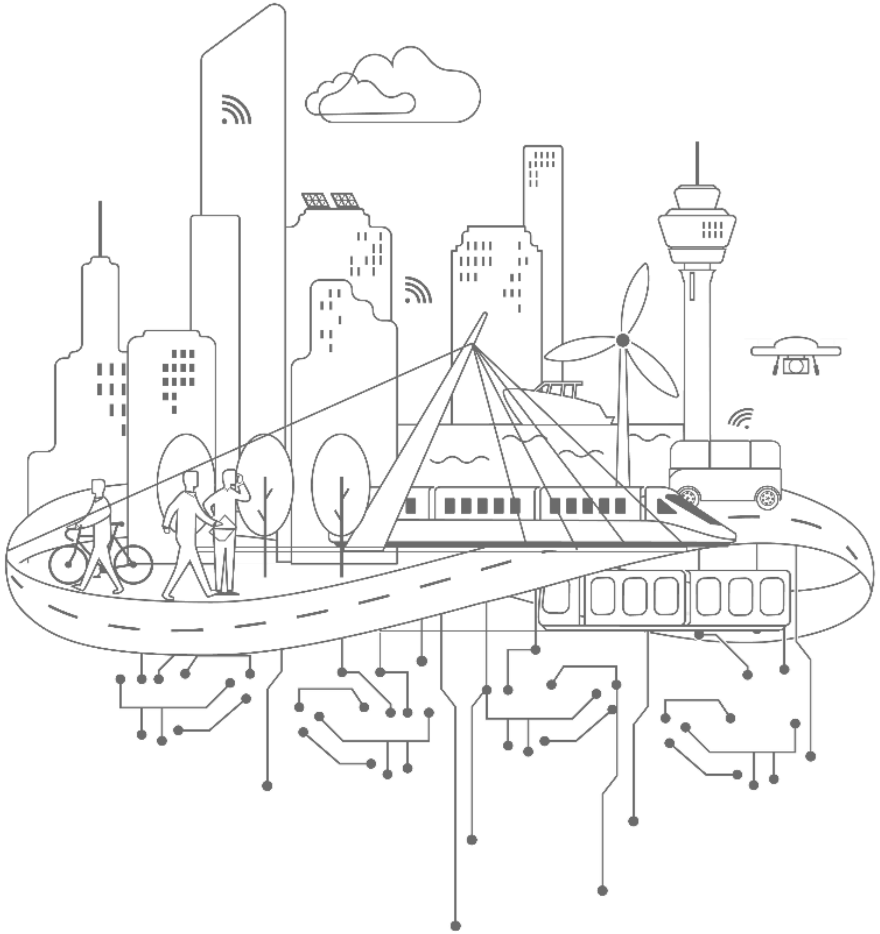

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Experience and recommendations for transition of city buses

A case example of Nagpur (Maharashtra), India

NAGPUR MUNICIPAL CORPORATION

SmartCity नागपूर

AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT

23 July 2020 | Webinar

GREETINS FOR TODAY'S WEBINAR !

Carlos BELEM

Deputy Project Manager

Arthur TORIBIO

Bus Electrification,
Rolling Stock and Depot
Design Engineer

Joachim NALET

Project Manager
Public Transport Expert

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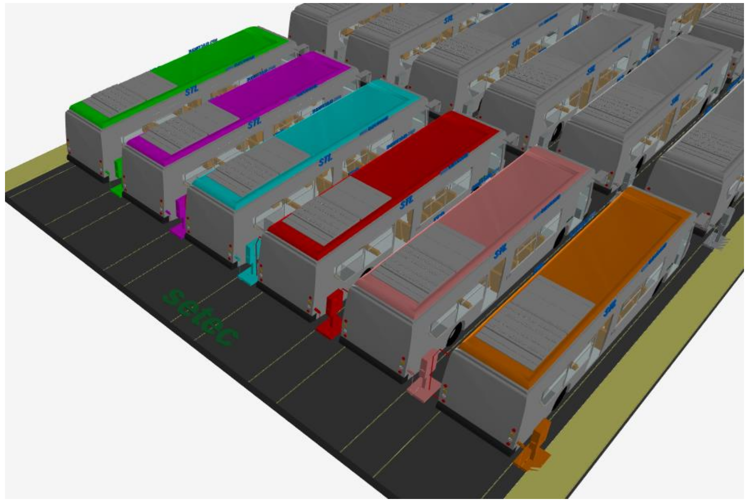
SETEC'S EXPERIENCE IN BUS ELECTRIFICATION STUDIES / PROJECTS



Our activities:

- Diagnosis of the bus network in order to propose sample lines relevant for the rest of the study
- State of the art and benchmark analysis for electric buses and battery power and charging systems
- Modelling and simulation of electricity consumption of sample bus lines according to topographic and operational parameters
- Pre-sizing of the corresponding required electrical infrastructures
- Identification and quantification of impacts on the bus network

Our references (since 2017):

Montréal bus network (Québec – Canada):

- *Electrification strategy study*
- *Stinson and Grand Est bus depots electrification*

Laval bus network (Québec – Canada):

- *Electrification strategy study*
- *Detailed electrification project (rolling stock & infra)*

Lévis, **Gatineau**, **Trois-Rivières**, **Saguenay**, **Yukon**, **Sherbrooke** city bus networks (Canada) + **Lyon** city bus network (France):

- *Electrification strategy study*

Tripoli bus network (Lebanon):

- *Electrical bus opportunity study*

MAIN ISSUES RELATED TO BUS ELECTRIFICATION

CITY BUS ELECTRIFICATION

Operational characteristics

- Bus routes topography
- Urban density
- Bus routes length and depot location

Direct and indirect costs

- Capital investment (buses and electric infrastructure)
- Operational expenses (electricity and recharging activities)
- Maintenance expenses (new activities and spare parts)

Recharge strategy

- "Fast" / Opportunity charging
- "Slow" / Depot charging
- Impact on deadhead and bus fleet

Battery autonomy

- Diesel / GNV = 250 to 350 km
- Electric battery = 30 to 240 km
- Battery lifespan

STEPS FOR BUS ELECTRIFICATION STUDIES

Steps for bus electrification studies:

Step 1 : Benchmark of available technologies

- Rolling Stock Benchmark (Batteries capacity, electrical consumption and efficiency, etc.)
- Electrical Infrastructures Benchmark (Charging stations, connection systems, etc.)
- ***Proposals / Options for strategy of recharge and Rolling Stock***

Step 2 : Vehicle electrical consumption simulations

- Operation data for the network / routes (routes timetables, passenger ridership over the line, etc.)
- Routes characteristics (Vertical alignment, lenght, quantity of stops, etc.)
- **Charging timetable and programming simulation (typical consumption per route)**

Step 3 : Electrical charging simulations

- Charging simulations
- Sizing of electrical infrastructures
- **CAPEX and OPEX definition**

pre-sizing

Our mission in Nagpur:

1. Nagpur Inception Mission & Input data analysis

Site visits and stakeholder meetings
Collected data analysis (urban and transport planning documents)
City Bus Service current operational data analysis

2. Mid-term vision for future PT services

Analysis of fleet augmentation needs compared to previous CMP
Mid-term vision for future public transport services in Nagpur

3. Engine options and O&M strategy

Benchmark for engine technology options
Plan for development of depots and charging stations
Optimized operational plan to optimize the use of fleet

4. Financial and contractual analysis

Financial model: possible CAPEX and OPEX (prudent / optimistic)
Optimization of contractual framework, scenarios analysis

5. Transition plan for bus fleet upgrade

Transition Plan with development phases, basis for deployment of electric bus service

6. Pre-Feasibility for E-buses deployment

Detailed description of identified priority corridors
Realignment and reinforcement of existing bus system

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Electrification Strategy

Bus motorization comparative analysis

Recharging strategy – fast / slow charging

Choice of rolling stock and electric infrastructure

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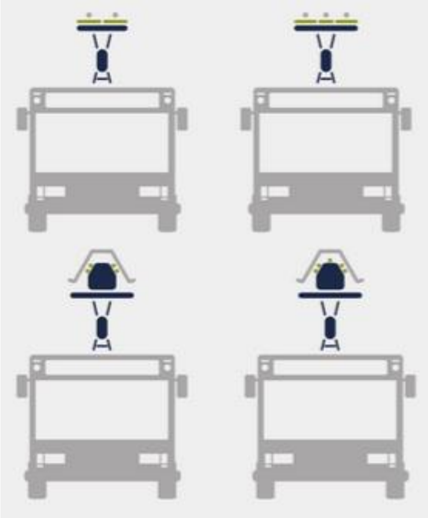
	Bus Up	Pantographe inversé	Prise Combo	Système par induction	SRS (système de recharge statique)
Système éprouvée	Charge rapide (Eindhoven(Pays-Bas), Oslo(Norvège)) Pas de retour sur la recharge lente	Charge rapide OPPCharge (Gothenburg (Suède), Stockholm (Suède), Hamburg (Allemagne)) Pas de retour sur la recharge lente	Charge lente éprouvé sur plus de 70 réseaux à l'international (France, Allemagne, Royaume-Uni, Italie, etc.) Système de charge combiné (CCS) normé	Charge rapide (Berlin, Mannheim (Allemagne), Bruges (Belgique),) Pas de retour sur la recharge lente	Charge rapide (Nice, tramway) Charge rapide bus non commercialisée à ce jour Pas de retour sur la recharge lente autobus
Contrainte physique	- Point de contact sur structure - Pantographe sur véhicule (~80 kg) - débattement maximal : ~1.1 m	- Point de contact sur le véhicule - Bras télescopique véhicule - Hauteur de débattement (5.3 à 4.6 m)	- Puissance possible < 350 kW - Longueur de connexion (borne à véhicule) 100 à 150 m	- Élément de captation sur véhicule - Système inductif au sol	- Élément de captation sur véhicule - Système inductif au sol
Puissance	30 à 600 kW	30 à 600 kW	50 à 150 kW	140 à 200 kW	> 200 kW
Exploitation/maintenance	(-) Fiabilité et disponibilité du pantographe sur le véhicule (-) Fiabilité en condition climatique extrême (neige, glace) non démontrée (-) Système développé pour la charge rapide	(+) Moins de contrainte liée aux conditions climatiques Accès (-) Bras télescopique par véhicule à recharger (-) Intervention de maintenance en hauteur	(-) Nécessite une manipulation pour la (dé-)connexion du véhicule	(+) Pas ou peu de retour sur les conditions climatiques (-) Système développé pour la charge rapide	(-) Pas ou peu de retour d'expérience sur la maintenance de ce système
CAPEX/OPEX	Surcoût sur le véhicule (pantographe) + maintenance associé ([illegible] en cours)	CAPEX [illegible] à [illegible] k$ / point de charge (dépendant du type de structure de fixation) OPEX (en cours)	CAPEX < 1 000 $ / prise + câble OPEX en cours	CAPEX en cours OPEX en cours	Nécessite 1 plot d'alimentation par place de remisage (En cours)



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BUS MOTORIZATION COMPARATIVE ANALYSIS

	ENVIRONMENTAL IMPACTS				OPERATION & MAINTENANCE				CAPITAL INVESTMENTS AND O&M EXPENSES			
	Tail-pipe emissions	GHG emissions	Passengers comfort	Noise generation	Technological maturity	Autonomy	Impact on depot design	Maintenance activity	Vehicle cost	Fuel cost	Vehicle maintenance cost (Europe)	Vehicle maintenance cost (India)
Diesel	− − −	− − −	+	− − −	+++	+++	+++	++	+++	−	+++	−
Hybrid	− −	− −	++	− −	++	+++	++	++	+	+	−	−
CNG	−	−	+	−	++	+++	−	++	++	++	++	+
H_2 Fuel cell	+++	+	+++	++	−	+++	−	++	− −	− −	− −	N/A
Electric	+++	+	+++	++	+	++	−	+++	−	+++	+	+++

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Infrastructure dimensioning factors are:

Operating hours (split or continuous)

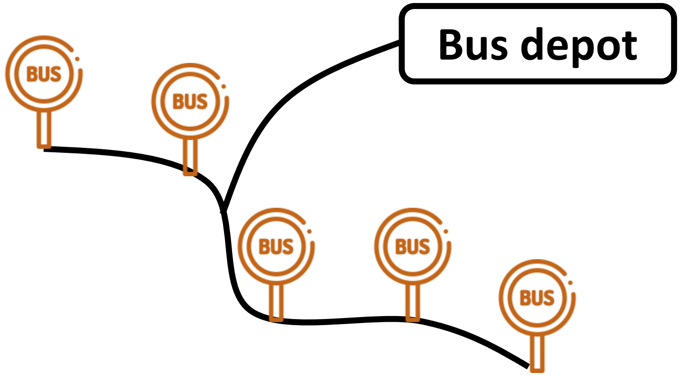
Number of vehicles to recharge

Number of **simultaneous recharges**

Energy consumption of vehicles depends on:

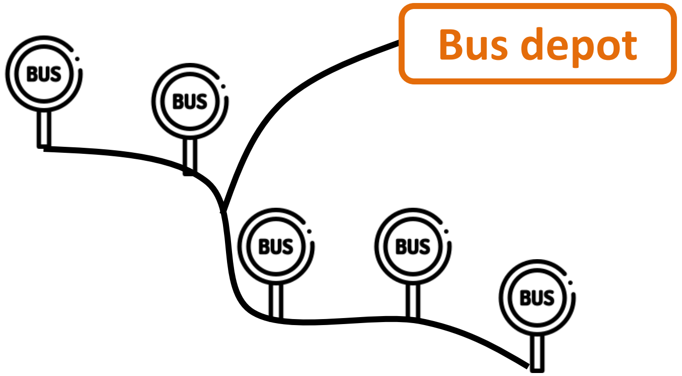
- city/route profile
- presence of auxiliary equipment
- battery type
- vehicle capacity
- vehicle commercial speed

VEHICLE RECHARGING STRATEGY



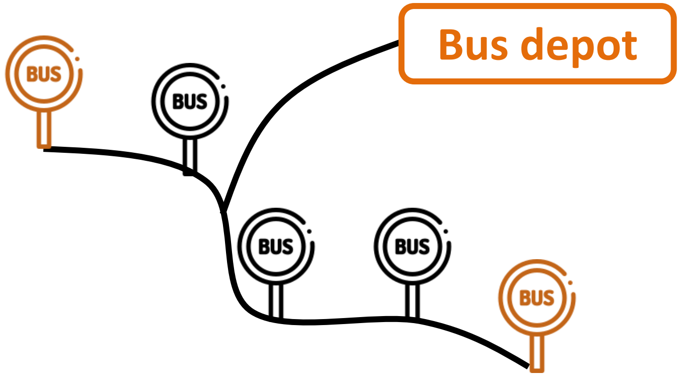
Opportunity charging

- Recharging is enough for a one-way trip or less
- Recharging at bus stops and/or at bus terminals
- Little impact on bus operation



Depot charging

- Recharging is enough for several hours / plural round-trips
- Recharging overnight (usually)
- May have some impact on bus operation (autonomy)



Mixed charging

- Recharging at bus terminals during operation hours and at bus depots (usually at night) for full battery charge
- 2 battery technologies may be required (adapted recharge performance)
- Little impact on bus operation

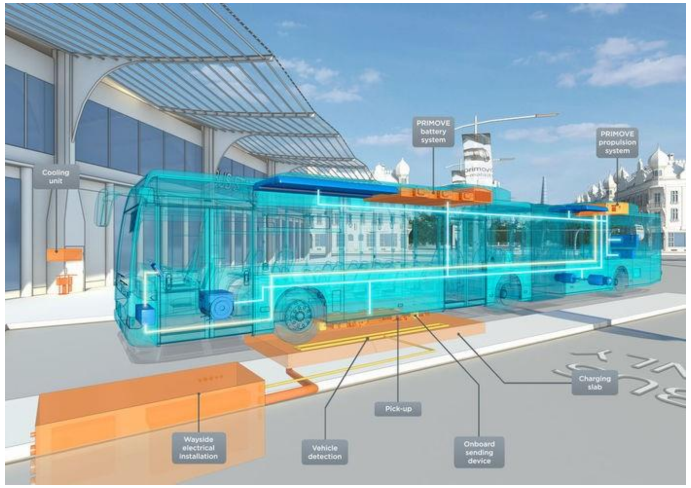
VEHICLE RECHARGING TECHNOLOGIES

Inverted pantograph (ABB)

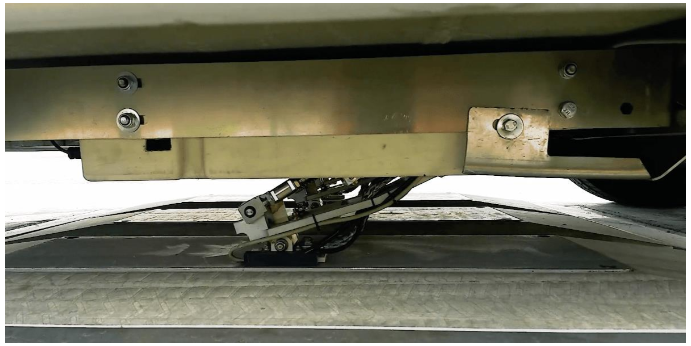
Bus-up pantograph (Heliox)

Wireless charging (BYD)

Ground induction charger (Bombardier)



VEHICLE RECHARGING TECHNOLOGIES

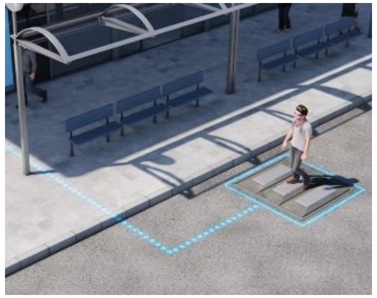



In-line ground based static charging (Alstom SRS)

Plug charging station in UK

Van Hool trolleybus (Geneva)

VEHICLE RECHARGING TECHNOLOGIES



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

The **CCS plug** has proven itself in various depots in Europe and Canada

CHOICE OF ROLLING STOCK

Minibuses – manufacturers based in India

Olectra K6

- Seating Capacity = 22 + Driver
- Maximum Power = 180kW
- Battery Specification = Li-ion Phosphate
- Range = Up to 200 km
- Charging Time = 3-4 Hours.
- Max Speed (kmph) = 80

Minibuses – other manufacturers



Tecnobus, Mellor, LDV, Karsan, Ford, GreenPower, MAN, Bluebus, Ebus, Lion

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CHOICE OF ROLLING STOCK

Midi-buses – manufacturers based in India

JBM Solaris ECOLIFE 9m Electric

- HV Battery = Lithium (type and operational voltage depending on specification)
- Charging system = Plug in and pantograph

Olectra K7

- Seating Capacity = 31 + Driver
- Maximum Power = 180kW
- Battery Specification = Li-ion Phosphate Battery
- Range = Up to 200 km
- Charging Time = 2-3 Hours.
- Max Speed (kmph) = 70

BYD 8.7m Midibus

- Seating capacity = 22 + driver
- Maximum speed = 70 km/h
- Range = Up to 200 km
- Connection type = Recharge AC or DC
- Charging cycle = 3h in average

CHOICE OF ROLLING STOCK

Standard buses – manufacturers based in India

STARBUS EV (Tata 4/12 Low Entry)

- HV Battery = Lithium-ion Battery Pack (~ 250 KWH and Scalable)
- Fast Charging = Yes (2 to 3 Hrs full charge)

JBM Solaris ECOLIFE 12m Electric

- HV Battery = Lithium (type and operational voltage depending on specification)
- Charging system = Plug in and pantograph

Olectra K9

- Battery Specification = Li-ion Phosphate Battery
- Range = Up to 300 km
- Charging Time = 4-5 Hours.

BYD 12m eBus

- Range = Up to 350 km
- Connection type = Recharge AC or DC
- Charging cycle = 4 to 5 hours in average

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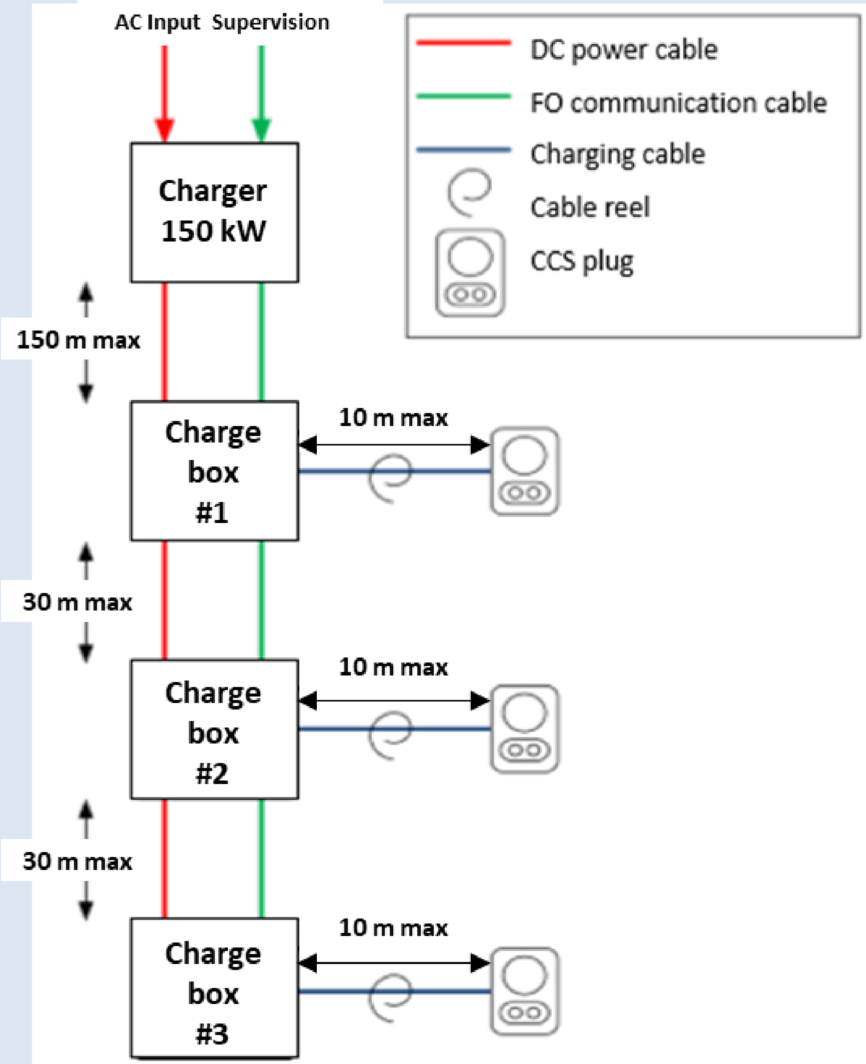
CHOICE OF ELECTRIC INFRASTRUCTURE (CHARGERS)

SINGLE CHARGING TERMINALS

SEQUENTIAL CHARGERS

Sequential charger are recommended as they **optimize infrastructure and energy consumption**



FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS

Nagpur's City Bus Service characteristics:

- Bus sizes: Standard (44 seats), Midi (32 seats) and Mini (21 seats) buses
- Travelled distance: **200 km per day per bus** (in average, minimum guaranteed per gross cost contract)
- Number of depots: **3 (+1 under construction)**
- Although Nagpur is situated on a **plateau**, **some areas are elevated**
- The curve radius of certain roads and the depots capacities **do not allow the circulation of articulated buses**
- The **city core area is very congested**
- Operating conditions include a relatively **large temperature range**, reaching up to 45°C in Summer and down to 10°C in Winter

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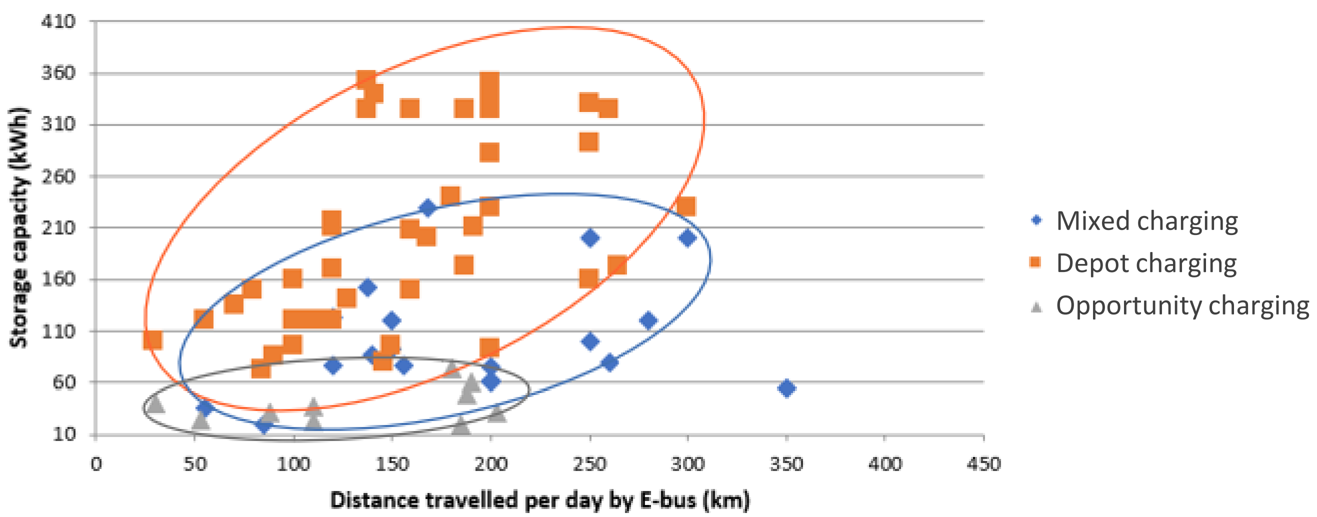
FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS



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

In the case of Nagpur city bus network, the **slow recharging strategy** (and therefore **depot charging technology**) is recommended considering the **average distance travelled per day**.

Indeed, the usual battery storage capacity enables to travel **up to 300 km without charging in-line**.

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FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS

→ Electric motor ratings: **120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)**

→ Battery types: **LFP (lithium-iron phosphate)** and **NMC (lithium nickel manganese)**

→ Connection system: **CCS plugs**

→ Thermal comfort: **refrigerated forced mechanical ventilation** or **glazing opening**

→ Charging infrastructure: **sequential chargers**

Electrification Impacts

Bus energy consumption and bus recharging simulations

Electric infrastructure dimensioning and depot area layout

Impacts on operation and maintenance activities

MAIN BUS ELECTRIFICATION IMPACTS

Bus fleet

- Definition of the bus recharge strategy (at depot, at stops and/or terminals)
- Estimation of bus fleet according to bus operational requirements and for the same service

Operation of buses

- Operational routes and distance to depots (deadhead mileage and bus recharging needs)
- Estimation of additional deadhead mileage and impacts on operational costs

Electric infrastructure

- Dimensioning of electric recharge infrastructure with / without a recharge smoothing strategy
- Estimation of the maximum power demand (subscription) and energy consumption

Maintenance equipment

- Technical specifications for electric workshops, maintenance workshops and battery storage rooms
- Need for new equipment, especially bus roof platforms and travelling cranes

Required surfaces and buildings

- Required battery storage room area and electric infrastructure maintenance workshop
- Required area on depot for the installation of bus chargers / bus recharge infrastructure

Human resources

- Operational: usually, need for additional drivers + training of drivers
- Maintenance: need for training (electric bus and infrastructure maintenance) and electric authorizations

STEPS FOR BUS ELECTRIFICATION STUDIES

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Step 3 : Electrical charging simulations

- Charging simulations
- Sizing of electrical infrastructures
- CAPEX and OPEX definition

ROLLING STOCK DATA (traction and regenerative braking performance, acceleration curves…) + **ROUTE DATA** (distance between stops, slopes, curves…) + **RIDERSHIP DATA** (quantity of passengers in the bus between each stop)

AUXILIARY'S CONSUMPTION and particularly HVAC. It's a function of external temperature + internal temperature required + quantity of passengers inside the bus (heating developed by humans) + sun radiations

VOLT@BUS

setec specialized software

Overall and average **CONSUMPTION** (traction, HVAC, auxiliaries, per km)

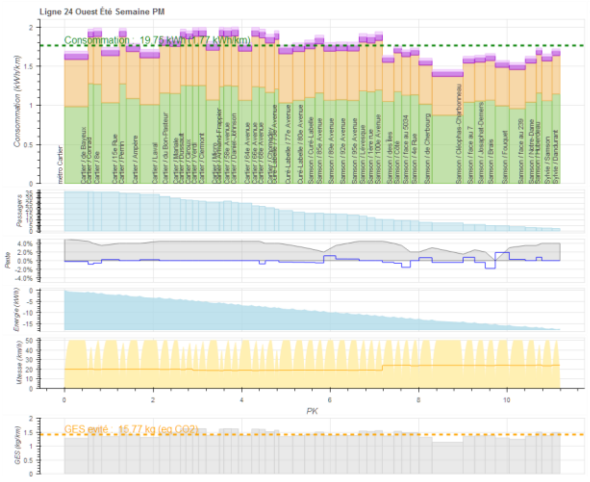
RIDERSHIP pattern (if available input data)

VERTICAL PROFILE of the route (slope)

CHARGING STATUS of the Rolling Stock battery (in remaining kWh)

SPEED PROFILE (km/h)

Analysis of **GREEN HOUSE GASES REDUCTION** compared to thermic buses



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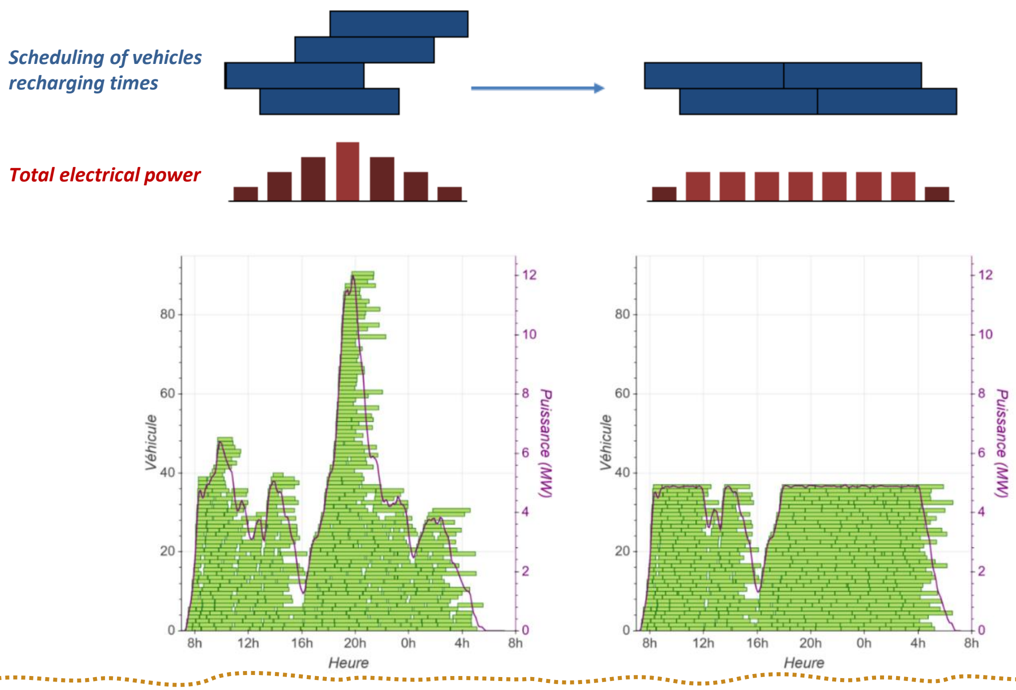

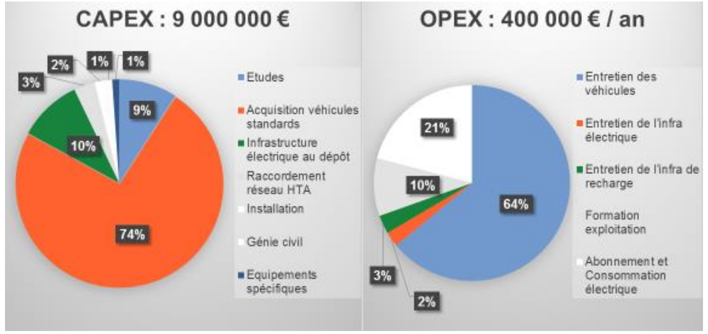

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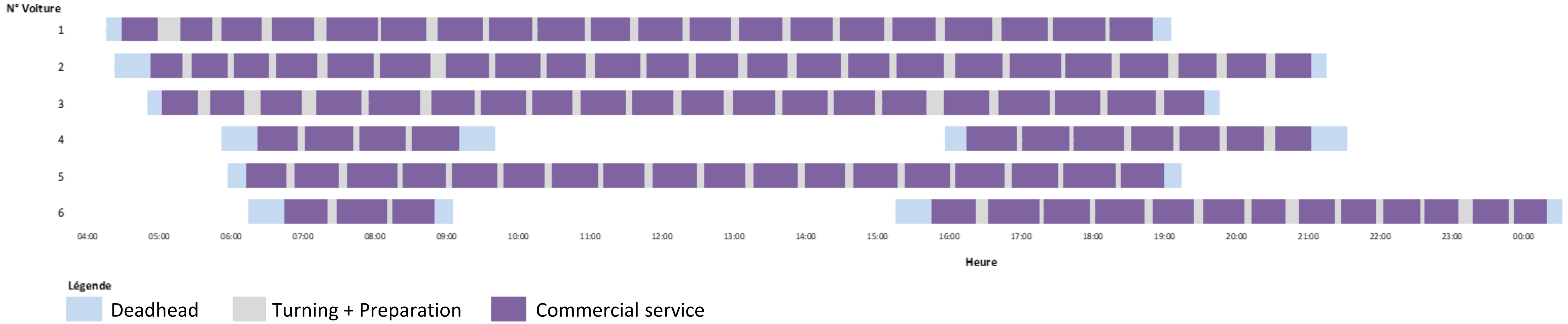
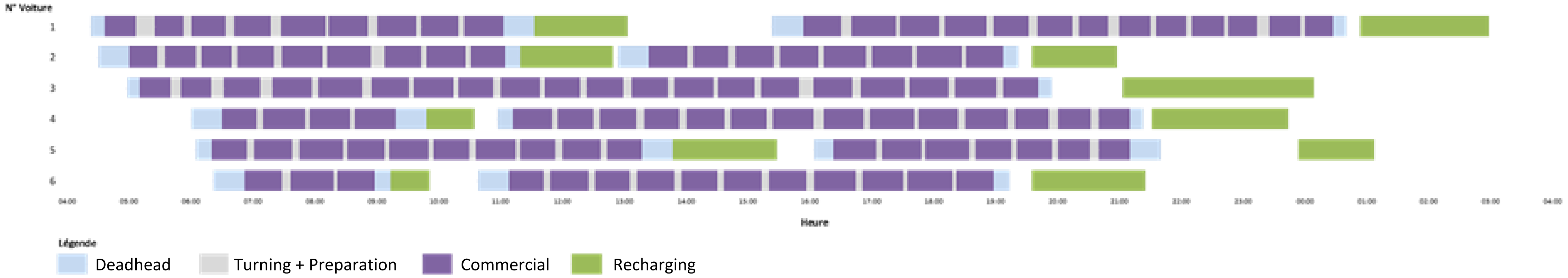
VEHICLES OPERATION CHARACTERISTICS

Operation of **thermal buses** → **Limit returns to depot** during operation hours



Operation of **electric buses** → **Limit bus distances** during operation hours



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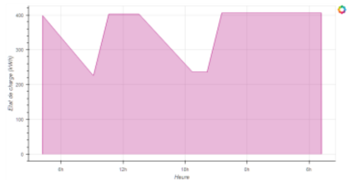
SLOW RECHARGING SIMULATION PRINCIPLES

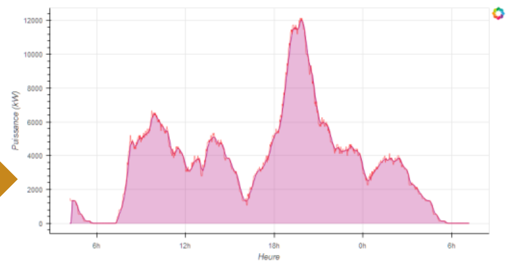
An **iterative approach** to optimize the installed/future electric infrastructure capacity

Operation data
(Distances, routes, timetable,…)



Discharge state of each bus

Recharging hours

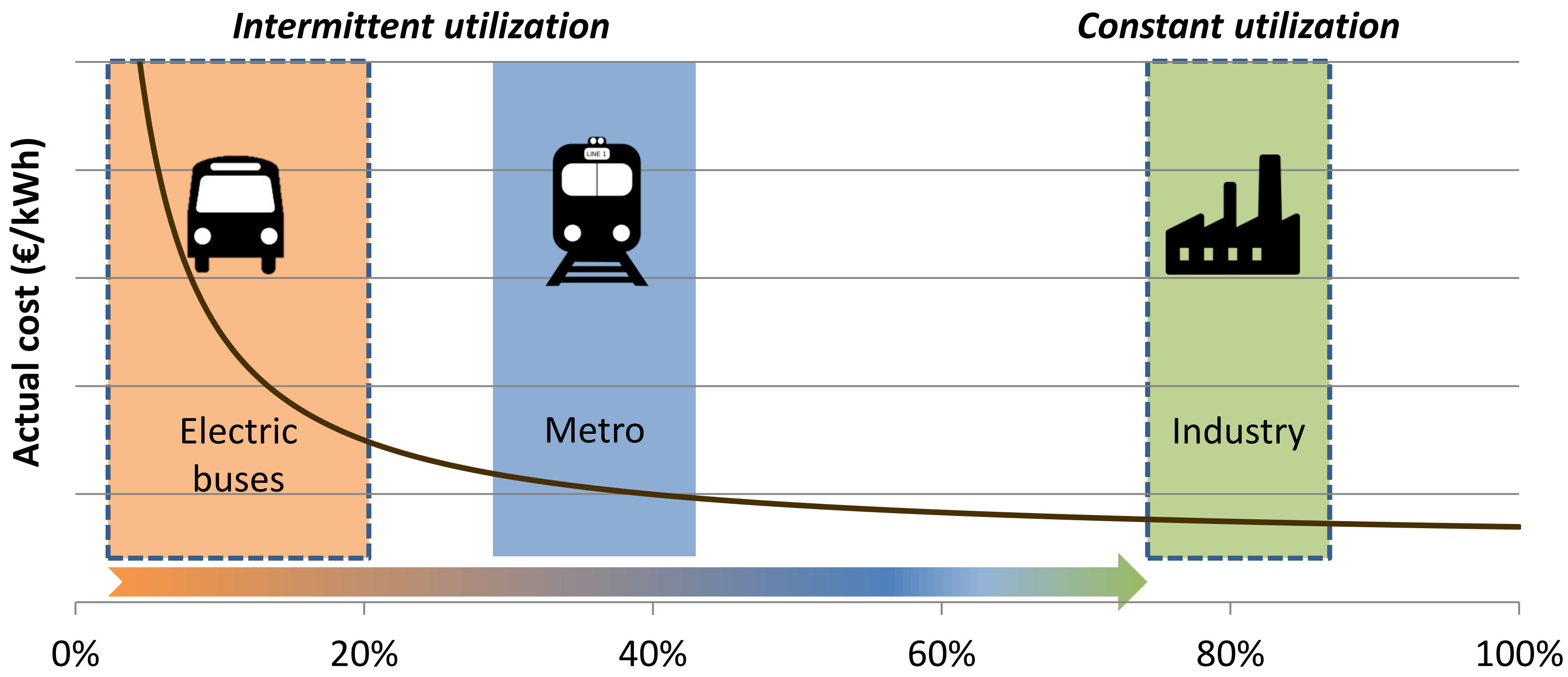


Depot area electricity consumption (for recharging buses)

Optimization

ELECTRIC ENERGY COST ISSUES

Electric energy use goal for a depot → Increase the **utilization factor**



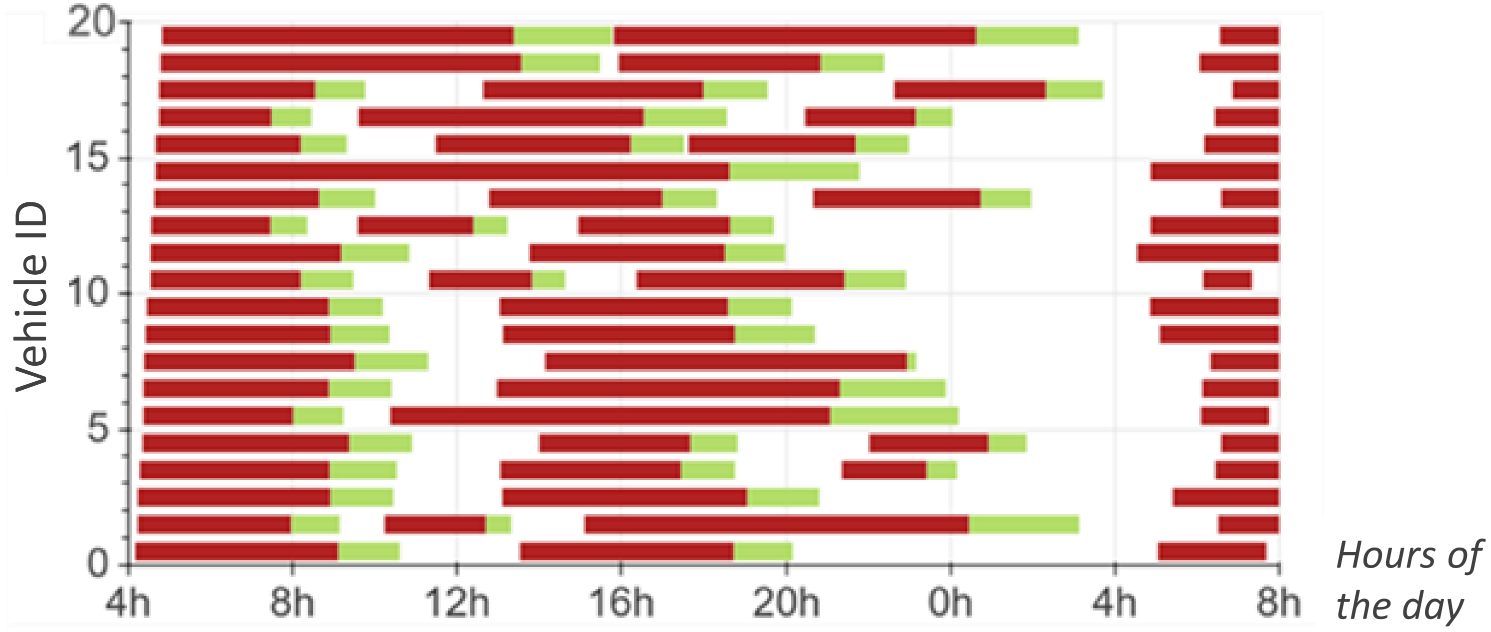
Utilization factor

Ratio between average and maximum/peak electric power (during utilization)

RECHARGING SCHEDULE EXAMPLE **WITHOUT** SMOOTHING

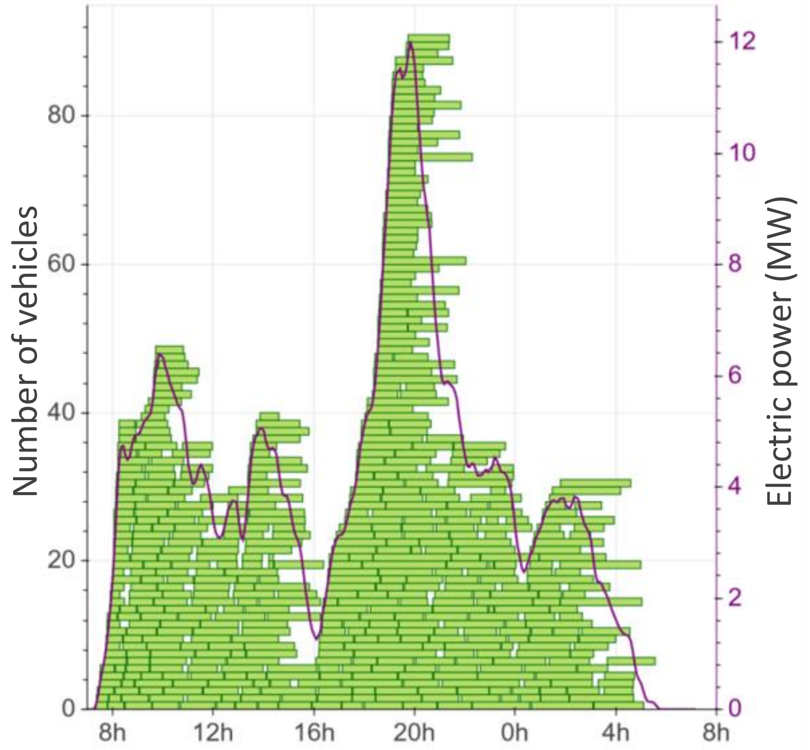
Bus recharges as soon as it returns to the depot

→ **Peak of electric power consumption**



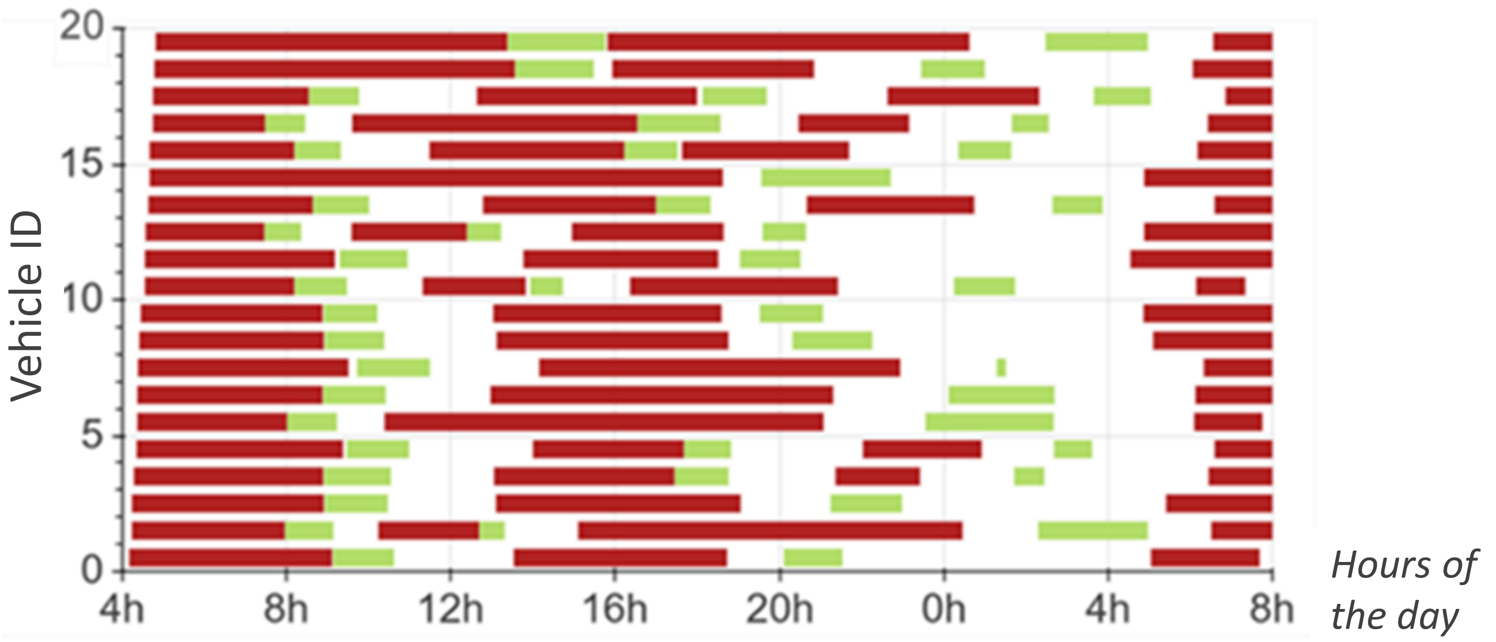
Vehicle in operation | Vehicle in depot area | Vehicle recharging

Peak electric power:	**12 MW**
Utilization factor:	**33 %**



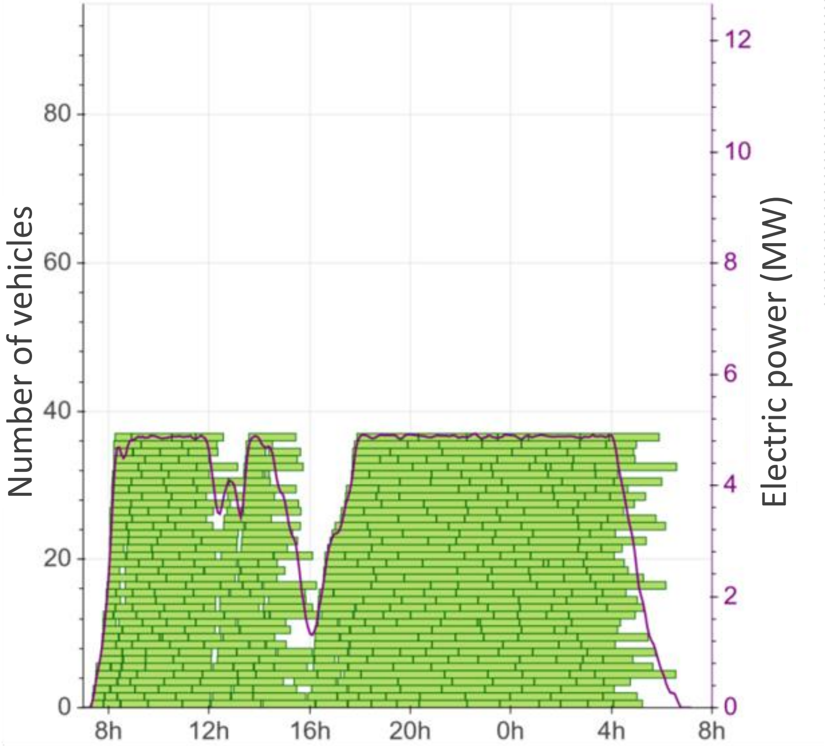
RECHARGING SCHEDULE EXAMPLE **WITH** SMOOTHING

Bus recharging optimized considering operation constraints
→ **Smoothing of electric power consumption**



Vehicle in operation | Vehicle in depot area | Vehicle recharging

Peak electric power: **5 MW**
Utilization factor: **85 %**



40% to 60% less electric power for the same recharge load requirement

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Electrification Preliminary Impacts Identification – Nagpur case

Electric infrastructure pre-sizing and depot area layout

Impacts on operation and maintenance activities

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pre-sizing

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City Bus Service current operational data analysis

2. Mid-term vision for future PT services

Analysis of fleet augmentation needs compared to previous CMP
Mid-term vision for future public transport services in Nagpur

3. Engine options and O&M strategy

Benchmark for engine technology options
Plan for development of depots and charging stations
Optimized operational plan to optimize the use of fleet

4. Financial and contractual analysis

Financial model: possible CAPEX and OPEX (prudent / optimistic)
Optimization of contractual framework, scenarios analysis

5. Transition plan for bus fleet upgrade

Transition Plan with development phases, basis for deployment of electric bus service

6. Pre-Feasibility for E-buses deployment

Detailed description of identified priority corridors
Realignment and reinforcement of existing bus system

FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS

R. K. City Bus Operations depot for Diesel buses in Nagpur:

- Parking/stabling area for a fleet of 144 buses
  - 79 standard buses (44 seats)
  - 50 Midi buses (32 seats)
  - 15 Minibuses (21 seats)
- Clay surfacing
- 6 maintenance pits
- Operation office (**containers**)

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FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS







Olectra Greentech – BYD depot for the E-buses in Nagpur:

- 1 "Office Building"
- 1 Pit Lane with overhead roof (not closed)
- **5 Charging Stations (80kW Chargers) with 2 standard plugs** (up to 10 buses can be simultaneously charged)
- **1 factory manufactured Transformer substation (11kV) – modular equipment**
- Fence/Wall around the site
- Clay surfacing

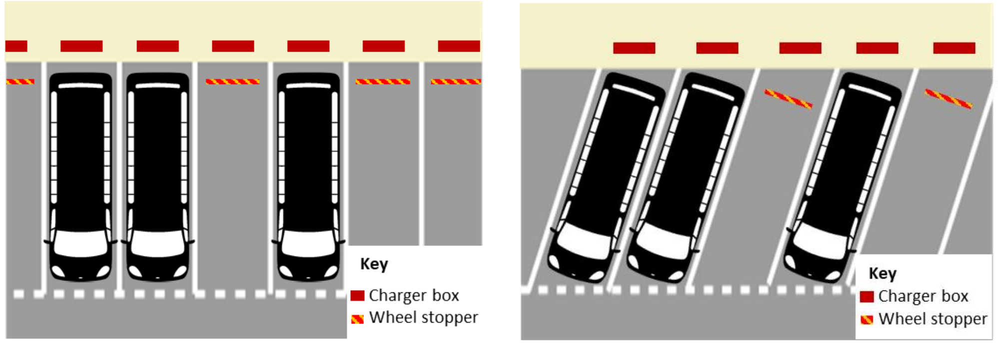
Depot area = enough for the storage and maintenance of the 5 E-Midi buses

Chargers are placed at the end (rear or front) of the vehicles. This is possible when the **vehicles are parked in a perpendicular or angle parking** (and not stacked).

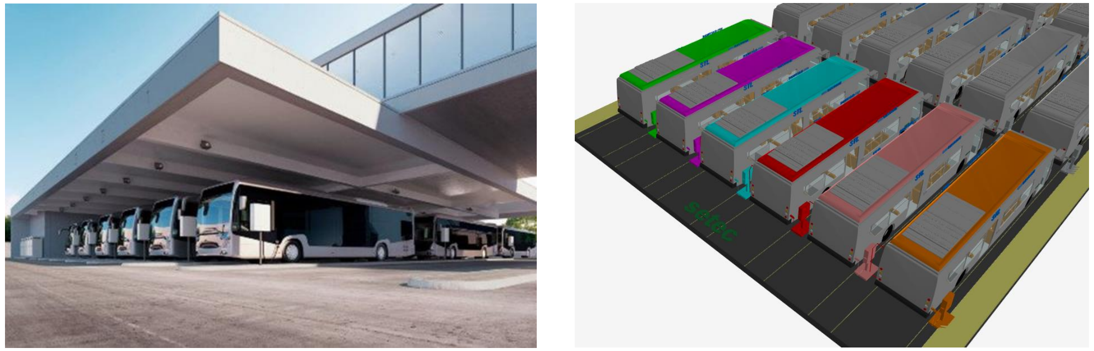
FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS

PARKING LAYOUT OPTIONS

INDIVIDUAL | STACKED

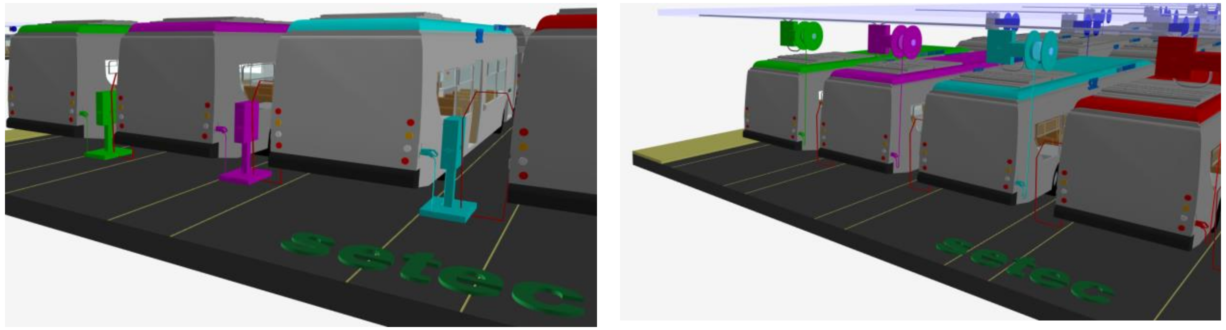


Typical individual parking layout (perpendicular and angled)



Example of stacked parking layouts (ABB and Laval, Canada)

Examples of individual parking layout (Paris, France)



3D model of stacked parking layout – ground (left) and aerial (right) recharging infrastructure (Laval, Canada)

FOCUS ON NAGPUR: OUR MAIN RECOMMENDATIONS

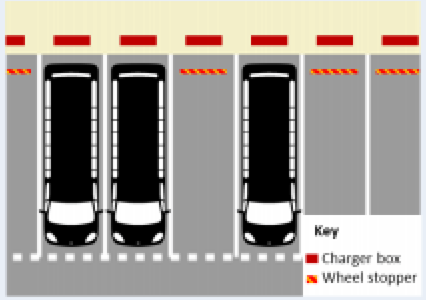
Depot charging infrastructure

Chargers

Depot infrastructure depends on each depot characteristics and the quantity of buses charging. Regarding the chargers, sequential charger is recommended as it optimizes infrastructure and energy consumption.

Parking layout

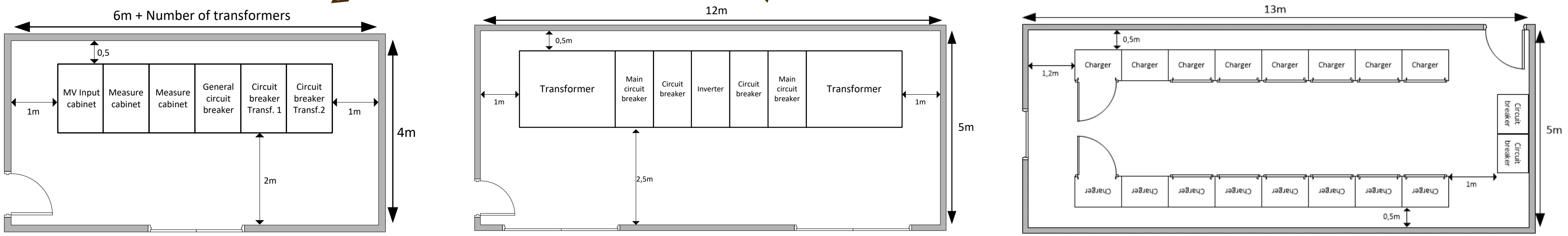
Regarding the typical bus depots in Nagpur, we recommend placing the charger boxes at the rear of parking places, protected by wheel stoppers.



Technical rooms

We recommend a modular infrastructure based on 3 rooms:

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



Typical technical room general layouts for Nagpur

Workshops upgrades

Specific equipment

- **Roof access bridge:** Vehicles have more and more components on the roof, it is recommended to provide working areas at height.
- **Overhead Crane:** Necessary for handling batteries and other traction equipment, which are located on the bus roof.
- **Bus washing machine:** Vertical gauge of the machine shall be compatible with electric buses

Workshop	Main specifications
Mechanical	It is considered that the overall surface area of the workshops remains similar to that for the maintenance of diesel buses. However, new distributions or redesigns of the mechanical workshop in favor of the high current electrical workshop are potentially necessary.
Electrical	
Electromechanical	
Electronic	
Oil storage room and equipment	This room size can be optimized due to the removal of the engine part.
Battery storage room	The ventilated battery room, secure and equipped with a slow charger, must be sized for the storage of a set of 3 to 5 battery units.

Required human resources and training impacts

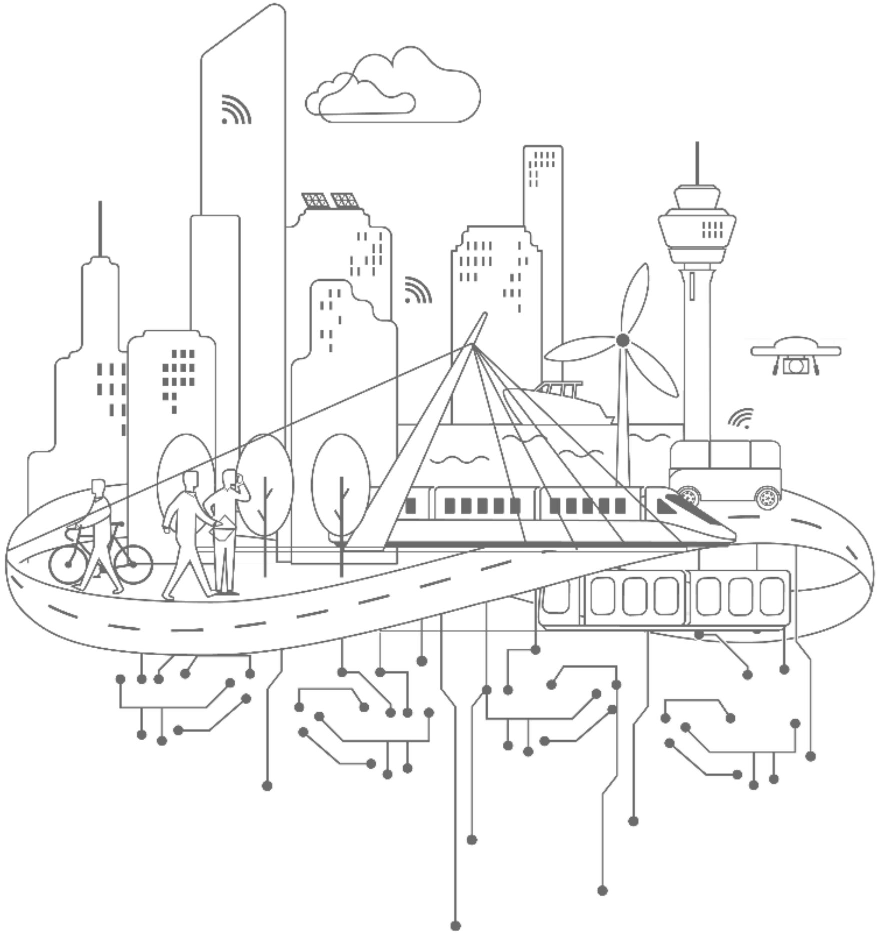
This report presents a qualitative and quantitative estimate of additional hours necessary for the operation and maintenance of electric buses, in terms of:

- Vehicle maintenance: There is a transfer of 20% of the time from the "Mechanical activities" to "Electrical activities",
- Charging infrastructure: For a bus depot hosting up to 50 buses, the estimated maintenance time is around 140 hours / year,
- Electrical infrastructure: For a bus depot hosting up to 50 buses, the estimated maintenance time is around 100 hours / year.

Suppliers of electric buses or charging systems always offer training when procuring electric buses, allowing staff upgrading on new tasks. In addition, our feedback from different electric bus manufacturers shows that approximately 80 hours of training are necessary for the maintenance staff.

For the bus drivers, the training consists mainly in the following tasks:

- Connect and disconnect electric buses at the charging station,
- Change in the driving habit: Driving should be more gradual in terms of acceleration.



THANK YOU!

FOR YOUR ATTENTION

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