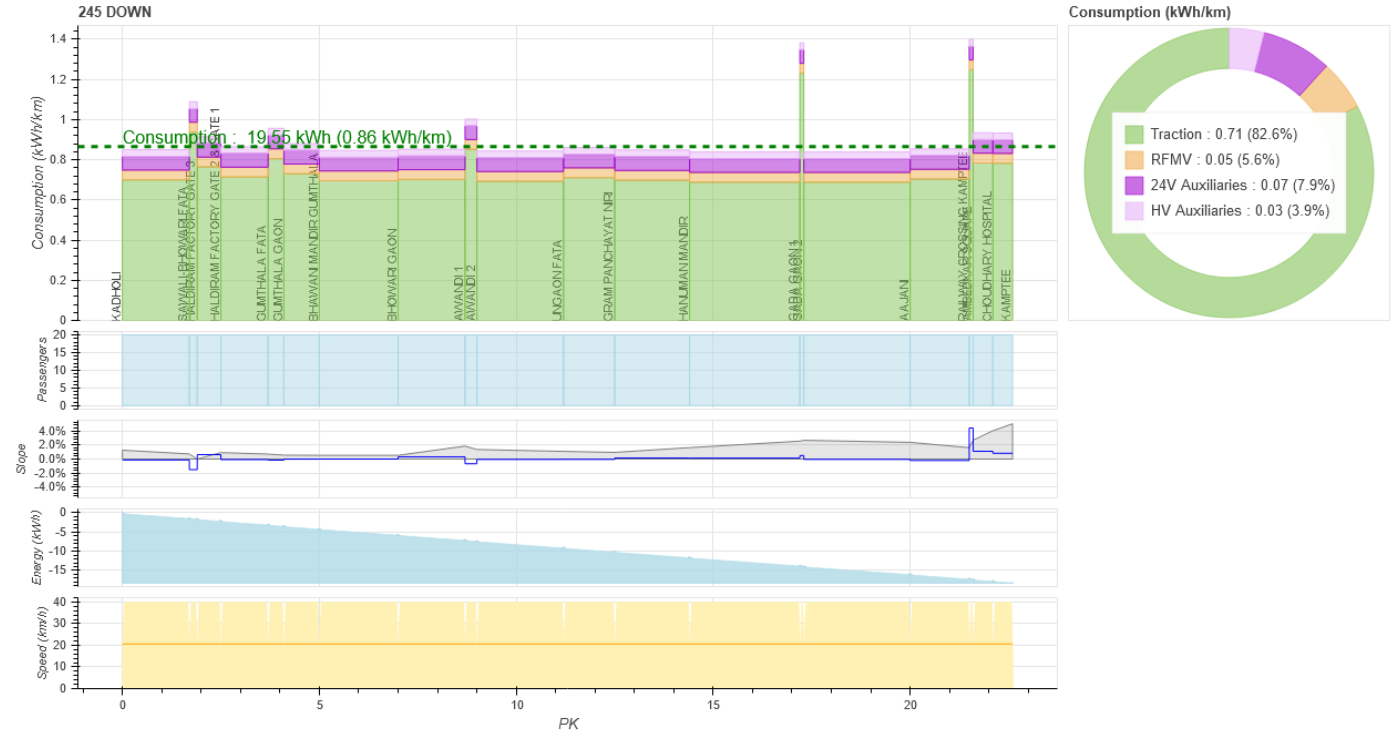
Route	Direction “UP”	Direction “DOWN”
135	 	 
155	 	 

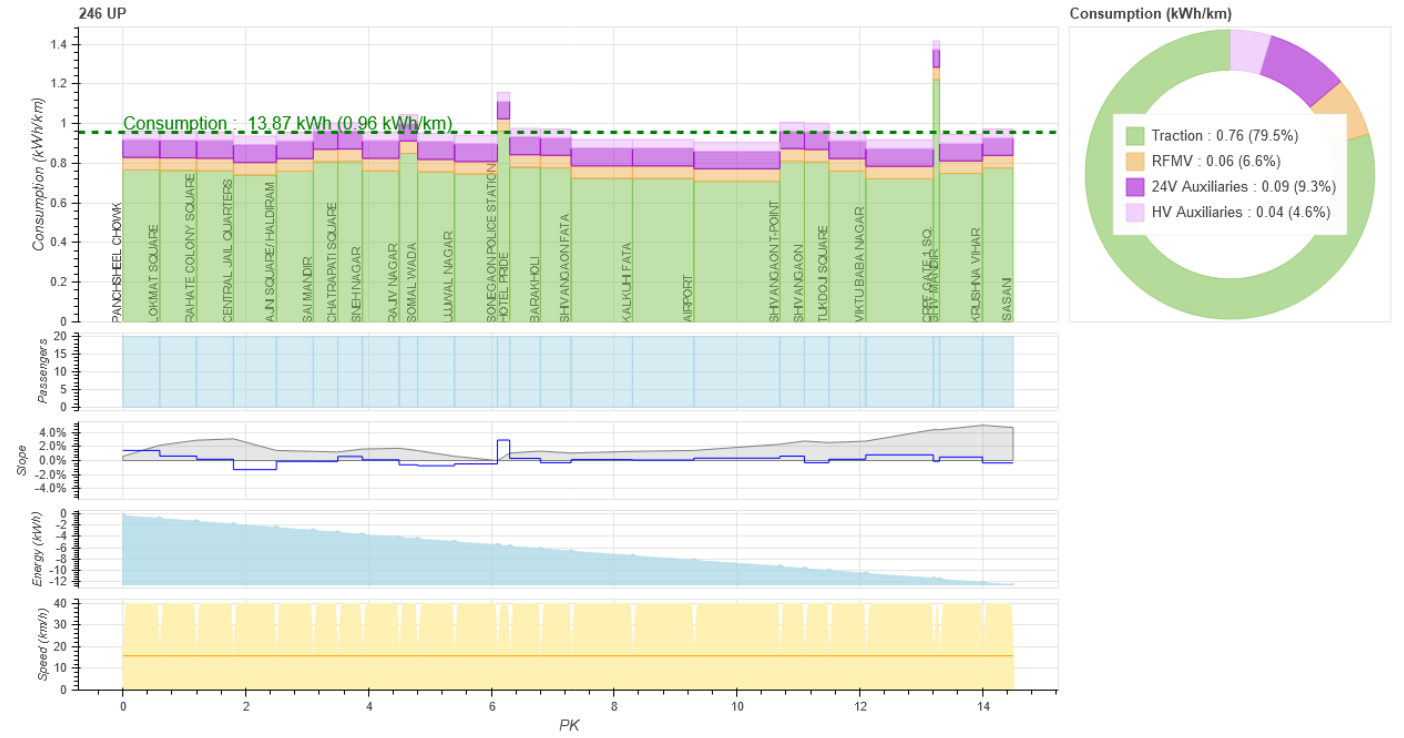
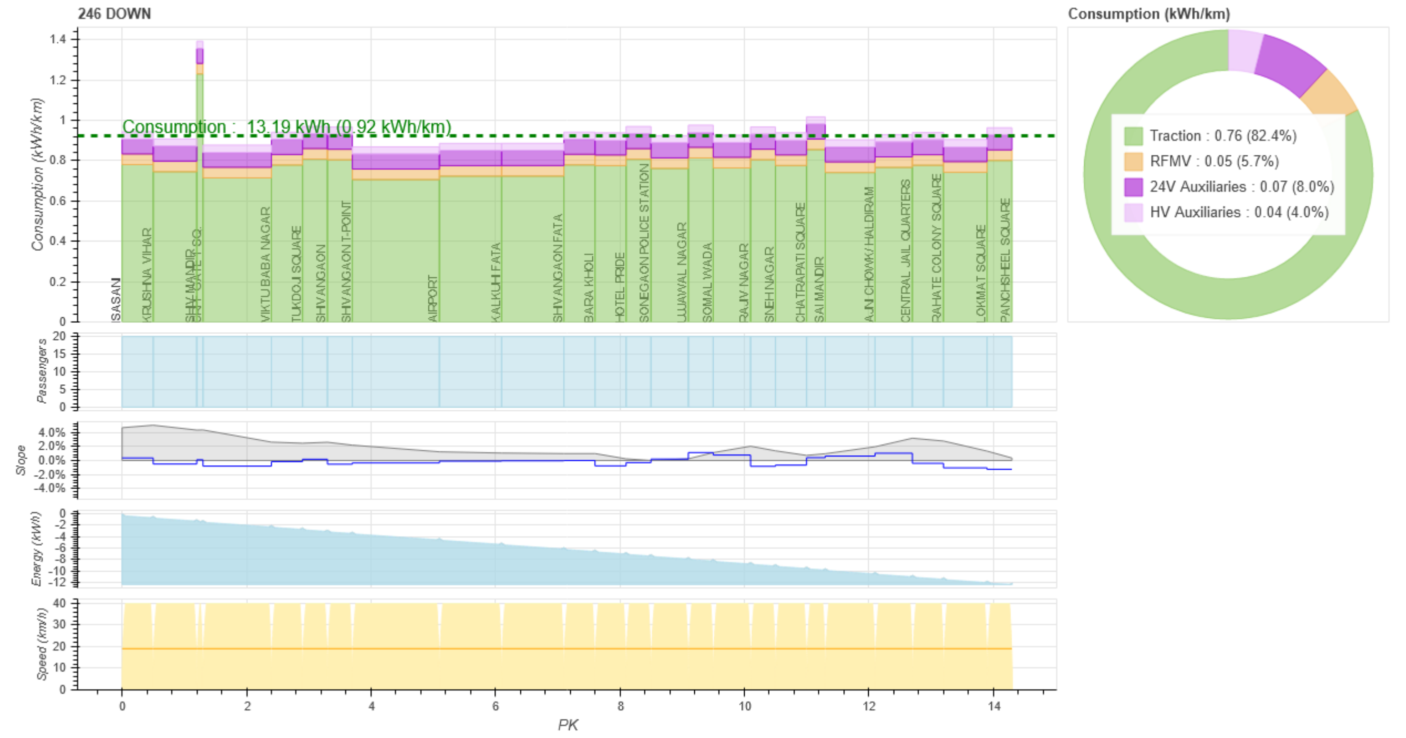
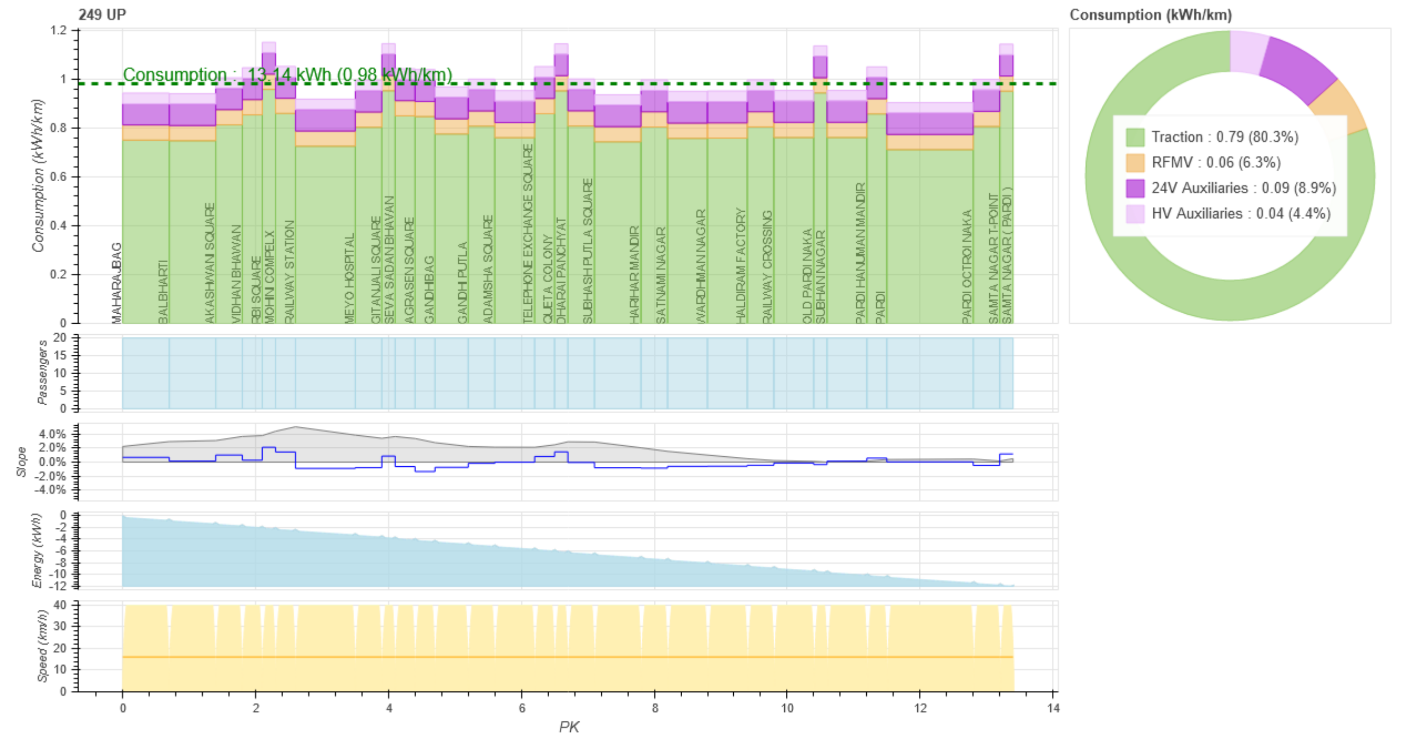
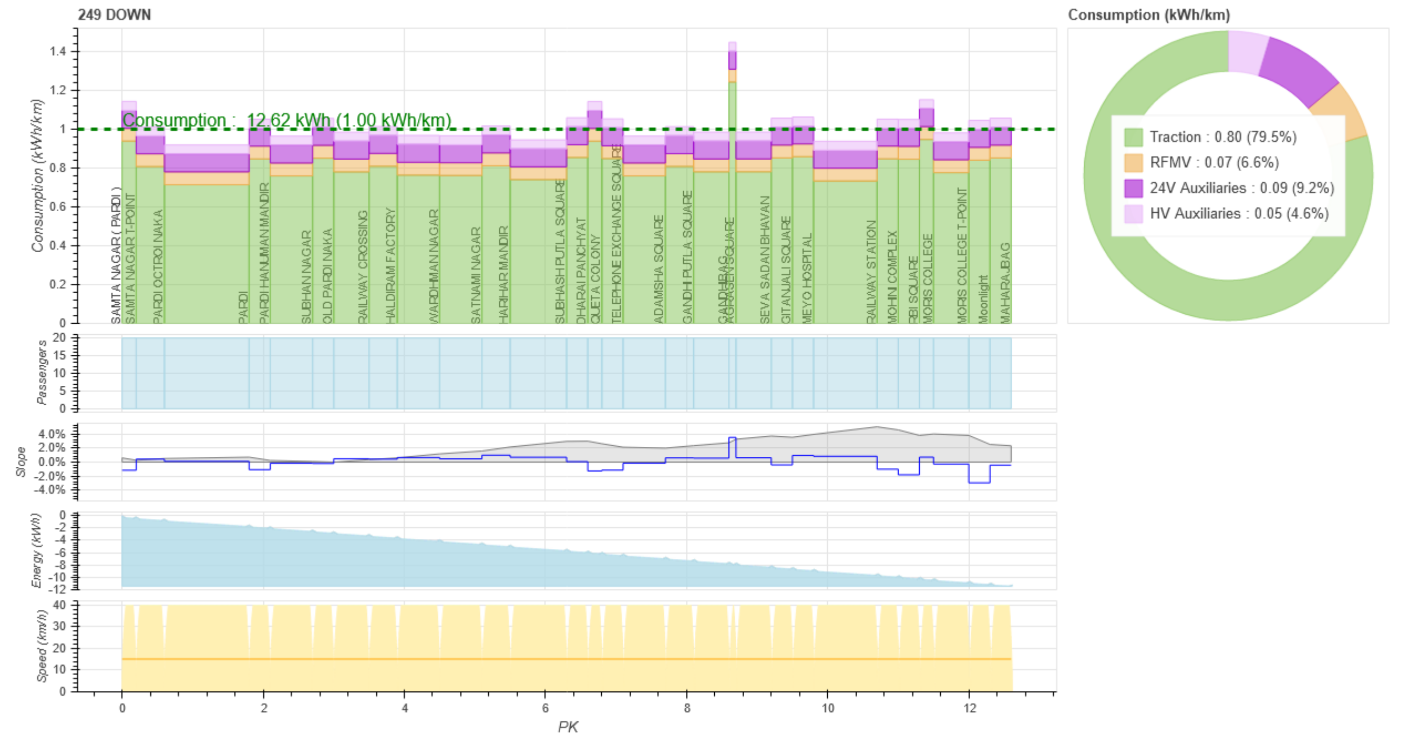
Route	Direction “UP”	Direction “DOWN”
174		
188		

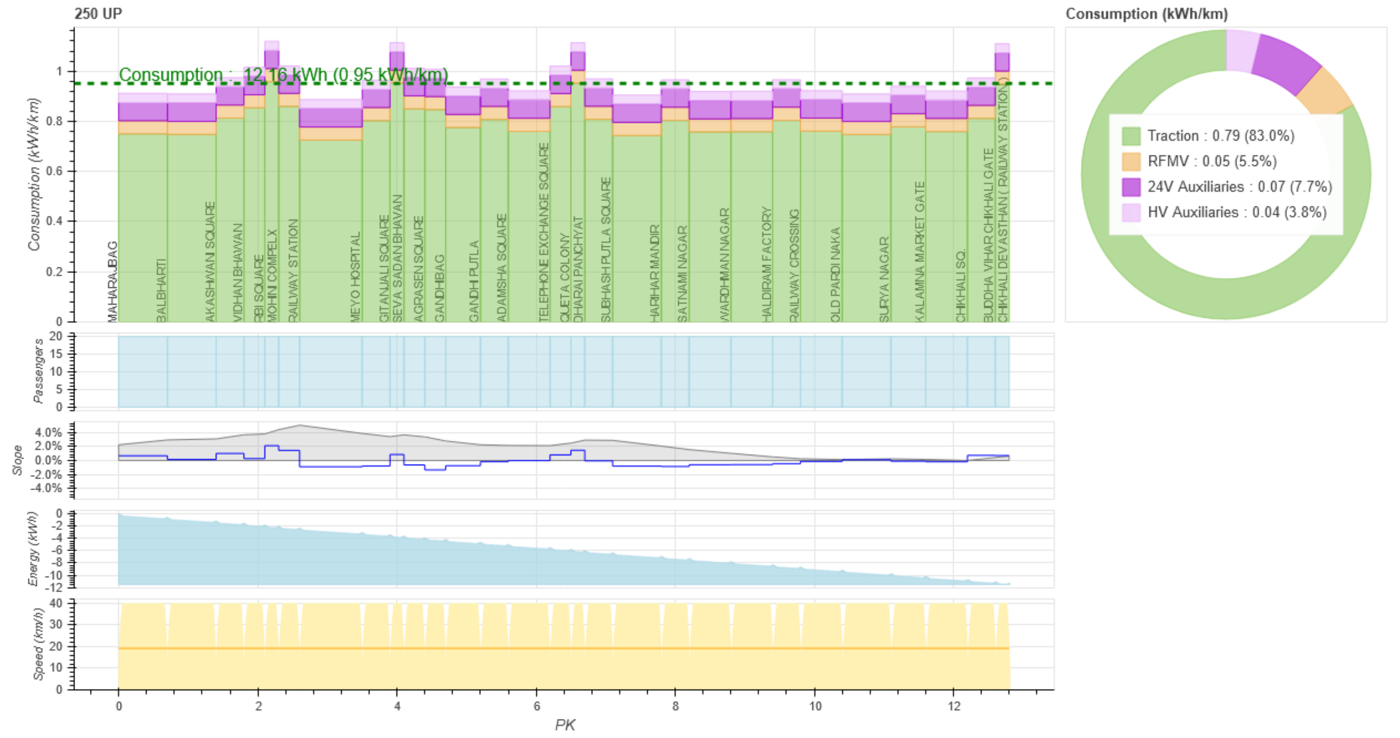
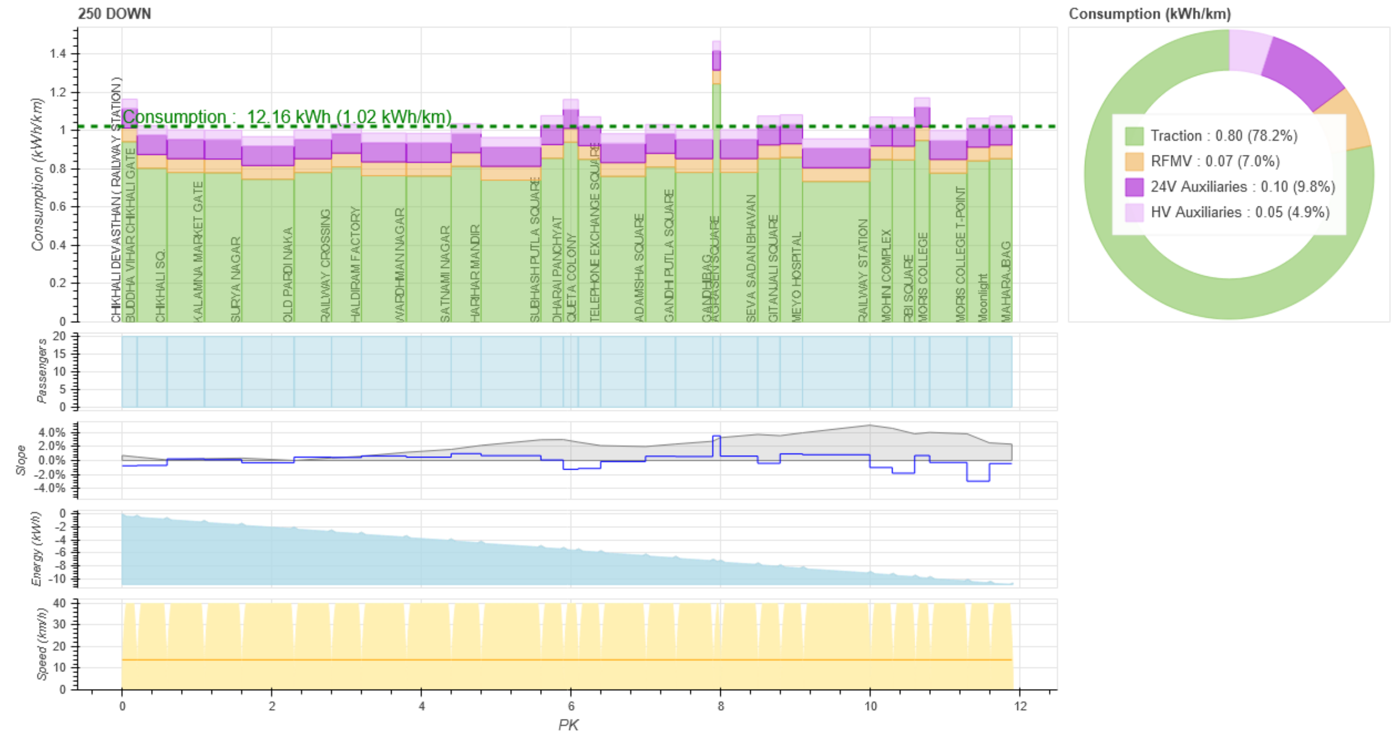
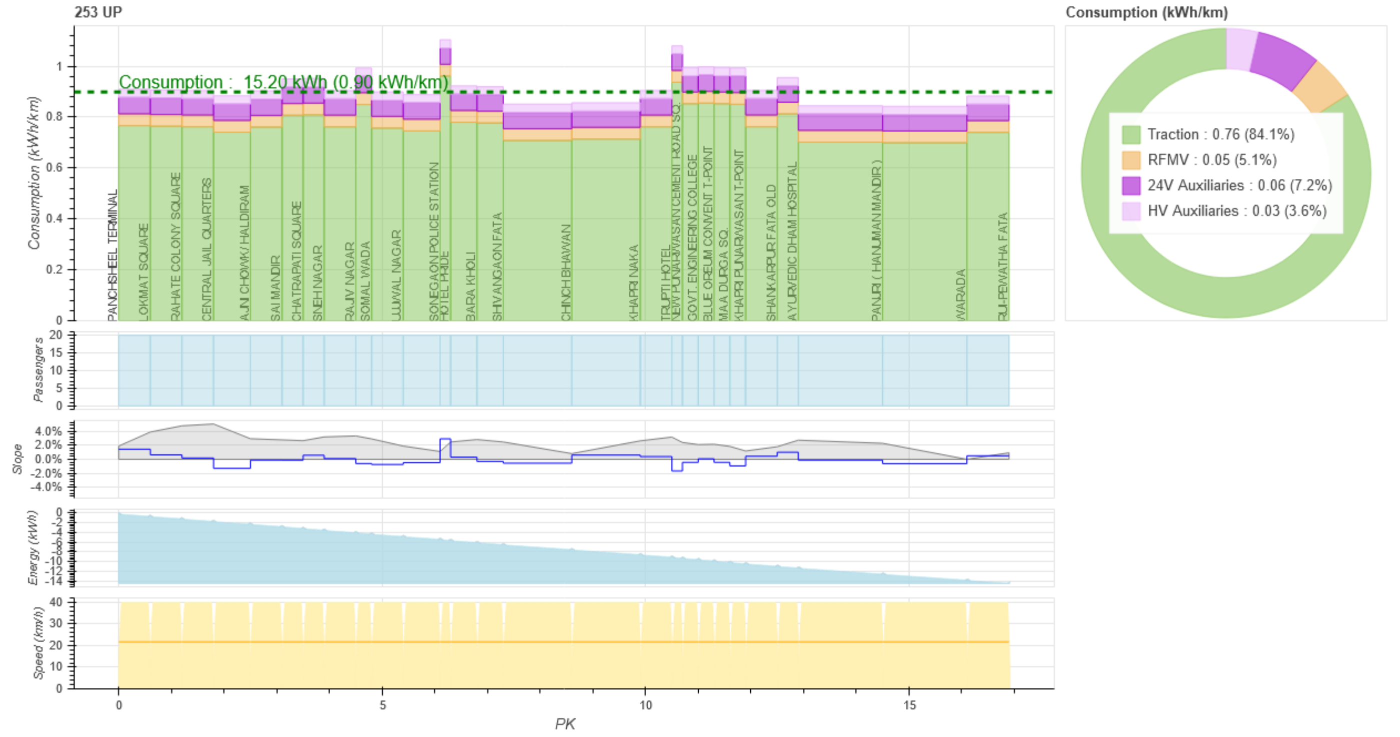
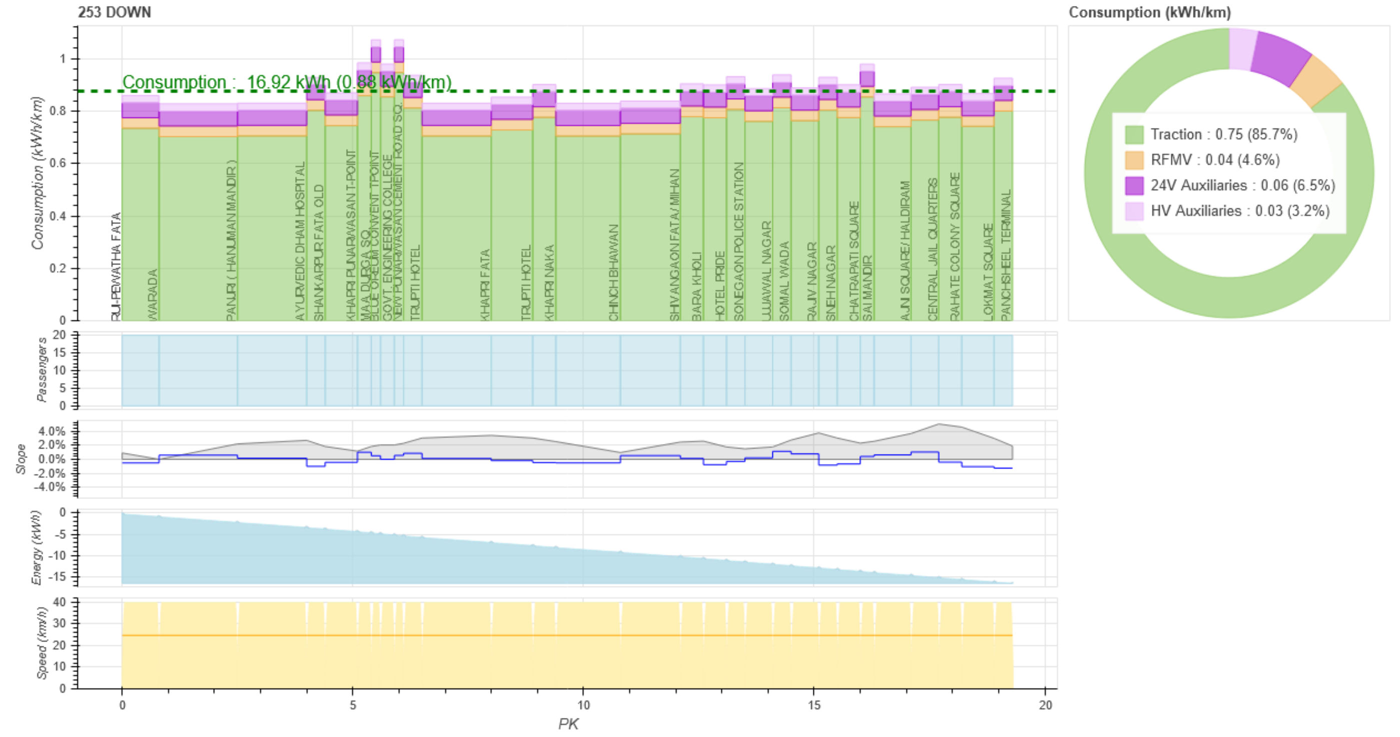
Route	Direction "UP"	Direction "DOWN"
210		
222		

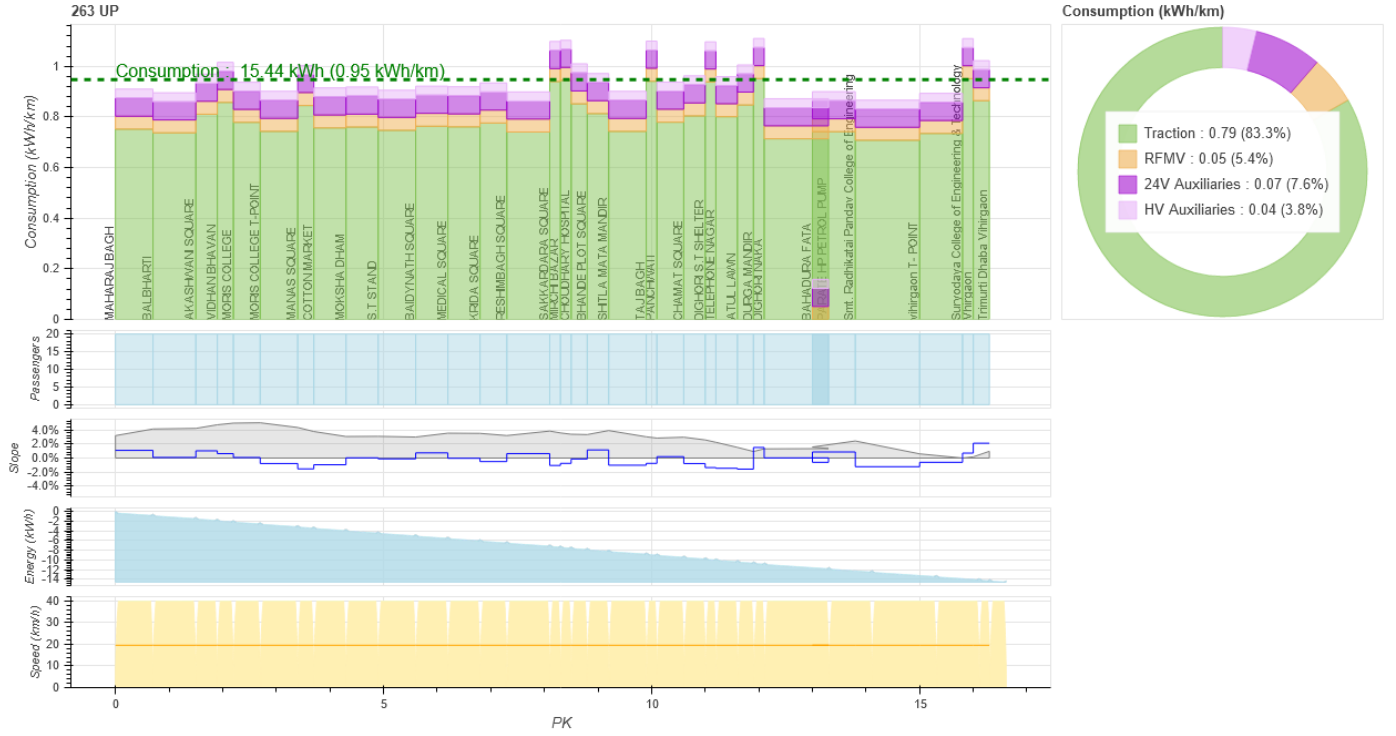
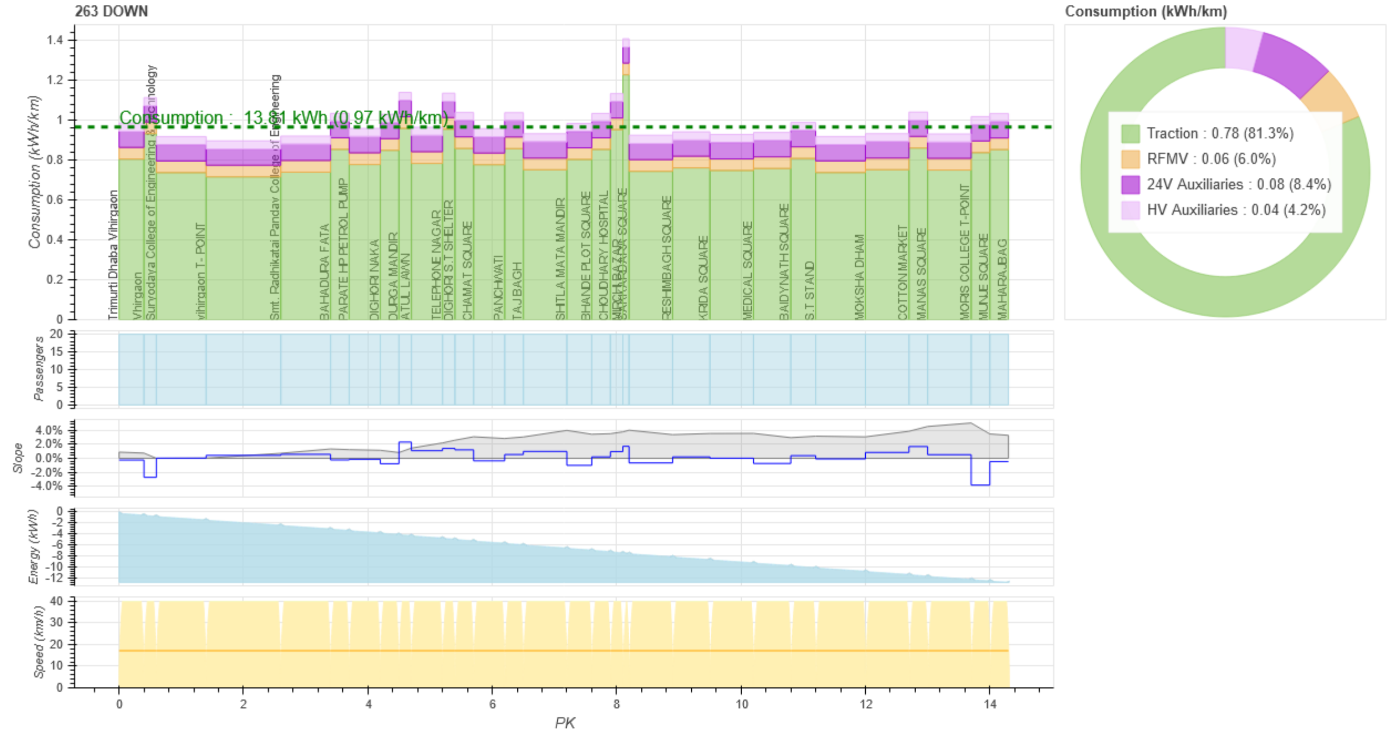
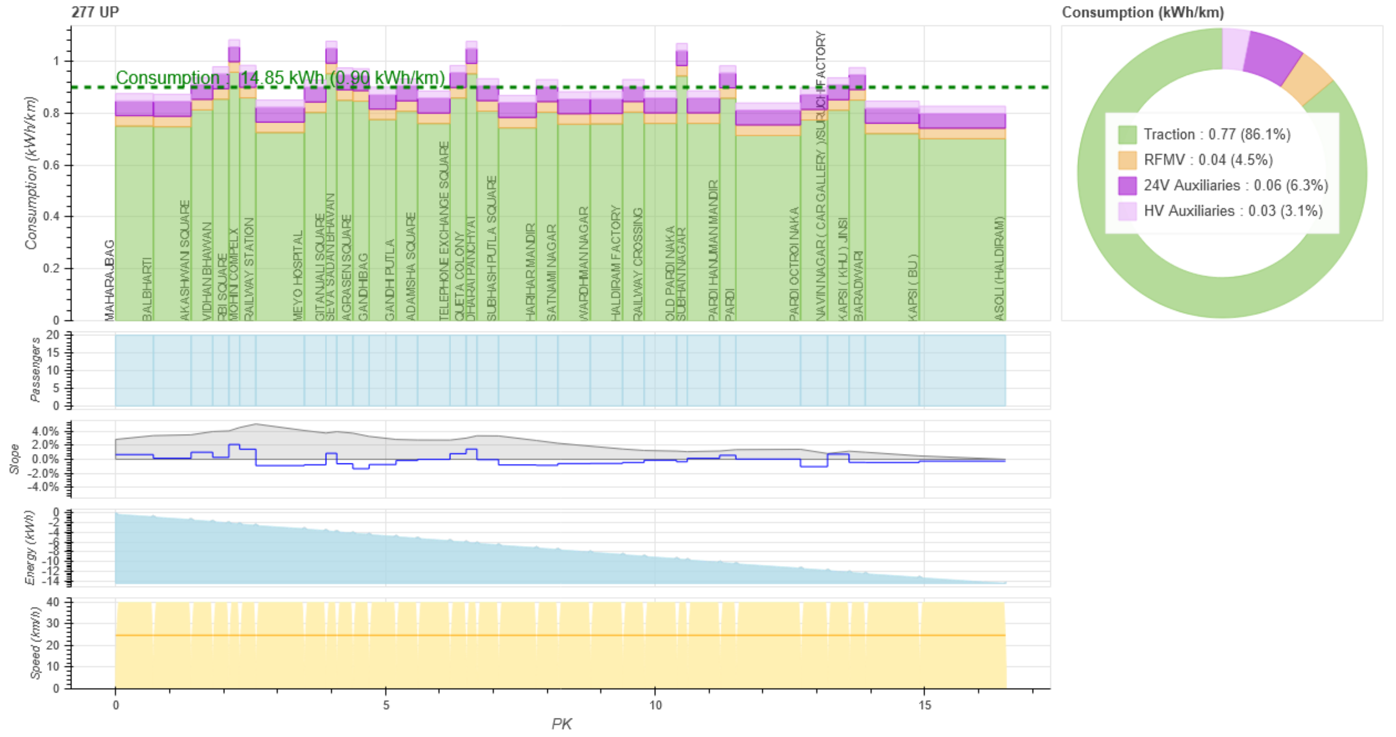
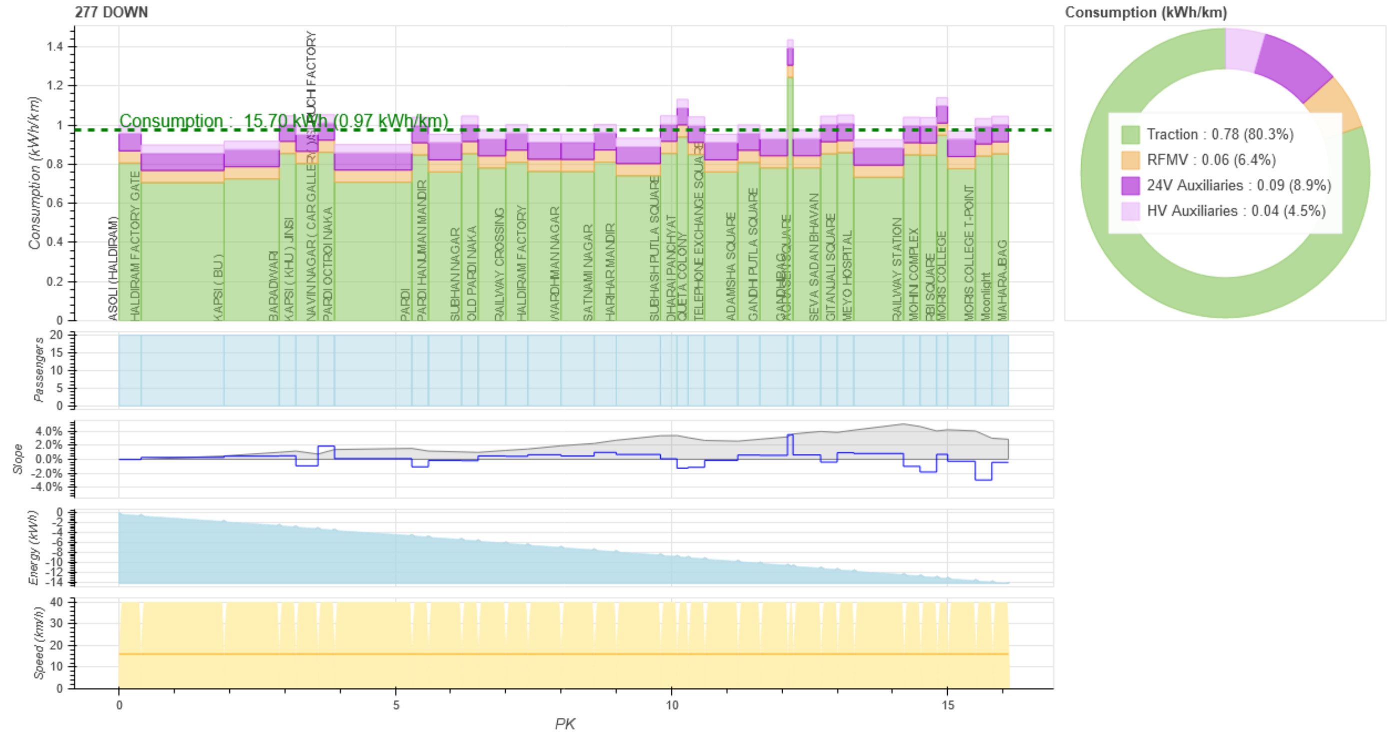
Route	Direction "UP"	Direction "DOWN"
228		
231		

Route	Direction "UP"	Direction "DOWN"
232		N/A
239		

Route	Direction “UP”	Direction “DOWN”
244		
245		

Route	Direction "UP"	Direction "DOWN"
246		
249		

Route	Direction “UP”	Direction “DOWN”
250		
253		

Route	Direction "UP"	Direction "DOWN"
263		
277		

E-buses depot charging simulations results - Scenario “400 kWh batteries”

KHAPRI NAKA BUS DEPOT

- Normal charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/01	107/01	05:40:00	14:15:00	195.1	166.2547	14:18:00	14:22:00	14:25:00	320	153.7453	162.5	1
107/01A	107/01A	13:35:00	23:20:00	217	186.1495	03:43:00	06:38:00	09:45:00	320	133.8505	320	15
107/02	107/02	05:50:00	14:20:00	194.8	166.1955	14:23:00	14:32:00	14:35:00	320	153.8045	177.5	2
107/02A	107/02A	13:45:00	22:45:00	193.9	165.7524	00:02:00	02:49:00	07:45:00	320	154.2476	320	18
107/03	107/03	06:05:00	14:35:00	193.8	165.347	14:38:00	14:42:00	14:45:00	320	154.653	165	1
107/03A	107/03A	13:55:00	23:00:00	193.7	165.422	01:59:00	04:46:00	08:35:00	320	154.578	320	7
107/04	107/04	05:50:00	21:35:00	323.3	275.7053	21:38:00	01:09:00	06:40:00	320	44.29472	320	21
107/05	107/05	06:30:00	15:25:00	197.6	168.5838	15:28:00	18:16:00	05:10:00	320	151.4162	320	1
107/05A	107/05A	14:15:00	23:25:00	193.5	165.0429	02:52:00	05:39:00	10:25:00	320	154.9571	320	18
107/06	107/06	06:40:00	15:35:00	200.4	170.6946	15:38:00	18:27:00	05:20:00	320	149.3054	320	2
107/06A	107/01	14:25:00	22:50:00	183.1	157.0235	01:12:00	04:59:00	07:55:00	162.5	5.476479	320	21
107/07	107/07	05:50:00	15:45:00	213.7	183.2723	15:48:00	18:42:00	05:20:00	320	136.7277	320	3
107/07A	107/02	14:35:00	23:15:00	182	158.6374	03:17:00	06:58:00	09:30:00	177.5	18.86261	320	14
107/08	107/08	06:55:00	15:55:00	194	165.5209	15:58:00	18:45:00	05:30:00	320	154.4791	320	4
107/08A	107/03	14:45:00	23:30:00	181.4	158.1772	03:32:00	07:18:00	10:35:00	165	6.822805	320	19
107/09	107/09	06:10:00	22:10:00	345.2	295.307	22:45:00	02:24:00	07:00:00	320	24.69298	320	9
107/10	107/10	06:20:00	22:20:00	342.9	292.2302	23:14:00	02:52:00	07:10:00	320	27.76976	320	10
107/11	107/11	07:40:00	22:30:00	325.4	277.467	23:42:00	03:14:00	07:30:00	320	42.53299	320	14
107/12	107/12	06:35:00	22:35:00	344.9	294.6822	00:01:00	03:40:00	07:35:00	320	25.31782	320	15
107/13	107/13	07:45:00	22:45:00	327.3	279.1104	23:48:00	03:21:00	07:40:00	320	40.8896	320	17
107/14	107/14	06:50:00	22:55:00	342.3	292.0213	23:27:00	03:05:00	08:10:00	320	27.97875	320	5

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/15	107/15	07:00:00	23:05:00	292.8	252.0961	02:27:00	05:49:00	08:35:00	320	67.90394	320	9
107/16	107/16	07:10:00	23:15:00	346.8	295.9589	02:29:00	06:08:00	08:55:00	320	24.04111	320	13
107/17G	107/17G	07:20:00	17:30:00	217.9	187.0322	17:33:00	20:29:00	05:30:00	320	132.9678	320	5
107/18G	107/18G	07:35:00	17:35:00	216.8	185.6588	17:38:00	20:33:00	05:40:00	320	134.3412	320	6
107/19	107/19	07:45:00	22:50:00	330.9	287.0782	00:22:00	03:58:00	07:45:00	320	32.92181	320	20
107/22G	107/22G	08:35:00	19:40:00	242.9	207.6064	19:43:00	22:47:00	05:50:00	320	112.3936	320	7
107/23G	107/23G	10:35:00	20:40:00	223.8	189.9056	20:43:00	23:40:00	06:10:00	320	130.0944	320	6
107/24G	107/24G	08:45:00	20:00:00	255	216.381	20:03:00	23:11:00	05:50:00	320	103.619	320	10
107/25G	107/25G	07:25:00	19:20:00	286.2	242.8563	19:23:00	22:41:00	05:50:00	320	77.14366	320	3
232/01	232/01	07:15:00	20:55:00	216.3	196.2577	20:58:00	23:58:00	06:20:00	320	123.7423	320	15
232/02	232/02	08:10:00	22:00:00	216.3	196.2577	22:03:00	01:03:00	06:50:00	320	123.7423	320	2
35/07G	35/07G	07:45:00	19:55:00	183.6	175.8343	19:58:00	22:49:00	05:50:00	320	144.1657	320	8
35/08G	35/08G	07:55:00	20:05:00	183.6	175.8343	20:08:00	22:59:00	06:05:00	320	144.1657	320	12
35/09G	35/09G	08:15:00	20:30:00	183.6	175.8343	20:33:00	23:24:00	06:10:00	320	144.1657	320	5
35/10G	35/10G	08:35:00	20:45:00	183.6	175.8343	20:48:00	23:39:00	06:20:00	320	144.1657	320	14
35/11G	35/11G	08:55:00	21:05:00	183.6	175.8343	21:08:00	23:59:00	06:30:00	320	144.1657	320	18
35/12G	35/12G	09:30:00	21:25:00	183.6	175.8343	21:28:00	00:19:00	06:30:00	320	144.1657	320	19
35/13G	35/13G	09:45:00	21:00:00	169.1	161.5382	21:03:00	23:49:00	06:20:00	320	158.4618	320	16
35/14G	35/14G	10:05:00	21:30:00	169.1	161.5382	21:33:00	00:19:00	06:35:00	320	158.4618	320	20
35/15G	35/15G	10:25:00	21:50:00	169.1	161.5382	21:53:00	00:39:00	06:40:00	320	158.4618	320	22
35/16G	35/16G	09:50:00	21:40:00	169.1	161.5382	21:45:00	00:31:00	06:40:00	320	158.4618	320	1
4/01	4/01	05:20:00	22:35:00	245.1	231.1279	23:52:00	03:05:00	07:35:00	320	88.87206	320	16
4/02	4/02	05:40:00	23:05:00	244.7	230.7465	02:05:00	05:18:00	08:35:00	320	89.25353	320	8
4/03	4/03	06:20:00	23:45:00	245.1	231.1279	03:38:00	06:51:00	13:55:00	320	88.87206	320	22

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
4/04	4/04	06:40:00	00:05:00	245.1	231.1279	00:34:00	03:47:00	14:15:00	320	88.87206	320	1
4/05	4/05	05:10:00	22:30:00	245.1	231.1279	23:13:00	02:26:00	07:25:00	320	88.87206	320	13
4/06	4/06	05:50:00	23:10:00	245.1	231.1279	01:58:00	05:11:00	08:55:00	320	88.87206	320	11
4/07	4/07	06:10:00	22:20:00	228.2	215.8726	22:48:00	01:55:00	07:15:00	320	104.1274	320	11
4/08	4/08	06:40:00	22:50:00	228.2	215.8726	00:22:00	03:29:00	07:45:00	320	104.1274	320	19
4/09	4/09	05:30:00	21:55:00	224.8	211.8148	22:50:00	01:56:00	06:50:00	320	108.1852	320	7
4/10	4/10	05:50:00	22:10:00	222.1	212.4226	22:13:00	01:19:00	07:00:00	320	107.5774	320	4
4/11G	4/11G	07:35:00	19:25:00	158.9	153.0783	19:28:00	22:10:00	05:50:00	320	166.9217	320	4
4/12G	4/12G	08:35:00	20:25:00	158.9	153.0783	20:28:00	23:10:00	06:10:00	320	166.9217	320	13
4/13G	4/13G	08:55:00	21:00:00	158.9	153.0783	21:03:00	23:45:00	06:30:00	320	166.9217	320	17
4/14G	4/14G	08:05:00	20:00:00	158.9	153.0783	20:03:00	22:45:00	06:00:00	320	166.9217	320	11
4/16G	4/16G	07:30:00	19:15:00	158.9	153.0783	19:18:00	22:00:00	05:50:00	320	166.9217	320	2
47/01	47/01	05:50:00	23:25:00	253.3	233.1971	03:24:00	06:38:00	10:05:00	320	86.8029	320	17
47/02	47/02	06:10:00	22:00:00	240.5	221.4594	22:52:00	02:02:00	06:55:00	320	98.54056	320	8
47/03	47/03	06:30:00	22:25:00	239.4	219.8093	23:02:00	02:11:00	07:20:00	320	100.1907	320	12
47/04G	47/04G	08:55:00	20:00:00	158.4	145.72	20:03:00	22:42:00	05:50:00	320	174.28	320	9
48/01	48/01	05:30:00	23:05:00	193	195.705	02:55:00	05:54:00	08:45:00	320	124.295	320	10
48/02	48/02	06:00:00	23:20:00	191.9	194.5438	03:08:00	06:07:00	09:50:00	320	125.4562	320	16
48/03	48/03	06:30:00	23:40:00	191.9	194.5438	05:02:00	08:01:00	13:45:00	320	125.4562	320	21
48/04	48/04	07:00:00	22:50:00	177	180.716	00:42:00	03:35:00	08:05:00	320	139.284	320	22
48/05G	48/05G	07:40:00	19:05:00	132.4	133.047	19:08:00	21:42:00	05:40:00	320	186.953	320	1
49/01	49/01	05:20:00	22:55:00	205	203.6844	23:43:00	02:45:00	08:15:00	320	116.3156	320	6
49/02	49/02	05:50:00	23:10:00	205	203.6844	02:14:00	05:16:00	08:55:00	320	116.3156	320	12
49/03	49/03	06:20:00	23:40:00	205	203.6844	04:01:00	07:03:00	13:35:00	320	116.3156	320	20
49/04	49/04	06:50:00	22:40:00	186.4	185.2109	22:44:00	01:39:00	07:40:00	320	134.7891	320	3

KHAPRI NAKA BUS DEPOT

- Optimized charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/01	107/01	05:40:00	14:15:00	195.1	166.2547	14:18:00	14:22:00	14:25:00	320	153.7453	162.5	1
107/01A	107/01A	13:35:00	23:20:00	217	186.1495	04:36:00	07:31:00	09:45:00	320	133.8505	320	15
107/02	107/02	05:50:00	14:20:00	194.8	166.1955	14:23:00	14:32:00	14:35:00	320	153.8045	177.5	2
107/02A	107/02A	13:45:00	22:45:00	193.9	165.7524	00:35:00	03:22:00	07:45:00	320	154.2476	320	18
107/03	107/03	06:05:00	14:35:00	193.8	165.347	14:38:00	14:42:00	14:45:00	320	154.653	165	1
107/03A	107/03A	13:55:00	23:00:00	193.7	165.422	02:15:00	05:02:00	08:35:00	320	154.578	320	7
107/04	107/04	05:50:00	21:35:00	323.3	275.7053	22:12:00	01:43:00	06:40:00	320	44.29472	320	21
107/05	107/05	06:30:00	15:25:00	197.6	168.5838	15:28:00	18:16:00	05:10:00	320	151.4162	320	1
107/05A	107/05A	14:15:00	23:25:00	193.5	165.0429	03:57:00	06:44:00	10:25:00	320	154.9571	320	18
107/06	107/06	06:40:00	15:35:00	200.4	170.6946	15:38:00	18:27:00	05:20:00	320	149.3054	320	2
107/06A	107/01	14:25:00	22:50:00	183.1	157.0235	01:46:00	05:33:00	07:55:00	162.5	5.476479	320	21
107/07	107/07	05:50:00	15:45:00	213.7	183.2723	15:48:00	18:42:00	05:20:00	320	136.7277	320	3
107/07A	107/02	14:35:00	23:15:00	182	158.6374	07:03:00	09:27:00	09:30:00	177.5	18.86261	315.2875	14
107/08	107/08	06:55:00	15:55:00	194	165.5209	15:58:00	18:45:00	05:30:00	320	154.4791	320	4
107/08A	107/03	14:45:00	23:30:00	181.4	158.1772	04:25:00	08:11:00	10:35:00	165	6.822805	320	19
107/09	107/09	06:10:00	22:10:00	345.2	295.307	22:46:00	02:25:00	07:00:00	320	24.69298	320	9
107/10	107/10	06:20:00	22:20:00	342.9	292.2302	01:55:00	05:33:00	07:10:00	320	27.76976	320	10
107/11	107/11	07:40:00	22:30:00	325.4	277.467	03:28:00	07:00:00	07:30:00	320	42.53299	320	14
107/12	107/12	06:35:00	22:35:00	344.9	294.6822	00:25:00	04:04:00	07:35:00	320	25.31782	320	15
107/13	107/13	07:45:00	22:45:00	327.3	279.1104	00:15:00	03:48:00	07:40:00	320	40.8896	320	17
107/14	107/14	06:50:00	22:55:00	342.3	292.0213	23:46:00	03:24:00	08:10:00	320	27.97875	320	5
107/15	107/15	07:00:00	23:05:00	292.8	252.0961	02:28:00	05:50:00	08:35:00	320	67.90394	320	9

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/16	107/16	07:10:00	23:15:00	346.8	295.9589	02:45:00	06:24:00	08:55:00	320	24.04111	320	13
107/17G	107/17G	07:20:00	17:30:00	217.9	187.0322	17:33:00	20:29:00	05:30:00	320	132.9678	320	5
107/18G	107/18G	07:35:00	17:35:00	216.8	185.6588	17:38:00	20:33:00	05:40:00	320	134.3412	320	6
107/19	107/19	07:45:00	22:50:00	330.9	287.0782	00:55:00	04:31:00	07:45:00	320	32.92181	320	20
107/22G	107/22G	08:35:00	19:40:00	242.9	207.6064	19:43:00	22:47:00	05:50:00	320	112.3936	320	7
107/23G	107/23G	10:35:00	20:40:00	223.8	189.9056	20:57:00	23:54:00	06:10:00	320	130.0944	320	6
107/24G	107/24G	08:45:00	20:00:00	255	216.381	20:03:00	23:11:00	05:50:00	320	103.619	320	10
107/25G	107/25G	07:25:00	19:20:00	286.2	242.8563	19:23:00	22:41:00	05:50:00	320	77.14366	320	3
232/01	232/01	07:15:00	20:55:00	216.3	196.2577	21:14:00	00:14:00	06:20:00	320	123.7423	320	15
232/02	232/02	08:10:00	22:00:00	216.3	196.2577	22:36:00	01:36:00	06:50:00	320	123.7423	320	2
35/07G	35/07G	07:45:00	19:55:00	183.6	175.8343	19:58:00	22:49:00	05:50:00	320	144.1657	320	8
35/08G	35/08G	07:55:00	20:05:00	183.6	175.8343	20:19:00	23:10:00	06:05:00	320	144.1657	320	12
35/09G	35/09G	08:15:00	20:30:00	183.6	175.8343	20:52:00	23:43:00	06:10:00	320	144.1657	320	5
35/10G	35/10G	08:35:00	20:45:00	183.6	175.8343	21:04:00	23:55:00	06:20:00	320	144.1657	320	14
35/11G	35/11G	08:55:00	21:05:00	183.6	175.8343	21:41:00	00:32:00	06:30:00	320	144.1657	320	18
35/12G	35/12G	09:30:00	21:25:00	183.6	175.8343	21:54:00	00:45:00	06:30:00	320	144.1657	320	19
35/13G	35/13G	09:45:00	21:00:00	169.1	161.5382	21:21:00	00:07:00	06:20:00	320	158.4618	320	16
35/14G	35/14G	10:05:00	21:30:00	169.1	161.5382	22:03:00	00:49:00	06:35:00	320	158.4618	320	20
35/15G	35/15G	10:25:00	21:50:00	169.1	161.5382	22:26:00	01:12:00	06:40:00	320	158.4618	320	22
35/16G	35/16G	09:50:00	21:40:00	169.1	161.5382	22:19:00	01:05:00	06:40:00	320	158.4618	320	1
4/01	4/01	05:20:00	22:35:00	245.1	231.1279	03:40:00	06:53:00	07:35:00	320	88.87206	320	16
4/02	4/02	05:40:00	23:05:00	244.7	230.7465	02:09:00	05:22:00	08:35:00	320	89.25353	320	8
4/03	4/03	06:20:00	23:45:00	245.1	231.1279	04:50:00	08:03:00	13:55:00	320	88.87206	320	22
4/04	4/04	06:40:00	00:05:00	245.1	231.1279	01:09:00	04:22:00	14:15:00	320	88.87206	320	1

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
4/05	4/05	05:10:00	22:30:00	245.1	231.1279	23:29:00	02:42:00	07:25:00	320	88.87206	320	13
4/06	4/06	05:50:00	23:10:00	245.1	231.1279	05:47:00	08:52:00	08:55:00	320	88.87206	319.9582	11
4/07	4/07	06:10:00	22:20:00	228.2	215.8726	02:37:00	05:44:00	07:15:00	320	104.1274	320	11
4/08	4/08	06:40:00	22:50:00	228.2	215.8726	00:48:00	03:55:00	07:45:00	320	104.1274	320	19
4/09	4/09	05:30:00	21:55:00	224.8	211.8148	23:06:00	02:12:00	06:50:00	320	108.1852	320	7
4/10	4/10	05:50:00	22:10:00	222.1	212.4226	23:17:00	02:23:00	07:00:00	320	107.5774	320	4
4/11G	4/11G	07:35:00	19:25:00	158.9	153.0783	19:28:00	22:10:00	05:50:00	320	166.9217	320	4
4/12G	4/12G	08:35:00	20:25:00	158.9	153.0783	20:44:00	23:26:00	06:10:00	320	166.9217	320	13
4/13G	4/13G	08:55:00	21:00:00	158.9	153.0783	21:30:00	00:12:00	06:30:00	320	166.9217	320	17
4/14G	4/14G	08:05:00	20:00:00	158.9	153.0783	20:03:00	22:45:00	06:00:00	320	166.9217	320	11
4/16G	4/16G	07:30:00	19:15:00	158.9	153.0783	19:18:00	22:00:00	05:50:00	320	166.9217	320	2
47/01	47/01	05:50:00	23:25:00	253.3	233.1971	04:08:00	07:22:00	10:05:00	320	86.8029	320	17
47/02	47/02	06:10:00	22:00:00	240.5	221.4594	22:56:00	02:06:00	06:55:00	320	98.54056	320	8
47/03	47/03	06:30:00	22:25:00	239.4	219.8093	03:08:00	06:17:00	07:20:00	320	100.1907	320	12
47/04G	47/04G	08:55:00	20:00:00	158.4	145.72	20:03:00	22:42:00	05:50:00	320	174.28	320	9
48/01	48/01	05:30:00	23:05:00	193	195.705	05:36:00	08:35:00	08:45:00	320	124.295	320	10
48/02	48/02	06:00:00	23:20:00	191.9	194.5438	06:56:00	09:47:00	09:50:00	320	125.4562	319.9582	16
48/03	48/03	06:30:00	23:40:00	191.9	194.5438	05:36:00	08:35:00	13:45:00	320	125.4562	320	21
48/04	48/04	07:00:00	22:50:00	177	180.716	01:28:00	04:21:00	08:05:00	320	139.284	320	22
48/05G	48/05G	07:40:00	19:05:00	132.4	133.047	19:08:00	21:42:00	05:40:00	320	186.953	320	1
49/01	49/01	05:20:00	22:55:00	205	203.6844	23:57:00	02:59:00	08:15:00	320	116.3156	320	6
49/02	49/02	05:50:00	23:10:00	205	203.6844	06:20:00	08:52:00	08:55:00	320	116.3156	319.6889	12
49/03	49/03	06:20:00	23:40:00	205	203.6844	04:59:00	08:01:00	13:35:00	320	116.3156	320	20
49/04	49/04	06:50:00	22:40:00	186.4	185.2109	03:49:00	06:44:00	07:40:00	320	134.7891	320	3

HIGNA NAKA BUS DEPOT

- Normal charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
106/01	106/01	04:55:00	21:50:00	204.5	197.96	22:09:00	01:09:00	06:10:00	320	122.04	320	5
106/02	106/02	05:35:00	22:25:00	207.8	201.1888	23:21:00	02:22:00	06:35:00	320	118.8112	320	13
106/03	106/03	05:45:00	22:30:00	206.3	200.4556	23:46:00	02:47:00	06:45:00	320	119.5444	320	15
106/04	106/04	05:55:00	22:40:00	215.2	209.7555	00:30:00	03:35:00	07:05:00	320	110.2445	320	20
106/05	106/05	06:05:00	23:05:00	222	215.1316	02:06:00	05:13:00	08:10:00	320	104.8684	320	9
106/07	106/07	06:25:00	23:15:00	215.2	209.7555	02:17:00	05:22:00	08:25:00	320	110.2445	320	12
106/08	106/08	06:35:00	23:25:00	206.9	201.2875	02:50:00	05:52:00	08:40:00	320	118.7125	320	15
106/10	106/10	07:05:00	23:50:00	208	202.4659	03:38:00	06:40:00	09:20:00	320	117.5341	320	20
106/11	106/11	07:15:00	00:10:00	208.9	203.3679	04:35:00	07:37:00	09:20:00	320	116.6321	320	21
106/12	106/12	07:25:00	00:25:00	214.7	207.091	02:48:00	05:52:00	09:40:00	320	112.909	320	1
135/01	135/01	05:20:00	22:30:00	286.6	265.3672	00:05:00	03:32:00	06:50:00	320	54.63282	320	17
135/02	135/02	05:50:00	22:40:00	287.4	265.8907	00:51:00	04:18:00	07:15:00	320	54.10928	320	22
135/03	135/03	06:00:00	22:05:00	270.2	249.9017	22:42:00	02:03:00	06:25:00	320	70.09831	320	9
135/04	135/04	08:05:00	23:40:00	270.2	249.9017	03:50:00	07:11:00	09:00:00	320	70.09831	320	18
135/05	135/05	07:15:00	22:20:00	239.7	222.186	23:10:00	02:20:00	06:30:00	320	97.81398	320	11
135/06	135/06	06:25:00	22:30:00	270	249.7198	23:35:00	02:56:00	06:40:00	320	70.28021	320	14
135/07	135/07	07:40:00	21:40:00	231.6	214.1916	21:43:00	00:50:00	06:10:00	320	105.8084	320	4
135/08	135/08	05:50:00	22:40:00	286.6	265.0689	00:20:00	03:47:00	07:00:00	320	54.93108	320	18
135/09	135/09	06:00:00	21:50:00	267.4	247.3017	21:53:00	01:13:00	06:15:00	320	72.69832	320	21
135/10	135/10	06:10:00	22:00:00	267.4	247.3017	22:30:00	01:50:00	06:20:00	320	72.69832	320	6
135/11	135/11	06:20:00	22:55:00	286.6	265.0689	01:15:00	04:42:00	07:20:00	320	54.93108	320	3
135/12	135/12	06:30:00	23:10:00	286.6	264.7644	02:16:00	05:43:00	08:20:00	320	55.23562	320	10

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
135/13G	135/13G	08:10:00	19:55:00	183.2	169.4238	19:58:00	22:47:00	05:35:00	320	150.5762	320	8
135/14G	135/14G	08:20:00	20:05:00	183.2	169.4238	20:08:00	22:57:00	05:45:00	320	150.5762	320	10
135/15G	135/15G	08:30:00	20:15:00	183.2	169.4238	20:18:00	23:07:00	05:45:00	320	150.5762	320	11
135/16G	135/16G	08:40:00	20:25:00	184.4	171.7047	20:28:00	23:18:00	05:50:00	320	148.2953	320	13
135/17G	135/17G	08:50:00	20:35:00	198.4	183.4996	20:38:00	23:32:00	05:50:00	320	136.5004	320	14
135/18G	135/18G	09:00:00	20:45:00	199	184.0642	20:48:00	23:43:00	06:00:00	320	135.9358	320	15
135/19G	135/19G	09:10:00	20:55:00	181.4	169.3327	20:58:00	23:47:00	06:00:00	320	150.6673	320	16
135/20G	135/20G	09:20:00	21:05:00	198.4	183.4996	21:08:00	00:02:00	06:00:00	320	136.5004	320	17
135/21G	135/21G	09:30:00	21:20:00	198.4	183.4996	21:23:00	00:17:00	06:05:00	320	136.5004	320	18
135/22G	135/22G	07:45:00	19:35:00	183.3	170.2119	19:38:00	22:27:00	05:30:00	320	149.7881	320	6
135/23G	135/23G	07:00:00	19:10:00	195	180.5299	19:13:00	22:06:00	05:20:00	320	139.4701	320	5
28/01	28/01	05:15:00	23:05:00	218.8	213.0738	02:22:00	05:28:00	08:10:00	320	106.9262	320	8
28/02	28/02	05:45:00	23:35:00	210.1	203.087	03:35:00	06:37:00	08:50:00	320	116.913	320	17
28/03	28/03	06:10:00	23:40:00	228.4	220.9423	03:13:00	06:22:00	09:10:00	320	99.05768	320	19
28/04	28/04	06:45:00	00:10:00	210.8	206.9647	04:21:00	07:25:00	09:30:00	320	113.0353	320	22
28/05	28/05	07:05:00	22:45:00	202	194.9722	23:46:00	02:45:00	07:15:00	320	125.0278	320	1
28/06	28/06	07:15:00	23:20:00	219.1	209.4157	02:59:00	06:04:00	08:35:00	320	110.5843	320	14
28/07	28/07	07:20:00	21:00:00	170.3	163.397	21:03:00	23:49:00	06:00:00	320	156.603	320	2
28/08G	28/08G	08:10:00	19:50:00	136.8	133.8775	19:53:00	22:28:00	05:35:00	320	186.1225	320	7
28/09G	28/09G	08:20:00	20:00:00	141.5	138.7133	20:03:00	22:39:00	05:45:00	320	181.2867	320	9
28/10G	28/10G	08:40:00	20:20:00	136.8	134.3962	20:23:00	22:58:00	05:50:00	320	185.6038	320	12
28/12G	28/12G	09:40:00	21:20:00	136.5	133.8558	21:23:00	23:58:00	06:10:00	320	186.1442	320	19
32/01	32/01	06:10:00	22:20:00	234.5	229.5491	23:01:00	02:14:00	06:35:00	320	90.45092	320	12
32/02	32/02	06:45:00	22:15:00	234.5	229.5491	23:00:00	02:13:00	06:30:00	320	90.45092	320	10

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
32/03	32/03	05:45:00	22:30:00	228.9	224.4265	23:50:00	03:01:00	06:45:00	320	95.57349	320	16
32/04G	32/04G	08:25:00	18:55:00	145	142.0848	18:58:00	21:36:00	05:15:00	320	177.9152	320	4
35/17G	35/17G	08:35:00	20:40:00	202.7	193.5966	20:45:00	23:43:00	05:55:00	320	126.4034	320	1
35/18G	35/18G	05:35:00	17:45:00	191.5	182.0235	17:48:00	20:42:00	04:55:00	320	137.9765	320	1
35/19G	35/19G	06:15:00	18:05:00	183.5	175.1588	18:08:00	20:59:00	05:00:00	320	144.8412	320	2
35/20G	35/20G	06:35:00	18:40:00	183.5	175.1588	18:43:00	21:34:00	05:10:00	320	144.8412	320	3
40/01	40/01	05:30:00	22:55:00	255.2	237.2711	00:53:00	04:09:00	07:25:00	320	82.72886	320	4
40/02	40/02	06:00:00	23:00:00	255.2	237.2711	01:38:00	04:54:00	08:05:00	320	82.72886	320	7
40/03	40/03	06:10:00	23:00:00	255.2	237.2711	01:53:00	05:09:00	07:45:00	320	82.72886	320	6
40/04	40/04	06:20:00	23:10:00	255.2	237.2711	02:23:00	05:39:00	08:20:00	320	82.72886	320	11
40/05	40/05	05:50:00	22:40:00	254.2	236.5947	01:16:00	04:32:00	07:05:00	320	83.40534	320	21
40/06	40/06	06:00:00	22:50:00	254.2	236.5947	23:52:00	03:08:00	07:15:00	320	83.40534	320	2
40/07	40/07	06:10:00	23:00:00	252.3	236.3251	01:12:00	04:28:00	07:40:00	320	83.6749	320	5
40/08	40/08	06:20:00	21:20:00	222.9	207.4719	21:23:00	00:27:00	06:10:00	320	112.5281	320	20
40/09	40/09	06:30:00	23:15:00	254.2	236.5947	02:25:00	05:41:00	08:30:00	320	83.40534	320	13
40/10	40/10	06:40:00	23:35:00	254.2	236.5947	03:04:00	06:20:00	08:40:00	320	83.40534	320	16
40/11	40/11	06:50:00	22:40:00	235.9	219.3905	00:01:00	03:10:00	07:00:00	320	100.6095	320	19
40/12	40/12	07:00:00	22:05:00	222.9	207.4719	22:31:00	01:35:00	06:20:00	320	112.5281	320	7
42/02G	42/02G	09:20:00	21:50:00	213	184.0527	21:53:00	00:48:00	06:20:00	320	135.9473	320	22
54/01	54/01	05:00:00	21:40:00	311.4	269.3459	21:43:00	01:12:00	06:10:00	320	50.65409	320	3
54/02	54/02	05:10:00	22:05:00	311.4	269.3459	22:50:00	02:19:00	06:25:00	320	50.65409	320	8

HIGNA NAKA BUS DEPOT

- Optimized charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
106/01	106/01	04:55:00	21:50:00	204.5	197.96	22:11:00	01:11:00	06:10:00	320	122.04	320	5
106/02	106/02	05:35:00	22:25:00	207.8	201.1888	23:21:00	02:22:00	06:35:00	320	118.8112	320	13
106/03	106/03	05:45:00	22:30:00	206.3	200.4556	03:23:00	06:24:00	06:45:00	320	119.5444	320	15
106/04	106/04	05:55:00	22:40:00	215.2	209.7555	00:49:00	03:54:00	07:00:00	320	110.2445	320	20
106/05	106/05	06:05:00	23:05:00	222	215.1316	03:04:00	06:11:00	08:10:00	320	104.8684	320	9
106/07	106/07	06:25:00	23:15:00	215.2	209.7555	03:45:00	06:50:00	08:25:00	320	110.2445	320	12
106/08	106/08	06:35:00	23:25:00	206.9	201.2875	06:27:00	08:37:00	08:40:00	320	118.7125	318.8173	15
106/10	106/10	07:05:00	23:50:00	208	202.4659	04:27:00	07:29:00	09:20:00	320	117.5341	320	20
106/11	106/11	07:15:00	00:10:00	208.9	203.3679	04:44:00	07:46:00	09:20:00	320	116.6321	320	21
106/12	106/12	07:25:00	00:25:00	214.7	207.091	02:56:00	06:00:00	09:40:00	320	112.909	320	1
135/01	135/01	05:20:00	22:30:00	286.6	265.3672	04:11:00	06:47:00	06:50:00	320	54.63282	318.8829	17
135/02	135/02	05:50:00	22:40:00	287.4	265.8907	01:15:00	04:42:00	07:05:00	320	54.10928	320	22
135/03	135/03	06:00:00	22:05:00	270.2	249.9017	23:26:00	02:47:00	06:25:00	320	70.09831	320	9
135/04	135/04	08:05:00	23:40:00	270.2	249.9017	03:50:00	07:11:00	09:00:00	320	70.09831	320	18
135/05	135/05	07:15:00	22:20:00	239.7	222.186	23:10:00	02:20:00	06:30:00	320	97.81398	320	11
135/06	135/06	06:25:00	22:30:00	270	249.7198	23:35:00	02:56:00	06:40:00	320	70.28021	320	14
135/07	135/07	07:40:00	21:40:00	231.6	214.1916	21:56:00	01:03:00	06:10:00	320	105.8084	320	4
135/08	135/08	05:50:00	22:40:00	286.6	265.0689	00:20:00	03:47:00	07:00:00	320	54.93108	320	18
135/09	135/09	06:00:00	21:50:00	267.4	247.3017	22:02:00	01:22:00	06:15:00	320	72.69832	320	21
135/10	135/10	06:10:00	22:00:00	267.4	247.3017	22:30:00	01:50:00	06:20:00	320	72.69832	320	6
135/11	135/11	06:20:00	22:55:00	286.6	265.0689	01:23:00	04:50:00	07:20:00	320	54.93108	320	3
135/12	135/12	06:30:00	23:10:00	286.6	264.7644	02:48:00	06:15:00	08:20:00	320	55.23562	320	10

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
135/13G	135/13G	08:10:00	19:55:00	183.2	169.4238	19:58:00	22:47:00	05:35:00	320	150.5762	320	8
135/14G	135/14G	08:20:00	20:05:00	183.2	169.4238	20:08:00	22:57:00	05:45:00	320	150.5762	320	10
135/15G	135/15G	08:30:00	20:15:00	183.2	169.4238	20:18:00	23:07:00	05:45:00	320	150.5762	320	11
135/16G	135/16G	08:40:00	20:25:00	184.4	171.7047	20:28:00	23:18:00	05:50:00	320	148.2953	320	13
135/17G	135/17G	08:50:00	20:35:00	198.4	183.4996	20:38:00	23:32:00	05:50:00	320	136.5004	320	14
135/18G	135/18G	09:00:00	20:45:00	199	184.0642	20:48:00	23:43:00	06:00:00	320	135.9358	320	15
135/19G	135/19G	09:10:00	20:55:00	181.4	169.3327	20:58:00	23:47:00	06:00:00	320	150.6673	320	16
135/20G	135/20G	09:20:00	21:05:00	198.4	183.4996	21:14:00	00:08:00	06:00:00	320	136.5004	320	17
135/21G	135/21G	09:30:00	21:20:00	198.4	183.4996	21:23:00	00:17:00	06:05:00	320	136.5004	320	18
135/22G	135/22G	07:45:00	19:35:00	183.3	170.2119	19:38:00	22:27:00	05:30:00	320	149.7881	320	6
135/23G	135/23G	07:00:00	19:10:00	195	180.5299	19:13:00	22:06:00	05:20:00	320	139.4701	320	5
28/01	28/01	05:15:00	23:05:00	218.8	213.0738	02:22:00	05:28:00	08:10:00	320	106.9262	320	8
28/02	28/02	05:45:00	23:35:00	210.1	203.087	06:53:00	08:47:00	08:50:00	320	116.913	317.1153	17
28/03	28/03	06:10:00	23:40:00	228.4	220.9423	07:18:00	09:07:00	09:10:00	320	99.05768	314.4553	19
28/04	28/04	06:45:00	00:10:00	210.8	206.9647	04:45:00	07:49:00	09:30:00	320	113.0353	320	22
28/05	28/05	07:05:00	22:45:00	202	194.9722	23:47:00	02:46:00	07:15:00	320	125.0278	320	1
28/06	28/06	07:15:00	23:20:00	219.1	209.4157	03:13:00	06:18:00	08:35:00	320	110.5843	320	14
28/07	28/07	07:20:00	21:00:00	170.3	163.397	21:06:00	23:52:00	06:00:00	320	156.603	320	2
28/08G	28/08G	08:10:00	19:50:00	136.8	133.8775	19:53:00	22:28:00	05:35:00	320	186.1225	320	7
28/09G	28/09G	08:20:00	20:00:00	141.5	138.7133	20:03:00	22:39:00	05:45:00	320	181.2867	320	9
28/10G	28/10G	08:40:00	20:20:00	136.8	134.3962	20:23:00	22:58:00	05:50:00	320	185.6038	320	12
28/12G	28/12G	09:40:00	21:20:00	136.5	133.8558	21:31:00	00:06:00	06:10:00	320	186.1442	320	19
32/01	32/01	06:10:00	22:20:00	234.5	229.5491	00:29:00	03:42:00	06:35:00	320	90.45092	320	12
32/02	32/02	06:45:00	22:15:00	234.5	229.5491	23:32:00	02:45:00	06:30:00	320	90.45092	320	10

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
32/03	32/03	05:45:00	22:30:00	228.9	224.4265	04:01:00	06:42:00	06:45:00	320	95.57349	319.6889	16
32/04G	32/04G	08:25:00	18:55:00	145	142.0848	18:58:00	21:36:00	05:15:00	320	177.9152	320	4
35/17G	35/17G	08:35:00	20:40:00	202.7	193.5966	20:45:00	23:43:00	05:55:00	320	126.4034	320	1
35/18G	35/18G	05:35:00	17:45:00	191.5	182.0235	17:48:00	20:42:00	04:55:00	320	137.9765	320	1
35/19G	35/19G	06:15:00	18:05:00	183.5	175.1588	18:08:00	20:59:00	05:00:00	320	144.8412	320	2
35/20G	35/20G	06:35:00	18:40:00	183.5	175.1588	18:43:00	21:34:00	05:10:00	320	144.8412	320	3
40/01	40/01	05:30:00	22:55:00	255.2	237.2711	01:06:00	04:22:00	07:25:00	320	82.72886	320	4
40/02	40/02	06:00:00	23:00:00	255.2	237.2711	01:43:00	04:59:00	08:05:00	320	82.72886	320	7
40/03	40/03	06:10:00	23:00:00	255.2	237.2711	01:56:00	05:12:00	07:45:00	320	82.72886	320	6
40/04	40/04	06:20:00	23:10:00	255.2	237.2711	02:23:00	05:39:00	08:20:00	320	82.72886	320	11
40/05	40/05	05:50:00	22:40:00	254.2	236.5947	01:25:00	04:41:00	07:05:00	320	83.40534	320	21
40/06	40/06	06:00:00	22:50:00	254.2	236.5947	23:59:00	03:15:00	07:15:00	320	83.40534	320	2
40/07	40/07	06:10:00	23:00:00	252.3	236.3251	01:14:00	04:30:00	07:40:00	320	83.6749	320	5
40/08	40/08	06:20:00	21:20:00	222.9	207.4719	21:42:00	00:46:00	06:10:00	320	112.5281	320	20
40/09	40/09	06:30:00	23:15:00	254.2	236.5947	02:38:00	05:54:00	08:30:00	320	83.40534	320	13
40/10	40/10	06:40:00	23:35:00	254.2	236.5947	06:48:00	08:37:00	08:40:00	320	83.40534	311.9073	16
40/11	40/11	06:50:00	22:40:00	235.9	219.3905	04:20:00	07:12:00	07:15:00	320	100.6095	319.8839	19
40/12	40/12	07:00:00	22:05:00	222.9	207.4719	22:24:00	01:28:00	06:20:00	320	112.5281	320	7
42/02G	42/02G	09:20:00	21:50:00	213	184.0527	22:17:00	01:12:00	06:20:00	320	135.9473	320	22
54/01	54/01	05:00:00	21:40:00	311.4	269.3459	21:51:00	01:20:00	06:10:00	320	50.65409	320	3
54/02	54/02	05:10:00	22:05:00	311.4	269.3459	22:50:00	02:19:00	06:25:00	320	50.65409	320	8

PATWARDHAN 2 BUS DEPOT

- Normal charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
111/01G	111/01G	08:35:00	20:20:00	162.9	154.9538	20:23:00	23:06:00	05:25:00	320	165.0462	320	6
20/01	20/01	05:25:00	22:35:00	292.5	261.2399	23:55:00	03:20:00	06:20:00	320	58.76012	320	7
20/02	20/02	05:40:00	22:55:00	293	261.6879	00:55:00	04:21:00	06:35:00	320	58.31212	320	10
20/03	20/03	05:55:00	23:15:00	272.8	245.3601	01:48:00	05:07:00	07:00:00	320	74.63986	320	17
20/04	20/04	06:15:00	23:35:00	274.5	245.6347	03:23:00	06:42:00	07:15:00	320	74.36533	320	7
20/05	20/05	06:35:00	23:55:00	291.3	261.4134	04:24:00	07:50:00	08:00:00	320	58.58665	320	12
20/06	20/06	06:55:00	00:15:00	291.3	261.4134	05:21:00	08:37:00	08:40:00	320	58.58665	319.9446	16
210/01	210/01	05:30:00	22:30:00	244.8	228.2024	22:33:00	01:45:00	06:15:00	320	91.79764	320	17
210/02	210/02	08:00:00	21:30:00	184	171.522	21:33:00	00:23:00	05:40:00	320	148.478	320	11
231/01	231/01	06:15:00	21:35:00	250.4	219.0965	21:38:00	00:47:00	05:45:00	320	100.9035	320	12
26/01	26/01	05:00:00	20:25:00	300	257.9253	20:28:00	23:52:00	05:25:00	320	62.07471	320	7
26/02	26/02	05:20:00	20:45:00	300	257.9253	20:48:00	00:12:00	05:30:00	320	62.07471	320	8
26/03	26/03	05:40:00	21:05:00	300	257.9253	21:08:00	00:32:00	05:40:00	320	62.07471	320	9
26/04	26/04	06:00:00	21:25:00	300	257.9253	21:28:00	00:52:00	05:40:00	320	62.07471	320	10
26/05	26/05	06:20:00	21:45:00	300	257.9253	21:50:00	01:14:00	05:45:00	320	62.07471	320	1
26/06	26/06	06:40:00	22:05:00	300	257.9253	22:11:00	01:35:00	06:00:00	320	62.07471	320	3
26/07	26/07	07:00:00	22:25:00	300	257.9253	22:28:00	01:52:00	06:15:00	320	62.07471	320	16
26/08	26/08	07:10:00	22:35:00	300	257.9253	23:09:00	02:33:00	06:20:00	320	62.07471	320	6
26/09	26/09	07:30:00	22:55:00	300	257.9253	00:26:00	03:50:00	06:35:00	320	62.07471	320	11
26/10	26/10	07:50:00	23:15:00	300	257.9253	00:57:00	04:21:00	07:00:00	320	62.07471	320	2
26/11	26/11	08:10:00	23:35:00	300	257.9253	03:22:00	06:46:00	07:20:00	320	62.07471	320	8
26/12	26/12	08:30:00	00:00:00	300	257.9253	04:59:00	08:23:00	08:30:00	320	62.07471	320	14

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
26/13	26/13	08:50:00	00:20:00	300	257.9253	05:10:00	08:34:00	08:50:00	320	62.07471	320	17
26/14	26/14	09:10:00	00:29:00	300	257.9253	04:51:00	08:15:00	09:10:00	320	62.07471	320	1
38/01	38/01	04:45:00	21:55:00	308.2	276.0379	21:58:00	01:29:00	05:55:00	320	43.96214	320	4
38/02	38/02	05:05:00	22:15:00	308.2	276.0379	22:18:00	01:49:00	06:05:00	320	43.96214	320	14
38/03	38/03	05:25:00	22:35:00	308.2	276.0379	22:44:00	02:15:00	06:20:00	320	43.96214	320	5
38/04	38/04	05:45:00	22:55:00	308.2	276.0379	00:50:00	04:21:00	06:40:00	320	43.96214	320	12
38/05	38/05	06:05:00	23:15:00	308.2	276.0379	01:17:00	04:48:00	06:55:00	320	43.96214	320	1
38/06	38/06	06:25:00	23:35:00	308.1	275.9451	02:18:00	05:49:00	07:10:00	320	44.05495	320	5
38/07	38/07	06:45:00	23:55:00	308.2	276.0379	03:53:00	07:24:00	07:50:00	320	43.96214	320	11
38/08	38/08	07:05:00	00:15:00	308.2	276.0379	05:03:00	08:32:00	08:35:00	320	43.96214	319.9912	15
38/15G	38/15G	07:15:00	19:10:00	206	184.5232	19:13:00	22:08:00	05:05:00	320	135.4768	320	3
54/03	54/03	05:50:00	22:10:00	302.7	260.5793	22:13:00	01:38:00	06:05:00	320	59.42075	320	13
54/04	54/04	06:05:00	22:25:00	302.7	260.5793	22:28:00	01:53:00	06:05:00	320	59.42075	320	15
54/05	54/05	06:20:00	22:40:00	302.7	260.5793	00:35:00	04:00:00	06:35:00	320	59.42075	320	9
54/06	54/06	06:35:00	22:55:00	296.2	255.304	01:41:00	05:04:00	06:40:00	320	64.69604	320	13
54/07	54/07	06:50:00	23:10:00	296.2	255.304	01:55:00	05:18:00	06:55:00	320	64.69604	320	16
54/08	54/08	07:05:00	23:25:00	296.2	255.304	01:32:00	04:55:00	07:05:00	320	64.69604	320	4
54/09	54/09	07:20:00	23:35:00	296.2	255.304	02:36:00	05:59:00	07:15:00	320	64.69604	320	6
54/10	54/10	07:35:00	00:00:00	295.9	255.0455	05:07:00	08:07:00	08:10:00	320	64.95452	319.8104	13
54/11G	54/11G	08:40:00	19:20:00	138.4	123.8892	19:23:00	21:54:00	05:20:00	320	196.1108	320	4
79/01	79/01	05:45:00	22:55:00	212.4	207.4261	01:52:00	04:56:00	06:45:00	320	112.5739	320	14
79/02	79/02	06:20:00	23:25:00	212.4	207.4261	01:38:00	04:42:00	07:05:00	320	112.5739	320	3
79/03	79/03	06:40:00	23:45:00	212.4	207.4261	04:24:00	07:28:00	07:35:00	320	112.5739	320	10
79/04G	79/04G	07:00:00	19:05:00	148.2	144.6544	19:08:00	21:47:00	04:45:00	320	175.3456	320	1

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
79/05	79/05	05:20:00	19:45:00	188	180.0018	19:48:00	22:41:00	05:20:00	320	139.9982	320	5
79/06	79/06	05:40:00	22:40:00	212.4	207.3594	00:15:00	03:19:00	06:25:00	320	112.6406	320	8
79/07	79/07	06:05:00	23:05:00	212.4	207.4261	01:56:00	05:00:00	06:50:00	320	112.5739	320	15
79/08	79/08	06:35:00	21:55:00	192.4	187.866	21:58:00	00:54:00	05:50:00	320	132.134	320	2
79/09	79/09	06:55:00	23:40:00	212.4	207.4261	04:03:00	07:07:00	07:30:00	320	112.5739	320	9
79/10G	79/10G	07:15:00	19:10:00	150.3	146.7334	19:13:00	21:53:00	05:00:00	320	173.2666	320	2

PATWARDHAN 2 BUS DEPOT

- Optimized charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
111/01G	111/01G	08:35:00	20:20:00	162.9	154.9538	20:23:00	23:06:00	05:25:00	320	165.0462	320	6
20/01	20/01	05:25:00	22:35:00	292.5	261.2399	23:55:00	03:20:00	06:20:00	320	58.76012	320	7
20/02	20/02	05:40:00	22:55:00	293	261.6879	00:55:00	04:21:00	06:35:00	320	58.31212	320	10
20/03	20/03	05:55:00	23:15:00	272.8	245.3601	02:51:00	06:10:00	07:00:00	320	74.63986	320	17
20/04	20/04	06:15:00	23:35:00	274.5	245.6347	03:23:00	06:42:00	07:15:00	320	74.36533	320	7
20/05	20/05	06:35:00	23:55:00	291.3	261.4134	04:24:00	07:50:00	08:00:00	320	58.58665	320	12
20/06	20/06	06:55:00	00:15:00	291.3	261.4134	05:57:00	08:37:00	08:40:00	320	58.58665	319.163	16
210/01	210/01	05:30:00	22:30:00	244.8	228.2024	23:23:00	02:35:00	06:15:00	320	91.79764	320	17
210/02	210/02	08:00:00	21:30:00	184	171.522	21:33:00	00:23:00	05:40:00	320	148.478	320	11
231/01	231/01	06:15:00	21:35:00	250.4	219.0965	21:38:00	00:47:00	05:45:00	320	100.9035	320	12
26/01	26/01	05:00:00	20:25:00	300	257.9253	20:28:00	23:52:00	05:25:00	320	62.07471	320	7
26/02	26/02	05:20:00	20:45:00	300	257.9253	20:48:00	00:12:00	05:30:00	320	62.07471	320	8
26/03	26/03	05:40:00	21:05:00	300	257.9253	21:08:00	00:32:00	05:40:00	320	62.07471	320	9
26/04	26/04	06:00:00	21:25:00	300	257.9253	21:28:00	00:52:00	05:40:00	320	62.07471	320	10
26/05	26/05	06:20:00	21:45:00	300	257.9253	21:50:00	01:14:00	05:45:00	320	62.07471	320	1
26/06	26/06	06:40:00	22:05:00	300	257.9253	22:11:00	01:35:00	06:00:00	320	62.07471	320	3
26/07	26/07	07:00:00	22:25:00	300	257.9253	23:02:00	02:26:00	06:15:00	320	62.07471	320	16
26/08	26/08	07:10:00	22:35:00	300	257.9253	23:09:00	02:33:00	06:20:00	320	62.07471	320	6
26/09	26/09	07:30:00	22:55:00	300	257.9253	00:26:00	03:50:00	06:35:00	320	62.07471	320	11
26/10	26/10	07:50:00	23:15:00	300	257.9253	00:57:00	04:21:00	07:00:00	320	62.07471	320	2
26/11	26/11	08:10:00	23:35:00	300	257.9253	03:22:00	06:46:00	07:20:00	320	62.07471	320	8
26/12	26/12	08:30:00	00:00:00	300	257.9253	05:22:00	08:27:00	08:30:00	320	62.07471	319.8619	14

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
26/13	26/13	08:50:00	00:20:00	300	257.9253	06:13:00	08:47:00	08:50:00	320	62.07471	318.945	17
26/14	26/14	09:10:00	00:29:00	300	257.9253	04:51:00	08:15:00	09:10:00	320	62.07471	320	1
38/01	38/01	04:45:00	21:55:00	308.2	276.0379	21:58:00	01:29:00	05:55:00	320	43.96214	320	4
38/02	38/02	05:05:00	22:15:00	308.2	276.0379	22:41:00	02:12:00	06:05:00	320	43.96214	320	14
38/03	38/03	05:25:00	22:35:00	308.2	276.0379	23:36:00	03:07:00	06:20:00	320	43.96214	320	5
38/04	38/04	05:45:00	22:55:00	308.2	276.0379	00:50:00	04:21:00	06:40:00	320	43.96214	320	12
38/05	38/05	06:05:00	23:15:00	308.2	276.0379	01:17:00	04:48:00	06:55:00	320	43.96214	320	1
38/06	38/06	06:25:00	23:35:00	308.1	275.9451	03:10:00	06:41:00	07:10:00	320	44.05495	320	5
38/07	38/07	06:45:00	23:55:00	308.2	276.0379	03:53:00	07:24:00	07:50:00	320	43.96214	320	11
38/08	38/08	07:05:00	00:15:00	308.2	276.0379	05:31:00	08:32:00	08:35:00	320	43.96214	319.6889	15
38/15G	38/15G	07:15:00	19:10:00	206	184.5232	19:13:00	22:08:00	05:05:00	320	135.4768	320	3
54/03	54/03	05:50:00	22:10:00	302.7	260.5793	22:28:00	01:53:00	06:05:00	320	59.42075	320	13
54/04	54/04	06:05:00	22:25:00	302.7	260.5793	22:54:00	02:19:00	06:05:00	320	59.42075	320	15
54/05	54/05	06:20:00	22:40:00	302.7	260.5793	00:35:00	04:00:00	06:35:00	320	59.42075	320	9
54/06	54/06	06:35:00	22:55:00	296.2	255.304	01:56:00	05:19:00	06:40:00	320	64.69604	320	13
54/07	54/07	06:50:00	23:10:00	296.2	255.304	02:31:00	05:54:00	06:55:00	320	64.69604	320	16
54/08	54/08	07:05:00	23:25:00	296.2	255.304	01:32:00	04:55:00	07:05:00	320	64.69604	320	4
54/09	54/09	07:20:00	23:35:00	296.2	255.304	02:40:00	06:03:00	07:15:00	320	64.69604	320	6
54/10	54/10	07:35:00	00:00:00	295.9	255.0455	05:22:00	08:07:00	08:10:00	320	64.95452	319.4812	13
54/11G	54/11G	08:40:00	19:20:00	138.4	123.8892	19:23:00	21:54:00	05:20:00	320	196.1108	320	4
79/01	79/01	05:45:00	22:55:00	212.4	207.4261	02:15:00	05:19:00	06:45:00	320	112.5739	320	14
79/02	79/02	06:20:00	23:25:00	212.4	207.4261	01:38:00	04:42:00	07:05:00	320	112.5739	320	3
79/03	79/03	06:40:00	23:45:00	212.4	207.4261	04:24:00	07:28:00	07:35:00	320	112.5739	320	10
79/04G	79/04G	07:00:00	19:05:00	148.2	144.6544	19:08:00	21:47:00	04:45:00	320	175.3456	320	1

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
79/05	79/05	05:20:00	19:45:00	188	180.0018	19:48:00	22:41:00	05:20:00	320	139.9982	320	5
79/06	79/06	05:40:00	22:40:00	212.4	207.3594	00:15:00	03:19:00	06:25:00	320	112.6406	320	8
79/07	79/07	06:05:00	23:05:00	212.4	207.4261	02:24:00	05:28:00	06:50:00	320	112.5739	320	15
79/08	79/08	06:35:00	21:55:00	192.4	187.866	21:58:00	00:54:00	05:50:00	320	132.134	320	2
79/09	79/09	06:55:00	23:40:00	212.4	207.4261	04:03:00	07:07:00	07:30:00	320	112.5739	320	9
79/10G	79/10G	07:15:00	19:10:00	150.3	146.7334	19:13:00	21:53:00	05:00:00	320	173.2666	320	2

E-buses depot charging simulations results - Scenario “350 kWh batteries”

KHAPRI NAKA BUS DEPOT

- Normal charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/01	107/01	05:40:00	14:15:00	195.1	166.2547399	14:18:00	14:42:00	14:45:00	280	113.7452601	172.5	1
107/01A	107/01A	13:35:00	23:20:00	217	186.1495380	03:08:00	06:05:00	10:25:00	280	93.85046198	280	16
107/02	107/02	05:50:00	14:20:00	194.8	166.1955463	14:23:00	14:52:00	14:55:00	280	113.8044537	187.5	2
107/02A	107/02A	13:45:00	22:45:00	193.9	165.7524411	00:15:00	03:04:00	07:55:00	280	114.2475589	280	21
107/03	107/03	06:05:00	14:35:00	193.8	165.3470205	14:38:00	15:02:00	15:05:00	280	114.6529795	175	3
107/03A	107/03A	13:55:00	23:00:00	193.7	165.4220307	23:30:00	02:19:00	08:45:00	280	114.5779693	280	8
107/04	107/04	05:50:00	14:45:00	193.9	165.5373225	14:48:00	15:12:00	15:15:00	280	114.4626775	175	1
107/04A	107/04A	14:05:00	21:35:00	149.2	128.5430753	21:38:00	00:12:00	06:50:00	280	151.4569247	280	21
107/05	107/05	06:30:00	14:55:00	197.6	168.5838183	14:58:00	15:22:00	15:25:00	280	111.4161817	172.5	2
107/05A	107/05A	14:15:00	23:25:00	193.5	165.0429404	03:42:00	06:31:00	13:45:00	280	114.9570596	280	19
107/06	107/06	06:40:00	15:05:00	200.4	170.6946348	15:08:00	15:32:00	15:35:00	280	109.3053652	170	3
107/06A	107/06A	14:25:00	22:50:00	183.1	157.0235207	00:34:00	03:20:00	08:15:00	280	122.9764793	280	22
107/07	107/07	05:50:00	15:15:00	213.7	183.2723019	15:18:00	15:42:00	15:45:00	280	96.72769812	157.5	1
107/07A	107/07A	14:35:00	23:15:00	182	158.6373928	03:15:00	06:01:00	10:05:00	280	121.3626072	280	15
107/08	107/08	06:55:00	15:25:00	194	165.5208533	15:28:00	16:02:00	16:05:00	280	114.4791467	200	2
107/08A	107/01	14:45:00	23:30:00	181.4	158.1771947	03:45:00	07:14:00	13:55:00	172.5	14.32280527	280	20
107/09	107/09	06:10:00	15:35:00	216	185.4943126	15:38:00	16:12:00	16:15:00	280	94.5056874	180	3
107/09A	107/02	14:55:00	22:10:00	149	128.1878332	23:04:00	02:15:00	07:20:00	187.5	59.31216679	280	13
107/10	107/10	06:20:00	16:15:00	213.7	182.4170413	16:18:00	19:14:00	05:10:00	280	97.58295868	280	1
107/10A	107/03	15:05:00	22:20:00	149	128.1883249	23:44:00	03:00:00	07:25:00	175	46.81167507	280	14
107/11	107/11	07:40:00	16:25:00	196.2	167.6538072	16:28:00	19:18:00	05:20:00	280	112.3461928	280	2

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/11A	107/04	15:15:00	22:30:00	149	128.1883249	23:50:00	03:06:00	07:35:00	175	46.81167507	280	17
107/12	107/12	06:35:00	16:35:00	213.2	182.4786365	16:38:00	19:34:00	05:20:00	280	97.52136347	280	3
107/12A	107/05	15:25:00	22:35:00	151.5	130.5786649	00:24:00	03:42:00	07:45:00	172.5	41.92133506	280	20
107/13	107/13	07:45:00	16:45:00	198.1	169.2971999	16:48:00	19:39:00	05:30:00	280	110.7028001	280	4
107/13A	107/06	15:35:00	22:45:00	149	128.1883249	22:50:00	02:08:00	07:45:00	170	41.81167507	280	6
107/14	107/14	06:50:00	16:55:00	213.3	182.5628012	16:58:00	19:54:00	05:30:00	280	97.43719882	280	5
107/14A	107/07	15:45:00	22:55:00	148.8	127.8335746	23:16:00	02:39:00	08:35:00	157.5	29.66642542	280	5
107/15	107/15	07:00:00	23:05:00	292.8	252.0960605	00:44:00	04:08:00	08:55:00	280	27.90393948	280	10
107/16	107/16	07:10:00	17:15:00	217.8	186.5004333	17:18:00	20:16:00	05:40:00	280	93.49956675	280	7
107/16A	107/08	16:05:00	23:15:00	150.3	129.2256292	03:03:00	06:10:00	09:50:00	200	70.77437077	280	14
107/17G	107/17G	07:20:00	17:30:00	217.9	187.0321793	17:33:00	20:31:00	05:50:00	280	92.96782072	280	8
107/18G	107/18G	07:35:00	17:35:00	216.8	185.6587868	17:38:00	20:35:00	05:50:00	280	94.34121323	280	9
107/19	107/19	07:45:00	17:00:00	201.7	177.264988	17:03:00	19:57:00	05:40:00	280	102.735012	280	6
107/19A	107/09	16:15:00	22:50:00	150.5	129.5803796	22:54:00	02:09:00	08:10:00	180	50.41962042	280	4
107/22G	107/22G	08:35:00	19:40:00	242.9	207.6063952	19:43:00	22:49:00	05:50:00	280	72.39360484	280	3
107/23G	107/23G	10:35:00	20:40:00	223.8	189.905579	20:43:00	23:42:00	06:20:00	280	90.09442099	280	9
107/24G	107/24G	08:45:00	20:00:00	255	216.38096	20:03:00	23:13:00	06:05:00	280	63.61903995	280	5
107/25G	107/25G	07:25:00	19:20:00	286.2	242.8563411	19:23:00	22:43:00	05:50:00	280	37.14365891	280	2
232/01	232/01	07:15:00	20:55:00	216.3	196.2577341	20:58:00	00:00:00	06:30:00	280	83.74226588	280	15
232/02	232/02	08:10:00	22:00:00	216.3	196.2577341	22:15:00	01:17:00	07:10:00	280	83.74226588	280	11
35/07G	35/07G	07:45:00	19:55:00	183.6	175.8343021	19:58:00	22:51:00	06:00:00	280	104.1656979	280	4
35/08G	35/08G	07:55:00	20:05:00	183.6	175.8343021	20:08:00	23:01:00	06:10:00	280	104.1656979	280	13
35/09G	35/09G	08:15:00	20:30:00	183.6	175.8343021	20:34:00	23:27:00	06:20:00	280	104.1656979	280	8
35/10G	35/10G	08:35:00	20:45:00	183.6	175.8343021	20:48:00	23:41:00	06:30:00	280	104.1656979	280	14

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
35/11G	35/11G	08:55:00	21:05:00	183.6	175.8343021	21:08:00	00:01:00	06:40:00	280	104.1656979	280	18
35/12G	35/12G	09:30:00	21:25:00	183.6	175.8343021	21:28:00	00:21:00	06:40:00	280	104.1656979	280	19
35/13G	35/13G	09:45:00	21:00:00	169.1	161.5382009	21:03:00	23:51:00	06:30:00	280	118.4617991	280	16
35/14G	35/14G	10:05:00	21:30:00	169.1	161.5382009	21:33:00	00:21:00	06:40:00	280	118.4617991	280	20
35/15G	35/15G	10:25:00	21:50:00	169.1	161.5382009	21:53:00	00:41:00	06:55:00	280	118.4617991	280	10
35/16G	35/16G	09:50:00	21:40:00	169.1	161.5382009	21:43:00	00:31:00	06:50:00	280	118.4617991	280	22
4/01	4/01	05:20:00	22:35:00	245.1	231.1279432	00:24:00	03:39:00	07:40:00	280	48.87205682	280	19
4/02	4/02	05:40:00	23:05:00	244.7	230.7464737	23:45:00	03:00:00	08:55:00	280	49.25352633	280	9
4/03	4/03	06:20:00	23:45:00	245.1	231.1279432	04:07:00	07:22:00	14:25:00	280	48.87205682	280	23
4/04	4/04	06:40:00	00:05:00	245.1	231.1279432	01:20:00	04:35:00	14:35:00	280	48.87205682	280	1
4/05	4/05	05:10:00	22:30:00	245.1	231.1279432	00:04:00	03:19:00	07:40:00	280	48.87205682	280	18
4/06	4/06	05:50:00	23:10:00	245.1	231.1279432	01:58:00	05:13:00	09:30:00	280	48.87205682	280	12
4/07	4/07	06:10:00	22:20:00	228.2	215.8726247	00:03:00	03:12:00	07:30:00	280	64.12737527	280	15
4/08	4/08	06:40:00	22:50:00	228.2	215.8726247	22:53:00	02:02:00	08:05:00	280	64.12737527	280	3
4/09	4/09	05:30:00	21:55:00	224.8	211.8147729	21:58:00	01:06:00	07:00:00	280	68.18522713	280	23
4/10	4/10	05:50:00	22:10:00	222.1	212.4226453	22:47:00	01:55:00	07:15:00	280	67.5773547	280	12
4/11G	4/11G	07:35:00	19:25:00	158.9	153.0782847	19:28:00	22:12:00	05:50:00	280	126.9217153	280	11
4/12G	4/12G	08:35:00	20:25:00	158.9	153.0782847	20:28:00	23:12:00	06:20:00	280	126.9217153	280	7
4/13G	4/13G	08:55:00	21:00:00	158.9	153.0782847	21:03:00	23:47:00	06:35:00	280	126.9217153	280	17
4/14G	4/14G	08:05:00	20:00:00	158.9	153.0782847	20:03:00	22:47:00	06:10:00	280	126.9217153	280	6
4/16G	4/16G	07:30:00	19:15:00	158.9	153.0782847	19:18:00	22:02:00	05:50:00	280	126.9217153	280	1
47/01	47/01	05:50:00	23:25:00	253.3	233.1970978	03:22:00	06:38:00	13:35:00	280	46.80290221	280	18
47/02	47/02	06:10:00	22:00:00	240.5	221.4594445	22:05:00	01:17:00	07:00:00	280	58.54055553	280	1
47/03	47/03	06:30:00	22:25:00	239.4	219.8092542	23:54:00	03:05:00	07:35:00	280	60.19074581	280	16

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
47/04G	47/04G	08:55:00	20:00:00	158.4	145.719987	20:03:00	22:44:00	06:10:00	280	134.280013	280	12
48/01	48/01	05:30:00	23:05:00	193	195.7050261	01:20:00	04:21:00	08:55:00	280	84.29497391	280	11
48/02	48/02	06:00:00	23:20:00	191.9	194.5437515	03:09:00	06:10:00	10:35:00	280	85.4562485	280	17
48/03	48/03	06:30:00	23:40:00	191.9	194.5437515	03:23:00	06:24:00	14:15:00	280	85.4562485	280	22
48/04	48/04	07:00:00	22:50:00	177	180.7160086	01:09:00	04:04:00	08:35:00	280	99.28399135	280	23
48/05G	48/05G	07:40:00	19:05:00	132.4	133.0469991	19:08:00	21:44:00	05:50:00	280	146.9530009	280	10
49/01	49/01	05:20:00	22:55:00	205	203.6843871	23:15:00	02:19:00	08:35:00	280	76.3156129	280	7
49/02	49/02	05:50:00	23:10:00	205	203.6843871	02:18:00	05:22:00	09:45:00	280	76.3156129	280	13
49/03	49/03	06:20:00	23:40:00	205	203.6843871	03:07:00	06:11:00	14:05:00	280	76.3156129	280	21
49/04	49/04	06:50:00	22:40:00	186.4	185.2109254	22:46:00	01:43:00	07:45:00	280	94.78907464	280	2

KHAPRI NAKA BUS DEPOT

- Optimized charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/01	107/01	05:40:00	14:15:00	195.1	166.2547	14:18:00	14:42:00	14:45:00	280	113.7453	172.5	1
107/01A	107/01A	13:35:00	23:20:00	217	186.1495	04:27:00	07:24:00	10:25:00	280	93.85046	280	16
107/02	107/02	05:50:00	14:20:00	194.8	166.1955	14:23:00	14:52:00	14:55:00	280	113.8045	187.5	2
107/02A	107/02A	13:45:00	22:45:00	193.9	165.7524	01:26:00	04:15:00	07:55:00	280	114.2476	280	21
107/03	107/03	06:05:00	14:35:00	193.8	165.347	14:38:00	15:02:00	15:05:00	280	114.653	175	3
107/03A	107/03A	13:55:00	23:00:00	193.7	165.422	00:03:00	02:52:00	08:45:00	280	114.578	280	8
107/04	107/04	05:50:00	14:45:00	193.9	165.5373	14:48:00	15:12:00	15:15:00	280	114.4627	175	1
107/04A	107/04A	14:05:00	21:35:00	149.2	128.5431	22:33:00	01:07:00	06:50:00	280	151.4569	280	21
107/05	107/05	06:30:00	14:55:00	197.6	168.5838	14:58:00	15:22:00	15:25:00	280	111.4162	172.5	2
107/05A	107/05A	14:15:00	23:25:00	193.5	165.0429	05:29:00	08:18:00	13:45:00	280	114.9571	280	19
107/06	107/06	06:40:00	15:05:00	200.4	170.6946	15:08:00	15:32:00	15:35:00	280	109.3054	170	3
107/06A	107/06A	14:25:00	22:50:00	183.1	157.0235	02:20:00	05:06:00	08:15:00	280	122.9765	280	22
107/07	107/07	05:50:00	15:15:00	213.7	183.2723	15:18:00	15:42:00	15:45:00	280	96.7277	157.5	1
107/07A	107/07A	14:35:00	23:15:00	182	158.6374	04:40:00	07:26:00	09:50:00	280	121.3626	280	15
107/08	107/08	06:55:00	15:25:00	194	165.5209	15:28:00	16:02:00	16:05:00	280	114.4791	200	2
107/08A	107/01	14:45:00	23:30:00	181.4	158.1772	05:42:00	09:11:00	13:55:00	172.5	14.32281	280	20
107/09	107/09	06:10:00	15:35:00	216	185.4943	15:38:00	16:12:00	16:15:00	280	94.50569	180	3
107/09A	107/02	14:55:00	22:10:00	149	128.1878	23:26:00	02:37:00	07:20:00	187.5	59.31217	280	13
107/10	107/10	06:20:00	16:15:00	213.7	182.417	16:18:00	19:14:00	05:10:00	280	97.58296	280	1
107/10A	107/03	15:05:00	22:20:00	149	128.1883	03:24:00	06:40:00	07:25:00	175	46.81168	280	14
107/11	107/11	07:40:00	16:25:00	196.2	167.6538	16:28:00	19:18:00	05:20:00	280	112.3462	280	2
107/11A	107/04	15:15:00	22:30:00	149	128.1883	00:58:00	04:14:00	07:35:00	175	46.81168	280	17

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
107/12	107/12	06:35:00	16:35:00	213.2	182.4786	16:38:00	19:34:00	05:20:00	280	97.52136	280	3
107/12A	107/05	15:25:00	22:35:00	151.5	130.5787	01:54:00	05:12:00	07:45:00	172.5	41.92134	280	20
107/13	107/13	07:45:00	16:45:00	198.1	169.2972	16:48:00	19:39:00	05:30:00	280	110.7028	280	4
107/13A	107/06	15:35:00	22:45:00	149	128.1883	03:48:00	07:06:00	07:45:00	170	41.81168	280	6
107/14	107/14	06:50:00	16:55:00	213.3	182.5628	16:58:00	19:54:00	05:30:00	280	97.4372	280	5
107/14A	107/07	15:45:00	22:55:00	148.8	127.8336	23:16:00	02:39:00	08:35:00	157.5	29.66643	280	5
107/15	107/15	07:00:00	23:05:00	292.8	252.0961	02:26:00	05:50:00	08:55:00	280	27.90394	280	10
107/16	107/16	07:10:00	17:15:00	217.8	186.5004	17:18:00	20:16:00	05:40:00	280	93.49957	280	7
107/16A	107/08	16:05:00	23:15:00	150.3	129.2256	06:43:00	09:50:00	10:05:00	200	70.77437	280	14
107/17G	107/17G	07:20:00	17:30:00	217.9	187.0322	17:33:00	20:31:00	05:50:00	280	92.96782	280	8
107/18G	107/18G	07:35:00	17:35:00	216.8	185.6588	17:38:00	20:35:00	05:50:00	280	94.34121	280	9
107/19	107/19	07:45:00	17:00:00	201.7	177.265	17:03:00	19:57:00	05:40:00	280	102.735	280	6
107/19A	107/09	16:15:00	22:50:00	150.5	129.5804	04:12:00	07:27:00	08:10:00	180	50.41962	280	4
107/22G	107/22G	08:35:00	19:40:00	242.9	207.6064	19:43:00	22:49:00	05:50:00	280	72.3936	280	3
107/23G	107/23G	10:35:00	20:40:00	223.8	189.9056	21:04:00	00:03:00	06:20:00	280	90.09442	280	9
107/24G	107/24G	08:45:00	20:00:00	255	216.381	20:03:00	23:13:00	06:05:00	280	63.61904	280	5
107/25G	107/25G	07:25:00	19:20:00	286.2	242.8563	19:23:00	22:43:00	05:50:00	280	37.14366	280	2
232/01	232/01	07:15:00	20:55:00	216.3	196.2577	21:21:00	00:23:00	06:30:00	280	83.74227	280	15
232/02	232/02	08:10:00	22:00:00	216.3	196.2577	22:15:00	01:17:00	07:10:00	280	83.74227	280	11
35/07G	35/07G	07:45:00	19:55:00	183.6	175.8343	19:58:00	22:51:00	06:00:00	280	104.1657	280	4
35/08G	35/08G	07:55:00	20:05:00	183.6	175.8343	20:30:00	23:23:00	06:10:00	280	104.1657	280	13
35/09G	35/09G	08:15:00	20:30:00	183.6	175.8343	20:59:00	23:52:00	06:20:00	280	104.1657	280	8
35/10G	35/10G	08:35:00	20:45:00	183.6	175.8343	21:12:00	00:05:00	06:30:00	280	104.1657	280	14
35/11G	35/11G	08:55:00	21:05:00	183.6	175.8343	21:56:00	00:49:00	06:40:00	280	104.1657	280	18

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
35/12G	35/12G	09:30:00	21:25:00	183.6	175.8343	22:08:00	01:01:00	06:40:00	280	104.1657	280	19
35/13G	35/13G	09:45:00	21:00:00	169.1	161.5382	21:31:00	00:19:00	06:30:00	280	118.4618	280	16
35/14G	35/14G	10:05:00	21:30:00	169.1	161.5382	22:26:00	01:14:00	06:40:00	280	118.4618	280	20
35/15G	35/15G	10:25:00	21:50:00	169.1	161.5382	22:54:00	01:42:00	06:55:00	280	118.4618	280	10
35/16G	35/16G	09:50:00	21:40:00	169.1	161.5382	22:40:00	01:28:00	06:50:00	280	118.4618	280	22
4/01	4/01	05:20:00	22:35:00	245.1	231.1279	01:11:00	04:26:00	07:40:00	280	48.87206	280	19
4/02	4/02	05:40:00	23:05:00	244.7	230.7465	00:27:00	03:42:00	08:55:00	280	49.25353	280	9
4/03	4/03	06:20:00	23:45:00	245.1	231.1279	05:55:00	09:10:00	14:25:00	280	48.87206	280	23
4/04	4/04	06:40:00	00:05:00	245.1	231.1279	02:54:00	06:09:00	14:35:00	280	48.87206	280	1
4/05	4/05	05:10:00	22:30:00	245.1	231.1279	01:04:00	04:19:00	07:40:00	280	48.87206	280	18
4/06	4/06	05:50:00	23:10:00	245.1	231.1279	03:16:00	06:31:00	09:30:00	280	48.87206	280	12
4/07	4/07	06:10:00	22:20:00	228.2	215.8726	00:52:00	04:01:00	07:30:00	280	64.12738	280	15
4/08	4/08	06:40:00	22:50:00	228.2	215.8726	03:58:00	07:07:00	08:05:00	280	64.12738	280	3
4/09	4/09	05:30:00	21:55:00	224.8	211.8148	23:06:00	02:14:00	07:00:00	280	68.18523	280	23
4/10	4/10	05:50:00	22:10:00	222.1	212.4226	23:49:00	02:57:00	07:15:00	280	67.57735	280	12
4/11G	4/11G	07:35:00	19:25:00	158.9	153.0783	19:28:00	22:12:00	05:50:00	280	126.9217	280	11
4/12G	4/12G	08:35:00	20:25:00	158.9	153.0783	20:53:00	23:37:00	06:20:00	280	126.9217	280	7
4/13G	4/13G	08:55:00	21:00:00	158.9	153.0783	21:43:00	00:27:00	06:35:00	280	126.9217	280	17
4/14G	4/14G	08:05:00	20:00:00	158.9	153.0783	20:03:00	22:47:00	06:10:00	280	126.9217	280	6
4/16G	4/16G	07:30:00	19:15:00	158.9	153.0783	19:18:00	22:02:00	05:50:00	280	126.9217	280	1
47/01	47/01	05:50:00	23:25:00	253.3	233.1971	05:16:00	08:32:00	13:35:00	280	46.8029	280	18
47/02	47/02	06:10:00	22:00:00	240.5	221.4594	23:30:00	02:42:00	07:00:00	280	58.54056	280	1
47/03	47/03	06:30:00	22:25:00	239.4	219.8093	00:46:00	03:57:00	07:35:00	280	60.19075	280	16
47/04G	47/04G	08:55:00	20:00:00	158.4	145.72	20:16:00	22:57:00	06:10:00	280	134.28	280	12

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
48/01	48/01	05:30:00	23:05:00	193	195.705	02:09:00	05:10:00	08:55:00	280	84.29497	280	11
48/02	48/02	06:00:00	23:20:00	191.9	194.5438	04:49:00	07:50:00	10:35:00	280	85.45625	280	17
48/03	48/03	06:30:00	23:40:00	191.9	194.5438	05:35:00	08:36:00	14:15:00	280	85.45625	280	22
48/04	48/04	07:00:00	22:50:00	177	180.716	02:32:00	05:27:00	08:35:00	280	99.28399	280	23
48/05G	48/05G	07:40:00	19:05:00	132.4	133.047	19:08:00	21:44:00	05:50:00	280	146.953	280	10
49/01	49/01	05:20:00	22:55:00	205	203.6844	23:40:00	02:44:00	08:35:00	280	76.31561	280	7
49/02	49/02	05:50:00	23:10:00	205	203.6844	02:40:00	05:44:00	09:45:00	280	76.31561	280	13
49/03	49/03	06:20:00	23:40:00	205	203.6844	05:04:00	08:08:00	14:05:00	280	76.31561	280	21
49/04	49/04	06:50:00	22:40:00	186.4	185.2109	03:34:00	06:31:00	07:45:00	280	94.78907	280	2

HIGNA NAKA BUS DEPOT

- Normal charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
106/01	106/01	04:55:00	21:50:00	204.5	197.96	21:53:00	00:55:00	06:20:00	280	82.04003	280	23
106/02	106/02	05:35:00	22:25:00	207.8	201.1888	23:03:00	02:06:00	06:40:00	280	78.81117	280	12
106/03	106/03	05:45:00	22:30:00	206.3	200.4556	23:37:00	02:40:00	06:45:00	280	79.5444	280	14
106/04	106/04	05:55:00	22:40:00	215.2	209.7555	00:22:00	03:29:00	07:05:00	280	70.24455	280	18
106/05	106/05	06:05:00	23:05:00	222	215.1316	01:59:00	05:08:00	08:10:00	280	64.86838	280	7
106/07	106/07	06:25:00	23:15:00	215.2	209.7555	02:09:00	05:16:00	08:35:00	280	70.24455	280	12
106/08	106/08	06:35:00	23:25:00	206.9	201.2875	02:43:00	05:47:00	08:40:00	280	78.71253	280	14
106/10	106/10	07:05:00	23:50:00	208	202.4659	03:17:00	06:21:00	09:20:00	280	77.53414	280	19
106/11	106/11	07:15:00	00:10:00	208.9	203.3679	03:53:00	06:57:00	09:30:00	280	76.63214	280	20
106/12	106/12	07:25:00	00:25:00	214.7	207.091	03:57:00	07:03:00	12:50:00	280	72.90897	280	22
135/01	135/01	05:20:00	22:30:00	286.6	265.3672	23:46:00	03:15:00	06:50:00	280	14.63282	280	15
135/02	135/02	05:50:00	22:40:00	287.4	265.8907	01:18:00	04:47:00	07:15:00	280	14.10928	280	21
135/03	135/03	06:00:00	22:05:00	270.2	249.9017	22:52:00	02:15:00	06:30:00	280	30.09831	280	8
135/04	135/04	08:05:00	23:40:00	270.2	249.9017	03:39:00	07:02:00	09:10:00	280	30.09831	280	17
135/05	135/05	07:15:00	22:20:00	239.7	222.186	23:02:00	02:14:00	06:35:00	280	57.81398	280	10
135/06	135/06	06:25:00	22:30:00	270	249.7198	23:23:00	02:46:00	06:45:00	280	30.28021	280	13
135/07	135/07	07:40:00	21:40:00	231.6	214.1916	21:43:00	00:52:00	06:10:00	280	65.80842	280	3
135/08	135/08	05:50:00	22:40:00	286.6	265.0689	00:07:00	03:36:00	07:00:00	280	14.93108	280	17
135/09	135/09	06:00:00	21:50:00	267.4	247.3017	21:53:00	01:15:00	06:15:00	280	32.69832	280	21
135/10	135/10	06:10:00	22:00:00	267.4	247.3017	22:11:00	01:33:00	06:20:00	280	32.69832	280	5
135/11	135/11	06:20:00	22:55:00	286.6	265.0689	23:55:00	03:24:00	07:25:00	280	14.93108	280	2
135/12	135/12	06:30:00	23:10:00	286.6	264.7644	02:17:00	05:46:00	08:25:00	280	15.23562	280	10

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
135/13G	135/13G	08:10:00	19:55:00	183.2	169.4238	19:58:00	22:49:00	05:45:00	280	110.5762	280	8
135/14G	135/14G	08:20:00	20:05:00	183.2	169.4238	20:08:00	22:59:00	05:45:00	280	110.5762	280	10
135/15G	135/15G	08:30:00	20:15:00	183.2	169.4238	20:18:00	23:09:00	05:50:00	280	110.5762	280	11
135/16G	135/16G	08:40:00	20:25:00	184.4	171.7047	20:28:00	23:20:00	05:50:00	280	108.2953	280	13
135/17G	135/17G	08:50:00	20:35:00	198.4	183.4996	20:38:00	23:34:00	05:55:00	280	96.50039	280	14
135/18G	135/18G	09:00:00	20:45:00	199	184.0642	20:48:00	23:45:00	06:00:00	280	95.93585	280	1
135/19G	135/19G	09:10:00	20:55:00	181.4	169.3327	20:58:00	23:49:00	06:00:00	280	110.6673	280	16
135/20G	135/20G	09:20:00	21:05:00	198.4	183.4996	21:08:00	00:04:00	06:05:00	280	96.50039	280	17
135/21G	135/21G	09:30:00	21:20:00	198.4	183.4996	21:23:00	00:19:00	06:10:00	280	96.50039	280	18
135/22G	135/22G	07:45:00	19:35:00	183.3	170.2119	19:38:00	22:29:00	05:35:00	280	109.7881	280	6
135/23G	135/23G	07:00:00	19:10:00	195	180.5299	19:13:00	22:08:00	05:30:00	280	99.47007	280	5
28/01	28/01	05:15:00	23:05:00	218.8	213.0738	02:18:00	05:26:00	08:20:00	280	66.92624	280	8
28/02	28/02	05:45:00	23:35:00	210.1	203.087	03:08:00	06:12:00	09:00:00	280	76.91295	280	16
28/03	28/03	06:10:00	23:40:00	228.4	220.9423	03:32:00	06:43:00	09:20:00	280	59.05768	280	18
28/04	28/04	06:45:00	00:10:00	210.8	206.9647	04:50:00	07:56:00	09:40:00	280	73.0353	280	21
28/05	28/05	07:05:00	22:45:00	202	194.9722	00:53:00	03:54:00	07:15:00	280	85.02776	280	22
28/06	28/06	07:15:00	23:20:00	219.1	209.4157	02:49:00	05:56:00	08:40:00	280	70.58427	280	13
28/07	28/07	07:20:00	21:00:00	170.3	163.397	21:04:00	23:52:00	06:00:00	280	116.603	280	2
28/08G	28/08G	08:10:00	19:50:00	136.8	133.8775	19:53:00	22:30:00	05:35:00	280	146.1225	280	7
28/09G	28/09G	08:20:00	20:00:00	141.5	138.7133	20:03:00	22:41:00	05:45:00	280	141.2867	280	9
28/10G	28/10G	08:40:00	20:20:00	136.8	134.3962	20:23:00	23:00:00	05:50:00	280	145.6038	280	12
28/12G	28/12G	09:40:00	21:20:00	136.5	133.8558	21:23:00	00:00:00	06:10:00	280	146.1442	280	19
32/01	32/01	06:10:00	22:20:00	234.5	229.5491	23:12:00	02:27:00	06:35:00	280	50.45092	280	11
32/02	32/02	06:45:00	22:15:00	234.5	229.5491	22:44:00	01:59:00	06:30:00	280	50.45092	280	9

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
32/03	32/03	05:45:00	22:30:00	228.9	224.4265	23:52:00	03:05:00	07:00:00	280	55.57349	280	16
32/04G	32/04G	08:25:00	18:55:00	145	142.0848	18:58:00	21:38:00	05:20:00	280	137.9152	280	4
35/17G	35/17G	08:35:00	20:40:00	202.7	193.5966	20:43:00	23:43:00	06:00:00	280	86.40343	280	15
35/18G	35/18G	05:35:00	17:45:00	191.5	182.0235	17:48:00	20:44:00	05:00:00	280	97.9765	280	1
35/19G	35/19G	06:15:00	18:05:00	183.5	175.1588	18:08:00	21:01:00	05:10:00	280	104.8412	280	2
35/20G	35/20G	06:35:00	18:40:00	183.5	175.1588	18:43:00	21:36:00	05:15:00	280	104.8412	280	3
40/01	40/01	05:30:00	22:55:00	255.2	237.2711	00:55:00	04:13:00	07:40:00	280	42.72886	280	3
40/02	40/02	06:00:00	23:00:00	255.2	237.2711	00:26:00	03:44:00	07:45:00	280	42.72886	280	4
40/03	40/03	06:10:00	23:00:00	255.2	237.2711	01:36:00	04:54:00	08:05:00	280	42.72886	280	5
40/04	40/04	06:20:00	23:10:00	255.2	237.2711	02:02:00	05:20:00	08:20:00	280	42.72886	280	9
40/05	40/05	05:50:00	22:40:00	254.2	236.5947	00:32:00	03:50:00	07:15:00	280	43.40534	280	20
40/06	40/06	06:00:00	22:50:00	254.2	236.5947	00:58:00	04:16:00	07:20:00	280	43.40534	280	23
40/07	40/07	06:10:00	23:00:00	252.3	236.3251	01:41:00	04:59:00	08:10:00	280	43.6749	280	6
40/08	40/08	06:20:00	21:20:00	222.9	207.4719	21:23:00	00:29:00	06:10:00	280	72.52813	280	20
40/09	40/09	06:30:00	23:15:00	254.2	236.5947	02:30:00	05:48:00	08:30:00	280	43.40534	280	11
40/10	40/10	06:40:00	23:35:00	254.2	236.5947	03:18:00	06:36:00	08:50:00	280	43.40534	280	15
40/11	40/11	06:50:00	22:40:00	235.9	219.3905	00:03:00	03:14:00	07:05:00	280	60.60946	280	19
40/12	40/12	07:00:00	22:05:00	222.9	207.4719	22:32:00	01:38:00	06:25:00	280	72.52813	280	6
42/02G	42/02G	09:20:00	21:50:00	213	184.0527	21:53:00	00:50:00	06:20:00	280	95.94732	280	22
54/01	54/01	05:00:00	13:05:00	164.4	142.7286	13:08:00	13:22:00	13:25:00	280	137.2714	172.5	1
54/01A	54/01A	12:50:00	21:40:00	163.5	141.9006	21:43:00	00:23:00	06:10:00	280	138.0994	280	4
54/02	54/02	05:10:00	14:00:00	164.4	142.7286	14:03:00	16:43:00	04:55:00	280	137.2714	280	1
54/02A	54/01	13:25:00	22:05:00	163.5	141.9006	22:33:00	01:56:00	06:25:00	172.5	30.59939	280	7

HIGNA NAKA BUS DEPOT

- Optimized charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
106/01	106/01	04:55:00	21:50:00	204.5	197.96	22:24:00	01:26:00	06:20:00	280	82.04003	280	23
106/02	106/02	05:35:00	22:25:00	207.8	201.1888	03:38:00	06:37:00	06:40:00	280	78.81117	279.9925	12
106/03	106/03	05:45:00	22:30:00	206.3	200.4556	23:38:00	02:41:00	06:45:00	280	79.5444	280	14
106/04	106/04	05:55:00	22:40:00	215.2	209.7555	00:22:00	03:29:00	07:00:00	280	70.24455	280	18
106/05	106/05	06:05:00	23:05:00	222	215.1316	02:33:00	05:42:00	08:10:00	280	64.86838	280	7
106/07	106/07	06:25:00	23:15:00	215.2	209.7555	06:43:00	08:32:00	08:35:00	280	70.24455	276.7862	12
106/08	106/08	06:35:00	23:25:00	206.9	201.2875	02:50:00	05:54:00	08:40:00	280	78.71253	280	14
106/10	106/10	07:05:00	23:50:00	208	202.4659	07:18:00	09:17:00	09:20:00	280	77.53414	278.5666	19
106/11	106/11	07:15:00	00:10:00	208.9	203.3679	04:22:00	07:26:00	09:30:00	280	76.63214	280	20
106/12	106/12	07:25:00	00:25:00	214.7	207.091	04:30:00	07:36:00	12:50:00	280	72.90897	280	22
135/01	135/01	05:20:00	22:30:00	286.6	265.3672	23:46:00	03:15:00	06:45:00	280	14.63282	280	15
135/02	135/02	05:50:00	22:40:00	287.4	265.8907	01:28:00	04:57:00	07:05:00	280	14.10928	280	21
135/03	135/03	06:00:00	22:05:00	270.2	249.9017	22:55:00	02:18:00	06:30:00	280	30.09831	280	8
135/04	135/04	08:05:00	23:40:00	270.2	249.9017	07:18:00	09:17:00	09:20:00	280	30.09831	275.3452	17
135/05	135/05	07:15:00	22:20:00	239.7	222.186	23:20:00	02:32:00	06:35:00	280	57.81398	280	10
135/06	135/06	06:25:00	22:30:00	270	249.7198	03:49:00	06:57:00	07:00:00	280	30.28021	279.959	13
135/07	135/07	07:40:00	21:40:00	231.6	214.1916	21:51:00	01:00:00	06:10:00	280	65.80842	280	3
135/08	135/08	05:50:00	22:40:00	286.6	265.0689	04:01:00	07:12:00	07:15:00	280	14.93108	279.9453	17
135/09	135/09	06:00:00	21:50:00	267.4	247.3017	22:03:00	01:25:00	06:15:00	280	32.69832	280	21
135/10	135/10	06:10:00	22:00:00	267.4	247.3017	22:11:00	01:33:00	06:20:00	280	32.69832	280	5
135/11	135/11	06:20:00	22:55:00	286.6	265.0689	00:05:00	03:34:00	07:25:00	280	14.93108	280	2
135/12	135/12	06:30:00	23:10:00	286.6	264.7644	02:35:00	06:04:00	08:25:00	280	15.23562	280	10

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
135/13G	135/13G	08:10:00	19:55:00	183.2	169.4238	19:58:00	22:49:00	05:45:00	280	110.5762	280	8
135/14G	135/14G	08:20:00	20:05:00	183.2	169.4238	20:08:00	22:59:00	05:45:00	280	110.5762	280	10
135/15G	135/15G	08:30:00	20:15:00	183.2	169.4238	20:18:00	23:09:00	05:50:00	280	110.5762	280	11
135/16G	135/16G	08:40:00	20:25:00	184.4	171.7047	20:28:00	23:20:00	05:50:00	280	108.2953	280	13
135/17G	135/17G	08:50:00	20:35:00	198.4	183.4996	20:38:00	23:34:00	05:55:00	280	96.50039	280	14
135/18G	135/18G	09:00:00	20:45:00	199	184.0642	20:50:00	23:47:00	06:00:00	280	95.93585	280	1
135/19G	135/19G	09:10:00	20:55:00	181.4	169.3327	20:58:00	23:49:00	06:00:00	280	110.6673	280	16
135/20G	135/20G	09:20:00	21:05:00	198.4	183.4996	21:14:00	00:10:00	06:05:00	280	96.50039	280	17
135/21G	135/21G	09:30:00	21:20:00	198.4	183.4996	21:23:00	00:19:00	06:10:00	280	96.50039	280	18
135/22G	135/22G	07:45:00	19:35:00	183.3	170.2119	19:38:00	22:29:00	05:35:00	280	109.7881	280	6
135/23G	135/23G	07:00:00	19:10:00	195	180.5299	19:13:00	22:08:00	05:30:00	280	99.47007	280	5
28/01	28/01	05:15:00	23:05:00	218.8	213.0738	02:21:00	05:29:00	08:20:00	280	66.92624	280	8
28/02	28/02	05:45:00	23:35:00	210.1	203.087	03:09:00	06:13:00	09:00:00	280	76.91295	280	16
28/03	28/03	06:10:00	23:40:00	228.4	220.9423	03:32:00	06:43:00	09:10:00	280	59.05768	280	18
28/04	28/04	06:45:00	00:10:00	210.8	206.9647	05:00:00	08:06:00	09:40:00	280	73.0353	280	21
28/05	28/05	07:05:00	22:45:00	202	194.9722	01:17:00	04:18:00	07:15:00	280	85.02776	280	22
28/06	28/06	07:15:00	23:20:00	219.1	209.4157	07:03:00	08:37:00	08:40:00	280	70.58427	271.8976	13
28/07	28/07	07:20:00	21:00:00	170.3	163.397	21:07:00	23:55:00	06:00:00	280	116.603	280	2
28/08G	28/08G	08:10:00	19:50:00	136.8	133.8775	19:53:00	22:30:00	05:35:00	280	146.1225	280	7
28/09G	28/09G	08:20:00	20:00:00	141.5	138.7133	20:03:00	22:41:00	05:45:00	280	141.2867	280	9
28/10G	28/10G	08:40:00	20:20:00	136.8	134.3962	20:23:00	23:00:00	05:50:00	280	145.6038	280	12
28/12G	28/12G	09:40:00	21:20:00	136.5	133.8558	21:31:00	00:08:00	06:10:00	280	146.1442	280	19
32/01	32/01	06:10:00	22:20:00	234.5	229.5491	23:31:00	02:46:00	06:35:00	280	50.45092	280	11
32/02	32/02	06:45:00	22:15:00	234.5	229.5491	22:44:00	01:59:00	06:30:00	280	50.45092	280	9

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
32/03	32/03	05:45:00	22:30:00	228.9	224.4265	23:53:00	03:06:00	06:50:00	280	55.57349	280	16
32/04G	32/04G	08:25:00	18:55:00	145	142.0848	18:58:00	21:38:00	05:20:00	280	137.9152	280	4
35/17G	35/17G	08:35:00	20:40:00	202.7	193.5966	20:43:00	23:43:00	06:00:00	280	86.40343	280	15
35/18G	35/18G	05:35:00	17:45:00	191.5	182.0235	17:48:00	20:44:00	05:00:00	280	97.9765	280	1
35/19G	35/19G	06:15:00	18:05:00	183.5	175.1588	18:08:00	21:01:00	05:10:00	280	104.8412	280	2
35/20G	35/20G	06:35:00	18:40:00	183.5	175.1588	18:43:00	21:36:00	05:15:00	280	104.8412	280	3
40/01	40/01	05:30:00	22:55:00	255.2	237.2711	01:03:00	04:21:00	07:40:00	280	42.72886	280	3
40/02	40/02	06:00:00	23:00:00	255.2	237.2711	00:40:00	03:58:00	07:45:00	280	42.72886	280	4
40/03	40/03	06:10:00	23:00:00	255.2	237.2711	01:36:00	04:54:00	08:05:00	280	42.72886	280	5
40/04	40/04	06:20:00	23:10:00	255.2	237.2711	02:02:00	05:20:00	08:20:00	280	42.72886	280	9
40/05	40/05	05:50:00	22:40:00	254.2	236.5947	00:51:00	04:09:00	07:05:00	280	43.40534	280	20
40/06	40/06	06:00:00	22:50:00	254.2	236.5947	01:29:00	04:47:00	07:20:00	280	43.40534	280	23
40/07	40/07	06:10:00	23:00:00	252.3	236.3251	01:44:00	05:02:00	08:10:00	280	43.6749	280	6
40/08	40/08	06:20:00	21:20:00	222.9	207.4719	21:42:00	00:48:00	06:10:00	280	72.52813	280	20
40/09	40/09	06:30:00	23:15:00	254.2	236.5947	03:01:00	06:19:00	08:30:00	280	43.40534	280	11
40/10	40/10	06:40:00	23:35:00	254.2	236.5947	03:18:00	06:36:00	08:50:00	280	43.40534	280	15
40/11	40/11	06:50:00	22:40:00	235.9	219.3905	04:12:00	07:12:00	07:15:00	280	60.60946	279.9739	19
40/12	40/12	07:00:00	22:05:00	222.9	207.4719	22:32:00	01:38:00	06:25:00	280	72.52813	280	6
42/02G	42/02G	09:20:00	21:50:00	213	184.0527	22:17:00	01:14:00	06:20:00	280	95.94732	280	22
54/01	54/01	05:00:00	13:05:00	164.4	142.7286	13:08:00	13:22:00	13:25:00	280	137.2714	172.5	1
54/01A	54/01A	12:50:00	21:40:00	163.5	141.9006	21:57:00	00:37:00	06:10:00	280	138.0994	280	4
54/02	54/02	05:10:00	14:00:00	164.4	142.7286	14:03:00	16:43:00	04:55:00	280	137.2714	280	1
54/02A	54/01	13:25:00	22:05:00	163.5	141.9006	23:07:00	02:30:00	06:25:00	172.5	30.59939	280	7

PATWARDHAN 2 BUS DEPOT

- Normal charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
111/01G	111/01G	08:35:00	20:20:00	162.9	154.9538	20:23:00	23:08:00	05:25:00	280	125.0462	280	6
20/01	20/01	05:25:00	22:35:00	292.5	261.2399	22:38:00	02:05:00	06:25:00	280	18.76012	280	18
20/02	20/02	05:40:00	22:55:00	293	261.6879	00:28:00	03:56:00	06:40:00	280	18.31212	280	11
20/03	20/03	05:55:00	23:15:00	272.8	245.3601	01:50:00	05:11:00	07:00:00	280	34.63986	280	17
20/04	20/04	06:15:00	23:35:00	274.5	245.6347	03:06:00	06:27:00	07:30:00	280	34.36533	280	7
20/05	20/05	06:35:00	23:55:00	291.3	261.4134	04:26:00	07:54:00	08:00:00	280	18.58665	280	10
20/06	20/06	06:55:00	00:15:00	291.3	261.4134	05:25:00	08:47:00	08:50:00	280	18.58665	279.9879	15
210/01	210/01	05:30:00	22:30:00	244.8	228.2024	22:33:00	01:47:00	06:20:00	280	51.79764	280	17
210/02	210/02	08:00:00	21:30:00	184	171.522	21:33:00	00:25:00	05:45:00	280	108.478	280	11
231/01	231/01	06:15:00	21:35:00	250.4	219.0965	21:38:00	00:49:00	05:45:00	280	60.90354	280	12
26/01	26/01	05:00:00	20:25:00	300	257.9253	20:28:00	23:54:00	05:30:00	280	22.07471	280	7
26/02	26/02	05:20:00	20:45:00	300	257.9253	20:48:00	00:14:00	05:40:00	280	22.07471	280	8
26/03	26/03	05:40:00	21:05:00	300	257.9253	21:08:00	00:34:00	05:40:00	280	22.07471	280	9
26/04	26/04	06:00:00	21:25:00	300	257.9253	21:28:00	00:54:00	05:40:00	280	22.07471	280	10
26/05	26/05	06:20:00	21:45:00	300	257.9253	21:48:00	01:14:00	05:50:00	280	22.07471	280	13
26/06	26/06	06:40:00	22:05:00	300	257.9253	22:08:00	01:34:00	06:05:00	280	22.07471	280	4
26/07	26/07	07:00:00	22:25:00	300	257.9253	22:28:00	01:54:00	06:15:00	280	22.07471	280	15
26/08	26/08	07:10:00	22:35:00	300	257.9253	23:11:00	02:37:00	06:20:00	280	22.07471	280	6
26/09	26/09	07:30:00	22:55:00	300	257.9253	00:57:00	04:23:00	06:40:00	280	22.07471	280	10
26/10	26/10	07:50:00	23:15:00	300	257.9253	02:08:00	05:34:00	07:05:00	280	22.07471	280	18
26/11	26/11	08:10:00	23:35:00	300	257.9253	02:40:00	06:06:00	07:20:00	280	22.07471	280	6
26/12	26/12	08:30:00	00:00:00	300	257.9253	04:45:00	08:11:00	08:35:00	280	22.07471	280	13

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
26/13	26/13	08:50:00	00:20:00	300	257.9253	05:22:00	08:48:00	09:10:00	280	22.07471	280	16
26/14	26/14	09:10:00	00:29:00	300	257.9253	05:14:00	08:40:00	13:05:00	280	22.07471	280	17
38/01	38/01	04:45:00	13:05:00	155.3	139.128	13:08:00	13:22:00	13:25:00	280	140.872	175	1
38/01A	38/01A	13:05:00	21:55:00	154.9	138.7659	21:58:00	00:37:00	06:00:00	280	141.2341	280	2
38/02	38/02	05:05:00	13:25:00	155.3	139.128	13:28:00	13:42:00	13:45:00	280	140.872	175	1
38/02A	38/01	13:25:00	22:15:00	154.9	138.7659	22:18:00	01:39:00	06:05:00	175	36.2341	280	14
38/03	38/03	05:25:00	13:45:00	155.3	139.128	13:48:00	14:02:00	14:05:00	280	140.872	175	1
38/03A	38/02	13:45:00	22:35:00	154.9	138.7659	22:46:00	02:07:00	06:20:00	175	36.2341	280	5
38/04	38/04	05:45:00	14:05:00	155.3	139.128	14:08:00	14:22:00	14:25:00	280	140.872	175	1
38/04A	38/03	14:05:00	22:55:00	154.9	138.7659	00:37:00	03:58:00	06:35:00	175	36.2341	280	9
38/05	38/05	06:05:00	14:25:00	155.3	139.128	14:28:00	14:42:00	14:45:00	280	140.872	175	1
38/05A	38/04	14:25:00	23:15:00	154.9	138.7659	01:58:00	05:19:00	07:00:00	175	36.2341	280	16
38/06	38/06	06:25:00	14:45:00	155.2	139.0352	14:48:00	15:02:00	15:05:00	280	140.9648	175	1
38/06A	38/05	14:45:00	23:35:00	154.9	138.7659	02:10:00	05:31:00	07:15:00	175	36.2341	280	5
38/07	38/07	06:45:00	15:05:00	155.3	139.128	15:08:00	15:22:00	15:25:00	280	140.872	175	1
38/07A	38/06	15:05:00	23:55:00	154.9	138.7659	03:59:00	07:20:00	08:10:00	175	36.2341	280	11
38/08	38/08	07:05:00	15:55:00	155.3	139.128	15:58:00	18:37:00	04:45:00	280	140.872	280	1
38/08A	38/07	15:25:00	00:15:00	154.9	138.7659	04:51:00	08:12:00	08:40:00	175	36.2341	280	14
38/15G	38/15G	07:15:00	19:10:00	206	184.5232	19:13:00	22:10:00	05:20:00	280	95.47678	280	3
54/03	54/03	05:50:00	22:10:00	302.7	260.5793	22:13:00	01:40:00	06:05:00	280	19.42075	280	3
54/04	54/04	06:05:00	22:25:00	302.7	260.5793	22:28:00	01:55:00	06:15:00	280	19.42075	280	16
54/05	54/05	06:20:00	22:40:00	302.7	260.5793	00:17:00	03:44:00	06:35:00	280	19.42075	280	8
54/06	54/06	06:35:00	22:55:00	296.2	255.304	01:17:00	04:42:00	06:50:00	280	24.69604	280	13
54/07	54/07	06:50:00	23:10:00	296.2	255.304	01:57:00	05:22:00	06:55:00	280	24.69604	280	15

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
54/08	54/08	07:05:00	23:25:00	296.2	255.304	01:43:00	05:08:00	07:10:00	280	24.69604	280	3
54/09	54/09	07:20:00	23:35:00	296.2	255.304	01:37:00	05:02:00	07:15:00	280	24.69604	280	4
54/10	54/10	07:35:00	00:00:00	295.9	255.0455	04:01:00	07:26:00	08:30:00	280	24.95452	280	12
54/11G	54/11G	08:40:00	19:20:00	138.4	123.8892	19:23:00	21:56:00	05:20:00	280	156.1108	280	4
79/01	79/01	05:45:00	22:55:00	212.4	207.4261	00:52:00	03:58:00	06:45:00	280	72.57393	280	12
79/02	79/02	06:20:00	23:25:00	212.4	207.4261	00:40:00	03:46:00	07:05:00	280	72.57393	280	2
79/03	79/03	06:40:00	23:45:00	212.4	207.4261	04:01:00	07:07:00	07:50:00	280	72.57393	280	9
79/04G	79/04G	07:00:00	19:05:00	148.2	144.6544	19:08:00	21:49:00	05:00:00	280	135.3456	280	1
79/05	79/05	05:20:00	19:45:00	188	180.0018	19:48:00	22:43:00	05:25:00	280	99.99823	280	5
79/06	79/06	05:40:00	22:40:00	212.4	207.3594	23:57:00	03:03:00	06:35:00	280	72.64058	280	7
79/07	79/07	06:05:00	23:05:00	212.4	207.4261	01:42:00	04:48:00	06:55:00	280	72.57393	280	14
79/08	79/08	06:35:00	21:55:00	192.4	187.866	21:58:00	00:56:00	05:55:00	280	92.13403	280	1
79/09	79/09	06:55:00	23:40:00	212.4	207.4261	03:47:00	06:53:00	07:35:00	280	72.57393	280	8
79/10G	79/10G	07:15:00	19:10:00	150.3	146.7334	19:13:00	21:55:00	05:05:00	280	133.2666	280	2

PATWARDHAN 2 BUS DEPOT

- Optimized charging

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
111/01G	111/01G	08:35:00	20:20:00	162.9	154.9538	20:23:00	23:08:00	05:25:00	280	125.0462	280	6
20/01	20/01	05:25:00	22:35:00	292.5	261.2399	00:22:00	03:49:00	06:25:00	280	18.76012	280	18
20/02	20/02	05:40:00	22:55:00	293	261.6879	00:33:00	04:01:00	06:40:00	280	18.31212	280	11
20/03	20/03	05:55:00	23:15:00	272.8	245.3601	02:48:00	06:09:00	07:00:00	280	34.63986	280	17
20/04	20/04	06:15:00	23:35:00	274.5	245.6347	03:25:00	06:46:00	07:30:00	280	34.36533	280	7
20/05	20/05	06:35:00	23:55:00	291.3	261.4134	04:37:00	08:05:00	08:10:00	280	18.58665	280	10
20/06	20/06	06:55:00	00:15:00	291.3	261.4134	05:59:00	08:47:00	08:50:00	280	18.58665	279.7118	15
210/01	210/01	05:30:00	22:30:00	244.8	228.2024	23:31:00	02:45:00	06:20:00	280	51.79764	280	17
210/02	210/02	08:00:00	21:30:00	184	171.522	21:33:00	00:25:00	05:45:00	280	108.478	280	11
231/01	231/01	06:15:00	21:35:00	250.4	219.0965	21:38:00	00:49:00	05:45:00	280	60.90354	280	12
26/01	26/01	05:00:00	20:25:00	300	257.9253	20:28:00	23:54:00	05:30:00	280	22.07471	280	7
26/02	26/02	05:20:00	20:45:00	300	257.9253	20:48:00	00:14:00	05:40:00	280	22.07471	280	8
26/03	26/03	05:40:00	21:05:00	300	257.9253	21:08:00	00:34:00	05:40:00	280	22.07471	280	9
26/04	26/04	06:00:00	21:25:00	300	257.9253	21:28:00	00:54:00	05:40:00	280	22.07471	280	10
26/05	26/05	06:20:00	21:45:00	300	257.9253	21:48:00	01:14:00	05:50:00	280	22.07471	280	13
26/06	26/06	06:40:00	22:05:00	300	257.9253	22:23:00	01:49:00	06:05:00	280	22.07471	280	4
26/07	26/07	07:00:00	22:25:00	300	257.9253	23:02:00	02:28:00	06:15:00	280	22.07471	280	15
26/08	26/08	07:10:00	22:35:00	300	257.9253	23:11:00	02:37:00	06:20:00	280	22.07471	280	6
26/09	26/09	07:30:00	22:55:00	300	257.9253	01:08:00	04:34:00	06:40:00	280	22.07471	280	10
26/10	26/10	07:50:00	23:15:00	300	257.9253	03:52:00	07:02:00	07:05:00	280	22.07471	279.9547	18
26/11	26/11	08:10:00	23:35:00	300	257.9253	02:40:00	06:06:00	07:20:00	280	22.07471	280	6
26/12	26/12	08:30:00	00:00:00	300	257.9253	04:48:00	08:14:00	08:35:00	280	22.07471	280	13

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
26/13	26/13	08:50:00	00:20:00	300	257.9253	06:23:00	09:07:00	09:10:00	280	22.07471	279.6706	16
26/14	26/14	09:10:00	00:29:00	300	257.9253	06:12:00	09:38:00	13:05:00	280	22.07471	280	17
38/01	38/01	04:45:00	13:05:00	155.3	139.128	13:08:00	13:22:00	13:25:00	280	140.872	175	1
38/01A	38/01A	13:05:00	21:55:00	154.9	138.7659	21:58:00	00:37:00	06:00:00	280	141.2341	280	2
38/02	38/02	05:05:00	13:25:00	155.3	139.128	13:28:00	13:42:00	13:45:00	280	140.872	175	1
38/02A	38/01	13:25:00	22:15:00	154.9	138.7659	22:55:00	02:16:00	06:05:00	175	36.2341	280	14
38/03	38/03	05:25:00	13:45:00	155.3	139.128	13:48:00	14:02:00	14:05:00	280	140.872	175	1
38/03A	38/02	13:45:00	22:35:00	154.9	138.7659	22:46:00	02:07:00	06:20:00	175	36.2341	280	5
38/04	38/04	05:45:00	14:05:00	155.3	139.128	14:08:00	14:22:00	14:25:00	280	140.872	175	1
38/04A	38/03	14:05:00	22:55:00	154.9	138.7659	00:43:00	04:04:00	06:35:00	175	36.2341	280	9
38/05	38/05	06:05:00	14:25:00	155.3	139.128	14:28:00	14:42:00	14:45:00	280	140.872	175	1
38/05A	38/04	14:25:00	23:15:00	154.9	138.7659	02:59:00	06:20:00	07:00:00	175	36.2341	280	16
38/06	38/06	06:25:00	14:45:00	155.2	139.0352	14:48:00	15:02:00	15:05:00	280	140.9648	175	1
38/06A	38/05	14:45:00	23:35:00	154.9	138.7659	02:10:00	05:31:00	07:15:00	175	36.2341	280	5
38/07	38/07	06:45:00	15:05:00	155.3	139.128	15:08:00	15:22:00	15:25:00	280	140.872	175	1
38/07A	38/06	15:05:00	23:55:00	154.9	138.7659	04:04:00	07:25:00	08:00:00	175	36.2341	280	11
38/08	38/08	07:05:00	15:55:00	155.3	139.128	15:58:00	18:37:00	04:45:00	280	140.872	280	1
38/08A	38/07	15:25:00	00:15:00	154.9	138.7659	05:28:00	08:37:00	08:40:00	175	36.2341	279.9705	14
38/15G	38/15G	07:15:00	19:10:00	206	184.5232	19:13:00	22:10:00	05:20:00	280	95.47678	280	3
54/03	54/03	05:50:00	22:10:00	302.7	260.5793	22:38:00	02:05:00	06:05:00	280	19.42075	280	3
54/04	54/04	06:05:00	22:25:00	302.7	260.5793	23:19:00	02:46:00	06:15:00	280	19.42075	280	16
54/05	54/05	06:20:00	22:40:00	302.7	260.5793	00:17:00	03:44:00	06:35:00	280	19.42075	280	8
54/06	54/06	06:35:00	22:55:00	296.2	255.304	01:20:00	04:45:00	06:50:00	280	24.69604	280	13
54/07	54/07	06:50:00	23:10:00	296.2	255.304	02:31:00	05:56:00	06:55:00	280	24.69604	280	15

Task	Vehicle	Start	End	Distance (km)	Consumption (kWh)	Start of Charge	End of Charge	Next Task	Initial State of Charge (kWh)	End of task State of Charge (kWh)	State of Charge end of charge (kWh)	Charging Terminal
54/08	54/08	07:05:00	23:25:00	296.2	255.304	02:08:00	05:33:00	07:10:00	280	24.69604	280	3
54/09	54/09	07:20:00	23:35:00	296.2	255.304	01:52:00	05:17:00	07:15:00	280	24.69604	280	4
54/10	54/10	07:35:00	00:00:00	295.9	255.0455	04:17:00	07:42:00	08:30:00	280	24.95452	280	12
54/11G	54/11G	08:40:00	19:20:00	138.4	123.8892	19:23:00	21:56:00	05:20:00	280	156.1108	280	4
79/01	79/01	05:45:00	22:55:00	212.4	207.4261	00:58:00	04:04:00	06:45:00	280	72.57393	280	12
79/02	79/02	06:20:00	23:25:00	212.4	207.4261	00:51:00	03:57:00	07:05:00	280	72.57393	280	2
79/03	79/03	06:40:00	23:45:00	212.4	207.4261	04:09:00	07:15:00	07:50:00	280	72.57393	280	9
79/04G	79/04G	07:00:00	19:05:00	148.2	144.6544	19:08:00	21:49:00	05:00:00	280	135.3456	280	1
79/05	79/05	05:20:00	19:45:00	188	180.0018	19:48:00	22:43:00	05:25:00	280	99.99823	280	5
79/06	79/06	05:40:00	22:40:00	212.4	207.3594	23:57:00	03:03:00	06:35:00	280	72.64058	280	7
79/07	79/07	06:05:00	23:05:00	212.4	207.4261	02:19:00	05:25:00	06:55:00	280	72.57393	280	14
79/08	79/08	06:35:00	21:55:00	192.4	187.866	21:58:00	00:56:00	05:55:00	280	92.13403	280	1
79/09	79/09	06:55:00	23:40:00	212.4	207.4261	03:47:00	06:53:00	07:35:00	280	72.57393	280	8
79/10G	79/10G	07:15:00	19:10:00	150.3	146.7334	19:13:00	21:55:00	05:05:00	280	133.2666	280	2

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